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CHAPTER 6 SUMMARY

Chapter 6 addresses in detail the suitability of the reference repository location and its specific medium (basalt) for site characterization and for development as a repository. The discussion is presented according to the terms identified in the Nuclear Waste Policy Act of 1982 and the General Siting Guidelines (DOE, 1983b). Some of the guidelines discussed in Chapter 6 require information developed during site characterization (e.g., from borehole drilling and hydrological testing) before compliance can be demonstrated; others do not. Section 6.1 presents the rationale for distinguishing between these guidelines that do or do not require site characterization.

Section 6.2 deals with qualifying conditions (stated in the General Siting Guidelines) that do not require site characterization, such as the guideline on Site Ownership and Control (Section 960.4-2-8-2; DOE, 1983b). The narrative associated with this particular guideline (Subsection 6.2.1.1) notes that the reference repository location is on the Hanford Site in Washington, which has been under Federal control for the past 41 years. Many of its attributes (in particular those associated with its comparative remoteness) that led to its original selection as a Federal nuclear defense site also support its potential suitability as a repository site.

Section 6.3 deals with the qualifying conditions (guidelines) that do require site characterization, such as the guideline on Geohydrology (Section 960.4-2-1; DOE, 1983b). The narrative associated with this guideline (Subsection 6.3.1.1) notes that field and laboratory measurements will be needed as input to numerical simulation models to achieve the desired level of confidence required to reach a final conclusion on the qualifying condition. Thus, the conclusions reached in the analyses in Section 6.3, in the absence of site characterization data, are preliminary in nature.

The narrative for each guideline in this chapter follows the order presented below:

1. A restatement of the qualifying condition, defined by the General Siting Guidelines as "a condition that must be satisfied for a site to be considered acceptable with respect to a specific guideline."

2. A description of the evaluation process used by the Basalt Waste Isolation Project to consider the qualifying condition.

3. Statements of favorable conditions, potentially adverse conditions, and (when present in the General Siting Guidelines) disqualifying conditions accompanying the qualifying conditions to be addressed.

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- A favorable condition is defined as "a condition that, though not necessary to qualify a site, is presumed, if present, to enhance confidence that the qualifying condition of a particular guideline can be met."

- A potentially adverse condition is defined as "a condition that is presumed to detract from expected system performance unless further evaluation, additional data, or the identification of compensating or mitigating factors indicates that its effect on the expected system performance is acceptable."

- A disqualifying condition is defined as "a condition that, if present at a site, would eliminate that site from further consideration." No such disqualifying conditions are known to be present at the reference repository location.

4. A conclusion on the qualifying condition which evaluates the composite favorability of each qualifying statement. The reader should note that favorable and potentially adverse conditions can both exist for the same technical guideline. A combination of all favorable conditions and no potentially adverse conditions expected for a particular guideline may not necessarily result in a compliance with particular qualifying condition. Nor will any definite combination of favorable and potentially adverse conditions result in a predetermined qualification or disqualification. These preliminary conclusions also estimate the degree to which the Basalt Waste Isolation Project expects that the information obtained and the analyses performed during site characterization will reduce the uncertainty of meeting each qualifying condition.

Tables 6-A and 6-B briefly list the conclusions on the ability of the reference repository location to meet the qualifying conditions. Because discussions of these conditions frequently refer the reader to sections discussing related information in previous chapters, Table 6-C presents a cross-reference matrix of such sections.

Finally, Section 6.4 provides an overview of the analytical methods used by the Basalt Waste Isolation Project to provide a preliminary assessment of site suitability, to identify sensitive parameters or areas (e.g., isolation, safety, or related functions) that require specific attention during site characterization and to help design activities of the Project that will identify and mitigate problems in areas important to safety or to the function of the repository. This section is divided into preclosure performance assessment and postclosure performance assessment.

The preliminary postclosure performance assessment evaluates the long-term performance of the reference repository at the Hanford Site on

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Table 6-A. Qualifying conditions that do not need site characterization. (Sheet 1 of 2)

Qualifying condition	Current compliance status
Technical guidelines:	
Site Ownership and Control (both guidelines)	The evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition. This condition is met since the site is owned by the Federal Government and controlled by the U.S. Department of Energy
Population Density and Distribution	~~The evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition.~~ This condition appears to be met as a result of low Hanford Site population densities and very low projected offsite radiation doses
Meteorology	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. This condition appears likely to be met due to the remoteness of the site and atmospheric dispersion characteristics
Offsite Installations and Operations	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. This condition appears likely to be met based on analyses of radionuclide releases from nearby installations and operations
Environmental Quality	The evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition. This condition appears likely to be met since current information suggests that through compliance with applicable environmental regulations the environment will be protected during all phases of repository activity
Socioeconomic Impacts	The evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition. This condition is met since there are no significant adverse social and (or) economic impacts on nearby communities
Transportation	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. This condition is met for transportation of radioactive waste to the reference repository location

The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying conditions.

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Table 6-A. Qualifying conditions that do not need site characterization. (Sheet 2 of 2)

Qualifying condition	Current compliance status
Systems guidelines:	
Preclosure Radiological Safety	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. This condition appears to be met based on site remoteness, low population density adjacent to the reference repository location, and very low projected radiation exposure to the general public
Environmental, Socioeconomic, and Transportation	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. This condition is met based on environmental, socioeconomic, and transportation considerations

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Table 6-B. Qualifying conditions that ~~need~~ require site characterization. (Sheet 1 of 2)

Qualifying condition	Current compliance status
Geohydrology	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. Available evidence appears to support a preliminary finding that the reference repository location could meet this condition, although uncertainty exists
Geochemistry	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. Available evidence suggests a preliminary finding that the reference repository location meets this condition
Rock Characteristics	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. The reference repository location appears likely to meet this condition based on the expected characteristics of the host rock, although uncertainty exists.
Climatic Changes	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. Significant changes in climatic conditions are not expected to occur over the next 10,000 years; therefore, the reference repository location meets this condition
Erosion	The evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition. Erosional processes are not expected to result in radionuclide releases at the reference repository location; therefore, this condition is met
Dissolution	The evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition. Dissolution features are not present in basalt; therefore, this condition is met by the reference repository location
Tectonics (postclosure)	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. Tectonic processes and events are not expected to result in radionuclide releases at the reference repository location; therefore, this condition appears likely to be met

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Table 6-B. Qualifying conditions that ~~need~~ require site characterization. (Sheet 2 of 2)

Qualifying condition	Current compliance status
Natural Resources	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. Natural resources are generally scarce at or near the reference repository location; therefore, this condition appears to be met
Surface Characteristics	The evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition. The reference repository location meets this condition since it is located on well-drained, generally flat terrain
Hydrology	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. The reference repository location appears to meet this condition since technology is available for repository construction, operation, and closure
Preclosure System Guideline (costs)	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. The reference repository location appears to meet this condition since reasonable technology is available and current cost estimates ~~are very uncertain~~ between sites are comparable within current uncertainty levels
Postclosure System Guideline	The available evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition. The natural and engineered barrier systems at the reference repository location are likely to achieve compliance with this condition

Table 6-C. Sections related to Chapter 6 discussions. (Sheet 1 of 2)

	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6
QUALIFYING CONDITIONS THAT DO NOT NEED SITE CHARACTERIZATION					
SITE OWNERSHIP AND CONTROL		3.4.1	4.2.2.6	5.2.3.6	6.2.1.1/6.2.1.3
POPULATION DENSITY AND DISTRIBUTION	2.3.6	3.6.1	4.2.2.1	5.2.3.1	6.2.1.2
METEOROLOGY		3.4.3	4.1.2.4		6.2.1.4
OFFSITE INSTALLATIONS AND OPERATIONS	2.3.7				6.2.1.5
ENVIRONMENTAL QUALITY	2.3.8	3.4	4.1.2.3/4.2.1.3	5.2.1.3	6.2.1.6
SOCIOECONOMIC IMPACTS	2.3.9	3.6	4.1.2.2/4.2.2	5.2.3	6.2.1.7
TRANSPORTATION		3.5		5.2.2	6.2.1.8
PRECLOSURE RADIOLOGICAL SAFETY					6.2.2.1
ENVIRONMENTAL, SOCIOECONOMIC, AND TRANSPORTATION					6.2.2.2 (see Subsections 6.2.1.6, 6.2.1.7, and 6.2.1.8 above)

Table 6-C. Sections related to Chapter 6 discussions. (Sheet 2 of 2)

	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6
QUALIFYING CONDITIONS THAT NEED SITE CHARACTERIZATION					
GEOHYDROLOGY	2.3.1 (2.1.1/2.1.3 or 2.1.3.1/2.1.4)				6.3.1.1
GEOCHEMISTRY			4.1.3.1		6.3.1.2
ROCK CHARACTERISTICS	2.3.10				6.3.1.3
CLIMATIC CHANGES					6.3.1.4
EROSION	2.3.2				6.3.1.5
DISSOLUTION	2.3.3				6.3.1.6
TECTONICS	2.3.4/2.1.2	3.2.3	4.1.1.2		6.3.1.7/6.3.3.4
NATURAL RESOURCES (HUMAN INTERFERENCE)	2.3.5				6.3.1.8
SURFACE CHARACTERISTICS					6.3.3.1
HYDROLOGY	2.3.11/2.1.3/2.1.4	3.3.1/3.3.2	4.2.1.2	5.2.1.2	6.3.3.3
POSTCLOSURE SYSTEM GUIDELINES					6.3.2
PRECLOSURE SYSTEM GUIDELINE (COSTS)					6.3.4
PERFORMANCE ASSESSMENT					6.4

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the basis of existing computer models and site data. The computer models predict the effectiveness of the isolation system, primarily in terms of the following subsystems:

- The waste package - the waste form and any containers, shielding, packing, and other materials immediately surrounding an individual waste container.
- The repository seal - the underground facility (not including the waste package) and shafts.
- The site - that natural, or geologic, barrier that extends from the boundaries of the waste package subsystem and repository seal subsystem to the accessible environment. In basalt geology, the site subsystem is assumed to consist of the emplacement horizon, the adjacent basalt flow top, and the sequence of dense basalt flow interiors, interbedded sediments, and flow tops along the predominant ground-water flow path to the accessible environment.

Preliminary performance assessments are presented here for two time periods: 10,000 years and 100,000 years. Also, the computer models predict the long-term performance for two cases: a reference case, which reflects expected conditions and behavior of the systems; and the performance limits case, which reflects only a minimum level of isolation performance by the engineered barriers (waste package and repository seals). The above probabilistic analyses indicate ground-water travel time, potential radionuclide release rate, and cumulative potential radionuclide release, in short, the confidence level associated with compliance with ~~a~~ regulatory standard~~s or criteria~~s.

A first step in such an analysis is a preliminary system performance assessment for each subsystem. The assessment of the waste package indicated that two radionuclides (carbon-14 and iodine-129) provide the significant portion of the total potential release. The potential cumulative releases computed for the waste package subsystem were then used as input for the preliminary analysis of the repository seals.

Probability analyses ~~Monte Carlo trials~~ for the repository seal subsystem for the reference case (for mean hydraulic conductivities of 10^{-10} meters per second (feet per second)) indicate zero release in 10,000 years. In all cases, the calculated cumulative release was due solely to carbon-14 and iodine-129.

The performance of the site subsystem is measured according to pre-waste-emplacment ground-water travel times, and post-waste-emplacement radionuclide releases to the accessible environment. ~~The probability of travel time exceeding 1,000 years is greater than 0.95.~~ The median travel time is 17,000 years [to 86,000] when only the travel time through the flow top is considered. Significantly longer travel times could result when the dense interior of the basalt flow is also used.

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When looked at in concert, the results of the above preliminary performance assessments for the subsystems lead to the following determinations:

- Potential releases are dominated by the nonsorptive radionuclides carbon-14 and iodine-129.
- Other radionuclides have little likelihood of contributing to potentially significant releases, even in the 100,000-year time interval.
- Travel time exceeds 10,000 years; release is, by definition, zero for this time period.

The next step incorporates the results of the above subsystem performance assessment into a preliminary system performance assessment. At this point the assessment determines how major parameters that affect subsystems, such as solubility, may affect overall system performance. It also determines the effect of key subsystem performance parameters on cumulative releases. Results to date indicate that the low solubility of radionuclides, as well as the sorptive interactions between waste and packing material, or between waste and the minerals of the host rock along the ground-water flow path provide chemical barriers that reduce the potential release of most radionuclides. Also, the physical and chemical barriers act in concert; these barriers provide the basis for the expectation that the overall system will meet the regulatory standards for effectively isolating the waste from the accessible environment.

In summary, the preliminary performance assessment indicates that:

- Only two key radionuclides (carbon-14 and iodine-129) are likely to contribute significantly to potential releases.
- If the predominant ground-water flow path is along a basalt flow top, as modeled, the expected ground-water travel time to the accessible environment has a median value of between 17,000 and 80,000 years, ~~and a 95 percent confidence of being 1,000 years or greater~~. The basalt flow top pathway is considered to be a conservative assumption
- The long-term isolation performance of the total system appears to be relatively insensitive to the performance of the engineered barriers because of the natural geochemical environment and the expected long ground-water travel times.
- The waste package subsystem appears to be able to provide substantially complete containment of the radionuclides for a duration in excess of 1,000 years.

Thus, no current evidence suggests that the Basalt Waste Isolation Project site would be disqualified under the Postclosure System Guideline.

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Chapter 6

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

6.1 GUIDELINES THAT DO AND DO NOT REQUIRE SITE CHARACTERIZATION

(To be prepared by the U.S. Department of Energy-Headquarters.) which must be applied

Thus, a number of guidelines have been developed to determine the suitability of the Hanford Site for a repository of high level waste and spent fuel. Some of these guidelines need information developed during site characterization (e.g., from borehole drilling and hydrological testing) before compliance can be demonstrated; others do not. Sections 6.2 and 6.3 of this chapter evaluate each guideline by defining the information available, considering favorable conditions, identifying potentially adverse conditions, and then arriving at a conclusion. Where data is lacking, the conclusions are tentative and are so stated. Section 6.4 describes the efforts underway to assess how well a geologic repository at the reference repository location would meet applicable occupational and environmental release requirements. Section 6.2 deals with those qualifying conditions that do not require site characterization.

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

6.2.1 Technical guidelines

6.2.1.1 Site Ownership and Control (Section 960.4-2-8-2)

6.2.1.1.1 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."

6.2.1.1.2 Evaluation process

Lands within the reference repository location and the remainder of the Hanford Site have been under the jurisdiction of the Federal Government since 1943 (see Section 3.4.1). The Hanford Site is presently

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managed by the U.S. Department of Energy. The lands designated for the reference repository location consist of acquired lands plus section 10 and part of section 4, Township 12 North, Range 25 East of the Willamette Meridian, which is public domain (see Fig. 2-29). Sections 10 and 4 have been withdrawn from all forms of appropriation under the public land laws including the mining and mineral leasing laws and have been reserved for use by the U.S. Atomic Energy Commission in connection with its Hanford Operations. The pertinent part of the applicable Public Land Order 1273 (BLM, 1956) reads as follows:

> "Subject to valid existing rights, the following-described public lands in Washington are hereby withdrawn from all forms of appropriation under the public-land laws, including the mining and the mineral-leasing laws, and reserved for use of the Atomic Energy Commission in connection with its Hanford Operations."

All functions of the U.S. Atomic Energy Commission with respect to the Hanford Site and certain other locations have been transferred to the Secretary of Energy. As a result, sections 10 and 4, Township 12 North, Range 25 East of Willamette Meridian, are under the jurisdiction of the U.S. Department of Energy, which holds that land pursuant to the above-described provisions of Public Land Order 1273.

Most of the Hanford Site south of the Columbia River is fenced and (or) posted to prohibit access by unauthorized personnel. The State of Washington has an easement through the Hanford Site for Route 240. A portion of Route 240 crosses a corner of the reference repository location. This easement is fenced on both sides and is patrolled to control access to the Hanford Site (including the proposed location for repository surface facilities). Access to the proposed surface facilities ~~location~~ of the reference repository location can only be gained by passing through one of the several security check points.

6.2.1.1.3 Favorable condition

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

The reference repository location on the Hanford Site meets the requirements of this favorable condition since the Federal Government owns and the U.S. Department of Energy presently runs and controls the land and all mineral rights.

The Hanford Site has been under the jurisdiction of the Federal Government since 1943. The lands designated as the reference repository location consist of acquired land plus sections that have been withdrawn from all forms of appropriation under the public land laws including the mining and mineral leasing laws. Present ownership and control of the land and all surface and subsurface mineral rights is by the Federal Government and the U.S. Department of Energy.

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6.2.1.1.4 Potentially adverse condition

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

There are no projected land-ownership conflicts since the U.S. Department of Energy controls the land; therefore, the reference repository location does not have this potentially adverse condition.

The present ownership and control of the Hanford Site by the Federal Government and the U.S. Department of Energy precludes any land-ownership conflicts (see Subsection 6.2.1.1.2).

6.2.1.1.5 Conclusion on qualifying condition

The reference repository location on the Hanford Site meets the site ownership qualifying condition and will continue to meet this qualifying condition. Supporting this finding are the following major factors:

- Lands within the reference repository location and the remainder of the Hanford Site have been under the jurisdiction of the Federal Government since 1943.
- Present ownership and control of the Hanford Site reference repository location and all surface and subsurface mineral rights is by the Federal Government and the U.S. Department of Energy.
- Access to proposed surface facilities ~~location~~ of the reference repository location is controlled by the U.S. Department of Energy.

There is little or no uncertainty associated with this conclusion.

6.2.1.2 Population Density and Distribution (Section 960.5-2-1)

6.2.1.2.1 Qualifying condition

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

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6.2.1.2.2 Evaluation process

Information pertaining to the proximity of the Hanford Site to population centers can be obtained from the 1980 census. The nearest highly populated area to the Hanford Site is Richland, Washington, which had a population of 33,578 in 1980 (BOC, 1981). Richland lies 35 kilometers (22 miles) southeast of the reference repository location. The 1980 census data on the population of incorporated cities and counties within 80 kilometers (50 miles) of the Hanford Meteorological Station (located in the northeast portion of the reference repository location) are shown in Figure 6-1. Intensive farming is carried out along the Yakima River Valley and to the north and east of the Hanford Site on the Columbia Basin Irrigation Project (see Subsection 2.1.2.1). West of the Hanford Site is the Yakima Firing Center, which is operated by the U.S. Army and has restricted access (see Fig. 6-1). Currently, the U.S. Department of Energy and its contractors employ approximately 12,000 workers at the Hanford Site, of which 3,500 work in the vicinity of the reference repository location.

By analogy with doses generated by defense processing and waste management activities, it appears that projected radiation doses will not exceed allowable limits (see Subsections 3.4.2.7, 5.2.1.3.6, 6.2.1.5, and 6.4.1).

Socioeconomic data, including past and projected population densities, are contained in Section 3.6.1.

6.2.1.2.3 Favorable conditions

Both of the favorable conditions for this guideline are closely related and are discussed together.

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

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

Both favorable conditions on site remoteness and low population density are met by the reference repository location. The reference repository location is remote from highly populated areas and has no onsite population.

The Hanford Site lands are within the jurisdiction of the Federal Government. Adjoining lands are privately owned, with the exception of those areas controlled by the State of Washington, county, and city governments. The closest Indian reservation is ~~owned by~~ that of the Yakima Indian Nation and is located approximately 26 kilometers (16 miles) west of the Hanford Site, 50 kilometers (30 miles) from the proposed reference repository location. The Umatilla Indian Reservation is located approximately 85 kilometers (53 miles) southeast of the Hanford Site, 120 kilometers (75 miles) from the reference repository location. The three towns nearest the proposed repository site are Richland

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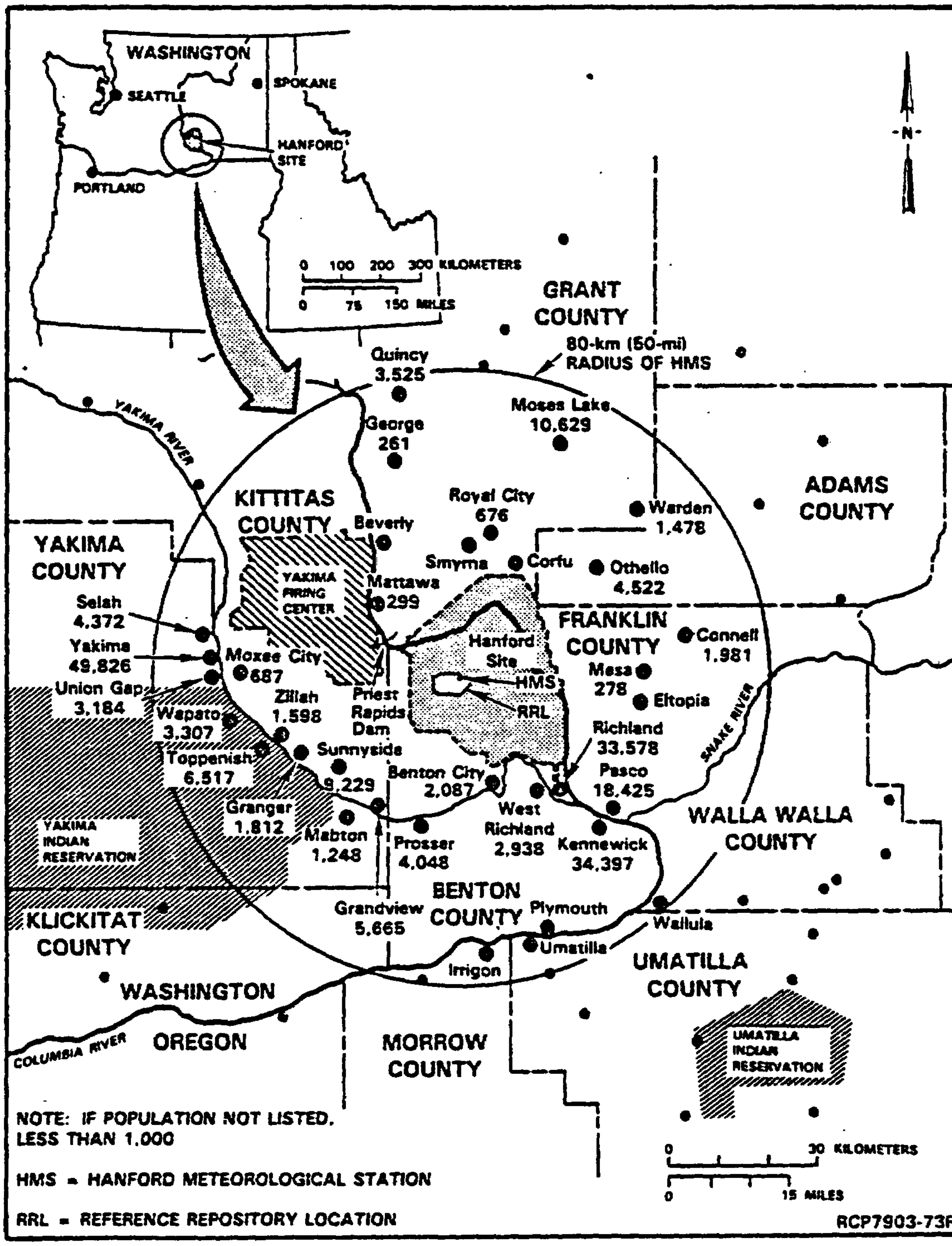

Figure 6-1. United States census populations for 1980 of cities within an 80-kilometer (50-mile) radius of the Hanford Meteorological Station.

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(35 kilometers (22 miles)), Kennewick (45 kilometers (28 miles)), and Pasco (45 kilometers (28 miles)). Their 1980 populations were 33,578, 34,397, and 18,425, respectively. The remoteness of the reference repository location from populated areas is evident in Figure 6-1.

6.2.1.2.4 Potentially adverse conditions

Both of the potentially adverse conditions are related and are discussed below.

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

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

Neither of these potentially adverse conditions are present at the reference repository location on the Hanford Site. There is no permanent population within the boundaries of the reference repository location.

There are no residential or seasonal individuals located within the 48 square kilometers (18 square miles) of the projected site boundaries of the reference repository location. The reference repository location is near the center of the Hanford Site, which is already committed to nuclear activities. There are approximately 700 daytime individuals, and an additional 700 shift workers, working within the boundaries of the reference repository location, and 3,500 individuals working in the vicinity of the reference repository location, employed in nuclear related jobs. The three towns nearest the reference repository location are Richland (35 kilometers (22 miles)), Kennewick (45 kilometers (28 miles)), and Pasco (45 kilometers (28 miles)). Their 1980 populations were 33,578, 34,397, and 18,425, respectively. The population density in 1980 was 1,050 persons per square mile for Richland, 2,218 persons per square mile for Kennewick, and 1,175 persons per square mile for Pasco. At the county level, the population density for Benton County is 25 persons per square kilometer (64 persons per square mile); for Franklin County it is 11 persons per square kilometer (28 persons per square mile).

6.2.1.2.5 Disqualifying conditions

"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

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

The reference repository location is not disqualified for any of the above three disqualifying conditions. The site is not located in or adjacent to a highly populated area and an extensive Emergency Preparedness Program is already in place for the Hanford Site. There is little or no uncertainty in relation to this disqualifying condition.

The reference repository is located on the Hanford Site, which has been under Federal jurisdiction since 1943. Land adjacent to the Hanford Site is privately owned, with the exception of those areas controlled by Washington State, county, and city governments (see Fig. 3-37). Because access to the Hanford Site is controlled by the U.S. Department of Energy, there are no highly populated areas within 20 kilometers (12 miles) of the reference repository location (see Fig. 6-1). The city of Richland, with a 1980 population of 33,578 (BOC, 1981, p. 13), is approximately 35 kilometers (22 miles) southeast of the reference repository location and is the closest population center. The cities of Kennewick (1980 population of 34,397 (BOC, 1981, p. 12)) and Pasco (1980 population of 18,425 (State of Washington, 1982, p. 3)) are both located approximately 45 kilometers (28 miles) southeast of the reference repository location. The density of population settlement in 1980 was 1,050 persons per square mile for Richland, 2,218 persons per square mile for Kennewick, and 1,175 persons per square mile for Pasco. The closest Indian reservation is occupied by the Yakima Indian Nation and is located approximately 26 kilometers (16 miles) west of the Hanford Site, 50 kilometers (31 miles) from the reference repository location (see Fig. 6-1).

The U.S. Department of Energy has a Radiological Emergency Response Plan and Emergency Procedures for the Hanford Site (DOE, 1982d, 1982b) that conform to DOE Order 5500.3 (DOE, 1981b). Furthermore, the Plan and Procedures agree, in general, with NUREG 0654/FEMA REP-1, Rev. 1 (NRC, 1980), "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparation in Support of Nuclear Power Plants." There is no reason to believe that these plans and procedures could not be expanded to cover a repository on the Hanford Site.

In addition, an Emergency Response Plan (WPPSS, 1983) has been approved by the U.S. Nuclear Regulatory Commission for two commercial power reactors (Washington Public Power Supply System plants WNP-1 and -2) located on 834.1 hectares (2,061 acres) of ~~leased Hanford Site land~~ (see Fig. 3-40). This plan is developed in conjunction with the State of Washington and Benton/Franklin Counties Fixed Nuclear Facility Emergency Response Plans, all of which have been developed to meet the intent of NUREG 0654/FEMA-REP-1, Rev. 1, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of

Hanford Site land leased by the U.S. Department of Energy to the Washington Public Power Supply System

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Nuclear Power Plants" (NRC, 1980). A coordinated training program exists among the U.S. Department of Energy, the reactor owner-operator (the Washington Public Power Supply System), Benton and Franklin Counties, and the State of Washington in order to implement a unified effort to assess hazards, make decisions, and initiate action to protect public health during an emergency.

These emergency preparedness plans are continually updated to reflect changed or additional criteria developed by the U.S. Nuclear Regulatory Commission or U.S. Federal Emergency Management Agency.

6.2.1.2.6 Conclusions on qualifying condition

The available evidence does not support a finding that the site is not likely to meet the population density and distribution qualifying condition. The following major factors support this preliminary finding:

- The nearest highly populated area is 35 kilometers (22 miles) from the reference repository location.

- There is no permanent population on the reference repository location. Doses to individuals working in the vicinity of the area are monitored to ensure compliance with applicable federal standards.

There is little or no uncertainty associated with these major factors supporting this preliminary finding.

Other factors that relate to this preliminary finding are:

- All estimates of radiation dose to public, from normal operations to the worst case incident, indicate exposures to be well within 10 CFR 20, 10 CFR 60, and 40 CFR 191, Subpart A (see Section 6.4.1).

- Existing meteorological conditions indicate that repository operations would not result in doses to the general public above allowable limits (see Subsection 6.2.1.4).

Some of the relevant data for these evaluations contain uncertainties requiring that assumptions be made, and thus result in subjective evaluations. Among the sources of uncertainty are:

- Dose calculations are based on a repository design in the conceptual stage.

- Atmospheric dispersion modeling has not been conducted for radionuclide releases at the reference repository location.

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6.2.1.3 Site Ownership and Control (Section 960.5-2-2)

6.2.1.3.1 Qualifying condition

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

6.2.1.3.2 Evaluation process

Lands within the reference repository location and the remainder of the Hanford Site have been under the jurisdiction of the Federal Government since 1943. The Hanford Site is presently managed by the U.S. Department of Energy. The lands designated as the reference repository location consist of acquired lands plus section 10 and part of section 4, Township 12 North, Range 25 East of the Willamette Meridian, which is public domain. Sections 10 and 4 have been withdrawn from all forms of appropriation under the public land laws including the mining and mineral leasing laws and have been reserved for use by the U.S. Atomic Energy Commission in connection with its Hanford Operations. The pertinent part of the applicable Public Land Order 1273 reads as follows:

> "Subject to valid existing rights, the following-described public lands in Washington are hereby withdrawn from all forms of appropriation under the public-land laws, including the mining and the mineral-leasing laws, and reserved for use of the Atomic Energy Commission in connection with its Hanford Operations."

All functions of the U.S. Atomic Energy Commission with respect to the Hanford Site and certain other locations have been transferred to the Secretary of Energy. As a result, Sections 10 and 4, Township 12 North, Range 25 East of Willamette Meridian, are under the jurisdiction of the U.S. Department of Energy, which holds that land pursuant to the above-described provisions of Public Land Order 1273.

Most of the Hanford Site south of the Columbia River is fenced and (or) posted to prohibit access by unauthorized personnel. The State of Washington has an easement through the Hanford Site for Route 240. A portion of Route 240 crosses the reference repository location. This easement is fenced on both sides and patrolled to control access to the Hanford Site (including the proposed location for surface facilities). Access to the proposed surface facilities ~~location~~ of the reference repository location can only be gained by passing through one of the several security check points.

6.2.1.3.3 Favorable condition

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

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The reference repository location meets this favorable condition since the Federal Government owns and the U.S. Department of Energy controls the land plus all mineral and water rights.

The Hanford Site has been under the jurisdiction of the Federal Government since 1943. The lands designated as the reference repository location consist of acquired land plus sections that have been withdrawn from all forms of appropriation under the public land laws including the mining and mineral leasing laws. Present ownership and control of the land and all surface and subsurface mineral rights is by the U.S. Department of Energy.

6.2.1.3.4 Potentially adverse condition

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

This potentially adverse condition does not exist at the reference repository location since the Federal Government owns and the U.S. Department of Energy controls the land under study.

There are no projected land-ownership conflicts. The U.S. Department of Energy currently controls the land within the boundaries of the reference repository location.

6.2.1.3.5 Conclusion on qualifying condition

The reference repository location on the Hanford Site meets the site ownership qualifying condition and will continue to meet this qualifying condition. Supporting this finding are the following major factors:

- Lands within the reference repository location and the remainder of the Hanford Site have been under the jurisdiction of the Federal Government since 1943.
- Present ownership and control of the Hanford Site reference repository location and all surface and subsurface mineral rights is by the Federal Government and the U.S. Department of Energy.
- Access to the proposed surface facilities ~~location~~ of the reference repository location is controlled.

There is little or no uncertainty associated with this conclusion.

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6.2.1.4 Meteorology (Section 960.5-2-3)

6.2.1.4.1 Qualifying condition

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

6.2.1.4.2 Evaluation process

Section 3.4.3 summarized climatological, meteorological, and diffusion conditions of the Hanford Site, based on data archived at the Hanford Meteorological Station from 1945 through 1980. These data are assumed suitable for evaluating meteorological conditions at the reference repository site at this time. A complete summary of wind, temperature, moisture, diffusion data, etc., at the Hanford Meteorological Station is given in Stone et al. (1983). Some differences between atmospheric conditions measured at the Hanford Meteorological Station and other sections of the reference repository location are expected based on localized topographic conditions. Atmospheric dispersion models can account for some of these localized topographic influences although a determination will have to be made to decide if monitoring at the site is needed to verify atmospheric model results.

Diffusion conditions at Hanford are generally good, although poor diffusion circumstances (light winds, shallow mixing depth, low level inversion and stable conditions) can and do occur, particularly during the winter under a northwest flow regime. The same conditions can be found during the summer, although they occur less frequently. Diffusion conditions are best under strong wind speeds and deep mixing depths, which are frequently found during the summer. While average wind speed at the Hanford Meteorological Station is on the order of 10 to 16 kilometers (6 to 10 miles) per hour, peak gusts exceeding 80 kilometers (50 miles) per hour occur relatively often. These circumstances usually exist under a southwest flow regime accompanying a synoptic disturbance.

6.2.1.4.3 Favorable condition

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

This favorable condition has a high likelihood of being met. Existing meteorological conditions combined with low population density and distance to highly populated areas indicate that repository operations would control radiation doses to the general public within applicable limits.

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Detailed atmospheric dispersion modeling has not been conducted for radionuclide releases at the reference repository location. Effects of these on any member of the public are estimated at this time (see Section 6.4.1). The frequency of favorable dispersion conditions as reported at the Hanford Meteorological Station, combined with the proposed repository location, leads to the conclusion that a number of favorable factors exist that are expected to allow repository operation to comply with the limits established by the U.S. Nuclear Regulatory Commission in 10 CFR 20 (NRC, 1982d) and by the U.S. Environmental Protection Agency in proposed 40 CFR 191, Subpart A (EPA, 1982). Due to the low population density of the surrounding area and the distance from the proposed repository site to population centers, routine repository operations would not be expected to result in radiation exposure to members of the general public. ~~Repository emissions, under routine operating conditions, are not expected to contain radioactivity above natural background levels.~~ In the final environmental impact statement for disposal of commercially generated radioactive wastes (DOE, 1980), it was calculated that even for the most severe operational accident postulated for a repository (dropping a container down a repository shaft), the maximum individual would receive a 70-year whole body radiation dose of approximately 0.04 millirems. The repository design will incorporate filtration/adsorption systems to limit gaseous radioactive emissions below the levels allowed by the U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency (see Section 5.1.1).

6.2.1.4.4 <u>Potentially adverse condition</u>

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

This potentially adverse condition for the preclosure meteorology guideline is not substantively present at the reference repository location. The site is remote from highly populated areas and emissions are expected to be effectively dispersed.

The combined effects of the prevailing meteorological conditions in the vicinity of the reference repository location, the low population density of the surrounding area, and the distance from the proposed repository to population centers indicate that repository emissions are not expected to result in exposure to the general public greater than those allowable under the requirement specified in Section 960.5-1(a)(1) of the General Siting Guidelines.

6.2.1.4.5 <u>Potentially adverse condition</u>

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

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This potentially adverse condition does not exist at the reference repository location. Such extreme weather conditions do not occur or rarely occur at the Hanford Site.

Extreme weather phenomena rarely occur in the Hanford Site region. Hurricanes do not occur on the Hanford Site. Tornadoes/funnel clouds, as discussed in Subsection 3.4.3.1, are a rare occurrence. From 1916 to 1983 ~~there have been~~ 22 tornadoes were sighted within a 160-kilometer (100-mile) radius of the Hanford Meteorological Station. The recurrence interval at any one point within this radius is estimated to be one tornado per 146,000 years (Stone et al., 1983). Other conditions with high winds are thunderstorms and summertime afternoon drainage winds. Severe winter storms are seldom experienced in the Hanford Site region.

Meteorological phenomena that will be considered for design and operating bases of the repository have been identified (DOE, 1982e) and include the following:

- The probability and expected characteristics of a tornado occurring in the Hanford Site support a Class III designation for the region for design purposes.

- The structures at the reference repository location will be designed to withstand a basic wind (fastest mile) velocity of 130 kilometers per hour (80 miles per hour), based on observed and recorded information from the Hanford Meteorological Station.

- The American National Standards Institute (ANSI, 1972) provides weights of snow packs for the Hanford Site region. The 100-year ~~return period~~ ground-level snow pack is 98 kilograms per square meter (20 pounds per square foot).

- The number of thunderstorms observed in the Hanford Site area has ranged from 3 to 23 per year, averaging 11 per year. Lightning strike frequency for a 125-meter (410-foot) structure can be estimated at one every 4.44 years (ERDA, 1975) for the area.

- The "worst-case" duststorm, or the storm which had the largest calculated time-integrated dust loading, was observed by the Hanford Meteorological Station to have a dust loading of 160 milligrams per hour per cubic meter, lasting 18 hours, for an average dust loading of 8.9 milligrams per cubic meter. The highest average loading for any 1-hour period is 100 milligrams per cubic meter.

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6.2.1.4.6 Conclusion on qualifying condition

The available meteorological evidence does not support a finding that the site is not likely to meet the qualifying condition. Major factors supporting this preliminary finding include the following:

- Existing meteorological conditions combined with low population density and distance to highly populated areas indicate that repository operations would control radiation doses to the general public within the allowable limits.
- Due to the low population density of the surrounding area and the distance from the proposed repository site to highly populated areas, routine repository operations would not be expected to result in radiation exposure to members of the general public.
- Repository emissions, under routine operating conditons, are not expected to contain radioactivity above natural background levels.

Some uncertainties are related to the major supporting factors including:

- Atmospheric dispersion modeling has not been conducted for radionuclide releases at the reference repository location.

6.2.1.5 Offsite Installations and Operations (Section 960.5-2-4)

This section will address the impacts of nearby industrial, transportation, and defense installations on the candidate repository site and the cumulative effect of routine radioactive releases from a repository and nearby nuclear facilities subject to the requirements of 40 CFR 190 and 40 CFR 191 (EPA, 1977, 1982).

6.2.1.5.1 Qualifying condition

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

6.2.1.5.2 Evaluation process

Both radiological and nonradiological effects of offsite installations and operations on the candidate repository site will be evaluated. For a discussion of radiological background and the impact of

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Hanford Site defense waste activities, refer to Subsection 3.4.2.7. Figure 3-28 depicts current land use on the Hanford Site.

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Impacts of offsite facilities at the candidate repository site were considered during Basalt Waste Isolation Project site identification studies (WCC, 1981). Screening guidelines were adopted that excluded, to the extent possible, potential repository sites that were subject to the effects of manmade hazards. These guidelines addressed potentially adverse effects from aircraft impact, hazardous facilities, transportation systems, induced seismicity, subsurface mineral exploration and extraction, and national defense and security facilities that were interpreted as attractive military targets.

radioactive waste management and disposal facilities,

Manmade hazards that were identified in the vicinity of the reference repository location included high altitude jet routes that cross the site, a nearby ~~hazardous facility (radioactive waste management facilities)~~; and the national defense and security aspects of nearby Hanford Site operations. The high altitude commercial jet route crossing the site presents a negligible risk to repository facilities. The principal hazard to repository operations from nearby hazardous facilities on the Hanford Site would result from impacts of explosive, corrosive, or flammable materials that could generate missiles, fire, shock waves, or vapor clouds. The most likely impact would be caused by a release of toxic gases. Such an event could cause the temporary suspension of repository operations under adverse meteorologic conditions, but would not permanently impair repository performance. ~~While nearby defense nuclear facilities on the Hanford Site are potential military targets, the unattractiveness of a nuclear waste repository as a target of terrorist activities and the existing security systems at the Hanford Site minimize national defense and security risks at the reference repository location.~~

Radioactive emissions to unrestricted areas from nuclear waste repositories are governed by 10 CFR 20 (NRC, 1982d) (as referenced by 10 CFR 60 (NRC, 1982a) and 40 CFR 191, Proposed Rule (EPA, 1982)). In 10 CFR 20, the U.S. Nuclear Regulatory Commission requires that radioactive effluent meet specified concentration guides and that the dose to an individual in unrestricted areas be limited to 500 millirem per year whole-body. In 40 CFR 191, Subpart A requires that repository operations in addition to all other commercial nuclear fuel cycle facilities covered by 40 CFR 190 (EPA, 1977) do not result in whole-body doses to members of the public greater than 25 millirem per year. Nuclear facilities operated by the U.S. Department of Energy at the Hanford Site are subject to standards set forth in DOE Order 5480.1A (DOE, 1981a), which is effectively identical to 10 CFR 20.

Maximum

Radioactive emissions and associated dose rates to the public from repository operations that might be located at the Hanford Site have been estimated and are presented in Section 6.4.1. The projected dose is sensitive to assumptions concerning storage and handling capacity of the facility, age of the waste, and whether or not the facility is designed to accept, store, disassemble, and package spent fuel. The conceptual design

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for the nuclear waste repository in basalt was based on the receiving and handling of prepackaged spent fuel and high-level nuclear waste. Under these conditions radioactive emissions would only occur if externally contaminated or leaking containers were received or if intact containers are damaged at the repository. The disassembly, storage, and packaging of spent fuel would have a potential for gaseous radioactive emissions. Based on estimated routine radioactive gaseous emissions from spent fuel disassembly and packaging operations, the annual dose to an individual living 2 kilometers (1.2 miles) from the point of release would be approximately 0.5 millirem. ~~It should be noted that such an individual does not exist, since~~ the Hanford Site boundaries preclude the public from living close to the waste processing areas.

Commercial nuclear facilities located within the Hanford Site boundaries include the Washington Public Power Supply System generating station adjacent to the N Reactor, the Washington Public Power Supply System power reactor site (two reactors held in various stages of completion and one reactor ~~now~~ commercially producing electricity), and a commercial low-level radioactive waste burial site. The Exxon Nuclear Company, Inc. fuel fabrication facility is located immediately adjacent to the southern boundary of the Hanford Site.

The U.S. Department of Energy oversees four major operating areas at the Hanford Site. The 100 Areas include facilities for the N Reactor and the eight deactivated production reactors along the Columbia River (see Fig. 3-37). The reactor fuel-processing and waste management facilities in the 200 ~~Areas are~~ adjacent to the reference repository location. The 300 Area, just north of the City of Richland, contains the reactor fuel manufacturing facilities and research and development laboratories. The Fast Flux Test Facility is located in the 400 Area approximately 8.8 kilometers (5.5 miles) northwest of the 300 Area.

Radiation dose equivalent resulting from emissions from existing Hanford Site facilities are calculated by the Pacific Northwest Laboratory for the U.S. Department of Energy on an annual basis as part of a comprehensive Environmental Surveillance Program (Sula et al., 1983). Measurements are made of external radiation and samples are collected for analysis of concentration of radioactive materials.

- Atmosphere.
- Columbia River.
- Ground water.
- Foodstuffs.
- Wildlife.
- Soils and vegetation.

These data are used to calculate the dose to a hypothetical individual whose location and characteristics are chosen to maximize the combined doses from all realistically available explosure pathways. The maximum dose to an individual is believed to represent an appropriate

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means of demonstrating compliance with regulatory standards. Based on analysis of 1982 environmental surveillance data, the Pacific Northwest Laboratory (Sula et al., 1983) stated that:

> "The quantities of radionuclide releases associated with 1982 operations were too small to be measured once dispersed in the offsite environment. As a result, the potential offsite doses could only be estimated by using computerized models that predict concentrations of radioactive materials in the environment and subsequent radiation doses on the basis of radionuclides released to the environment. . .The radiation doses estimated by these models were quite small and well below our ability to measure directly. Although the uncertainty associated with these calculations has not been specified, it is relatively large. As a result, these doses should be viewed as conservatively calculated best estimates of potential dose impact of 1982 Hanford operations."

The calculated annual maximum individual dose commitment (whole-body) from 1982 Hanford Operations amounted to 0.1 millirem.

This figure includes calculated emissions from all commercial and defense nuclear facilities on the Hanford Site. Planned operation of the U.S. Department of Energy PUREX facility and the Washington Public Power Supply System nuclear power reactors would add to the calculated dose from 1982 operations. The projected annual maximum individual dose (whole body) from the operation of all three Washington Public Power Supply System reactors is approximately 2.7 millirem (WPPSS, 1977). Calculated doses from PUREX are 0.012 millirem (WPPSS, 1977; DOE, 1982a). Therefore, the total annual maximum individual dose commitment from all existing and currently planned commercial and defense nuclear facilities is approximately 2.8 millirem. When combined with the estimated dose from preclosure repository operations of 0.5 millirem (see Section 6.4.1), the total annual dose to a maximum individual residing near the Hanford Site is 3.3 millirem.

6.2.1.5.3 Favorable condition

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

This favorable condition is not met by the reference repository location since there are other nuclear facilities at the Hanford Site that are subject to the requirements of 40 CFR 191, Subpart A.

Radioactive emissions subject to consideration under 40 CFR 191, Subpart A, include ~~commercial nuclear fuel cycle facilities on the Hanford Site, including the Washington Public Power Supply System nuclear reactor facilities, the steam generating facility adjacent to the N-Reactor, and the Exxon Nuclear fuel fabrication facility. Other~~ research and defense nuclear facilities on the Hanford Site, ~~described previously (see Subsection 3.4.2.7), are subject to U.S. Department of Energy radiological protection standards in DOE Order 5480.1A (DOE, 1981a)~~. ~~AND ARE SUBJECT TO REGULATIONS UNDER SECTION 112 OF THE CLEAN AIR ACT~~

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6.2.1.5.4 Potentially adverse condition

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

This potentially adverse condition exists at the reference repository location. Design basis accidents at nearby facilities could result in temporary disruption of repository operations or closure.

Low-probability accidents at nearby hazardous facilities in the 200 Areas could result in temporary disruption of repository operations. The actual and projected releases from other nuclear installations in the vicinity of the proposed repository site are substantially less than the standards of 40 CFR 190 and draft 40 CFR 191, Subpart A.

Potentially hazardous installations and operations on the Hanford Site vicinity were identified during the Basalt Waste Isolation Project site screening studies (WCC, 1981). To the extent possible, those potential repository sites that were subject to effects of manmade hazards were eliminated from consideration. The residual risk from manmade hazards was judged to be acceptable.

6.2.1.5.5 Potentially adverse condition

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

This potentially adverse condition is not present at the reference repository location. Actual and projected radioactive releases are substantially less than federally established exposure standards.

Offsite installations subject to 40 CFR 190 (EPA, 1977) and 40 CFR 191, Subpart A, (EPA, 1982), include commercial nuclear fuel cycle facilities planned or in operation at the Hanford Site. In addition, the U.S. Department of Energy operated nuclear facilities subject to DOE Order 5480.1A (DOE, 1981a) are in operation or in the planning stages. During routine operations, the calculated maximum individual annual dose commitment due to current and projected commercial facilities and the U.S. Department of Energy operated nuclear facilities (including estimated repository emissions) is approximately 3.3 millirems (see Subsection 6.2.1.5.2). This value is substantially less than the annual 25-millirem exposure limit set by the U.S. Environmental Protection Agency.

6.2.1.5.6 Disqualifying condition

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

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The reference repository location is not disqualified on the basis of this disqualifying condition. The proximity of the reference repository location to existing potentially hazardous and nuclear defense facilities is not expected to pose irreconcilable conflicts. From a siting standpoint, many of the attributes of the Hanford Site, particularly those associated with its comparative remoteness, also support its potential suitability as a repository site. Sufficient area exists within the reference repository location to allow a buffer zone between the proposed repository surface facilities and the 200 West Area, the nearest of the potentially hazardous and defense-related activity areas.

During construction, operation, closure, or decommissioning of a repository, the principal potential hazard from nearby facilities would result from the accidental release of ~~toxic gases or~~ radioactive particulates. Such an event could cause the temporary suspension of repository operations under adverse meteorological conditions, but would not permanently impair construction work or repository performance. Nearby defense nuclear facilities are potential military targets; therefore, an effective security force is utilized to protect these facilities. ~~Location of a repository at the~~ reference repository location would benefit from the existing security measures already in place at the Hanford Site.

Design basis accidents at nearby nuclear defense-related facilities could result in temporary disruption of repository construction, operations, closure, or decommissioning. Low probability accidents at nearby potentially hazardous facilities in the 200 Areas could result in temporary disruption of repository construction and (or) operation.

The actual and projected releases from these nearby facilities are substantially less than the standards of 40 CFR 190 (EPA, 1977) and draft 40 CFR 191, Subpart A (EPA, 1982).

6.2.1.5.7 Conclusions on qualifying condition

The available evidence does not support a finding that the site is not likely to meet the offsite intallations and operations qualifying condition. Major factors which support this conclusion are summarized below:

- A screening process was used to select the candidate repository site that addressed and avoided potentially adverse effects from nearby facilities and manmade hazards.

- Actual and projected radioactive releases from the U.S. Department of Energy-operated nuclear facilities are substantially less than federally established exposure standards.

Specific uncertainties related to the above major supporting factors include:

- The presence of other nuclear installations and operations subject to requirements of 40 CFR 190 and 40 CFR 191.

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- Design basis accidents at nearby nuclear defense-related facilities that could result in temporary disruption of repository construction, operations, closure, or decommissioning.

6.2.1.6 Environmental Quality (Section 960.5-2-5)

6.2.1.6.1 Qualifying condition

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

6.2.1.6.2 Evaluation process

The reference repository location is situated on the U.S. Department of Energy-controlled 1,500-square kilometer (570-square mile) Hanford Site, which has been dedicated to nuclear activities since 1943. Environmental analyses conducted for the U.S. Department of Energy existing nuclear activities ~~suggest~~ indicate that compliance with environmental laws and regulatory requirements would not be a problem if a repository is located at the Hanford Site (ERDA, 1975; DOE, 1982a, 1983a). The Hanford Site is not located within the boundaries of a significant nationally protected natural resource. Construction and operation of a repository would not be inconsistent with existing land use plans and impacts associated with these activities would be relatively minor. No adverse environmental effects, which cannot be mitigated, have been found (see Section 5.2).

6.2.1.6.3 Favorable conditions

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

The reference repository location is anticipated or projected to meet all procedural and substantive environmental requirements in this favorable condition.

The U.S. Department of Energy, through the Generic Requirements for a Mined Geologic Disposal System (DOE, 1984), has established a policy to assure incorporation of environmental protection goals in the formulation and implementation of a repository system. Given this philosophy and the long-lead time to repository construction activities, the U.S. Department of Energy does not anticipate any problems in meeting procedural and

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substantive environmental requirements applicable to the site and the proposed activities. ~~A listing of some of these requirements is as follows:~~ A preliminary list of laws and other legal requirements which may apply to a repository at the reference repository location is set forth below:

- National Environmental Policy Act of 1969 (Public Law 91-190).
- Nuclear Waste Policy Act of 1982 (Public Law 97-425).
- Endangered Species Act of 1973 (Public Law 93-205, ~~16 USC 1531, et seq.~~).
- Fish and Wildlife Coordination Act, 16 USC Section 661, et seq.
- The Clean Air Act of 1963 (Public Law 97-23, ~~42 USC 1857, et seq.~~)
- State of Washington Plan for Implementation of the Clean Air Act.
- Noise Control Act of 1972 (Public Law 92-574, ~~86 Stat. 1234~~).
- National Historic Preservation Act, 16 USC Section 470 et seq.
- Resource Conservation and Recovery Act of 1976 (Public Law 94-580, ~~42 USC 3251, et seq.~~).
- Archaeological Resources Preservation Act, P.L. 96-95, 16 USC Section 470aa.
- ~~Federal Water Pollution Control Act~~ The Clean Water Act (Public Law 97-117, ~~33 USC 1251~~).
- Regulations of the Benton-Franklin-Walla Walla Counties Air Pollution Control District.

why here and not here?

6.2.1.6.4 <u>Favorable condition</u>

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

Based on available data, it is likely that potential adverse environmental impacts can be mitigated to an insignificant level for a proposed repository at the reference repository location.

It is projected that this favorable condition will be met by the reference repository location. Current information suggests that through compliance with applicable environmental regulations the environment will be protected during all phases of repository activity.

The potential for significant adverse environmental impact of locating a repository on the Hanford Site is discussed in Section 5.2. Information currently available leads the U.S. Department of Energy to believe that a repository can be constructed and operated at the Hanford Site in ~~the~~ a manner that assures that the environment will be adequately protected in compliance with this guideline. A final conclusion will be reached after additional environmental studies are conducted. The repository would be designed to mitigate any remaining environmental impacts to the extent reasonably achievable and to meet applicable regulations. Detailed documentation of site acceptability under this guideline would be included in the environmental impact statement accompanying the Site Recommendation Report if the Hanford Site is ultimately selected by the U.S. Department of Energy for recommendation to the President of the United States as a repository site.

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6.2.1.6.5 Potentially adverse condition

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

The reference repository location is not projected to be in major conflict with Federal, State, or local environmental regulations; therefore, this potentially adverse condition does not apply.

Environmental analyses conducted for the U.S. Department of Energy existing nuclear activities on the Hanford Site (ERDA, 1975; DOE, 1982a, 1983a) suggest that compliance with applicable environmental requirements will not be a problem if a repository is located at the Hanford Site.

6.2.1.6.6 Potentially adverse condition

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

The reference repository location is not projected to create significant adverse environmental impacts that cannot be avoided or mitigated.

The potential significant adverse environmental impact of locating a repository on the Hanford Site is discussed in Section 5.2. Currently, there are no projected significant adverse environmental impacts that cannot be avoided or mitigated. Plans for repository activity will take into account potential impacts and mitigation measures will be factored into repository design decisions.

6.2.1.6.7 Potentially adverse condition

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

This potentially adverse condition is not present at the reference repository location due to the present use, ownership, and location of the potentially acceptable site.

The reference repository location is situated on the U.S. Department of Energy 1,500-square kilometer (570-square mile) Hanford Site, which has been dedicated to nuclear activities since 1943. The presence of a repository on the Hanford Site does not present any significant adverse environmental impacts to any nationally protected natural resources. For more information, see detailed discussion on disqualifying condition in this technical guideline (see Subsection 6.2.1.6.11) and in the Site Characterization Report for the Basalt Waste Isolation Project (DOE, 1982e)

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6.2.1.6.8 Potentially adverse condition

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

This potentially adverse condition does not exist at the reference repository location since there are (1) no significant protected resource areas within or adjacent to the reference repository location, and (2) no significant adverse environmental impact from repository activities are projected.

There are no significant State or regionally protected resource areas in the vicinity of the reference repository location. The presence of a repository on the Hanford Site would not impact any such area due to the proposed repository location on the U.S. Department of Energy-controlled Hanford Site. For more information, see detailed discussion on disqualifying condition (see Subsection 6.2.1.6.11) in this technical guideline in the Site Characterization Report for the Basalt Waste Isolation Project (DOE, 1982e).

6.2.1.6.9 Potentially adverse condition

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

This potentially adverse condition is not present at the reference repository location since there are (1) no significant Native American resources within or immediately adjacent to the reference repository location, and (2) no significant adverse impacts are projected for resources distant from the reference repository location.

In 1981 and again in 1982, archaeological field surveys were conducted to intensively investigate the reference repository location. These studies concluded that none of the repository undertakings will have an effect on significant Native American cultural resources (Rice, 1984a, 1984b). Therefore, although there are areas of significant native American resources on the Hanford Site, the distance of the repository from these resources indicate there will be no projected significant adverse environmental impacts.

6.2.1.6.10 Potentially adverse condition

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

This potentially adverse condition is not present at the reference repository location since there are no known threatened or endangered species inhabiting the site.

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At this time, there are no state or federally recognized threatened or endangered plant or animal species known to inhabit the reference repository location. There are, however, a few species that are federally/state recognized (e.g., bald eagle) or state recognized (candidates for Federal listing; e.g., Ferruginous hawk) that do ~~migrate~~ NEST ON OR NEAR THE RRL ~~through the Hanford Site~~ (see Subsection 3.4.2.5). Observations for their occurrence, and the presence of critical habitat, within the proposed repository site will continue to determine if the species will be compromised by the repository or its support facilities (see Section 4.1).

6.2.1.6.11 Disqualifying conditions

"Any of the following conditions shall disqualify a site:

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

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

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

The siting of a repository at the reference repository location is not projected to have unacceptable adverse impacts on the quality of the environment. Two things that serve to minimize potential environmental impacts are: (1) the remoteness of the reference repository location from human habitation, and (2) the absence of any federally recognized threatened and endangered species at the repository location. Significant Federal or State protected resources do not exist at or near the reference repository location; hence, no conflicts exist.

The reference repository location is not disqualified as a potentially acceptable site due to environmental quality concerns. Little or no uncertainty is related to the evaluation of this disqualifier.

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The reference repository location is situated on the U.S. Department of Energy 1,500-square kilometer (570-square mile) Hanford Site, which has been dedicated to nuclear activities since 1943. Environmental analyses conducted for existing nuclear activities administered under the U.S. Department of Energy suggest that compliance with applicable environmental laws and regulatory requirements would not be a problem if a repository is located at the Hanford Site. No adverse environmental effects that threaten the health or welfare of the public or the quality of the environment, which cannot be mitigated, have been found (ERDA, 1975, pp. III.1-1 through III.1-47; DOE, 1982a, 1982c, 1983a). Also, the Puget Sound Power & Light Company and the Washington Public Power Supply System have independently conducted environmental analyses at the Hanford Site for the purpose of siting, constructing, and operating nuclear power plants. No major environmental impacts, which could not be mitigated, were identified (PSPL, 1981, pp. 4-i through 4.5-5; WPPSS, 1981b, pp. 4.1-1 through 4.5-2). Impacts associated with building a repository on the Hanford Site are discussed in Chapter 5.

Impacts associated with building a repository on the Hanford Site are projected to be confined to a local area (i.e., impacts are limited to a specific area on the Hanford Site). Major site construction impacts would be associated with surface support facilities for the repository. Repository related development away from the repository site would consist of transportation facilities, utilities, and the visitors center.

Transportation to the repository site would be provided by an access road from Route 240 and by connections to the existing Hanford Site road and railroad networks (see Section 3.1.5). Rail traffic, originating at the Burlington Northern Railroad yard in Pasco, would be transferred at the Hanford Site boundary to Hanford locomotives. A helicopter landing pad would also be provided at the reference repository location.

Incoming utilities would consist of water, electric power, and telephone. Raw water would be supplied from the Columbia River by an existing river pump station, which would be modified by the addition of new pumps and other appurtenant equipment. A new buried pipeline would connect these pumps to the repository site. Two new 13.8-kilovolt transmission lines, routed over separate parallel rights-of-way, would connect the repository to the existing Hanford Site power system. A new overhead telephone line would connect the repository to the Hanford Site telephone network.

A visitors center will be sited to afford access to the public.

By making connections with existing Hanford Site facilities, environmental impacts away from the repository site would be minimized. Also, prior to decisions regarding construction, environmental evaluations would be conducted and used as input to the final decisions. Construction practices to minimize impacts would be employed including dust suppression and soil stabilization. ~~Typically,~~ impacts associated with a repository would be no greater than those associated with other major construction projects on the Hanford Site (PSPL, 1981, pp. 4-i through 4.5-5; WPPSS, 1981b, pp. 4.1-1 through 4.5-2).

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BASED ON CURRENT DESIGN (SECTION 5.1.2)

The repository site would consist of an 80-hectare (200-acre) central process area located over and contained within the surface projection of the 544-hectare (1,334-acre) subsurface facility. Surrounding the projection of the subsurface facility to the surface would be a 2-kilometer (1.3-mile) control zone with an area of approximately 3,840 hectares (9,000 acres). The total area enclosed by the outside boundary of the control zone would be approximately 4,247 hectares (10,500 acres). The entire central process area would be surrounded by a double security fence (see Fig. 5-7).

~~(Based on current design (Section 5.1.2))~~

The major construction impacts at the repository site would be the selective clearing and grading of over 80 hectares (200 acres) of shrub-steppe terrain (i.e., all of the central process area plus an area outside the central process area for a parking lot, helicopter landing pad, and a mine-water percolation pond). Any topsoil stripped at this time would be stockpiled for future use and planting. Throughout the design, construction, and operation of the repository, every effort would be made to achieve an environmental balance that results in minimal damaging effect on wildlife. The removal of vegetation would be minimized. Ongoing environmental monitoring continues to show no threatened or endangered species residing within the proposed repository site.

Following clearing and grading, the culverts, drainage structures, and the lower, large-diameter storm sewers would be installed. Excavations and embankments would be formed; storm drainage ditches and structures would be constructed. Dust and erosion control measures would continue during the entire construction phase until final paving, erosion control, and planting are provided.

The remoteness of the site from human habitation and from occupied Hanford Site facilities would minimize the effects of any high construction noise levels. Effective muffler systems would be used on heavy equipment during construction to minimize adverse environmental impacts. Impacts on members of the general public would meet the requirements of the Noise Control Act of 1972.

At this time, there are no federally recognized threatened or endangered animal species or their critical habitats known to occur within the reference repository location. However, although not common within the reference repository location area, the bald eagle (Haliaeetus leucocephalus), which is a threatened bird species, and the peregrine falcon (Falco peregrinus), an endangered species, (FWS, 1980, pp. 33768 through 33781) have been sighted infrequently within the area boundaries during field investigations. Three additional bird species that occur within the reference repository location area are now being considered as potential candidates for protection on the Federal threatened and endangered species list. These are the ferruginous hawk (Buteo regalis), Swainson's hawk (Buteo swainsoni), and the long-billed curlew (Numenius americanus), all of which nest within or near the reference repository location area. Although not yet given official protection, these species

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are being included in biological investigations. Every effort has been and will continue to be made to minimize impacts on critical habitat during site characterization activities.

The reference repository location is not located within the boundaries of a significant nationally protected natural resource (see Fig. 3-28) nor would activities at the reference repository location irreconcilably conflict with designated uses of any protected resources encompassed by the disqualifying criteria. Some areas of the Hanford Site are managed under a multipurpose concept by the U.S. Department of Energy, the primary purpose of which is to act as a buffer zone for the U.S. Department of Energy nuclear activities. The closest area is 130 square kilometers (50 square miles) of Hanford Site lands north of the Columbia River, designated as the Saddle Mountain National Wildlife Refuge and managed under revocable permit from the U.S. Department of Energy by the U.S. Fish and Wildlife Service. There are also seven islands within the Hanford reach of the Columbia River, which are part of the McNary National Wildlife Refuge. The reference repository location is approximately 7 kilometers (4 miles) from the Saddle Mountains Wildlife Refuge and 26 kilometers (16 miles) from the McNary National Wildlife Refuge. The Hanford reach of the Columbia River, which includes the entire length of the river within the Hanford Site, is the last free-flowing section of the Columbia River. This portion of the river has been proposed as a potential wild, scenic, or recreational river under the Wild and Scenic Rivers Act (USDA, 1970, p. 16693). The Arid Lands Ecology Reserve on the Hanford Site is a 310-square kilometer (120-square mile) tract administratively set aside as a buffer zone for the protection and study of native plant and animal ecosystems, consistent with nuclear activities on the Hanford Site. This area is managed by the U.S. Department of Energy. Repository support facilities or the restricted area would not be located within the boundaries of this reserve. The presence of a repository on the Hanford Site is not expected to present irreconcilable differences with the previously designated use of these areas since they were established to act primarily as buffer zones for nuclear activities on at the Hanford Site.

The closest state-managed area is 220 square kilometers (85 square miles) of Hanford Site land north-northeast of the Columbia River, the Wahluke Wildlife Recreation Area (see Fig. 3-37). This area, approximately 17 kilometers (11 miles) from the reference repository location, is managed for the U.S. Department of Energy under revocable permit by the State of Washington Department of Game. The presence of a repository on the Hanford Site is not expected to present irreconcilable differences with the previously designated use of this area. This area was set aside by the U.S. Department of Energy, and continues to serve as a buffer zone around the U.S. Department of Energy operations on the Hanford Site.

Radioactive emissions and associated estimates of dose rates to the public from repository facilities that might be located at the Hanford Site have been calculated. These calculations are preliminary since preclosure safety analyses have not been completed. Preclosure radiological safety is discussed in Subsections 6.2.2.1 and 6.4.1.4.

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Shipments of nuclear waste to the repository would be in accordance with applicable Federal regulations. Currently, the U.S. Nuclear Regulatory Commission and the U.S. Department of Transportation regulate the transportation of radioactive materials. Transportation and packaging criteria and standards are outlined in the Code of Federal Regulations (NRC, 1982b, pp. 71-1 through 71-23; DOT, 1981). The environmental impacts of transportation activities have been addressed (NRC, 1977, pp. 1 through 892; Wilmot et al., 1983, pp. 3 through 63). The normal radiological impacts of nuclear waste transportation are small in comparison to naturally occurring ambient radiation levels. The potential radiological consequences of transportation accidents are controlled primarily by the highly damage-resistant shipping containers required under current Federal regulations. Although these radiological impacts are of less significance, they are directly related to transportation distance. The localized environmental impacts due to transportation will be determined in part by the availability and capacity of existing highway and rail routes and the existence of heavily populated areas along these routes (see Subsection 6.2.1.8). If selected as a repository, the environmental impact statement, which will be prepared to support the Site Recommendation Report, will provide detailed information on the environmental impacts of waste transportation.

6.2.1.6.12 Conclusion on qualifying condition

~~The available evidence does not support a finding that the site is not likely to~~ meets the environmental quality qualifying condition. Major factors which support this ~~preliminary~~ finding are:

- Environmental analyses conducted for the U.S. Department of Energy existing nuclear activities suggest that compliance with environmental laws and regulatory requirements would not be a problem if a repository is located at the Hanford Site.

- The reference repository location is not within the boundaries of a significant nationally protected natural resource.

- Construction and operation of a repository would not be inconsistent with existing land use plans.

- No adverse environmental effects that threaten the quality of the environment, which cannot be mitigated, have been found.

- There are no federally recognized threatened or endangered animal species or their critical habitats known to occur within the reference repository location.

- There are areas of significant native American resources on the Hanford Site; however, the distance of the repository from these resources indicate there will be no significant adverse impacts.

- Significant Federal or State protected resources do not exist at or near the reference repository location; hence, no conflicts exist.

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Uncertainties associated with these preliminary findings include the following:

- Impact projections are based on repository design in the conceptual stage.
- Three avian species present at the reference repository location are candidates for Federal listing as threatened or endangered species.

6.2.1.7 Socioeconomic Impacts (Section 960.5-2-6)

6.2.1.7.1 Qualifying condition

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

6.2.1.7.2 Evaluation process

The area surrounding the Hanford Site had an unusual growth history from 1973 to 1981 that has been dominated, and primarily influenced, by growth in energy-related projects and the construction of nuclear power plants. After 1981, the rapid and unanticipated slowdown of major construction projects dramatically reversed a decade-long pattern of exceptionally rapid growth.

The socioeconomic impacts of a repository on the Hanford Site are not expected to be significant. The overall size of the repository work force and the resource requirements of the project are quite small (see Section 5.1) relative to the scope of development activities the area has experienced in the past (see Section 3.6). The work force requirements during the first 20 years of repository development imply annual rates of change in projected baseline employment and population of only about 1 percent per year over the first 5 years of repository construction. This rate of growth could be absorbed without significant adverse impacts.

Detailed information on expected effects of repository activities on socioeconomic conditions are presented in Section 5.4. Additional information can be found in the report entitled Nuclear Waste Repository in Basalt: Preliminary Socioeconomic Assessment, prepared by Cluett et al. (1984).

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6.2.1.7.3 Favorable condition

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

This favorable condition is met by the communities where repository support staff could reside. The local communities presently have existing services to absorb project-related population changes.

Due to the extraordinary high growth experienced in the area between 1973 and 1981, planning and development led to increased capacities in community services and housing (see Section 3.6). However, the largely unanticipated cutback in the job market in 1981 has left the area with capacities beyond the needs of the current conditions (Cluett et al., 1984). The area surrounding the Hanford Site is expected to have a large absorptive capacity into the 1990's (see Section 5.2.3). This means that employment and population growth caused by repository activities can be readily assimilated by the area. Roads, schools, utilities, and housing are all expected to have the ability to accept additional people in the area without stress.

6.2.1.7.4 Favorable condition

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

This favorable condition is not met since miners are not locally available.

Detailed information on the composition of the needed work force, especially during repository construction, is currently not available. However, since the size of the construction force even during the peak years is only approximately 1,100, it is unlikely to exceed the available capacity of construction workers with various skills in the region. (Subsection 3.6.1 addresses the large local population growth observed between 1973 and 1981 due to construction activity on the Washington Public Power Supply System nuclear power plants.) Lack of mining activity in the area means that miners are not likely to be available locally. However, the relatively small number of in-migrating miners (less than 700) required, compared to the population of the area surrounding the Hanford Site, will have little or no impact on the socioeconomic conditions of the region.

6.2.1.7.5 Favorable condition

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

This favorable condition is met since the projected employment, business, and community opportunities will strengthen the local community.

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The employment and population growth implied by the repository activities should represent an opportunity for the area to reach fuller use of its human and physical resources, which are presently under utilized due to the unanticipated slowdown of major construction projects in the area.

6.2.1.7.6 Favorable condition

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

The local economy will not be substantially disrupted by repository related needs; therefore, this favorable condition is met.

A repository on the Hanford Site will likely have the effect of providing additional stability to economic conditions in the area as well as to the perception by residents of stability and the relative permanence of employment opportunity (see Subsection 5.2.3.2).

6.2.1.7.7 Potentially adverse condition

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

This potentially adverse condition is not present since the affected community can absorb these community and governmental impacts.

Due to the recent slowdown in the economic sector of the affected area, there is an under utilization of community services, housing, schools, etc. (see Section 3.6.3). Therefore, a repository on the Hanford Site ~~may~~ represents an opportunity for the area to reach fuller utilization of its resources. Socioeconomic impacts of a repository are projected to be positive.

6.2.1.7.8 Potentially adverse condition

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

This potentially adverse condition is present in the affected area. An adequate labor force of miners is not presently available.

The affected area has a highly skilled labor force available, with the exception of miners (see Section 3.6.2). Miners will need to in-migrate.

6.2.1.7.9 Potentially adverse condition

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

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This potentially adverse condition is not present in the affected area. The Federal Government already owns the necessary water rights for development activities at the reference repository location.

There is no need for repository-related purchase or acquisition of water rights since the ~~Federal Government owns the water rights for the Hanford Site, which include the reference repository location~~. Raw water will be supplied from the Columbia River by an existing pump station to meet the average demand of 2.6 cubic meters per minute (700 gallons per minute) (see Subsection 6.3.3.3.5).

6.2.1.7.10 Potentially adverse condition

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

This potentially adverse condition does not apply to the affected area since the existing economy can absorb the community, business, and governmental services related to repository construction and operation.

The potential for major disruptions of primary sectors of the economy of the affected area is very low (see Section 5.2.3).

6.2.1.7.11 Disqualifying condition

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

Based on expected repository construction methods, operation designs and waste isolation performance following closure, a repository built in the reference repository location is not anticipated to significantly degrade water quality or reduce water quantities from major sources of offsite supplies. Therefore, the evidence does not support a finding that the reference repository location is disqualified.

Chapter 5 identified the surface and subsurface facilities to be constructed in support of repository development in addition to examining the environmental effects of locating a repository at the reference repository location. This information along with discussions in the rock characteristics and the performance assessment sections of Chapter 6, suggest that the only potential for significantly degrading water quality results from radionuclide releases following closure. Shaft construction is designed to permanently seal off aquifers using grouts and muds. Repository room construction and operations would take place within a basalt flow interior, away from ground-water sources. Therefore, routine repository construction and operation should not degrade water quality.

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The capability of basalt in the reference repository location to prevent radionuclides from degrading water quality depends on a number of factors which include: waste isolation capability of the engineered barriers (e.g., waste package and repository seal system), ground-water flow paths and travel times, radionuclide inventory, radionuclide half-life, and radionuclide solubility and sorption. The preliminary performance assessment results given in Section 6.4.2 address these factors along with uncertainties in the existing data base and modeling process. ~~These studies suggest that only~~ two radionuclides present in the waste inventory, carbon-14 and iodine-129, are likely to significantly contribute to waste releases. However, once released, these radionuclides are not expected to exceed the allowable release limits proposed by the U.S. Environmental Protection Agency (EPA, 1982). Thus, preliminary analyses suggest that basalt has the capacity to isolate radionuclides and prevent significant degradation of ground-water quality.

As noted in Section 6.3.1.1.11, the ground-water currently existing at the depth of the proposed repository is not suitable for human consumption or crop irrigation. These deep ground waters contain natural chemical constituents (e.g., high fluoride, high sodium, and high salinity concentration) which require removal or treatment before use.

The second part of the above disqualifying statement deals with impacting water quantities. Sections 6.2.1.7.9 and 6.3.3.3.5 address the topics of water right ownership and water availability. In summary, these sections state that the U.S. Department of Energy presently ~~owns~~ the Hanford Site water rights and the water quantity needed for repository construction, operation, and closure is a small percentage of the current water use at the Hanford Site. Therefore, no significant reduction of water quantity from major sources of offsite supplies is expected.

6.2.1.7.12 Conclusion on qualifying condition

~~The available socioeconomic evidence does not support a finding that the site is not likely to~~ meets the qualifying condition. This preliminary finding is based on the following major factors:

- Projected employment and population growth caused by repository activities can be readily assimilated by the area. Roads, schools, utilities, and housing are all expected to have the ability to accept additional people in the area without stress.

- Projected employment, business, and community opportunities will strengthen the local community.

- Growth in the current primary sections of employment are expected to continue in the future without disruption due to repository-related needs.

- There is no need for repository-related purchase or acquisition of water rights since the Federal Government owns the water rights for the Hanford Site, which includes the reference repository location.

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- A technically qualified labor force (except for hard-rock miners) is located nearby in the Tri-Cities and the surrounding areas.

Some of the relevant data for socioeconomic evaluations contain uncertainties requiring that assumptions be made, and thus result in subjective evaluations. Among the sources of uncertainty are the following:

- Detailed information on the size and composition of the needed work force, especially during repository construction, is currently not available.

- Future characteristics of the socioeconomic conditions in the affected area are difficult to accurately forecast.

6.2.1.8 Transportation (Section 960.5-2-7)

6.2.1.8.1 Qualifying condition

"The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (i) will not conflict irreconcilably with the previously designated use of any resource listed in 960.5-2-5(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."

6.2.1.8.2 Evaluation process

The major components of the evaluation process for this guideline are discussed below. Additional information on transportation is contained in the Transportation Appendix.

6.2.1.8.2.1 Relevant Data. Evaluation of the Hanford Site's compliance with the transportation guideline is based upon a compilation of information on existing transportation systems and repository planning. Much of this information is presented or cited elsewhere in this document (see Section 3.1.5). The information relevant to the transportation guideline evaluation can be categorized as follows:

1. Characteristics of existing local and regional transportation routes.

2. Current transportation capabilities and practices.

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3. Transportation cost and risk analyses for potentially acceptable repository sites.

4. Conceptual planning for repository access routes.

5. Projected numbers and capacities of shipments.

6.2.1.8.2.2 Assumptions and data uncertainty. Some of the relevant data for transportation evaluations contain uncertainties requiring that assumptions be made, and thus result in subjective evaluations. Among the sources of uncertainty are the following:

1. Repository design and the design of repository access routes are in a conceptual stage.

2. Future characteristics of the transportation system (e.g., physical condition, traffic density, etc.) at the time of repository operation are difficult to accurately forecast.

3. The percentages of nuclear waste shipments by a given mode (i.e., truck, rail) or over a specific route cannot be accurately predicted and are influenced by many factors outside the jurisdiction of repository planners.

4. Design information on new generations of nuclear waste shipping casks ~~needed~~ which are planned for shipments to a repository is not yet available.

6.2.1.8.2.3 Analysis. Specific information presented and cited elsewhere in this document (see Sections 3.5 and 5.2.2) has been used, where possible, to evaluate the favorable, potentially adverse, and qualifying conditions stated in the transportation guideline. The analyses are qualitative to a degree consistent with the data uncertainties identified above, and in some cases rely heavily on the judgments of professionals familiar with transportation matters.

6.2.1.8.3 Favorable condition

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

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

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

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

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

(v) Such routes bypass local cities and towns."

This favorable condition is met by the reference repository location, since proposed access routes possess all of the five favorable characteristics listed.

The proposed access routes from local existing highways and railroads to the repository site are short extensions of the existing highway and railroad networks that serve the Hanford Site (see Fig. 3-42 through 3-45). These routes are each approximately 4.8 kilometers (3 miles) in length. These access routes are economical to construct because they are short and surface conditions (e.g., soil bearing capacity, topography, drainage, etc.) are such that only minimal grading or other surface preparation work is required. Federal condemnation is not required to acquire rights-of-way for the access routes, since the proposed access routes lie entirely within the Hanford Site, which is already controlled by the Federal Government.* (See also discussions under Subsection 6.2.1.3, "Site Ownership and Control.") No tunnels or bridges would be required, and the topography is sufficiently flat that little, if any, cutting and filling would be required. The flat topography, together with the abundant open land surrounding the proposed repository site, permits access-route layouts that are free of sharp curves, steep grades, and potential for landslides or rockslides. Proposed access routes from existing highway and railroad networks are remote from cities and towns.

6.2.1.8.4 Favorable condition

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

This favorable condition ~~appears to be~~ is met, since the proposed repository location is within approximately 4.8 kilometers (3 miles) of local highways and railroads that provide access to regional highways and railroads and that do not currently require significant upgrading or reconstruction to meet repository transportation needs.

The response to this favorable condition addresses proximity to both local and regional highways, since there is not a clear distinction between local and regional highway routes for the Hanford Site. The existing highway route of approximately 40 kilometers (25 miles), which is

*If alternate highway access from Route 240 to the west of the proposed repository site is also provided, only the first few feet of such access would lie outside the Hanford Site boundary. ~~Negotiation with the State of Washington Highway Department would be required to provide this segment.~~ The Department of Energy has the right to provide a new intersection with Route 240 under existing easements; such an intersection would be designed to meet the State of Washington design standards.

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contained within the boundaries of the Hanford Site, could be considered to be a local route from the standpoint that its use is restricted to official Hanford Site business rather than travel by the general public. However, for the analysis of this favorable condition, which really addresses the lengths of access routes that must be constructed, it is immaterial whether these access routes connect to local or regional routes.

As described in Section 3.1.5, the local and regional highway network provides ready access from the vicinity of the proposed repository site to the two major interstate highways on which materials being transported to the repository by truck could travel (Interstate 90 to the north and Interstate 84 to the south). These highways routinely carry a volume of truck traffic that is large in comparison to the expected traffic enroute to the reference repository location. Weight restrictions below legal-weight truck limits are unlikely to be imposed; overweight truck shipments by special permit will be avoided as a matter of policy. Thus, no significant upgrading or reconstruction of local and regional highways, other than construction of the three-mile access road to the repository, appears justified specifically on the basis of transportation associated with the repository. Specific local and regional routes deemed acceptable for radioactive waste shipments will be identified by the State of Washington in accordance with the U.S. Department of Transportation Regulation HM-164 (see Transportation Appendix). Regional highway access to Interstate 84 will soon be improved by new segments of Interstate 82 and Interstate 182, which are currently under construction. The new Interstate 82 will connect directly with Interstate 84 and with the new Interstate 182 together these new interstate highways will permit shipments via interstate highways all the way to the south end of Richland, Washington, from Interstate 84.

The local railroad network, also described in Section 3.1.5, provides ready access to two major railroads with classification and switching yards at Pasco, Washington, and Hinkle, Oregon. Analogous to the existing local highway situation, neither shipment volumes nor railcar weights associated with repository shipments appear to justify significant upgrading or reconstruction of the local railroad networks. A 4.8-kilometer (3-mile) access spur from the existing railroad network to the repository site is needed.

6.2.1.8.5 Favorable condition

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

This favorable condition is met for all three shipping modes mentioned (highway, rail, and inland navigable waterway).

The response to this favorable condition at least partially relies on the response to the previous favorable condition, since there is not a clear distinction between local and regional routes for the Hanford Site. A literal interpretation of this favorable condition for highway routes is that it addresses lengths of access routes, plus lengths of local routes, to reach a regional route. As noted earlier, the needed access route is approximately 4.8 kilometers (3 miles) and ~~an assumed local route (existing) through the Hanford Site is approximately 40 kilometers (25 miles) to the state highway~~ could be directly connected to a state highway (Route 24). Alternatively, a 4.8-kilometer (3-mile) access route ~~could be connected directly to a state highway (Route 240).~~ and an assumed local route (existing) through the Hanford Site is approximately 40 kilometers (25 miles) to the state highway.

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As described in Section 3.1.5, the proposed repository site has reasonable access to two major interstate highways. Access to Interstate 90 to the north and Interstate 84 to the south requires approximately 185 and 120 kilometers (115 and 75 miles), respectively, of travel over the local and regional highway network. Similarly, approximately 64 and 128 kilometers (40 and 80 miles) of rail travel over the local railroad network provides access to the main railway classification yards at Pasco, Washington and Hinkle, Oregon, respectively. Barge transport of radioactive materials is not intended, but repository equipment and construction and operating supplies could be transported up the Columbia River by barge. Transloading capability for barge shipments exists at a Port of Benton facility located approximately 11 kilometers (7 miles) from the proposed repository site.

6.2.1.8.6 Favorable condition

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

This favorable condition is met by virtue of the railroad service by two major railroads (Union Pacific and Burlington Northern) with switching capability at two nearby classification yards (see Fig. 3-42) (Pasco, Washington and Hinkle, Oregon).

Long-distance railroad shipments to the Tri-Cities, Washington, area can be transported over mainline railways that have few interchange points within the western states at which crew or equipment changes would be required. Transfer of railroad shipments from the railroad companies to the existing Hanford railroad system, which is operated by Rockwell Hanford Operations under contract to the U.S. Department of Energy, is performed ~~at an intertie a few miles southeast of Richland, Washington;~~ thus, only this one interchange point exists between the major classification yards and the proposed repository site (see Section 3.5).

6.2.1.8.7 Favorable condition

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

This favorable condition is not met by the reference repository location as long as truly comparable siting options exist at locations closer to the projected waste sources in the central and eastern United States (Fig. 6-2).

Total projected life-cycle transportation costs and risks for several potentially acceptable sites are shown in the Transportation Appendix and summarized in Chapter 7. Comparison of the tabulated cost and risk values show a range of approximately a factor of two; that is, transportation

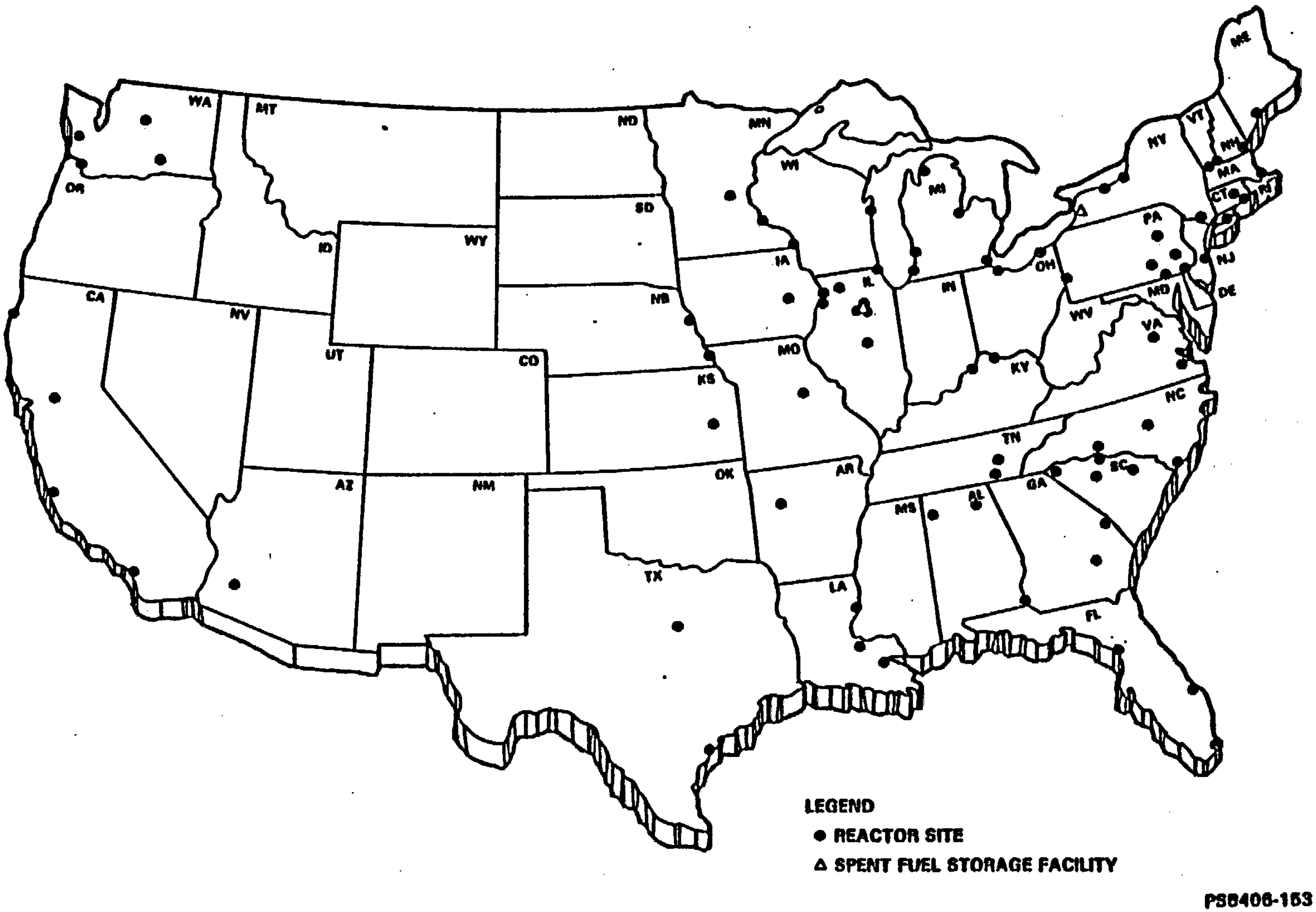

Figure 6-2. Location of existing and planned commercial reactors and storage facilities with light water reactor commercial spent fuel (taken from DOE, 1983c, p. 18).

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costs and risks for the most distant site (the Hanford Site) are about twice those of the site nearest to projected waste sources. The life-cycle transportation cost for the Hanford Site (roughly 2 to 6 billion dollars, depending on fuel cycle and transportation mode assumptions) is smaller than the estimated repository life-cycle cost of roughly 10 billion dollars. Population radiation exposures due to transportation are estimated to be no more than approximately 0.03 percent of those attributable to background radiation. Fatalities associated with transportation will increase no more than approximately 0.02 percent as a result of radioactive material transportation to a repository at the Hanford Site.

6.2.1.8.8 Favorable condition

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

This favorable condition could be satisfied for transportation to the reference repository location. For each transport mode (truck, rail, and barge), several competing companies already provide routine service to the Tri-Cities area.

The Tri-Cities area is served by 18 local, regional, and national trucking lines, 2 major railroad companies, and 7 major barge companies. Rail service from the Tri-Cities metropolitan area to the Hanford Site is provided by a U.S. Department of Energy contractor using U.S. Department of Energy-owned equipment and tracks. All of the commercial transportation companies, with the possible exception of a few small trucking firms, have the capability to handle waste shipments destined for the repository, as does the U.S. Department of Energy railroad.

6.2.1.8.9 Favorable condition

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

Since no legal impediments with regard to waste transportation now exist within the State of Washington or adjoining states, this favorable condition is satisfied by the reference repository location.

State legislation in Washington that would restrict shipments to a commercial radioactive waste disposal site located at the Hanford Site on land leased from the state was later ruled unconstitutional. Other than this legislative effort, no serious attempts to restrict radioactive waste transportation within Washington and adjoining states have been made.

6.2.1.8.10 Favorable condition

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

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This favorable condition appears to be met for waste shipments to the reference repository location. Plans, procedures, and capabilities for response to radioactive waste transportation accidents have already been developed by the State of Washington, in conjunction with previous radioactive material shipments.

Washington has strong radioactive material control programs and recognizes the State and local primary responsibility for responding to transportation accidents involving radioactive material. The State of Washington has established emergency teams and procedures for dealing with such accidents, and agreements with the U.S. Department of Energy regarding additional technical support, if needed. The Federal Emergency Management Agency is coordinating the development of a Federal response plan covering all types of radiological incidents, and has provided guidance to state and local governments for preparing their own radiological emergency response plans, including transportation accidents.

6.2.1.8.11 Favorable condition

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

This favorable condition is met by the region encompassing the reference repository location. Disruptions of transportation due to weather conditions are uncommon in the region. Major highway closures due to adverse weather are typically infrequent and of short duration.

The meteorology in the vicinity of the Hanford Site is described in Section 3.4.3. The truck transportation mode is the one most prone to interruption due to weather. The weather conditions in southeastern Washington most likely to cause highway closure are high-velocity wind gusts, causing poor visibility due to airborne dust and debris; and snow and (or) ice, causing poor traction for vehicles. Both of these conditions are generally seasonal (e.g., winds in spring; snow and ice in winter), but do not cause highway closures with sufficient frequency to be considered routine. These infrequent highway closures are typically short in duration (a few hours to a day).

6.2.1.8.12 Potentially adverse conditions

The potentially adverse conditions associated with the siting guideline for radioactive waste transportation are stated as follows:

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

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

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

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

None of these potentially adverse conditions apply to transportation of radioactive waste to the reference repository location. Each of the above potentially adverse conditions is addressed only briefly here. The first three characteristics are generally an antithetical statement of the selected favorable condition addressed in Subsection 6.2.1.8. A discussion of the fourth (local characteristic) is presented below.

Items (1) and (2) above address the costs, ease of construction, and potential hazards of truck and rail access routes. These access route characteristics were addressed in the statements concerning Favorable Condition (1) (see Subsection 6.2.1.8.3). The potentially adverse conditions are not present at the reference repository location, since the needed access routes are short, inexpensive and easy to construct, and free of terrain-related potential hazards.

Potentially Adverse Condition (3) pertains to the need for significant reconstruction or upgrading of existing local highways and railroads providing access to regional and national transportation systems. As indicated in the response to Favorable Condition (2) (see Subsection 6.2.1.8.4), the existing local highway and railroad routes appear to be adequate to handle the needs of the Tri-Cities area within the foreseeable future. The incremental transportation density attributable to a repository at the Hanford Site is small in comparison to the current traffic and, by itself, would not justify significant improvements to the existing local highways and railroads.

Potentially Adverse Condition (4) is similar in scope to Favorable Condition (5) (see Subsection 6.2.1.8.7), in that both pertain to transportation-related costs, environmental impacts, and risks to the public health and safety. However, Favorable Condition (5) addresses the effect of repository location relative to potential waste sources (i.e., transportation distances); whereas, Potentially Adverse Condition (4) addresses the possible effects of "local conditions." The major local condition that could adversely impact transportation costs would be a large distance from regional or national transportation networks to the reference repository site via local highways and railroads. As noted in the response to Favorable Condition (3), the proposed repository site is sufficiently close to major interstate highways (185 kilometers (115 miles)) and railroad classification yards (128 kilometers (80 miles)) that local transportation is a small fraction of total shipping distance. The local condition that could result in a locally high environmental impact or risk to public health and safety is a large exposed population,

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which can be expressed arithmetically as the cumulative product of shipping distance and population density. For the Hanford Site, the local highways and railroads providing access to regional or national transportation networks are reasonably short and pass through areas of low population density. Therefore, Potentially Adverse Condition (4) above is not considered to be a~~n~~ ~~exceptionally~~ negative factor in assessing suitability of the Hanford Site from a transportation standpoint.

6.2.1.8.13 Conclusion on qualifying condition

A final conclusion on the qualifying condition for transportation cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1).

The available evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition. Major factors that support this finding are:

- Access routes to the reference repository location would not pass through or otherwise conflict with any component of the National Park System, National Wildlife Refuge System, National Wilderness Preservation System, National Wild and Scenic Rivers System, or any comparably significant State-protected resource (reference to Section 960.5-2-5(d)(2) and (3) of the General Siting Guidelines (DOE, 1984a)).

- Access routes would have no undesirable features that would require unique design or construction methods or special features on transportation system components, including the transportation packaging.

- Environmental impact and risks to public health and safety of the proposed access routes are acceptably low, since these routes are short and pass only through areas of zero population density.

- Projected risks, costs, and other impacts of waste transportation have been considered in repository siting, and transportation operations shall be conducted in compliance with applicable regulations.

Specific uncertainties related to the above major supporting factors are as follows:

- The designs of the repository and its associated access routes are currently in a preliminary stage.

- Future characteristics of the transportation system cannot be accurately forecast.

- Future shipping cask designs have not yet been developed.

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- Specific future usage of specific transportation routes cannot be forecast.

- The transportation modal split (i.e., between truck and rail) cannot be accurately forecast at this time.

6.2.2 System guidelines

"The guidelines in this Subpart specify the factors to be considered in evaluating and comparing sites on the basis of expected repository performance before closure. The preclosure guidelines are separated into three system guidelines and eleven technical guidelines." This section specifically addresses Preclosure Radiological Safety (Section 960.5-1(1)) and Environment, Socioeconomics, and Transportation (Section 960.5-1(2)) System Guidelines.

6.2.2.1 Preclosure Radiological Safety (Section 960.5-1(a)(1))

6.2.2.1.1 Qualifying condition

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

6.2.2.1.2 Evaluation process

The following technical guidelines are relevant to the evaluation of this system guideline:

- Population Density and Distribution (Subsection 6.2.1.2).
- Meteorology (Subsection 6.2.1.4).
- Offsite Installations and Operations (Subsection 6.2.1.5).

During preclosure repository operations, the principal potential radiological exposure pathway for members of the public is through atmospheric release. Meteorological characteristics of the site affect the travel time, direction, and dispersion of radionuclides released from a repository during normal or abnormal operating conditions. Meteorological characteristics of the Hanford Site with respect to applicable qualifying conditions are described in Section 3.4.3.

The engineered features of the repository are designed to prevent or mitigate atmospheric releases of radioactivity. The quantity of radioactive releases during normal operations or as a result of hypothetical accident conditions are highly dependent on the types of waste handled and processing operations performed at the repository.

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Receipt and handling of prepackaged waste will involve negligible releases under normal operating conditions. Receipt and packaging of spent fuel assemblies will involve minor releases of fission gases, similar in kind to those experienced in spent fuel handling and storage facilities at nuclear power reactors (see Section 6.4.1).

The demography (see Subsection 6.2.1.2) of the area affects potential population doses from repository releases. Richland, Washington, (population 33,578) is the nearest population center to the reference repository location, at a distance of approximately 35 kilometers (22 miles), and is downwind of the prevailing winds from the northwest. The nearest public access in the vicinity of the reference repository location is at Route 240, which crosses the Hanford Site. Therefore, a hypothetical population dose would be attenuated by lateral dispersion over a 35-kilometer (22-mile) distance.

Site ownership and control is important from the standpoint of restricting access to areas that could place members of the public at risk. Because the reference repository location and surrounding Hanford Site are under the control of the U.S. Department of Energy, public access is restricted.

Compliance of the repository with radiological exposure criteria set forth in 40 CFR 191, Subpart A (EPA, 1982), will be judged along with contributing releases from other nearby commercial nuclear installations. Total estimated exposure to a maximum individual in the Hanford Site vicinity from all current and projected releases from commercial and defense nuclear installations and repository operations is approximately 3.3 millirems per year (see Subsection 6.2.1.5.2). The anticipated small releases from a repository, in addition to the contributing releases from other facilities, will represent a small fraction of the allowable 25-millirem annual individual exposure.

6.2.2.1.3 Conclusion on Qualifying Condition

A final conclusion on the qualifying condition for preclosure radiological exposures cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1).

The available evidence regarding preclosure radiological exposures does not support a finding that the site is not likely to meet the qualifying condition. Major factors that support this preliminary finding are summarized below:

- The nearest highly populated area is 35 kilometers (22 miles) from the reference repository location. There is no permanent population on the reference repository location. Due to the low population density of the surrounding area and the distance from the proposed repository site to highly populated areas, routine

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repository operations would not be expected to result in radiological exposure of the general public above applicable requirements.

- Doses to individuals working in the vicinity of the area are monitored to ensure compliance with applicable Federal standards.

- Existing meteorological conditions indicate that repository operations would not result in doses to the general public above allowable limits (see Subsection 6.2.1.4).

- The engineered features of the repository are designed to prevent or mitigate atmospheric releases of radioactivity. Repository emissions, under routine operating conditions, are not expected to contain radioactivity above natural background levels.

Specific uncertainties related to the major factors are summarized as follows:

- Dose calculations are based on a repository design in the conceptual stage.

- Atmospheric dispersion modeling has not been conducted for radionuclide releases at the reference repository location.

- The ~~presence of~~ releases from other nuclear installations and operations subject to requirements of 40 CFR 190 and 40 CFR 191 have not yet been precisely identified.

- The quantity of radioactive releases during normal operations or ~~as a~~ result of hypothetical accident conditions ~~are~~ highly dependent on the types of waste handling and processing operations performed at the repository.

6.2.2.2 Environment, Socioeconomics, and Transportation (Section 960.5-1(a)(2))

"The system elements pertinent to this guideline will in general consist of (1) the people who may be affected, including their lifestyles, sources of income, social and aesthetic values, and community services; (2) the air, land, water, plants, animals, and cultural resources in the areas potentially affected by such activities; (3) the transportation infrastructure; and (4) the potential mitigating measures that can be used to achieve compliance with this guideline."

6.2.2.2.1 Qualifying condition

"To the extent practicable, the repository and its support facilities shall be sited, constructed, operated, closed, and decommissioned to (1) protect the quality of the environment in the affected area and mitigate significant adverse environmental impacts, considering technical,

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social, economic, and environmental factors, and (2) protect the socioeconomic welfare of the general public in the affected area. The projected risks, costs, and other impacts of waste transportation shall be considered in repository siting, and transportation operations shall be conducted in compliance with applicable Federal regulations and with those applicable State and local regulations and ordinances that are consistent with Federal regulations."

6.2.2.2.2 Evaluation process

The following technical guidelines are relevant to the evaluation of this system guideline:

- Environmental Quality (Subsection 6.2.1.6).
- Socioeconomic Impacts (Subsection 6.2.1.7).
- Transportation (Subsection 6.2.1.8).

The evaluation of the reference repository location with respect to the disqualifying conditions of the Environmental Quality guideline has previously indicated that it is not a significant problem (see Subsection 6.2.1.6). The evaluation of qualifying conditions, favorable conditions, and potentially adverse conditions for environmental quality, socioeconomic impacts, and transportation were evaluated in Subsections 6.2.1.6, 6.2.1.7, and 6.2.1.8, respectively.

6.2.2.2.3 Conclusion on qualifying condition

A final conclusion on the qualifying condition for environment, socioeconomics, and transportation cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1).

The available evidence does not support a finding that the site is not likely to meet the qualifying condition on environment, socioeconomics, and transportation. Major factors which support this preliminary finding are summarized below:

- Environmental analyses conducted for the U.S. Department of Energy's existing nuclear activities suggest that compliance with environmental laws and regulatory requirements would not be a significant problem if a repository is located at the Hanford Site. X

- The reference repository location is not within the boundaries of a significant nationally protected natural resource.

- Construction and operation of a repository would not be inconsistent with existing land use plans.

- No adverse environmental effects that threaten the quality of the environment, which cannot be mitigated, have been identified.

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- There are no federally recognized threatened or endangered animal species or their critical habitats known to occur within the reference repository location.

- Significant Federal or State protected resources do not exist at or near the reference repository location; hence, no conflicts exist.

- Projected employment and population growth caused by repository activities can be readily assimilated by the area. Roads, schools, utilities, and housing are all expected to have the ability to accept additional people in the area without stress.

- A technically qualified labor force (except for hard-rock miners) is located nearby in the Tri-Cities and the surrounding areas.

- Growth in the current primary sections of employment are expected to continue in the future without disruption due to repository-related needs.

- There is no need for repository-related purchase or acquisition of water rights since the Federal Government owns the water rights for the Hanford Site, which includes the reference repository location.

- The access routes to the reference repository location would have no undesirable features that would require unique design or construction methods or special features on transportation system components, including packaging.

- The environmental impact and risks to public health and safety of the proposed access routes are acceptably low, since these routes are short and pass only through areas of zero population density.

- The proposed repository is within 4.8 kilometers (3 miles) of local highways and roads that have access to regional and national highways and railroads and do not require significant upgrading.

- Plans, procedures, and capabilities for response to waste transportation accidents have already been developed by the State of Washington.

- Disruptions of transportaton due to adverse weather are uncommon in the region.

Uncertainties that are associated with the above factors include the following:

- Impact projections were based on a repository design in the conceptual stage.

- Three avian species present at the reference repository location are candidates for Federal listing as threatened or endangered species.

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- Detailed information on the size and composition of the needed work force, especially during repository construction, is currently not available.

- Future characteristics of the transportation system (e.g., physical condition, traffic density, etc.) at the time of repository operation are difficult to estimate in the future.

- The percentages of nuclear waste shipments by a given mode (i.e., truck, rail) or over a specific route cannot be accurately predicted and are influenced by many factors outside the jurisdiction of repository planners.

Another factor related to this discussion is that transportation costs and risks for the most distant site (the Hanford Site) are greater than those of the site nearest to projected waste sources. The life-cycle transportation cost for the Hanford Site is small in comparison to an estimated repository life-cycle cost of roughly 10 billion dollars. Population radiation exposures and fatalities associated with transportation are estimated to increase no more than 0.03 and 0.02 percent, respectively.

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

Section 6.2 considered guidelines that do not require site characterization; Section 6.3 treats those guidelines that do require site characterization. In these cases, the conclusions are based on evaluations that ~~sometimes~~ lack substantial site-specific subsurface data.

Final conclusions will not be made until necessary site characterization activities are completed.

are preliminary at this point in time and

6.3.1 Postclosure Technical Guidelines (Section 960.4-2)

6.3.1.1 Geohydrology (Section 960.4-2-1)

6.3.1.1.1 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."

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6.3.1.1.2 Evaluation process

The process of evaluating the above qualifying condition implies an intricate assessment of geologic, hydrologic, and geochemical information involving field and laboratory measurements, interpretive judgment, and numerical simulation techniques. These activities are accounted for within the Basalt Waste Isolation Project by separate groups dedicated to field study, data analysis, and performance assessment. Owing to the interdisciplinary nature of geohydrologic investigations, the Basalt Waste Isolation Project maintains close interaction among these respective investigative components. At the same time, the Basalt Waste Isolation Project is attempting to foster internal and external peer reviews as well as formal opportunities for technical and programmatic interactions with the U.S. Nuclear Regulatory Commission and other involved or affected Federal, State, Indian, and public agencies.

Specifically, the field studies involve a program of hydrologic measurements that include such hydrogeologic parameters as transmissivity, storativity, effective thickness, hydraulic diffusivity, hydraulic head, and dispersivity, as well as interpreted parameters such as hydraulic conductivity, effective porosity, barometric and tidal efficiencies, etc. The primary method of data acquisition involves transient stress testing of aquifers and water-level measurements via surface-based boreholes. Plans call for such testing to be carried out at various scales to ascertain data appropriate to several spheres of investigation. A detailed, site-specific characterization of the preferred candidate horizon is planned using mined, underground exploratory shafts testing facilities. Another type of field evaluation involves the chemical assessment of surface and ground-water samples.

Further data reduction, interpretation, and evaluation against other, collateral data is carried out to formulate a conceptual model (physical description) of the geohydrologic system. This activity provides a means of identifying alternative models from which a consensus is sought on model-input parameters used in the performance evaluation. Information assimilated at this level includes definition of principal hydrostratigraphic units, delineation of their associated potentiometric surface configurations and physical geometries, identification of recharge and discharge mechanisms and rates, delineation of hydraulic property values and their spatial distributions, evaluation of time-variant properties of the system under natural and artificial stresses, and use of alternative data sources (such as hydrochemical and isotopic data) in order to develop corroborative lines of evidence in support of an evolving conceptual understanding of the hydrologic system. One of the critical geologic inputs to developing this conceptual model is an understanding of the past and anticipated hydrologic impacts of a slowly changing geomorphic and tectonic setting.

This conceptual model serves as the physical basis for numerical simulations of the system performance; these numerical simulations represent the primary tools for predicting ground-water travel times and radionuclide transport under expected and reasonable scenario conditions.

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In the course of conducting field studies, data analyses, and performance assessments, a developing awareness of the level of uncertainty and of the additional information needed serve to guide future data acquisition.

6.3.1.1.3 Favorable condition

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

A final conclusion on this favorable condition for pre-waste-emplacement ground-water travel times cannot be made at this time based on available data and existing wide range of conceptual ground-water models. However, a preliminary finding on favorable conditions is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) so that qualifying conditions might be compared between potentially acceptable sites prior to site nomination and recommendation (see Section 6.1). Therefore, it is stated that available data and current understanding of the ground-water system do not support a finding that the reference repository location is not likely to meet this favorable condition. This favorable condition appears met because ground-water travel times to the accessible environment along pathways of likely radionuclide travel are expected to be greater than 10,000 years.

Over the past few years, a number of preliminary, independent model studies have evaluated potential ground-water flow paths and travel times. These studies present a broad range of travel time estimates because currently available geohydrologic data do not strongly support a single or narrow range of interpretation of overall ground-water movement and flow rates beneath the Hanford Site. In addition, uncertainties exist regarding the large-scale representativeness of available rock permeability, effective porosity, and hydraulic head gradient values, which are critical in predicting ground-water travel times and radionuclide movement. Investigators used substantial interpolation and judgment to prepare their data inputs to ground-water flow models. As a result, considerable uncertainty currently exists in ~~these~~ predicted travel times. The most pertinent of these studies are summarized in Table 6-1 and are discussed in more detail in Subsection 6.3.1.1.11. Recent probabilistic estimates of ground-water travel times based on known or estimated permeability distributions are addressed in Section 6.4.2. Most of the travel times reported in the past have been single values without an estimate of the probability of occurrence.

As addressed and qualified in Section 6.4.2, stochastic simulations of horizontal ground-water movement along a basalt flow top were recently conducted to examine the effects of hydraulic properties and their uncertainty on predicted ground-water travel times. Simulations for three cases were considered: (1) the flow top transmissivity as a stochastic parameter (i.e., represented by a probability distribution) but the hydraulic gradient and effective thickness held constant, (2) transmissivity and hydraulic gradient as stochastic parameters and effective

Table 6-1. Reported estimates of ground-water travel times.

Study	Purpose of study	Ground-water travel times distance and/or direction	Reported ground-water time
LATA (1981) (Los Alamos Technical Associates, Inc., and Intera Environmental Consultants, Inc.)	Initial estimates of ground-water movement from hypothetical repository	Northward, 12 km (7.5 mi) to the Columbia River	33,000 yr
Dove et al. (1981) (Pacific Northwest Laboratory)	Demonstration of numerical modeling capability	Northward, 12 to 16 km (7.5 to 10 mi) to the Columbia River	13,000 to 17,000 yr
Arnett et al. (1981) (Rockwell Hanford Operations)	Estimate ground-water travel times from reference repository location	Southeast, 32 km (20 mi) to beneath the Columbia River	30,000 yr
NRC (1983b) (U.S. Nuclear Regulatory Commission)	Evaluation of data uncertainties in estimates of ground-water travel times	10 km (6.2 mi) from hypothetical repository	20 to greater than 40,000 yr
Clifton et al. (1983) (Rockwell Hanford Operations)	Probabilistic estimation of travel times based on known permeability distributions	10 km (6.2 mi) within flow top of host rock	Median ground-water travel time of 17,000 yr
Section 6.4.2 of this environmental assessment	Probabilistic estimation of travel times based on known ~~permeability~~ transmissivity distributions and expected hydraulic gradient and effective thickness ranges	10 km (6.2 mi) within flow top of host rock	Median ground-water travel times ranging between 17,000 and 86,000 yr (see subsection 6.4.2.3.5)

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thickness held constant, and (3) transmissivity, hydraulic gradient, and effective thickness treated as stochastic parameters. Probability curves for ground-water travel time from the repository to the accessible environment boundary at 10 kilometers (6.2 miles) were calculated and graphically compared.

The median ground-water travel times for the three cases are 17,000, 86,000, and 81,000 years, respectively. The associated standard deviations of the log-travel time values are 0.71, 0.77, and 0.96, respectively. Results for the last two cases show significantly longer median travel time values; this is explained by the increased tortuosity of the flow path produced by the greater degree of spatial variability introduced by varying the hydraulic gradient and effective thickness parameters.

As discussed in Section 3.3.2.1, the mean hydraulic conductivities (both horizontal and vertical) of flow interiors are expected to be several orders of magnitude smaller than typical flow top values. Thus, ground-water travel times that would also include movement through a flow interior(s) are anticipated to be much longer than the above travel times calculated to occur solely within flow tops.

It should be emphasized that all ground-water travel times given in Table 6-1 are very preliminary. Where data were limited, investigators made interpretations or assumptions. Additional changes are expected in future predictions of ground-water travel times as data are collected during site characterization. As new data become available, uncertainties in the areal (horizontal) and stratigraphic (vertical) distribution of hydrologic properties and the geohydrologic setting of the reference repository location will be reduced. The combination of existing information and planned data gathering activities discussed in Subsection 6.3.1.1.11 and in Section 4.1 have a good likelihood of quantifying pre-waste-emplacement ground-water travel times with the confidence needed for the licensing process. Studies have currently progressed to the point where types of rock property variations have been identified (Gephart et al., 1983), and experiments are quantifying uncertainties in the existing data base. These uncertainties will be integrated into performance assessment studies for future estimates of ground-water travel times.

6.3.1.1.4 Favorable condition

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

A final conclusion on this favorable condition regarding the affect of past hydrologic processes, if continued, on waste isolation cannot be made at this time. This is due to the preliminary understanding of the nature and rates of hydrologic processes operating within the geologic

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setting during the Quaternary Period and the uncertainty associated with geohydrologic property distributions. However, a preliminary finding on favorable conditions is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) so that qualifying conditions might be compared between potentially acceptable sites prior to site nomination and recommendation (see Section 6.1). Therefore, it is stated that the current estimation of the rate, probability of occurrence, and projected impact of identified major hydrologic processes on waste isolation does not support a finding that the reference repository location is not likely to meet this favorable condition. This favorable condition appears met because the hydrologic processes operating during the Quaternary Period are expected to have had mostly transient, local, and shallow effects on the hydrologic systems. This should not affect the ability of a deep geologic repository to isolate waste.

The time period addressed under this favorable condition extends from approximately 1.6 million years before present (beginning of Quaternary Period) to 100,000 years into the future. Examples of geologic processes that may impact the ground-water flow system during such a time period are outlined in Table 6-2. The likelihood of occurrence and hydrologic effects of these processes are currently not quantified. However, it is expected that any potential hydrologic impacts would be mostly transient, localized and shallow phenomena that would not significantly change the waste isolation potential of the deep basalt environment. If deep hydraulic head or hydraulic property changes should occur, the projected retardation characteristics of radionuclides in a basalt environment and conservatism already integrated into performance assessment predictions (see Section 6.4.2) are expected to result in no net adverse effect or change of the ability of the repository and host rock to isolate waste over the next 100,000 years. INSERT (X)

6.3.1.1.5 Favorable condition

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

A final conclusion on this favorable condition addressing characterization and modeling ease cannot be made at this time based on available data. However, a preliminary finding on favorable conditions is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) so that qualifying conditions might be compared between potentially acceptable sites prior to site nomination and recommendation (see Section 6.1). Therefore, it is stated that available data and current understanding of th[illegible] /drologic system do not support a finding that the reference repository location is not likely to meet this favorable condition. This favorable condition appears to be ~~met because the basic~~ geologic framework of the reference repository location is established and the existing hydrologic data base is providing a basis for developing reasonable preliminary conceptual models and performance assessment simulations. A program to develop the necessary models has been formulated in conjunction with the Nuclear Regulatory Commission.

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Furthermore, the ability of the repository to isolate waste over the next 100,000 years would not be expected to change (i.e., would not allow net adverse effects) if deep hydraulic head or hydraulic property changes were to occur. This statement is based on the projected retardation characteristics of radionuclides in a basalt environment, and on the conservatism already integrated into performance assessment predictions (see Section 6.4.2).

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Table 6-2. Potential, geologic, or climatologic processes and their hydrologic effects.

Climatologic or geologic process	Possible hydrologic effect
GLACIATION	
Pluvial climate established Surface drainage changes Stress loading	Alteration of recharge/discharge rates and areas Changes in hydraulic heads and gradients Near surface lowering of rock permeability due to ice loading
TECTONICS	
Activation of new or reactivation of old tectonic zones Microearthquakes	Creation of new ground-water flow paths or blockage of existing paths Local alteration of hydraulic head patterns and gradients Local changes in hydrologic property distributions Flow system interconnection or blockage
VOLCANISM	
Renewed Columbia River Basalt Group volcanism Dike generation Volcanic mudflows (lahars)	Alteration of stream drainages Confinement of existing unconfined aquifer Local redistribution of hydraulic heads Flow system(s) interconnection or blockage

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This favorable condition contains a phrase that should be interpreted before a response is given. The phrase is "can be readily characterized and modeled with reasonable certainty." First, the words "can be" are interpreted in the future sense, that is to say, based on present knowledge, is there a reasonable expectation that the geohydrologic system can be readily characterized and modeled as a result of site characterization? Second, "readily characterized and modeled with reasonable certainty" is interpreted to mean that the geohydrologic system can be characterized and modeled with the confidence required for repository licensing using reasonably available investigative technology.

The basic stratigraphic, structural, and tectonic setting of the Hanford Site, as based on available data, are contained in summary reports (e.g., Myers, Price et al., 1979; Myers and Price, 1981; DOE, 1982e; Caggiano and Duncan, 1983; and Long and WCC, 1984). Such available data have enabled geologists to establish many aspects of the stratigraphic, structural, and tectonic setting of the reference repository location and vicinity. As addressed in the U.S. Department of Energy (DOE, 1982e), and in this environmental assessment, uncertainties regarding the geologic setting remain and site characterization activities are underway to answer questions essential for satisfying licensing requirements.

Knowledge of the subsurface hydrology of the reference repository location and vicinity is less advanced than that of geology. As addressed in Section 3.3.2, reconnaissance testing has already identified preliminary hydraulic properties of basalt flow tops, flow interiors, and sedimentary interbeds, as well as broad hydraulic head distributions. In addition, a range of reasonable conceptual ground-water flow models have been developed. Because of the preliminary nature of available hydrologic information, a large uncertainty is associated with the data. For this reason, several data-gathering activities have been initiated/planned, such as installation of additional piezometers, large-scale pumping (stress) tests, more tracer testing, and an Exploratory Shaft Program (see Section 4.1). These studies are being planned and carried out in consultation with such organizations as the U.S. Geological Survey and the U.S. Nuclear Regulatory Commission. For example, the basic piezometer layout and large-scale pump test approvals for characterizing the reference repository location was agreed upon between the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission (DOE/NRC, 1983). Although the specifics of this agreement will change as data are collected, yet the principals involved believe that the reference repository location has a high likelihood of being characterized and modeled with the reasonable certainty needed for licensing decisions. Already the water level data collected from three new piezometer suites installed in and near the reference repository location and apparently supporting earlier concepts on onsite hydraulic head distributions (Yeatman and Bryce, 1984a, 1984b). This is providing additional confidence that the reference repository location can be characterized using available investigative technology.

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Site characterization data will refine the conceptual (descriptive) understanding of the hydrologic setting as needed to quantitatively address, with reasonable confidence, critical licensing questions regarding past, present, and anticipated ~~future~~ behavior of the ground-water system.

6.3.1.1.6 Favorable condition

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

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

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

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

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

Available information suggests that the second and third conditions ~~characteristics~~ of this favorable condition ~~is~~ are met, and the first and fourth conditions are not met by the reference repository location. Therefore, this favorable condition is met based on a low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.

Existing data for addressing Favorable Condition 4(i) suggest that the hydraulic conductivity of basalt flow interiors (i.e., host rock layer), where repository construction would take place, is very low. Basalt flow tops and sedimentary interbeds separating flow interiors normally have hydraulic conductivities greater than those in flow interiors. Thus, the geohydrologic system consists of alternating rock layers having low to high hydraulic conductivities. Based on available data, basalt appears to meet the first part of this favorable condition regarding a host rock of low hydraulic conductivity. However, basalt does not appear to meet the second half of the condition (i.e., low hydraulic conductivity for surrounding geohydrologic units). Studies directed at specifically quantifying information needed to fully address this favorable condition are discussed in Section 4.1.

Within basaltic rocks, ground-water occurrence and movement is mostly within selected flow tops and sedimentary interbeds that are permeable, as discussed in Sections ~~2.1~~ 2.1.4 and ~~3.1.8~~ 3.3.2. The basalt flow interiors separating individual flow tops and interbeds appear to act as semiconfining, low-permeability aquitards through which some (yet unquantified) vertical

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leakage occurs along cooling fracture or structural discontinuities. As noted in the above referenced sections, the concept of lateral ground-water movement along flow contacts/interbeds and low flow-interior permeabilities has been suggested by several field investigations (e.g., LaSala et al., 1973; Newcomb, 1965; Luzier and Burt, 1974; DOE, 1982e). Field studies addressing the quantification of vertical leakage across basalt flow interiors are discussed in Section 4.1.

Ground water moving from the vicinity of a repository would travel through fractures in the flow interior of the host basalt layer (i.e., candidate repository horizon) before reaching basalt flow tops or bedrock structural discontinuities. Thus, lying between the repository and land surface are some 20 separate basalt flows having flow interiors of low hydraulic conductivity and flow tops/interbeds possessing a wide range of hydraulic conductivity values.

Ten hydrologic tests have been conducted across the dense entablature and colonnade portions of individual flow interiors at depths from approximately 350 to 1,190 meters (1,150 to 3,900 feet) beneath the Hanford Site. Horizontal hydraulic conductivities measured were generally less than or equal to 10^{-11} meter per second (10^{-6} foot per day). Low hydraulic conductivities for flow interiors have also been reported by other investigators within the Hanford Site and Columbia Plateau (e.g., LaSala and Doty, 1971; Newcomb, 1982). Field tests quantifying vertical hydraulic conductivities and evaluating test methodologies within flow interiors are in progress. An initial ratio type test conducted by Spane et al. (1983) suggests a vertical hydraulic conductivity less than 10^{-11} meter per second (10^{-6} foot per day) for a test zone in the Rocky Coulee flow interior. (Results from this test also indicate that the use of the ratio method for determining vertical hydraulic conductivity of flow interiors may be of limited application.) As discussed in Section 4.1, measurements of the vertical hydraulic conductivity of flow interiors are a central activity in the planned large-scale pump test and the Exploratory Shaft Program.

In lieu of direct measurements, model-calculated and statistical estimates of the vertical-to-horizontal anisotopic ratio for hydraulic conductivity within flow interiors have been reported by U.S. Department of Energy (DOE, 1982e) and Sagar and Runchal (1982). The ratios obtained were 2 to 1 and 3.5 to 1, respectively. Thus, once several field measurements become available, it is anticipated that vertical hydraulic conductivity of undeformed basalt flow interiors will be of approximately the same order of magnitude as horizontal hydraulic conductivity values currently reported.

After ground water travels through cooling fractures or other pathways within a basalt interior, it may enter a flow contact. Commonly, these contacts represent the nearest potential aquifer (i.e., high permeability rock layer) to a repository. To date, nearly 200 single-hole hydrologic tests have been conducted in flow tops and interbeds in some 35 separate boreholes across the Hanford Site. These data indicate that within both the Saddle Mountains Basalt and Wanapum Basalt flows, the

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hydraulic conductivities of most individual flow tops and interbeds range between 10^{-4} and 10^{-7} meter per second (approximately 10^{1} and 10^{-2} foot per day) with a geometric mean of approximately 10^{-5} meter per second (10^{0} foot per day). Most hydraulic conductivity values within Grande Ronde Basalt flow tops range between 10^{-5} and 10^{-9} meter per second (10^{0} and 10^{-4} foot per day) with a geometric mean of approximately 10^{-7} meter per second (10^{-2} foot per day) (Long and WCC, 1984). The general uncertainties of these numbers are addressed in Section 3.1.3. 3.3.2.1

Existing hydraulic head data for addressing Favorable Condition 4(ii) in the Cold Creek syncline near the reference repository location suggest that the head gradient in the shallow basalts is downward while that in the deeper basalts (where the host rock exists) is either horizontal or possessing a slight upward gradient. Though existing data suggest that basalt may meet this favorable condition, additional piezometers have been recently installed in and around the reference repository location, and new monitoring plans are being implemented to resolve data uncertainty (see Section 4.1). Preliminary data collected from these piezometers appear to confirm the predominantly horizontal and low hydraulic gradients previously thought to exist across the deep basalts in the reference repository location (Yeatman and Bryce, 1984a, 1984b).

When the available piezometric data from shallow and deep basalts (as outlined in Section 3.1.3 3.3.2) are combined with existing preliminary hydraulic head information collected on a progressive drill and test basis (DOE, 1982e; Long and WCC, 1984), a preliminary understanding appears to emerge of the broad head patterns that might exist across the Hanford Site. The western Hanford Site, that region closest to the Rattlesnake Hills, Yakima Ridge, and Umtanum Ridge, appears to be a recharge area for the shallow basalts. There, hydraulic heads decrease with depth. Eastward across the Hanford Site, heads become more uniform with depth in the central Cold Creek syncline. This suggests lateral ground-water movement. Close to the Columbia River, heads either increase with depth or have a variable pattern suggesting potential discharge. In deep basalts, available hydraulic head data suggest either generally uniform heads or a slight upward gradient within the Cold Creek syncline, which includes the area occupied by the reference repository location. The dominant head changes, characteristic of shallower basalts, do not appear to exist in the deeper basalts.

The above statements on hydraulic head patterns are not given as conclusions, but rather as conceptualizations based on information available by to researchers at the time of their studies and on data uncertainties as noted in Section 3.1.3 3.3.2. The existing hydraulic head data for addressing Favorable Condition 4(iii) suggests that the lateral head gradient in geohydrologic units is low. Vertical head gradients were addressed in the previous favorable condition. Available lateral and vertical head data suggests that this favorable condition is met by the reference repository location, although additional studies are required to develop a final conclusion (see Section 4.1).

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Table 6-3 shows a comparison of areal head gradients between boreholes located inside and outside the reference repository location (Fig. 6-3). Though the rock intervals selected for head comparisons are within the Grande Ronde Basalt flow, the gradients given appear typical of other basalt flow tops (DOE, 1982e). These heads were collected during hydrologic reconnaissance studies when heads were measured in new boreholes on a progressive drill and test sequence as the borehole was deepened over a time period of several months. Heads measured using this technique are considered preliminary because of possible local head disturbances resulting from hole emplacement, hydrologic tests, and natural head changes over time. Baseline hydraulic heads for these same basalts are now being collected within and near the reference repository location in new piezometers and across the Hanford Site in existing shallow and deep piezometers.

On an average, the areal hydraulic head gradient across the Cold Creek syncline, where the boreholes in Table 6-3 are located, appears to be low (approximately 10^{-4} meter per meter (10^{-4} foot per foot)).

Relative to Favorable Condition 4(iv), the present conceptual understanding of ground-water movement from a repository involves flow through a basalt interior of low hydraulic conductivity and then into a flow top(s) of higher hydraulic conductivity. Likely radionuclide pathways to the 10 kilometers (6.2 miles) accessible environment would be along flow tops. Because rocks of higher hydraulic conductivity generally have a higher effective porosity (and vice versa), radionuclide movement would have taken place in basalt layers having both low and high effective porosities. Therefore, this fourth subpart of Favorable Condition 4 is not met by the reference repository location. condition

Estimates of effective porosity are obtained from field tracer experiments such as described in Gelhar (1982) and Leonhart et al. (1982). To date, two tracer tests have been performed within a single horizon (the McCoy Canyon flow top) within the Grande Ronde Basalt flow. Estimates for the effective thickness (nH) of the test horizon ranged between approximately 2×10^{-3} to 3×10^{-3} meter (0.006 to 0.01 feet). Data suggest that the effective porosity of this flow top is between 1 and 0.01 percent. Additional tracer testing must be performed before the required understanding of effective porosities within flow tops and flow interiors is reached. Studies directed toward collecting these data are discussed in Section 4.1.

6.3.1.1.7 Favorable condition

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

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

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Table 6-3. Comparison of apparent areal head gradients for selected basalt flows in the Grande Ronde Basalt.

Stratigraphic flow interval	Comparison of observed heads[a] (m above mean sea level)		Average[b] head gradient between boreholes (m/m)
	HEAD IN RRL-2	HEAD IN DC-15	
Rocky Coulee	121.0	118.5	10^{-4}
Cohassett	121.5	119.0	10^{-4}
Umtanum	123.5	121.5	10^{-4}
	HEAD IN DC-16A	HEAD IN DC-15	
Rocky Coulee	122.0	118.5	10^{-4}
Cohassett	122.0	119.0	10^{-4}
	HEAD IN RRL-14	HEAD IN RRL-2	
Cohassett	124.5	121.5	10^{-3}
Umtanum	123.5	123.5	--
	HEAD IN RRL-14	HEAD IN DC-16A	
Cohassett	124.5	122.0	10^{-3}

NOTE: 1 meter = 0.3048 foot.

[a]Observed hydraulic heads as measured in basalt flow tops during a progressive drill and test hydrologic evaluation sequence. Value given to nearest 0.5 meter. Borehole separations between RRL-2/DC-15, DC-16A/DC-15, RRL-14/RRL-2, and RRL-14/DC-16A are 35, 34, 2.6, and 4.2 kilometers (22, 21, 1.6, and 2.6 miles), respectively.

[b]Average head gradients are rounded to the nearest order of magnitude.

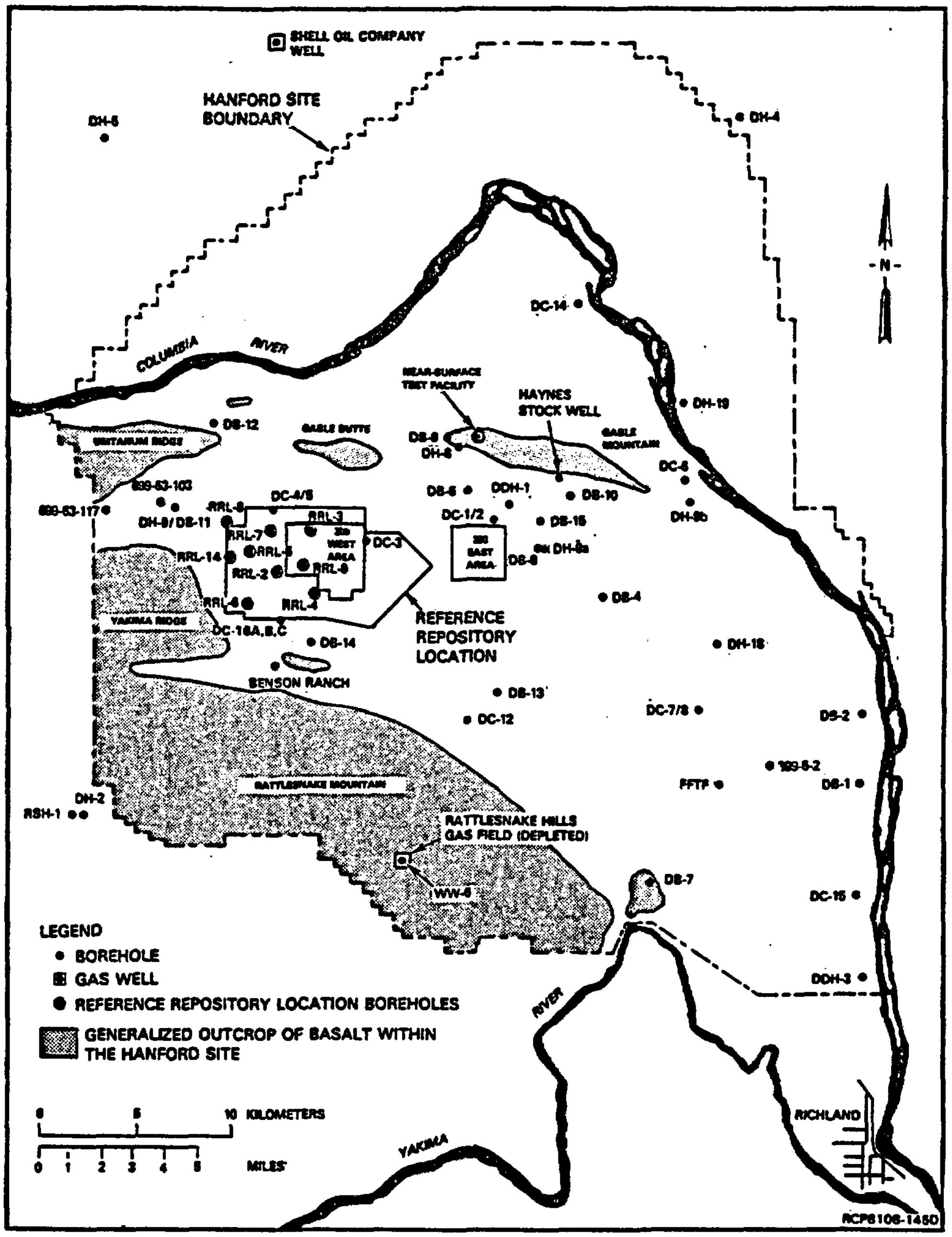

FIGURE 6-3. LOCATION MAP FOR SELECTED BOREHOLES

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

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

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

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

This favorable condition only applies to an unsaturated zone. This condition does not apply to the reference repository location since the candidate basalt horizons are located below the water table (i.e., in a water saturated environment).

6.3.1.1.8 Potentially adverse condition

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

A final conclusion on this potentially adverse condition for expected changes in pre-waste- versus post-waste-emplacement geohydrologic conditions cannot be made at this time based on available data. However, a preliminary finding on potentially adverse conditions is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) so that qualifying conditions might be compared between potentially acceptable sites prior to site nomination and recommendation (see Section 6.1). Therefore, it is stated that available data, current understanding of the ground-water system, and performance assessment results do not support a finding that the reference repository location is likely to have this potentially adverse condition. This potentially adverse condition does not appear to be present because ground-water travel times to the accessible environment (and thus associated radionuclide transport) under post-waste-emplacement conditions are not expected to be significantly different from pre-waste-emplacement travel times.

Changes to the geohydrologic conditions surrounding a repository would primarily occur as a result of thermal loading. This loading is predicted to extend only a limited distance (perphaps a few hundred meters) from the repository. Such a distance is a relatively small portion of the 10 kilometers (6.2 miles) separating the repository from the accessible environment. Therefore, any change to the local hydraulic characteristics resulting from thermal loading should not have a significant impact on the total ground-water travel time calculated from within the flow top of the host rock to the accessible environment. As noted in Subsection 6.3.1.1.3, the median pre-waste-emplacement ground-water travel times currently calculated do not take credit for fluid movement through the flow interior of the host rock. If this was factored into calculations, then travel times to the accessible environment would be much longer than now predicted.

Subsection 6.4.2.3.5.1 presents the median pre-waste-emplacement ground-water travel times within a basalt flow top to the accessible environment for three separate simulation cases. No significant post-waste-emplacement changes to these travel times are expected. Since radionuclides travel in response to ground-water conditions and geochemical retardation factors, no significant increase in radionuclide transport is expected as a result of potential post-waste-emplacement changes in the geohydrologic environment.

6.3.1.1.9 Potentially adverse condition

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

The deep basalt ground waters existing along potential ground-water flow paths from the host rock to the accessible environment contain natural chemical constituents that would require removal or treatment before these waters would be suitable for human consumption and crop irrigation. Therefore, this potentially adverse condition does not exist in the reference repository location.

A portion of the total dissolved solids concentrations of basalt ground waters consists of fluoride. As noted in Table 3-1 of Section 3.1.3, fluoride concentrations of 11 to 44 parts per million characterize the Grande Ronde Basalt ground-water system. This is the basalt formation where the feasibility of repository construction is being studied. The maximum fluoride concentrations for safe drinking water as established by the U.S. Environmental Protection Agency (EPA, 1976) is approximately 2.4 parts per million, depending on sample temperature. Thus, this regulatory limit is exceeded by all Grande Ronde Basalt ground waters sampled beneath the Hanford Site as well as all Wanapum Basalt and Grande Ronde Basalt ground waters sampled within the Cold Creek syncline in which the reference repository location lies. Treatment of these ground waters would be necessary before human consumption.

From the standpoint of crop irrigation, sodium and salinity concentrations in the Grande Ronde Basalt ground waters appear to be of concern. Irrigation waters of high sodium content (expressed as a sodium adsorption ratio) can cause soils to crust and swell, thus, decreasing permeability and contributing to drainage and salinity control problems (Bohn et al., 1979). Waters are divided into four classes in respect to sodium hazard: low, medium, high, and very high, depending on the

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electrical conductance of the water. At electrical conductivity values of 100 micromho per centimeter, the dividing points between the above four classes are: 10, 18, and 26. With increasing salinity (e.g., at 2,250 micromho per centimeter), the corresponding dividing points are approximately 4, 9, and 14 (Allison, 1964). The Grande Ronde Basalt ground waters beneath the Hanford Site, ~~which have an electrical conductivity of approximately 1,500 micromho per centimeter,~~ fall within the "very high" range (i.e., sodium adsorption ratio values in the 30's and 40's) in both of the above salinity cases.

Total salt (salinity) concentration is probably the most important criterion to establish irrigation water quality. On the basis of electrical conductivity measurements, waters are divided into four classes: low, medium, high, and very high salinity. The dividing points between classes are electrical conductivity values of 250, 750, and 2,250 micromho per centimeter (Allison, 1964). The Grande Ronde Basalt ground waters within the Cold Creek syncline have an electical conductivity of approximately 1,500 micromho per centimeter and, thus, fall in the high salinity range.

6.3.1.1.10 Potentially adverse condition

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

Stratigraphic and structural features that could contribute to the difficulty of characterizing or modeling the geohydrologic system of the reference repository location have been identified in the geologic setting. Therefore, this ~~is a~~ potentially adverse condition is likely present at the reference repository location.

Sections 3.2 and 3.3 outline the basic geologic and hydrologic setting of the Hanford Site with emphasis on the reference repository location. A portion of that discussion addresses the types of geologic features known to exist in Columbia Plateau, some of which have been identified in or near the reference repository location. Such features can have varying effects on creating geologic complexity as well as impacting ground-water and solute movement. Section 4.1 outlines plans for geohydrologic characterization directed at identifying these types of features (whichever ones may exist in or near the reference repository location) so that their influence on ground-water movement and modeling complexity can be evaluated. Section 6.4.2 outlines the approach used to numerically model geohydrologic data.

The features shown in Figure 3-36 represent natural discontinuities in a layered basalt mass, which can introduce spatial changes (in either direction (anisotopic conditions) or position (heterogeneous conditions)) in the distribution of rock and hydrologic properties. The existance of any one or more of these features and their possible effects on

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ground-water movement, rock stability, and repository design/construction is a primary focus of the site characterization program. Inferred or known bedrock structures in the Cold Creek syncline have been reported in Myers (1981) and Caggiano and Duncan (1983).

6.3.1.1.11 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."

A final conclusion on this disqualifying condition for pre-waste-emplacement ground-water travel times is not possible at this time. Additional data need to be collected to define the geohydrologic properties of the ground-water environment in and surrounding the reference repository location. However, a preliminary finding on disqualifying conditions is required by the General Siting Guidelines (DOE, 1984a) so that potentially acceptable sites might be identified and compared for nomination and recommendation. Therefore, based on available data and current understanding of the ground-water system, the pre-waste-emplacement ground-water travel time to the accessible environment is expected to be greater than 1,000 years. The available evidence does not support a finding that the reference repository location is disqualified.

6.3.1.1.11.1 Ground-water travel time. Over the past few years, a number of preliminary, independent numerical model studies have been performed that evaluated potential ground-water flow paths and travel times (DOE, 1982e). Collectively, these studies present a broad range of travel time estimates. For the most part, these ranges exist because currently available geohydrologic data do not permit a single interpretation of overall ground-water movement and flow rates beneath the Hanford Site. In addition, uncertainties exist regarding the large-scale applicability of available rock permeability, effective porosity, and hydraulic head values that are important to predictions of ground-water travel times and radionuclide movement. Substantial interpolation and judgment were required by investigators to prepare their data inputs to ground-water flow models. As a result, considerable uncertainty currently exists in these predicted travel times. Most past travel times reported have been single values without an estimate of the probability of occurrence for the ground-water travel time given. The most pertinent of these preliminary studies are summarized below And in Table 6-10

In 1978, a ground-water study was performed by Los Alamos Technical Associates, Inc. and Intera Environmental Consultants, Inc. (LATA, 1981). This study was intended to provide initial numerical simulations of the Pasco Basin ground-water flow system (in which the Hanford Site lies) and first estimates of ground-water and radionuclide movement from the vicinity of a hypothetical repository in basalt, using available information. Various assumptions were made in this analysis regarding how basalts are layered and the permeability of these layers. The repository

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location was assumed to be within the Umtanum flow of the Grande Ronde Basalt flow near the eastern boundary of the reference repository location. The calculated flow path was northward along a distance of approximately 12 kilometers (7.5 miles) to the Columbia River with a ground-water travel time of 33,000 years.

A second study was performed by the Pacific Northwest Laboratory for the U.S. Office of Nuclear Waste Isolation during 1979 to 1980 (Dove et al., 1981). The purpose of that study was to conduct an initial assessment of a hypothetical repository in the Columbia River basalts as a demonstration of numerical modeling capabilities and to help develop research approaches for such modeling. An important feature of the study was an attempt to define some of the subsurface geologic and hydrologic model boundaries of the Pasco Basin from a much larger model of the Columbia Plateau. Ground-water flow paths calculated were northward to the Columbia River with path lengths ranging from approximately 12 to 16 kilometers (7.5 to 10 miles). Ground-water travel times to the Columbia River were calculated to be between 13,000 and 17,000 years.

Another Pasco Basin ground-water model study was conducted by Rockwell Hanford Operations in 1981 (Arnett et al., 1981). Available data were used and model boundary conditions were estimated. Assumptions were made regarding rock layering and the ratio of horizontal to vertical permeability of these layers. Results showed a ground-water flow path of 60 kilometers (37 miles) to the southeast, passing beneath the Columbia River near the southeast boundary of the Pasco Basin. Ground-water travel time to that location was calculated to be greater than 100,000 years. Travel time from the reference repository location to beneath the Columbia River north of Richland, Washington, (a distance of approximately 32 kilometers (20 miles)) was approximately 30,000 years.

The U.S. Nuclear Regulatory Commission performed a study wherein the sensitivity of ground-water flow paths and travel times to different geohydrologic concepts and data was examined. A range of ground-water travel times from 20 years to over 40,000 years was calculated using ranges of available data and various assumptions for porosity and vertical permeability of basalt layers (NRC, 1983). ~~p. D-11).~~ It was stated that the U.S. Nuclear Regulatory Commission staff does "not endorse the use of travel-time calculations based upon these Nuclear Regulatory Commission simulations to characterize repository behavior." Rather, their objective in performing the calculations was to simply illustrate "the very large uncertainties in estimates of pre-emplacement groundwater travel times at the Hanford Site based on the current BWIP data" (NRC, 1983, p. D-10).

In 1983, ~~T~~the Pacific Northwest Laboratory ~~has recently~~ completed an independent review of the Basalt Waste Isolation Project (Burnham, 1983). Under the hydrology discussions it is stated (Burnham, 1983, p. vi) "at this point, no data disqualify the site on the basis of hydrology. The complexity of the multi-flow basalt system leads us to conclude that the Hanford Site will require a major characterization effort to resolve hydrologic uncertainties to the point where performance assessment predictions can be made and defended. . . .In spite of these complexities,

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it is our conclusion that, in all probability, the Hanford Site will demonstrate a pre-emplacement groundwater traveltime in excess of 1,000 years when fully characterized." As a clarification of the term "complexity," it is stated (Burnham, 1983, p. 3.7): "Complexity, while more relevant for basalts, is by no means unique to basalts. Because of the depths proposed for siting repositories, all repository sites are likely to face similar difficulties. These siting depths generally mean that multiple, interacting, and deep ground-water flow systems will require characterization and understanding."

A ground-water travel time analysis based on the probability of occurrence for given travel times was completed by Clifton et al. (1983, pp. 1 through 10) to examine methods for dealing with ground-water travel time uncertainty based on existing permeability data. Statistical data on permeabilities from Grande Ronde Basalt flow tops were used in the calculation of a probability distribution of ground-water travel times from a repository to the accessible environment (10 kilometers (6.2 miles) distant). An important assumption of the analysis was that ground-water flow was horizontal and in a single flow top. The hydraulic head gradient and porosity were assumed constant. An estimate of the statistical probability of given travel times was presented. These results indicate that there is a greater than 95 percent probability of ground-water travel times exceeding 1,000 years for the flow path examined. This calculation also produced a median travel time to the accessible environment of 17,000 years. Ground-water travel times and ranges of data for other possible flow paths (such as suggested in Gephart et al., 1983, pp. 1 through 10) will be evaluated as these paths are identified and characterized. Additional details of this study by Clifton et al. (1983) are continued in Section 6.4.2. This section also describes two more recent ground-water travel time estimates based on probability distributions of hydraulic gradients and effective thicknesses. ~~Since~~ there ~~are fewer of these~~ data available as compared to transmissivity values, these properties were assigned probability distributions ~~based on that~~ believed to be within likely ranges for the flow top simulated. The median ground-water travel times for these two simulations are 86,000 and 81,000 years. The uncertainties and standard deviations of these estimates are addressed in Section 6.4.2. It is important to emphasize that these ground-water travel time estimates are median values based on probability estimates. Thus, as graphically depicted in Section 6.4.2, there is a finite probability that these likely travel times are either under-or over-estimated. Data collected during site characterization will help reduce the present large uncertainty associated with these estimates.

Again it should be emphasized that all ground-water travel time predictions mentioned in this environmental assessment are preliminary. Where data are limited, interpretations and assumptions were made by each group of investigators. Additional predictions of expected pre-waste-emplacement ground-water travel times will be proposed as new data are collected (see Section 4.1).

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As part of the research into understanding ground-water movement in basalt, an interagency hydrology working group was formed in 1983. This group consists of representatives from the U.S. Geological Survey, Pacific Northwest Laboratory, and the Basalt Waste Isolation Project who are sharing data and conducting computer model studies to more closely define hydrologic properties and ground-water flow dynamics within and surrounding the Pasco Basin. Information generated from this program will help to refine future calculations of ground-water travel times.

6.3.1.1.11.2 Radionuclide releases. The capability of the reference repository location to meet radionuclide release requirements set in Section 960.4-1 (System Guideline) depends on a number of factors and characteristics including: performance of the engineered barriers (e.g., waste package and repository seal system), ground-water flow paths and travel times, radionuclide inventory, radionuclide half-life, and radionuclide solubility and sorption.

The solubility of radionuclides in a ground-water system and the sorption of these radionuclides on the surrounding rock are important factors in understanding potential radionuclide releases because they control the rate and amount of radionuclide releases to the ground water and, thus, radionuclide transport to the accessible environment. For example, sorption is a natural chemical or physical process that can significantly retard radionuclide movement through the rock and minerals contacted and, in effect, make radionuclide travel times much longer than that of ground water. Because practically all radionuclides in nuclear waste have been experimentally shown to exhibit some degree of sorption, it is an important geochemical characteristic of the reference repository location to understand.

Laboratory measurements obtained to date suggest that the basalts beneath the Hanford Site exhibit radionuclide sorption characteristics (Salter et al., 1981; Salter and Jacobs, 1982). This favorable condition results from the sorptive capacity of many primary and secondary minerals that exist in the basalt system. Based on available preliminary data, only two radionuclides, carbon-14 and iodine-129, appear to be nonsorbing and, therefore, are expected to travel at the velocity of ground water. (The sorptive and transport characteristics of other key radionuclides such as technetium-99, selenium-79, neptunium-237, plutonium-239 and -242, and tin-126 are also being studied.) Radionuclides exhibiting sorptive characteristics would migrate more slowly than the ground water. In the case of carbon-14, preliminary data show that the release rate to ground water is expected to be controlled by its solubility characteristics, which depend on its chemical form in nuclear waste. The radionuclide iodine-129, on the other hand, is highly soluble and nonsorbing. Preliminary estimates of the amounts of iodine-129 in the projected waste inventories show that this radionuclide is not expected to exceed the maximum allowable release limit specified in the proposed U.S. Environmental Protection Agency standard (EPA, 1982).

Whereas the overall geochemical characteristics of the basalts appear favorable (see Subsection 6.3.1.2) and preliminary calculations of radionuclide transport indicate a good probability of ~~acceptable~~ low radionuclide releases from a repository relative to EPA limits, definitive statements concerning compliance with release requirements in Section 960.4-1 (System Guideline) cannot be made at this time. Additional data are needed to fully characterize the geochemical environment of the deep basalts and to quantify the uncertainties in such factors as solubility and sorption. Future characterization programs are planned to collect the required data (see Section 4.1).

6.3.1.1.11.3 Reducing data uncertainty. Reviews of the geohydrologic data base and (or) hydrology program in 1982 for basalt were conducted by several organizations, including the U.S. Nuclear Regulatory Commission (NRC, 1983), U.S. Geological Survey (Robertson, 1983), Golder Associates (1983), Pacific Northwest Laboratory (Burnham, 1983), as well as the Basalt Waste Isolation Project itself (DOE, 1982e). Each organization identified uncertainties in available information. For example, the U.S. Geological Survey (Robertson, 1983, p. 5) noted: "We do not believe that the hydraulic conductivity, head gradient, and effective porosity data are sufficient or reliable enough to allow velocity calculations to be made with an accuracy of greater than approximately 2 or 3 orders of magnitude." All reviewers have noted that much additional information is needed before definitive statements can be made regarding ground-water travel times. This is the reason why an intense, ongoing, and planned data collection program is underway.

Unless geohydrologic properties and energy gradients are perfectly known within a ground-water flow system, there must always be some uncertainty associated with the ground-water travel times predicted. The amount of uncertainty depends on how well the spatial variability of geohydrologic parameters are known. This, in turn, depends on the amount and quality of available data defining the flow system. Thus, to reduce the uncertainty in a predicted ground-water travel time, it is necessary to provide a higher degree of spatial resolution of hydrologic parameters within the ground-water system.

Uncertainties in the areal and stratigraphic (vertical) distribution of hydrologic properties and the geohydrologic setting of the reference repository location are being addressed through comprehensive, ongoing, and planned field studies (see Section 4.1). These include the following:

- Tests for large-scale measurements of hydrologic properties (DOE/NRC, 1983).
- Shallow and deep piezometer installations around the reference repository location to measure hydraulic heads and their temporary changes.
- Identification and monitoring of hydraulic heads in regional wells off the Hanford Site.

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- Performance of additional tracer tests to better understand the effective porosity in basalt and how a radionuclide might disperse or spread.

- Additional small-scale hydrologic tests in single and dual boreholes.

- Additional tests to determine the effect of drilling mud on hydrologic test results.

- Updating and refining the hydrologic conceptual model for the Hanford Site and vicinity.

- Hydrologic testing in the exploratory shafts to evaluate geohydrologic properties and variations in fracture characteristics of an interior of a basalt flow (Rockwell, 1983a).

Uncertainties regarding the geochemical environment and its effects on radionuclide sorption are also undergoing continued research (see Section 4.1). Specific items being investigated include the following:

- Geochemical modeling of the basalt and ground-water system.

- Evaluation of ground-water sampling techniques and quality.

- Field and laboratory Eh (i.e., reduction and oxidation potential) measurements.

- Possible influence of fluoride, organic carbon, dissolved gas (methane), and colloids on radionuclide solubilities and transport.

- Possible radiation-induced processes enhancing radionuclide mobility.

- Sorption studies of key radionuclides on site-specific minerals likely found along ground-water flow paths.

As new geohydrologic data become available, data uncertainties will change according to research findings and the level of detail examined. When little was known about the Columbia River Basalt Group, geohydrologic concepts were rather simple and the perceived uncertainty appeared small. Additional data have since provided a better assessment of the magnitude of these uncertainties in the geohydrologic system. The combination of existing information and planned data should be able to qualify if basalt does or does not meet the specified performance requirements. Studies have currently progressed to the point where many natural rock property variations have been identified (Gephart et al., 1983), and experiments are quantifying uncertainties in the existing data base. These uncertainties are now being integrated into performance assessment studies so that ground-water travel times and radionuclide transport rates can be more reliably estimated.

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6.3.1.1.12 Conclusion on qualifying condition

A final conclusion on the qualifying condition for Geohydrology cannot be made based on currently available data. However, a preliminary finding is reqqired by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1). Therefore, it is believed that the available evidence does not support a finding that the site is not likely to meet the qualifying condition. The present and expected characteristics of the geohydrologic setting of the reference repository location appear compatible with the containment and isolation of nuclear waste. Expected radionuclide releases from the engineered system into the accessible environment are likely to meet regulatory requirements.

The major factors supporting this preliminary finding are:

- The median ground-water travel time to the accessible environment are estimated to be in excess of 10,000 years along flow paths of likely radionuclide travel. Pre-waste-emplacement travel times starting within the flow top of the host rock have median values of 17,000 to 86,000 years depending upon assumptions (see Section 6.4.2). By factoring in ground-water flow time through the flow interior of the host rock, ground-water travel times to the accessible environment are expected to be longer than the times noted above.

- The geohydrologic system is expected to be characterized and modeled with the required confidence needed for licensing decisions. Presently, ground-water conceptual and numerical models are developed and favorable hydrologic conditions such as low (10^{-4} meter per meter (10^{-4} foot per foot)), predominantly horizontal gradients and low host rock hydraulic conductivities (10^{-11} meter per second or 10^{-6} feet per day) appear to exist in the reference repository location.

- The geochemical characteristics of the deep basalts appear favorable for limiting radionuclide migration and extending waste canister lifetimes. Reducing ground-water conditions and the presence of smectite clays and zeolites contribute to radionuclide retardation. In addition, under repository conditions, the basalt itself will likely alter the variety of clays and zeolite phases that enhance radionuclide sorption.

- Ground-water resource potential in the deep basalts appear to be much smaller compared to available shallow ground water and surface water resources. In addition, the deep ground water has sodium and salinity concentrations that are of concern relative to crop migration and has fluoride concentrations that exceed by a factor up to 20 the safe drinking water standards established by the U.S. Environmental Protection Agency.

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- The general geologic and climatic characteristics that would affect the deep geohydrologic system are also known. These characteristics are considered favorable though structural and stratigraphic features known to exist in the Columbia Plateau could contribute to the difficulty in characterizing or modeling the geohydrologic system. There is no evidence to suggest that the long-term, low-average rate of deformation (40 to 80 meters per million years (130 to 260 feet per million years)), arid climate, and current rates of geomorphic processes are expected to change within the central Pasco Basin over possibly the next 100,000 years. Therefore, no significant change to the nature and rates of hydrologic process are expected during the same time period.

- The engineered-barrier system, in concert with natural site characteristics, is expected to constrain radionuclide releases to a small fraction of allowable limits.

The above statements are based upon the extensive, though preliminary data base, and a general understanding of ground-water movement in and around the reference repository location that remains to be confirmed. Uncertainties are identified in the data sections of this environmental assessment, as well as in the guideline evaluation sections of Chapter 6 and the performance assessment Section 6.4.2. Specific uncertainties related to the findings above include:

- The lateral and vertical distribution of hydrologic properties and hydraulic head values with specific emphasis on vertical hydraulic conductivities of basalt flow interiors and effective porosities of both flow tops and flow interiors.

- The lack of a single or narrow range of conceptual models to describe ground-water flow.

- An understanding of the geohydrologic setting of the reference repository location and potential influence of stratigraphic and structural discontinuities.

- Influence of possible complexing agents and radiation processes on radionuclide sorption characteristics.

- Sorption behavior of key radionuclides on site-specific minerals.

- Representativeness of expected model-generated ground-water travel times and radionuclide transport rates.

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6.3.1.2 Geochemistry (Section 960.4-2-2)

6.3.1.2.1 Qualifying condition

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

6.3.1.2.2 Evaluation process

The expected geochemical characteristics of the basalt at the Hanford Site based on the presently available data base potentially represent one of the most favorable aspects of basalt for assuring the safe containment and long-term isolation of nuclear waste. The most credible mechanism for radionuclide release from a repository in basalt is dissolution of the nuclear waste form in repository ground water and subsequent transport through the engineered and geohydrologic systems. Two of the most important processes that control this potential release and transport are radionuclide solubility and sorption. These processes are highly dependent on the geochemical environment of a repository site.

Laboratory studies by the Basalt Waste Isolation Project have focused on evaluating the steady-state or solubility-limited concentrations of radionuclide release to repository ground water over a range of site-specific conditions and in the presence of basalt and reference engineered barrier materials (Apted and Myers, 1982; Myers et al., 1983, Grandstaff et al., 1983; Coles and Apted, 1983). Sorption studies on primary and secondary (alteration) minerals of site-specific basalt show that these mineral phases have high sorptive capacity for many key radionuclides (Salter et al., 1981; Barney, 1981; Salter and Jacobs, 1982). Laboratory tests have also been conducted to evaluate the controls of geochemical parameters (e.g., pH, oxidation potential (Eh), and ground-water composition) by basalt/ground-water reactions (Apted and Myers, 1982; Lane et al., 1983a, 1983b; Jantzen, 1983; Grandstaff et al., 1983). In particular, these tests have indicated that basalt rapidly imposes a reducing environment in coexisting ground waters. Theoretical studies of Jacobs and Apted (1981), Apted and Long (1982), and Apted and Myers (1982) suggest that Eh values within the range of -0.4 plus or minus 0.1 volts at a pH of 9.2 plus or minus 0.5 at 60°C are expected in this geochemical environment. The experimental work to date has been completed with crushed basalt, which is typical of the waste package packing material but not the host rock. Thus, it is inferred from these data that multivalent radionuclides will enter the host rock from the waste package in a reduced oxidation state having interacted with crushed basalt. On the other hand, the actual Eh or range of Eh values in the host rock must be inferred indirectly at this time in the Basalt Waste Isolation Project

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studies. The existence of ferrous iron-bearing alteration products that fill basalt fractures, notably hydrated iron oxides, occasionally pyrite, and possibly smectite clays (Benson and Teague, 1982, pp. 595 through 613), as well as the relative concentrations of members of redox couples dissolved in the ground water (e.g., S^{2-}-SO_4^{2-}, CH_4-CO_2), jointly suggest that reducing conditions exist in the basalt host rock. Calculation of the exact Eh in the host rock suffers from lack of thermodynamic and characterization data such that further estimates will require additional laboratory and (or) field experimental data.

Based on thermodynamic arguments (Early et al., 1982), many radionuclide-bearing solids, containing redox-sensitive elements such as technetium, uranium, neptunium, and plutonium, decrease in solubilities, with decreasing redox potential. Because redox-sensitive solution species may or may not respond to the redox-controlling reactions imposed by the basalt plus ground-water system, each radionuclide of concern must be demonstrated to be responsive to the redox conditions in the basalt-specific system. Preliminary tests on technetium (Bondietti and Francis, 1979; Coles and Apted, 1983) and uranium (Grandstaff et al., 1983) have confirmed that basalt can cause the reduction of these elements to less soluble solution species.

Regarding the available geochemical data base, a recent independent review of the Basalt Waste Isolation Project by Pacific Northwest Laboratory (Burnham, 1983, p. VI) states "analysis of geochemical data leads us to conclude that on the basis of the DOE siting guidelines, the Hanford basalt has several favorable attributes and no seriously unfavorable ones. Favorable attributes include pre-emplacement reducing conditions, neutral pH, average radionuclide complexing potential, and alteration mineralogy that increases adsorption potential and lowers permeability."

It should be noted that the U.S. Nuclear Regulatory Commission has presented arguments that emphasize the uncertainty of Eh estimates for the basalt geochemical system (NRC, 1983). The Basalt Waste Isolation Project recognizes the need to refine these estimates and is actively engaged in continuing laboratory and field tests to confirm this model.

6.3.1.2.3 Favorable condition

"(1) The nature and rates of the geochemical processes operating within the geological 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."

On the basis of available information, this favorable condition appears to be met by the reference repository location. The existing and anticipated geochemical processes in basalt appear to effectively retard the movement of many radionuclides.

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During the Quaternary Period the geochemical process that has dominated within the Columbia River Basalt Group is low-temperature (approximately 140°F (60°C)) diagenesis, involving basalt/ground-water reactions (Benson and Teague, 1982). These reactions involve slow alteration of primary basaltic phases, such as glassy mesostasis and pyroxene, coupled with precipitation and growth of secondary alteration phases, such as zeolite, clay, amorphous iron hydroxides, silica, and pyrite. The expected continuation of this process for the next 100,000 years would ensure control of pH at mildly alkaline conditions and a reducing Eh, as well as maintaining the current, low-ionic strength (less than or equal to 0.018) (DOE, 1982e) ground water. These conditions are favorable toward the ability of the geologic repository to isolate radioactive waste products.

Laboratory, field, and calculation studies have been completed on the basalt/water system, both at low temperatures (212°F (100°C)) (Benson and Teague, 1982; Deutsch et al., 1982; Jacobs and Apted, 1981; Smith et al., 1980; Jantzen, 1983) and at higher (greater than 212°F (100°C)) temperatures (Apted and Myers, 1982; Myers et al., 1983; Grandstaff et al., 1983; Lane et al., 1983a, 1983b). The results of these initial investigations indicate that ground-water composition, including Eh and pH, are rapidly controlled and buffered by the coexisting basalt. Furthermore, the expected Eh of -0.4 plus or minus 0.1 volts and pH of 9.2 plus or minus 0.5 at aproximately 60°C would be a favorable environment for the isolation of many radionuclides. It should be noted that these experiments were completed with fresh basalt and further work is being completed to determine Eh-pH buffering capacity of the basalt, as well as the effects of long-term hydrothermal alteration on basalt Eh-pH buffering capacity (see Subsection 4.1.1.6). The secondary phases produced by this slow alteration process are found to fill the fractures and open vugs of the basalts. These fractures and vugs represent the primary, expected pathway of any radionuclide-bearing ground water. The existing secondary phases, which are also the secondary phases expected to form after repository construction (see Subsection 6.3.1.2.5) have been demonstrated to strongly adsorb and, hence, retard the movement of many radionuclides (Salter et al., 1981; Barney, 1981; Salter and Jacobs, 1982). The low concentrations of many potential complexing species (chloride, sulfate, and carbonate) will contribute to the formation of relatively insoluble radionuclide-bearing solids and tend to reduce significantly the migration of radionuclides from the engineered barriers system. Another potential complexing agent is fluoride, which does exist in relatively high quantities. However, the importance of fluoride complexation in deep ground water is reduced because of the alkaline pH (Early et al., 1982).

It should be noted that a chemical reducing agent (hydrazine) has been used to simulate chemical reducing conditions. The effects of hydrazine on radionuclide sorption behavior are being evaluated to confirm the validity of existing data.

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6.3.1.2.4 <u>Favorable condition</u>

"(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."

This favorable condition is projected to be met by the reference repository location on the basis of available geochemical information. Existing data suggest that conditions promoting precipitation and sorption of radionuclides are characteristic of the geochemical conditions in the reference repository location. The extent and role of organic material (in interbeds and associated flow tops) in the formation of radionuclide complexes is presently unknown.

The effect of the ambient site geochemical environment on both precipitation and sorption of radionuclides is favorable for many radionuclides (see Subsection 6.3.1.2.3).

The existence of organic complexing species and the formation of colloids within the geologic setting is not yet understood. The difficulty of obtaining representative deep ground-water samples from mud-drilled boreholes has prevented the identification and study of organic species. Therefore, the extent and significance of organic complexants with respect to radionuclide transport remains to be quantified. However, generally speaking, the basalt host rock and associated interbeds are unlikely to contain substantial concentrations of organic complexes. Because colloids are chemically metastable and mechanically filterable (Stumm and Morgan, 1981; Olofsson et al., 1982), it is expected that colloids formed in a basaltic environment will tend to coalesce onto existing alteration solids that line fractures or be physically removed from the ground water before the colloid can contribute significantly to radionuclide migration. A more definitive resolution of this question is anticipated when a ground-water sampling program is conducted from the exploratory shafts and from results of the ground-water/basalt/radionuclide interaction testing.

6.3.1.2.5 <u>Favorable condition</u>

"(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."

Based on presently available data, this favorable condition appears to be met by the reference repository location. Rock temperature increases around the repository are not expected to cause irreversible or significant changes to the sorptive properties of existing secondary minerals retarding radionuclides. Hydrothermal alteration of basalt glass (and possibly other primary phases) results in the formation of highly sorptive clays and zeolites.

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The alteration minerals formed from hydrothermal reaction of basalt at high temperatures (greater than or equal to $100^{\circ}C$) (Apted and Myers, 1982; Allen et al., 1983; Lane et al., 1983b; Grandstaff et al., 1983) are closely similar to both the existing alteration mineral assemblage that lines the fractures of the basalt (Smith, 1980) and the lower temperature (approximately $60^{\circ}C$), diagenetic alteration minerals that continue to form slowly in basalts at the Hanford Site (Benson and Teague, 1982). Up to at least $200^{\circ}C$, this result is expected for the hydrothermal alteration of basalt (Winkler, 1974; Giggenbach, 1981; Browne, 1982). This assemblage of minerals includes zeolites, clays, feldspars, silica phases, pyrite, and other minerals. Because of the similarity of high temperature alteration phases (in many cases, the identical phases) to those presently in the basalt, any change in the thermal conditions of a repository is not expected to cause any reduction in the sorption properties of the fracture-lining minerals in the thermal zone that retard radionuclide transport.

6.3.1.2.6 Favorable condition

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

This favorable condition is projected to be met at the reference repository location based on the present data base.

Radionuclide release rate calculations are extremely sensitive to both characteristics of the hydrologic system and geochemical parameters. Data on both of the processes continues to be gathered, checked, and evaluated, and the actual values of parameters such as permeability, porosity, oxidation potential, and pH display a range in values. Current calculations of radionuclide release rate based on expected hydrologic flow rates and solubility/sorption considerations (Early et al., 1982) have been made by the Basalt Waste Isolation Project, both for release from a waste package (Relyea and Wood, 1984; Wood, 1980) and at the site boundaries of a repository in basalt (Clifton et al., 1983). The numerous assumptions that these models are based on are presented in the preceding references. The present models indicate that under expected conditions, and using the site-specific data, less than 0.001 percent per year of the total radionuclide inventory would dissolve for a repository located in basalt. (For ~~additional~~ related information, see the discussion on the waste package subsystem performance in Subsection 6.4.2.3.3.)

6.3.1.2.7 Favorable condition

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

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Based on available data, this favorable condition appears to be met for most radionuclides expected to be emplaced in a geologic repository at the reference repository location.

It is assumed that this potentially favorable condition refers to a reduction in the projected peak time of releases of radionuclides to the accessible environment rather than the peak concentration of releases. The following analysis is framed within that context.

The geochemical and physical properties of the basalt at the Hanford Site act to promote the retardation and isolation of many radionuclides that may be released into the repository hydrologic system. A retardation factor (R) of 10 would necessitate, assuming constant environmental conditions, the following condition:

> Assigning an approximate value of 3.0 grams per cubic centimeter for basalt density and a value of 0.1 for porosity of the flow top (DOE, 1982) would then require a sorption coefficient (K_d) such that:
>
> K_d greater than or equal to 0.3
>
> for any radionuclide that is to be retarded by a factor of 10 or greater.

Batch sorption studies using basalt, alteration minerals of basalt, and interbed materials (Salter et al., 1981; Barney, 1981; Salter and Jacobs, 1982) have been performed. Radionuclides such as uranium, plutonium, neptunium, and technetium that can exist in several different oxidation states tend to exhibit zero to near-zero K_d values under oxidizing conditions but are effectively adsorbed by alteration phases under reducing conditions. Several radionuclides (carbon and iodine) do not adsorb in the basalt geochemical environment and will not be retarded. Therefore, if the expected geochemical conditions are observed in the repository location, and the sorption values are representative of the system, the favorable condition appears to be met for most radionuclides.

It should be noted that additional retardation mechanisms such as matrix diffusion will tend to reduce further the migration rate of radionuclides in the ground-water flow system. Because of the difficulty of quantifying and verifying the effects of matrix diffusion the Basalt Waste Isolation Project does not take credit for it in meeting radionuclide release requirements.

6.3.1.2.8 Potentially adverse condition

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

Ground-water conditions in the host rock should not compromise expected repository performance; therefore, this potentially adverse condition is not expected at the reference repository location.

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There are several geochemical factors in analysis of the ground water at the Hanford Site that need to be evaluated with respect to adverse effects on the performance of the engineered barrier system and release rate of radionuclides. Geochemical factors that are currently under investigation by the Basalt Waste Isolation Project (see Section 4.1) include (1) fluoride content of the ground water, (2) organic carbon content of the ground water, (3) the possible upward migration of deep ground water in the vicinity of the reference repository location, (4) dissolved gas (especially methane) content of the ground water, and (5) natural colloids.

Estimates of radionuclide solubility under expected repository conditions (Early et al., 1982) indicate that the range in measured concentrations of fluoride, chloride, sulfate, and dissolved silica do not seem to alter significantly the computed solubility results for these radionuclides. Recent experimental studies by Cleveland et al. (1983a), however, suggest that plutonium solubility in ground water from a flow top of a Grande Ronde Basalt flow in the Pasco Basin is enhanced by the high fluoride concentration of the water. In addition, related studies with neptunium and americium (Cleveland et al., 1983b) indicate that these radionuclides also display increased solubility in basalt ground water compared to ground water from shale. These observations have not been confirmed and it must be noted that the studies were carried out in the absence of a solid basalt phase with no mechanism for controlling Eh or for evaluating the importance of colloids. Consequently, the applicability of the results to a nuclear waste repository in basalt remains to be demonstrated. In comparison, Early et al. (1982) recognize the possibility of inadequacies in the thermodynamic data base they used for deriving solubility estimates. Ongoing site-specific studies by the Basalt Waste Isolation Project and other agencies using appropriate test oxidation states, reference barrier materials, basalt, and ground water will help resolve this issue.

The potential significance of dissolved organic carbon content in the Hanford Site ground waters is that such material may form complexes with radionuclides, resulting in higher apparent solubilities, and, hence, higher release rates. Means (1982) found approximately 0.3 milligram per liter of fulvic acids in a single sample of ground water from Grande Ronde Basalt in borehole DC-6 (see Fig. 6-3). Olofsson and Allard (1983) have performed a literature survey to document available information relative to complexing of actinides with naturally occurring humic and fulvic acids. They cite results from studies showing that both humic and fulvic acids can form very strong complexes with all oxidation states of these radionuclides. An evaluation of the existing organic carbon content and the relative importance of these acids in the basalt geochemical environment are included in future planned characterization studies. In addition, the only organic characterization information available for Hanford Site ground waters is limited to total organic carbon analyses for approximately 50 samples. These results suggest that drilling fluid contamination leads to high total organic carbon values but that ground waters from extensively pumped horizons usually have total organic carbon concentrations of less than 1 milligram per liter, a value consistent with the DC-6 sample examined by Means (1982). However, as noted above,

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present data indicate that there does not appear to be an appreciable amount of these organic complexants in deep basalt ground water. Thus, organic complexation is not considered a major problem; although, investigations will continue to characterize the organic carbon in Hanford Site ground waters.

Recent hydrochemical data collected from boreholes in the reference repository location suggest that ground water relatively enriched in sodium (greater than 300 milligrams per liter) and chloride (up to approximately 500 milligrams per liter) may be migrating upward in the vicinity of the reference repository location (see Subsection 3.3.2.4). There is no available information that identifies the precise location or provides constraints on the rate of the proposed vertical flow. Furthermore, it is uncertain whether this hypothesised process constitutes an adverse condition with respect to radionuclide solubilities or the stability of the engineered barrier system.

Recently, dissolved methane at concentrations up to approximately 700 milligrams per liter has been measured in ground-water samples from several Grande Ronde Basalt flows within the reference repository location. Dissolved methane, by itself, probably does not constitute a problem as an organic complexant for radionuclides. However, gamma radiolysis of synthetic Grande Ronde Basalt ground water in the absence of basalt, containing approximately 700 milligrams per liter of dissolved methane, has demonstrated that high molecular weight organic solids (similar to polyethylene) may form under dose rates of 3×10^5 roentgen per hour. In the presence of basalt, however, initial test data indicate that these polyethelene-like organics are not formed (McGrad, 1984). Testing is in progress to further identify reaction products in the presence of basalt and engineered barrier materials and their effect on radionuclide release behavior.

The potential effects of alpha radiolysis on radionuclide migration from the engineered barriers system have not yet been studied by the Basalt Waste Isolation Project. Theoretical studies of Neretnieks (1982) and Neretnieks and Aslund (1983) suggest that alpha radiolysis of water within a breached canister will lead to production of a strong oxidant, hydrogen peroxide. As a result, some redox-sensitive radionuclides may exhibit higher oxidation states in which sorption and pecipitation reactions will be less effective means of retardation. The importance of alpha radiolysis in the basalt reepository environment and its impact on waste isolation is currently under investigation.

Natural colloids in ground waters could adsorb radionuclides and promote more rapid transport and release of radionuclides. The presence of natural colloids existing in Grande Ronde Basalt ground water has not been demonstrated. The bulk of previous drilling involves the use of bentonite-based drilling fluids; thus, any colloid sampled from these ground waters was suspect. Consequently, at present no determination of colloids in Grande Ronde Basalt ground water has been attempted. Unambiguous determination of the presence of natural colloids in ground waters must await large-scale pump tests in rotary-drilled boreholes in the reference repository location.

6.3.1.2.9 Potentially adverse condition

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

The basalt geochemical environment is projected to maintain a high affinity for sorptive radionuclides. Degradation of rock strength is not expected to occur due to existing geochemical processes or conditions. Therefore, it appears likely that this potentially adverse condition is not present at the reference repository location.

Potentially adverse geochemical processes that might enhance radionuclide mobility in the engineered barrier system are discussed in the Subsection 6.3.1.2.8. With the exception of radiation-induced factors, other factors (organic content, fluoride content, and colloids) could affect radionuclide sorption. Studies are underway to address these concerns (see Section 4.1). With regard to the degradation of rock strength by geochemical processes, the only potentially degrading process is the dissolution of basalt phases (primarily glass), which line the fractures. These reactions are unlikely to occur at a significant rate outside the thermal zone imposed on the host rock by waste emplacement. Inside the thermal zone, these processes are not expected to have a noticeable affect on rock strength because the glassy phases constitute only a very small percentage of the total infilling material (e.g., less than 10 percent for the Umtanum flow and less than 3 percent for the Cohassett) (Long and WCC, 1984, p. I-125). The clay minerals which constitute the major portion of fracture infilling are not expected to change significantly in character as a result of any geochemical alteration at deviated temperatures.

6.3.1.2.10 Potentially adverse condition

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

All available evidence supports non-oxidizing geochemical conditions at depth in the reference repository location. Therefore, this potentially adverse condition does not appear to be present at the reference repository location.

Field measurements of Eh in the Grande Ronde Basalt flows range from +0.2 to -0.2 volts. However, these values cannot be considered reliable because of the difficulties involved in the accurate measurement of in situ Eh (Stumm and Morgan, 1981, pp. 490 through 493). Consequently, a variety of indirect methods have been used to determine other estimates of Eh values. These methods are based on thermodynamic calculations using reactions among observed solid phases and considering the absence of specific solid phases and (or) dissolved species in the basalt system. These include the following:

1. The coexistance of titano-magnetite with secondary ion-bearing phases such as pyrite, nontronite, smectite, and mixed ferrous-ferric oxyhydroxides.

2. The lack of naturally occurring hematite.

3. The occassional occurrence of sulfide ion coexisting with sulfate, and methane coexisting with carbon dioxide.

Estimates of Eh from these couples converges at an Eh of -0.4 ± 0.1 volt. Additional supporting evidence was recently obtained by Jantzen (1983) by equilibrating deionized water with basalt at ambient repository temperatures. The low redox potential (approximate or equal to 0.4 volts) was simulated using this approach.

6.3.1.2.11 <u>Conclusions on qualifying conditions</u>

A final conclusion on the qualifying condition for geochemistry cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable comparison of potentially acceptable sites prior to site nomination and recommendation.

Analysis of available geochemical evidence of the reference repository location supports a finding that the site meets this qualifying condition and is likely to continue to meet the qualifying condition. This preliminary conclusion is based on the following factors:

- Naturally occurring alteration phases of the basalt are the same as or ~~closely~~ similar to those expected to form under repository conditions and are highly sorptive for many radionuclides.

- The repository and host basalt geochemical environment is reducing and tends to result in low solubilities and high sorption for many radionuclides.

- Modeling studies indicate that less than 0.001 percent per year of the total radionuclide inventory will dissolve for a repository in basalt.

- Changes in rock strength due to dissolution reactions in fractures and the basalt matrix will be insignificant.

~~While~~ Although these factors support the conclusion that the qualifying condition is met, several uncertainties currently exist. These uncertainties include the following:

- Incomplete understanding of the effects of potential complexants such as fluoride and organics.

- Incomplete thermodynamic data base for theoretical solubility calculations.

- Incomplete knowledge of the importance of colloids in the basalt geochemical system.

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- Incomplete knowledge of the potential effects of radiolysis on radionuclide containment of the engineered barriers system.

Experimental and theoretical studies that will address these uncertainties are either in progress or planned.

6.3.1.3 Rock Characteristics (Section 960.4-2-3)

6.3.1.3.1 Qualifying condition

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

6.3.1.3.2 Evaluation process

All relevant data, data uncertainties, assumptions, and analyses that were used to characterize the isolation capabilities of the rock mass are presented in Sections 6.3.1.3.3. (Favorable Conditions) and 6.3.1.3.4 (Potentially Adverse Conditions). Much of the data and analyses referenced in this report have been previously published in the Site Characterization Report (DOE, 1982e) and Repository Horizon Identification Report (Long and WCC, 1984).

6.3.1.3.3 Favorable condition

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

Based on available data, the preferred candidate horizon (Cohassett flow) should provide a sufficiently thick and laterally extensive host rock to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation. The option to select from four candidate horizons (Rocky Coulee, Cohassett, McCoy Canyon, and Umtanum flows) provides further flexibility at depth when selecting a repository host rock horizon. Therefore, the reference repository location appears to meet this favorable condition.

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A detailed discussion of the four candidate flow thicknesses and areal extent is presented in Subsection 6.3.3.2.3. ~~Included within~~ which includes ~~Subsection 6.3.3.2.3 is~~ the rationale for choosing 30 meters (98 feet) as the required dense interior thickness for repository development. The thickness criteria ~~for~~ 30 meters (98 feet) was initially chosen to meet the preclosure qualifying condition. ~~that~~ The preclosure qualifying condition requires adequate thickness to accommodate the construction, operation and closure of the underground facility, not cause undue hazard to personnel, and be ~~technically~~ feasible on the basis of reasonably available technology. ~~such that construction, operation, and closure of the underground facility can be conducted within the available thickness.~~

Based on the performance assessment studies presented in Section 6.4.2, ~~it is apparent that~~ the 30-meter (98-foot) dense interior thickness criteria is also more than adequate to ensure isolation. Results of these performance assessment studies indicate that there is a very high probability that U.S. Department of Energy guidelines, U.S. Nuclear Regulatory Commission criteria, and U.S. Environmental Protection Agency standards will be met without taking credit for any of the natural ~~barrier~~ isolation characteristics of the dense interior. The criteria in 10 CFR 60.113 (NRC, 1982a) requires that pre-waste ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years. Preliminary performance assessment studies indicate that the range of expected median ground-water travel times could be on the order of 17,000 to 86,000 years (see subsection 6.4.2.3.5). These ground-water travel times were computed from a starting point located in the flow top overlying the emplacement horizon at the downstream edge of the repository to the accessible environment, which was taken to be at 10 kilometers (6.2 miles) from the starting point flow path. This is a very conservative ~~study~~ and does not include, or take credit for, the natural isolation benefits of the dense interior. Therefore, ground-water travel times from the emplacement horizon can be expected to be much greater, since groundwater flow must pass through the relatively less permeable dense interior.

Even though flow through the relatively less permeable dense interior basalt is not required to meet the pre-waste emplacement groundwater travel time criteria set by the Nuclear Regulatory Commission, the maintenance of a thick dense interior barrier between the repository horizon and the flow top is favorable.

Factors that may affect the isolation characteristics of the dense interior are ~~present~~ as follows:

1. Extent of the disturbed rock zone and what effect this zone will have on the hydraulic conductivity of the dense interior host rock.

2. Development of a large-scale failure or fracture zone extending deep into or through the thickness of the dense interior.

Evaluation of the first item involves determining if the disturbed rock zone around the excavation could reduce the undisturbed thickness of the dense interior such that the isolation characteristics of the host rock is adversely affected. The development of a disturbed rock zone is due to blast/boring rock damage, and deformation due to a redistribution of excavation- and thermal-induced stresses from construction and waste replacement. The disturbed rock can be divided into a blast damage, a plastic, and an elastic zone (Fig. 6-4). Studies have been conducted by Lawrence Berkeley Laboratory (1983) and Kelsall et al. (1982) to estimate

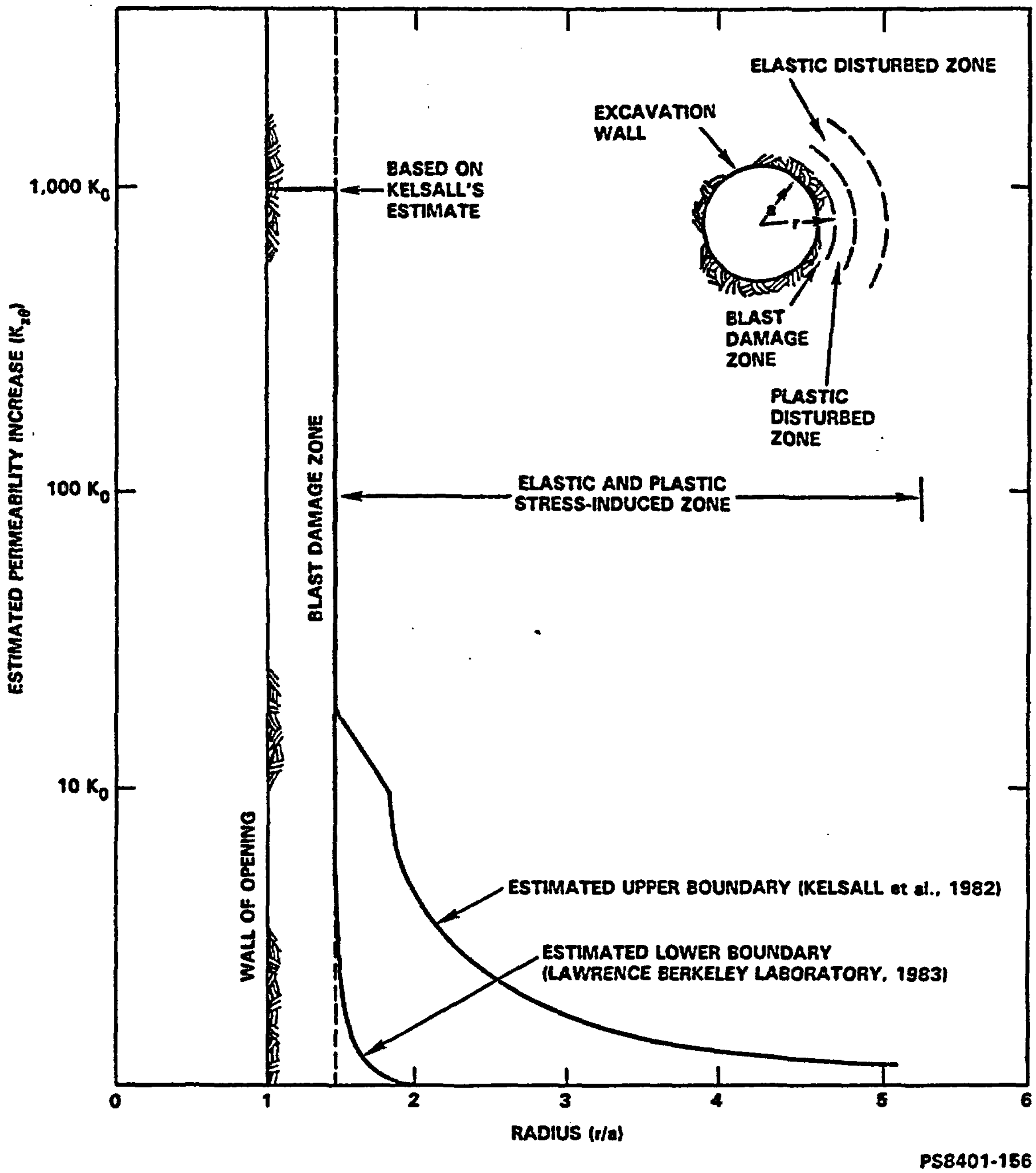

FIGURE 6-4. Estimated Range of permeabilities (K_z) in the disturbed rock zone for the direction parallel to the axis of the opening.

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the extent of the disturbed rock zone. The Lawrence Berkeley Laboratory (1983) study indicates the plastic zone would extend from 1.0 to 1.03 radii from the excavation center. The elastic zone was estimated to extend outward from the plastic zone to 3.0 radii from the excavation center. Kelsall et al. (1982) estimated the plastic zone to extend between 1.0 and 3.2 radii with the elastic zone extending to 8.6 radii. The major difference between the two studies was the value of the rock mass strength used. Kelsall et al. (1982) used a more conservative (lower) estimate of rock mass strength that resulted in a larger disturbed zone. Neither study addressed thermal-induced stresses. As a result, the expected disturbed rock zone resulting from excavation- and thermal-induced stresses is interpreted to be intermediate between the results presented by Lawrence Berkeley Laboratory (1983) and Kelsall et al. (1982). The effects that in situ stress conditions and underground opening shapes have on the development of the disturbed rock zone have been studied by the Lawrence Berkeley Laboratory in a preliminary fashion.

Lawrence Berkeley Laboratory (1983) and Kelsall et al. (1982) also estimated the permeability changes that would develop in the disturbed rock zone. Usually, the development of a disturbed rock zone results in an increase in permeability. Permeability increases in the direction parallel to the excavation as a result of the disturbed rock zone (see Fig. 6-4). No increase in permeability in the radial direction is expected since excavation- and thermal-induced tangential stresses tend to close radial fracture apertures. The stress-induced zone, as shown in Figure 6-4, includes both the plastic and elastic disturbed rock zones. The Lawrence Berkeley Laboratory (1983) report also suggested that permeability increases in the blast damage zone will tend to be equal in all directions and extend approximately 0.5 to 1.0 meter (1.6 to 3.3 feet) into the rock when controlled blasting methods are used. From these studies it is interpreted that the effective hydraulic thickness of the host rock is not reduced due to the development of a relatively small blast damage zone and the fact that the radial permeability of the stress-induced zone is not expected to increase.

The second item, which considers the potential for developing large-scale failure or fracture zones extending deep into or through the thickness of the dense interior, has not yet been fully evaluated. This potential failure mechanism can be attributed to the high in situ horizontal stresses existing in the reference repository location and superimposed thermal-induced horizontal stresses. Correspondingly, the vertical in situ stresses are apparently only lithostatic with little influence due to heating because of the large size of the repository and the ability of the rock mass above the repository to dilate upward when heated. This large deviatoric stress (horizontal stress greater than vertical stress) could produce large-scale shear deformations and fracturing of the rock mass in areas of dense interior thinning above or below the repository horizon.

However, the repository design is flexible enough that the development of this failure mechanism is unlikely. Preconstruction exploratory programs, as described in Subsection 6.3.3.2.3, will be used

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to identify areas of thinning such that either the subsurface repository development can be directed towards areas of thicker dense interior or the thermal load per acre can be reduced by increasing the placement hole spacing. Such design flexibility should ensure that a large-scale failure or fracture zone would be unlikely.

This discussion has only considered the host rock thickness and its effect on the isolation capabilities relative to the waste emplacement areas. Shafts within the shaft pillar area will penetrate all basalt flows above the host rock repository elevation. In addition, the drilled and lined shafts may extend below the dense interior of the repository horizon to allow room for the emplacement of the shafts friction hoist-tail ropes. This should not pose a waste isolation problem at closure if the backfill used for filling the access drifts, between the waste panel area and the shaft, is designed such that radionuclide travel times along the drifts are adequate to limit radionuclide releases (see Subsection 6.4.2.3.4).

It can be concluded that there is sufficient thickness and areal extent within the host rock dense interior to ensure isolation, although the isolation capabilities of the reference repository location do not rely on the natural ~~barrier~~ isolation characteristics of the dense interior.

6.3.1.3.4 Favorable condition

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

The host rock is expected to satisfy this favorable condition due to its relatively low coefficient of thermal expansion. In addition, ~~it is expected that~~ hydrothermal alteration of the basalt is expected to seal fractures~~,~~ resulting in improved host rock isolation characteristics. Therefore, it appears that this favorable condition is present due primarily to the low coefficient of thermal expansion of the basalt, and secondarily, due to the hydrothermal alteration of the basalt and subsequent sealing of fractures by secondary mineralization ~~of the fractures~~.

Laboratory testing of intact basalt rock from the Hanford Site has been conducted to determine the thermal conductivity and thermal expansion properties of the rock. The results of this testing are presented in Table 6-4. For comparison, thermal properties of other rock types are presented in Tables 6-5 and 6-6.

A comparison of the thermal properties from these tables shows that the thermal conductivity of the basalt flows on the Hanford Site (see Table 6-4) is generally lower than other rock types such as granite, quartz monzonite, limestone, and salt, but comparable to welded tuff, shale, and sandstone (see Tables 6-5 and 6-6). ~~Thermal expansion values for basalt fall within the lower range observed for most other rocks.~~ From these same tables it can be seen that the basalt flows under consideration have coefficients of thermal expansion (Table 6-4) which are less than all other rock types presented in Tables 6-5 and 6-6.

Table 6-~~8~~4. Thermal properties of Hanford formation basalt flows.

Property	Grande Ronde Basalt		Saddle Mountains Basalt
	Cohassett flow	Umtanum flow	Pomona flow
Heat capacity (cal/g^oC)			
No. of samples	3	9	26
Linear regression	$Cp=0.183 + 1.95 \times 10^{-4}T$*	$CP=0.206 + 1.4 \times 10^{-4}T$*	$Cp=0.202 + 1.24 \times 10^{-4}T$*C
Standard deviation			
of y about x	2.23×10^{-3}	0.0164	0.0153
slope	6.17×10^{-6}	2.69×10^{-5}	1.54×10^{-5}
Thermal conductivity (W/m-K)			
No. of samples	6	11	30
Mean	1.51	1.71	1.85
Standard deviation	0.152	0.478	0.38
Range	1.31-1.74	1.27-2.46	1.16-2.65
80% confidence interval	1.42-1.60	1.51-1.91	1.76-1.94
Coefficient of thermal Expansion ($/^oC$)			
No. of samples	2	9	38
Mean	6.02	6.51	6.40
Standard deviation	0.42	0.33	1.16
Range	5.72-6.31	5.93-7.00	4.80-8.73
80% confidence interval	5.11-6.92	6.36-6.67	6.17-6.64

NOTE: T = Temperature (^oC): 20^o to 200^oC.

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Table 6-5. Thermal rock properties.

Rock type	Temperature	Thermal conductivity (W/m°C)	Thermal expansion (10^{-6}/°C)
Quartz Monzonite[a]		2.1-3.4	
Salt (Louisiana)[b]	40°C	4.0	
Salt (Louisiana)[b]	300°C	2.2	
Tuff[c]	90°C		8.9±1.6
Tuff[d]		2.4	
Tuff[d]		1.55	
Salt[e]	110°C	2.08-6.11	
Granite[e]		1.99-2.85	
Shale[e]		1.47-1.68	
Tuff (welded)[e]		1.20-1.90	
Tuff (unwelded)[e]		0.40-0.80	
Basalt[e]		1.16-1.56	

[a] Data taken from Durham (1982, Fig. 3 and 4, pp. 5 and 6).
[b] Data taken from Morgan (1979, p. 5).
[c] Data taken from Lappin (1980, p. 31).
[d] Data taken from Klasi et al. (1981, p. 10).
[e] Data taken from Wang et al. (1983, Table 3.8, p. 34).
[F] Data taken from Clark (1966, Table 6-10, p. 94).

Rock type	Temperature	Thermal conductivity (W/m°C)	Thermal expansion (10^{-6}/°C)
Granites and rhyolites[F]			8±3
Andesites and diorites[F]			7±2
Basalts, gabbros, and diabase[F]			5.4±1
Sandstones[F]			10±2
Quartzites[F]			11
Limestones[F]			8±4
marbles[F]			7±2
slates[F]			9±1
Tuff[g]		1.7-2.6	9-12
Granites[h]		2.4-2.8	6-8
Salt[i]		4.5	40

[g] Data taken from SCE (3/81/83)
[h] Data taken from Agapito et al (1977)
[i] Data Taken from Token (1983)

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Table 6-~~8~~6. Thermal rock properties.

	Temperature (^{o}C)	Generic basalt	Generic shale	Generic granite	Generic salt
Thermal expansion ($\epsilon\mu/^{o}C$)	NA	5.40	8.10	8.10	40.0
Thermal conductivity (W/m-k)	0	1.16	1.68	2.85	6.11
	50	1.19	1.61	2.70	5.02
	100	1.26	1.54	2.56	4.20
	150	1.31	1.52	2.44	3.60
	200	1.37	1.51	2.34	3.11
	300	1.49	1.49	2.15	2.49
	400	1.56	1.47	1.94	2.08

NOTE: Taken from DOE (1979, pp. 7.2.17, 7.2.20, 7.2.23, 7.2.26).

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types. The values are commonly somewhat lower than those for granite and tuff, and substantially lower than values for salt. It should be noted that these values are for intact rock and may not reflect properties of the rock mass, especially in closely jointed conditions. A complete analysis of the potential for improvement in isolation capability will require additional laboratory testing, in situ field testing, and numerical analysis.

From laboratory testing, it is apparent that the basalt host rock behaves in a very brittle manner. It is not expected that the basalt dense interior rock will have sufficient ductility to seal repository-related fractures. The ductility of a material generally becomes more noticeable at higher temperatures and pressures. Limited Basalt Waste Isolation Project laboratory triaxial compression testing at higher temperatures has not produced a transition from brittle to ductile behavior. In addition, laboratory testing at higher confinement stresses (34 megapascals (4,900 pounds per square inch)) has also not produced a transition to ductile behavior. Bauer et al. (1981, p. 74) has reported brittle behavior of basalt samples at confining stresses as high as 100 megapascals (14,400 pounds per square inch) and temperatures of 820°C (1,508°F), which represent conditions more severe than expected in the repository.

Interactions between the host rock, ground water, and elevated temperatures may improve the isolation characteristics of the host rock. Hydrothermal alterations of basalt should decrease the permeability of the rock mass due to the formation of secondary minerals in fractures and vesicular zones and flow tops. It is expected that the formation of secondary minerals will tend to seal fractures, thus, decreasing the permeability of the host rock. Subsection 6.3.1.6.5 provides further discussion of this potential fracture sealing characteristic.

Further laboratory and field testing at elevated temperatures and pressures will be required to satisfactorily characterize the rock mass thermomechanical behavior and potential for hydrothermal alteration. Additional thermal property characterization in the laboratory and field must be continued to better determine the effects that thermal loading will have on the host rocks isolation capabilities.

6.3.1.3.5 Potentially adverse condition

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

Preliminary information and studies indicate that this potentially adverse condition appears not to exist at the reference repository location. The need to ensure waste containment or isolation does not impose a restriction on repository construction techniques. Neither the underground excavation technique nor the rock support reinforcement system is critical to ensure waste containment or isolation.

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Preliminary performance assessment modeling of the ground-water travel time indicates that the range of expected median ground-water travel times could be on the order of 17,000 to 86,000 years (see Subsection 6.4.2.3.5) and that the fastest ground-water flow path assumes radionuclide release in the flow top with horizontal flow within the flow top to the accessible environment 10 kilometers (6.2 miles) from the repository. The fastest flow path is not the path along the damaged rock zone and up the shaft to the accessible environment at the surface (see Subsection 6.4.2.5.2).

The rock excavation technique and the rock support/reinforcement system should be selected to maintain safety and accessibility during construction and the retrievable storage phase. Drill and blast excavation techniques are well developed from tunneling and mining in hard rock and could be used for excavation of the underground openings; therefore, no new technology is required. Similarly, rock support systems consisting of rock bolts and shotcrete (see Subsection 6.3.3.2.4) appear to be sufficient to meet the operational and long-term stability requirements imposed by safety; therefore, no new technology is required. The potential for rock burst, other than local spalling, is considered low and has no impact on the long-term ground-water travel times and, hence, does not require measures for prevention or control that are beyond reasonably available technology to ensure waste containment or isolation.

The operation of the repository proposed in basalt is similar to that proposed for other host media and no new technology appears to be necessary to ensure waste containment or isolation. At the reference repository location, present repository layout studies include horizontal emplacement of single containers in short holes drilled into the wall of the storage rooms (see Subsection 5.1.4.1). This storage configuration was selected to optimize storage room shape with respect to the existing in situ stresses, to minimize disturbance to the dense interior of the candidate flow, and to optimize retrievability. The storage hole will be lined with packing material using engineering measures considered within reasonably available technology, although some design, development, and testing of components will be required. Similarly, the transporter and emplacement technique will require design development and testing, but is not considered beyond reasonably available technology.

The closure of the repository will require the emplacement of a seal system that includes backfilling, bulkheads, and grouting as illustrated in Figure 6-7. The performance objectives of these seal components are to ensure long hydraulic travel times and limited ground-water flux through the shafts and drifts.

The basic material component for backfilling is crushed rock removed during mining. A backfill with relatively low permeability can be produced by mixing the crushed rock with clay, provided that clay fills the interconnected voids between the crushed rock aggregate, and provided that there is a tight interface with the host rock. Formation of a tight interface should be assisted by the use of a swelling clay material such as bentonite, which has a low permeability and swells on contact with ground water.

It should be noted that the performance requirements for backfills that would be placed in the shafts have not been determined but performance assessment of the repository seal subsystem has assumed that the in place hydraulic conductivity (permeability) will be less than the damaged rock zone, or less than 10^{-10} meters (feet) per second.

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Preliminary performance studies have shown that the inherent geologic and hydrologic characteristics of the site are such that the isolation of the site is maintained without relying on artificial engineering measures to ensure isolation. These studies have shown that the shortest path to the accessible environment is through the dense interior and flow tops and not along the distrubed rock zone and up the shaft (subsection 6.4.2.5.2). Therefore, the engineered sealing system is not critical for ensuring isolation. In addition, performance assessment studies (subsection 6.4.2.3.5) show that median grount-water travel times through the flow top to the accessible environment range between 17,000 to 86,000 years. These ground-water travel times are much greater than the 1000-year ground-water travel time criteria set forth in 10 CFR 60.113 (NRC, 1982a); therefore, any failure scenarios or geologic anomalies which may effect the isolation characteristics of the dense interior capability of meeting the EPA standard for cumulative releases to the accessible environment.

A compacted crushed basalt/bentonite mixture is expected to satisfy this objective, and, if necessary, grouting can be utilized. Placement techniques may have to be developed and tested by large-scale prototype demonstration, but is not considered beyond reasonably available technology.

Bulkheads are defined as dense seal components that are small in volume relative to sections of backfill. One function of bulkheads may be to limit ground-water flow internally within the seal as well as the seal-host rock interface and in the disturbed rock zone surrounding the penetration. Interface flow can be reduced effectively by inducing a high compressive stress normal to the interface. Development of high interface stress by expansive bulkheads should be assisted by high stiffness of the basalt host rock. Candidate materials for use in bulkheads are cement-like materials, such as concretes, and clay-bearing materials, particularly those that contain "swelling" clays (e.g., smectites).

To reduce the effective conductivity of the disturbed rock zone at selected hydraulic cutoff locations, the disturbed rock zone joints and fractures will be pressure injected with grout using grout curtain construction techniques similar to that used to improve rock foundations at dam sites (ASCE, 1982). These techniques have been well developed and there are many published case histories (ASCE, 1982, p. 259). The staged grout curtain method currently in use if flexible and the process can be field adjusted. The performance can be monitored by computer-assisted methods (ASCE, 1982, p. 340) and additional stages of grout injected until the desired performance objective is achieved. Following this stepwise method, the host rock cutoff site is injected, tested, injected, and tested repeatedly until the measured hydraulic conductivity is attained.

To ensure grout penetration, injection pressures can be used up to levels limited by concerns for host rock hydrofracturing or failure of the shaft liner system. With the grout curtain complete, portions of the liner, its supporting grout, and damaged host rock-liner grout interface will be removed to provide a quality interface for shaft interior plug components constructed with low permeability expansive plug materials (e.g., bentonite-basalt).

Preliminary performance assessment modeling of the repository seal subsystem (see Subsection 6.4.2.3.4) indicates that radionuclide transport through the backfilled excavations is not the controlling path for radionuclide transport to the accessible environment. The controlling pathway for radionuclide migration is through the damaged annulus of rock around each opening. Backfilling planned in conceptual repository designs for the reference repository location include placement of a mixture of crushed basalt with bentonite. Placement of this material does not require development of new technology.

Performance assessment (see Subsection 6.4.2.3.4) evaluated the potential radionuclide release via the damaged rock zone around repository openings to the shaft and up to the Vantage interbed through the damaged rock zone around the shaft. The Vantage interbed was assumed to be 133 meters (______ feet) above the repository horizon. The analysis evaluated a range of mean hydraulic conductivities for the damaged rock zone ranging from 10^{-7} to 10^{-10} meters (_____ to ______ feet) per second. In no single Monte Carlo trial, for all cases analyzed, did the calculated cumulative release of radionuclides exceed the U.S. Environmental Protection Agency limit within 10,000 years.

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Planned engineering measures are not necessary to ensure waste containment or isolation. Preliminary performance assessment modeling has indicated that groundwater travel time requirements can be met without a relatively impermeable rock mass between the emplaced waste and the nearest flow top. The planned engineering measures are for the purposes of repository worker safety and to maintain the integrity of the rock mass as a redundant containment barrier. The planned engineering measures, which are not required for purposes of waste containment or isolation, are within reasonably available technology.

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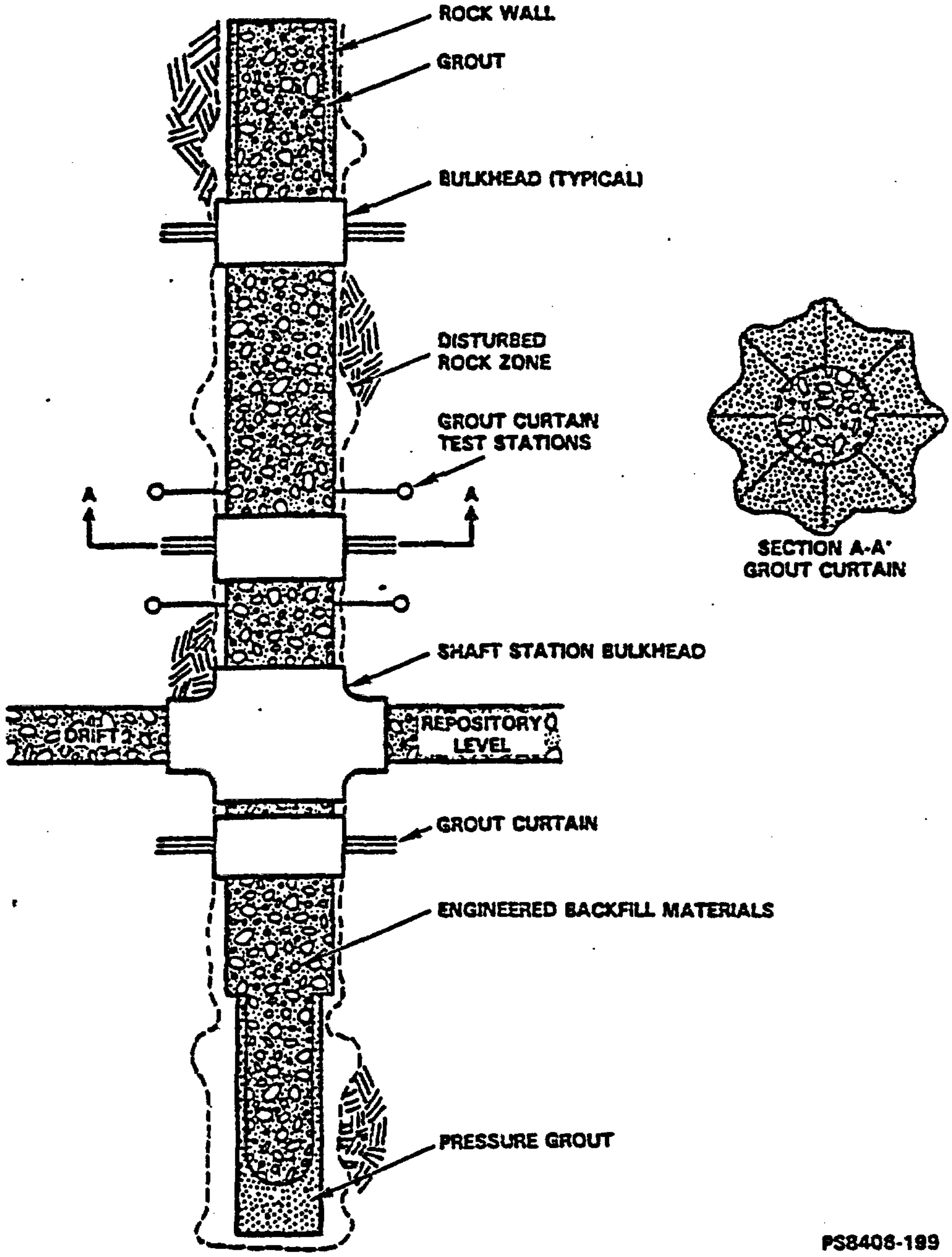

Figure 6-7. Shaft seal design concept.

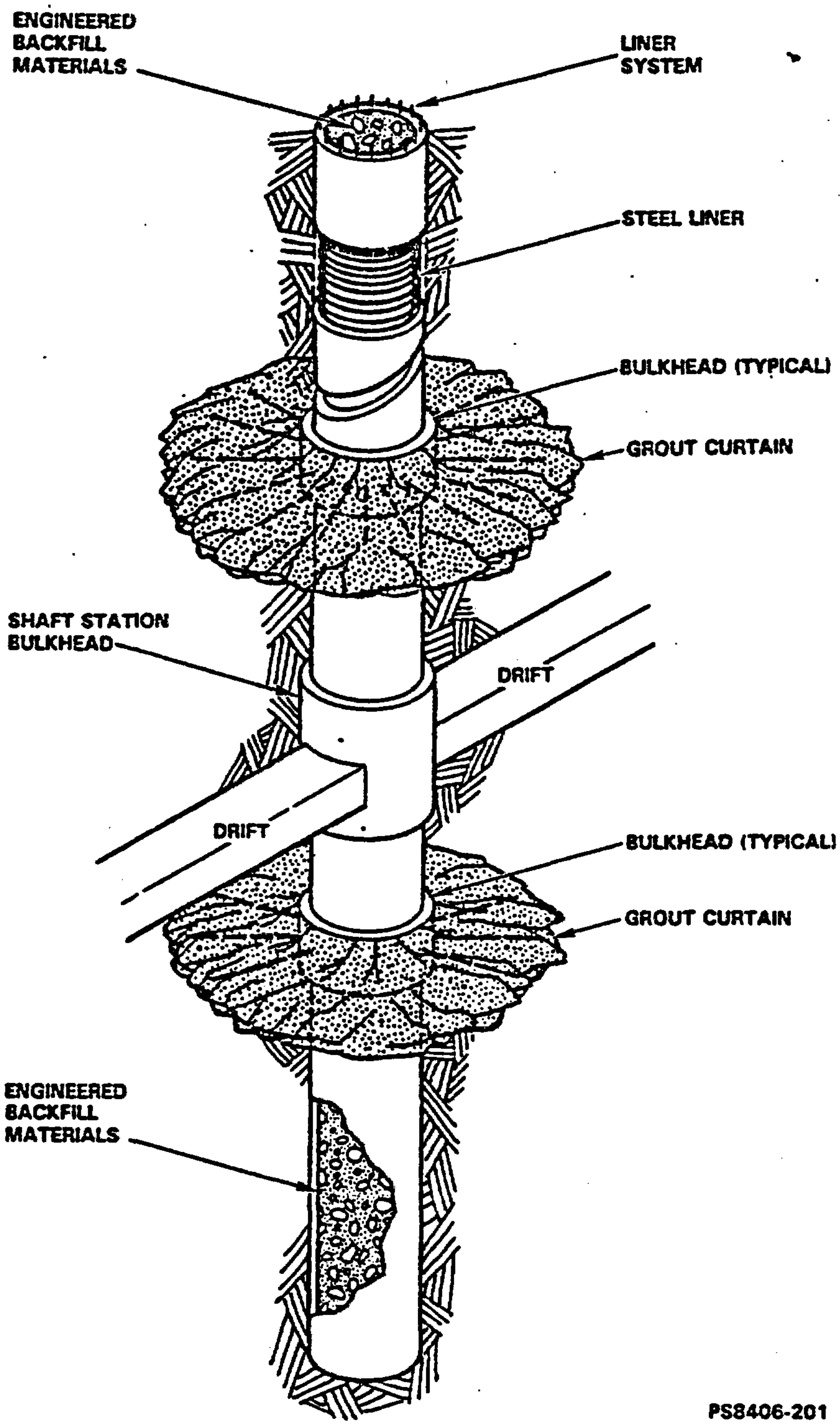

Figure 6-7 (cont.). Shaft seal design concept.

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It should be noted that the performance requirements for backfills which would be placed in the shafts have not been determined. Some backfill components may possess low hydraulic conductivity to restrict the flow of ground water. On the other hand, it may be desirable for the backfill to possess a relatively high effective porosity to reduce ground-water flow velocity (increase travel times) or to act as a sorptive sink for any radionuclides released from the waste packages.

Bulkheads are defined as dense seal components that are small in volume relative to sections of backfill. One function of bulkheads may be to limit ground-water flow internally within the seal as well as the seal-host rock interface and in the disturbed rock zone surrounding the penetration. Interface flow can be reduced effectively by inducing a high compressive stress normal to the interface. Development of high interface stress by expansive bulkheads should be assisted by high stiffness of the basalt host rock. Candidate materials for use in bulkheads are cement-like materials, such as concretes, and clay-bearing materials, particularly those that contain "swelling" clays (or smectites).

A second fuction for bulkheads is to support the wall-rock surrounding the excavation, if required, and thereby forestall creep failure and (or) slump into the engineered pathways.

6.3.1.3.6 Potentially adverse condition

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

Further investigations will be required to adequately assess the effects that thermal-induced fracturing will have on the isolation characteristics of the host rock. Until that time the high in situ stress field at the Hanford Site must be regarded as sufficient cause to consider this potentially adverse condition present. Based on preliminary information, hydration and dehydration of mineral components are expected to only effect the isolation potential of localized areas within the host rock, such as the disturbed rock zone, but are not expected to compromise the total inherent natural isolation characteristics of the host rock. Brine does not exist in a basalt geologic medium. Physical, chemical, or radiation-related phenomena that could effect waste containment or isolation are found in Subsection 6.3.1.2 (geochemistry).

Thermal-induced fracturing may develop by a variety of mechanisms that extend from grain to room or repository scale. The smallest scale of thermal-induced fracturing occurs at the grain scale. This type of fracture mechanism is due to the development of differential thermal expansion of the composite mineral grains and the generation of new grain boundaries. A second fracture mechanism occurs at the pore scale. The development of this mechanism is due to the difference in thermal expansion properties of the host rock and the water that fills its pores.

However, it should be noted that preliminary performance-assessment studies (see subsection 6.4.2.3.5) show that median ground-water travel times through the flow top to the accessible environment range between 17,000 to 86,000 years; therefore, no thermal-induced fracturing scenarios through the dense interior host rock are expected to compromise the ground-water travel time criteria set forth in 10 CFR 60.113 (NRC, 1982a).

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A third fracture mechanism occurs on a larger scale due to the development of high deviatoric excavation- and thermal expansion-induced compressive stresses (major principal stress minus minor principal stress). If this type of shear fracturing develops, it would be expected to occur in the crown or floor of the placement hole or placement room excavations. In these areas, large deviatoric stresses can develop due to the excavation- and thermal expansion-induced compressive tangential stresses and the reduction in radial stress near the boundary of the excavation. The potential development of these stress-induced instabilities around placement rooms or placement holes may be controlled by reducing the thermal load (increase placement hole spacing). As discussed in Subsection 6.3.3.2.3, there is more than adequate room for expanding the repository since the size of the current repository conceptual design is only approximately one-fifth the size of the reference repository location.

Repository-scale shear fractures can possibly develop in either a seismic or aseismic fashion above or below the waste panels if a thinning occurs in the dense interior of the host rock, and (or) the combination of excavation- and thermal-induced stresses approach the dense interior rock mass strength. Due to higher rock mass moduli in the host rock dense interior versus lower rock mass moduli in the flow tops and vesicular zones will tend to further concentrate excavation- and thermal-induced stresses around openings within a thin dense interior. The potential occurrence of such repository-scale shear fractures will be controlled through the use of a preconstruction exploratory program (see Subsection 6.3.3.2.3) to ensure that the repository is being developed in areas of adequate thickness. The repository design will be flexible enough such that if areas of dense interior thinning are encountered the repository development will either be redirected to areas of thicker dense interior or the thermal load per acre will be reduced by increasing the placement hole spacing. Further analyses must be conducted to evaluate the effect of thinning on the potential development of through-going fractures. From these analyses, guidelines will be developed defining adequate thickness for given thermal loading.

The potential for inducing seismic events or aseismic (quasi-static) shear failures during thermal loading of the repository region has not yet been fully analyzed. The seismic events might appear similar to microearthquake swarm activity previously observed at the Hanford Site. Such phenomena might be associated with zones of fanning columns oriented more critically to the principal stress or with faults that go undetected during exploration and construction. Numerical analysis is needed to examine the conditions under which these events might occur and to determine the limitations on thermal load necessary to avoid them.

Field data on the development of microfracturing and shear fracturing due to thermal loading has not been obtained. However, information relative to rock degradation due to high rock temperatures (490°C (915°F)) is available from the Full Scale Heater Test #2 conducted in the Pomona basalt at the Gable Mountain Near Surface Test Facility on the Hanford Site (see Fig. 3-37). Even though these temperatures were very much in excess of the maximum temperatures expected in the repository, no

Further studies need to be conducted to better identify the controlling mechanisms for this potential failure and to establish an appropriate failure criteria.

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spalling or slabbing was observed in the before-heating and after-heating photographs. Several minor openings of existing small fractures and the creation of new small fractures were observed. In addition, laboratory testing of a limited amount of rock core from areas of rock adjacent to the heater showed a reduction in the intact strength of the rock after heating. These results are in agreement with the approximate 20 percent reduction of intact strengths obtained from laboratory testing of Pomona basalt rock core heated to 200°C (390°F)) (FSI, 1981, p. 14-5).

Cross-hole seismic tests in the near vicinity of the heater at Full Scale Heater Test #2 following cooldown showed a significant decrease in the rock mass sonic velocity near the heater relative to velocities recorded away from the heater (King, 1984, p. 29). Velocities of 16 to 65 percent of those measured prior to heating were recorded, with the lowest velocities found in a zone less than 1.5 meters (feet) from the heater hole wall. This indicates a reduction in rock elastic modulus in this area that is thought to reflect slip-and-opening (dilation) of joints caused by (1) high thermal-induced stress magnitudes in the basalt adjacent to the container holes, and (or) (2) thermal-induced stress gradients developed from high temperature gradients. Such results would suggest a corresponding decrease in permeability in this region.

The information from the Near-Surface Test Facility is somewhat qualitative with regard to predicting the response of the host rock to thermal loading. It should be remembered that the Full Scale Heater Test was conducted under a relatively low in situ stress environment; whereas, the in situ stress environment of the Cohassett dense interior will be much greater. In addition, the repository functional design criteria limits temperatures in the basalt adjacent to the waste container to 300°C (570°F) or less. This is significantly less than the 490°C (914°F) temperatures developed in the basalt adjacent to the Full Scale Heater Test borehole. Due to the differing conditions between the Full Scale Heater Test at the Near-Surface Test Facility and the Cohassett flow dense interior, it is currently not possible to estimate a quantitative effect of thermal-induced fracturing and fracture opening on the isolation characteristics of the host rock.

The effects that hydration or dehydration may have on the isolation characteristics of the ~~host rock need to be considered. Any effects that hydration or dehydration may have on the~~ intact basalt should be insignificant; whereas, these same conditions may have significant effects on the fracture infilling minerals. Dehydration will be accompanied by infilling shrinkage, with a resulting potential for increased fracture permeability and decreased joint and rock mass strength and stiffness (see Subsection 6.3.1.3.5).

Identification of the fracture infilling within the RRL-2 borehole (see Fig. 6-4) has shown a high percentage of smectite clay (montmorillonite) and zeolite. The Cohassett flow fracture infilling averaged approximately 89 percent smectite clay and 9.3 percent zeolite; whereas, the Umtanum flow averages 53 percent smectite clay and 37 percent

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zeolite (Long and WCC, 1984, Table I-24, p. I-125). Smectite clays have high swell/shrink potentials and this potential problem is further magnified by the high percentage of smectite clay.

After waste panel development and container emplacement, temperatures in the host rock surrounding the subsurface openings will increase with time. The fracture infilling minerals, such as the smectite clay and zeolite, will be most affected by heating and begin to dehydrate and shrink. Clays dehydrate by losing interlayer water at lower temperatures and structural water (hydroxyl groups) at high temperatures. Dehydration temperatures of interlayer water is a function of temperature and in general slightly above the boiling point of water at any given pressure. The dehydration of a smectite clay at pressures of 0.1 and 30 megapascals (14.5 to 4,300 pounds per square inch) is illustrated in Figures 6-7 and 6-8. Note the relative insignificant change in temperature at which strucutral water is dehydrated at different pressures. The loss of structural water is irreversible and produces permanent alteration of the clay.

For a limiting temperature design criteria of 300°C (570°F) in the rock, it is expected that interlayer water dehydration of the clays will occur in the fracture infilling within the disturbed rock zone adjacent to the container hole because of the lower hydraulic heads and high temperatures within this region. At further distances from the container hole and beyond the disturbed rock zone, dehydration is not expected due to higher hydraulic heads (DOE, 1982e, Vol. II, p. 11.3-30). Interlayer water may also be dehydrated from the clay infilling within the disturbed rock zone surrounding the placement rooms. The occurrence and extent of dehydration effects will depend on the waste panel areal heat load, since the maximum temperatures surrounding the placement rooms (Baxter and Topcubasi, 1982, Fig. 6, p. 33) are expected to be very close to the 126°C (259°F) temperature shown in Figure 6-7 at which clay interlayer water begins to be lost at a confinement stress of 0.1 megapascals (14.5 pounds per square inch).

It is therefore expected that the hydration or dehydration effects may only be local and that the natural isolation characteristics of the host rock will not be compromised. Only the fracture infilling within the disturbed rock zones around the placement holes and rooms are expected to dehydrate and possibly shrink resulting in increased permeabilities and reduced isolation characteristics. The magnitude of this potential shrinkage may be reduced due to the consolidated nature of the clay infilling. The in situ water content of the clay infilling is unknown. If the clay infilling is consolidated to an extent such that its in situ water content is not much greater than the shrinkage limit of the clay infillings, then very little shrinkage would be possible due to dehydration.

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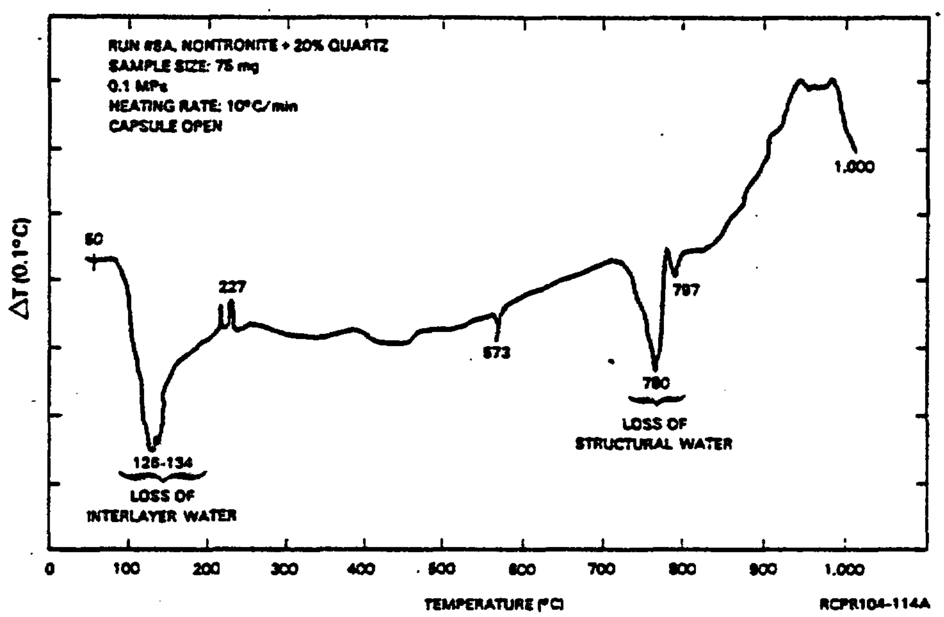

Figure 6-8. Dehydration of fracture mineralization at 0.1 megapascals (after DOE, 1982e, Vol. II, p. II.3-29).

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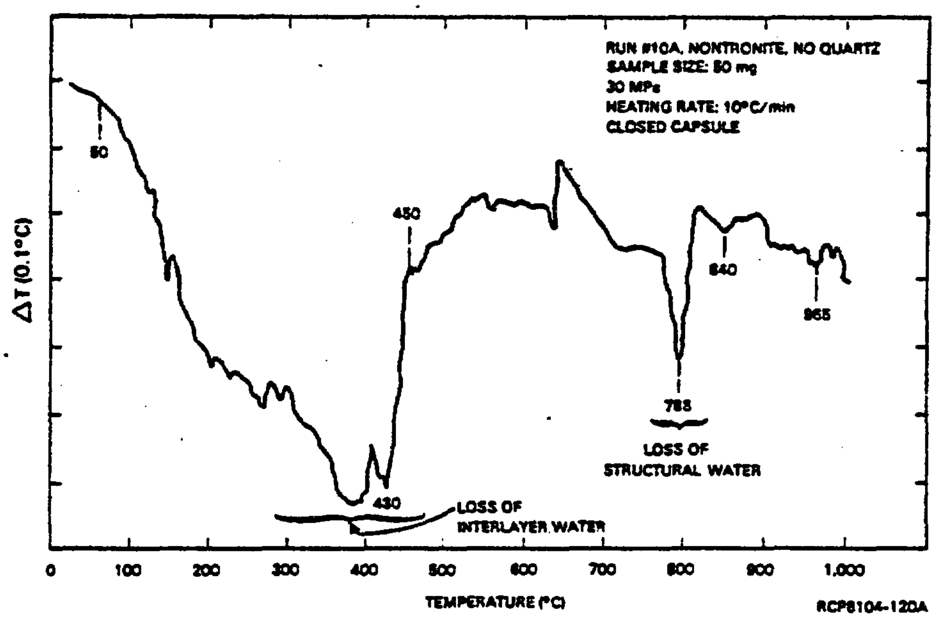

Figure 6-9. Dehydration of fracture mineralization at 30 megapascals (after DOE, 1982e, Vol. II, p. II.3-29).

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6.3.1.3.7 Potentially adverse condition

Therefore it is considered that this condition is not present amongst

"(3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with pre-waste-emplacement conditions."

Based on preliminary data and studies it is not ~~possible to conclusively determine if~~ expected that the reference repository location has a combination of geologic structure, hydrologic conditions, and thermal properties such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with pre-waste-emplacement conditions. Further studies are necessary to adequately access these characteristics.

The two characteristics that will have the greatest impact on the isolation capabilities of the host rock when heated are (1) the thickness of the flow tops and dense interior flows above the repository, and (2) their corresponding hydraulic conductivities. These characteristics have the greatest impact on isolation due to the apparent slight upward vertical hydraulic gradient of the host rock and a bouyancy effect produced by thermal loading.

Preliminary long-term performance studies have been conducted to evaluate the migration of radionuclides through the ground-water system to an accessible environment (DOE, 1982e, pp. 12.0-1 through 12.4-54); Long and WCC, 1984, pp. I-280 through I-316). From these studies it was noted that the effect of thermal loading bouyancy overshadows the in situ upward vertical gradient and, therefore, becomes the dominant mechanism for radionuclide movement. The regional, horizontal gradients do not significantly have an influence until the ground-water pathlines move into the flow top where they will be reoriented from vertical to effectively horizontal, due to the higher hydraulic conductivity of the flow top. The nearly vertical flow in the low-conductivity dense basalt and nearly horizontal flow in the higher conductivity flow top is characteristic of a layered system with highly contrasting hydraulic conductivities. This type of layered system will generally produce a stair-stepped effect as the ground-water pathlines pass through the series of dense interiors and flow tops. Therefore, the thickness and hydraulic conductivity of each subsequent dense interior that the pathlines pass through will affect the ground-water travel time; hence, the host rock isolation characteristics.

Due to the uncertainties and variable nature of the dense interior thicknesses and hydraulic conductivities, the effect that these properties may have on isolation characteristics of a heated host rock are presently difficult to access. In thin dense interiors, which are heated, the potential exists for the development of large-scale shear deformations and fracturing. ~~(see Subsections 6.3.1.3.3 and 6.3.1.3.6). Such a potential rock failure, which in turn can influence the host rocks isolation capabilities of the host rock has not yet been fully analyzed.~~ isolation

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However, it should be noted that even if the integrity of the dense interior is compromised the sites isolation capabilities, with respect to the accessible environment, will still be more than adequate to meet the ground-water travel time criteria set forth in 10 CFR 60.113 (NRC, 1982 a). See subsections 6.3.1.3.3, 6.3.1.3.6, and 6.4.2.3.5 for further discussions of heated generated factors which may influence the host rock isolation characterists.

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This potential failure scenario is unlikely due to the use of preconstruction exploration programs to identify areas of dense interior thinning (see subsection 6.3.3.2.3) used in conjunction with a flexible design that will allow for developing the areas of the dense interior host rock with adequate thickness. As an alternative, the thermal load per acre can be reduced so that thermal-induced stresses will not induce large scale failures (see subsection 6.3.1.3.3). However, even if this unlikely failure scenario were to occur, it would not compromise the isolation capability of the reference repository location as described in this subsection.

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Other characteristics of the host rock such as its geochemical properties are not expected to adversely affect the isolation capabilities of the host rock when heated. High temperature alteration of the host rock will produce new minerals similar to existing minerals lining the basalt fractures. Therefore, heating of the host rock is not expected to significantly change the sorption properties of the fracture-lining minerals. Further discussions of the geochemical properties of the host rock are presented in Subsection 6.3.1.2.5 and Long and Woodward-Clyde Consultants (Long and WCC, 1984, pp. I-122 through I-132, I-210 through I-215, I-217 through I-223).

6.3.1.3.8 Conclusion on qualifying condition

After evaluating the present and expected conditions of the host rock, it appears that the reference repository location is likely to meet this qualifying condition. Potentially unfavorable conditions that have not been evaluated or confirmed or potentially favorable or unfavorable conditions that would have insignificant effects were not considered in this qualifying condition decision.

The qualifying condition decision was primarily based on the thickness and extensiveness of the dense interior host rock. In addition, the decision was weighted by the fact that any thickness anomalies that were detected during the site investigations or during construction could be resolved by redirecting the waste panel locations to areas with thicker dense interiors.

Another important factor that was heavily weighted in evaluating the Hanford Site was the favorable results of long-term thermal-hydrological performance assessment studies. Uncertainty studies conducted in this same area also showed favorable results.

In conclusion, it should be emphasized that extensive, further investigations and studies need to be conducted to adequately assess the suitability of the Hanford Site for a high-level waste repository. Therefore, the completion of site characterization activites, particularly the exploratory shafts, will be necessary in order to reach a final conclusion on this guideline.

6.3.1.4 Climatic Changes (Section 960.4-2-4)

6.3.1.4.1 Qualifying condition

"The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting."

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6.3.1.4.2 Evaluation process

The paleoclimatic record indicates the Pasco Basin has been the site of proglacial to interglacial climatic setting during the Quaternary Period. Among the contributing factors for climatic change leading to global mid-latitude glaciation are: fundamental changes in atmospheric circulation, air/sea interactions, variations in atmospheric carbon dioxide, explosive volcanic activity, and solar variability (Mitchell, 1965, pp. 891 through 896). The most widely supported forcing mechanism for climatic change, however, is attributed to changes in the Earth/Sun geometry (i.e., the Milankovith hypothesis). On the basis of these parameters, several climatic simulation models have been designed to assess the effects of future glaciation on the Hanford Site (Stottlemyre et al., 1981; Petrie et al., 1981; Craig et al., 1983). ~~The use of~~ isotope geochemistry and paleomagnetic data indicate major world wide glaciations have occurred at ~~periods of~~ approximately 100,000 years for at least the last 800,000 years (Table 6-2). Interglacial intervals, however, represent only ~~approximately~~ 10 percent of the total glacial/interglacial cycle (Barry, 1983, p. 394).

Evidence from deep sea cores (CLIMAP, 1984, p. 216) suggest the last interglacial interval (118,000 to 125,000 years before present) was extremely similar to the present climate. The paleoclimatic record also indicates several ~~or more~~ temporary ice retreats (interstades) may occur with each major glaciation. Glacial cycles are usually characterized by relatively long periods of ice buildup before a glacial maximum is reached, then, sudden termination followed by an interstadial or interglacial interval.

Potentially adverse conditions due to future climatic changes include erosion (see Subsection 6.3.1.5) or increase runoff and ground-water recharge as a result of seasonal proglacial meltwater or catastrophic release of floodwaters from ice-dammed lakes associated with another glacial period. Floodwaters were released several times during the Pleistocene, and subsequently dammed behind the hydraulic constriction in the Horse Heaven Hills at Wallula Gap, causing short-lived flooding in the Pasco Basin (Fig. 6-2) (see Section 3.2.2). Since the end of the Pleistocene (10,000 years before present), the surface of the Pasco Basin has changed at a very slow rate. Thus, geomorphic and hydrologic conditions are not expected to adversely effect the site during the present or future interglacial periods.

Results from palynological investigations primarily north of the Pasco Basin indicate the early postglacial period, lasting from 13,000 to 10,000 years ago, was cooler and moister than today (Mack et al., 1976, pp. 390 through 397; 1978c, pp. 499 through 506; Nickmann, 1979, p. iii; Nickmann and Leopold, 1980, p. 14). Additional evidence for this viewpoint has come from studies of rockfall frequencies in caves, from deposition of eolian sediments, from the buildup of organic debris (Fryxell, 1964, p. 273), and from the rates of accumulation of fanglomerates due to presumably greater runoff (Brown, 1970, p. 29).

Table 6-9. Age of glacial terminations - summary of published estimates.[a]

Termination	Broecker and Van Donk (1970)	Kukla (1970)	Shackleton and Opdyke (1973)	Kukla (1975)	Ruddiman and McIntyre (1976)	Hays et al. (1976)	Average (10^3)
I	11,000	10,500	13,000	11,000	13,500	10,000	11.5 $^{-1}_{+2}$
II	127,000	128,000	128,000	128,000	127,000	127,000	128.0 $^{-1}_{+0}$
III	225,000	243,000	251,000	245,000	220,000	247,000	240.0 $^{-20}_{+10}$
IV	300,000	333,000	347,000	335,000	315,000	336,000	330.0 $^{-30}_{+20}$
V	380,000	370,000	440,000	415,000	380,000	425,000	400.0 $^{-30}_{+40}$
VI		485,000	502,000	480,000	455,000		480.0 $^{-25}_{+20}$
VII		600,000	592,000	575,000	515,000		570.0 $^{-55}_{+30}$
VIII			647,000	635,000	605,000		630.0 $^{-25}_{+20}$
IX		726,000	706,000	700,000			710.0 $^{-10}_{+15}$
X		845,000	782,000				810.0 $^{-30}_{+35}$

Source complied by Kukla et al. (1981).

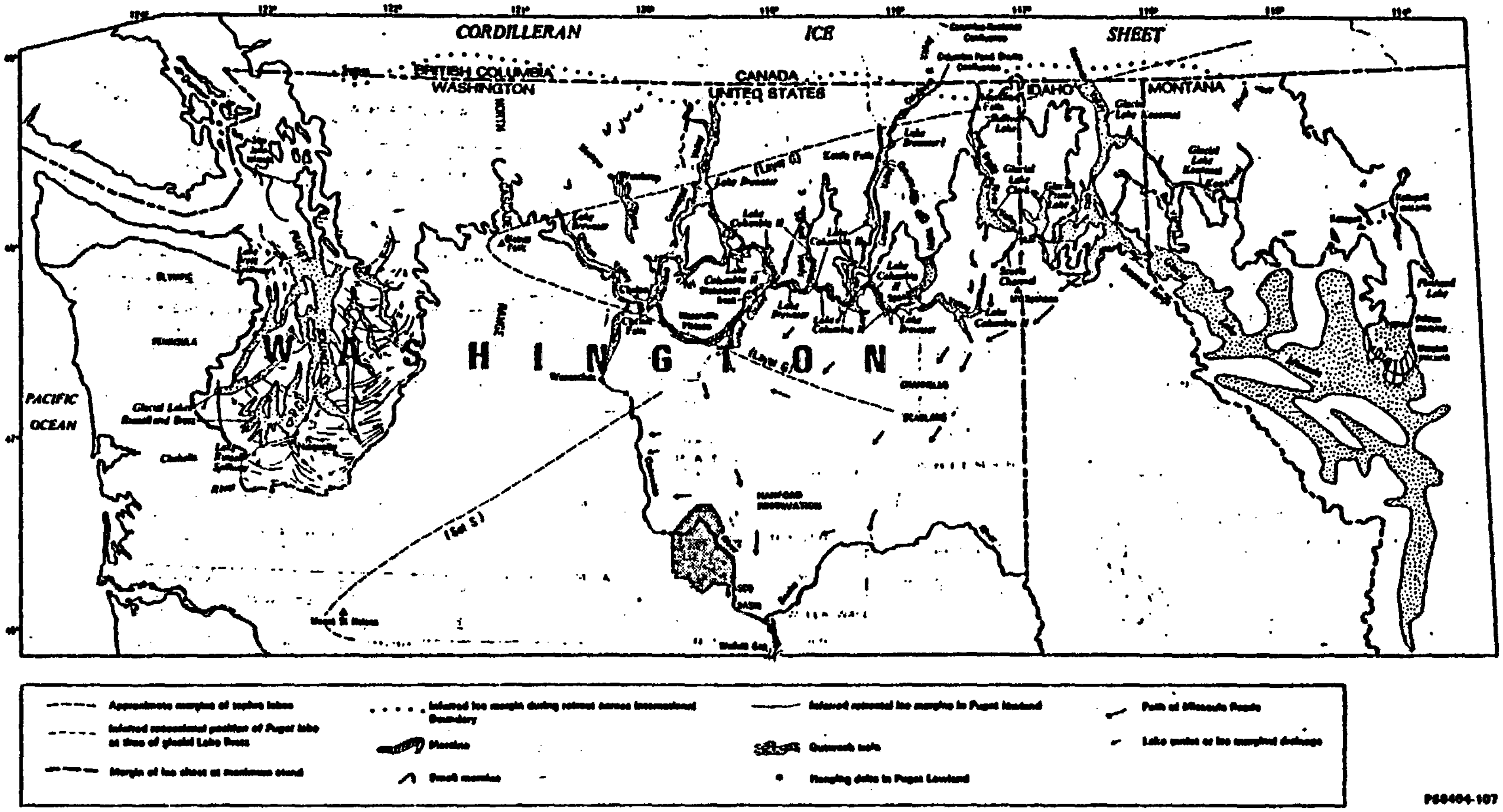

Figure 6-10. Inferred generalized margin of Cordilleran ice sheet and glacial lakes approximately 12,000±1,000 years before present (after Waitt and Thorson, 1983, pp. 62 and 63).

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The change to a warmer, drier climate approximately 8,000 years ago has been confirmed by many investigators. The relative aridity has been deduced from changes in plant species (Mack et al., 1976, pp. 390 through 397; 1978a, pp. 956 through 966; 1978b, pp. 956 through 966; 1978c, pp. 241 through 255; 1979, pp. 212 through 225; Nickmann, 1979, p. 53; Nickmann and Leopold, 1980, p. 15; Hansen, 1947, pp. 86 through 92), lessened frost activity (Fryxell, 1964, p. 273), increased wind deposits (ERDA, 1975, p. II.3-10; Brown, 1970, p. 31), changes in fauna (Brown, 1970, p. 31; Frison, 1975, pp. 289 through 300; Knudson, 1980, pp. 477 through 479), changes in mountain glacier size and location (Porter, 1977, pp. 101 through 116), and changes in patterned ground distribution (Mack et al., 1976, pp. 390 through 397). The warm, dry climate that appears to have developed approximately 8,000 years ago lasted approximately 4,000 years. Many of the mammal species that inhabited the Columbia Plateau migrated or became extinct during this time period. The effective precipitation, which had been enough to support the extensive grassland of the region, was reduced resulting in many changes in vegetation distribution (Mack et al., 1976, pp. 390 through 397; 1978c, pp. 499 through 506; Nickmann, 1979, p. 54). Active sand dunes were formed on the Hanford Site and at other locations throughout eastern Washington State (ERDA, 1975, p. II.3-10). Some of these now-stabilized dunes contain ash beds from the Mount Mazama eruption 6,700 years ago in southern Oregon (Fryxell, 1965, pp. 1288 through 1290). This evidence indicates that the dunes were formed 6,000 to 7,000 years ago (ERDA, 1975, p. II.3-10).

A third period of Holocene climatic change, to conditions slightly cooler and moister than today, is thought to have occurred roughly between 3,000 or 4,000 years and 1,500 years before present. This change is somewhat controversial, since palynological evidence is present at some sites but absent at other sites (Mack et al., 1978a, pp. 449 through 506; 1979, pp. 212 through 225). The modern climate appears to have prevailed in the region since 1,500 years ago (Mack et al., 1978c, pp. 241 through 255).

Geologic data suggest that little runoff has occurred since late Pleistocene or early Holocene times (Brown, 1970, p. 29). Based on topographic arguments and geologic information, Kukla (1979, pp. XIII-1 through XIII-8) has concluded that the long-term change in mean annual precipitation since the last glacial episode is probably within the range of recent year-to-year variability. The annual precipitation at the Hanford Site has averaged 16.1 centimeters (6.3 inches) and, since 1913, has varied between 7.6 and 29.1 centimeters (3 and 11.5 inches) (Stone et al., 1983, p. IV-2). Mean annual precipitation since 13,000 years ago is projected to be within a factor of 2 of the present mean annual precipitation of approximately 16 centimeters (6 inches) (Stottlemyre et al., 1981).

Alpine glaciers in the Cascade Range were greatly expanded relative to their present day size during the last great ice advance of continental ice sheets. However, the closest advance of these continental ice sheets to the Hanford Site is marked by the Withrow Terminal Moraine,

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approximately 130 kilometers (21 miles) north of the reference repository location. Porter's investigation (Porter, 1977, pp. 101 through 116) of the glaciation thresholds, at the maximum ice advance of the last glacial interval, supports the view that the accumulated precipitation for the season during the ice advance was probably no more than 30 percent greater than present day values.

6.3.1.4.3 Favorable condition

"(1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation."

The climate in the Hanford Site region has been arid or semiarid for at least the last 3 million years. The climatic conditions are expected to remain essentially unchanged over the next 100,000 years, except for a colder, drier climate associated with a postulated glacial advance. The surface water systems associated with preglacial and interglacial periods are not expected to significantly change. Therefore, the waste isolation potential of the reference repository location should not be adversely affected for the next 100,000 years. This favorable condition appears to be met.

The climate of the Pasco Basin has remained arid to semiarid for at least the last 3 million years, as indicated by the presence of calcic paleosols in upper Ringold Formation and younger strata. The overall regional precipitation pattern, controlled primarily by the Cascade Range, is not likely to change significantly over the next 100,000 years. Climates during glaciation are reported to be both colder and drier (Barry, 1983, pp. 401 and 402); thus, increased runoff or erosion within the Pasco Basin are not expected during periods of glacial advance. Large accumulations of wind blown sediment (loess) deposited in eastern Washington State during the Pleistocene are believed to reflect the overall cold and dry periglacial conditions that existed along glacial margins in the past. Melting of glacial ice during periods of interstadial ice retreat may result in increased runoff and glaciofluvial channeling. However, potential erosion within the Pasco Basin in the near future is limited to depths at or above temporary base levels at Wallula Gap (50 meters (164 feet) elevation). Over the long term, the potential for fluvial or glaciofluvial incision is ultimately controlled by sea level. Climatically induced changes in base level over the next 1 million years are most likely to come about through future global glaciation. Conceivably, based on world-wide Pleistocene sea level fluctuations, regional base level could drop from 100 meters (328 feet) to as much as 250 meters (820 feet) below present sea level (WCC, 1980). The uppermost candidate horizon in the reference repository location is generally greater than 580 meters (1,900 feet) below sea level (Long and WCC, 1984, p. I-35). Fluvial headward erosion from such a drop in sea level could incise no closer than 330 meters (1,083 feet) above the uppermost candidate horizon if the maximum drop in sea level were to occur (see Subsection 6.3.1.5).

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The geomorphic effects of catastrophic flooding are considered to be negligible, since the net effect within the reference repository location would be sediment aggradation. Relatively minor cut-and-fill sequences have been observed within and around the reference repository location, but none have incised into underlying deposits more than several meters. The main channels for Pleistocene catastrophic floods have been located north and east of the reference repository location (Tallman et al., 1979, pp. 44 through 48; Myers, Price et al., 1979, p. III-66). The topographic control on the position of these channels (basalt ridges) would be expected to remain the same for potential future floods and, therefore, major incision within the reference repository location is not likely. Approximately 175 to 200 meters (575 to 656 feet) of sediments overlie the top of the basalt in the reference repository location. Less than 50 meters (164 feet) are flood deposits; the remainder belongs to the Miocene-Pliocene Ringold Formation. On the basis of borehole data, the Ringold Formation has not been eroded in the reference repository location below an elevation of 150 meters (492 feet) during the Quaternary Period.

On the basis of the paleoclimate model of Craig (1983; Fig. 21), two major ice advances are predicted for the next 100,000 years. According to Craig's (1983) model, the first major glacial advance is predicted to begin around 15,000 years and to continue for approximately 10,000 years before retreating. This advance, however, is not expected to extend south far enough to cause ice damming or subsequent catastrophic flooding (Craig, 1983; Fig. 21). A second major advance is predicted to begin in approximately 35,000 years and to reach a maximum after another 25,000 years (60,000 years from now). Ice dams created by this advance could likely cause catastrophic floods. The impact of catastrophic flooding on the confined aquifer and ground-water flow paths or the potential for induced seismicity has not been addressed in detail. The short duration of such floods (estimated to be weeks or less; Baker, 1973, pp. 20 through 22), however, suggests that the impact on the recharge of confined aquifers would be minor.

6.3.1.4.4 Favorable condition

"(2) A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period."

Currently, data from the Columbia Plateau are limited for determining climatic changes throughout the Quaternary Period. The significance of these changes, relative to their effect on the hydrologic system, is unknown (see Subsection 6.3.1.1.4). However, since glaciers have impinged on the northern and western margins of the Columbia Plateau and proglacial floodwaters have scoured the Channeled Scabland of eastern Washington State, it would appear that this favorable condition might not be met.

There is no evidence to suggest that glaciers have ever reached the central Columbia Plateau or the reference repository location. However, glaciers and proglacial meltwaters have modified the land surface of portions of the Columbia Plateau. It is assumed that ~~this~~ these Quaternary

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glacial and glacial-related events had an effect on the hydrologic system of the Columbia Plateau. The effect on the hydrologic system will be evaluated during site characterization.

6.3.1.4.5 Potentially adverse condition

"(1) Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock."

The underground facilities of a repository in basalt would be in a saturated host rock. Therefore, this potentially adverse condition does not apply to the reference repository location.

6.3.1.4.6 Potentially adverse condition

"(2) Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment."

The climate of the Hanford Site region is not expected to significantly change over the next 10,000 years. Thus, the present ground-water flow system is expected to remain relatively unaffected. Since the ground-water system is not yet characterized, the effects of any future climatic changes on radionuclide transport is not known at this time, but the effects are not expected to significantly increase the transport of radionuclides to the accessible environment. Therefore, the available evidence does not support a finding that this potentially adverse condition exists at the reference repository location.

Proglacial catastrophic flooding, similar to the Pleistocene flooding events, appears to be the most probable disruption scenario associated with climatic changes that could affect the hydrologic system. There is little chance of significant renewed glaciation in the State of Washington in the next 10,000 years. In addition, ground-water impacts from proglacial flooding are likely to be limited to localized shallow recharge increases and subsequent increases in stream runoff. The very short transient nature of catastrophic floods (i.e., less than 2 weeks) is such that significant effects at the repository depth ~~is~~ are not expected.

6.3.1.4.7 Conclusion on qualifying condition

A final conclusion on the qualifying condition for climatic changes cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1). The available evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition.

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Among the potentially adverse effects associated with climatic change are increases in surface runoff leading to erosion or changes in ground-water flow. Significant erosion is not considered likely over the next 100,000 years based on the past geologic record (see Subsection 6.3.1.5). Increases in runoff are likely to occur over the next 100,000 years, either through catastrophic floods or seasonally by proglacial streams. However, due to the short-lived nature of catastrophic floods, changes in the deep ground-water flow system at repository depths are not expected.

6.3.1.5 Erosion (Section 960.4-2-5)

6.3.1.5.1 Qualifying condition

"The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

In predicting the likelihood of potentially disruptive erosional processes, the DOE will consider the climatic, tectonic and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period."

6.3.1.5.2 Evaluation process

In evaluating the potential for future disruption of a repository through erosion, the effects of past and present erosional processs must be identified. A variety of surficial processes have been at work since a major regional incision of the Ringold Formation took place sometime after 3.3 million years before present. A remnant of the Ringold Formation paleosurface is preserved at an elevation of approximately 275 meters (902 feet) along the White Bluffs 16 kilometers (10 miles) northeast of the reference repository location.

In the reference repository location, incision of the Ringold Formation paleosurface and lateral planation produced a younger paleosurface (see Fig. 3-21) that is preserved south of the Umtanum Ridge bar (see Fig. 3-5). This buried surface (see Fig. 3-21), represented by the erosional top of the Ringold Formation, trends parallel to the present Cold Creek Valley, suggesting an ancestral Cold Creek origin. North and east of Umtanum Ridge bar, the younger paleosurface was eroded, apparently by Pleistocene catastrophic floods. Within the reference repository location, maximum incision occurred in the southeastern portion of the reference repository location (see Fig. 3-21) where the Ringold Formation is eroded to an elevation of less than 137 meters (450 feet) above mean sea level.

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Partial infilling of the ancestral Cold Creek Valley with locally derived alluvium occurred before and perhaps between periods of catastrophic flood deposition during the Pleistocene Epoch. As a result of catastrophic floods entering the Pasco Basin from the west, a major geomorphic feature, the Umtanum Ridge bar, developed in the reference repository location. This streamlined, compound flood bar accumulated south of Umtanum Ridge and on the south flank of a northwest-southeast trending flood channel (see Fig. 3-5). Flood channels in the Pasco Basin eroded to an elevation of 83 meters (272 feet) northeast of the reference repository location between Gable Mountain and Gable Butte (Fecht, 1978) and 50 meters (164 feet) at Wallula Gap (WCC, 1980), the outlet for floodwaters from the Pasco Basin. The Umtanum Ridge bar acted to confine erosion to the north while causing net deposition in the lee direction. As a result, the Cold Creek paleosurface (see Fig. 3-21) south of Umtanum Ridge bar was preserved under the accumulating cover of slack-water flood deposits.

Since the last catastrophic flood around 13,000 years before present, the reference repository location surface has undergone only minor local reworking through fluvial and eolian processes.

The potential for incision at the reference repository location in the near future is currently estimated to be less than 50 meters (164 feet) in elevation defined by local base-level control at Wallula Gap located 80 kilometers (50 miles) southeast of the reference repository location. However, fluvial processes in Cold Creek Valley located at the western boundary of the reference repository location have been only intermittently active since the last major flood event, approximately 13,000 years before present (Skaggs and Walters, 1981). Therefore, only minimal incision in the Cold Creek Valley in and adjacent to the reference repository location is expected in the near future.

The potential for incision over the long term is ultimately controlled by the sea level. Changes in base level over the next 1 million years are most likely to come about through glacio-eustatic changes in sea level. Conceivably, based on Pleistocene sea level fluctuations, regional base level could drop 100 meters (328 feet) to as much as 250 meters (820 feet) below present sea level (WCC, 1980). The uppermost candidate horizon (the Rocky Coulee flow) in the reference repository location is generally greater than 650 meters (2,133 feet) below sea level. In the unlikely case of headward erosion from such a drop in sea level advancing to the site, erosion could proceed no closer than 400 meters (1,312 feet) above the uppermost candidate horizon. This is supported by the fact that the site of the proposed repository has been located within a structural basin subsiding since at least the early to middle Miocene time (17.0 to 15.5 million years before present) (Caggiano and Duncan, 1983). Therefore, under the present tectonic regime, depths to a proposed repository should increase with time.

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6.3.1.5.3 Favorable condition

"(1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the directly overlying ground surface."

This favorable condition appears to be met at the reference repository location since site conditions permit emplacement of waste at a depth of greater than 300 meters (984 feet). The depths of the four candidate horizons (Rocky Coulee, Cohassett, McCoy Canyon, and Umtanum flows) are all greater than 850 meters (2,789 ft.) below ground surface (see Section 3.1.2).

6.3.1.5.4 Favorable condition

"(2) A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than one chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment."

The reference repository location appears to meet this favorable condition since there is little, if any, chance of erosion leading to releases of radionuclides to the accessible environment over the next 10,000 years. This preliminary conclusion is based on an estimate of erosional relief on the Ringold Formation and the geomorphic control that sea level has on limiting depth of erosion as described in Subsection 6.3.1.5.2.

The top of the Ringold Formation, along the White Bluffs, 22 kilometers (14 miles) northeast of the reference repository location, represents the level of the ancestral Columbia River in the Pasco Basin approximately 3.3 million years ago. The present maximum relief on the eroded Ringold Formation surface then represents the maximum amount of incision that could have taken place during the Quaternary Period. The maximum relief for the top of the Ringold Formation surface between the reference repository location and White Bluffs is 135 meters (443 feet). Depths to the uppermost candidate horizon (Rocky Coulee flow) in the reference repository location are greater than 850 meters (2,789 feet) below the ground surface. Therefore, since 3.3 million years ago, maximum incision in the reference repository location has been equivalent to less than 16 percent of the depth to the uppermost candidate horizon.

Because depth of erosion is geomorphically controlled by base level, future incision is limited to depths above minimum sea level. Past glacio-eustatic sea levels have dropped as low as 250 meters (820 feet) below the present levels during the Pleistocene Epoch. Using this as an ultimate base level, erosion at the site could proceed no farther than 400 meters (1,312 feet) above the uppermost candidate horizon.

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6.3.1.5.5 Favorable condition

"(3) Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure."

This favorable condition appears to be met by the reference repository location since waste is not expected to be exhumed during the first one million years after repository closure.

The depth of the candidate horizons and the geologic setting of the reference repository location are such that waste exhumation would not be expected to occur during the first one million years after repository closure. Waste exhumation through erosion is not likely since the Ringold Formation surface within the reference repository location has not been eroded below an elevation of 135 meters (443 feet) over the last 3.3 million years. The uppermost candidate horizon (Rocky Coulee flow) is at an elevation of minus 650 meters (2,133 feet). The only possible mechanisms for erosion of this depth are through tectonic uplift of the repository area or a drastic glacio-eustatic lowering of sea level. However, based on the past geologic setting (see Subsection 6.3.1.5.2), neither of these scenarios is expected, especially considering that the site is located in a structural basin subsiding since at least the early to middle Miocene (17.0 to 15.5 million years).

6.3.1.5.6 Potentially adverse condition

"(1) A geologic setting that shows evidence of extreme erosion during the Quaternary Period."

The reference repository location does not show evidence of extreme erosion during the Quaternary Period. Therefore, this potentially adverse condition does not exist at the reference repository location.

The present site has not undergone sustained extreme erosion during the Quaternary Period and is not expected to do so in the foreseeable future. Brief episodes of Pleistocene catastrophic flooding have produced significant erosion on parts of the Columbia Plateau. However, because of the protection provided by Umtanum Ridge and the Umtanum Ridge bar (see Fig. 3-5), the net effect of these floods on the reference repository location has been depositional. Assuming a similar source and mechanics of flooding, future catastrophic floods should also aggrade rather than erode the site.

6.3.1.5.7 Potentially adverse condition

"(2) A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste."

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This potentially adverse condition does not exist at the reference repository location. The nature and rates of geomorphic processes in the Columbia Plateau are not expected to affect the ability of a repository to isolate waste for 10,000 years after closure.

The only geomorphic process to adversely affect the site would be exhumation through incision to repository depth. This is not considered possible based on any combination of geologic, climatic, or tectonic processes that have operated during the Quaternary Period (see Subsections 6.3.1.5.2 and 6.3.1.5.5).

6.3.1.5.8 Disqualifying condition

"The site shall be disqualified if site conditions do not allow all portions of the underground facility to be situated at least 200 meters below the directly overlying ground surface."

The depth of the uppermost candidate horizon is greater than 850 meters (2,789 feet) below the ground surface at the reference repository location. Potential erosion scenarios suggest that this depth is more than sufficient to maintain over 400 meters (1,312 feet) between the ground surface and a repository. Therefore, the available evidence does not support a finding of disqualification. Little or no uncertainty is present in making this determination.

The four candidate horizons (Rocky Coulee, Cohassett, McCoy Canyon, and Umtanum flows) are located at depths greater than 850 meters (2,789 feet) below the ground surface of the reference repository location (see Section 3.2.1). The 850-meter (2,789-foot) depth far exceeds the 200-meter (650-foot) depth contained in the disqualifying condition, even considering a maximum erosion scenario of 250 meter (820 feet) reduction of sea level associated with glacio-eustatic changes, and the unlikely case of headward erosion advancing to the site from such a drop in sea level. The erosion is not expected to proceed lower than 400 meters (1,812 feet) above the uppermost candidate horizon (Rocky Coulee flow).

The net effect of future catastrophic flooding within the reference repository location would probably be sediment deposition (DOE, 1982e, p. 3.4-4). Of the existing 175 to 200 meters (574 to 656 feet) of sediments overlying the shallowest basalts in the reference repository location, less than 50 meters (164 feet) are flood deposits; the remainder is the Ringold Formation (between 3.3 and 10.5 million years ago), formed during the Miocene-Pliocene epoch (between 2 and 23 million years ago), which was not eroded during multiple-Pleistocene catastrophic floods (DOE, 1982e, p. 3.4-4).

The main channels of Pleistocene floodwater are located north and east of the reference repository location (DOE, 1982e, p. 3.4-4). The topographic control (basalt ridges) on the position of these channels would remain the same for potential future floods. Therefore, major incision within the reference repository location would not be likely.

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6.3.1.5.9 Conclusion on qualifying condition

A final conclusion on the qualifying condition for erosion cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1). The available evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition.

The potential for erosional processes leading to radionuclide releases is not considered possible based on available data on past and present climatic, tectonic, and geomorphic conditions during the Quaternary Period (see Subsection 6.3.1.5.2). This preliminary finding is based on the following major factors:

- Depths for the proposed reference repository that far exceed potential future base levels.
- Future tectonic movements that should result in relative lowering of a repository.
- Continued net deposition associated with future catastrophic floods south of Umtanum Ridge and the Umtanum Ridge bar.

6.3.1.6 Dissolution (Section 960.4-2-6)

6.3.1.6.1 Qualifying condition

"The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

In predicting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified."

6.3.1.6.2 Evaluation process

Rocks of the Columbia River Basalt Group and intercalated Ellensburg Formation are generally not subject to dissolution. Dissolution features or dissolution fronts have not been found, nor are such features expected to be found in the reference repository location. Investigations have shown that hydrothermal reactions occur along cooling joints where dissolution of basalt glass has resulted in precipitation of secondary minerals including iron smectite, zeolites, and cristobalite (see Section 6.3.1.2). However, only a very small percentage of the rock are expected to undergo these reactions. This suggests dissolution will not significantly decrease rock strength or increase rock permeability at the reference repository location.

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6.3.1.6.3 Favorable condition

"No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period."

This favorable condition is met by the basalts at the reference repository location. Active dissolution does not occur in a basalt geologic medium (see Subsection 6.3.1.6.5).

6.3.1.6.4 Potentially adverse condition

"Evidence of significant dissolution within the geologic setting--such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse--such that a hydraulic interconnection leading to a loss of water isolation."

This potentially adverse condition does not exist in the Columbia River Basalt Group since active dissolution does not occur in a basaltic medium (see Subsection 6.3.1.6.5).

6.3.1.6.5 Disqualifying condition

"The site shall be disqualified if it is likely that, during the first 10,000 years after closure, active dissolution as predicted on the basis of the geologic record, would result in a loss of waste isolation.".

Active dissolution fronts do not occur in basalt. Therefore, the reference repository location is not disqualified based on this dissolution condition. However, some minor dissolution could occur in fractures in the basalt rock. A description of this process is presented below. Little or no uncertainty is involved in meeting this determination.

Chemical reactions of the basalt in the presence of heat and water generally lead to the dissolution of some minerals (primary minerals) found in the existing fractures and porous flow top portions of the basalt. This dissolution is coupled with the precipitation of other minerals called secondary minerals. The evidence indicates that the sum of these reactions is a net decrease in the porosity and amount of interconnection of the basalt (DOE, 1982e, pp. 6.4-1 through 6.4-14). The primary and secondary minerals, which coexist with the rock in and around the repository, are considered relatively insoluble. Data indicate the coexisting ground water is already at saturation (a solution that contains the maximum amount of dissolved material) with respect to most of the minerals of the basalt (DOE, 1982e, pp. 6.1-11 through 6.1-16). No significant dissolution, therefore, is expected to occur even at the elevated temperatures anticipated within the repository area.

The origin and history of the basalts at the Hanford Site have been extensively studied (see Sections 2.1.1 and 3.1.2). Evidence indicates that these basalts were erupted as lava flows 6 to 17 million years ago. As each flow was emplaced, its top developed vesicles (spherical cavities)

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due to expulsion of dissolved gases. Subsequent flows buried earlier flows, creating a sequence each with its own vesicular flow top. After emplacement, the flows cooled and crystallized a number of primary minerals, including pyroxene, plagioclase, magnetite, olivine, and apatite (DOE, 1982e, pp. 6.1-11 through 6.1-16). Glass of variable proportion and composition (Noonan et al., 1980, pp. 1 through 8) was also formed during rapid cooling of basalt flows. Cooling also led to the development of cooling cracks or fractures arising from thermal contraction of the basalt.

Continued burial and cooling of basalt resulted eventually in low-temperature (less than 100°C) alteration of the basalt, particularly along the fractures and flow tops that presented preferential pathways to the influx of ground water. This alteration appears to have caused the dissolution of the primary phases, especially the glass (Allen and Strope, 1983, pp. 1 through 10), with the subsequent precipitation from ground water of secondary minerals (Benson and Teague, 1982, pp. 1 through 18). These secondary minerals have been characterized and include smectite clay (principally nontronite), zeolite (principally clinoptilolite), and silica (DOE, 1982e, pp. 6.1-16 through 6.1-24; Benson and Teague, 1982, pp. 1 through 18). The formation of these secondary minerals has led to the filling of most fractures and many of the vesicles of the flow tops (Long and WCC, 1984, pp. I-122 through I-133). The coupled dissolution and precipitation of minerals during alteration of basalt appears, therefore, to have led to a general decrease in the interconnection of fractures and flow tops that dominate the hydrologic pathways in basalts (Long and WCC, 1984, pp. I-122 through I-133).

To confirm the expectation that similar dissolution/precipitation reactions will continue to occur after emplacement of nuclear waste, field tests and laboratory hydrothermal tests on basalt have been conducted. Preliminary tests show that the preferential dissolution of interstitial glass leads to the precipitation of secondary alteration minerals similar to those observed in natural fractures and vesicles (Apted and Myers, 1982, pp. 15 through 34; Grandstaff et al., 1983, pp. 1 through 20; Lane et al., 1983b, pp. 1 through 10; Long and WCC, 1984, pp. I-218 through I-221). Previous laboratory tests on basalt (Vandegrift et al., 1983, pp. 227 through 248), and granite and tuff (Moore et al., 1983, pp. 445 through 453) also indicate that hydrothermal alteration of silicate rocks (such as basalt) can lead to rapid clogging of pores and fractures by formation of secondary minerals, thus effectively plugging hydrologic pathways for the potential migration of radionuclides.

6.3.1.6.6 Conclusion on qualifying condition

A final conclusion on the qualifying condition for dissolution cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1). The available evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition.

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Dissolution features are not considered present in basalt because its chemical and physical properties preclude significant dissolution. Chemical reactions of the basalt in the presence of heat and water lead to the dissolution of some minerals (primary minerals) found in the flow tops and existing fractures. However, these features occur in only a very small percentage of the rock.

6.3.1.7 Tectonics (Section 960.4-2-7)

6.3.1.7.1 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.

In predicting the likelihood of potentially disruptive tectonic processses or events, the DOE will consider the structural, stratigraphic, geophysical and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period."

6.3.1.7.2 Evaluation process

Data used to assess the tectonic conditions of the reference repository location and the tectonic processes that have been operating at the site for the past 15 million years include the following:

- Stratigraphic and structural information provided on geologic maps and cross sections that represent interpretations of direct observation and measurement of rock exposed at ground surface, direct observation of rock in core, extrapolation of observations between exposures and between boreholes, interpretation of exploration geophysical surveys (airborne and ground magnetic, gravity, seismic reflection and refraction, and magnetotelluric surveys), and limited exploratory trenching (Myers, Price et al., 1979; Myers, 1981; WPPSS, 1981a).

- Instrumental and historical (pre-instrumental) records of seismicity derived from published catalogs and from interpretation of recordings of earthquakes made on seismometers of various types, but mostly short-period, single-component vertical seismometers.

- Interpretations of geophysical anomalies that represent changes or contrasts in electrical, density, or magnetic properties of unexposed rocks, generally in fairly narrow zones (Myers, Price et al., 1979).

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- Interpretation of seven geodetic surveys conducted by the U.S. Geological Survey across the Hanford Site. The trilateration array surveyed consists of 19 stations and 29 lines that have been periodically surveyed using a single-color laser geodolite (Rohay and Davis, 1983).

Tectonic data have been summarized in a number of geologic reports (e.g., see Section 2.1.1), most recently Caggiano and Duncan (1983).

Interpretations and techniques of interpretation of geologic mapping, exploration geophysical surveys, earthquake monitoring, and geodetic surveys are state-of-the-art techniques and/or are given in specific geologic reports or procedures. Interpretation and analysis techniques are too lengthy to discuss in the space allotted. Interpretations of the tectonic stability of the reference repository location are preliminary because of the following:

- Interpretations of subbasalt stratigraphy and structure are too sketchy to permit adequate testing of tectonic models.

- Detailed monitoring of seismicity in the candidate horizons at proposed repository depth is only beginning, so comparisons of the nature and rate of stress release between the reference repository location and surrounding areas can not be made yet.

- Reconnaissance level geologic mapping is complete (Myers, Price et al., 1979), but detailed studies of specific structures and interpretation of geophysical anomalies in the area of the reference repository location are ongoing.

- Kinematic analyses of fold development and the relationship of folding to faulting for Yakima folds remains to be completed.

6.3.1.7.3 Favorable condition

"The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than one chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment."

This favorable condition is expected to be met for igneous activity. The expected effects from the average low rate of long-term deformation of the Central Columbia Plateau also appear favorable, although there is considerable uncertainty. Therefore, the available evidence does not support a finding that the reference repository location is not likely to meet the favorable condition.

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Columbia River Basalt Group volcanism ceased approximately 6 million years ago (McKee et al., 1977). The youngest unit of Columbia River Basalt Group in the reference repository location is the 10.5-million-year-old Elephant Mountain Member of the Saddle Mountains Basalt (Myers, 1981). There are no known hot springs in the area of the reference repository location, nor is the area one of high heat flow as might be expected in an area of Quaternary volcanism (Caggiano and Duncan, 1983). Quaternary volcanism has occurred in the western Columbia Plateau where Columbia River Basalt Group onlaps the Cascade Range; however, volcanism of the Simcoe volcanic series appears more closely allied to volcanism of the Cascade Range because of its calc-alkaline composition compared with tholeiitic basalt of the Columbia River Basalt Group.

Deformation of Columbia River Basalt Group in the central and western Columbia Plateau into the east-west and northwest-trending, anticlinal folds of the Yakima Fold Belt was underway by late Grande Ronde Basalt time (16.5 million years ago) (Caggiano and Duncan, 1983). Thrust and reverse faults parallel to the axes of these folds have been mapped on anticlinal ridges (Myers, Price et al., 1979; Swanson et al., 1979, 1981). Northwest-trending, steeply dipping faults have been interpreted to be strike-slip faults, although the amount of displacement along such faults appears to be low (less than 5 kilometers (3 miles)). Developing structural relief in the Miocene indicates that deformation was underway at long-term, average rates of 40 to 80 meters per million years (131 to 262 feet per million years) (Reidel et al., 1983). Projecting these rates of structural uplift on anticlinal ridges to the present accounts for the present structural relief of basalt flows on Rattlesnake Mountain and the Saddle Mountains suggesting that deformation has been ongoing at long-term, low-average rates for at least 15 million years. Focal mechanism solutions of earthquakes indicate that the north-south nearly horizontal compression that formed these ridges is still ongoing (Rohay and Davis, 1983). Shortening of the lines of a trilateration survey similarly suggest that deformation is ongoing at low rates of strain that are compatible with geologically determined rates for the Miocene.

The rate and pattern of deformation determined for the Pasco Basin area of the central Columbia Plateau is preliminary and remains to be confirmed. Consequence analyses of disruptive event scenarios to determine the effects of this pattern and style of deformation on waste isolation over the next 10,000 years have yet to be performed. In the judgment of experts surveyed in a recent Delphi analysis to test this method for evaluating disruptive event scenarios, this pattern of deformation should continue and not significantly affect waste isolation for a repository in the reference repository location over the next several thousand years (Davis et al., 1983). Final analyses of disruptive event scenarios involving tectonic effects remain to be performed.

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6.3.1.7.4 Potentially adverse condition

"(1) Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period."

This potentially adverse condition exists within the geologic setting of the reference repository location since faults that have been active during the Quaternary Period are observed within the Columbia Plateau.

Deformation that was underway in the Miocene at long-term, low average rates can explain the present structural relief of several flows of the Saddle Mountains Basalt and Wanapum Basalt on Rattlesnake Mountain and the Saddle Mountains (Reidel et al., 1983). Geodetic surveying as well as the level, pattern, and distribution of small earthquakes indicate that deformation is continuing at present and appears to follow trends that were established by at least Miocene time (Rohay and Davis, 1983). The timing and role of faulting in the deformational process are not clearly understood at this time. Thus, it is not certain to what depths mapped faults extend, when in structural evolution they developed, or the mechanical relationship between folding and faulting. The age of development and last movement of many faults remain to be clearly determined.

A thrust fault located approximately 9 kilometers (5 miles) northwest of the reference repository location and separating two second-order anticlines with opposite vergence on Gable Mountain has been interpreted as a tear fault (PSPL, 1982; NRC, 1982c). Trenching through the central Gable Mountain fault (see Fig. 3-22) has revealed displacements in stratified sands of presumably very late Wisconsinan age that continue along the trends of displacement in the basalt and interbeds. The displacements were observed along approximately 335 meters (1,100 feet) of the fault, with the maximum observed displacement approximately 6 centimeters (0.2 feet) (PSPL, 1982). These data suggest that the central fault on Gable Mountain is still active; however, data from the instrumental period of earthquake monitoring at the Hanford Site suggest that the central fault is not seismically active. Other faults (such as associated with the Rattlesnake-Wallula alignment (see Fig. 3-22)) have been assumed active in the absence of definitive evidence to the contrary and because this structure continues along the northwest trend of steeply dipping faults that appear active in the area of Wallula Gap (WPPSS, 1981a; NRC, 1982c). These faults do not appear to be active seismogenic structures based on the apparent lack of association of these structures with instrumentally located earthquakes over the past 14 years (Caggiano and Duncan, 1983).

Deformation at long-term, average low rates of strain would appear to provide a favorable environment for isolation of radioactive waste in a repository; however, though planned, detailed modeling has yet to be performed on tectonic effects and their potential for changes in the travel direction or rate of ground-water flow and the transport of radionuclides (Section 6.4.2).

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Diapirism is a deformational phenomenon involving materials of very low shear strength and typically involves evaporites such as gypsum, anhydrite, or salt. There are no known salt strata interbedded within or underlying the Columbia River Basalt Group; therefore, diapirism is not a concern for the reference repository location.

Relative to the stable Palouse slope that has been used as a datum, uplift on Rattlesnake Mountain and the Saddle Mountains and subsidence of the Cold Creek syncline appears to be continuing at long-term, average low rates (Reidel and Fecht, 1981). These rates, when projected 10,000 or more years into the future, would lead to increased elevation of Rattlesnake Mountain and the Saddle Mountains, and further subsidence of basalt strata in the Cold Creek syncline, neither of which would lead to increased potential for erosion of the candidate horizons in the Cold Creek syncline. Therefore, uplift and subsidence continuing along the extant pattern and rates would appear not to jeopardize isolation of radioactive waste at the reference repository location.

Columbia River Basalt Group volcanism ceased approximately 6 million years ago (McKee et al., 1977). The youngest unit of the Columbia River Basalt Group in the reference repository location is the 10.5-million-year old Elephant Mountain Member of the Saddle Mountains Basalt (Myers, 1981). No known hot springs are in the area of the reference repository location, nor is the area one of high heat flow as might be expected in an area of Quaternary volcanism (Caggiano and Duncan, 1983). Quaternary volcanism has occurred in the western Columbia Plateau where the Columbia River Basalt Group onlaps the Cascade Range; however, volcanism of the Simcoe volcanic series appears more closely allied to Cascade volcanism because of its calc-alkaline composition compared with tholeiitic basalt of the Columbia River Basalt Group. Currently, the Columbia Plateau is considered to have been volcanically inactive during the Quaternary Period.

6.3.1.7.5 Potentially adverse condition

"(2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation."

~~The effects from~~ recurrence of a large historical earthquake on subsurface facilities at the reference repository location is not expected to affect waste containment or isolation, although considerable uncertainty exists that will be addressed in site characterization. Therefore, the available evidence does not support a finding that this potentially adverse condition exists at the reference repository location.

Deformation of Columbia River Basalt Group in the central Columbia Plateau has apparently been proceeding at long-term, average low rates under a regime of nearly north-south, nearly horizontal compression for at least 15-million years (Caggiano and Duncan, 1983). The pattern of folding accompanied by faulting appears to have been established during Miocene time, but an exact mechanical model of deformation has not yet been developed. Available data do not permit the precise determination of

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slip/recurrence rates on specific faults; however, the pattern and timing of deformation as currently interpreted suggest that slip rates of faults during late Cenozoic time have been low. Such a pattern would suggest that earthquakes would be relatively small and recurrence rates generally long compared with active tectonic regimes such as the plate boundary regime in California. This pattern is supported by the following evidence:

- The largest earthquake recorded on the Columbia Plateau is a magnitude 5.75 located on the Blue Mountain front.

- The average recurrence interval for a large earthquake (magnitude 6.5) on a 20-kilometer (12-mile) segment of the Rattlesnake-Wallula alignment is estimated to be at least between 10,000 and 100,000 years (NRC, 1982c).

- During 15 years of instrumental monitoring of earthquakes in the vicinity of the Hanford Site, the largest recorded earthquake is a magnitude 4.4 located more than 40 kilometers (24 miles) northeast of the boundary of the reference repository location. The largest earthquake recorded in the Pasco Basin is a magnitude 3.8 located approximately 10 kilometers (6.2 miles) north of the boundary of the reference repository location. Earthquakes in the Pasco Basin are generally shallow (most are less than 5 kilometers (3 miles) deep) and generally small (less than magnitude 2.5); however, swarms of small, shallow earthquakes have been recorded along the margins of the Pasco Basin, but none have been recorded in the reference repository location (see Subsection 2.1.1.3).

6.3.1.7.6 Potentially adverse condition

"(3) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase."

Neither tectonic investigations nor historical earthquake records suggests that the frequency or magnitude of earthquakes within the Columbia Plateau would increase. It does not appear that this potentially adverse condition exists within the geologic setting of the reference repository location.

The areas reported to be most seismically active are along and beyond the margins of the plateau in Puget Sound (Myers, Price et al., 1979), the Cascade Range, and along the front of the Blue Mountains. Larger earthquakes that have occurred in the Puget Sound lowland are interpreted to have depths greater than 30 kilometers (18.6 miles) and to be related to subduction of the Juan de Fuca Plate beneath the North American Plate. Larger events in the western Columbia Plateau appear similar to recent events in the Cascade Range, which seem to be occurring on nearly north-south to northwest striking strike-slip faults. Events in the

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central Columbia Plateau seem to be restricted to a shallow 28-kilometer (17.4-mile) thick crust, with most occurring in the upper 10 kilometers (6.2 miles). These events seem to be small (generally less than magnitude 3.0, but ranging up to magnitude 4.4), largely reverse slip events occurring on steeply dipping planes of generally east-west orientation under nearly north-south compression. Events along the front of the Blue Mountains occur near the intersection of two prominent geologic structural trends--the northwest trend of the Rattlesnake-Wallula alignment, and the northeast trend of the Hite fault system (see Fig. 3-22). The largest known event in the Columbia Plateau occurred on July 15, 1936, along the front of the Blue Mountains (WPPSS, 1981a). This event is reported to be a magnitude 5.75. Focal mechanisms for the 1936 event (though poorly constrained) indicate probable strike slip along a northeast-trending fault. Focal mechanism solutions for two instrumentally recorded, more recent events close to the source of the 1936 event--a magnitude 4.1 in April 1979 and a magnitude 3.8 in March 1983--also suggest that the motion was dominantly strike slip along either northeast or northwest-trending planes. The axes of maximum compression determined for these events was nearly west-east, somewhat different from the nearly north-south compression characteristic of the central Columbia Plateau.

Earthquake sizes, focal mechanisms, and axes of compression suggest that the Pasco Basin area of the central Columbia Plateau is subjected to a somewhat different stress regime or responds differently to the same stress field affecting the larger region. If magnitude 4 to magnitude 6 earthquakes were to occur in the vicinity of a waste repository in the Cold Creek syncline, the vibratory ground motion could affect the design of surface and subsurface facilities, depending on the distance at which the earthquakes occurred from a repository. Empirical data indicate that mines and mined tunnels are not adversely affected by earthquakes large enough to cause damage (often severe) to surface buildings and facilities. Detrimental effects are noted only if the rupturing fault intersects the mine or tunnel. However, changes in the behavior of springs and in the inflow of water into mines following earthquakes suggest that some changes in ground-water flow may be brought about by fault rupture. When the site is characterized, design earthquakes and ground motions will be determined so that potential effects of both vibratory ground motion and changes in ground-water flow can be assessed.

Earthquakes are not currently associated with mapped geologic structures, nor do hypocenters align in a manner suggestive of unmapped buried faults in the Pasco Basin area. Composite focal mechanism solutions for events of presumably similar origin suggest that slip occurs on different planes, and not along one planar zone; therefore, it is assumed that several planes are slipping during events within one swarm of earthquakes.

Because it is generally assumed that earthquakes result from the propagation of energy released when rock fractures and/or slips during rupture, some faults must exist that are seismogenic. Judging from the

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size of earthquakes and the distribution of events, the size of such faults must be small (tens of meters to a few square kilometers (tens of feet to a few square miles)).

The pattern and rate of deformation in the Columbia Plateau that appears to have been in effect since the Miocene is not anticipated to change over the lifetime of a repository. Therefore, there is no indication from the available record of geologic and tectonic evolution that the pattern, frequency, or distribution of earthquakes should change over the next several thousand years in the reference repository location. The current plan (see Section 4.1) for seismic surveillance should provide data to get detailed recurrence curves for the reference repository location area, which can be compared with recurrence data from the 14-year operating regional array and the more than 100 years of historical earthquake data.

6.3.1.7.7 <u>Potentially adverse condition</u>

"(4) More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located."

Seismic activity within the Columbia Plateau occurs less frequently and at lower magnitudes than in other areas of the Pacific Northwest (Myers, Price et al., 1979). Therefore, it appears that this potentially adverse condition does not exist within the geologic setting of the reference repository location.

Historical seismicity, as well as instrumentally recorded events, shows the Columbia Plateau to be an area of low-to-moderate earthquakes (see Subsection 2.1.1.3 and Section 3.2.4) (Rasmussen, 1967; WPPSS, 1981a). Most earthquake activity in Washington State occurs in the Puget Sound lowlands. This zone continues to the south in the Willamette Valley of Oregon. The zone of relatively high activity continues to the northwest into British Columbia in the area of southern Vancouver Island, the Straits of Georgia, and the Straits of Juan de Fuca. Near the center of Vancouver Island, the zone of high activity appears to turn westward and join the zone of high earthquake activity along active, spreading centers and transform faults.

Earthquakes as large as magnitude 7.0 and at depths down to approximately 70 kilometers (40 miles) have occurred in the Puget Sound area. Historic seismicity, as well as instrumentally recorded events, shows that this is an area where moderate to high levels of stress have been relieved over the nearly 150 years of record. Most earthquakes, and in fact most larger events, occur at depths of more than 10 kilometers (6 miles) in distinct contrast to the Columbia Plateau. The structure(s) responsible for this activity is deeply buried by thick, extensive Quaternary sediment, some of which is offset by faults.

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East of the Columbia Plateau, earthquake activity appears to be relatively low, except for a zone extending northwestward from the generally north-trending Intermountain Seismic Belt, across southern Idaho north of the Snake River Plain into eastern Oregon. This latter zone, known as the Idaho Seismic Belt, is an area of shallow earthquakes identified from felt reports, and more recently from instrumental records, and extends through the Idaho Batholith Province. Earthquakes in this area are generally shallow, less than 15 kilometers (9 miles), low-to-intermediate magnitude (magnitude less than 6.1), frequently of swarm type, and correlate in part with post-Miocene faults where geologic mapping is of reasonable quality. The Snake River Plain appears to be an area of low earthquake activity from both historical felt reports and instrumental surveys.

One of the largest earthquakes that was felt over a large area of the Pacific Northwest occurred on December 14, 1872, in a remote mountainous area of sparse population. This earthquake was not recorded by instruments, so its size and location had to be determined from a few written records, some of which appeared days to months after the event. A panel of experts was formed to review felt reports and accounts of the December 14, 1872, event (WPPSS, 1977b). The panel concluded that the 1872 earthquake occurred in the area enclosed by the Modified Mercalli intensity VIII isoseismal line from Lake Chelan on the south to southern British Columbia on the north in the North Cascades-Okanogan Highlands area. It apparently had a depth greater than 10 kilometers (6 miles), was followed by several aftershocks, and was probably a low-stress-drop earthquake. The resultant isoseismal map indicates that the earthquake was felt over an area of approximately 1,300,000 square kilometers (500,000 square miles), but the large felt area may have been the cumulative effect of the main shock plus several aftershocks.

Subsequent reviews and hearings in the late 1970's by the U.S. Nuclear Regulatory Commission resulted in some agreement on the December 14, 1872, earthquake. It was agreed that the epicenter is in a broad region in the North Cascades-Okanogan Highlands, which is a distinct tectonic province separate from the Columbia Plateau. It is unlikely that such an event could occur in the Columbia Plateau.

6.3.1.7.8 Potentially adverse condition

"(5) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system."

It does not appear that natural phenomena would create large-scale surface-water impoundments resulting in significant changes to the regional ground-water flow system. This potentially adverse condition is not projected to exist within the geologic setting of the reference repository location.

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Slope instability along bluffs of the Columbia River (located approximately 14 kilometers (9 miles) northeast of the reference repository location) is evident where topographic features indicate relatively recent landslides (late Holocene to historic times). Scarps (indicative of sliding) as well as slide masses are evident along parts of the White Bluffs (see Fig. 3-37), especially where the ground-water level in the sediments overlying the basalt has been raised in recent years by irrigation of crop lands. Morphologic evidence also indicates areas of slope instability along the deeply incised channel of the Columbia River downriver from Wallula Gap where the Columbia River has incised the Horse Heaven Hills (see Fig. 2-13). The volumes of material in these slides appear insignificant in affecting the course of the Columbia River, or in damming or partially damming the river. Even if the river were to be dammed by a slide of magnitude much larger than those in evidence today, it would probably be an ephemeral event not lasting more than a few years, and the net effect on a change in the elevation of the water table in the unconfined aquifer would probably be no more than a few meters (feet). The effects of this change on the unconfined and confined aquifers in the reference repository location would need to be assessed.

Damming of the Columbia River by volcanism or the products thereof is unlikely in the Pasco Basin area. However, there is geologic evidence of blocking of the gorge of the ancestral Columbia River by flows of the Columbia River Basalt Group in Miocene time, producing temporary lakes of unknown dimension. High alumina basalts also blocked the gorge of the ancestral Columbia River, in the area where it flows through the Cascade Range, approximately 2,000,000 years ago (Tolan, 1982). This blockage occurred in the Cascade Range approximately 320 kilometers (200 miles) downstream from the closest point of the reference repository location from the Columbia River. The volume and rapidity of movement of these flows were sufficient to fill the existing channel causing the ancestral Columbia River to relocate to its present channel. Assuming lava flows were to inundate the Columbia River channel in the area of the present-day Columbia River gorge through the Cascade Range, the blockage would probably result in a small obstruction. The blockage is expected to be temporary. In a worst case scenario, a blockage could impound surface waters in topographic depressions along the course of the Columbia River and its tributaries. Surface-water could conceivably be impounded as far upstream as the Pasco Basin. This impoundment would be expected to temporarily change local shallow ground-water flow systems with less long-term impact on deeper regional flow systems.

6.3.1.7.9 Potentially adverse condition

"(6) Potential for tectonic deformations--such as uplift, subsidence, folding, or faulting--that could adversely affect the regional ground-water flow system."

The potential for tectonic deformation is reasonably known, but the effects such deformation would have on the regional ground-water flow system remain to be addressed in site characterization. Therefore, the available evidence does not support a finding that this potentially adverse condition exists in the reference repository location.

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Assuming that tectonic deformation will continue at long-term, low-average rates as it apparently has since at least the Miocene, tectonic deformation during the postclosure period of a repository is reasonably assured (see Subsection 2.1.1.2 and Section 3.2.3). The impact that such deformation will have on the travel direction or rate of ground-water flow is a matter that remains to be addressed (see Subsection 6.4.2. Scenarios involving faulting have been identified and will be assessed.

6.3.1.7.10 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 nature and rates of fault movement or other ground motion at the reference repository location are not expected to result in a loss of waste isolation. The reference repository location is not disqualified based on the postclosure tectonic disqualifying condition.

The pattern and timing of deformation of the central Columbia Plateau, as currently interpreted, suggests that slip rates of faults during the late Cenozoic time have been low. Such a pattern would suggest that earthquakes and rupture planes would be relatively small and recurrence rates generally long (see Subsection 6.3.1.7.5). Since empirical data indicate that mines are not adversely affected by earthquakes large enough to cause damage (often severe) to surface facilities, it would appear ground motion from recorded small to moderate earthquakes located near the reference repository location should not adversely affect waste isolation. Recurrence rates for moderate earthquakes are long, up to at least between 10,000 to 100,000 years for large moderate earthquakes; ~~and also~~ indicate the relative infrequent nature of moderate earthquakes in the central Columbia Plateau.

Detremental affects to mines are noted if rupturing faults intersect mine walls. Therefore, major consideration was given to siting the reference repository location away from areas of known or suspected faulting (see Section 2.2). Structural analysis of Yakima Folds in the central Columbia Plateau shows little or no deformation has occurred in synclinal troughs. The reference repository location has been sited near the trough of the Cold Creek syncline. Current seismic data suggest that the probability of ground motion at a repository in the reference repository location is low and related to small earthquakes. Rupture planes from small earthquakes are not expected to lead to a loss of waste isolation. Isolation of a repository in the reference repository location can be maintained without relying on the retardation capability and the integrity of the dense interior of the host flow.

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6.3.1.7.11 Conclusion on qualifying condition

A final conclusion on the qualifying condition for tectonics cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1). The available evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition.

This preliminary interpretation is based on the rate, pattern, and timing of deformation of the Columbia River Basalt Group, the low-to-moderate seismicity along with the areal distribution and size of earthquakes, the low heat flow and unlikely renewal of basaltic or other volcanism in the central Columbia Plateau, and the unlikely significant changes in ground-water pathways or travel time as a result of tectonic processes or events. Studies used to arrive at this preliminary interpretation are summarized in Caggiano and Duncan (1983) and include stratigraphic and structural investigations, seismic monitoring and seismological investigations, geophysical investigations and interpretations of anomalies, and geodetic monitoring. The preferred interpretation is that deformation is following a pattern established at least 15 million years ago in the Miocene in which structures have been developing under nearly north-south, nearly horizontal compression at long term, average low rates of strain. The pattern of developing structural relief during eruption of the Columbia River Basalt Group from at least 14.5 to 10.5 million years ago (which is supported by the decreasing dip of progressively younger sedimentary strata on the flanks of anticlinal ridges) apparently continues to the present. Projection of the growth rates of major anticlinal folds in the Saddle Mountains and Rattlesnake Mountain from the Miocene accounts for the present elevation of basalt flows in these two Yakima fold ridges. The size, pattern, and distribution of earthquakes in the central Columbia Plateau along with focal mechanism solutions suggest continuing strain under nearly north-south, nearly horizontal compression. Seven surveys, of a trilateration array across the Hanford Site since 1972, suggest compression at very low rates compatible with geologically determined rates of deformation, although the data may not be beyond the limits of error of the instruments used to measure changing line lengths.

~~While~~ although the preferred interpretation is one of continuing deformation under nearly north-south, nearly horizontal compression at long-term, average low rates, the possibility of shorter periods in which deformation proceeded at higher rates (i.e., a more episodic pattern and rate of deformation compared with a long-term, average low rate) cannot be dismissed at this time. The rate and timing of deformation in other Yakima folds needs to be confirmed as does the low rate of strain determined geodetically. Instrumental monitoring of shallow microearthquakes in the reference repository location needs to be conducted to determine the recurrence of microearthquakes in the reference repository location, source parameters for these events, and any effects

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of such rupture on ground-water pathways and travel times. The relationship of folding to faulting, as well as the relationship of deformation in basalt to sub-basalt structure, need to be determined as a check on the possible episodicity of deformation and the potential for rupture of a fault from the sub-basalt basement through a repository.

6.3.1.8 Human Interference (Section 960.4-2-8)

"The site shall be located such that activities by future generations at or near the site will not be likely to affect waste containment and isolation. In assessing the likelihood of such activities, the DOE will consider the estimated effectiveness of the permanent markers and records required by 10 CFR Part 60, taking into account site-specific factors, as stated in Sections 960.4-2-8-1 and 960.4-2-8-2, that could compromise their continued effectiveness."

6.3.1.8.1 Natural Resources qualifying condition (Section 960.4-2-8-1)

"The site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1."

6.3.1.8.2 Evaluation process

Data to assess the natural resources in the region of the reference repository location include the following:

1. Past oil and gas production and present oil and gas exploration.

2. Past coal production.

3. Past gold production.

4. Past industrial rock and mineral production.

5. Economic analysis of the area within 100 kilometers (62 miles) of the Hanford Site.

6. Projected net value of mineral resources upon the next 25 years.

7. Past ground-water production.

6.3.1.8.3 Favorable condition

"(1) No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource."

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There are ~~presently~~ currently 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~~ at the reference repository location. Therefore, this favorable condition appears likely to be met at the reference repository location.

The 200,000-square kilometer (78,000-square mile) area underlain by the Columbia River Basalt Group, including the area within 100 kilometers (62 miles) of the reference repository location, is not part of a known metalliferous or petroliferous geologic province. The most current natural resource evaluation of the Pasco Basin is presented in Geosciences Group, George Leaming Associates (GG/GLA, 1981). The following discussion is summarized from this report and a resource evaluation by Newell Campbell that is in progress. The Geosciences Group, George Leaming Associates (GG/GLA, 1981) report is mainly directed at the Hanford Site, which includes the reference repository location, and the Campbell evaluation is directed toward the Columbia Basin (the Columbia Plateau of the State of Washington).

No commercial production of coal has been recorded from within 100 kilometers (62 miles) of the Hanford Site. Within the Pasco Basin, relatively thin, low-grade coaly zones (lignite) in sediments interbedded with basalt flows of the Columbia River Basalt Group have been shown by analysis of geophysical logs and vitrinite reflectance to be too thin, impure, and of low rank to be attractive for potential exploration and development in the foreseeable future.

A small, depleted, low-pressure, natural gas field that was in production from 1929 to 1941 is present at the southern edge of the Hanford Site, 11 kilometers (7 miles) south of the reference repository location. No other current or past commercial production of petroleum or natural gas has been reported within 100 kilometers (62 miles) of the Hanford Site. Interpretation of carbon and hydrogen isotopic data for methane gas from confined aquifers of the Wanapum Basalt and Saddle Mountains Basalt flows in the vicinity of the Hanford Site suggests that the gas probably originated at shallow depths, from terrestrial carbonaceous matter in the interbeds of the Ellensburg Formation rather than from marine sediments at depth. On the basis of the relatively small carbonaceous-matter content and limited volume of sedimentary interbeds, it is concluded that intrabasalt potential for natural gas development in the site area is relatively unattractive. At today's economics, the old Rattlesnake Hills gas field is noncommercial.

Oil and gas potential of sediments postulated to underlie the Columbia Plateau at depths in excess of 3,000 meters (10,000 feet) is unknown, but is currently being tested by a deep well that is being drilled by Shell Oil Company and Atlantic Richfield Company. Three other wells have been completed by Shell Oil Company. ~~and a fourth is currently being tested.~~ The Columbia Plateau is considered a frontier area; three completed wells were deemed noncommercial by Shell Oil Company, but natural gas was recovered from two wells. The fourth well is located in the Saddle Mountains structure approximately 26 kilometers (16 miles) north of the reference repository location (see Fig. 6-3). Geologic information derived from this well is proprietary, but testing is going on. This well penetrated the basalt at a depth of nearly 3,658 meters (12,000 feet) and is the deepest well in the State of Washington (over 5,180 meters (17,000 feet)).

All exploration activity is directed toward the anticlinal ridges with the sediment sequence beneath the basalt as the target horizon. The Columbia River Basalt Group is the cap rock for the natural gas that has been found. Based on available data, no traps occur in these sedimentary rocks in the structural-low of the Pasco Basin. Furthermore, any hydrocarbons that might have been generated under the Pasco Basin should have migrated away from the synclinal area, where the basalt is thickest, to the anticlinal ridges. With the extreme basalt thickness as a detriment to drilling economics at today's high drilling cost, the synclinal areas of the Pasco Basin are poor drilling prospects. The present drilling activity by the major petroleum companies indicates the Cold Creek syncline is not a favorable target, especially when anticlinal ridges that could provide structural traps for petroleum reservoirs are present in the area.

With the exception of small gold placers, no high-unit-value metallic mineral resources with significant commercial potential are known to occur, or are believed likely to occur, within the Columbia River Basalt Group or in overlying or interbedded sediments within 100 kilometers (62 miles) of the Hanford Site. Mineral potential in sub-basalt sediments is not known, but the great depth from surface to these rocks within the Pasco Basin (3,000 meters (10,000 feet) or more) precludes foreseeable exploration and development of possible minerals within sub-basalt sediments.

Occurrences of relatively low-unit-value industrial rocks and minerals within 100 kilometers (62 miles) of the Hanford Site consist of peat, diatomaceous earth, pumicite, quarry rock, and sand and gravel. Such resources are surficial in occurrence and are not concentrated within the Pasco Basin relative to the remainder of the Columbia Plateau. Current mineral industry activities within 100 kilometers (62 miles) of the Hanford Site are limited to production of diatomaceous earth, sand and gravel, and crushed stone--all from surface-mining operations.

Economic analysis of the area within 100 kilometers (62 miles) of the Hanford Site indicates that the gross value of known resources of diatomaceous earth, sand and gravel, stone, peat, placer gold, and the probable gross value of remaining undiscovered natural gas resources within the Columbia River Basalt Group is about $470.5 million. Subtracting estimated costs of exploration, development, production, and wholesale marketing from the gross resource value leaves a net value of $33.0 million. Present net value of known resources and resources likely to be recovered over the next 25 years is between $7.3 and $10.4 million, depending on the discount rate used to compute present value.

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Projected net value of mineral resources over the next 25 years for the 10-county area within 100 kilometers (62 miles) of the Hanford Site is $62 per inhabitant. For the 11-county remainder of the Columbia Plateau, projected net mineral resource value averages $98 per inhabitant.

In 1978, personal income derived from extraction of geologic resources in the 10 counties within 100 kilometers (62 miles) of the Hanford Site was $4.5 million or $77 per square kilometer ($30 per square mile) and $8.40 per capita. In the remaining 11 counties of the Columbia Plateau, comparable figures were $126 per square kilometer ($49 per square mile) and $10.33 per capita. In the same year, the mining industry of the 10-county area closest to the Hanford Site provided 0.5 job per 1,000 inhabitants. Comparable figures for the remainder of the Columbia Plateau were 0.7 jobs per 1,000 inhabitants. By comparison, exploitation and exploration for geologic resources in a state such as New Mexico in 1978 provided 23 jobs per 1,000 inhabitants. Projected government revenues derived from mining in the 10-county area nearest the Hanford Site over the next 25 years is $0.36 per 1980 inhabitant. By comparison, the 11-county remainder of the Columbia Plateau, comparable figures are $0.16 per inhabitant.

It is concluded that the mineral industry within 100 kilometers (62 miles) of the Hanford Site, and including the reference repository location, is a relatively insignificant component of employment, personal income, and governmental revenue derived from all economic sources. Geologic assessment of the area and vicinity suggests that they are relatively unattractive for future subsurface mineral exploration and development relative to other areas of the Columbia Plateau and the western United States.

6.3.1.8.4 Favorable condition

"(2) Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel from the host rock to the accessible environment."

The deep basalt ground waters beneath the reference repository location do not contain total dissolved solids equal to or greater than 10,000 parts per million. Therefore, this favorable condition is not met by the reference repository location.

The values for total dissolved solids for basalt ground waters along likely radionuclide travel paths to the accessible environment are less than 1,000 parts per million (Gephart et al., 1979, p. III-187). Average values for total dissolved solids for the deep basalt ground waters are: Lower Saddle Mountains Basalt--413, Upper Wanapum Basalt--324, and Grande Ronde Basalt--648.

6.3.1.8.5 Potentially adverse condition

"(1) Indications that the site contains naturally occurring materials, whether or not actually identified in such form that

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(i) economic extraction is potentially feasible during the forseeable 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 extraction of natural gas or other naturally occurring materials from the reference repository location is not considered to be commercially attractive or potentially feasible in the foreseeable future, nor are such materials beneath the reference repository location considered of greater gross value, net value, or commercial potential than elsewhere in the Columbia Plateau. Therefore, this potentially adverse condition does not appear to exist at the reference repository location.

The Columbia Plateau is not part of a known metalliferous or petroliferous geologic province (GG/GLA, 1981), although the Columbia Plateau may be a source for natural gas. A discussion of natural resource evaluations of the Columbia Plateau is presented in Subsection 6.3.1.8.3.

Significant hydrocarbon accumulations require four conditions to occur: (1) adequate source beds to generate hydrocarbons, (2) porous and permeable beds to act as reservoir rock, (3) a cap rock to prevent escape of hydrocarbons, and (4) a trapping mechanism. ~~Presently~~ Currently, the Yakima Fold Belt of the Columbia Plateau is being explored for its natural gas potential by Shell Oil Company and Atlantic Richfield Company. Other major petroleum companies have leased land on the plateau for mineral rights including ~~all~~ land surrounding the Hanford Site to the north, east, west, and south. Although source beds may exist beneath the basalt and the Columbia River Basalt Group appears to act as a cap rock, present exploration activity has not found adequate reservoir rocks. The trapping mechanism for hydrocarbons is the anticlinal ridges; because the reference repository location is in a syncline with a thick basalt sequence (more than 3,000 meters (10,000 feet)), the site is considered to be commercially unattractive and economic extraction is not considered feasible in the foreseeable future.

6.3.1.8.~~5~~6 Potentially adverse condition

"(2) Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation."

There has not been, nor is there currently, any subsurface mining or extraction activities for resources in the reference repository location. Therefore, this potentially adverse condition does not exist at the reference repository location.

The only evidence of mining or extraction for natural resources within the reference repository location is the existence of sand and gravel quarries. No subsurface mining or extraction for resources has taken place within the reference repository location. The quarries are excavated pits that generally do not exceed 18 meters (60 feet) in depth.

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Quarry operations at this depth will not affect waste isolation or containment in a repository situated 850 meters (2,789 feet) below the ground surface.

6.3.1.8.6 <u>Potentially adverse condition</u>

"(3) Evidence of drilling within the site for any purpose other than repository-site evaluation to a depth sufficient to affect waste containment and isolation."

This potentially adverse condition does not exist at the reference repository location, since boreholes for other than the purpose of repository site evaluation are significantly shallower than the candidate repository horizons and would not affect waste isolation or containment.

Boreholes drilled in the reference repository location for purposes other than repository site evaluation generally were not deeper than the top of the basalt sequence, although a few borings were drilled into the upper part of the Saddle Mountains Basalt. These boreholes are used for measuring water levels and collecting ground-water samples as part of the Hanford shallow ground-water monitoring programs. The only boreholes penetrating into the Wanapum Basalt and Grande Ronde Basalt flows in the reference repository location were drilled for the purpose of repository site evaluation.

6.3.1.8.7 <u>Potentially adverse condition</u>

"(4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources."

This potentially adverse condition does not exist at the reference repository location. The reference repository location contains low value material common to the rest of the Columbia Plateau.

The area within 100 kilometers (62 miles) of the reference repository location is not part of a known metalliferous or petroliferous geologic province (see Subsection 6.3.1.8.3). There is no evidence to suggest significant concentrations of any naturally occurring mineral or rock that is unique to the reference repository location. Common construction materials (sand, gravel, and basalt) are found within the reference repository location; however, these materials are readily available outside the site area. Exploration for natural gas is being conducted on the Columbia Plateau (see Subsection 6.3.1.8.4). Exploration drilling has been targeted for anticlinal ridges and not in structural depressions such as the Cold Creek syncline in which the reference repository is located.

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6.3.1.8.8 Potentially adverse condition

"(5) Potential for foreseeable human activities--such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments--that could adversely change portions of the ground-water flow system important to waste isolation."

There is a potential for foreseeable human activities, particularly ground-water withdrawal for the purposes of irrigation and discharges of significant quantities of waste water to the unconfined system in and around the reference repository location (see Section 2.1.4). However, insufficient data are presently available to reasonably determine if such human activities could adversely change portions of the ground-water flow system, which is important to waste isolation. Therefore, it is assumed that this potentially adverse condition could be present at the reference repository location.

The geohydrologic system within, surrounding, or affecting the reference repository location is presently being investigated through surface and subsurface exploration (see Section 4.1). In like manner, the likelihood of these human activities that might impact the ground-water flow system, which is important to waste isolation, is also under study. Once this information is gathered and analyzed, reasonable estimates can be made regarding expected changes in the ground-water flow system due to various human activities.

6.3.1.8.9 Disqualifying condition

"A site shall be disqualified if--

(1) Previous exploration, mining, or extraction activities for resources of commercial importance at the site have created significant pathways between the projected underground facility and the accessible environment; . . ."

The available data show a lack of major previous exploration, mining, or extraction of resources in the reference repository location. This data base is not expected to change. Therefore, this disqualifying condition (1) does not apply to the reference repository location. Little or no uncertainty is involved in making this decision.

The Hanford Site has a limited history of commercial, mineral, or ground-water exploration and extraction activities. No known mining, exploration, or extraction activities have occurred at the reference repository location other than surface extraction of sand and gravel, and basalt. Surface mining activities have not created significant pathways between the projected repository underground facilities and the accessible environment.

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Detailed information on ground-water use within the Pasco Basin and the surrounding region has been summarized in U.S. Department of Energy (DOE, 1982e, pp. 5.1 through 5.189). Primarily, water demand in the Pasco Basin is satisfied by supplies from surface-water sources. Ground-water withdrawals comprise less than 10 percent of the total water demand. Approximately 50 percent of the total number of water wells within both the Columbia Plateau and the Pasco Basin are used for households, and it can be generalized that most of the wells are relatively shallow (less than 150 meters (492 feet) deep). Agriculture represents one-third of the total number of wells, and industrial users are a comparatively small segment of the total number (see Section 2.1.4 and Subsection 3.3.1.5).

Within the Pasco Basin, in the upper Cold Creek Valley where irrigated agriculture activities have been expanding, the average water-level elevation within the Priest Rapids Member of the Wanapum Basalt has declined approximately 10 meters (33 feet) over the last 3 years. However, these activities are greater than 5 kilometers (3 miles) away from the reference repository location, and the upper Cold Creek Valley may be isolated hydrologically from the projected underground facility (i.e., there is a possible bedrock structural discontinuity that represents an impediment to lateral ground-water flow (Gephart et al., 1983, pp. 1 through 10; Gephart and Price, 1983, pp. 151 through 158)). Studies are underway to address this possible hydrologic barrier identified in Figure 2-1 and discussed in Section 4.1. These activities do not create significant pathways between the facility and the accessible environment.

Studies of the Hanford Site have not disclosed any other evidence of commercial enterprises that have disturbed the geologic setting or could potentially create significant pathways between the repository and the accessible environment.

6.3.1.8.~~10~~ 11 Disqualifying condition

"A site shall be disqualified if--

(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."

Possible future activities to recover presently valuable natural mineral resources (high-unit value or oil and gas) outside the controlled area are not expected to lead to an inadvertent loss of waste isolation; therefore, the reference repository location does not appear disqualified.

Two valuable natural mineral resources, gold placers and natural gas, have been recovered from outside the controlled area, but are not present within the vicinity of the reference repository location. Small gold placers, located on gravel bars along the Columbia River were worked during the Great Depression. Possible future mining of gold placers would also be conducted in surficial deposits above the Columbia River Basalt

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Group. These possible mining activities would not be expected to impact the isolation of radioactive waste in the reference repository location.

Two potential sources of natural gas in the vicinity of the reference repository location are (1) within the Columbia River Basalt Group, and (2) beneath it. A small, depleted, low-pressure, natural gas field that was in production from 1929 to 1941 is present on Rattlesnake Mountain at the southern edge of the Hanford Site (11 kilometers (7 miles) south of the reference repository location). At today's economics, the old Rattlesnake Hills gas field is noncommercial. If gas fields were to exist elsewhere within the basalts of the Columbia Plateau, they would be associated with anticlinal ridges of the Yakima Fold Belt outside the Hanford Site and, like the Rattlesnake Hills gas field, small and low pressure. This is because the hydrocarbons would migrate to the anticlinal ridges, which could provide the structural traps. Activities used to recover gas from these fields would not be expected to affect waste isolation in the reference repository location on the Hanford Site.

Presently, the Yakima Fold Belt of the Columbia Plateau is being explored for its natural gas potential by Shell Oil Company and Atlantic Richfield Company. Three wells have been completed by Shell Oil Company and a fourth is currently being tested. Three wells were deemed noncommercial, but natural gas was recovered from two. The primary exploration horizon in all cases is the sedimentary rocks below the Columbia River Basalt Group. No specific information is available to suggest if the sedimentary rocks beneath the Columbia Plateau contain economical quantities of natural gas. Because the anticlinal ridges appear to be the principal hydrocarbon trap and any hydrocarbons will migrate to that area, the anticlinal ridges are now and are expected to continue to be the principal areas of exploration for hydrocarbons in the Columbia Plateau. The reference repository location lies within a large syncline that is not a structurally favorable exploration target.

Activities associated with the recovery of natural gas from wells drilled on anticlinal ridges of the Yakima Fold Belt outside the Pasco Basin and into sedimentary rocks at depths of greater than 3,000 meters (10,000 feet) below the ground surface would not be expected to affect waste isolation in the reference repository location.

6.3.1.8.10 Conclusion on qualifying condition

A final conclusion on the qualifying condition for human interference (see Subsection 6.3.1.8) cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1). The available evidence does not support a finding that the site is not likely to meet the qualifying condition.

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The major factors that support the preliminary finding are:

- Natural resources are generally scarce at or near the reference repository location, except for sand, gravel, and basalt that have been locally quarried for construction projects. These surficially mined materials are readily available outside the reference repository location.

- As addressed in Subsection 6.3.1.1.11, deep ground waters beneath the reference repository location contain natural chemical constituents that would require removal or treatment before these waters would be suitable for human consumption and (or) crop irrigation.

- Three hydrocarbon exploration wells have been deemed by Shell Oil Company to be noncommercial and a fourth is being tested. Exploration targets are the deep sedimentary horizons (3,658 meters (12,000 feet)) beneath anticlinal ridges interpreted to be the potential traps where hydrocarbons migrate. The reference repository location occurs in a structurally unfavorable area where exploration is unlikely to occur.

The principal uncertainties in the human interference qualifying condition are related to hydrocarbon exploration. In spite of the fact that the reference repository location lies in a structurally unfavorable area, it is not known if hydrocarbons in economical quantities are present beneath the thick sequence of basalt of the Columbia Plateau.

6.3.2 Postclosure System Guidelines (Section 960.4-1)

6.3.2.1 Qualifying condition

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

6.3.2.2 Evaluation process

Compliance with this qualifying condition will be assessed using analyses of radionuclide transport from the proposed repository to the

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accessible environment based on laboratory and field data. The essential elements of such analyses are as follows:

- A conceptual model of the engineered barrier system and the host rock setting that depicts features, conditions, and processes important to repository system performance.
- A numerical model or suite of submodels that represents the conceptual model.
- A representative data base including uncertainty distributions necessary for application of the numerical models.
- An understanding of the nature, effects, and likelihood of disruptive events and processes that might significantly alter the performance of the repository system.

Development and application of the assessment methodology and data base needed for demonstration of compliance with the qualifying condition is ongoing. Ground-water travel times are an important aspect for demonstration of compliance. Based on available data and current preliminary interpretation of the ground-water system, ground-water travel times to the accessible environment from the repository are likely to be greater than 1,000 years as specified in 10 CFR Part 60 (NRC, 1982a) (see Subsection 6.3.1.1.13). Radionuclide transport is another important factor in determining compliance with this guideline. An initial analysis of projected cumulative release at the accessible environment, based on limited laboratory and field data, for the 10,000 years after repository closure suggests that the probability of meeting the standard specified in 40 CFR 191 (EPA, 1982) is high (see Section 6.4.2). For this analysis, no credit was taken for retardation of ground-water or nuclide movement in the dense host rock flow interior. It appears that iodine-129 and carbon-14 (neither of which are sorbed on packing materials or pathway minerals) are the only radionuclides with the potential for reaching the accessible environment in 10,000 years.

6.3.2.3 Conclusion on qualifying condition

A final conclusion on the qualifying condition for the postclosure system guideline cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1).

The available evidence does not support a finding that the site is not likely to meet the qualifying condition. Major factors that support this preliminary finding are summarized below:

- A geohydrologic setting in which ground-water travel time to the accessible environment is likely to exceed 10,000 years.

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- A geochemical environment that is likely to inhibit corrosion of metal containers, suppress the dissolution of most radionuclides in the waste, and retard the movement of radionuclides (relative to the movement of water) along pathways to the accessible environment.

- A system that is unlikely to be altered unfavorably by construction of the repository or the presence of radioactive waste, or by natural or human-induced events or processes.

The principal uncertainties related to the major factors that support the preliminary finding are the validity of the conceptual geohydrologic model utilized for radionuclide transport analysis and the values of key geohydrologic and geochemical parameters. Of primary importance are definition or identification of:

- Vertical conductivity of dense interior basalt.

- Discrete geologic features that might allow significant vertical transport of radionuclides.

- Element solubilities in the prevailing environment.

- Retardation mechanisms along radionuclide transport pathways.

6.3.3 Preclosure technical guidelines

6.3.3.1 Surface Characteristics (Section 960.5-2-8)

6.3.3.1.1 Qualifying condition

"The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in Section 960.5-1(a)(3) can be met during repository siting, construction, operation, and closure."

6.3.3.1.2 Evaluation process

The reference repository location is situated in an area of low relief approximately midway along the length of the Cold Creek Valley. See Figure 3-21 for a topographic map of the reference repository location.

Subsection 3.1.3.1 details many specifics regarding the flood history and flood potential of the Columbia and Yakima Rivers under natural and dam-failure conditions. In addition, it addresses the flash-flood potential for the Cold Creek watershed in which the reference repository location lies. In summary, Subsection 3.1.3.1 states that the land surface elevation within the reference repository location ranges between 190 and 245 meters (625 and 800 feet) above mean sea level. This

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topographic level effectively protects the location from conceivable flood scenarios for the Columbia and Yakima Rivers, including both natural flooding and dam-breach or failure scenarios.

There exists a small potential for shallow flash-flooding of limited extent within the reference repository location. Analyses suggest that approximately 9 square kilometers (3.5 square miles) of the reference repository location might be inundated by a probable maximum flood in the Cold Creek watershed. The shallowest portions of this flood might extend into the area considered for repository surface support facilities. Using conservative data inputs, a maximum flood depth of about 2.3 meters (7.7 feet) was calculated along the southwestern border of the reference repository location (Skaggs and Walters, 1981). This area is the topographically lowest point within the reference repository location. The recurrence interval of this probable maximum flood is once every 20,000 to 100,000 years. In the same analyses, a 100-year peak stage flood was estimated to have a much smaller flood extent than the probable maximum flood with a depth of approximately 1 meter (3 feet) above the valley floor. This depth does not reach any area considered for repository support facilities. Also, the duration of these floods would be short and present no danger to subsurface repository facilities. Some flow is expected to cover the Route 240 roadbed, which is located along the western boundary of the reference repository location. However, access to the repository would be continued from the north or east. As detailed in Subsection 6.3.1.5.2, the reference repository location surface has undergone only minor local fluvial and eolian reworking over the last 13,000 years.

6.3.3.1.3 <u>Favorable condition</u>

"(1) Generally flat terrain."

This favorable condition is met at the reference repository location since the site is located on generally flat terrain.

The ~~proposed repository~~ reference repository location is flat and is surrounded by an area of generally flat terrain for at least a 1.5-kilometer (0.9-mile) radius. Areas of moderate to high relief lie 1.5 kilometers (0.9 miles) north of the ~~site~~ reference repository location along the southern edge of Umtanum Ridge bar, 4.0 kilometers (2.5 miles) west along Yakima Ridge, and 6.5 kilometers (4.0 miles) south along the base of Rattlesnake Mountain (see Fig. 3-21).

6.3.3.1.4 <u>Favorable condition</u>

"(2) Generally well-drained terrain."

This favorable condition is met at the reference repository location since the site is located on well-drained terrain.

According to Skaggs and Walters (1981), there is a possibility for short-term surface flooding over the proposed repository. However, the

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lack of evidence for flood plain deposition or surface runoff within 1 kilometer (0.6 mile) of the repository indicates that the site has not undergone surface flooding since the last Pleistocene catastrophic flood (13,000 years before present). The lack of surface runoff features suggests the relatively porous surficial sediments are effective in keeping the surface well drained and preventing surface runoff from developing in the reference repository location north and east of the Cold Creek flood plain (see Fig. 3-30). See Subsection 3.3.1.3 regarding the historical and projected flooding potential of the Hanford Site and reference repository location.

6.3.3.1.5 Potentially adverse conditions

"Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of flood plains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository."

This potentially adverse condition is not present at the reference repository location.

Elevations within the reference repository location range between 190 and 245 meters (625 and 800 feet) above mean sea level. ~~This~~ These elevations effectively protects the reference repository location from conceivable flood scenarios for the Columbia and Yakima Rivers, including both natural flooding and dam-breach or -failure scenarios (see Subsection 3.3.1.3).

A potential for shallow flash flooding of limited extent exists within the reference repository location (see Subsection 3.3.1.3.5). This phenomenon would primarily occur in the lowland southwestern portion of the reference repository location along the drainage channel of the Cold Creek syncline. Water depth in this area could reach approximately 1 meter (3 feet) above the valley floor. Water, however, would not reach areas considered for repository surface support facilities.

The duration of any flash floods would be short and present no danger to surface or subsurface facilities. Some flood water could cover the Route 240 roadbed, but the repository would still be accessible from the north or east.

6.3.3.1.6 Conclusion on qualifying condition

A final conclusion on the qualifying condition for surface characteristics cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1).

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The available evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition. Major factors which support this finding are:

- The reference repository location is generally flat.
- The terrian is well-drained and the meteorological conditions are considered arid (average rainfall of 15.9 centimeters (6.25 inches) per year).
- No evidence of surface flooding for the last 13,000 years.

Little or no uncertainty is associated with these factors.

6.3.3.2 Rock Characteristics (Section 960.5-2-9)

6.3.3.2.1 <u>Qualifying condition</u>

"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) the repository construction, operation, and closure will not cause undue hazard to personnel; and (3) the requirements specificed in Section 960.5-1(a)(3) can be met."

6.3.3.2.2 <u>Evaluation process</u>

Evaluation of the Hanford Site rock characteristics preclosure performance has been based on previously conducted geomechanics field, laboratory, and numerical studies; conceptual designs; and evaluation of past construction experience in hard rocks. The results of these studies have been used in conjunction with geological and hydrological data to evaluate the suitability of the deep basalt flows at the Hanford Site as a possible siting location for a nuclear waste repository, and to assess the performance of the repository. All relevant data, data uncertainties, assumptions, and analyses that were used to characterize the rock mass behavior, relative to the repository preclosure performance, are presented in the favorable conditions and potentially adverse conditions of this section. Much of the data and analyses referenced here has been published in the Site Characterization Report (DOE, 1982e) and Repository Horizon Identification Report (Long and WCC, 1984), where complete descriptions of available data specific to the Hanford Site are presented.

6.3.3.2.3 <u>Favorable conditions</u>

"(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."

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Based on available data, the preferred candidate horizon (Cohassett flow) should provide a sufficiently thick and laterally extensive host rock to allow significant flexibility in selecting configuration and location of the underground facility. to ensure isolation. The option to select from four candidate horizons (Rocky Coulee, Cohassett, McCoy Canyon, and Umtanum flows) provides further flexibility at depth when selecting a repository host rock horizon. Therefore, the reference repository location appears to meet this favorable condition.

Numerous factors can contribute to the variability of a basalt flow thickness and the percentage of flow top thicknesses versus total flow thickness. Extrusive rocks characteristically exhibit variations in their lateral extent and thickness owing to their origin of having flowed across the earth over a preexisting surface. The flow thickness is ultimately controlled by factors such as flow volume, rate of eruption, flow viscosity, and pre-existing topographic features. Factors that affect the flow top thickness include: the physical environment within which the flow is extruded and solidified, the amount of outgassing from the newly erupted magma or from the terrain on which the flow erupted, and deranged drainage that could cause water to flow over the top of molten magma, or the rapid emplacement of the basalt flow into a lake deeper than the thickness of the flow resulting in thick flow tops (Long and WCC, 1984, pp. I-137 through I-139).

A sufficiently thick and laterally extensive dense interior host rock is desirable in the candidate flow horizon to provide more favorable conditions with respect to repository constructibility, stability, and radionuclide isolation. The dense interior is a relatively strong rock with a low permeability. Flow tops generally have poorer rock mass quality and higher permeabilities relative to the dense flow interiors. Therefore, repository excavations that penetrate a flow top may develop instabilities, ground-water inflow problems, in addition to compromising the isolation potential of a dense interior (see Subsection 3.3.2.2).

Vesicular zones within a flow interior are expected to have excavation characteristics more closely resembling a flow interior than a flow top. However, data supporting a strong understanding of the vesicular zone characteristics are presently limited. Preliminary data indicates that the intact rock strength of the vesicular zone is approximately 60 percent of the dense interior intact strength. The effects of this lower strength on the stability of an excavation in the vesicular zone is as yet undetermined since in situ stress measurements within the vesicular zone are not available and it is unknown whether the in situ horizontal stresses within the vesicular zone are lower due to its lower stiffness.

Host rock dense interior thickness and areal extent necessary for repository development are dependent on the size requirements of the repository. Areal requirements of the repository contained in the current conceptual design (see Section 5.1), were based on the need to store 70,000 metric tons (77,162 tons) of heavy metal waste. Additional factors which influence the size of the repository are waste age, backfill

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Total flow thickness and dense interior flow thickness varies with lateral position and is difficult to quantify from a limited number of boreholes. Exposures of all four candidate flows are available at outcrops and these outcrops indicate the consistency of flow thickness in those areas (in general, the outcrops are 29 to 40 km from the RRL). (continue with paragraph 6, Page 6-148)

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~~properties~~, rock temperature limits, rock stress limits, and functional design criteria. In the current conceptual ~~design~~ consideration of these design criteria, storage requirements, and in situ stress magnitudes (vertical stress = 23.2 megapascals (3,365 pounds per square inch), minimum horizontal stress = 33 megapascals (4,786 pounds per square inch), and maximum horizontal stress = 58 megapascals (8,412 pounds per square inch)) results in a 1,929- by 4,148-meter (6,330- by 13,608-foot) or 800.3-hectare (1,977-acre) subsurface ~~repository~~ (RKE/PB, 1984, preliminary drawings 1 through 13). Due to the uncertainty inherent in measuring in situ stresses in basalt the required size of the repository was also determined by increasing the in situ mean stresses by two standard deviations. This increase resulted in the following stress magnitudes: 23.2 megapascals (3,365 pounds per square inch) vertical stress, 37.3 megapascals (5,409 pounds per square inch) minimum horizontal stress, and 72.9 megapascals (10,571 pounds per square inch) maximum horizontal stress, which results in a 3,296- by 4,148-meter (10,814- by 13,608-foot) or 1,367 hectare (3,378-acre) subsurface repository. This higher stress state produces ~~an~~ approximately 71 percent increase in repository area requirements.

subsurface repository layout, facility a

Vertical repository requirements are dependent on factors such as room height and desired drift grade for drainage. Room heights vary from 4.48 meters (14.7 feet) in the shaft pillar area to 3.26 meters (10.7 feet) in the waste panel area. Drift grades are ~~presently~~ currently designed at a uniform 0.5 percent grade; however, the repository design will be flexible enough that waste panel drift grades may be altered so that the slope of the waste panels will be approximately equal to the slope of the flow. This can be accomplished by using a preconstruction exploratory program to better identify the slope and thickness of the dense interior within the proposed waste panel area. Such a program will also identify areas of local thinning or large-scale discontinuities, such as faults, if they exist. Recommended exploratory methods will consist of exploratory drifts driven in advance of the waste panel and used in conjunction with other exploratory methods such as geophysical methods, horizontal- and inclined-probe feeler holes, and vertical exploratory boreholes drilled from the exploratory drifts.

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A conservative estimate of the required ~~dense interior~~ host rock thickness for repository development is 30 meters (98 feet). This was determined in the waste panel area by requiring three room heights above and three room heights below the placement rooms, plus another 7 meters (23 feet) to account for variations in ~~flow dip and drift dip~~ dip of both the flow and drifts. In the shaft pillar area, only two room heights above and below the shaft pillar rooms plus another 7 meters (23 feet) to account for variations in flow dip and drift dip ~~was~~ were considered. The use of three room heights above and below the rooms is very conservative since most of the stress redistribution occurs within the first room height from the excavation. Only two room heights were used in the shaft pillar area since thermal-induced stresses will be insignificant in this portion of the repository.

23 meters (75 feet)

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Even this expanded repository size requires only 33 percent of the 4047 hectare (10,000 acre) reference repository location.

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The requirement of 30m (98 ft.) thickness of host rock for repository development is consistent with the 24m (79 ft.) minimum dense interior thickness screening criterion used to help identify candidate horizons (see section 2.3.3, Identification of Preferred Candidate Repository Horizon). The 24m (79 ft.) criterion excluded flows with less than 24m (79 ft.) of dense interior in any one of three boreholes (RRL-2, RRL-6, and RRL-14). Thus, this criterion focused on the minimum measured thickness at given locations; whereas, the condition of interest here is the suitability of the site for development of a repository over a given area. As noted in the previous paragraph, at any single point in the RRL, 23m (75 ft.) thickness of dense interior is considered to be adequate. This value is approximately equivalent to the 24m (79 ft.) used for screening. The requirement of 30m (98 ft.) takes in to account the dip of the flow and the dip ~~of the~~ drifts over the area in which the repository would be developed. The conservative 30m (98 ft.) thickness is an estimate ~~which~~ that may be reduced as more site specific data is obtained.

Thickness data obtained from boreholes and outcrop exposures throughout the northwest Pasco Basin are presented in Table 6-5a and illustrates both the thickness of the dense interior below the flow top and the dense interior thickness below the deepest vesicular zone in each of the four candidate flows. Borehole and outcrop locations are shown on the isopach map in Figure 3-15. The data in Table 6-5a are further subdivided into two groups. The first group consists of thickness data from throughout the northwest Pasco Basin, while the second group consists of thickness data from only boreholes within a 13-kilometer (8-mile) radius of borehole RRL-2. The second group of data is more representative of the thicknesses which may be expected in the reference repository location. Thickness data for the entire northwest Pasco Basin are presented for the purpose of showing the laterally extensive nature of the four candidate flows. The isopach map in Figure 3-15 further illustrates the areal extensiveness of the Cohassett flow's dense interior below its persistent vesicular zone.

From the statistical summarization of the thickness data (mean and standard deviation) presented in Table 6-5a through 6-5d a preliminary estimate of the minimum expected host rock thickness within all candidate flows can be made for a corresponding confidence level. When considering only thickness data from the seven boreholes within a 13-kilometer (8-mile) radius of borehole RRL-2, it is found that both the Cohassett flow dense interior thickness below the flow top and its dense interior thickness below the persistent vesicular zone have at least a 95 percent confidence that the 30-meter (98-foot) thickness criteria is satisfied (Table 6-5b). Confidence that the Rocky Coulee and Umtanum flows satisfy the thickness criteria can be seen from Tables 6-5a and 6-5c to be at least 90 percent. From the McCoy Canyon thicknesses presented in Table 6-5c, it can be seen that for all the confidence levels given the corresponding thicknesses are less than the thickness criteria, although the mean dense interior thickness below the flow top is 33.2 meters (109 feet).

The lateral extensive nature of the four candidate flow host rocks are illustrated by the thickness data presented in Tables 6-5 through 6-5d. Further evidence of the lateral extensive nature of the Cohassett flow can be seen in the isopach map of Figure 3-15. When considering this data plus the 4,047-hectare (10,000-acre) size of the reference repository location, it is apparent that there is more than adequate flexibility to locate the proposed 800.3-hectare (1,977-acre) subsurface repository.

Based on the previous discussions, it is concluded that the Rocky Coulee, Cohassett, and Umtanum flows are sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility; whereas the McCoy Canyon flow marginally meets the thickness requirement, but exhibits satisfactory lateral extent. The option to choose from four candidate flows provides further flexibility with respect to depth. The greater dense interior thickness within the Cohassett flow makes it the preferred candidate flow horizon.

Table 6-8. Thickness data for the four potential repository flows.

Borehole No.	Rocky Coulee flow		Cohassett flow		McCoy Canyon flow		Umtanum flow	
	DIBFT	DIBVZ	DIBFT	DIBVZ	DIBFT	DIBVZ	DIBFT	DIBVZ
GROUP I DATA[a]								
DC-1/2	45.4	25.9	78.4	48.2	27.8	21.9	52.2	52.2
DC-3	NA	NA	73.5	46.0	NA	NA	47.2	47.2
DC-4/5	43.9	27.7	74.9	45.1	42.4	33.5	45.5	39.4
DC-12	41.8	22.9	57.0	38.1	31.6	24.6	55.3	51.8
RRL-2	46.6	25.9	74.7	45.1	33.8	14.2	25.6	25.6
RRL-6	46.2	22.7	67.5	43.2	30.5	30.5	41.7	41.7
RRL-14	30.5	30.5	62.5	35.6	33.2	26.6	39.6	39.6
DC-6	41.7	22.8	65.5	38.6	40.0	29.0	59.4	55.7
DC-7/8	45.9	21.6	46.0	46.0	30.6	30.6	46.9	46.9
DC-14	55.5	16.5	62.7	33.2	35.3	14.9	19.8	19.8
DC-15	45.1	27.4	41.5	41.2	34.8	0.0	45.4	45.4
DDH-3	61.3	33.3	39.6	39.6	25.9	16.1	58.2	58.2
RSH-1	NA	NA	58.9	23.5	NA	NA	51.2	51.2
DH-4	13.5	9.5	52.7	19.8	28.2	13.2	27.4	27.4
DH-5	45.4	22.2	60.9	25.3	48.7	27.1	54.9	54.9
Emmerson Nipple	37.8	26.2	66.4	45.1	40.8	40.8	37.8	37.8
Sentinel Gap	37.8	37.8	64.3	42.1	55.5	55.5	75.0	75.0
GROUP II DATA[b]								
DC-1/2	45.4	25.9	78.4	48.2	27.8	21.9	52.2	52.2
DC-3	NA	NA	73.5	46.0	NA	NA	47.2	47.2
DC-4/5	43.9	27.7	74.9	45.1	42.4	33.5	45.5	39.4
DC-12	41.8	22.9	57.0	38.1	31.6	24.6	55.3	51.8
RRL-2	46.6	25.9	74.7	45.1	33.8	14.2	25.6	25.6
RRL-6	46.2	22.7	67.5	43.2	30.5	30.5	41.7	41.7
RRL-14	30.5	30.5	62.5	35.6	33.2	26.6	39.6	39.6

NOTE: Data is given in meters; 3.048 meters = 1 foot. DIBFT = Dense interior below flow top. DIBVZ = Dense interior below vesicular zone. NA = Not applicable.

[a]Group I data: all available data.

[b]Group II data: data within a 13-kilometer (8-mile) radius of the RRL-2 borehole.

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Table 6-9. Horizon thickness statistics for the Rocky Coulee flow.

Data sample population	Mean thickness	Thickness standard deviation	Thickness for various confidence levels (left hand tail) $\bar{x} - k\ s$			
	$\bar{x}$	s	84.1% k=1.000	90.0% k=1.282	95.0% k=1.645	97.7% k=2.000
			DIBFT[a]			
Group I data	46.1	13.6	32.5	28.7	23.7	18.9
Group II data	43.9	9.75	34.2	31.4	27.9	24.4
			DIBVZ[b]			
Group I data	45.3	13.4	31.9	28.1	23.3	18.5
Group II data	42.5	9.19	33.3	30.7	27.4	24.1

NOTE: Data given in meters; ~~3.048 meters = 1 foot.~~ 1 meter = 3.28 feet

[a]DIBFT: Dense interior below flow top.

[b]DIBVZ: Dense interior below vesicular zone.

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Table 6-9. Horizon thickness statistics for the Rocky Coulee flow.

Data sample population	Mean thickness	Thickness standard deviation	Thickness for various confidence levels (left hand tail) $\bar{x} - k\ s$			
	$\bar{x}$	s	84.1% k=1.000	90.0% k=1.282	95.0% k=1.645	97.7% k=2.000
			DIBFT[a]			
Group I data	46.1	13.6	32.5	28.7	23.7	18.9
Group II data	43.9	9.75	34.2	31.4	27.9	24.4
			DIBVZ[b]			
Group I data	45.3	13.4	31.9	28.1	23.3	18.5
Group II data	42.5	9.19	33.3	30.7	27.4	24.1

NOTE: Data given in meters; ~~3.048 meters = 1 foote~~ 1 meter = 3.28 feet
[a]DIBFT: Dense interior below flow top.
[b]DIBVZ: Dense interior below vesicular zone.

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Table 6-10. Horizon thickness statistics for the Cohassett flow.

Data sample population	Mean thickness	Thickness standard deviation	Thickness for various confidence levels (left hand tail) $\bar{x} - k\ s$			
	$\bar{x}$	s	84.1% k=1.000	90.0% k=1.282	95.0% k=1.645	97.7% k=2.000
			DIBFT[a]			
Group I data	61.6	11.4	50.2	47.0	42.8	38.8
Group II data	69.8	7.75	62.1	59.9	57.1	54.3
			DIBVZ[b]			
Group I data	38.6	8.54	30.1	27.7	24.6	21.5
Group II data	43.0	4.54	38.5	37.2	35.5	33.9

NOTE: Data given in meters; ~~3.048 meters = 1 foot.~~ 1 meter = 3.28 feet
[a]DIBFT: Dense interior below flow top.
[b]DIBVZ: Dense interior below vesicular zone.

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Table 6-11. Horizon thickness statistics for the McCoy Canyon flow.

Data sample population	Mean thickness	Thickness standard deviation	Thickness for various confidence levels (left hand tail) $\bar{x} - k\ s$			
	$\bar{x}$	s	84.1% k=1.000	90.0% k=1.282	95.0% k=1.645	97.7% k=2.000
			DIBFT[a]			
Group I data	35.9	8.22	27.7	25.4	22.4	19.5
Group II data	33.2	4.98	28.2	26.8	25.0	23.2
			DIBVZ[b]			
Group I data	25.2	13.1	12.1	8.4	3.7	0.0
Group II data 25.2 →	6.8 →	18.4 →	16.5 →	14.0 →	11.6 →	→

NOTE: Data given in meters; ~~3.048 meters = 1 foot~~ 1 meter = 3.28 feet
[a]DIBFT: Dense interior below flow top.
[b]DIBVZ: Dense interior below vesicular zone.

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Table 6-12. Horizon thickness statistics for the Umtanum flow.

Data sample population	Mean thickness	Thickness standard deviation	Thickness for various confidence levels (left hand tail) $\bar{x} - k\ s$			
	$\bar{x}$	s	84.1% k=1.000	90.0% k=1.282	95.0% k=1.645	97.7% k=2.000
			DIBFT[a]			
Group I data	46.1	13.6	32.5	28.7	23.7	18.9
Group II data	43.9	9.75	34.2	31.4	27.9	24.4
			DIBVZ[b]			
Group I data	45.3	13.4	31.9	28.1	23.3	18.5
Group II data	42.5	9.19	33.3	30.7	27.4	24.1

NOTE: Data given in meters; ~~3.048 meters = 1 foot.~~ 1 meter = 3.28 feet
[a]DIBFT: Dense interior below flow top.
[b]DIBVZ: Dense Interior below vesicular zone.

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6.3.3.2.4 Favorable condition

"(2) A host rock with characteristics that would require minimal or no artifical support for underground openings to ensure safe repository construction, operation, and closure."

Preliminary evaluations of rock support/reinforcement requirements based solely on empirical methods and conservative judgement suggest that some artificial support may ~~will~~ be required for repository construction, operation, and closure. The rock support requirements based on both Barton et al. (1974) "Q" system and Bieniawski's (1973, 1976, 1979) "Geomechanics RMR (Rock Mass Rating)" system, applied to the expected conditions at the reference repository location by Barton (1984) and Voss (1984), are rock bolts and shotcrete. The Barton et al. (1984) method indicates only shotcrete (5-centimeter (2-inch) fiber reinforced shotcrete) for excavations in the entablature. This level of artificial support is considered minimal in comparison to other underground mining operations but because of the uncertainty of the impact of thermal-induced stresses in the storage rooms on the need for artificial support, this favorable condition is not present at the basalt site.

Underground openings in the past were usually supported against failure by either timber posts, cribs, steel sets, or arches. Modern practice in hard rock excavations is to utilize the inherent strength available in the rock mass (even if fractured) through the use of rock bolts, shotcrete, wire mesh, or a combination of these elements. In some poor rock conditions, these may be supplemented by cast-in-place concrete with or without steel sets or arches. Cast-in-place concrete and steel set support systems serve to passively restrain the rock and does not utilize the inherent rock mass strength relative to the rock bolt, wire mesh, and shotcrete support system. Rock bolts may also carry or support some loose blocks in the roof or wall, but their main purpose is to utilize the rock mass strength by applying a small confinement or restraining stress to the jointed rock mass around the opening and by limiting excess deformations. ~~thus, producing improved~~ This restraining stress and limitation of deformation enhances block interlocking and ~~greater~~ normal stress development along the joint surfaces, which result in greater joint shear strength. The improved block interlocking and greater joint shear strength results in higher rock mass strength and, therefore, ~~requiring~~ less rock support/reinforcement.

Subsurface excavation instabilities can generally be categorized as structurally controlled, structurally controlled stress induced, or stress induced. Structurally controlled instabilities are more characteristic of excavations in low to moderate stress environments at depths less than 500 to 1,000 meters (1,640 to 3,280 feet) (Hoek, 1981). These types of failures are generally associated with blocky, jointed, or bedded rock that kinematically has the potential for developing gravity falls from the roof or sidewalls. Therefore, this type of instability is dependent on rock characteristics such as in situ stress, joint strength, joint condition (e.g., infilling, roughness), and joint orientation, persistence, and spacing. Other influencing factors are the excavation shape, size, and orientation.

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Stress-induced opening instabilities develop under very high stress conditions where the stresses induced around the excavation exceeds the strength of the rock mass surrounding the opening. In this type of excavation, ~~instability of the intack rock strength~~ the strength of the intact rock is important since intact rock must be fractured for the excavation instability to develop. Whereas, in a structurally controlled stress-induced opening instability, rock mass failure develops primarily along an unfavorably oriented discontinuity.

Hydraulic fracturing stress measurements and laboratory testing have been conducted to determine the in situ stress state and the strength of the host rock within the reference repository location. Preliminary results from this testing have indicated high intact rock strengths and high ratios of horizontal to vertical in situ compressive stress, with the horizontal stress estimated as approximately 2.5 times that of the lithostatic vertical stress. Evidence supportive of this stress condition at the repository depths includes core discing and borehole spalling (Rockwell, 1983).

Due to the high in situ stress ratio and the relatively ~~large~~ high stress magnitudes, ~~the development of~~ structurally controlled instabilities are not likely to predominate. ~~Therefore, considering the depth of the proposed repository (approximately 1,000 meters (3,280 feet)) and the existence of high-horizontal stresses, core discing, and borehole spalling, the potential exists for the development of stress-induced instabilities more so than structurally controlled instabilities.~~

Common methods for evaluating excavation support requirements can be categorized as empirical, numerical, and observational. The most commonly used method of providing preliminary evaluations of excavation support requirements is the empirical method, with numerical and observational methods used as verification. Numerical methods are not always reliable due to the difficulty in modeling the rock-structure interaction and estimating the appropriate rock mass strength and deformation properties. The use of observational methods will not be possible until excavation begins from the exploratory shafts.

The design of underground structures in fractured rock commonly begins with the use of one or more classification schemes developed from compilations of numerous case histories. Empirical methods have been developed from these classification schemes to estimate rock support or reinforcement requirements based on geologic, engineering, and design data. The two most commonly used classification systems are the "Q" system developed by Barton et al. (1974), and the "Geomechanics RMR" system developed by Bieniawski (1973, 1976, 1979). Both of these systems have been used to classify the rock mass quality of the Cohassett flow dense interior and estimate the rock support requirements that might be expected in the dense interior. Using the "Q" system, the rock mass quality of the Cohassett flow dense interior was classified as "very poor" to "fair." With the "Geomechanics RMR" system, the same basalt rock mass is classified as "fair" to "good." The discrepancy between these two systems

Although local structure controlled block fallouts can be expected, stress-induced instabilities are expected to control excavation support requirements.

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is due to their different definitions of what constitutes a "poor" or "fair" quality rock mass. Both methods, however, result in comparable support recommendations.

Numerical values used in the assessment of the "Geomechanics RMR" system and the "Q" system are given in Table 6-8 and 6-8 respectively. The "RMR" system rates the colonnade better than the entablature because of the high joint spacing and higher rock quality designation in the colonnade. The "Q" system rates the entablature of higher quality, therefore, requiring less rock support than the colonnade. The major cause for the lower rating for the colonnade, with Barton's system, is the massive nature of the rock (e.g., higher rock quality designation, high joint spacing) places the colonnade into the "mild rock burst" category, thereby, requiring a higher stress reduction factor than for the entablature. Note that in application of the "Q" system, Barton (1984) considered the thermal-induced stresses on the rock support requirements by increasing the stress reduction factor (see Table 6-8; Barton, 1984, pp. 69 and 72). Figure 6-12 (Barton, 1984, p. 80) shows the extreme ranges and design ranges selected by Barton to represent the expected conditions throughout the repository. Although bolt and shotcrete support requirements were estimated for all drift types in the repository (the support requirements differ because of size, shape, thermal loading, direction relative to stress field, etc.), an example of the support recommended by Barton (1984, pp. 84 and 85) for preliminary design and costing purposes is presented. For the placement rooms, panel entry, and main entry in the colonnade, Barton (1984) recommended 5 centimeters (____ inches) of fiber reinforced shotcrete for the entablature, and bolts on 0.8-meter (____ inch) spacing, plus 5 centimeters (____ inches) of fiber-reinforced shotcrete for the colonnade. Barton recommended that two to four percent of the excavation be assumed to exhibit the extreme conditions that require bolts on 0.8-meter (____-inch) spacing, plus 20 centimeters (_____ inches) of fiber-reinforced shotcrete.

Other empirical methods, such as Laubscher and Taylor (1976) methods, were also used to evaluate the Cohassett flow dense interior support requirements. Laubscher and Taylor modified the "Geomechanic RMR" system (Bieniawski, 1973, 1976) to account for the influences of weathering, stress state, and blasting on support requirements in deep underground mining experiences in South Africa. This method was considered since most of the case history studies used by Barton and Bieniawski to develop their empirical methods were from depths less than 1,000 meters (3,280 feet). The stress levels in the Cohassett flow are expected to be greater than most of the case histories used by Barton and Bieniawski to develop empirical methods; therefore, the adjustments by Laubscher and Taylor to Bieniawski's "Geomechanics RMR" might be appropriate to account for this higher stress state. These adjustments for high stress states may also be considered to evaluate the potential increase in support requirements due to thermal-induced stresses. Using the empirical method of Laubscher and Taylor results in slightly greater rock support recommendations than Bieniawski's "Geomechanic RMR" system, but the recommendations were still within the maximum bounds of the previously recommended range of rock support.

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TABLE 6-13. Geomechanics Classification of Repository Excavations in the Cohassett Flow (from Voss, 1984)

Parameter	Parameter Value				Parameter Rating			
	Entablature		Colonnade		Entablature		Colonnade	
	Low	High	Low	High	Low	High	Low	High
Intact Rock Strength (MPa)	282	301	261	315	15	15	15	15
Rock Quality Designation	30	50	70	90	8	13	13	20
Joint Spacing (m)	0.037	0.059	0.063	0.098	5	5	10	10
Joint Condition	slightly rough surfaces, separation <1 mm, highly weathered walls				20	20	20	20
Groundwater	ratio of joint water pressure to maximum stress between 0.1 and 0.2				7	7	7	7
Joint Orientation Adjustment	fair to unfavorable				-10	-5	-10	-5
Total RMR Rating	-	-	-	-	45	55	55	67
Class	-	-	-	-	Fair	-	Fair to Good	

RECOMMENDED ROCK SUPPORT

- For "fair rock"; systematic bolts 3 m (12 ft) long spaced 1.5 to 2 m (5 to 6 ft) in the roof and walls with wire mesh in the crown. Five to ten cm (2 to 4 in.) of shotcrete on the roof and 2.5 cm (1 in.) on the walls.

- For "good rock"; locally bolts 3 m (10 ft) long in the roof spaced 2.5 m (8 ft) apart with occasional wire mesh. 5 cm (2 in.) of shotcrete where required.

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TABLE 6-14. Rock Mass Quality Classification of Repository Excavation in the Cohassett Flow (from Barton, 1984)*

Parameter	Parameter Value: Entablature	Parameter Value: Colonnade	Parameter Rating: Entablature Worst	Parameter Rating: Entablature Best	Parameter Rating: Colonnade Worst	Parameter Rating: Colonnade Best
Rock Quality Designation	30-50	70-90	30	50	70	90
Joint Set Number	3 joint sets to 3 joint plus random	2 joint sets plus random to 3 joint sets	12	9	9	6
Joint Roughness Number	smooth to rough, undulating	slickoxided to smooth, undulating	2	3	1.5	2
Joint Alteration Number	softening or low friction clay mineral coatings-small quantities of swelling clay		4	4	4	4
Joint Water Reduction Factor	minor to medium inflow or pressure	minor inflow	0.66	1.0	1.0	1.0
Stress Reduction Factor	high stress, tight structure (σ_C/σ_1 = 4.6)	mild rock burst (σ_C/σ_1 = 4.7)	1 2	0.5 (roof) 1 (walls)	6	4
Stress Reduction Factor (with thermal loading)			2 3	1 (roof) 2 (walls)	8	6
Q Rating (ambient)			0.8 0.4	8.3 (roof) 4.2 (walls)	0.5	1.9
Q Rating (thermal)			0.4 0.3	4.1 (roof) 2.1 (walls)	0.4	1.2
Class (ambient)			Very poor to fair rock		Very poor to poor rock	

* Design ranges shown; Barton (1984) also states extreme values.

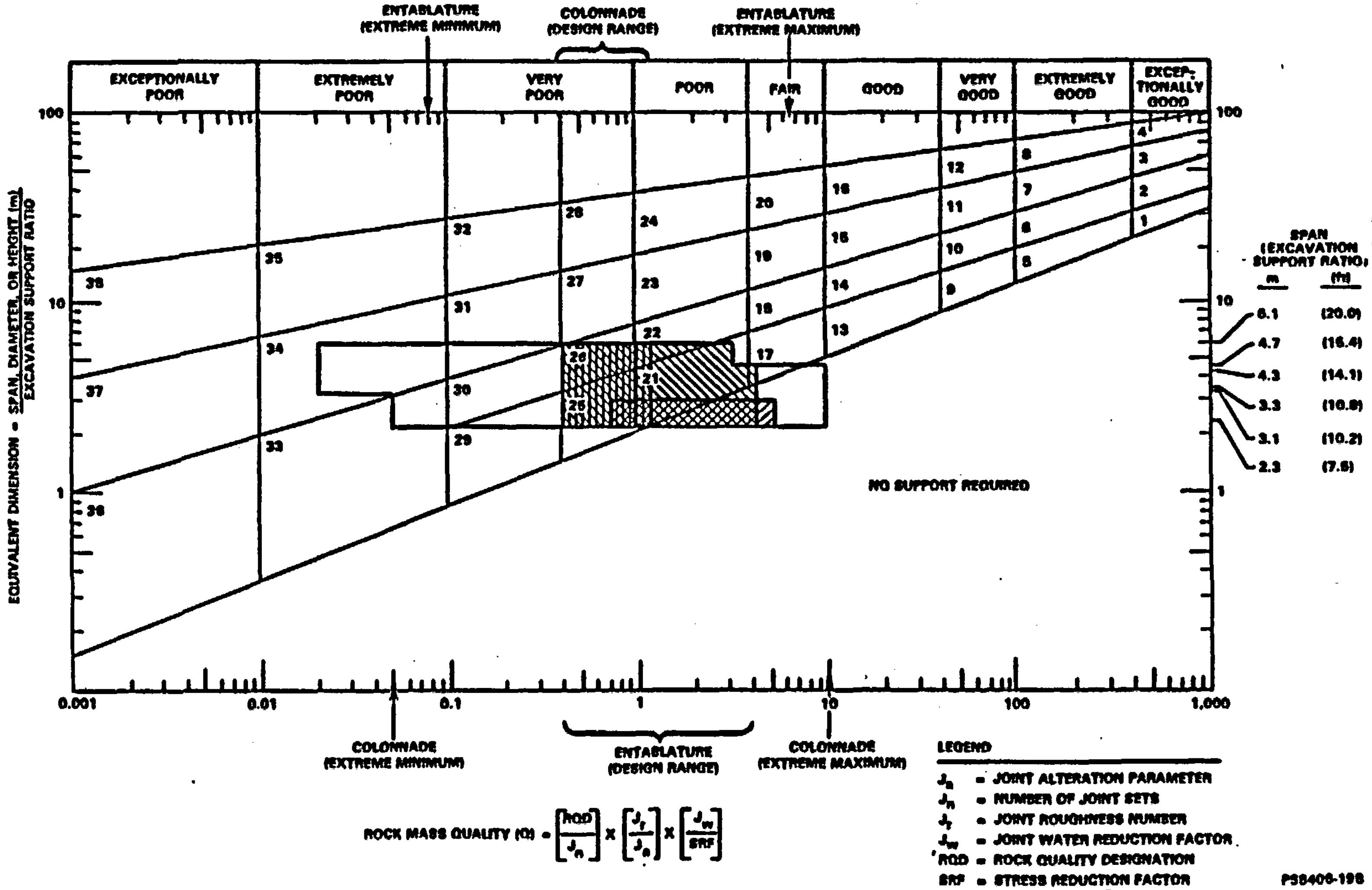

Figure 6-11. Rock support categories relevant to design range and extreme value qualities for the Cohassett flow. The left-handed shear in the large rectangle is caused by the factor 3.0 x J_n for intersections. Small innter rectangle represents wall support categories.

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It should be noted that these are empirical methods based on case history studies (of only excavation induced stresses) most of which are quite dissimilar to the rock type, temperature, and stress environment that will be encountered in a repository located in the Cohassett flow. Caution should be exercised when using these empirical methods to estimate support requirements at the reference repository location. The largest part of the data base used by Barton and Bieniawski to develop their empirical methods was obtained from shallower depth case history studies with lower stress levels than exist at the candidate horizons. Therefore, many of the case history studies, which Barton and Bieniawski used to develop their empirical methods, were probably from structurally controlled instability environments instead of the stress-induced instability environment as is expected to be experienced at the reference repository location. To confirm the empirical method estimates of rock support requirements, other methods of evaluating rock support (e.g., numerical and observational) will be used. During the proposed exploratory shafts test program, observational methods will be utilized to better evaluate and confirm support requirements.

Thermal-induced stresses were included in the Barton analysis and indicated that the support requirements in the placement rooms could increase with no support upgrade expected in the main access drifts and shaft area. Any increase in support requirements due to thermal-induced stresses will be determined in relation to the repository waste panel layout design and container placement density.

The potential for mild rock bursts cannot be discounted and is addressed in the disqualifying statement (see Subsection 6.3.3.2.10). However, the type of rock burst expected in the low-extraction ratio excavation planned for the repository is described as spalling or slabbing, that effects a small volume of rock. This type of event can be controlled by rock bolts with enlarged bearing plates (Barton, 1984, p. 81), bolts applied immediately after excavation (Saito et al., 1983, p. ___), and (or) fiber-reinforced shotcrete (Barton, 1984, p. 85). All these support categories are within the range of the recommended support category suggested by Barton (1984) and estimated by Voss (1984) from the "RMR" system. Hence, excessive support is not considered necessary to ensure safe repository construction, operation, and closure.

6.3.3.2.5 Potentially adverse condition

"(1) A host rock that is suitable for repository construction, operation, and closure, but is so thin or laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility."

Based on available data, the preferred candidate horizon (Cohassett flow) should provide a sufficiently thick and laterally extensive host rock to allow sufficient flexibility in selecting the configuration and location of the underground facility. The option to select from four candidate horizons (Rocky Coulee, Cohassett, McCoy Canyon, and Umtanum flows) provides further flexibility at depth when selecting a repository

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host rock horizon. Therefore, this potentially adverse condition does not exist at the reference repository location. Refer to Subsection 6.3.~~1.3.5~~ 3.2.3 for the details addressing this potentially adverse condition.

6.3.3.2.6 Potentially adverse condition

> "(2) In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility."

Based on preliminary investigations, the need for engineering measures beyond reasonably available technology are not expected in the construction of the repository shafts and underground facilities ~~(Rockwell, 1984w)~~. All geologic and hydrologic conditions known to exist at the Hanford Site have previously been encountered in mining or civil excavation sites, although all conditions have not been encountered at any one particular project setting. Because of the long-term requirements for the repository operating life and postclosure constraints, some excavation and support methods may require either testing or development to suit the needs of the repository in an optimum manner. All expected testing or development needs are not considered to be beyond reasonably available technology. Major factors that must be or are currently being addressed are presented independently for shafts and underground facilities. Many of the constraints to the methods discussed are nontechnical issues that are related to cost and schedule of repository construction. Excavation and testing of the exploratory shafts will provide additional information by which the preliminary information can be more definitively evaluated.

Various alternative methods of shaft excavation have been considered during conceptual design of the repository. These alternatives included:

- Ream and slash.
- Blind hole mechanical excavation.
- Drill and blast.
- Blind hole drilling.
- Combination blind hole drilling (in the upper formations) and drill and blast .

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The ream and slash techniques are not considered technically feasible and have been eliminated from consideration due to inherent ground-water inflow and bottom access contraints. Blind hole mechanical excavation has also been eliminated from consideration as it requires equipment development that is considered to be beyond reasonably available technology. Both drill and blast and blind hole drilling are considered to be technically feasible in the size range to 4.6 meters (15 feet) in diameter and to an approximate depth of 1,312 meters (4,000 feet) expected for a repository. A combination of drill and blast and blind hole drilling is not being considered at this time as they do not [redacted] a significant technical, cost, or schedule advantage. The alternative selection between drilling or drill and blast is largely based on nontechnical considerations, including safety, cost, and schedule.

Drill and blast shaft sinking methods have been considered during the conceptual design stage. The methodology of construction would incorporate known technology, including standard controlled blasting techniques, mucking procedures, and concrete lining furnished with a steel membrane for watertightness. Ground-water control may require drilling of boreholes from the surface, or perhaps the shaft interior to allow grouting, freezing, or pumping of the aquifers in advance of excavation. These techniques are considered to be within the state-of-the-practice of the industry. However, blind hole drilling has been selected in lieu of drill and blast methods. Technical advantages in areas that include: the accuracy requirements of drilling the small-diameter freeze or grout holes, freezing durations, rock wall damage due to blasting, and the safety of the underground personnel favor drilling over the drill and blast alternative. Nonetheless, drill and blast shaft sinking methods are technically feasible.

Blind hole drilling has been selected as the most viable alternative shaft excavation method to be applied to the Hanford Site geologic setting. Since no deep large-diameter shafts exist on the Hanford Site to provide first-hand experience, the preliminary conclusion that blind hole drilling technology is reasonably available has been established by review of: (1) geotechnical information defined by the ongoing studies, (2) extensive and successful ongoing (small-diameter) drilling program, and (3) experience gained from other blind hole drilling projects where constraints, similar to those which may be encountered during shaft construction at the reference repository location, have been overcome. Major factors supporting blind drilled shafts include:

- A drilled shaft will produce a minimum of disturbance to the rock immediately adjacent to the excavation (Kelsall, 1982; Cottam, 1983).
- The projected shaft construction rate will be greater than for other approaches considered (RKE/PB, 1984).
- The drilling and lining method has been previously applied to overcome artesian hydrologic conditions (Hunter, 1983; Presley, 1981).

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- Blind shaft drilling precludes the need for personnel underground until shaft construction is completed, thus, providing a significant safety ~~attribute.~~ factor.

The excavation of the exploratory shafts will provide the information needed to demonstrate the viability of blind shaft drilling for repository construction at the reference repository location. Studies have been conducted to assess the potential occurrence and impact of geologic hazards for excavating the exploratory shafts, including a comprehensive analysis to assess constraints to shaft drilling (Morrison-Knudsen Co., Inc., 1984a; Webster, 1984). Studies and experience from drilling large-diameter shafts at other sites indicate that the potentially constraining factors include:

- Jamming or lodging of the downhole tools due to slabbing or spalling of the wall rock.

- High inflow of ground-water; or conversely the loss of drilling fluid circulation.

- Capacity ~~Capability~~ of the rig or tools to meet the ~~considering~~ shaft conceptual design dimensions.

- Accurate alignment of the hole.

- Assure adequate rock stability during installation of the liner.

- Prevention of water movement along the ~~Grouting and sealing of the~~ shaft wall/liner annulus.

Experience from other sites indicates that problem zones encountered during ~~by~~ drilling small-diameter borings are generally analogous to the problem zones that can be expected from the larger blind drilled shafts. These analogies are not completely accurate ~~necessarily direct correlations~~ because many different conditions can affect ~~impair~~ drilling at any site. Scaling factors between the shaft size and

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geologic conditions (e.g., presence of joints or discontinuities) cannot be completely understood prior to site specific excavation; which is an inherent risk to any shaft excavation regardless of techniques or rock type.

Since the inception of geotechnical investigations for the Hanford Site, in excess of 80 coreholes and rotary drilled boreholes ranging in size from 7.6 to 44.5 centimeters (3 to 17.5 inches) have been completed. More than 30 coreholes have been drilled to depths in excess of 1,148 meters (3,500 feet) (Myers et al., 1981; Rockwell, 1984x, 1984y, 1984z). The information provided by this drilling activity has established a data base that has allowed drilling on the Hanford Site to progress and engineering assessments to be established.

The reference repository location has been the focus of concentrated drilling activity during the past three years. During this period more than 4,268 meters (14,000 feet) of core drilling and 8,232 meters (27,000 feet) of rotary drilling have been completed with no major complication or the loss of a borehole (Rockwell, 1984x, 1984y, 1984z). This drilling experience provides evidence of the geologic situation that must be successfully addressed during construction of the repository shafts. Recognizing the difficulty in extrapolation between small-diameter boreholes and large-diameter shafts, the high degree of success in drilling on the Hanford Site is a positive indication that drillability, hydrologic conditions, and stability concerns can be successfully overcome.

Corehole drilling in the reference repository location has encountered discing of the cored rock. The core discing phenomena has not presented a problem to the drilling activity except for minor problems such as jamming of the core barrel. This is not a problem directly applicable to fragmentation of the rock by rotary drilling methods since they do not include a core barrel. However, the influence of a high, anisotropic stress field that may be contributing to the discing is a concern that must be addressed. It is believed that stress relief may result in spalling of the borehole walls. Minor deterioration of the existing boreholes on the Hanford Site has been observed, but has not resulted in the bridging or collapse of any of the boreholes. Evidence to date indicates that once stress relief has occurred the borehole walls stabilize. This evidence includes continued testing of the boreholes that frequently requires reentry with downhole equipment and instrumentation. As a precautionary measure, a tri-cone roller bit of borehole gauge is first lowered into the hole for cleaning prior to instrument installation. From past experience the clean out tools pass to the bottom of the boreholes unobstructed. A small amount of fill is frequently present in the bottoms of the holes. This material is primarily due to the long-term deterioration of the drilling fluid or mud that cakes on the borehole walls and eventually sloughs and falls to the bottom of the unlined hole.

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During shaft drilling, hole instability is largely mitigated by the drilling fluid that exerts greater than hydrostatic pressure against the hole walls. This pressure provides a means of temporary support prior to installation of the shaft liner. Stress relief or structural failures that may occur ~~that~~ could result in spalling of large wedges or blocks of rock ~~that are~~ dislodged from the shaft wall which could ~~and~~ fall into the fluid filled hole. The blocks of basalt may break off beneath, along side of, or above the downhole tool assembly. In the event that rock instability is encountered, corrective action procedures have been developed to remove the broken rock from the hole or to condition the hole, if required, prior to the resumption of normal drilling operations (Morrison-Knudsen Co., Inc., 1983a; Webster, 1984).

Drilling fluid losses have been experienced on the Hanford Site. These losses generally take place in the Saddle Mountains Basalt formation interbeds, specifically the Ellensburg formation (Rockwell, 1984y). Past on-site drilling experience has allowed the evolution of drilling fluid programs to address and avoid this constraint. Loss of circulation will be monitored by accounting for the volume of drilling fluid being used. Some losses, such as evaporation of fluid from the mud pit, will be estimated analytically. In the event that conditions indicate a loss of fluid, preventive measures such as the use of lost circulation control agents will be employed. This is a common drilling industry practice. If standard procedures such as this are not adequate in addressing this condition, the placement of a concrete plug will be used ~~relied on~~ to condition the hole and to ~~greatly~~ reduce or eliminate the loss of circulation (Morrison-Knudsen Co., Inc., 1984, 1983b).

All confined aquifers at the reference repository location can be described as artesian. None of the pressure heads encountered rise above approximately 54 meters (165 feet) below ground surface (see Subsection 6.3.1.1.6). Consequently, high water pressure effects can be adequately addressed by controlling the height and density of the column of drilling fluid in the hole. To offset the ground-water pressure and temporarily stabilize the hole wall the drilling fluid is designed and prepared prior to penetrating

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an aquifer. The location of the aquifer and the pressure anticipated will have been determined from prior drilling experience. However, the drilling fluid levels are monitored very carefully at several points to assist in minor modifications to the fluid design. As the over-balance of fluid from the shaft to the aquifer is established, a filter cake of the drilling fluid material adheres to the shaft wall in the aquifer zone, thereby reducing or preventing water movement or perturbation to the drilling progress. This commonly applied drilling industry procedure does not require significant modification for shaft drilling at the reference repository location.

The experiences at other large-diameter drilling sites establish that the drilling of 4.6-meter (15-foot) diameter shafts at the Hanford Site is not beyond reasonably available technology. Some examples of large-diameter shafts include: Summer Falls, Washington; Amchitka Island, Alaska; the Agnew Mine in Leinster, West Australia; Crown Point Mine, Grants, New Mexico; Tonopah, Nevada, and the Nevada Test Site, Mercury, Nevada (Table 6-15). Although none of these experiences replicate the geologic and design considerations of the potential nuclear waste repository shafts at the reference repository location, the accumulated knowledge of these experiences establish that reasonably available technology exists to address the expected geologic and hydrologic conditions. ~~Following each of these experiences, the operators have~~ Large diameter shaft drilling industry experience incl. documented ~~concerns and~~ constraints to the drilling operations that have resulted in rapid advancements of the ~~drilling~~ industry's technical ability. ~~to blind hole drill large diameter shafts.~~

The excavation of the exploratory shafts (see Section 4.1) will provide experience necessary for refining the design of the repository shaft drilling equipment and techniques. To address constraints to drilling the exploratory shafts, a fault-tree analysis approach was applied (Webster, 1984). The operational indicators of the exploratory shaft drilling equipment were individually critiqued considering potentially adverse downhole conditions. Comprehensive solutions are provided that address ~~each~~ conditions that might be encountered. ~~and~~ The study indicates that prevention or recovery measures are available to address the constraining events identified. The drilling parameters discussed in this analysis include: weight on the bit and total weight, rotary table revolutions per minute, rotary table torque, drilling rate, air pressure, fluid rate, fluid volume, hole alignment, and general bottom hole conditions considering return of the drilled material (Webster, 1984). As these parameters are collectively assessed, the information gained during drilling of the ES shafts will be used to refine the site specific repository drilling techniques.

Geodril, Inc., Rig. No. 32, which is expected to be used for the exploratory shafts, was used to drill the ~~above referenced~~ 3.05-meter (120-inch) diameter Tonopah shaft. Subsequent to that excavation, the rig has been primarily used in the petroleum industry for drilling of very deep holes. One of the Rig No. 32 borings was a gas well that was extended to a depth of 9,583 meters (31,441 feet) (Loffland Bros., Inc., 1974). Since the rig's manufacture in 1968, it has been modified and up~~dated~~graded and is currently rated as one of four rigs capable of drilling the

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exploratory shafts at the reference repository location (Morrison-Knudsen Co., Inc., 1983a). Independent reports have been prepared to define shaft drilling design and development needs (RKE/PB, 1984; Fenix and Scisson, 1983; Morrison-Knudsen Co., Inc., 1984). Equipment, such as Geodril Rig No. 32, can be modified to be capable of drilling repository-size shafts to depths of approximately 1,220 meters (4,000 feet) at the reference repository location. — continued no new ¶

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Table 6-15. Comparison of case history sizes to the Basalt Waste Isolation Project.

	Approximate hole diameter (in.)	Approximate depth (ft)	Rock type(s)
Basalt Waste Isolation Project	180	3,400	Basalt
(1) Nevada Test Site[a]	36-110	1,100-4,200	Volcanic tuff/rhyolite/granite
(2) Amchitka	90	6,150	Breccia/basalt
(3) Agnew	168	2,460	Schist/metagabbro/gneiss
(4) Summer Falls	90	60-80	Basalt
(5) Tonopah	120	4,750	Volcanic tuff/rhyolite
(6) Crown Point	72 & 120	2,188 & 2,243	Shale/sandstone

NOTE: 1 centimeter = 0.394 inch; 1 meter = 3.281 feet.

[a]Collectively refers to several big holes drilled at the Nevada Test Site.

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To drill a 4.6-meter (15-foot) hole, the diameter expected to be required for repository access (RKE/PB, 1984), specific modifications to the Geodril Rig would be required. An evaluation of the capabilities of Geodril Rig No. 32 is provided in Table 6-16 (Morrison-Knudsen Co., Inc., 1984). Potential ~~These~~ modifications include a larger rotary table mechanism capable of providing up to 69,150 kilogram-meters (500,000 foot-pounds) of peak torque capacity. ~~This~~ Such capacity currently exists within the industry.

Experience from drilling the Agnew mine ventilation shaft at Leinster, West Australia, provides a representative hardrock case history. This shaft was drilled to a depth of 807 meters (2,460 feet) at a diameter of 4.6 meters (14 feet). The drilling was curtailed 301 meters (918 feet) short of its intended depth of 1,108 meters (3,378 feet) after experiencing structural problems with the unique mast and rotary support beams provided with the Hughes CSD-300 drill rig. This failure was not related to torque capacity, but resulted from excessive, unanticipated lateral vibration in the rig superstructure (Richardson, 1984). The rock mass excavated was comprised of metagabbro, schist and gneiss, with compressive strength values that ranged from 207 to 407 megapascals (30,000 to over 59,000 pounds per square inch). This range of rock strength compares to the Cohassett flow, which has a mean compressive strength of 290 megapascals (42,050 pounds per square inch) and ranges from approximately 214 to 408 megapascals (31,000 to 59,000 pounds per square inch) (Rockwell, 1983b). The average torque required to drill the metagabbro and schist exceeded 27,660 kilogram-meters (200,000 foot-pounds). The Hughes rig was capable of applying 69,150 kilogram-meters (500,000 foot-pounds)) of peak torque capacity and was successful in addressing the hardrock conditions. The 328 days ~~of~~ total duration ~~operation~~ accounted for an average production rate of approximately 2.5 meters (7.5 feet) of advance per day. Some of the delays incurred resulted from inability to manufacture spare parts in the remote West Australian location. The Agnew mine had previously sunk an exploratory shaft to the same geologic horizon using drill and blast methods. This shaft excavation required nearly three years to complete and experienced difficulties resulting in the loss of 5 lives and 63 lost-time accidents. The drilled portion of the Agnew ventilation shaft resulted in one lost-time accident (Richardson, 1984). The Agnew experience not only substantiates the safety aspects of drilling, but also provides the information needed to refine designs of the rig superstructure to address vibration concerns when drilling through hard rock formations.

In addition to drilling capability, a functional repository shaft requires a liner to provide permanent ground support and to avoid ground-water intrusion. The shaft liner will be designed to withstand the potential hydrostatic pressure that might be encountered with a factor of safety of greater than 1.5. Alignment of the drill hole will be maintained during drilling to assure that the liner can be properly placed. The alignment of the drill hole is a function of the drilling operation and relies on proper tensioning of the drill string, rate of advance, and maintenance of the stabilizers, to provide a balance between the revolutions per minute and the weight on the bit to assure proper stabilization. ~~These~~ Such parameters are continually checked and analyzed against downhole alignment surveys to assure the drill hole straightness. The technology for placement of the liner ↕ page break

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(12A)

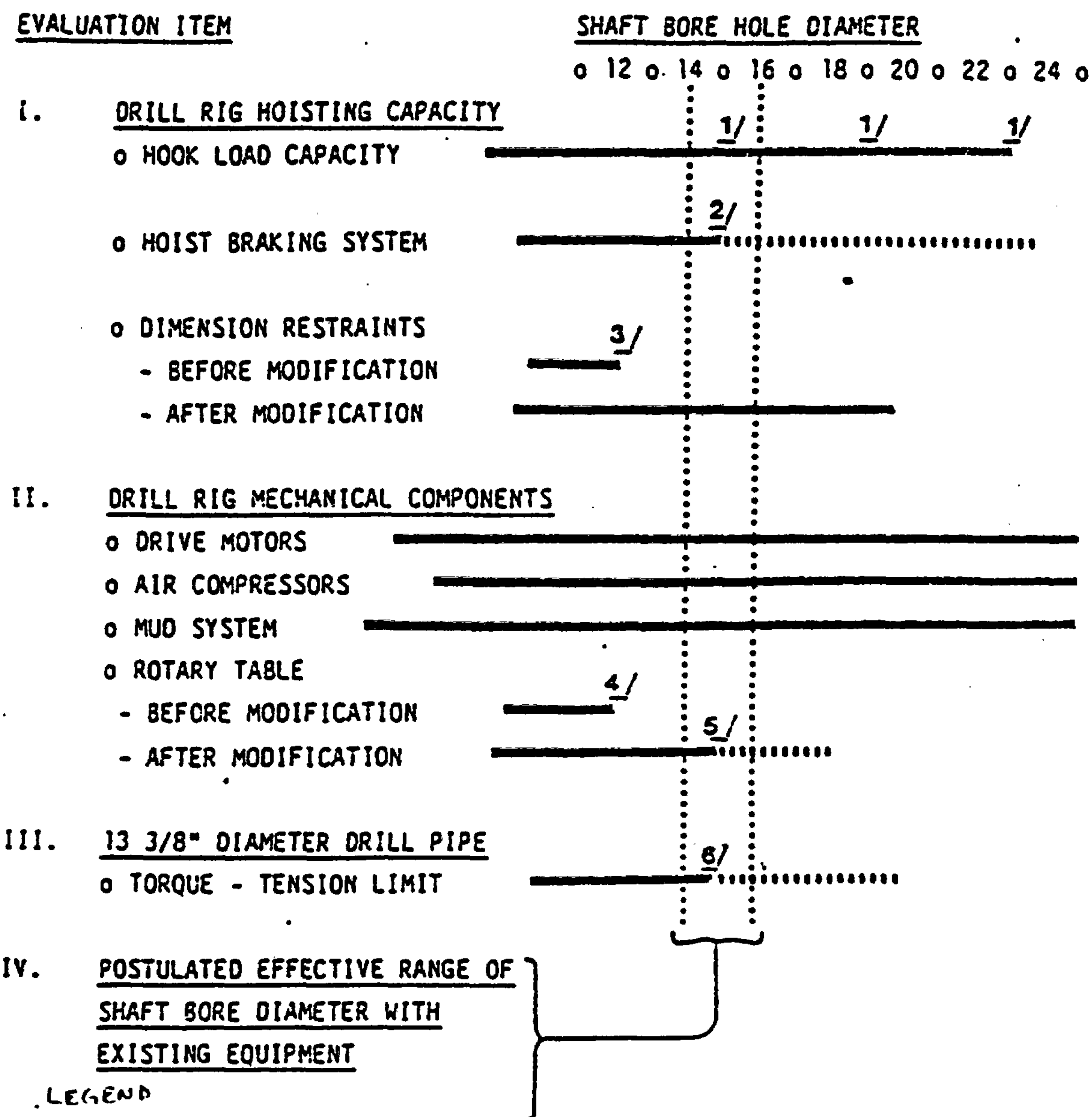
~~FIGURE X.Y. D.D.D~~
Table 6-16.

GEODRIL RIG 32

LARGE DIAMETER SHAFT EVALUATION

~~(Source M-K, 1983)~~ 1984(a) Source: Morrison-Knudsen, ~~1983(a)~~ 1984

Evaluation of major features affecting capability of Geodril Rig 32 and government furnished 13 3/8" diameter drill pipe to drill large diameter shafts.



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Solid line ——— Rated capacity

dashed line - - - - potential capacity

DRAFT ~~Figure 1~~ Foot Notes to Table 6-16 ~~Figure XX. DDD~~

1/ Rig 32 has a rated hoisting capacity of 1,555,000 pounds. At a shaft bore diameter range of 15-19 feet the hoisting capacity is adequate for a loading of 20,000 pounds per cutter; at a bore diameter range of 19-23 feet the hoisting capacity is adequate for a loading of 15,000 pounds per cutter.

2/ Current hoist braking system is adequate for loads of 1,000,000 pounds. A second braking system of equal capacity can be added if required.

3/ Dimensional restraints refer to vertical and horizontal clearance under the drilling floor of the rig. Current clearance is adequate for the Exploratory Shaft (ES). A shaft of larger diameter (i.e., larger than ES) will require raising of the substructure an additional 20-25 feet to more effectively accommodate tools and casing.

4/ Present rotary table was/is sized for the 110 inch diameter ES and has a working upper limit of 160,000 foot-pounds.

5/ Drilling of shaft(s) larger in diameter than the ES will require installation of a stronger rotary table. Geodril has received quotations on table with a working limit of 300,000 foot-pounds. This table will readily handle a 15 foot diameter shaft bore hole with adequate reserve for torque "spikes".

6/ The recommended maximum torque-tension loading of the existing ES 13 3/8 inch drill pipe (250,000 foot-pounds) is theoretically reached at about 4,000 feet with a 15 foot diameter drilling assembly. If lighter drilling assemblies can be used the effective diameter can be extended, perhaps to approximately 20 feet.

~~7/ Conversion factors - c~~

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has been demonstrated elsewhere (Table 6-17). There are concerns, however, about the rate of installation of the liner (RKE/PB, 1984). A repository-sized shaft will require liners composed of high strength alloy steel. Field welding will require lengthy controlled cool down periods to avoid microfractures in the steel adjacent to the welds. During the time that the liner is being installed, the drill hole wall is supported by the drilling fluid, and is potentially subject to time-dependent deterioration. Planned engineering studies may result in an alternate method of joining the liner segments to significantly reduce the installation time required, thus, minimizing the potential of hole deterioration.

After installation, the liner will be grouted into place through slotted grout line guides attached to the outer steel liner wall. A portland cement grout will be placed in the liner/rock wall annulus, supporting the liner in the hole and preventing the movement of water along the annulus. The gel strength, density, and viscosity contrasts between the grout and the drilling fluid in the hole during grouting will be adjusted to allow displacement of the drilling fluid by the grout. Inspection of the grout integrity and any secondary (chemical) grouting needed will be provided through inspection portholes that will be preinstalled in the liner. The need for secondary grouting is not anticipated; however, the provision to do so has been established according to industry practice (Cobbs, 1981). A chemical sealant will provide an additional barrier at selected intervals (see Subsection 6.3.1.3.5). This procedure was successfully relied on at the Crown Point shaft (Hunter, 1981). These zones will be capable of being tested throughout the repository life to confirm the integrity of the seal and to allow any needed repairs. The liner and grouting process will rely on currently available materials and technology.

The excavation technique planned for development of the repository facility is currently the drill and blast method. This technique has been in wide use for civil and mining projects and no new technology development activities will be required. Field tests to optimize equipment selection, blast hole patterns, and drill bits may be required during the exploratory shaft or early development, but this is considered standard engineering practice.

The possibility of encountering high water inflows in the proposed repository waste panel areas must be considered in evaluating this potentially adverse condition. During the construction of any underground facility, the potential can exist that a highly transmissive water-bearing zone may be penetrated that would produce an inflow of large quantities of water under high pressure. This is a very hazardous condition that must always be considered before development of any underground facility. However, no new technology is required to either seal off areas of high ground-water inflow or to pump this water to the surface.

Table 6-17. Case histories of steel and composite liners

Case number and location	Diameter (ft)		Depth (ft)	Type of liner	Comments
	Drilled	Casing I.D.			
1. Amchitka, AK	7.5	4.5	6,150	Steel	--
2. Piceance Creek, CO	10.0	8.0	2,371	Steel	Drilled to 11.75 ft, for upper 195 ft.
3. Crown Pt., NM	10.0	7.1	2,190	Steel	Also second (smaller) shaft
4. Tonapha, NV	10.0	-	4,846	Steel	--
5. Amchitka, AK	10.0	-	4,550	Steel	--
6. New Mexico	16.5	14.0	784	Steel	--
7. Beatrix, Holland	25.0	18.5	1,650	Composite	Outer shell: Welded channels Inner shell: bolted channels
8. Saskatchewan, Canada	-	18.2	2,188	Composite	Inner steel: 46 mm (1.8 in.) Outer steel: 41 mm (1.6 in.) Core: 686 mm (27 in.)
9. North Yorkshire, England	-	18.0	3,110	Composite	Inner steel: 51 mm (2.0 in.) Outer steel: 41 mm (1.6 in.) Core: 762 mm (30 in.)
10. Huckelhoven Aachen, West Germany	14.7	10.2	1,312	Composite	Outer steel shell only: 10-25 mm (0.39-1 in.) Core: 300 mm (12 in.)

NOTE: Taken from RKE/PB (1984, Engineering Study V). ~~3.048~~ 3.281 meters = ~~1~~ foot.
Composite liner is a combination of steel ~~and~~ concrete within a steel shell. Correct!

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Hydrologic studies, which are in progress as part of site characterization, indicate that this condition is not likely because of the low permeability of the basalt flow dense interior where the repository would be constructed. Although highly productive aquifers exist at the reference repository location (DOE, 1982) at hydrostatic pressures up to 9.65 megapascals (1,400 pounds per square inch) depending on depth, the low permeability of the basalt flow dense interior would prevent the rapid inflow of large quantities of ground water (Rockwell, 1983, pp. 39 through 43). However, due to the possible existence of local anomalies, specific precautions will be taken during the construction to ensure the safety of personnel. These precautions include the following:

1. During the initial breakout from shaft stations and the excavation of all openings, a forward-probing pilot or feeler hole operation will be undertaken. Long, small-diameter holes will be drilled ahead of the excavation to detect any water, gas, or other anomalies that might be present. The finalized repository design would provide flexibility so that any anomalous zone encountered during the probing operation could be further investigated prior to proceeding with excavation. Pressure grouting methods would be utilized to seal these zones, or they would be avoided, thus, providing for the safety of personnel.

2. In addition to the precautions taken to detect water-bearing zones, the repository design would provide pumping stations and sumps at the bottom of each shaft that could pump large quantities of water from the repository, if necessary. During early construction when pumping stations are being constructed, emergency pumps would be located in the shaft sump to provide the capability of removing appropriate quantities of ground water.

Although some ground-water inflow into the repository openings is anticipated, significantly large ground-water inflows will be avoided by implementing standard engineering methods, as described above. Thus, the risk to underground personnel will be reduced to acceptable levels (Rockwell, 1984c).

In situ rock characteristics that may affect opening stability and require rock support beyond that which is commonly available must also be considered. Estimates of rock support requirements were previously discussed in Subsections 6.3.1.3 and 6.3.3.2.4. Long-term performance under elevated temperatures may require development and (or) testing of rock-bolt-rock interaction, grout performance, and shotcrete/rock bonding. The development of long-term rock support systems ~~are~~ is not considered beyond reasonably available technology.

The potential of rock bursts occurring during construction or later periods of thermal-induced loadings should be considered in assessing the need for technology development. Subsection 6.3.1.3 addresses the impact of rock bursts on the support requirements and concludes that no major change or addition is required. However, should rock bursting be a more significant problem than anticipated, several existing techniques (see

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Subsection 6.3.3.2.10) are available to mitigate their effect. These methods are: destressing, microseismic source location and monitoring for prediction, and enchanced support.

The presence of a significant quantity of toxic or flammable gas in an underground facility during construction or operation could result in a potentially hazardous condition for the health and safety of personnel. However, the conditions expected at the reference repository location are not as adverse as in many existing coal mines so no new technology is required. Some ground-water samples obtained from the reference repository horizon have been partially saturated (approximately 50 percent) with methane gas (Rockwell, 1983). Methane has been produced commercially from wells in the vicinity of the reference repository location from depths of 213, 305, and 1,097 meters (700, 1,000, and 3,600 feet) (Rockwell, 1981). Ongoing exploration in the vicinity of the Saddle Mountains has indicated the presence of methane gas below the basalt mantle (Tri-City Herald, 1983). However, it is not expected that significant quantities of such gases will enter the excavated openings since they are introduced by virtue of being dissolved and (or) entrained in the ground-water inflow that, as described previously, is expected to be limited in volume. Specific precautions, however, will be taken during the design, construction, and operation of the repository to accommodate this potentially adverse condition as follows:

1. The ventilation system for the repository is designed to provide the excess flow of ventilation air required to dilute any methane gas that might otherwise be encountered and to exhaust this gas from the underground facility (Rockwell, 1984d).

2. During repository construction, methane monitoring, forward probing, pilot or feeler holes, and the sampling of ground water would be conducted to assure that the presence of methane gas would be detected.

The effect of high rock temperature (51°C (124°F)) on the health and safety of personnel working in underground facilities is a potentially adverse condition (Rockwell, 1983, p. 10), but here again the conditions expected at the repository horizon are less severe than at existing underground mines so the need for new technology is not expected. This potentially adverse condition can be mitigated by the use of refrigeration equipment and, if necessary, by the use of partially insulated vests containing dry ice. Thus, while heat stress is of concern relative ~~at~~ the health and safety of personnel, this occurrence can be mitigated by application of safety provisions proven acceptable in the general mining industry.

An additional concern is the ground-water temperature, which will be 51°C (124°F) by virtue of its storage in rock of the same temperature. Sudden outbursts of this hot water could cause injury to personnel. Suitable clothing will be provided to protect workers. Water outbursts or inundations will be avoided by exploratory drilling at the repository level prior to mining.

Based on the discussions presented in this subsection, no engineering measures beyond reasonably availably technology for construction of shafts or underground facilities are anticipated.

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6.3.3.2.7 Potentially adverse condition

"(3) Geomechanical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure."

Maintenance of the underground openings in basalt could be due to time-dependent deformation of the rock mass (creep), or thermal-induced stress increases. Existing openings in basalt (near-surface) and other openings in similar hard rock at depth suggest that excessive maintenance will not be required. Maintenance may include rebolting or reapplication of shotcrete in areas where deterioration of the support system is detected. Stress increases from the heat-generating waste will be controlled by selection of the waste-emplacment density so that excessive stress-induced maintenance will not be required. Therefore, it is expected that this potentially adverse condition is not present at the Basalt Waste Isolation Project reference repository location.

Two approaches can be made in evaluating maintenance requirements, an observational (or empirical) approach and a deterministic approach. The first assumes that experience from existing underground structures can provide guidelines for the design in question; whereas the latter assumes that a design is based on an understanding of the cause and effects of the controlling factors and that these factors can be quantified. As with many aspects of repository design, neither approach is entirely satisfactory. The empirical approach lacks comaparable case histories, while in the deterministic approach, not all mechanisms of the rock mass response and the interaction between the rock mass and rock support/reinforcement systems have been quantified.

However, some aspects of the potentially adverse condition can be quantified by observation and comparison with maintenance problems encountered at other locations. For example, case history studies in basalt (not at depth) and other hard rocks at comparable depths suggest that support systems can be installed that require minimum maintenance during construction and pre-waste-emplacement. Snoqualmie Falls hydroelectric project includes turbine chambers, head and tail race tunnels, and other railroad tunnels that were excavated in basalt in the early 1900's and require minimum maintenance. Some of these excavations have no artificial rock support. Similarly, accessways in many underground mines located at greater depths and with higher in situ stresses than for the projected repository in basalt require minimum maintenance. Examples include mines in the Coeur d'Alene mining district in Idaho and the deep underground mines in South Africa.

The basaltic rock characteristics, depth, and stress conditions suggest that a combination of rock bolts, wire mesh, and shotcrete will be adequate (see Subsection 6.3.3.2.4). Although there are concerns about the potential for slabbing or minor rock burst during construction, these should be predictable and controllable with the rock support/reinforcement system. The methods of selection of the rock support system discussed in Subsection 6.3.3.2.4 include provision for selection of the support system to meet a minimum maintenance requirement. In the Barton et al. (1974)

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method, the excavation support ratio is selected to reflect the user requirement for different degrees of safety. The excavation support ratio, which reduces the effective span, reflects construction practice in that the degree of safety and support demanded by an excavation is determined by the purpose, presence of machinery, and personnel. For example, an excavation support ratio of 1.0 is used for power stations, major roads and railway tunnels, civil defense chambers, portals, and intersections; whereas, a value of 3 to 5 can be used for temporary mine openings. A low-value of excavation support ratio is used when no roof falls can be tolerated and when a minimum of long-term maintenance is required. In selecting the suggested rock support systems for the Basalt Waste Isolation Project repository in the Cohassett flow, Barton (1984, p. 78) used an excavation support ratio of 1.0 for the main entries and intersections and 1.3 for the rooms in the storage areas. Lower excavation support ratios of 0.8 and 1.0 for these openings do not impact the support recommendations. This illustrates that the rock support systems recommended for the Basalt Waste Isolation Project repository from existing empirical evidence are expected to be conservative and, hence, require a minimum of maintenance.

The empirical methods are of little use in projecting underground maintenance during the thermal loading period because of the lack of past experience. However, the basaltic rock mass in the dense interior is not the type of rock commonly associated with long-term ground control problems as in the case of shales, evaporites (salt), and other rocks with low rock-mass qualities (as rated by the Barton et al. (1974) "Q" system, or Bieniawski's (1973) "Geomechanics RMR" system). Full-scale testing at the exploratory shaft test facilities is expected to provide the first demonstration of the effect of heating on the stability of the basaltic rock mass and provide insight relative to the long-term maintenance requirements of the repository.

The deterministic method often starts from simplified assumptions as to the mechanical and thermomechanical response of the rock mass. For example, Figure 6-13 illustrates the expected placement room and placement hole crown stresses versus time (due to increased temperatures). This illustration is based on a linear elastic analysis of a waste panel area with a placement room spacing of 76 meters (220 feet), placement hole spacing of 25.9 meters (85 feet), and an areal heat load of 172.7 kilowatts per hectare (69.9 killowatts per acre) as presented in the Conceptual System Design Description (RKE/PB, 1983). Besides the increase in stress due to temperature increases, there may also be a reduction in rock mass strength, as previously discussed in the second potentially adverse condition in Subsection 6.3.1.3.

The response of the basaltic rock mass in the vicinity of the opening is not expected to respond elastically as assumed in the analysis represented by Figure 6-13; these new uncertainties are caused by blast-induced damage and stress-induced slip along pre-existing jointing in the basalt. The rock support system ensures that the immediate rock blocks around the opening stay in place and is not intended to ensure that all the rock is maintained in an elastic condition. Hence, there is not a

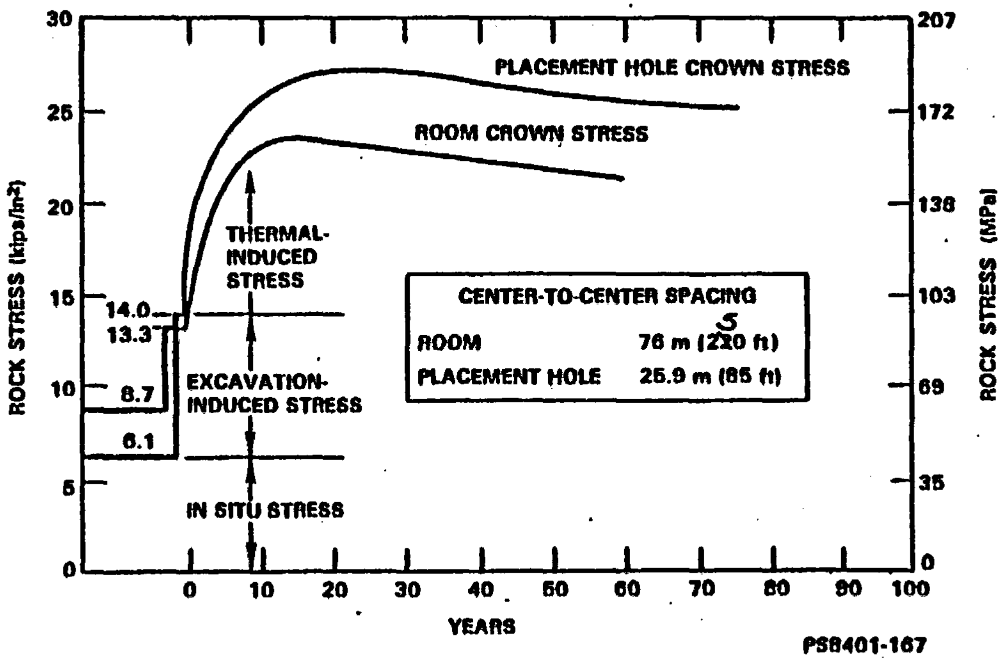

Figure 6-12. Maximum theoretical thermoelastic rock stresses with variations in time for an insitu stress ratio of 2.0 (after RKE/PB, 1983, p. 6-31).

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one-to-one correspondence between thermoelastic stresses or stress concentrations around the opening and rock support requirements. In fact, if stress relief did not occur by joint slip in the vicinity of the opening then the potential and severity of rock bursts would be significantly higher. In the rock support evaluation in Subsection 6.3.3.2.4, the expected highly fractured nature of the entablature relative to the colonnade is a favorable condition according to Barton (1984) because of the stress relief and reduced potential of rock bursts.

When estimating the standup time for an opening or the amount of cleanup and rehabilitation required to maintain a stable opening for a given period of time, the creep behavior of the rock mass becomes another important factor. Even if the stress environment is static, there may be delayed opening instabilities due to the gradual creep of the rock mass.

Insufficient information has been obtained to adequately evaluate the creep behavior of the basaltic rock mass in the repository environment. The intact basalt behaves as a brittle material and is expected to show little tendency to creep. A potential for joint creep does exist due to the amount of smectite clay present within the columnar joint clay infilling. Even though the clay infilling contains approximately 89 percent smectite clay (Long and WCC, 1984), the clay is very indurated and produces a well-healed columnar joint approximately 1 millimeter (0.04 inch) thick. This factor, combined with the degree of joint interlocking, will reduce the tendency for rock mass creep around the openings.

Additional uncertainty in evaluating rock mass creep is introduced when rock temperatures increase following waste emplacement. The temperature increase will produce higher stresses around the subsurface openings and reduce the rock mass strength. Such a condition will tend to increase the possibility of rock mass creep around the subsurface openings.

If insignificant creep or inelastic deformation develops due to the higher temperature environment, the possibility of developing a rock bursts condition should be considered. Inelastic deformation or creep around the subsurface openings will produce a softer behaving rock in this region, and redistribute stresses further from the opening as to not allow levels of high-elastic strain energy to be stored in the rock adjacent to the opening. If inelastic deformation or creep do not develop around the opening under thermal loading, then high levels of elastic strain energy may be stored, increasing the potential or frequency of rock bursts. Rock bursts would require cleanup and rehabilitation of the rock support/reinforcement system.

It is difficult to evaluate the requirement for subsurface opening maintenance based on the geomechanical properties of the rock mass and the deterministic approach. Even if further basalt creep data is obtained from laboratory and field testing, the use of this information in opening stability studies will only result in very coarse approximations of opening maintenance requirements. If excessive time-dependent deformation

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(A) Many joint surfaces show only partial coatings of infill material with basalt-to-basalt contacts. Laboratory shear strength tests (Mitchell, 1984) on natural joints indicate that basalt-basalt contacts control the shear strength of the joints, not the infill material. This factor, combined with the irregular nature of the joint surfaces and their lack of lateral continuity produces an interlocking structure that is not expected to creep.

(B) In addition, the creep rate is generally thermally activated. So, even under static stress conditions, the creep rate would increase at high temperatures.

(C) However, the creep rate in basalt for the temperature changes anticipated around the emplacement rooms (less than 150°C (302°F)) and for the stress changes designed to be acceptable for safety and compatible with the selected ground support system, is not expected to be excessive and should not require extensive maintenance.

(D) Groundwater conditions can potentially cause some maintenance problems either associated with corrosion of rock bolts, deterioration or exfoliation of shotcrete, and erosion in areas of groundwater inflow. Localized grouting and (or) drainage systems will be undertaken during construction to minimize potential groundwater inflow and its long term effect on the anticipated ground support system. Some regrouting could be required during the operating and retrievable storage phase of the repository.

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(creep) or rock bursts occur when the thermal load is developed, some subsurface opening maintenance can be expected. ~~A full knowledge of~~ actual maintenance requirements ~~will have to await completion of~~ underground excavation. Alternatively, the rock support/reinforcement system can be upgraded to minimize maintenance.

6.3.3.2.8 Potentially adverse condition

"(4) Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation."

Based on preliminary data, no major safety hazards or retrieval problems are expected due to chemical- or radiation-related phenomena. Thermal-induced fracturing on various scales, and hydration and dehydration of thin infillings in joints are all possible, although proper selection of container placement locations and densities, performance monitoring methods, rock support/reinforcement systems, and borehole liners will limit the effects on safety and retrievability. Further investigations will be required to adequately assess the effects that any thermal-induced fracturing will have on safety and retrievability. However, since thermal testing has not been conducted at depth, it is assumed that this potentially adverse condition is persent at the reference repository location. Refer to Subsection 6.3.1.3.6 for the details addressing this potentially adverse condition.

6.3.3.2.9 Potentially adverse condition

"(5) Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems."

Geologic features that could compromise the safety of repository personnel because of water inflow or construction problems have been identified in boreholes and (or) outcrops. Therefore, it is assumed that this potentially adverse condition exists at the reference repository location.

Stratigraphic or structural features known to occur in basalt flows (see Subsection 3.3.2.1), must be evaluated with respect to their potential effect on the safety of repository personnel. Brine pockets and active dissolution fronts do not exist in a basalt medium (see Subsections 6.3.1.1.12 and 6.3.1.6). Listed below are basalt flow geologic features that may compromise the safety of the repository construction and operation:

- Flow-top breccias, resulting in roof stability problems and water inflow.

- Pillow palagonite zones or other structures of flow bottoms, resulting in water inflow into drifts or potential invert instability.

- Spiracles, faults, shear zones, or other local discontinuities traversing the basalt flow, with or without connection to the nearest aquifer(s), resulting in potential water inflow or stability problems.

- Vesicular or brecciated zones (sheet, column, or chimney) within the flow interior, resulting in possible water inflow or stability problems.

- Nearly horizontal, platy fracture zones, resulting in possible local roof instabilities.

- Columnar fans, resulting in possible roof instabilities.

- Zones of low rock strength, higher than expected stress levels, or otherwise adverse conditions, resulting in potential local stability problems.

Penetration of flow tops and vesicular zones may produce roof instabilities and water inflow due to the lower strength and higher hydraulic conductivity of these intraflow features of basalt. Flow-top rock strengths are only approximately 20 percent of the dense interior strengths; vesicular strengths are only approximately 55 percent. Reported hydraulic conductivities of the host rock dense interiors are less than 10^{-11} meters per second (10^{-6} feet per day). Most flow tops have hydraulic conductivities between 10^{-4} and 10^{-9} meters per second (10^{1} and 10^{-4} feet per day). These expected low hydraulic conductivities for flow interiors should not produce water inflows that would be a safety hazard to personnel.

Other possible basalt flow features, such as pillow palagonite zones and columnar fans, have not been identified in the Cohassett flow within the reference repository location. Pillow palagonite zones have not been encountered in Grande Ronde Basalt penetrated by boreholes within the Pasco Basin (Long and WCC, 1984, Vol. I, p. I-135). Pillowed zones have been identified in the base of the McCoy Canyon flow along the Columbia River north of the Pasco Basin, where it thickens to as much as one-half the total flow thickness (Long and Davidson, 1981, pp. 5-1 through 5-55). The significance of pillow zones is that they are likely to be more permeable than either dense interiors or nonbrecciated flow tops and possibly produce a water inflow problem.

Columnar fans have been identified in all the candidate horizons (Rocky Coulee, Cohassett, McCoy Canyon, and Umtanum flows) in outcrops surrounding the Pasco Basin. These same geologic features have not been identified in any boreholes. Areas of structurally controlled, stress-induced, opening instabilities may develop in areas where these fans are penetrated.

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Localized opening instabilities may also develop in the roof if horizontal, platy fractures are encountered. Such geologic features have not been identified from the boreholes but have been identified as tectonic features in the Cohassett flow at Sentinel Gap (Long, 1978, p. 28). Other horizontal and vertical tectonic features have also been identified in the Grande Ronde Basalt at Sentinel Gap. These features are associated with anticlinal ridges and are not expected to be found in the synclinal troughs within which the reference repository is located.

If stratigraphic or structural features are encountered that may compromise the safety of personnel, it is recommended that a flexible design be used such that the repository waste panels can be relocated in more geologically favorable areas. As previously described in the first favorable condition statement in the section, exploratory drifts, geophysical methods, and horizontal and vertical feeler boreholes may be used to identify any unfavorable geologic features. The flexible design of the repository will allow for waste panel relocation away from these unfavorable areas.

6.3.3.2.10 Disqualifying condition

"The site shall be disqualified if the rock characteristics are such that the activities associated with repository construction, operation, or closure are predicted to cause significant risk to the health and safety of personnel, taking into account mitigating measures that use reasonably available technology."

Available geomechanics data obtained to date from laboratory, field, and in situ testing, and case history studies of similar underground construction projects suggest that the effects of potentially hazardous conditions on the construction, operation, and closure of a repository at the reference repository location is not expected to cause significant risk to the health and safety of personnel. This takes into account mitigating measures that use reasonably available technology. Therefore, the available evidence does not support a finding that the reference repository location is disqualified.

A preliminary assessment of excavated opening stability has been performed utilizing both analytical techniques and empirical methods. Using measured rock strength and in situ stresses, numerical analyses were performed to determine repository opening shapes and spacings that result in acceptable rock stresses. It is difficult, however, to deduce the degree of roof support required from these analyses. Therefore, empirical methods for roof support determination were used (Barton et al., 1974; Bieniawski, 1973; Hoek, 1980). These methods (developed from previous field experience), widely used in the underground construction industry, relate various parameters associated with rock quality to the degree of roof support required. The results of this assessment suggest that roof support requirements in the reference repository horizon would vary from spot rock bolting to the use of pattern tensioned rock bolting with wire mesh and shotcrete. In actual practice, roof support requirements in different areas of the repository will vary depending on local rock

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~~These~~ The results of these assessments indicate that the ground conditions will require some form of artificial support. The degree of support will vary with location, shape and function of each opening but all proposed openings should be constructable without causing significant risk to the health and safety of personnel. The recommended rock support requirements differ depending on the method used and the ~~intra flow~~ intraflow structure, but both Bieniawski and Barton's methods indicate either bolting or shotcrete or a combination of both will be required (see subsection 6.3.3.2.4).

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~~conditions and the period of time that the opening would be routinely~~ excavation ~~occupied by operating personnel~~. These empirical methods do not apply directly to the stability of excavated openings and related ~~roof~~ support when the rock is heated by emplaced nuclear waste. However, by application of rock thermal property data and stress information determined from the use of analytical techniques, an estimate of the degree of opening stability and the roof support required can be made. These results suggest that potential underground instabilities can be mitigated by available roof-support technology during the repository construction phase, as well as during the operational phase. In situ testing will be required to confirm these predictions. INSERT 1

A phenomenon associated with opening instability is rock bursts, not only in the roof, but also in the walls of the opening. Rock bursts can result from localized high-stress conditions and cause sections of the roof and walls of the opening to be explosively ejected. The potential for rock bursts represents a personnel safety concern. Case history studies and analyses suggest that severe rock bursts would generally not occur in the reference repository horizon. INSERT 2 However, in the event that mild rock bursts are experienced during excavation of repository openings, remedial actions utilizing available technology could be taken to mitigate the consequences of their occurrence and thereby minimize risks to the safety of personnel. A microseismic monitoring system will be used in conjunction with other performance monitoring techniques in an attempt to predict ~~detect~~ rock bursts ~~prior to their~~ occurrence. ~~and allow for early evacuation of personnel from the affected area.~~ INSERT 3 Remedial actions might include destressing the rock near the face of the opening by blasting the zone of highly stressed rock with a small charge of explosive, and reinforcing the rock with tensioned rock bolts (Karwoski et al., 1979, pp. 1 through 47; Saito et al., 1983, p. D206).

While some water inflow into excavated openings is anticipated, the volumetric flow rate is expected to be minimal based on current knowledge. Water inflows could occur if the excavations encountered local anomalies; however, directional borehole probing prior to excavation should minimize this possibility. The presence of methane in the openings could occur by virtue of being introduced with any water inflow. Adequate ventilation will mitigate these hazards. Heat stress on personnel due to high rock temperature could be controlled by proper ventilation. Mitigating measures can avoid significant risk to operating personnel.

Each of these potentially hazardous rock characteristics is discussed more fully below.

6.3.3.2.10.1 Excavated opening instabilities. Three methods are commonly employed to assess the stability of excavated openings and to estimate roof support requirements. These methods include (1) analytical techniques, (2) empirical methods, and (3) monitoring and observation. All three methods are expected to be employed at the reference repository location to assess roof support requirements.

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However, by selection of the waste emplacement density and the rock support system, adequate protection of health and safety of personnel can be ensured. Application of the empirical techniques to the proposed waste emplacement configuration (waste emplacement density described in Section 5.1) Barton (1984) results in no significant change in rock support requirements even though the thermoelastic-induced stresses add up to 50% of the existing horizontal stresses.

INSERT 2

The empirical method of Barton (1973) places the BWIP repository in the Cohassett flow in only the "mild rock burst" conditions even for the placement rooms under thermal loading.

INSERT 3

Remedial actions might include destressing highly stressed rock by blasting (Karwoski et al., 1979, pp. 1 through 47), reinforcing the rock with tensioned rock bolts (Saito et al., 1983, p. D-206), or supporting the rock by using fiber-reinforced shotcrete (Barton, 1984).

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Analytical techniques generally rely upon numerical models to estimate the total stress acting on the rock mass. Total stress includes in situ stress, excavation-induced stress, and the thermal-induced stress resulting from heating of the rock by emplaced nuclear waste. In order to assess the stability of an excavated opening, the total stress acting upon the rock is compared to the strength of the rock mass. Roof support requirements are estimated from the results of this comparison. At the present time, analytical techniques are of limited utility for estimating repository roof support requirements for the following two reasons:

1. Reliable estimates of rock mass strength within the reference repository horizon are not available, but must be inferred from tests on intact rock samples in the laboratory. Due to the closely spaced and interlocking nature of the basalt joint system, estimates of rock mass strength from laboratory tests on intact rock samples are subject to considerable error. Rock mass strength cannot be fully assessed until the exploratory shafts are completed and extensive geomechanics testing is conducted within the reference repository horizon.

2. Analytical techniques are of limited utility in estimating roof support requirements due to the difficulty encountered in modeling the interaction between the rock mass and the roof support system. The roof support system, for example, might consist of rock bolts (long steel rods) cemented along their entire length with grout (cement) into holes drilled from the excavated opening into the surrounding rock. The rock bolts tend to pin blocks of intact rock together and thereby "stiffen" the roof and walls of an excavated opening. At the present time, analytical techniques are being developed to assess excavated opening stability and to further assist in the determination of required roof support using empirical methods.

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Empirical methods historically have been developed by observing the stability of openings under a wide range of conditions and relating this stability to rock characteristics. The adequacy of a specific roof support method for a rock of given quality is inferred from the stability or instability exhibited by the opening over an extended period of time. Empirical methods are generally employed as a first rough approximation of rock quality and the associated roof support requirements. and support requirements

Two different empirical methods (the Geomechanics Classification System (Bieniawski, 1979, pp. ___) and the "Q" System (Barton et al., 1974, pp. 189 through 236)), and laboratory and field test data have been utilized to assess rock mass quality within the reference repository horizon ~~(Rockwell, 1984a). The results of this assessment suggest that roof support requirements in the reference repository horizon would vary from spot rock bolting to the use of pattern tensioned rock bolting with wire mesh and shotcrete~~. In actual practice, roof support requirements in different areas of the repository will vary depending on local rock conditions and the period of time that the opening would be routinely occupied by operating personnel. A final determination of required roof

INSERT 2

(see subsection 6.3.3.2.4, Barton 1984, and Voss 1984)

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Analytic techniques are used to assess stress and deformations around openings and are used primarily to select room shapes, nuclear waste emplacement configurations and to assess overall room stability. Analytical techniques are not sufficiently developed to be used directly in the selection of specific rock support components but the analysis indicates support requirements.

INSERT 2

Application of the empirical techniques of Barton et al (1974) and Bieniawski (1979) by Barton (1984) and Voss (1984) respectively, presented in ~~Section 6.2~~ Subsection 6.3.3.2.4, indicate either bolts, shotcrete or a combination of the two.

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support in the repository would be made from information obtained during the exploratory shafts tests and from observations of local rock characteristics.

The empirical methods for support estimates were not based on case histories involving thermally-induced stresses and therefore have no specific provision for examining heated rock masses. However, Barton (see Table 6-B in Barton, 1984, pp. 69 and 72) analyzed the case of thermally induced stresses on rock support requirements by increasing the Stress Reduction Factor in the "Q" System approach. The result was that support requirements for the emplacement rooms increased, but still consisted of a rock bolt and shotcrete system. No support increase was estimated for main access drifts and the shaft area. A better prediction of the degree of support required will be possible during exploratory shaft facilities excavation and the performance of in situ thermal tests.

Monitoring and observation of excavated opening stability will be undertaken when the exploratory shafts are completed and access to the reference repository horizon is obtained. Direct observation of the rock mass behavior and the roof support system under a variety of conditions will be employed as a means of confirming the preliminary predictions made using the analytical techniques and empirical methods discussed above. These observations will include the as-excavated condition of the opening as well as the heated condition.

6.3.3.2.10.2 Rock bursts. A hazard that might be encountered during excavation of repository opening is a rock burst. A rock burst can occur in a highly stressed, brittle rock when stored energy in the rock mass is suddenly released. A high-stress environment and brittle rock condition in the reference repository location are indicated from the occurrence of core discing (Lehnhoff et al., 1982, p. 1) and borehole spalling (Rundle and Kim, 1983, p. 8) and confirmed by hydrofracturing test results (Kim and Haimson, 1982, pp. 54 through 58; Rundle and Kim, 1983, p. 10). Thermal-induced rock stressed might also increase the potential for rock bursts.

Core discing is a phenomenon in which rock cores recovered from a borehole self-fracture into a series of thin discs, similar in appearance to a stack of poker chips. Core discing is normally associated with high levels of in situ stress. Core discing has been observed in boreholes at the Hanford Site and at various depths.

Borehole spalling is a phenomenon describing the appearance of the wall of a vertical borehole in which wedge-shaped failure zones form on the opposing sides of the borehole wall and the rock in these zones spalls. Borehole spalling is normally associated with high levels of in situ stress. It has been observed in several boreholes at the Hanford Site.

Hydrofracturing is a method for in situ stress measurement from a borehole and involves fracturing a sealed-off segment of a borehole by pressurizing it with water. Although this technique has some uncertainty

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associated with the data interpretation, it is the only currently accepted method for measuring in situ stress from the surface. Hydrofracturing tests at the candidate repository horizons have been performed in four boreholes at the Hanford Site. Test results indicate a horizontal-to-vertical stress ratio [redacted] ~~More hydrofracturing tests will be performed from the surface, and a determination~~ of in situ stresses by the overcoring method will be obtained during the exploratory shaft test program.

Case history studies show that severe rock bursts are generally not associated with the excavation of isolated openings but are commonly related to excavation in areas overstressed by adjacent openings or with high rock extraction ratios (Blake, 1972, pp. 1 through 64). However, rock bursts have been experienced in single drift headings (Saito et al., 1983, pp. D203 through D206). These rock bursts are generally associated with excavation into a highly stressed area and may occur at the face of an opening or at a point further back from the face where the stress concentration around the opening reaches a maximum.

The occurrence of severe rock bursts is generally not expected in the reference repository horizon for two reasons:

1. The rock extraction ratio (the percent of rock excavated) in the current repository design is less than ~~6~~ percent and is, therefore, far below the rock extraction ratios encountered in typical mining operations where rock bursts have been observed. Thus, the stress effect of one repository opening on an adjacent opening is minimized.

2. ~~Based on engineering judgment~~ it is expected that the closely spaced and interlocking nature of the basalt joints will tend to dissipate strain energy around openings through deformation in a nonviolent fashion, resulting in a reduced likelihood of rock bursts. In the event that mild rock bursts are experienced during excavation of repository openings, remedial action could be taken to mitigate the consequences. The methods commonly employed to mitigate rock bursts include: destressing the rock near the face of the opening by blasting the zone of highly stressed rock with a small charge of explosive, and reinforcing the rock with tensioned rock bolts, with or without wire mesh (Karwoski et al., 1979, pp. 1 through 47).

Deep underground openings in rock other than basalt that have evidenced core discing and borehole spalling have been safely excavated (Saito et al., 1983, pp. D203 through D206; Bai et al., 1983, pp. D271 through D273).

In summary, while the potential for rock bursts represents a concern relative to the safety of personnel, the potential for such rock bursts cannot be fully assessed until the exploratory shafts are completed and experience is gained in the excavation of openings in the reference repository horizon.

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6.3.3.2.10.3 Water inflow under high pressure. During the construction of underground facilities, the potential exists that unintentional excavation into highly pervious, localized zones might produce hazardous conditions if the inflow of large quantities of water occurs under high pressure. Hydrologic studies, which are in progress as part of the site characterization, have found high water pressure (e.g., approximately 9.65 megapascals (1,400 pounds per square inch)) present in the vicinity of the candidate horizon. The repository will be located in a dense interior host rock of low permeability (hydraulic conductivity less than 10^{-11} meters per second (10^{-6} feet per day)) and bounded by a more permeable flow top and flow bottom. The flow top and flow bottom provide the most likely source of water inflow into the underground facilities. Geologic anomalies such as local fracture zones, faults, and thinning of the dense interior may provide a means of access for water inflow into the repository facilities (see Subsection 3.3.2.1). However, the following precautions can be implemented during design and construction to identify anomalous zones and control high water inflows if they are encountered.

1. During the initial breakout from the shaft stations and the excavation of all openings, a forward probing operation could be undertaken. Long, small-diameter holes could be drilled ahead of the excavation to detect any geologic conditions that may produce high water inflows. The final repository design is expected to be flexible enough so that any anomalous zone encountered during the probing operation can be further investigated prior to implementing water inflow control measures, or continuing the repository development in a more favorable area. In the waste panel area, pressure grouting and dewatering are methods that can be used to seal or control inflow from high water producing areas. Grouting, freezing, or dewatering can be used to seal or control inflow from high water producing areas during construction.

2. In addition to the precautions taken to detect water-bearing zones, the repository design would provide pumping stations and sumps ~~at the bottom of each shaft,~~ which could pump large quantities of water from the repository. During early construction when pumping stations were being constructed, temporary ~~emergency~~ pumps would be located in the shaft sump to provide the capability of removing appropriate quantities of water.

Implementation of these precautions are expected to improve safety and reduce risk to an acceptable level for underground personnel.

6.3.3.2.10.4 Presence of gas. The presence of a methane gas in an underground facility during construction or operation could result in a potentially hazardous condition for the health and safety of personnel. Ground water from the Grande Ronde Basalt in the reference repository location are 50 percent saturated with methane gas. At formation conditions, the gas is dissolved in the ground water at a concentration of

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approximately 800 parts per million (i.e., approximately 0.1 percent by weight). Since the methane is dissolved in ground water, the amount of gas in the underground facilities will be directly dependent on the quantities of water inflow entering the facilities.

Specific precautions can be taken during the design, construction, and operation of the repository to mitigate potential hazards due to the presence of methane. These precautions would include the following:

1. The ventilation system for the repository would be designed to provide the flow of ventilation air required to dilute any methane gas concentrations below 0.25 percent and to exhaust this gas from the underground facility.

2. Controlling or reducing water inflow into the repository to reduce methane hazards.

3. Monitoring of ventilation air for the presence of methane would be conducted to ensure that hazardous concentrations are not allowed to develop.

4. During the operational phase, inactive drifts would be either continuously ventilated or sealed with no ventilation until the drift is reopened.

5. In the event the repository is classified as a "gassy mine," equipment and operating procedures would comply with applicable State and Federal regulations.

As additional data are gathered regarding methane in the reference repository location, changes to design and monitoring methods will be made as warranted so that an acceptable degree of safety will be maintained for construction and operating personnel.

6.3.3.2.10.5 High rock temperature. The effect of high rock temperature (124°F (51°C)) on the health and safety of personnel working in underground facilities is a potentially adverse condition (Rockwell, 1984, p. 10). To ensure that this potentially adverse condition is mitigated, the following precautions and procedures would be followed:

1. A repository ventilation system designed so that the air temperature and relative humidity in the working areas could be maintained at or below 80°F (27°C) and 30 percent, respectively, in compliance with the limits set by the American Conference of Government Industrial Hygienists (Rockwell and KE/PB, 1982, p. 58).

2. Emergency egress features included in the repository design and operating procedures to evacuate personnel quickly should ventilation provisions fail.

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3. Periodic medical examinations of all personnel working in the underground facility to ensure that individual health and safety are maintained.

Thus, while heat stress is of concern relative to the health and safety of personnel, this occurrence can be mitigated by application of safety provisions proven acceptable in the general mining industry.

6.3.3.2.11 <u>Conclusion on qualifying condition</u>

The results of the preliminary studies suggest that thickness and lateral extent of the host rock should be found suitable for accommodation of the repository. The construction of the repository by currently available construction methods and technology is achievable. The stability of excavated openings is expected to be maintained without undue risk to the health and safety of personnel by using currently available mitigating measures. However, the full potential for opening instabilities and rock bursts cannot be fully assessed until underground in situ testing is completed within the reference repository horizon and more sophisticated numerical analyses are conducted. Other potentially adverse conditions, including water inflow under high pressure, the presence of gas, and high rock temperatures, are also not expected to cause undue risk. Therefore, after evaluating the present and expected conditions of the host rock, it appears that the reference repository location meets this qualifying condition.

6.3.3.3 Hydrology (Section 960.5-2-10)

6.3.3.3.1 <u>Qualifying condition</u>

"The site shall be located such that the geohydrologic setting of the site will (1) be compatible with the activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in Section 960.5-1(a)(3) to be met."

6.3.3.3.2 <u>Evaluation process</u>

Rock strength, stress field, and hydrologic conditions affect the performance of underground openings. A number of such openings have been constructed in nonbasaltic media and are operating under comparable stress field and hydrologic conditions estimated for the reference repository location. There are no such underground openings constructed in basalt (see Subsections 6.3.1.3 and 6.3.3.2). Thus, the only available information to determine the geomechanical and geohydrologic characteristic of deep basalt has been from limited in situ and laboratory tests.

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6.3.3.3.3 Favorable condition

"(1) Absence of aquifers between the host rock and the land surface."

Aquifers exist between the candidate repository horizons and the land surface; therefore, this favorable condition is not met.

The principal basalt aquifers exist within selected sedimentary interbeds and basalt flow tops of the upper two basalt formations. Within the Saddle Mountains Basalt, the Rattlesnake Ridge, Cold Creek, and Mabton interbeds are frequent sources of large ground-water quantities, in addition to flow tops of the Elephant Mountain and Umatilla Members (see Fig. 3-6). Flow tops within the Priest Rapids, Roza, and Frenchman Springs Members of the Wanapum Basalt are also known to be aquifers. Fewer aquifers appear to exist within the Grande Ronde Basalt in the northern Pasco Basin. The chemical quality of these ground waters, relative to human consumption and crop irrigation, is outlined in Subsection 6.3.1.1.11.

Within the Pasco Basin, the principal aquifers tapped by farmers for large-scale irrigation are also the sedimentary interbeds and flow tops of the Saddle Mountains Basalt and Wanapum Basalt.

As described by Gephart et al. (1983) and graphically depicted in Long and Woodward-Clyde Consultants (Long and WCC, 1984), flow top hydraulic conductivity values are heterogeneous and therefore what may be termed an aquifer in one location may not qualify as such in a second location. However, the identified aforementioned aquifers in the Saddle Mountains Basalt and Wanapum Basalt appear to be a rather common feature of the local basalt sequence. In addition, an unconfined aquifer of variable hydrologic character overlies the basalts beneath most of the Pasco Basin (see Subsection 3.1.3.2). Thus, aquifers exist between the candidate repository horizons and the land surface.

6.3.3.3.4 Favorable condition

"(2) Absence of surface-water systems that could potentially cause flooding of the repository."

The reference repository location lies above the flood plain of the Columbia and Yakima Rivers and would not be affected by flooding. A shallow flash flood potential across the southwest portion of the reference repository location exists from Cold Creek. However, any inundation into the area of proposed repository surface facilities could be controlled by routine engineering measures and would not affect repository operations. Flood waters from a 100-year peak flood do not reach any area presently considered for repository facilities. Therefore, this favorable condition exists for the reference repository location.

Subsection 3.3.1 details the flood history and potential of the Columbia and Yakima Rivers under natural and dam-failure conditions. In addition, it addresses the flash-flood potential for the Cold Creek

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watershed in which the reference repository location lies. In summary, the land surface elevation within the reference repository location ranges between 190 and 245 meters (625 and 800 feet) above mean sea level. At this elevation the reference repository location is protected from both natural flooding and dam-breach scenarios.

There does exist a potential for shallow flash-flooding of limited extent within the reference repository location. Analyses suggest that the southwest corner of the reference repository location might be inundated by a probable maximum flood in the Cold Creek watershed (see Fig. 3-30). The shallowest portions of this flood might extend into the area considered for repository surface support facilities. Using conservative data inputs, a maximum flood depth of 2.3 meters (7.7 feet) was calculated (Skaggs and Walters, 1981). This is the topographic low point within the reference repository location. Theoretically, the recurrence interval of a probable maximum flood cannot be defined. In the analyses by Skaggs and Walters, the 100-year peak stage flood was estimated to have a smaller lateral extent than the probable maximum flood. The 100-year flood was estimated to have a depth of approximately 1 meter (3 feet) above the valley floor. These waters do not reach any area considered for repository facilities. The duration of these floods would be short and present no danger to subsurface repository facilities. Some flooding is expected to cover the Route 240 roadbed, which is located along the western boundary of the reference repository location (see Fig. 3-44). However, access to the repository would be maintained from the north and east.

6.3.3.3.5 Favorable condition.

"(3) Availability of the water required for repository construction, operation, and closure."

Ample water supplies are available for repository construction, operation, and closure; therefore, this favorable condition is met.

Water quantity estimates for the repository are provided in Raymond Kaiser Engineers, Inc./Parsons, Brinkerhoff, Quade & Douglas, Inc. (RKE/PB, 1983). The average daily water demand for repository construction, operations, and surface facility support has been estimated at 2.6 cubic meters (approximately 700 gallons) per minute (Gimera, 1983). The water would be supplied to the repository from the Columbia River via either a new water line approximately 11.9 kilometers (7.4 miles) long or a pipeline from the existing water distribution system in the 200 Areas (see Fig. 3-25).

The surface flow of the Columbia River ranges between 6.1×10^4 and 2.7×10^5 cubic meters (1.6×10^7 and 7.2×10^7 gallons) per minute (WPPSS, 1981). Water usage for waste management activities in the 200 Areas of the Hanford Site is approximately 42 cubic meters (1×10^4 gallons) per minute (Rockwell, 1982). This water is withdrawn from the Columbia River along the northern portion of the Hanford Site. The general layout of the water distribution system for the 200 Areas is discussed in Summers (1975). Alternate water supplies are also available from the unconfined and confined aquifers.

Water demand from all repository operations would be approximately 6 percent of the present water usage for waste management and chemical processing activities at the Hanford Site. Excess water accumulated in the repository would be pumped to the surface and stored in retention ponds.

6.3.3.3.6 Potentially adverse condition

"Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure."

The technology to control ground water during repository construction, operation, and closure is reasonably available. Therefore, this potentially adverse condition is not projected to exist at the reference repository location. A more complete statement concerning this determination is provided in Subsection 6.3.3.2.6.

Where is the next ¶? (It was here in last draft)

6.3.3.3.7 Disqualifying condition

"A site shall be disqualified if, based on expected ground-water conditions, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure."

Current construction data, case history studies of underground construction projects, and understanding of the basalt geohydrologic environment suggest that the ground-water conditions likely encountered in basalt during exploratory shaft construction and repository construction, operation, or closure will require only available, or reasonably available, technology. Therefore, the available evidence does not support a finding that the reference repository location is disqualified.

Access shafts to the preferred candidate horizon will penetrate several aquifers (see Subsection 6.3.3.3.3). Potential ground-water inflow can be controlled using available techniques such as grouts/muds for blind bored shafts. Shaft completions across aquifers involve steel liner emplacement and grout seals (refer to Subsection 6.3.3.2.6).

The waste emplacement rooms of a repository or test rooms of the exploratory shaft will be constructed within the flow interior of the preferred candidate horizon. This flow interior is expected to have a low permeability (see Subsection 3.3.2.1.1) and, therefore, low ground-water inflow. Based on available information and understanding, water seepage into the excavated tunnels is anticipated to occur along fracture sets rather than to be uniformly distributed along the tunnel walls. Large water inflows could result from unintentional tunnel penetration of high permeable zones; however, standard borehole probing in advance of

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excavation should minimize such a possibility. Available grouting and dewatering technology can enable the safe completion of underground construction should localized zones of high permeability be encountered within a flow interior.

The specific sections listed below address the availability of engineering technology for the safe construction of shafts and tunnels under expected ground-water conditions and rock characteristics.

Sections	Topics
4.1.1.6	Exploratory shaft(s) construction.
5.1.3 and 6.3.1.3.5	Engineering technology available for repository activities.
6.3.3.2.6	In situ characteristics and conditions requiring measures beyond reasonably available technology.
6.3.3.2.9	Geologic features possibly encountered.
6.3.3.2.10	Rock characteristics related to rock bursts, water inflow, gas inflow, and high working temperatures.

Broad discussions of the range of possible rock conditions encountered and the technology available to mitigate any resulting adverse conditions are addressed throughout Subsections 6.3.1.3 and 6.3.3.2. These subsections also address the uncertainty in available knowledge regarding the existence and significance of some stratigraphic and structural features that may contribute to ground-water flow.

6.3.3.3.8 Conclusion on qualifying statement

A final conclusion on the qualifying condition for hydrology cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1).

The available evidence does not support a finding that the site is not likely to meet the qualifying condition. Major factors ~~which~~ that support this preliminary finding are summarized below:

- The reference repository location lies above the flood plain of the Columbia and Yakima Rivers and would not be affected by flooding.
- Ample water supplies are available for repository construction, operation, and closure.

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- The technology to control ground water during repository construction, operation, and closure is reasonably available.

- Ground water conditions likely encountered in basalt during exploratory shaft construction and repository construction, operation, or closure will require only available, or reasonably available, technology.

Specific undertainties related to the major supporting factors are:

- There are no underground openings constructed in basalt; therefore, the only available information to determine the geomechanical and geohydrologic characteristic of deep basalt has been from limited in situ and laboratory tests.

- There does exist a potential for shallow flash-flooding of limited extent within the reference repository location.

Another factor related to the preliminary finding is the existence of aquifers between the candidate repository horizons and the land surface. The principal basalt aquifers exist within selected sedimentary interbeds and basalt flow tops of the upper two basalt formations.

6.3.3.4 Tectonics (Section 960.5-2-11)

6.3.3.4.1 Qualifying condition

"The site shall be located in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity on repository construction, operation, or closure will be such that the requirements specified in Section 960.5-1(a)(3) can be met."

6.3.3.4.2 Evaluation process

The tectonic processes that have operated on the Columbia Plateau over the past few hundred years are the same processes expected to be operating during repository constuction, operation, and closure. The data gathered to assess these tectonic processes include: (1) stratigraphic and structural information gathered from geologic maps, interpretive cross sections obtained by direct observation at the ground surface and (or) borehole data, geophysical interpretation of magnetic, gravity, seismic reflection, seismic refraction, and magnetotelluric surveys, and (2) historical seismicity derived from published catalogs and newspapers, instrumental seismicity from records of earthquake locations and focal mechanisms.

The most current summary of the present tectonic setting ~~is summarized most currently~~ is found in a report by Caggiano and Duncan (1983). See ~~Sub~~sections ~~3.2.1.4, 3.2.1.5 and 6.3.1.7.3 through 6.3.1.7.9~~ 3.2.3 and Subsection 6.3.1.7 for additional details.

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Interpretations of the tectonic stability within the geologic setting of the reference repository location are preliminary because: (1) interpretations of subbasalt stratigraphy and structure are too sketchy to permit adequate testing of tectonic models; (2) detailed monitoring of seismicity in the candidate horizons at proposed repository depth is only beginning; (3) reconnaissance geologic mapping is complete, but detailed studies of specific structures and interpretation of geophysical anomalies in and near the area of the reference repository location are ongoing; and (4) kinematic analyses of fold development and of the relationship of folding to faulting remain to be completed.

The adverse tectonic condition that would appear to preclude development of a repository is that of an active fault (either seismogenically active or actively creeping). Tectonically active faults do not appear to be present in the reference repository location based on existing data and interpretations. If they occurred in the reference repository location, wide inactive fault zones containing large quantities of fault gouge and ground water might affect the ease of excavation and the volume of water to be pumped from an enlarging excavation. Additional rock support measures might be needed in such zone(s), but such problems can generally be accommodated during construction.

Columbia River Basalt Group volcanism ceased approximately 6-million years ago (McKee et al., 1977). The youngest flow in the reference repository location area is the 10.5-million-year-old Elephant Mountain Member of the Saddle Mountains Basalt (Myers, 1981). There are no known hot springs in or near the reference repository location, nor is the area one of high heat flow (Caggiano and Duncan, 1983). This evidence suggests that renewal of Columbia River Basalt Group volcanism is extremely unlikely during the period of construction and operation of a repository in the reference repository location. Thus, volcanism is not anticipated to be a concern in constructing a repository. Airfall ash generated during any future eruptions of volcanoes in the Cascade Range (e.g., Mount St. Helens) located approximately 180 kilometers (112 miles) west of the reference repository location, should not affect construction underground and should pose only minimal disturbance for a limited period of time for surface operations.

6.3.3.4.3 Favorable condition

"The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities."

Nuclear reactors and processing plants are currently operating on the Hanford Site. These facilities include the WNP-2 nuclear power plant that was recently licensed by the U.S. Nuclear Regulatory Commission. Since these operating nuclear facilities are near the reference repository location this favorable condition appears to be met.

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Deformation of Columbia River Basalt Group in the central plateau has been proceeding at long-term low-average rates under a regime of nearly north-south, nearly horizontal compression for at least 15-million years (Caggiano and Duncan, 1983). The pattern of folding accompanied by faulting appears to have been established during Miocene time, but an exact mechanical model of deformation has not yet been developed. It has been argued that faults are both a cause and a consequence of folding (Price, 1982; NRC, 1982c), based mostly on the spatial arrangement and geometric character of anticlinal structures. Available data do not permit determination of slip/recurrence rates on most faults; however, the pattern and timing of deformation as currently interpreted suggest that slip rates of faults during late Cenozoic time have been low. Available data have been used to determine slip rates for the Central Fault on Gable Mountain and the Rattlesnake Wallula Alignment, and these support the interpreted low rate of deformation. Using data obtained during drilling and trenching, the slip rate for the Central Fault was determined to be approximately 0.005 millimeters (0.0002 inches) per year (PSPL, 1982b). Based on tectonic models of Bentley (1980), Davis (1981), and Laubscher (1981), NRC (1982c) calculated a slip rate of approximately 0.01 millimeters (4×10^{-5} inches) per year for the RAW. This pattern of deformation suggests that earthquakes would be relatively small and recurrence rates generally long compared with active tectonic regimes such as the plate boundary regime in California. The level and distribution of instrumentally recorded earthquakes over the past 14 years support this interpretation (Rohay and Davis, 1983).

There have been numerous nuclear facilities for the processing, storage, and disposal of nuclear waste for both defense and commercial purposes at the Hanford Site since operations began in 1943 (ERDA, 1975). These nuclear facilities have been constructed and operated in a safe manner during this 41-year period.

The newest nuclear facility is the recently licensed WNP-2 nuclear power plant of the Washington Public Power Supply System. The Safe Shutdown Earthquake for this nuclear power plant is a magnitude 6.5 earthquake that occurs on the Rattlesnake-Wallula alignment at a distance of approximately 19.5 kilometers (12.1 miles) from WNP-2 at a depth of approximately 15 kilometers (9.3 mi) (NRC, 1982c) (see Fig. 3-22). The corresponding zero period horizontal ground acceleration used to anchor response spectra for this plant is 0.25 gravity. This design acceleration is less than for those nuclear plants located west of the Cascade Range in Washington and Oregon and considerably less than those for plants at Diablo Canyon and San Onofre in California.

6.3.3.4.4 Potentially adverse condition

"(1) Evidence of active faulting within the geologic setting."

This potentially adverse condition applies to the reference repository location since faults active during the Quaternary Period exist in the Columbia Plateau.

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The age of the last movement of the many faults on the Columbia Plateau remains to be determined. Faults currently interpreted to be active include the central Gable Mountain faults, which are located 9 kilometers (5 miles) northeast of the reference repository location (PSPL, 1982; NRC, 1982c), and the area of Wallula Gap eastward to the Hite fault (WPPSS, 1981a), which is located more than 80 kilometers (50 miles) southeast of the reference repository location (see Fig. 3-22). Active faulting is discussed in Subsection 6.3.1.7.4.

6.3.3.4.5 <u>Potentially adverse condition</u>

"(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 effects from recurrence of a large historical earthquake on subsurface facilities at the reference repository location are unknown. Therefore, it is assumed that this potentially adverse condition exists within the geologic setting of the reference repository location.

The maximum reported earthquake within an 80-kilometer (50-mile) radius of the reference repository location was a magnitude 4.4 earthquake on the Royal Slope, the south flank of a Yakima fold approximately 35 kilometers (22 miles) north of the reference repository location. A historically reported earthquake on November 1, 1918, near Corfu, Washington (approximately 30 kilometers (19 miles) northeast of the reference repository location) (see Fig. 2-8), is listed as a Modified Mercalli Intensity V-VI, and may have been as large as magnitude 4.5. Ground motion generated by such events at these distances from the reference repository location is not believed to have produced any significant vibratory ground motion in the reference repository location.

In developing the seismic design for the Washington Public Power Supply System WNP-2 nuclear power plant on the Hanford Site (approximately 18 kilometers (11 miles) southeast of the reference repository location) (see Fig. 3-26), a maximum possible earthquake was determined for the Rattlesnake-Wallula alignment based on its assumed capability, assumed continuous length, and type of fault. A magnitude 6.5 earthquake with a recurrence of approximately 10,000 years or more (NRC, 1982c) corresponds to a 0.25 gravity zero period horizontal ground acceleration at the WNP-2 site, and this value was used to anchor response spectra used in the design of structures, components, and facilities. This same acceleration was used in the design of the Fast Flux Test Facility on the Hanford Site (see Fig. 3-26). Because the distance separating the reference repository location from the Rattlesnake-Wallula alignment is less than the distance for WNP-2, it may be that somewhat higher accelerations might be produced at the reference repository location.

Empirical data indicate that mines and mined tunnels generally are not adversely affected by earthquakes large enough to cause damage (often severe) to surface buildings and facilities. Detrimental effects are noted only if the rupturing fault intersects the mine or tunnel. However,

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changes in the behavior of springs and in the inflow of water into mines following earthquakes suggest that some changes in ground-water flow may be brought about by fault rupture. When the site is characterized, design earthquakes and ground motions will be determined so that potential effects of both vibratory ground motion and changes in ground-water flow can be assessed.

6.3.3.4.6 Potentially adverse condition

"(3) Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity."

It does not appear likely that an earthquake larger than predicted from historical seismicity could occur on the Columbia Plateau. Therefore, it appears that this potentially adverse condition does not exist within the geologic setting of the reference repository location.

As part of licensing of the Washington Public Power Supply System WNP-2 nuclear power plant at the Hanford Site, the U.S. Nuclear Regulatory Commission concluded that the Rattlesnake-Wallula alignment (see Subsection 3.2.3.7) located along the southwestern boundary of the Pasco Basin is capable of a magnitude 6.5 earthquake along segments of the fracture. This earthquake is larger than any historical or instrumentally-recorded earthquake on the Columbia Plateau. The recurrence interval for an earthquake of magnitude 6.5 or larger was estimated to be very large (greater than at least 10,000 years) (NRC, 1982c). However, this appears conservative since the youngest observed faulted sediments along the fracture are 70,000 years old and portions of the fracture have apparently not been faulted for at least 12 million years.

6.3.3.4.7 Disqualifying condition

"A site shall be disqualified if, based on the expected nature and rates of fault movement or other ground motion, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation or closure."

Existing engineering measures could be used, if needed, in an exploratory shaft or repository, since the probability of ground motion that could adversely affect a repository in the reference repository location during the preclosure period is low. Therefore, the reference repository location is not disqualified based on this preclosure tectonic disqualifying condition.

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The low probability of ground motion is based on the following evidence which has been summarized from discussion on tectonic disqualifying conditions:

- Seismicity of the Columbia Plateau is low to moderate (see Subsection 2.1.1.3 and Section 3.24).
- The recurrence rate of moderate-size earthquakes is long (see Subsection 6.3.1.7.5).
- The reference repository location was sited away from areas of known or suspected faults (see Section 2.2).
- The potential for diapirism or igneous activity is low (see Subsection 6.3.1.7.3).

6.3.3.4.8 Conclusion on qualifying condition

A final conclusion on the preclosure qualifying condition for tectonics cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3.2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1). The available evidence supports a finding that the site meets the qualifying conditions and is likely to continue to meet the qualifying condition.

This preliminary interpretation is based on the rate, pattern, and timing of deformaion of Columbia River basalt, the low to moderate seismicity along with the aerial distribution and size of earthquakes, the low heat flow and unlikely renewal of basaltic or other volcanism in the central plateau, and the likely ability of engineering design and construction techniques to deal with the characteristics of the natural environment. Studies used to arrive at this preliminary interpretation are summarized in Caggiano and Duncan (1983) and include stratigraphic and structural investigations, seismic monitoring and seismological investigations, geophysical investigations and anomalies, and geodetic monitoring. The preferred interpretation is that deformation is following a pattern established at least 15 million years ago in the Miocene in which structures have been developing under nearly north-south, nearly horizontal compression at long term, low average rates of strain. The pattern of developing structural relief during eruption of Columbia River basalt from at least 14.5 to 10.5 million years ago (which is supported by the decreasing dip of progressively younger sedimentary strata on the flanks of anticlinal ridges) apparently continues to the present. Projection of the growth rates of major anticlinal folds in the Saddle Mountains and Rattlesnake Mountain from the Miocene accounts for the present elevation of basalt flows in these two Yakima fold ridges. The size, pattern, and distribution of earthquakes in the central plateau along with focal mechanism solutions suggest continuing strain under nearly north-south, nearly horizontal compression. Seven surveys of a trilateration array across the Hanford Site since 1972 suggest compression

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at very low rates compatible with geologically determined rates of deformation, although the data are barely beyond the limits of error of the instruments used to measure changing line lengths.

~~While~~ although the preferred interpretation is one of continuing deformation under nearly north-south, nearly horizontal compression at long term, low average rates, the possibility of shorter periods in which deformation proceeded at higher rates (i.e., a more episodic pattern and rate of deformation compared with a long-term, low average rate) cannot be dismissed at this time. The rate and timing of deformation in other Yakima folds need~~s~~ to be confirmed as does the low rate of strain determined geodetically. Instrumental monitoring of shallow microearthquakes in the reference repository location needs to be conducted to determine the recurrence of microearthquakes in the reference repository location and probable levels of ground motion for use in design of subsurface facilities. The relationship of folding to faulting as well as the relationship of deformation in basalt to sub-basalt structure need to be determined as a check on the possible episodicity of deformation.

6.3.4 Preclosure System Guidelines (Section 960.5-1)

6.3.4.1 Preclosure Ease and Cost of Construction, Operation, and Closure (Section 960.5-1(a)(3))

6.3.4.1.1 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."

6.3.4.1.2 Evaluation process

Surface facilities, repository access shafts, and repository tunnels will be constructed using available mining and drilling technology (see Subsection 6.3.3.3.6). A highly skilled labor force for construction of nuclear facilities is available in the Tri-Cities area with the exception of miners. Miners will need to immigrate (see Subsection 6.2.1.7.8).

The high temperature environment at repository depth will require ventilation and air refrigeration to maintain a suitable working environment. Grouting and water removal will be used to remove excess water from the underground facility. These are characteristic features of deep mines. Studies are underway to determine technology requirements to maintain stable tunnels over the life of the repository. Repository closure will require backfilling with a mixture of crushed basalt and a radionuclide sorptive material. Handling and performance testing will be conducted to determine the best materials to use. Sealing of the access shafts will include concrete plugs, grout curtains, and backfill mixture. These are similar to the tunnel seal requirements at damsites.

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Preliminary estimates of relative repository life cycle costs are contained in Chapter 7 in that the basalt cost estimate of 7,020 million dollars (although higher than those for other potentially acceptable sites) falls within a high uncertainty factor usually associated with cost estimates at the conceptual design stage of a project. This cost estimate did not take advantage of cost reductions associated with alternative design options (see Section 5.1.3) being incorporated into the upgraded conceptual design for basalt, nor does it consider additional uncertainties associated with the operation and closure of repositories.

6.3.4.1.3 Conclusion on qualifying condition

A final conclusion on the qualifying condition for preclosure ease and cost of construction, operation, and closure cannot be made based on currently available data. However, a preliminary finding is required by Section 960.3-2-2-2 of the General Siting Guidelines (DOE, 1984a) to enable a comparison of potentially acceptable sites prior to site nomination and recommendation (see Section 6.1).

The available evidence does not support a finding that the site is not likely to meet qualifying condition. Two major factors which support this preliminary finding are summarized below:

- Surface facilities, repository access shafts, and repository tunnels will be constructed using available mining and drilling technology.
- The technology to control ground water during repository construction, operation, and closure is reasonably available.

Specific uncertainties related to the above factors include:

- Miners are not available in the Tri-Cities area, and will need to in-migrate (see Subsection 6.2.1.7.8).
- Studies are underway to determine technology requirements to maintain stable tunnels over the life of the repository.
- Handling and performance tests will be conducted to determine the best backfilling materials to use.
- The preliminary estimates of relative repository life cycle costs do not take advantage of cost reductions associated with alternative design options (see Section 5.1.3), nor do they consider additional uncertainties associated with the operation and closure of repositories.

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6.4 PERFORMANCE ASSESSMENT

The planning and impact chapters in this Environmental Assessment (Chapter 4, "Site Characterization Activities;" and Chapter 5, "The Repository") have provided an overview of the scope, extent, and potential impact of site characterization and repository development activities. The preceding sections of Chapter 6 have presented analyses, on a guideline-by-guideline basis, of the suitability for site characterization of the reference repository location. This section and the one that follows (Section 6.4.2, "Postclosure Performance Assessment") provides the reader with an overview of the analytical methods used by the Basalt Waste Isolation Project to provide (1) a preliminary assessment of site suitability based on data to date, (2) identify sensitive parameters or areas (e.g., isolation, safety, or functions related) that require specific attention during site characterization, (3) guide test program development, and (4) to help guide the design activities of the project in identifying and mitigating any problems in areas important to safety or to the function of the repository. Further details on the Basalt Waste Isolation Project planning will be found in forthcoming documentation.

6.4.1 Preclosure performance assessment

6.4.1.1 Scope

Preclosure performance assessment considers the repository operating period, which consists of waste transport and emplacement, possible waste retrieval, and permanent backfilling and sealing of the repository. The objective of such performance assessment activities are to assure compliance with regulatory criteria relating to occupational radiation exposure and potential release of radionuclides to the environment, as well as other safety related items, during repository construction, operation, and closure or possible retrieval. Both normal operating conditions and abnormal/accident events are considered in a preclosure performance assessment, which allows identification of sensitive areas. In general, the preclosure performance assessment involves identification of specific requirements to meet prescriptive regulatory criteria, and the performance of safety analyses to ensure compliance with overall repository performance criteria. Safety analysis involves identification of hazards, analysis of risk to health and safety, and the specification of preventive or mitigative measures to reduce or eliminate risk.

Assessment of preclosure performance is an iterative process of safety analysis during each repository and waste package design phase. As design evolves and operating procedures are developed, the safety analysis techniques become more detailed and more quantitative. Results then become inputs to succeeding phases of design and procedure development, either requiring changes in, or confirming the acceptability of repository design and operating procedures.

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6.4.1.2 Safety analysis methodology

The performance goals and acceptance criteria relating to public and occupational health and safety for repository operations are derived from applicable Federal, State, and local regulations and guidelines. Some criteria applicable to the preclosure period are expressly written for a nuclear waste repository (10 CFR 60 (NRC, 1982a), 40 CFR 191 (EPA, 1982)). Other criteria are derived from regulations for related nuclear or non-nuclear facilities and operations (e.g., Occupational Safety and Health Administration; Mine Safety and Health Administration). Criteria take the form of prescriptive requirements for specific subsystems, structures, and components, and general safety guidelines.

Applicable requirements are translated directly into specific design criteria, construction and operating specifications, or procedural requirements. Where overall performance goals and system performance criteria exist, safety analyses are employed to assess compliance. Similarly, safety analyses may be performed to confirm compliance with the requirements for design, construction, or operations; or to assess the effect of proposed deviations from such prescriptive requirements.

Such safety analyses follow a general procedure consisting of:

- Development of a systems description of the repository facility and its operational characteristics.
- Identification and characterization of potential hazards associated with normal operations.
- Selection, and characterization of accident or abnormal scenarios caused by internal or external events.
- Probabilistic risk analysis of the postulated event.
- Development of recommendations for preventive and mitigative measures.

6.4.1.3 Description of safety analysis methodology

6.4.1.3.1 <u>System description</u>

Safety analysis requires a detailed description of the process or system under evaluation. The system description is based on available design and test data that can be used to characterize repository construction, operation, decommissioning, and (or) retrieval operations under normal operational conditions. The system description is developed in sufficient detail to serve as the basis for subsequent safety analysis and is updated following the completion of each major design phase. Flow diagrams are utilized to describe repository operations and typically, identify associated personnel requirements and duration of each process.

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These flow diagrams allow an evaluation of occupational exposure to radioactive material and nonradiological hazards. Processes evaluated in this manner for potential radiation exposure and radiological release during the operating and decommissioning periods include receiving, inspecting, handling, transporting, and emplacing nuclear waste; monitoring and possible retrieval of waste prior to permanent closure; and permanent backfilling and sealing of pathways to the emplaced waste.

6.4.1.3.2 Characterization of normal operations hazards

This effort focuses on the identification and evaluation of subsystem operations that involve potential hazards. Hazardous material inventories and dispersal mechanisms that can impact safety under normal operating conditions are identified. Each hazard is then classified into appropriate categories, such as radiological, chemical, occupational, environmental, etc. A review of the repository design is performed to ensure compliance with established safety criteria. Hazards that warrant further quantitative analysis of associated consequences are identified. Prior to formal consequence analysis, preventive and (or) mitigative measures that can be incorporated as alternative design concepts or improved operating procedures are presented.

6.4.1.3.3 Select and characterize accident scenarios

For preclosure safety analysis, accident scenarios that may impact system safety are identified and described. Scenarios considered are those that can result in potential occupational radiation exposure or offsite radiological release. Accident conditions that may be created by events induced within and external to the facility are examined. Mining accidents, severe environmental conditions, and man-induced events are considered. Failure modes and effects analyses and fault-tree analyses are used to evaluate accident conditions resulting from equipment failure and (or) operator error within the facility.

6.4.1.3.4 Probabilistic risk analysis

Potential consequences of a particular chain of events are evaluated and quantified. The consequence analysis includes evaluation of contaminant source terms, transport pathways, and radiological dose consequences. Source terms are quantified through detailed analysis of previously described accident scenarios. Release characteristics will depend on the type of initiating event (e.g., fire, explosion) and the fraction of waste inventory involved. Within the facility, transport pathways are determined by ventilation system performance, radioactive waste system capabilities, and the anticipated response of monitoring systems and personnel to accident conditions. Environmental pathways through air and water are evaluated with appropriate models. Radiological dose to the public and to repository personnel are calculated considering the population exposed and doses accumulated through the processes of direct exposure, inhalation, ingestion, or immersion.

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Probabilities of occurrence are assigned to accident-initiating events and succeeding events, and probability distributions are assigned to relevant parameters. Analysis of probability and consequence yields a measurement of risk. An assessment of the probability of violating a given performance requirement is then made.

6.4.1.3.5 Recommendation of preventive and mitigative measures

The consequence-based analysis culminates in the confirmation of acceptability of the existing or proposed design, or in the recommendation of specific means of improving the repository design with respect to system safety. Preventive measures are ~~utilized~~ to preclude the possibility of an accident occurring; ~~whereas,~~ mitigative measures are designed to minimize the consequences of an accident and permit recovery from accident conditions. Recommendations are tailored to revising pertinent safety design criteria, identification of alternate design concepts that meet functional requirements with greater safety, or modifying operating procedures. Because this task represents an integration of safety analysis studies with the repository design, the final list of recommendations will be the result of a cooperative effort between performance assessment activities and the repository architect/engineer.

6.4.1.4 Evaluation of preclosure repository performance

Potential radiological hazards resulting from normal and abnormal repository operations are summarized below. Mine safety is discussed in Subsection 6.3.3.2.

6.4.1.4.1 Normal operating conditions

Waste handling operations pose some potential for radiation exposure to repository workers. Radiation exposure hazards have been identified, along with existing and recommended design features and procedures to minimize this risk (RKE/PB, 1983). Design features that eliminate or reduce these risks include shielding, radiation monitors and alarms, personnel radiation dosimeters, access control, control of waste transport paths, provision of hot cell seals, and adequate design margins in hoisting systems. Design features and operating procedures will ensure that radiation exposure to personnel will be maintained within 10 CFR 20 limits. Previous studies indicate occupational exposure rates of approximately 0.6 rem per year (Jones, 1983).

6.4.1.4.2 ~~Analysis of routine radiological releases from preclosure repository operations~~ Analysis of releases under routine operations

The conceptual design for a nuclear waste repository in basalt was based on the receiving and handling of prepackaged spent fuel and high-level waste (see Section 5.1.2). Under these conditions radioactivity would not be released from the facility under routine operating conditions. Radioactivity would be released from repository

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facilities only in the event that externally contaminated or leaking containers were received or damaged at the repository. However, as required by the Nuclear Waste Policy Act (enacted after completion of the latest conceptual repository design) repository facilities will be required to receive and package spent fuel assemblies as the primary waste form. The storage and handling of spent fuel assemblies presents a much greater potential for routine release of radioactivity than repository operations involving prepackaged fuel or high-level waste. Analysis of the potential releases from the handling of spent fuel is used to approximate the anticipated dose to members of the public from routine repository operations.

When spent fuel assemblies are received at the repository, they would likely be stored in a manner similar to that employed at commercial nuclear power reactors (a licensed process). Spent fuel assemblies would then be disassembled and the individual fuel rods would be consolidated in a close packed array in a welded steel container. The principal mechanism for release of radioactivity during these operations occurs during disassembly operations, which may be performed by pulling the rods from the end fittings, mechanically sawing the guide tubes, or the use of a laser cutting technique. Results of a previous study on the consequences of fuel rod disassembly can be used to approximate the radiological impacts of a spent fuel repository on the Hanford Site (Nuclear Assurance Corp., 1981). This study assumed that disassembly would be performed by mechanically pulling the fuel rods from their end fittings. Based on actual experience with light water reactors, which has shown that swelling of fuel pins tends to result in 0.1 to 0.3 percent of the fuel rods in the reactor sticking in the spacers, it was conservatively assumed that 1 percent of the spent fuel rods were swollen enough to become stuck. It was further assumed that 50 percent of the stuck fuel rods were ruptured during disassembly. This failure rate is also conservative because the equipment would be designed to release the fuel rod if the pulling force exceeded 100 pounds of force.

Failed fuel rods would be expected to release 30 percent of their gaseous fission product inventory, primarily in the form of krypton-85. This source term is consistent with guidance from the U.S. Nuclear Regulatory Commission on evaluating fuel handling accidents at nuclear power reactors (NRC, 1972). Assuming that a repository would be designed to receive and disassemble twenty-six 10-year-old spent fuel assemblies per day, 250 days per year (3,000 metric tons (3,300 tons) of heavy metal per year), and that krypton-85 activity is released at ground level over an 8-hour period each operating day, the 50-year dose commitment to an individual residing at the facility fence line (2,000 meters (6,560 feet) would be approximately 0.5 millirem per year. This dose is small in comparison to the U.S. Environmental Protection Agency standard of 25 millirem per year. The following list of assumptions, which were used in the estimation of radiological dose to the public from routine preclosure repository operations, have gone into this dose calculation.

1. The krypton-85 in 10-year-old spent fuel was 5.0×10^3 curies per metric ton of heavy metal.

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2. There were 0.4614 metric tons of heavy metal per assembly.

3. The release fraction for krypton-85 was 0.30.

4. The failed fuel rod fraction was 0.005.

5. There were 26 assemblies per day and 250 operating days per year.

6. There was a 50-year dose commitment of 4.9×10^{-4} (rem)(cubic meters)/(curies)(second).

7. The atmospheric dispersion factor (X/Q) for an 8-hour, ground-level release was 4.5×10^{-5} seconds per cubic meter.

Thus, the estimated dose was approximately 0.5 millirem per year.

6.4.1.4.3 Abnormal/accident conditions

Abnormal operating, or accident conditions leading to potential radiation exposure to personnel have been identified as follows (Jones and Geffen, 1984):

- An undetected contaminated cask, container, or vehicle in the waste handling area.
- Exposure to unsealed hot cell ports.
- Exposure to unshielded waste containers.
- Exposure to breached casks and drums.

Abnormal operating or accident conditions that could lead to a radiological release may result from the following low probability loss of containment incidents.

- Waste shaft hoist failure.
- Fuel assembly drop incidents.
- Natural phenomena.
- Explosion and fire.

6.4.1.4.4 Estimated dose consequences from hoist drop incident

Excluding severe natural phenomena, fires, and explosions, few waste handling operations in a repository possess the necessary source of energy required to breach containment of the waste forms. Exceptions to this condition include disassembly of the spent fuel assemblies, ~~minor~~ dropping incidents involving spent fuel assemblies, and hoist failure accidents during the lowering of the waste container to the repository level. Other repository operations involving potential accidents in the handling of packaged spent fuel in steel containers contained within a massive, shielded transfer cask are not capable of breaching containment of the waste package (Peping et al., 1981). The hoist drop incident, therefore, appears to present the greatest potential for breaching containment of the waste package.

The conditions necessary to cause dropping of a waste container down the shaft would require improbable multiple failures of redundant safety systems designed to prevent such an accident. Such safety systems are standard practice in the mining industry, accounting for the low failure rate of mine hoisting systems. However, irrespective of the probability of such an incident, because the above accident produces the maximum possible radiological consequences, ~~then~~ all other types of accidents should be bounded by the consequences of this event.

Waste containers are lowered to the repository level within a shielded, 27-metric-ton (30-ton) transfer cask. Therefore, breach of the transfer cask, waste container, and spent fuel cladding are required to initiate a release. Any airborne material would be entrained in the ventilation stream and transported upward through the waste shaft, exiting through a high-efficiency particulate air filtration system in the waste handling building. If the transfer cask and waste container were to free fall from the shaft collar to the repository level (approximately 1,000 meters (3,200 feet)), the transfer cask would be traveling at 140 meters (438 feet) per second. However, aerodynamic drag and frictional forces exerted by the cage guides and hoist ropes would reduce the impact velocity to some fraction of the free fall velocity. However, the impact velocity would likely remain high enough to breach the transfer cask and container. Evaluation of potential dose consequences from such an incident then requires an estimate of the quantity of particles released that are less than 10 micrometers in diameter. The sub-10-micrometer fraction is that which is readily entrained in the ventilation stream and, therefore, contributes directly to inhalation dose.

An experimental data base is generally lacking for preparing precise release estimates from a hoist drop event involving a spent fuel container. However, data on impact testing of simulated vitreous waste containers ~~is~~ are available from studies done by Pacific Northwest Laboratory (PNL, 1975). These data will be used to estimate the release fraction from a spent fuel waste form. The Pacific Northwest Laboratory data show that at the maximum impact velocity tested (37 meters (120 feet) per second), less than 0.1 weight percent of the glass was pulverized into sub-10-micrometer particles. Extrapolation of the data to higher velocities approaching those of the hoist drop scenario (approximately 100 meters (320 feet) per second) ~~are~~ is necessary for this analysis but ~~are~~ is subject to large uncertainties. However, the assumption that a maximum of 10 percent of the spent fuel waste package contents ~~are~~ is reduced to sub-10-micrometer size should serve as a conservative approximation of fines generation, considering that impact test data for relatively brittle glass waste forms may tend to overestimate the production of respirable fines for an event involving spent fuel. ~~An estimate can also be made of~~ The amount of sub-10-micrometer fines that can be entrained by the ventilation system can also be estimated.

The tests run on containers containing glass by Pacific Northwest Laboratory showed that, even if a container failed, only a small part of the broken glass could move because the remainder of the container and unbroken glass would serve as barriers. A crushable matrix material at the bottom of the shaft (e.g., aluminum honeycomb) could provide additional shock absorption and containment. In the absence of definitive test data, an extrapolation of the Pacific Northwest Laboratory test data suggests that up to 10 percent of the sub-10-micrometer fines could be entrained in the ventilation stream following a hoist drop incident.

This preliminary analysis suggests that approximately 1 percent of the contents of a spent fuel waste container would be pulverized into respirable size particles and entrained in the ventilation stream. Assuming that a waste container containing three 10-year-old pressurized water reactor assemblies was dropped down the shaft, preliminary estimates show that if 1 percent of the material in the container was released as respirable particles, and the air was filtered through a high-efficiency particulate air filtration system prior to atmospheric release, the fence-line dose to an individual over a 2-hour period could be approximately 100 millirem. The assumptions used in calculating the dose from a hoist drop event at the repository, are as follows:

1. The event involves one container containing three 10-year-old pressurized water reactor assemblies.

2. One percent of radionuclides released were in respirable form (10 micrometers) and 100 percent of fission gases were released.

3. The key radionuclides used to calculate the dose were strontium, cesium, plutonium, americium, and cerium (99 percent of inhalation dose from spent fuel).

4. The dose factor was 1.73×10^8 (rem)(cubic meters)/(second)(metric tons of heavy metal).

5. There were 1.38 metric tons of heavy metal per package.

6. The high-efficiency particulate air filter was 99.97 percent efficient.

7. Activity was released over a 2-hour period.

8. A 50-year individual dose commitment was calculated at a distance of 2,000 meters (656 feet).

9. The atmospheric dispersion factor (X/Q) was 1.5×10^{-4} seconds per cubic meter.

Thus, the estimated dose was approximately 100 millirem per event. While there is considerable uncertainty in this calculated exposure, it is believed to bound the consequences of accident events resulting from

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malfunctions of the waste handling system. This scenario shows the importance of maintaining adequate air filtration to minimize the consequences of such an event.

Natural phenomena effects (i.e., earthquakes, tornadoes, and high winds) are of concern primarily as common cause failure mechanisms that could initiate multiple failures. Design criteria for critical facilities and systems that are important to safety (i.e., high-efficiency particulate air filtration system) include consideration of these severe phenomena. The potential for a methane gas explosion is discussed in Subsection 6.3.3.2. Combustibles and explosives used in the mining operation will be controlled in accordance with applicable Federal regulations. These preliminary analyses indicate that pre-closure hazards will not vary significantly from similar types of large mining and(or) construction projects currently ongoing in the United States.

The following section (6.4.2) provides the performance assessment for the repository postclosure phase (i.e., after backfill of the underground waste and spent fuel storage). This performance assessment evaluates ground-water travel times and potential radionuclide releases to the accessible environment following closure of the repository.

6.4.2 Preliminary postclosure performance assessment

An evaluation of long-term repository performance is required for nomination of a proposed repository site. As specified by Federal regulations (EPA, 1982; NRC, 1983a), a performance assessment for a proposed repository site requires that a probabilistic risk assessment be used to evaluate compliance with the U.S. Environmental Protection Agency standard. The probabilistic risk assessment consists of an analysis of the three major repository subsystems: waste package, repository seals, and site. The probabilistic risk assessment considers uncertainties in: (1) field and laboratory data, (2) the theoretical completeness of the predictive models, and (3) the predictions of future conditions. The principal result of the probabilistic risk assessment is a curve (Ornstein et al., 1983; Ortiz and Wahi, 1983) depicting the relationship between possible radionuclide releases (i.e., consequences) and the probability (i.e., likelihood) of occurrence of those releases. The importance of the risk curve is that it can be compared to the U.S. Environmental Protection Agency standard to determine the acceptability of risks from a repository to future generations.

This section presents a preliminary performance assessment for each of the three major subsystems: waste package, repository seals, and site. The performance assessment is based on a probabilistic approach that accounts for data uncertainty. Where available data are not sufficient to permit calculation of probability distribution, values are assigned deterministically based on expert judgment. The data base used is derived from available field and laboratory measurements, conservative assumptions and expert judgment, and conceptual models that reflect current understanding of the geohydrologic and geochemical characteristics of basalts deep beneath the Hanford Site. The results of the subsystem performance analyses are combined to provide an estimate of postclosure performance for the total isolation system.

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The numerical results presented in this environmental assessment are not intended to demonstrate compliance with the postclosure system guideline or the regulatory criteria and standards, and are not final statements on the isolation capability of a repository in basalt. Rather, the assessment is intended to: (1) demonstrate the probabilistic assessment methodology, and (2) provide a quantitative perspective on potential long-term performance.

The scientific studies conducted at the Hanford Site over the past several years have yielded much data and understanding of the potential isolation performance of the basalt site. However, definitive predictions of postclosure performance will require a more comprehensive data base and broader understanding of the hydrogeologic system that will only be available after a complete and detailed site characterization. This preliminary performance assessment, together with other scientific evidence, provides a technical basis that defines the merit of further site characterization of the basalts beneath the Hanford Site. Moreover, the results of the performance assessment provide significant insight to the identification, ranking, and prioritization of data needs for the basalt site.

It is important to emphasize that the following performance assessment was conducted using a preliminary data base for the proposed repository site and vicinity. Where specific information was lacking, assumptions were made based on expert judgment. This approach of using a combination of known and judgmental data values for model input is in accordance with the site nomination and recommendation process as stated in Section 960-3-1-2-2 of the General Siting Guidelines (DOE, 1984a).

6.4.2.1 Scope and objectives

The scope of this preliminary postclosure performance assessment is limited to evaluating isolation performance of the undisturbed system. Unless otherwise specified, hydrogeologic conditions are assumed to be the same as before construction of a repository. Preliminary predictions of long-term performance are presented for two cases: (1) a reference case, and (2) a performance limits case. The performance analysis for the reference case is based on data and assumptions that are intended either to reflect expected conditions and behavior or to portray conditions more conservatively than expected (i.e., credit not taken for the isolation capability of spent fuel cladding). In contrast, the analysis for the performance limits case is based on data and assumptions that specify minimal isolation performance by only the engineered (waste package and repository seals) barriers. The effects of human intrusion and plausible disruptive events, conditions, and processes are also briefly examined.

Preliminary performance assessments are presented for: (1) the individual repository subsystems and (2) the total isolation system. First, a detailed analysis of subsystem performance for the first

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10,000 years was conducted, and is summarized here, to obtain probabilistic predictions for five performance measures:

- Waste package containment time.
- Radionuclide release rates from the waste package.
- Ground-water travel times through the site.
- Protection of major source of ground water for 1,000 years.
- Cumulative radionuclide releases to the accessible environment.

A probabilistic approach was used to estimate the ranges of uncertainties in the predictions of isolation performance; this information is generally not attainable by classical deterministic approaches that predict only single values.

Predictions for the five performance measures are compared to applicable regulatory criteria and standards to assess the likelihood that major repository subsystems will comply with U.S. Nuclear Regulatory Commission 10 CFR 60 (NRC, 1983a) regulations and U.S. Department of Energy General Siting Guidelines (DOE, 1984a), and that the total system will comply with U.S. Environmental Protection Agency 40 CFR 191 (EPA, 1984) draft standards. Then, to provide additional insights into long-term isolation performance, a separate analysis of the entire system was conducted that considers (1) the first 10,000 years and (2) the first 100,000 years after repository closure. System performance for these two cases is quantified in terms of potential radionuclide releases to the accessible environment.

This section of the Environmental Assessment is organized into six major subsections: (1) a description of the isolation subsystems of a mined geologic repository, (2) an assessment of subsystem performance, (3) an assessment of system performance, (4) summary of performance assessment results, (5) a discussion of human intrusion and disruptive events, and (6) conclusions from preliminary performance assessments.

6.4.2.2 Subsystems of a mined geologic repository

The repository isolation system consists of both engineered and natural barriers to radionuclide migration. From a system analysis standpoint, it is useful to represent these barriers as three major subsystems: (1) waste package, (2) repository seals, and (3) site. In this section, the nature and function of each subsystem and its components are briefly described. Subsequent sections present the conceptual representations, describe the important processes, and list the data bases used in assessing subsystem performance.

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6.4.2.2.1 Waste package subsystem

As defined by the U.S. Nuclear Regulatory Commission (NRC, 1983a), the term "waste package" includes the waste form and any containers, shielding, packing and other adsorbent materials immediately surrounding an individual waste container. The waste package is required to provide substantially complete containment of the nuclear waste for at least 300 to 1,000 years after repository closure. The current waste package design (see Subsection 6.4.2.3.3) for the proposed mined geologic repository in basalt consists of three major components: (1) waste form (spent fuel), (2) container, and (3) packing.

The U.S. Department of Energy strategy ~~presently~~ currently focuses on the disposal of spent nuclear fuel (DOE, 1984); thus, the waste packages will be designed to contain spent fuel from either pressurized water reactors or boiling water reactors. The waste form will consist of spent fuel assemblies or individual fuel rods consolidated into a more tightly packed arrangement. A typical spent fuel rod is approximately 3.7 meters (12 feet) long and is made of a zirconium-based metal tube called zircaloy. The metal tube is termed cladding and is highly resistant to corrosion. The nuclear fuel inside the tube typically consists of compressed and sintered cylindrical pellets of uranium oxide. Other waste forms (e.g., borosilicate glass or ceramics) may eventually be placed in the repository.

The spent fuel waste form will be contained within a carbon steel container. The function of this container is to maintain complete containment of the waste for 1,000 years or longer. Based on current information, the amount of corrosion of containers in an air/steam environment during the initial 50 years after emplacement is expected to be minor (Anderson, 1983). Corrosion of the container is likely to affect container lifetime after permanent closure of the repository, when the packing placed around the container becomes saturated with ground water. The rate at which corrosion proceeds is determined by the thermal and chemical environment at the surface of the container. The thickness of the container will be selected to: (1) compensate for corrosion, (2) withstand the in-place stresses, and (3) minimize effects of radiation on container life.

The main function of the packing surrounding the container is to control radionuclide release rates to the host rock by (1) limiting the rate of ground-water flow past the container, and (2) maintaining a reducing (i.e., low Eh) environment to enhance low solubilities of many radionuclides. A low permeability medium with strong adsorption properties is used to minimize radionuclide migration through the packing. Because of the low projected ground-water flow rates around the waste package, the principal radionuclide transport mechanism through the packing material will be molecular diffusion (Baca et al., 1984a; Relyea and Wood, 1984). Radionuclide release rates are also controlled by radionuclide solubility, and by adsorption in the packing material and host rock. The proposed packing material is a tailored mixture of 25 percent sodium bentonite clay and 75 percent (by weight) crushed basalt.

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6.4.2.2.2 Repository seals subsystem

The "repository seals subsystem" is defined as the underground repository facility (excluding the waste package), including the access shafts. The repository seals subsystem consists of the materials and barriers placed in the underground openings and beyond the boundary of the waste package subsystem. Materials placed in boreholes drilled from the ground surface within the controlled zone are also included as components of this subsystem. The repository seals subsystem is thus made up of four major components: (1) backfill, (2) emplacement-room seals, (3) drift seals, and (4) shaft seals (Rockwell, 1984a).

Backfill material placed in the engineered facility will be designed to inhibit ground-water flow and retard potential radionuclide migration. In addition, backfill material may provide structural support to underground openings in some areas of the repository. Backfill will also probably be placed in the vertical access shafts. Crushed basalt with bentonite clay currently is proposed for backfilling the drifts and emplacement rooms. The optimum composition and physical characteristics of backfill material to be used in shafts and boreholes ~~will~~ would be determined during site characterization.

Drifts are the manmade horizontal underground openings other than waste emplacement boreholes. They provide access for personnel, materials, utilities, and ventilation during repository development and operation. Drifts that provide access to boreholes in which waste will be emplaced are termed emplacement rooms. Seals may be placed as barriers at the entrance to each emplacement room, or within drifts accessing groups of rooms. Seal installations for emplacement rooms or drifts may require removal of local rock support systems, excavation of damaged rock, and installation of a low-permeability material to fill the cross section of the room. A ~~Such~~ well established technology such as injection grouting or a similar process, together with a bonding agent, may be used if deemed necessary between the seal material and the rock (Rockwell, 1984b) to seal fractures that may exist in the exposed rock at these seal locations.

To restrict ground-water flow through the repository, seals will probably be placed within the shafts. These seals will be designed to inhibit potential vertical migration of radionuclides through the repository shafts and to inhibit communication between aquifers in the strata above the repository through which the access shafts will pass. At specific locations in shafts where seals are placed, shaft liners and grout may be removed prior to seal emplacement, and the exposed surface prepared for sealing. Detailed methods and strategy for grouting and sealing will be developed in conjunction with the preliminary repository design.

6.4.2.2.3 Site subsystem

The "site subsystem" is that natural geologic barrier that extends from the boundaries of the waste package and repository seals subsystem to the accessible environment. The site subsystem consists of: (1) the

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emplacement horizon (i.e., dense basalt flow interior in which the waste containers are emplaced, (2) the overlying basalt flow top, and (3) the sequence of dense basalt, interbedded sediments, and flow tops along the predominant ground-water flow path(s) to the accessible environment. The repository could be located in the dense interior of one of four candidate basalt flows: Rocky Coulee, Cohassett, McCoy Canyon, and Umtanum. The Cohassett flow currently is the preferred candidate (Brown and Long, 1983; Rockwell, 1984c).

After closure of the repository, potential radionuclide flow paths from the emplacement horizon to the accessible environment must traverse two distinct hydrologic zones. The first zone is the thermally affected area around the repository. In this zone, water flow paths and travel times are controlled by a combination of natural hydraulic gradients and buoyancy forces induced by heat generated by the waste (Baca et al., 1981). This thermally influenced zone may extend several hundred meters vertically and horizontally from the edge of the repository. Ground-water flow in the second hydrologic zone, beyond the thermally affected zone, is controlled only by natural hydraulic gradients.

Potential radionuclide releases to the accessible environment during the time of interest (i.e., a 10,000-year period after closure) are a function of the release rate from the waste package and the rate of radionuclide migration through the site to the accessible environment. Based on current knowledge, the emplacement horizon is expected to contribute significantly to the isolation performance of the overall repository system. The dominant mechanism that could potentially transport radionuclides from the waste package to the accessible environment is ground-water flow within the basalt. For radionuclides that are adsorbed by minerals in the projected flow path, the effective transport velocities are much slower than the ground-water velocity. As a result, for most radionuclides, travel times to the accessible environment are generally much longer than ground-water travel times.

Ground-water travel times through the dense basalt layer vary because of the variability of rock transport-path properties. Local changes in site subsystem hydraulic properties during the period of peak thermal output from emplaced waste may arise from thermal-induced stresses around the underground facility. The heat may also affect site subsystem performance by changing (increasing or decreasing) the hydraulic conductivity of microfractures in the rock. Geochemical properties, such as host rock alteration rates and radionuclide adsorption, could also change because of the effect of elevated temperature on pH, Eh, ionic, and colloidal properties.

The basalt flow top of the emplacement horizon is a likely lateral ground-water flow path because of the existence of: (1) a slightly upward hydraulic head gradient (natural and thermal-induced) across the emplacement horizon; (2) expected low vertical conductivity of the basalt flow interior above the flow top of the emplacement horizon; and (3) greater hydraulic conductivity of the emplacement horizon flow top relative to that of the emplacement horizon flow interior. However, other alternative conceptual models (Gephart et al., 1983) of ground-water flow have been proposed that will be considered in future studies. Additional description of these conceptual models is given in Subsection 3.3.2.2.

The sequence of dense basalt flow interiors, interbedded sediments, and relatively porous flow tops surrounding the emplacement flow comprise the remainder of the geologic barrier of the site subsystem. Sources of data uncertainties are similar to those of the emplacement horizon and flow top, but are of decreasing significance to performance predictions as their distance from the repository increases.

6.4.2.3 Subsystem performance assessment

Ideally, the individual subsystems of a repository should provide a diverse series of barriers to radionuclide migration (i.e., a multiple barrier system providing defense-in-depth (White, et al., 1982)). This multiple barrier approach is intended to provide reasonable assurance that the total system will comply with the U.S. Environmental Protection Agency standard. The strategy adopted by the Basalt Waste Isolation Project for introducing reasonable assurance is based on an approach in which each subsystem of the repository is required, by itself, to achieve compliance with the U.S. Environmental Protection Agency standard, with high probability, at its designated boundary. This approach assures that the combined performance of the subsystems yields a higher probability (i.e., confidence) that the total system will meet the U.S. Environmental Protection Agency standard. The basic strategy of the approach is referred to as subsystem performance allocation.

In this section, preliminary performance assessments are presented for each of the major subsystems: waste package, repository seals, and site. The assessments were conducted using a stochastic analysis methodology (i.e., a statistical approach to the analysis of random variables) that accounts for uncertainties in input data and provides probabilistic predictions of the important performance measures. The performance assessments for each subsystem were conducted for a 10,000-year period after repository closure.

6.4.2.3.1 Stochastic analysis methodology

Stochastic analysis provides a means of explicitly relating confidence (or uncertainty) levels in model predictions to uncertainties in input data. Data uncertainties can arise from (1) limited laboratory or field measurements, and (2) incomplete understanding of complex physical or chemical interactions. Stochastic modeling can incorporate such uncertainties into the analytical process. In stochastic analysis, the objective is to calculate the distribution of predicted outcomes and construct probability distribution curves for the important performance measures. Generally, the means and standard deviations of the probability curves are of primary interest. The mean value of the probability curve is the average (or expected) value and generally corresponds to the centroid of the curve. The standard deviation is a measure of the spread (or dispersion) of values about the mean value.

A Monte Carlo method of random sampling usually is used for such stochastic simulations. This type of sampling method has been used in a variety of technical fields (Spainer and Gelbard, 1969; Freeze, 1975; NRC, 1983a) and is widely accepted by the scientific community. The analysis approach requires estimation of the probability distributions for uncertain input parameters and is implemented by means of four basic steps:

1. Random sampling of parameter values according to their probability distributions and parameter correlations (as necessary).

2. Assigning the values from step one to the appropriate stochastic input parameters.

3. Simulating the ground-water flow and transport processes using a deterministic computer model.

4. Recording the values of the output performance measure.

The computational process is repeated a large number of times until the final output, a probability curve, is well defined. The principal result of the stochastic simulation are cumulative or complementary-cumulative probability curves for the performance measures (i.e., ground-water travel time, radionuclide release rate, and cumulative radionuclide release). From this curve, the probability (or confidence level) of achieving compliance with a regulatory criteria or standard is estimated.

The Basalt Waste Isolation Project has developed various stochastic simulation models (Sonnichsen, 1984) to predict performance of major repository subsystems: the waste package, repository seals, and site. In general, these models use the approach illustrated by Figure 6-13, and as described above. In subsequent sections of this environmental assessment, the capability of the models is demonstrated with specific applications.

6.4.2.3.2 Identification of radionuclides for performance assessment

The spent fuel waste form placed in a mined geologic repository contains over 100 different radionuclides. Many of these radionuclides are not significant to long-term isolation performance because of their intrinsic properties. Such properties include short half-lives, low solubilities, and high adsorption. Thus, only a relatively small number of radionuclides need to be considered in assessing isolation performance. For purposes of this report, these radionuclides are defined as radionuclides that, if released in significant quantities (relative to the proposed U.S. Environmental Protection Agency release limits (EPA, 1984)) from the waste package and repository seals subsystems, potentially could reach the accessible environment within 10,000 years because of

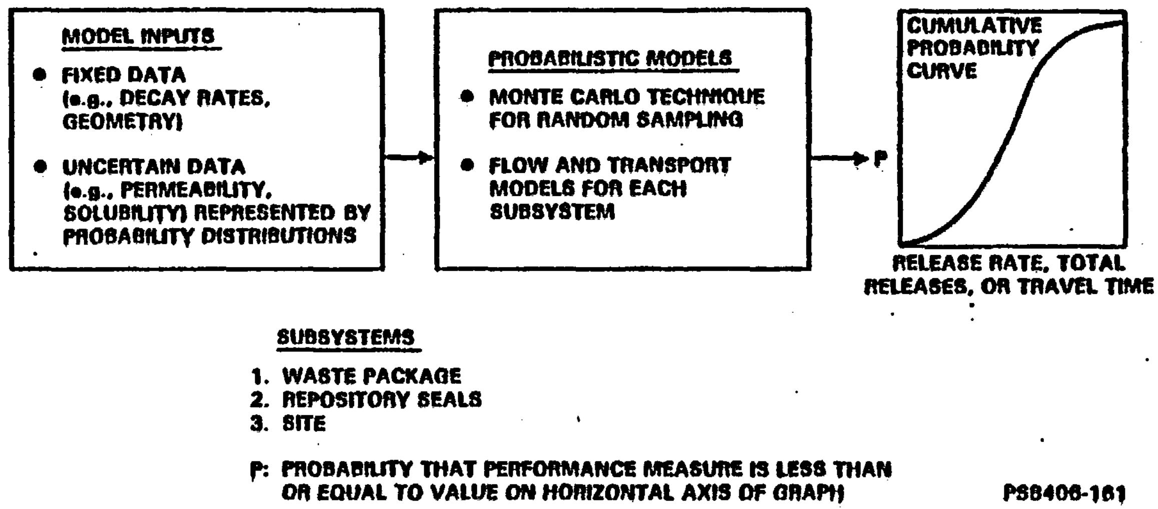

Figure 6-~~14~~13. Stochastic analysis applied to subsystem performance assessment.

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their (1) long half-lives, (2) large inventories, (3) high solubility, or (4) low adsorption. The radionuclides important to performance assessment were identified for the spent fuel waste form using a four-step selection procedure shown in Figure 6-14. The screening procedure was based on the following assumptions:

- The emplaced waste form is 10-year-old spent commercial reactor fuel.
- Complete disintegration of fuel cladding and container occurs after a 1,000-year containment period.
- Instantaneous dissolution of all waste form matrix occurs after the containment period.
- Water resaturates the repository immediately after closure.

The actual calculations for selecting the radionuclides were performed using a computer code. The computer code simulates radionuclide release from the container by modeling the processes of molecular diffusion, decay, and adsorption in a sequential manner. At each step of the procedure, radionuclides were eliminated from further consideration based on criteria described in the following paragraphs. After each step, the remaining radionuclides were listed in order of decreasing importance to performance assessment of the waste package, with respect to the selection criterion.

Step no. 1 - half-life. The waste package for a repository in basalt will be designed to contain the radioactive wastes for 1,000 years or longer. During this containment period, many radionuclides with short half-lives will decay to insignificant levels. Typically, a time equivalent to 10 half-lives is sufficient to reduce the inventory of any radionuclide to approximately 0.1 percent of its initial inventory (Kaplan, 1962). For example, a radionuclide with a half-life of 100 years (or less) would decay to 0.1 percent (or less) of its initial inventory in 1,000 years (container design-life). Therefore, radionuclides with half-lives of 100 years or less were eliminated from further consideration.

Step no. 2 - initial inventory. In the second step of the screening procedure, the inventory fraction (i.e., the ratio of maximum radionuclide inventory to the applicable U.S. Environmental Protection Agency release limit) was computed for each radionuclide and then compared to 1.0 percent. This criterion was selected because radionuclides with inventory fractions of less than 1.0 percent cannot significantly contribute to the total release, irrespective of their rates of release or rates of migration. The inventory fractions were calculated using radioisotope inventories reported by the U.S. Department of Energy (DOE, 1979). The radionuclide inventories were adjusted to account for the formation of daughter nuclides prior to this screening step.

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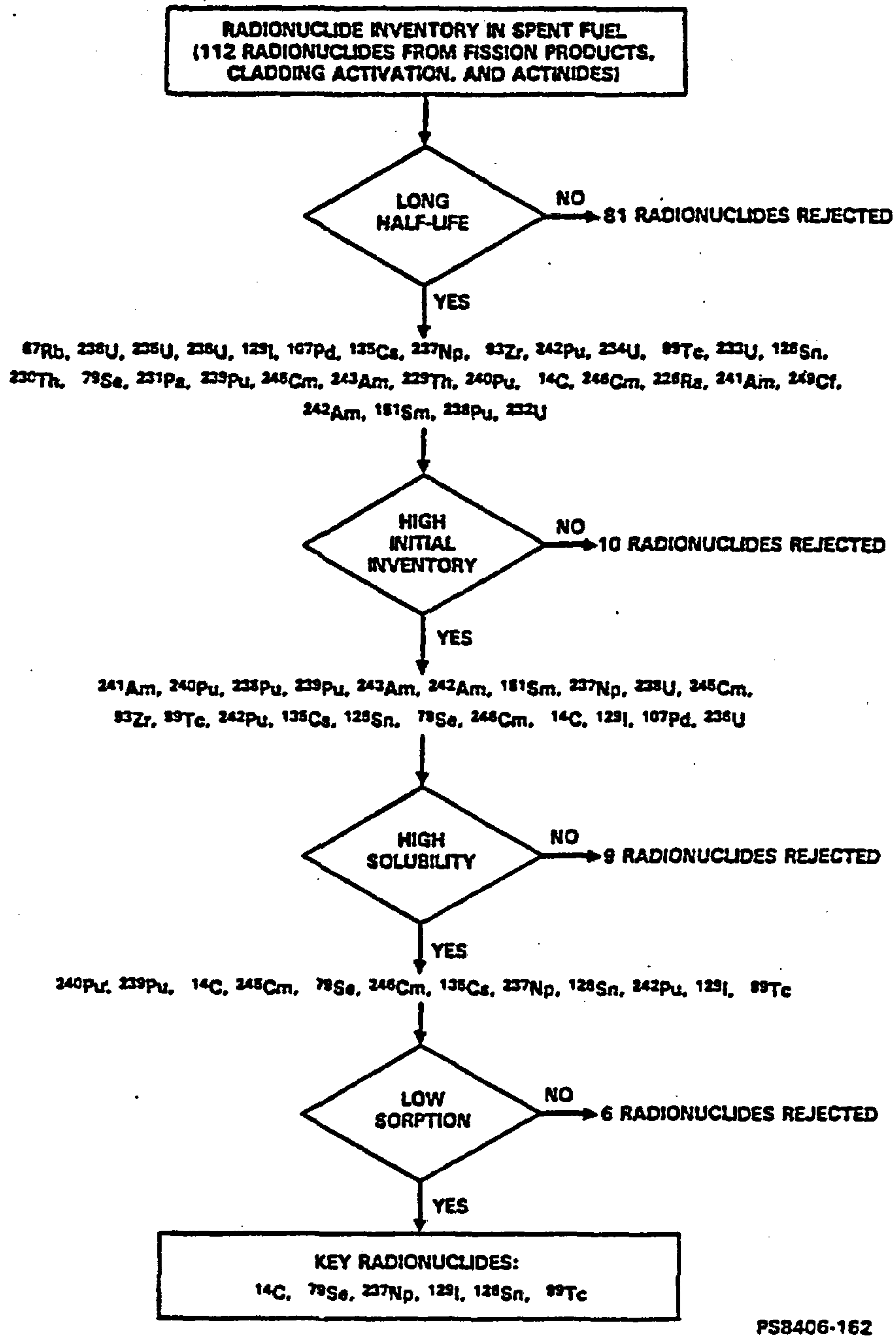

Figure 6-~~15~~ 14. Screening procedure used to identify key radionuclides.

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Step no. 3 - solubility. According to available conservative estimates (Salter and Jacobs, 1983; Early et al., 1982) and preliminary data, several radionuclides in the waste form have relatively low solubilities. The term solubility, as used here, is defined as the steady-state concentration (resulting from dissolution and precipitation) that limits the rate at which a radionuclide dissolves in the ground water. In general, low solubility together with diffusion-controlled mass-transport can usually limit radionuclide releases to insignificant amounts. As in the previous step, an "insignificant amount" is defined as a release fraction (i.e., calculated cumulative release from the waste package normalized to the U.S. Environmental Protection Agency release limit) that is less than or equal to 1.0 percent.

Step no. 4 - adsorption. Adsorption of radionuclides by the flow path minerals, waste container packing, or backfill is important because of its ability to retard radionuclide movement. The effects of this chemical process are manifested in terms of increased radionuclide travel times and reduced radionuclide releases. In this step of the selection procedure, a criterion of 1.0 percent cumulative-release fraction was used. Cumulative releases for each radionuclide were calculated as in the previous step, but with adsorption accounted for by applying a retardation factor (Freeze and Cherry, 1979). Conservative values (i.e., lowest current estimates) of adsorption coefficients (Salter and Jacobs, 1983) were used. The releases calculated across the waste package boundary were summed over 10,000 years to obtain cumulative releases for each radionuclide.

After applying these four screening steps, only six radionuclides remained that appeared to merit priority consideration in the postclosure performance assessment for a repository in basalt. These six radionuclides are: carbon-14, selenium-79, neptunium-237, iodine-129, tin-126, and technetium-99. The radionuclides of greatest significance to total system performance are probably carbon-14 and iodine-129 because of their relatively high solubilities, nonadsorptive properties, and relatively long half-lives. The degree to which radiocarbon exchanges with natural carbonate along the flow path is ~~presently~~ currently unknown. Such exchanges may have significant effects on limiting the rate of release. The relative importance of the six key radionuclides, with respect to releases from the waste package subsystem, are compared relative to carbon-14 in Figure 6-15.

In the subsequent analyses of subsystem performance, transport calculations were performed for these six radionuclides and for three isotopes of plutonium (plutonium-239, -240, and -242). The latter three isotopes were considered because of the relatively large inventory of plutonium in the waste form, and because of plutonium's ability to form colloids under some geochemical conditions.

6.4.2.3.3 Waste package subsystem performance

The basic function of the waste package subsystem is to provide engineered barriers in addition to the dominant barrier of the site subsystem. The U.S. Nuclear Regulatory Commission criteria (NRC, 1983a)

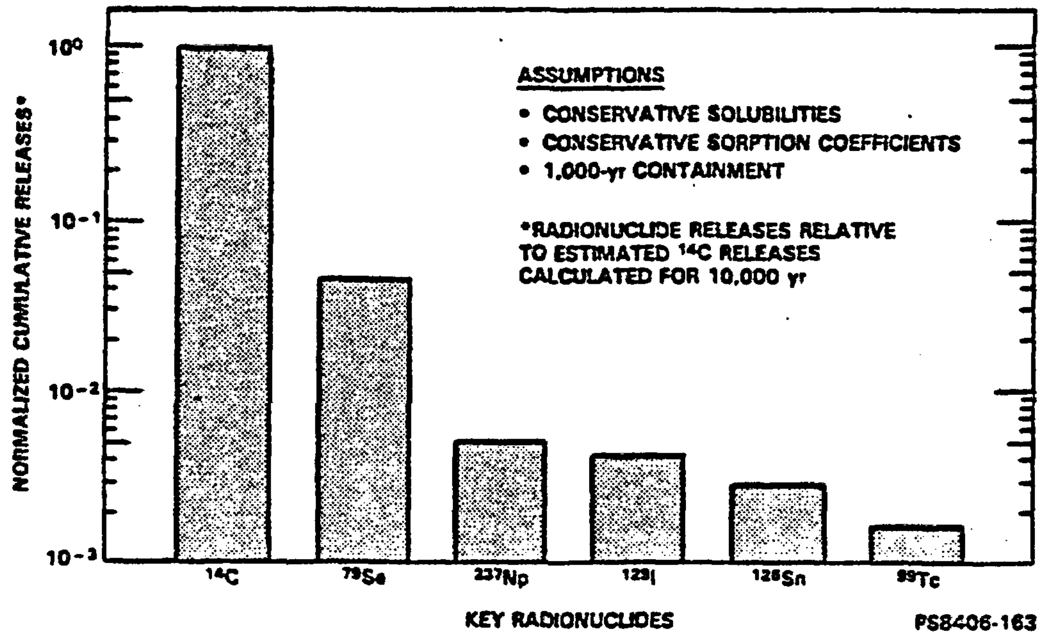

Figure 6-~~16~~15. ~~Importance of radionuclides relative to estimated carbon-14 releases from the waste package.~~ Comparative importance of radionuclides to assessment of isolation performance of the waste package sub-system.

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for performance of the engineered barriers require that: (1) waste packages provide substantially complete containment of the spent fuel for 300 to 1,000 years, and (2) the radionuclide release rate (after a 1,000-year containment) not exceed one part in 100,000 per year at the waste package boundary. This requirement does not apply to any radionuclide which is released at a rate less than 0.1 percent of the calculated total release rate limit. The U.S. Nuclear Regulatory Commission criteria provide for the specification of alternative numerical limits for waste package release rates, provided that there is reasonable assurance that the total system will achieve compliance with the proposed U.S. Environmental Protection Agency regulation (EPA, 1984).

Figure 6-16 illustrates the allowable release rates for typical spent fuel. The solid line consists of a horizontal segment representing the minimum release rate (0.1 percent x total release rate limit) needed for application of the 1×10^{-5} times inventory requirement, and a 45-degree segment representing 1×10^{-5} times the inventory. The release-rate limit is 1×10^{-5} times total inventory, or:

$(1 \times 10^{-5}) \times (1.6 \times 10^{3}) = 1.6 \times 10^{-2}$ curies per metric ton of uranium per year.

This release rate does not apply to any radionuclide released at a rate less than 0.1 percent of the calculated total release rate limit, or:

the minimum release rate needed for application of the 1×10^{-5} times inventory requirement = 0.001 x release rate limit = 1.6×10^{-5} curies per metric ton of uranium per year.

For any radionuclide, the allowable fractional release rate is equal to allowable release rate divided by inventory. Along the 45-degree line segment in Figure 6-16, the value is always 1×10^{-5}. At lower inventories, however, the allowable fractional release rate is the minimum 0.1 percent of the total release rate limit divided by the inventory. For selenium-79, the value is 1.6×10^{-5} divided by 3.5×10^{-1}, or 4.6×10^{-5}. This value is slightly less restrictive than the "one part in 100,000" constraint. For iodine-129, the minimum required release rate divided by inventory is approximately 5×10^{-4}, a fairly significant departure from "one part in 100,000." The U.S. Nuclear Regulatory Commission criterion, as interpreted for this report, is that a low inventory relaxes the criterion but does not exempt the radionuclide from regulation.

How well the current waste package design complies with the above criteria could affect compliance with the proposed U.S. Environmental Protection Agency regulation (EPA, 1984) for (1) the requirement for protection of major sources of ground water (see Subsection 6.4.3.7.4), and (2) the limits on cumulative radionuclide releases at the accessible environment boundary. For example, if performance of the waste package is such that a 1,000-year containment is achieved with high confidence, then there is reasonable assurance that the ground-water protection requirement

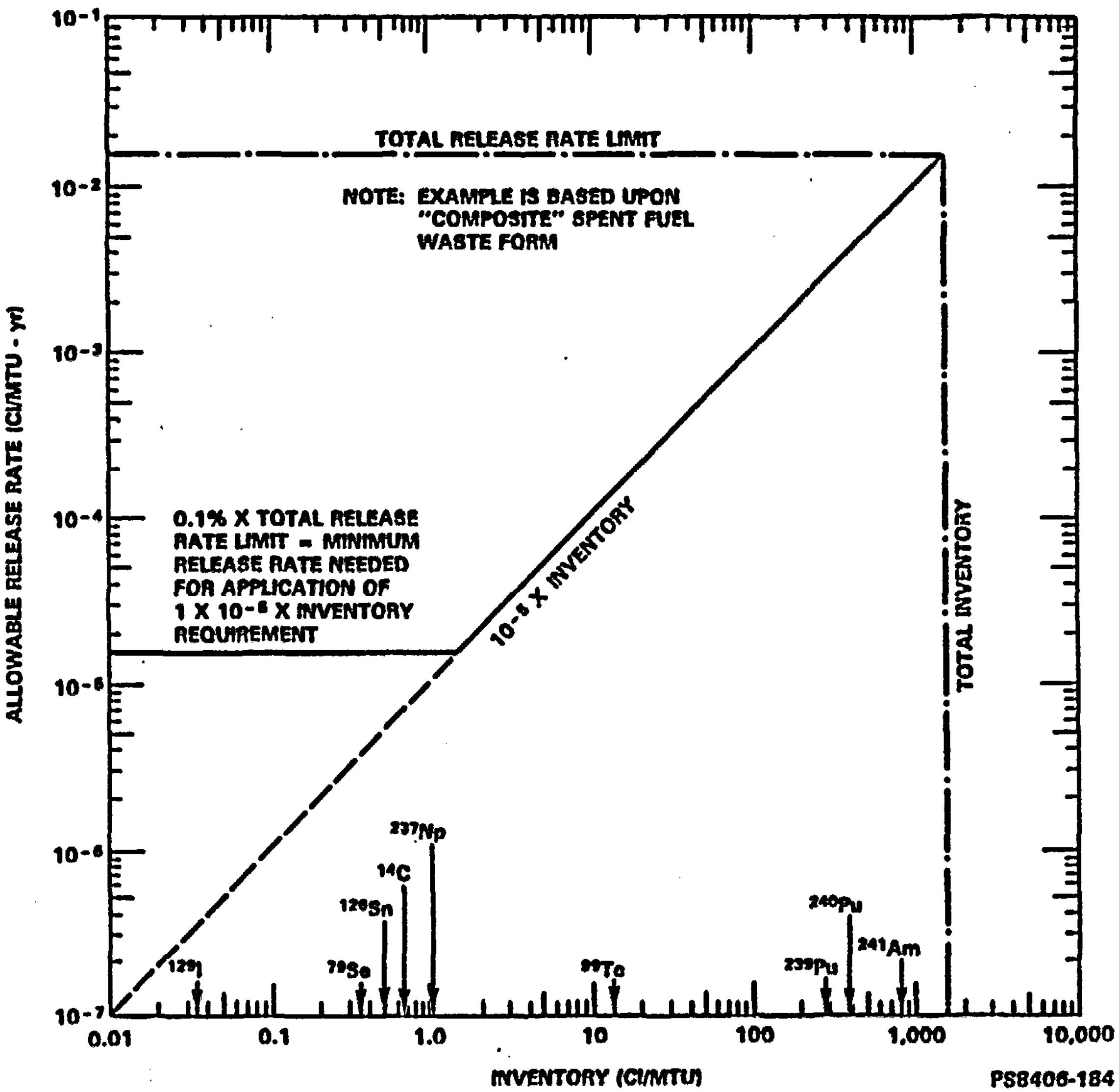

FIGURE 6-16. WASTE PACKAGE RELEASE RATE REQUIREMENT OF 10 CFR 60.

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would be met. Similarly, if performance of the waste package is such that there is high confidence that the cumulative radionuclide releases (at the waste package boundary) are less than the U.S. Environmental Protection Agency limits, then there is greater assurance that the site subsystem would comply with the release limits at the accessible environment boundary.

Stochastic simulations of waste package performance were conducted to examine the likelihood of compliance of subsystem performance with the U.S. Nuclear Regulatory Commission criteria, taking into account the ranges of uncertainties in the input data and parameters. The analysis of subsystem performance focuses on the first 10,000 years after closure and calculates probability curves for three performance measures: (1) container lifetime, (2) radionuclide release rates, and (3) cumulative radionuclide releases at the waste package boundary.

Methodology of analysis. The methodology developed for probabilistic evaluation of performance of the waste package subsystem consists of four steps: (1) definition of subsystem components and boundaries, and their synthesis into a conceptual model (Fig. 6-17), (2) development of a mathematical description and parameterization of processes that govern performance, (3) quantitative characterization of model parameters and their associated uncertainties, and (4) analysis of model output to ascertain the likelihood of compliance with performance criteria. The general nature of the various processes that govern performance of the waste package is reasonably well understood. However, due to uncertainties in the present definition of the geochemical environment and radionuclide properties, some of the model parameters may have a large range of possible values. To properly account for data uncertainty, stochastic methods were adopted for analyzing the performance of the waste package.

The corrosion model used to estimate the container lifetime is described in detail by Fish and Anantatmula (1983). This model estimates the rate of container corrosion in the predicted geochemical environment (e.g., with respect to temperature, oxygen supply, steam and (or) water saturation) around the waste package during the performance period of 10,000 years. The model input parameters are estimated from experimental data and from published information.

The model adopted for the estimation of release rates for this analysis is the computer code CHAINT-MC (Baca et al., 1984b). This computer code solves the convection-dispersive equation of mass transport in two- or quasi-three-dimensions, using the finite element method (Baca et al., 1984a). The computer code incorporates various processes that are important to radionuclide migration, such as chain decay, sorption, molecular diffusion and hydrodynamic dispersion. This model can be used under conditions of layering or arbitrary heterogeneity and anisotropy. To adapt the model for stochastic analysis, Monte Carlo simulations are performed. In this computer code, the radionuclide transport process is simulated repeatedly using parameter values obtained from the respective

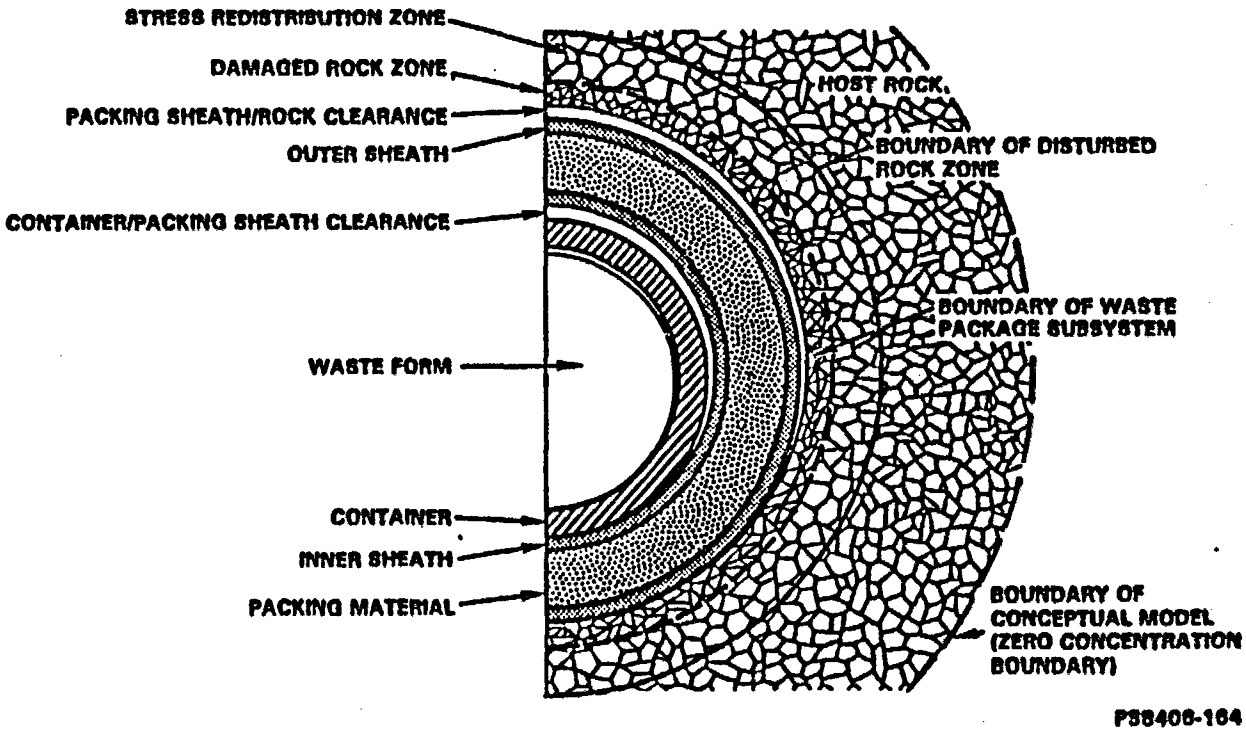

FIGURE 6-17. CONCEPTUAL MODEL USED IN WASTE PACKAGE PERFORMANCE ASSESSMENT.

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probability distribution of the parameter. Statistical analysis is then performed on the model output to obtain probability curves for the maximum fractional release rate and cumulative release.

Estimation of container lifetime. Although other materials are being studied, the current leading candidate material for the waste container is low-carbon steel. Based on container integrity under estimated stress conditions and allowing for estimated rates of corrosion, the current container conceptual design assumes a wall thickness of 8.3 centimeters (3.3 inches), out of which 7.5 centimeters (3 inches) is the corrosion allowance. The remaining thickness provides an allowance to accomodate the in-place stresses. For purposes of this analysis, the container lifetime is defined as the time at which this corrosion allowance is depleted, rather than the time at which the container actually fails.

Exposure of low-carbon steel to ground-water saturated packing at 200°-250°C (392°-452°F) results in the formation of an iron-rich clay, reducing subsequent corrosion of the underlying steel. At lower temperatures of 100°C (212°F), the corrosion rate is as much as seven times greater because of slower reaction kinetics in the formation of iron-rich clay. This analysis assumes that the container temperature will drop to 125°C (257°F) at 300 years after emplacment. The corrosion rate at less than 125°C (257°F) was taken to be the same as that at 100°C (212°F). The repository closure time was specified as 100 years after the emplacement of waste containers in the repository. The repository was specified to be saturated with ground water at closure and the only degradation mechanism considered was uniform corrosion.

The model parameters were defined in terms of their probability distributions. At this time, the limited data base does not allow distributions with well defined mean values to be specified. Therefore, uniform distributions were specified for all of the model parameters. With expansion of the data base in the future, the nature of the actual distributions should become apparent.

One thousand Monte Carlo simulations of the corrosion model were made. The principal results of the analysis are shown in Figure 6-18 as a cumulative probability distribution for the container lifetime. A point on this curve is the estimated probability of the container lifetime being less than the value of that point read on the horizontal axis of the graph. The probability that the container will fail in less than 1,000 years was estimated to be less than one in ten thousand. In order to use these results later, for the estimation of fractional and total releases, a best-fit (Gaussian) probability distribution with mean and standard deviations of 6,500 and 2,000 years, respectively, was obtained for the container lifetime.

Data for release rate analysis. Based on the considerations discussed in Subsection 6.4.2.3.2, nine radionuclides (carbon-14, iodine-129, technetium-99, selenium-79, neptunium-237, tin-126, and plutonium-239, -240, and -242) were considered in the waste package performance analysis. The waste package subsystem analysis was conducted for the current waste package conceptual design. The referenced design

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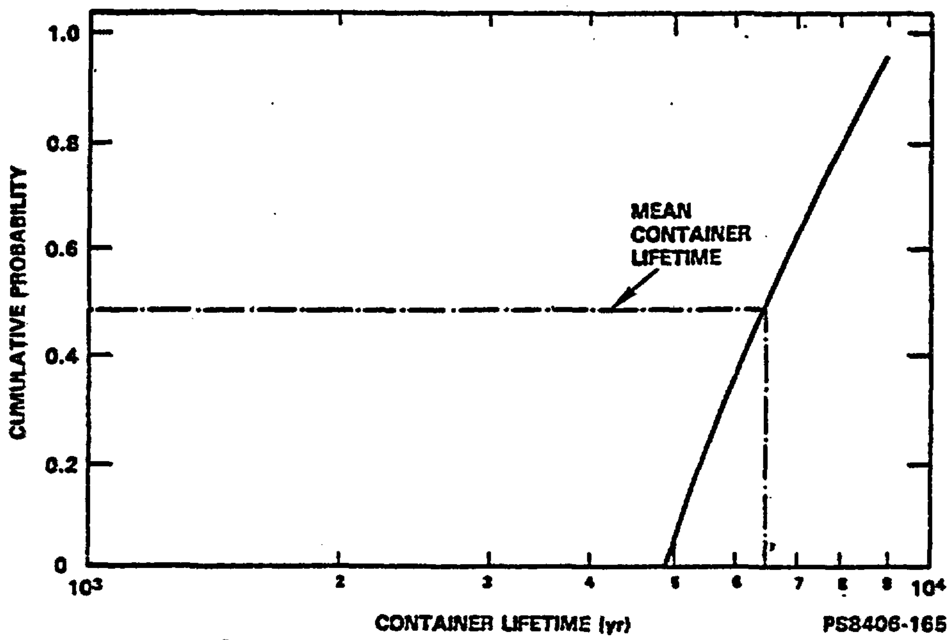

Figure 6-~~17~~ 18. Probability curve for container lifetime (i.e., depletion of corrosion allowance).

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specifies 50.3-centimeter- (19.8-inches-) outer-diameter containers with a wall thickness of 8.3 centimeters (3.3 inches) which are laid in 89-centimeter- (35-inch-) diameter boreholes with a center-to-center separation of 701 centimeters (276 inches). The 19-centimeter (7.5-inch) gap between the container and the borehole wall contains a 15-centimeter-thick (6-inch) prefabricated packing (see Fig. 6-17). At resaturation, the packing was assumed to swell to fill the entire gap. Accordingly, the waste package subsystem boundary was specified to be located 19 centimeters (7.5 inches) from the container's outer wall.

It was further assumed that during the drilling and excavation operations, a significant thickness, relative to the waste package diameter, of the host rock around the boreholes is disturbed. Outward from the borehole wall, a host rock thickness equal to one-fifth of the borehole radius was specified to be damaged to the extent that its permeability is the same as that of the waste container packing. Beyond the damaged rock zone, a rock thickness equal to one borehole radius was assumed to be stressed to the extent that its permeability is one order of magnitude greater than that of the undisturbed host rock. For the current design, the borehole is assumed to be surrounded by a damaged rock zone approximately 9 centimeters (3.3 inches) thick, which in turn is enclosed by a zone of induced stress 44.5 centimeters (16.5 inches) thick.

The data set used for modeling of waste package performance ~~are~~ is given in Tables 6-18 through 6-20. Three of the model parameters (container lifetime, radionuclide solubility, and adsorption) currently have significant uncertainties, and are therefore specified in terms of their probability distribution curves. The probability distribution for the container lifetime has been discussed in the previous subsections. Data on solubility and sorption ~~is~~ are limited. Current estimated ranges (Salter and Jacobs, 1983) are reported in Table 6-18. Most of the values for solubility reported in Table 6-18 are based on theoretical thermodynamic considerations. The small number of available experimental values precludes definition of a probability distribution by means other than expert judgment. In the absence of such information, and because radionuclide releases are sensitive to solubility, three different distributions were assigned to the solubility data. The distributions assumed were: uniform, loguniform, and lognormal. For the lognormal distribution, the probability of solubility being less than the higher value of the range is 95 percent; the probability of it being less than the lower value of the range is 5 percent. With additional field data, the probability distributions for radionuclide solubilities will become better defined in the future. Because the range of the sorption parameter values is within an order of magnitude, under the conditions of limited information, a uniform distribution was considered conservative and sufficient. All other parameter values (diffusion coefficient, porosity, etc.) and boundary conditions for this study were deterministically assigned.

Because of the low hydraulic conductivity of the packing material, and because container lifetime is such that buoyancy forces are dissipated before releases begin, the advective transport component (e.g., radionuclide migration produced by water movement) is relatively small.

Table 6-18. Radionuclide data set for assessment of performance.

Radionuclide	Inventory (Ci/~~mme~~ mtu)	EPA[a] limit (Ci/~~mmb~~ mtu)	Half-life (yr)	Specific activity (Ci/g)	Radioisotope solubility[b] (~~moles~~ mg/L)	Adsorption coefficient (ml/g)
Carbon-14	7.4×10^{-1}	1.0×10^{-1}	5.73×10^{3}	4.457	4.0×10^{-6} - 4.0×10^{-9}	0
Iodine-129	3.3×10^{-2}	1.0×0	1.59×10^{7}	1.74×10^{-4}	1.0×10^{0} - 1.0×10^{-2}	0
Neptunium-237	1.1×10^{0}	1.0×10^{-1}	2.14×10^{6}	7.05×10^{-4}	1.0×10^{-7} - 3.0×10^{-9}	2 - 10
Plutonium-239	2.9×10^{2}	1.0×10^{-1}	2.41×10^{4}	6.20×10^{-2}	1.2×10^{-8} - 1.8×10^{-11}	4 - 21
Plutonium-240	4.5×10^{2}	1.0×10^{-1}	6.53×10^{3}	2.28×10^{-1}	6.0×10^{-9} - 9.0×10^{-12}	4 - 21
Plutonium-242	1.6×10^{0}	1.0×10^{-1}	3.76×10^{5}	3.93×10^{-3}	2.0×10^{-9} - 3.0×10^{-12}	4 - 21
Technetium-99	1.3×10^{1}	1.0×10^{1}	2.13×10^{5}	1.70×10^{-2}	5.0×10^{-4} - 2.0×10^{-8}	0 - 15
Selenium-79	3.5×10^{-1}	1.0×10^{0}	6.50×10^{4}	6.96×10^{-2}	1.0×10^{-4} - 1.0×10^{-8}	0.8 - 4
Tin-126	4.8×10^{-1}	1.0×10^{0}	1.00×10^{5}	2.84×10^{-2}	3.0×10^{-6} - 3.0×10^{-11}	2 - 5

[a] U.S. Environmental Protection Agency.

[b] Computed by multiplying the element solubility by the isotopic fraction.

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Table 6-19. Hydraulic property data set for assessment of performance.

Parameter	Packing	Zone		
		Damaged rock	Disturbed rock	Host rock
Hydraulic conductivity (m/s)[a]	1.0×10^{-10}	1.0×10^{-10}	1.0×10^{-12}	1.0×10^{-13}[c]
Effective porosity	3.0×10^{-1}	1.0×10^{-3}	2.15×10^{-4}	1.0×10^{-4}
Diffusion coefficient (cm^2/s)[b]	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}

[a] ~~To convert m to ft, multiply by 3.281.~~ 1 m = 3.28 ft.

[b] ~~To convert cm^2 to $in.^2$ multiply by .155.~~ 1 cm^2 = 0.155 in^2.

[c] Horizontal hydraulic conductivity.

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Table 6-20. Container data set for assessment of performance.

Item	Current design specification
Container material type	low-carbon steel
Container outer radius	25.15 cm (9.9 in.)
Container wall thickness	8.3 cm (3.26 in.)
Container capacity (PWR[a] fuel)	1.85 metric tons (approximately 1.94 short tons) of uranium
Borehole radius	44.5 cm (16.5 in.)
Damaged rock thickness	2.5 cm (1 in.)
Disturbed rock thickness	44.5 cm (16.5 in.)

[a]Pressurized water reactor.

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Advective effects are generally insignificant for those radionuclides that are readily adsorbed (e.g., all except carbon-14 and iodine-129 in the list of nine radionuclides). Deterministic computer simulations for carbon-14 and iodine-129 transport revealed that advection had a negligible effect on their fractional and total releases. Radionuclide migration by molecular diffusion appears to be the primary mechanism for movement of radionuclides away from the waste package (Baca et al., 1984a; Relyea and Wood, 1984). Therefore, advection was neglected for all nine radionuclides in the transport calculations. Under these conditions, the migration occurs in a radial direction and is modeled as a quasi-two-dimensional process. The outer boundary of the conceptual model (Fig. 6-20) is 7.5 meters (24.6 feet) from the center of the container and is specified as a boundary of zero concentration. From various computer simulations, it was ascertained that this boundary should be at least 7.5 meters (24.6 feet) from the center of the container in order to minimize its effect on the release rate calculated at the waste package subsystem boundary. A discussion of boundary effects will be presented in future technical reports.

Estimates of release rates. The results of the analysis are shown in the form of complementary cumulative probability curves of (1) maximum fractional release rates and of (2) total releases during a 10,000-year period. These curves, for the case in which radionuclide solubility values are assumed to have a uniform distribution, are shown in Figures 6-19 and 6-20. For ease of comparison, the curves for all nine radionuclides are presented in the two figures and at a common scale.

The sensitivity of fractional and total releases to the assigned probability distribution of radionuclide solubility is indicated in Table 6-21. In this table, values at the 90 percent confidence level are shown (i.e., the probability is 90 percent that the actual values will be less than or equal to those in this table). From Table 6-21, it is apparent that the current waste package design does not meet the U.S. Nuclear Regulatory Commission fractional release criterion in 10 CFR 60 for iodine-129, for any of the three assumed probability distributions for solubility. However, the cumulative release of iodine at the waste package boundary is far less than the U.S. Environmental Protection Agency limit because of its small inventory in spent fuel. At the 90 percent confidence level, maximum fractional releases of carbon-14, selenium-79, tin-126, and technetium-99 are estimated to be close to the U.S. Nuclear Regulatory Commission criterion. The criterion is not exceeded (except for selenium-79) if a lognormal probability distribution is assigned to solubility values. Additional data on solubilities of these four nuclides are needed before likelihood of the waste package meeting the fractional release criterion confidently can be predicted. The fractional release rates of the remaining radionuclides (i.e., neptunium-237, plutonium-239, -240, and -242) are far less than the U.S. Nuclear Regulatory Commission criterion.

Results. Stochastic simulations of waste package performance were conducted to examine the effects of radionuclide solubilities on the predicted results. The analysis focused on calculations of containment

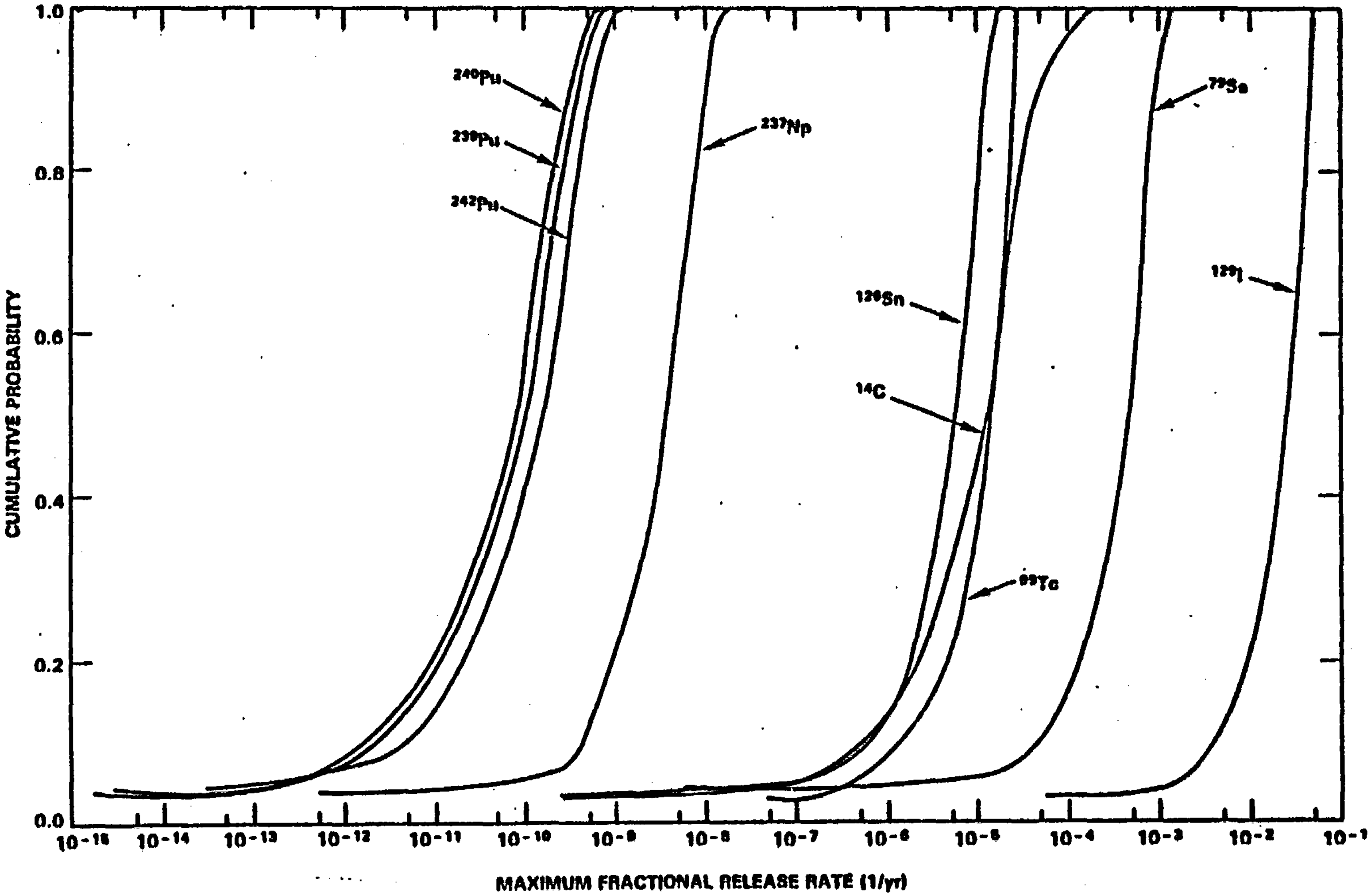

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Figure 6-19. Maximum fractional release at the waste package boundary. A uniform probability distribution is assumed for radionuclide solubility and adsorption values.

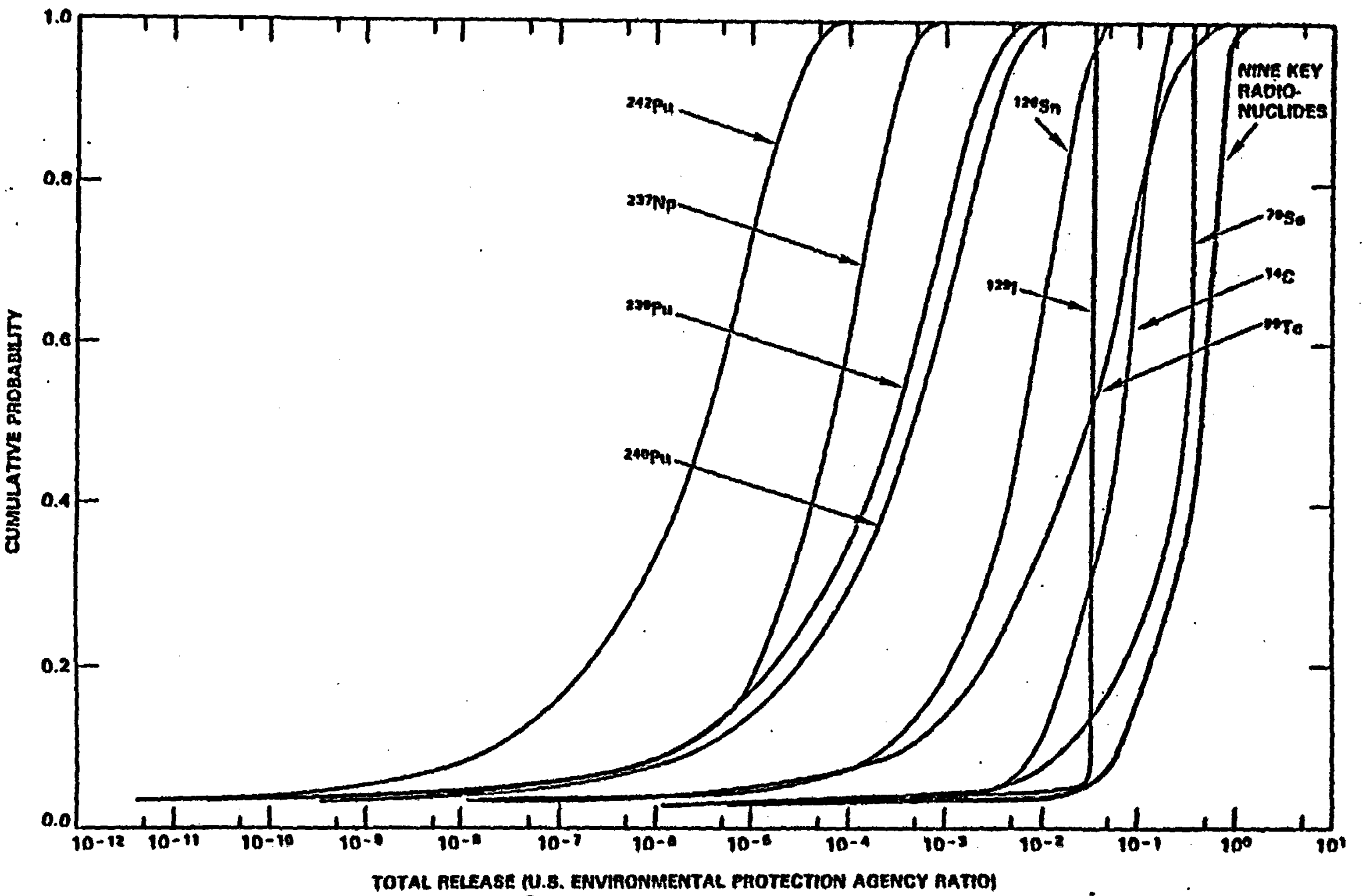

Figure 6-~~19~~ 20. Total cumulative release at the waste package boundary. (uniform probability distribution assumed for radionuclide solubility). A ... is ... and adsorption values

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Table 6-21. Radionuclide releases from the waste package subsystem boundary[a] at 90 percent confidence level.

Radionuclide	Maximum fractional rate (per yr.)[a]			Total release (EPA[b] ratio)[a]		
	Distribution for solubility values					
	Uniform	Loguniform	Lognormal	Uniform	Loguniform	Lognormal
Carbon-14	2.2×10^{-3}	1.2×10^{-4}	4.8×10^{-6}	1.3×10^{-1}	6.3×10^{-1}	2.9×10^{-2}
Iodine-129	4.2×10^{-2}	3.0×10^{-2}	1.7×10^{-2}	3.3×10^{-2}	3.3×10^{-2}	3.3×10^{-2}
Selenium-79	9.8×10^{-4}	3.6×10^{-4}	1.2×10^{-4}	3.2×10^{-1}	3.1×10^{-1}	7.7×10^{-2}
Tin-126	1.3×10^{-5}	1.3×10^{-5}	8.9×10^{-7}	2.3×10^{-2}	1.7×10^{-2}	6.1×10^{-4}
Technetium-99	4.7×10^{-5}	1.2×10^{-5}	2.2×10^{-6}	1.8×10^{-1}	3.1×10^{-2}	5.0×10^{-3}
Neptunium-237	9.3×10^{-9}	5.9×10^{-9}	3.3×10^{-9}	3.2×10^{-4}	1.8×10^{-4}	8.1×10^{-5}
Plutonium-239	3.7×10^{-10}	7.5×10^{-11}	8.0×10^{-12}	1.9×10^{-3}	3.1×10^{-4}	9.8×10^{-5}
Plutonium-240	2.8×10^{-10}	5.5×10^{-11}	6.5×10^{-12}	3.3×10^{-3}	5.2×10^{-4}	1.1×10^{-4}
Plutonium-242	5.7×10^{-10}	3.0×10^{-10}	6.6×10^{-11}	2.2×10^{-5}	9.1×10^{-6}	1.8×10^{-6}

[a]No credit taken for the contribution to waste package subsystem performance provided by spent fuel cladding. Calculations are for releases from a single, typical waste package and do not account for the overall inventory of waste packages.

[b]U.S. Environmental Protection Agency.

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times and radionuclide releases for radionuclides determined to be of potential concern. For the range of cases considered in the analysis, the results generally indicate the following:

- The container alone is expected, with high probability, to provide substantially complete containment of the radionuclides for more than 1,000 years.

- The fractional release rates at the waste package subsystem boundary, calculated for neptunium-237, plutonium-239, -240, and -242, should comply with the U.S. Nuclear Regulatory Commission criteria with high confidence. Calculated release rates for carbon-14, selenium-79, tin-126, and technetium-99 indicate that compliance with the release limit criterion depends on the model input for radionuclide solubility. The calculations for iodine-129 indicate that compliance with the fractional release rate limit is unlikely, by the current waste package design, because of the apparently high solubility of iodine, its nonadsorption property, and long half-life. Noncompliance for the fractional release rate of iodine-129 may be an artifact of conservative estimates of solubility. Additional laboratory investigations are needed to confirm or refine the theoretically derived values for iodine-129 solubility. The U.S. Nuclear Regulatory Commission criteria provide that alternative release limits may be specified. A higher fractional release limit for iodine is justifiable on the basis of its relatively small inventory in spent fuel.

- For all probability distributions of solubility and all radionuclides, the cumulative releases during 10,000 years have a high probability (i.e., greater than 0.90) of meeting the U.S. Environmental Protection Agency limits at the waste package subsystem boundary.

The latter preliminary result is particularly noteworthy because it suggests that the waste package subsystem could indeed act as a diverse and redundant barrier to the primary isolation barrier of the site subsystem. In addition, because of the expected long containment times, protection of major ground-water sources for 10,000 years could also be assured.

6.4.2.3.4 Repository seals subsystem performance

The basic function of the repository seals subsystem is to provide an engineered barrier to potential radionuclide migration. The barrier components of this subsystem, which are described in Subsection 6.4.2.2.2, are located between the waste package and site subsystems. Plausible pathways through the repository seals subsystem are in the emplacement room backfill and underground opening seals, the host rock of the emplacement horizon, and the disturbed rock zone surrounding the excavation. Of these three pathways, the fastest path is expected to be through the disturbed rock zone because of its higher permeability.

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In this subsection, ~~an assessment of~~ potential cumulative radionuclide releases through the disturbed rock zone ~~is presented.~~ The assessment is based on probabilistic computer simulations of potential releases during a 10,000-year period after closure. The performance of the repository seals subsystem is examined with and without the isolation contribution of the waste package subsystem. The computer simulations are used as a basis for evaluating the likelihood that the repository seals subsystem by itself would meet the U.S. Environmental Protection Agency standard.

Methodology. The approach developed for probabilistic evaluation of the repository seals subsystem was to calculate cumulative release during 10,000 years at the designated subsystem boundary, with releases normalized to the limits proposed in 40 CFR 191 (EPA, 1984). For purposes of introducing conservation, the present analysis specifies waste package containment time as zero, and release rates higher than those predicted in Subsection 6.4.2.3.3. Radionuclide transport is assumed to take place entirely by ground-water flow through the disturbed rock zone of the repository seals subsystem pathway.

The calculation of radionuclide release from the repository seals subsystem is based on a conceptual model illustrated in Figure 6-21. Releases from the repository seals subsystem were calculated at a boundary located at the intersection of the vertical access shafts with the Vantage interbed at the top of the Grande Ronde Basalt, a distance of approximately 133 meters (436 feet) above the emplaced waste. To introduce conservatism, the analysis assumes that 100 percent of the quantity of radionuclides released from the waste package migrates directly through the repository seals subsystem pathway, and 0 percent through the site subsystem. In essence, the repository seals subsystem is assumed to be a preferential pathway. A three-dimensional analysis of flow pathways for a repository in the basalt (Golder, 1983) estimated that only about 0.1 to 2.0 percent of the vertical ground-water flow entering the repository area then moves horizontally and enters the vertical shafts directly at the repository level. Approximately 0.2 to 6.5 percent of the ground-water flow across the repository area could traverse the emplacement horizon and then enter the vertical shafts by indirect pathways (Golder, 1983). Similar three-dimensional ground-water flow simulations conducted by Rockwell Hanford Operations (Cottam, 1983) have also indicated that less than 1 percent of the total ground-water flow through the repository is likely to enter the repository seals subsystem pathway.

As indicated by Figure 6-21, radionuclide migration along the repository seals subsystem pathway is assumed to be through the damaged annulus of rock around each opening, rather than through the backfill material placed in the openings at permanent closure. This assumption is conservative because, for the relative ranges of hydraulic properties expected for the damaged rock and backfill, ground-water velocity will be much greater through the damaged rock zone than through the backfill. The calculation of ground-water travel times through the repository seals subsystem was based on Darcy's law, which relates ground-water velocity to

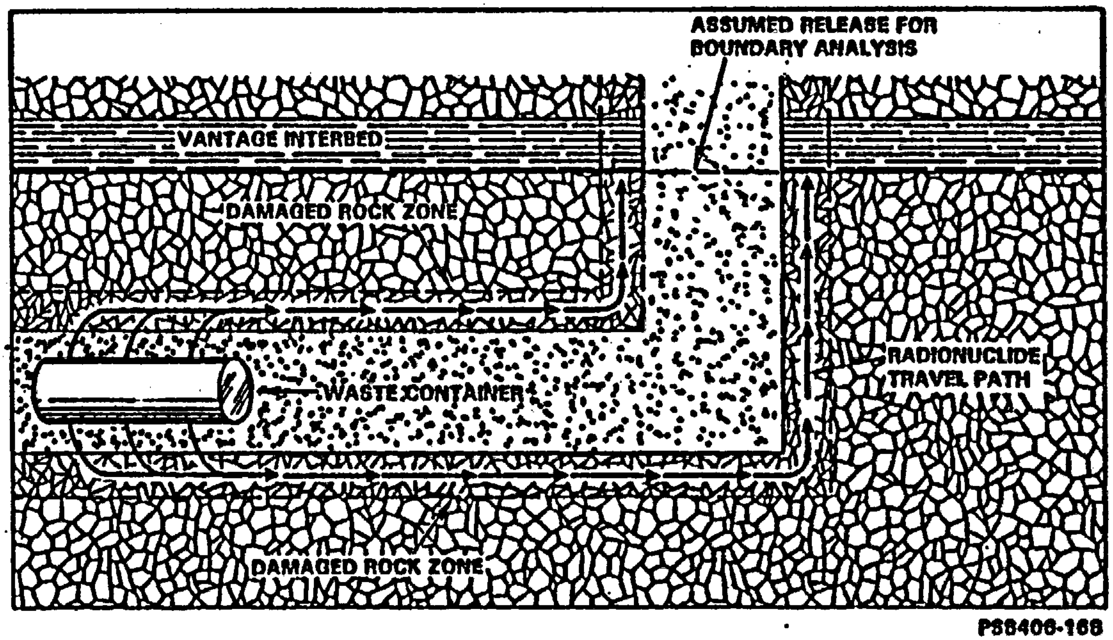

Figure 6-~~20~~21. Conceptual model used in repository seals subsystem performance assessment.

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porosity, hydraulic conductivity, and hydraulic gradient. The dominant hydraulic gradient is in a vertical direction, and is partially thermal-induced due to decay heat from the emplaced waste. The magnitude of the hydraulic gradient will consequently decrease with time, approaching the pre-emplacement hydraulic gradient after long time periods. Therefore, the radionuclide release rate and ground-water velocity through the shaft are also time-dependent, and were modeled as such.

Radionuclide releases at the repository seals subsystem boundary were computed using a probabilistic computer code (REPSTAT; see Sonnichsen, 1984). Parameters affecting radionuclide release rates from the waste package and radionuclide travel times to the subsystem boundary were assumed to be statistically distributed, based on specified probability density functions. Monte Carlo sampling was used to select values from those distributions as inputs to numerical models for calculation of waste package release rates, ground-water travel times, and cumulative radionuclide release. A cumulative probability curve for total radionuclide release was then constructed from the spectrum of the computer simulations.

In the reference case, the computer codes MAGNUM-2D and CHAINT (Baca et al., 1984b) were used to generate release rate curves as functions of time for a specified radionuclide, and for a specified set of values for parameters affecting the waste package release rate. A representation of ground-water flow around the waste package was generated using MAGNUM-2D. The code CHAINT computed the radionuclide concentration profile as a function of time in the region of the waste package, and the mass transport rate across the waste package boundary. Mass transport by diffusion, dispersion, and advection ~~were~~ was included in this analysis.

The release rate curves generated by the CHAINT computer code (Baca et al., 1984b) were approximated by linear and exponential functions in REPSTAT. The magnitudes of the release rates were varied in each Monte Carlo trial in REPSTAT according to the ratios of the radionuclide solubilities selected by the sampling process to the solubilities assigned in the CHAINT analysis. This process gave rise to stochastic distributions for waste package release rates that were then used in REPSTAT to generate cumulative probability curves for total radionuclide release from the waste package. As discussed in Subsection 6.4.2.3.3, the computer code CHAINT-MC (Baca et al., 1984b) was also used to generate cumulative probability curves for total radionuclide release from the waste package. These cumulative probability curves were then compared to those generated by REPSTAT. The release rates in REPSTAT were subsequently scaled to bring the cumulative probability curves for solubility from the REPSTAT and CHAINT-MC waste package analyses (for the case of uniform distributions for solubility) into close agreement. To simulate the case of minimal waste package performance, and to assure compatibility with the site subsystem analysis (see Subsection 6.4.2.3.5), these release rates were then increased by an additional scaling factor of 3.0. This factor is the approximate ratio of waste package release rates used in the site subsystem analysis to the release rates predicted by the computer code CHAINT-MC (see Subsection 6.4.2.3.3) using uniform probability distributions of solubility values.

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Data set for repository seals subsystem. The data used in this preliminary performance assessment of the repository seals subsystem are given in Table 6-22. In addition to the values for hydraulic conductivity in the damaged rock annulus indicated in the table, cumulative probability curves for total radionuclide release were generated for mean hydraulic conductivities of 10^{-9}, 10^{-8}, and 10^{-7} meters per second (approximately 10^{-4}, 10^{-3}, and 10^{-2} feet per day) in the damaged rock zone.

Results. The cumulative probability curves for total radionuclide release from the repository seals subsystem are shown in Figure 6-22. The vertical axis of the graph is the probability that the total radionuclide release at the subsystem boundary (during 10,000 years) is less than or equal to the value on the horizontal axis (expressed as fractions of the U.S. Environmental Protection Agency limit).

Separate distribution functions were generated for different mean values of hydraulic conductivity in the damaged rock zone to assess the sensitivity of radionuclide releases to this parameter. For mean hydraulic conductivities of 10^{-10} meters (3.28×10^{-10} feet) per second, zero release in 10,000 years was calculated for 1,000 Monte Carlo trials. Zero release for 1,000 Monte Carlo trials corresponds to the horizontal line at the top of Figure 6-22. This result means that there is a probability of 1.0 that release at the repository seals subsystem boundary is less than the minimum release value on the horizontal axis of Figure 6-22. In no single Monte Carlo trial, for all cases analyzed, did the calculated cumulative release exceed the U.S. Environmental Protection Agency limit of 1.0. In all cases, what releases did occur were attributable solely to the nonsorptive radionuclides, iodine-129 and carbon-14.

The principal reasons for the low calculated values of cumulative release are: (1) a low hydraulic driving force in the plane of the placement rooms and access drifts, (2) the relatively long path lengths through the repository seals subsystem and, consequently, long ground-water travel times, and (3) chemical retardation effects on the migration of adsorbing radionuclides. As a result, only carbon-14 and iodine-129, which are not adsorbed along the flow paths, arrive at the repository seals subsystem boundary, in quantities less than the EPA limit, in less than 10,000 years. The mean calculated releases for the cases analyzed are given in Table 6-23.

6.4.2.3.5 Site subsystem performance

The performance measures for the site subsystem are: (1) pre-waste-emplacement ground-water travel times, and (2) post-waste-emplacement radionuclide releases to the accessible environment. This section presents an analysis of these two performance measures. The stochastic analyses of ground-water travel times suggest the range of travel times in the basalts that plausibly may be expected, as well as the associated probabilities for specific travel times. The stochastic analysis is limited to consideration of only one conceptual model for ground-water

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Table 6-22. Data set for assessment of the repository seal subsystem.

Parameter	Median value	Distribution	Standard deviation[a]
Hydraulic gradient			
Constant horizontal	5.0×10^{-4}	lognormal	1.0
Constant vertical	10^{-3}	lognormal	1.0
Decaying vertical (initial gradient value)	2.9×10^{-2}	lognormal	1.0
Half-life (yr) of initial decay	1,100	lognormal	1.0
Hydraulic conductivity (K)			
Zone of damaged rock around repository seal subsystem	10^{-10} m/s	lognormal	2.30
Porosity (Φ)	$2.15 \times K(m/s)^{1/3}$	c	c
Sorption, Retardation factor (R)	$1 + \rho \times K_d/\Phi$	c	c
Repository geometry			
Borehole diameter	89.0 cm	discrete	b
Borehole length	6.1 m	discrete	b
Emplacement room length	920.0 m	discrete	b
Access drift length			
minimum	322.0 m	discrete	b
maximum	1,929.0 m	discrete	b
Shaft path length	133.0 m	normal[d]	b

[a]Standard deviation for the normal distribution of the natural logarithm of the parameter, except where otherwise indicated.

[b]Not applicable.

[c]Distribution of parameter is governed by distribution of input variables.

[d]A normal distribution was used to account for variations in the basalt flow thickness, except that only values less than or equal to 133.0 were used.

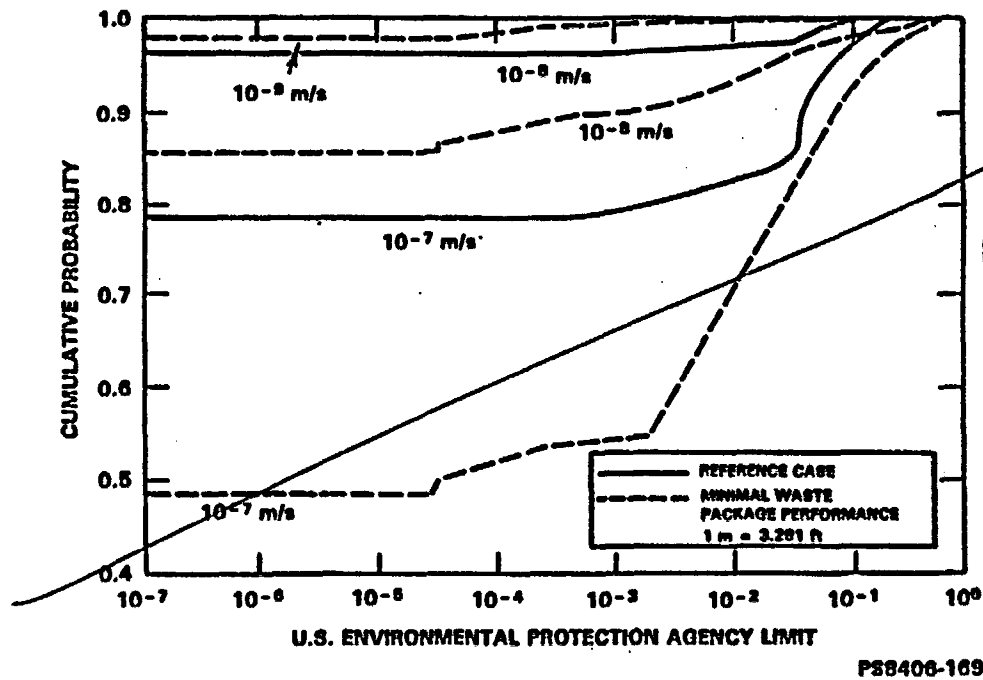

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FIGURE 6-22. TOTAL CUMULATIVE RADIONUCLIDE RELEASE AT THE REPOSITORY SEALS SUBSYSTEM BOUNDARY FOR VARIOUS MEAN CONDUCTIVITY VALUES.

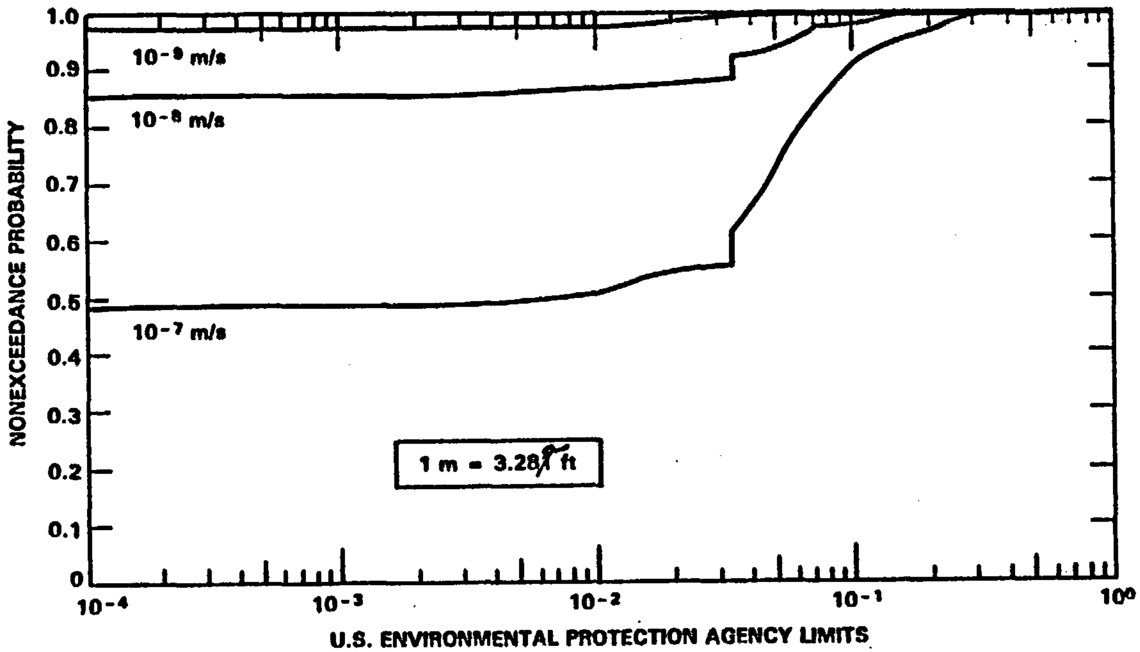
NONEXCEEDANCE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10⁻⁹ m/s
10⁻⁸ m/s
10⁻⁷ m/s
1 m = 3.281 ft
10⁻⁴
10⁻³
10⁻²
10⁻¹
10⁰
U.S. ENVIRONMENTAL PROTECTION AGENCY LIMITS

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Table 6-23. Mean (average) cumulative radionuclide release at the repository seal subsystem boundary during 10,000 years.

Mean hydraulic conductivity in the damaged rock zone (m/s)[a]	Release[b]
10^{-10}	0.0
10^{-9}	7.1×10^{-4}
10^{-8}	8.6×10^{-3}
10^{-7}	3.8×10^{-2}

[b] U.S. Environmental Protection Agency limits.

[a] 1 m = 3.28 ft.

Can we put the conversions on the table?

m/s (ft/s)

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flow paths. Other conceptual models of (see Subsection 3.3.2.2) ground-water flow through the basalts (Gephart et al., 1983) will be considered by future studies. Additional details of the stochastic analysis of ground-water travel times are presented in Clifton (1984).

Ground-water travel times. In general, ground-water travel time along a given pathline is a function of (1) transmissivity (or hydraulic conductivity), (2) effective thickness (or effective porosity), and (3) hydraulic gradient. Ground-water travel time is also a function of storage coefficient (or specific storage) if the ground-water flow regime is transient. The uncertainty in a predicted travel time depends on the spatial variability of the hydrogeologic parameters and the hydraulic gradients. The degree of this uncertainty can be represented by a probability distribution for predicted travel times that reflects the uncertainty and encompasses the range of plausible values.

For this analysis, the ground-water travel time is averaged over a relatively large distance (10 kilometers (6.2 miles)) and the hydrogeologic parameters are defined at a macroscopic scale that is significantly larger than the size of individual pores within which the flow actually occurs. Thus, the range of travel times in the probability distribution is not representative of the microscale variations in ground-water velocities that occur within and among the pores through which flow occurs.

Modeling approach. As was the case for the other subsystem performance analyses, the method used to stochastically simulate ground-water travel times was based on a Monte Carlo sampling technique (Clifton et al., 1983). First, a set of random-parameter spatial fields (e.g., representation of a medium consisting of a network of discrete blocks) was generated for the area of ground-water flow of interest. These spatial fields were subsequently input to the ground-water flow and travel-time equations. The solutions of these equations were the corresponding sets of ground-water travel times that were then used to construct the cumulative probability curves for ground-water travel times.

The computer code MAGNUM-MC was used to generate the stochastic simulations of pre-waste-emplacement ground-water travel times. MAGNUM-MC is a stochastic version of the finite-element computer code MAGNUM-2D, which simulates the coupled processes of ground-water flow and heat transfer in two-dimensions. A detailed description of the theoretical basis of MAGNUM-2D is given in Baca et al. (1984b).

The U.S. Nuclear Regulatory Commission criterion governing pre-waste-emplacement ground-water travel times states that "travel time along the fastest path of likely (post-waste-emplacement) radionuclide travel from the disturbed zone around the repository to the accessible

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environment. . .be at least 1,000 years" (NRC, 1983a). Disturbed zone is defined in 10 CFR 60 (NRC, 1984) as follows:

> "Disturbed zone means that portion of the controlled area whose physical or chemical properties have changed as a result of underground facility construction or from heat generated by the emplaced radioactive wastes such that the resultant change of properties may have a significant effect on the performance of the geologic repository."

An issue arising from the definition of disturbed zone is whether a "significant effect on the performance of the geologic repository" is a reason for excluding the disturbed zone's contribution to the estimated ground-water travel time. Substantial changes in the disturbed zone may occur as a result of mechanical, thermal, or chemical damage to the host rock near the waste packages. Physical changes, induced either by excavation or by thermal stresses imposed by the emplaced waste are likely to modify permeability of the host rock. The extent and magnitude of the effect are dependent on several factors, including drilling method and induced temperature, but for the range of methods and temperatures anticipated for a repository in basalt, the changes in permeability that occur beyond one radius from the emplacement hole/host rock interface are not likely to significantly affect repository performance (LBL, 1983).

The principal chemical changes (resulting from increased temperature) that could adversely affect performance are (1) alteration of clays (present as filling in the natural host rock fractures) to less sorptive phases, and (2) reduction of pH, with attendant increase in solubility for certain chemical species. However, the temperatures at which such alteration have been observed to occur in smectite clays typical of basalt secondary mineralization are substantially above the temperatures that will be induced by heat from the emplaced waste (Palmer et al., 1983). Changes in the pH are predictible and are not expected to cause significant, long-term increases in solubility. Chemical changes are, therefore, not anticipated to significantly disturb the host setting.

Two potentially favorable thermal effects have been hypothesized but have not been incorporated into this performance analysis. Omission of these favorable effects introduces an indeterminate conservatism into the overall assessment. First, thermally induced expansion stresses near the waste package could reduce fracture apertures and, therefore, reduce permeability. Second, sorptive minerals that precipitate a very short distance from a waste package in response to decreasing temperature may, in fact, clog rock pores and reduce matrix permeability.

The radial extent of significant induced fracturing resulting from blast damage and from relaxation of the rock surrounding the excavated opening typically ranges from approximately one radius beyond the borehole wall to a few radii beyond the borehole wall (LBL, 1983). This range is comparable to or less than the uncertainty in the average entablature thickness. As a result, an allowance of one or more emplacement hole

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radii for the width of the disturbed zone, in conjunction with a conservatively estimated entablature thickness, should provide a reasonable basis for analysis of pre-emplacement ground-water travel time.

In this analysis, no attempt was made conservatively to define the actual extent of the disturbed zone. Instead, the origin of the pathlines used to calculate ground-water travel time was assumed to be a point in the candidate horizon flow top immediately overlying the downstream edge of the repository. Ground-water travel time required for vertical flow between the repository and the overlying flow top was not taken into account in this analysis. However, if this vertical component of ground-water flow were considered, all travel times would be longer (see Clifton, 1984).

The accessible environment in this analysis was defined to be a boundary 10 kilometers (approximately 6.2 miles) downstream from the origin of the pathlines. This definition of accessible environment is consistent with the definition in Working Draft 4 of the U.S. Environmental Protection Agency standards (EPA, 1984).

The term accessible environment is defined in 40 CFR 191 (EPA, 1984)as a summation of the

> "(1) atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, (5) portions of the lithosphere that are beyond the controlled area* and the designated area, and (6) major sources of ground water that are beyond the controlled area or that are more than 2 kilometers (approximately 1.2 miles) in a horizontal direction from the original location of any of the radioactive wastes in a disposal system, whichever distance is greater."

As shown in Figure 6-23, certain aspects of this definition of accessible environment are unequivocal:

1. Surface waters and the atmosphere are part of the accessible environment at all distances.

2. The lithosphere is part of the accessible environment at all depths for distances beyond 10 kilometers (approximately 6.2 miles) from the repository.

3. The lithosphere is excluded from the accessible environment at all depths for distances within 2 kilometers (approximately 1.2 miles) of the repository.

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*See the referenced regulation for definitions of specialized terms used within these broader definitions.

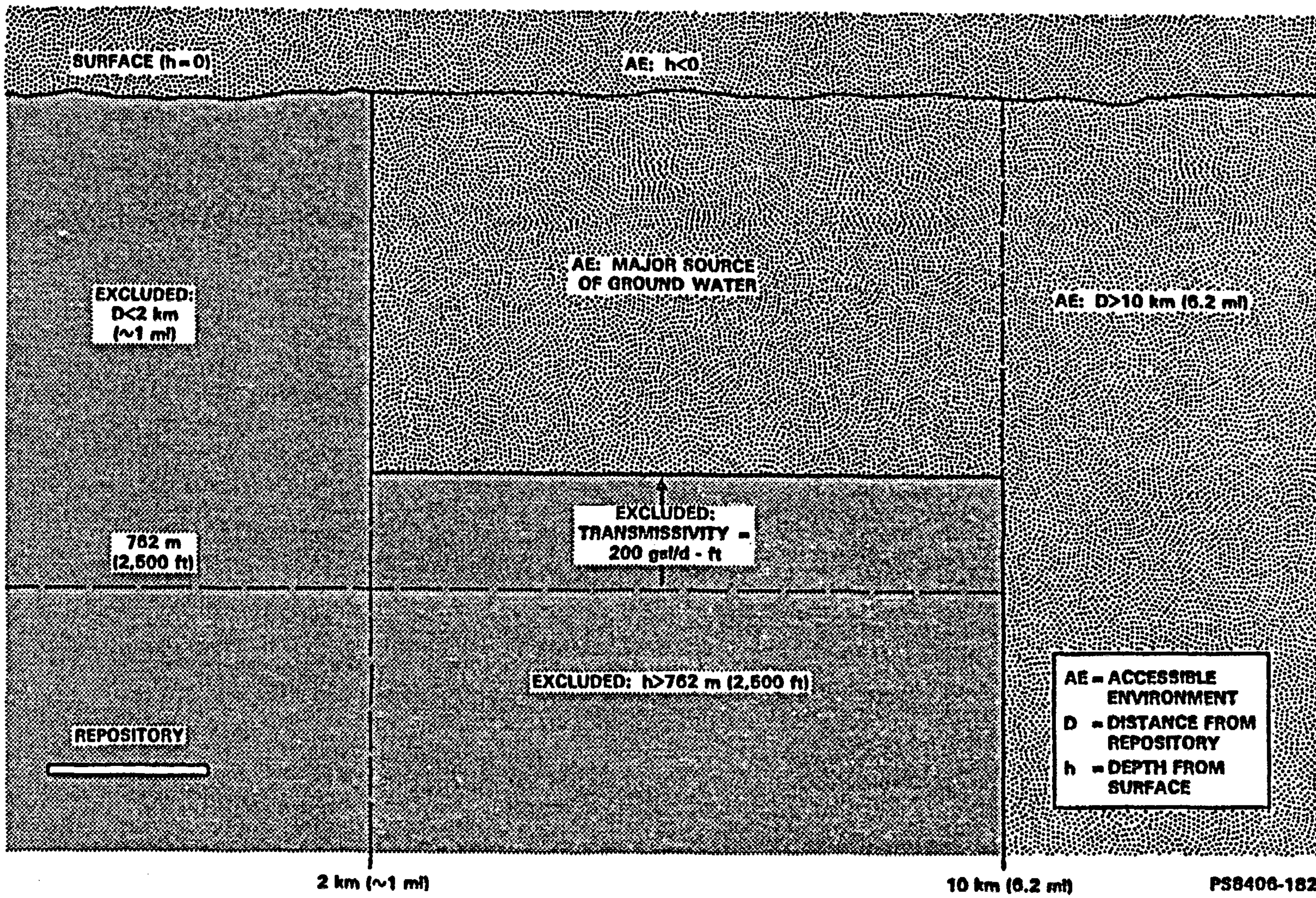

FIGURE 6-23. DEFINITION OF ACCESSIBLE ENVIRONMENT BOUNDARY

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4. Based on the definition of "major sources of ground water," the lithosphere is excluded from the accessible environment at depths below approximately 762 meters (2,500 feet) and at a distance less than 10 kilometers (approximately 6.2 miles) from the repository.

The hydrologic constraints stipulated in the definition of major sources of ground water could be applied to the area are shown in Figure 6-23 to divide that area into a portion included within the accessible environment and a portion excluded from the accessible environment. Ideally, the boundary would be a horizontal line and the final assignments of the restrictive terms, "included" or "excluded," would result in a designation as shown in Figure 6-23, with the excluded portion being defined as aquifers (above 762 meters (2,500 feet)) with a transmisivity less than 200 gallons per day per foot.

Definition of the term accessible environment affects how checks for compliance with the 40 CFR 191 (EPA, 1984) are made. Radionuclide transport from the repository can be envisioned to occur along various pathways originating throughout the repository and reaching the accessible environment at various points along the stair-step-shaped boundary shown in Figure 6-23. If the likely radionuclide pathways are the flow tops immediately above the repository, which are deeper than 762 meters (2,500 feet) below the surface, then the most important path lengths would be 10 kilometers (approximately 6.2 miles), despite the possibility that some radionuclides might reach the accessible environment at lesser distances. The performance assessment presented in this document is based on assignment of the first flow top above the repository as the principal flow path for most rapid radionuclide transport to the accessible environment. The possibility that other flow paths may be significant is clearly recognized, and the site characterization efforts are directed at defining the conceptual model that best portrays the actual physical system (see Subsection 3.3.2.2 and Gephart et al., 1983).

Data set for travel time analysis. Ground-water travel times were modeled stochastically in a continuous, flat-lying basalt flow top overlying the emplacement horizon (see Subsection 6.4.2.2.3). Ground-water flow in this basalt flow top was assumed to be steady-state, rather than transient.

Within the Cold Creek syncline, there are sufficient field data for ground-water transmissivity of Grande Ronde Basalt flow tops to statistically infer a governing log-normal probability distribution. The geometric mean of these transmissivities is 0.153 square meters (1.7 square feet) per day, and the standard deviation of log-transmissivity is 1.83. However, only a small amount of transmissivity data is available from the flow top of each basalt flow currently being considered as a candidate repository horizon. Therefore, the probability distributions of transmissivities within each candidate horizon flow top were assumed to be the same as the probability distributions of transmissivities from all Grande Ronde Basalt flow tops.

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In a first case, transmissivity was modeled stochastically while effective thickness and boundary conditions were assigned. The stochastic model developed was of a 10- by 20-kilometer (approximately 6- by 12-mile) "representative" Grande Ronde Basalt flow top in the Cold Creek syncline. This representation was a grid in which different values of transmissivity were probabilistically specified for each grid block.

Interpretations of available data suggest a preliminary conceptual model of ground-water flow in the deep basalts of the Cold Creek syncline in which ground water flows in a southeasterly direction with low hydraulic gradients (Gephart et al., 1983; also see Subsections 3.3.2 and 6.3.1.1.6). Because of these low gradients, assignments of boundary conditions to the model are difficult. The assignment of an effective thickness to the model is also difficult because such thicknesses have been determined within the deep basalts of the Cold Creek syncline at only one location (Gelhar, 1982; Leonhart et al., 1982; also see Subsection 3.3.2.1.2). A constant regional hydraulic gradient of 10^{-3} meters per meter (10^{-3} foot per foot) was used for the flow top. This gradient is approximately one order of magnitude greater than most of the gradients thus far observed in the deep basalts of the Cold Creek syncline. The effective thickness of 4×10^{-2} meters (0.13 feet) is the product of an assigned effective porosity of 5×10^{-3} for the flow top and a mean apparent thickness of Grande Ronde Basalt flow tops of 8 meters (approximately 26 feet). This effective porosity is believed, on the basis of currently available information, to be representative of effective porosities of deep basalt flow tops at a scale comparable to the scale of this modeling study. Only two field-derived effective thicknesses for a flow top of the Grande Ronde Basalt beneath the Hanford Site are currently available (Leonhart et al., 1982). The range of effective porosities suggested by this test includes the effective porosity used in this analysis.

In the second case, similar computer simulations were performed, but the hydraulic gradient, as well as transmissivity, was varied in a probabilistic manner (Clifton, 1984). The value for effective thickness was fixed, rather than varied probabilistically.

A third case was analyzed in which the effective thickness, transmissivity and hydraulic gradient were all varied probabilistically. Thus, the third case represents a probabilistic simulation of ground-water flow in which all three hydraulic properties are treated as uncertain and spatially variable parameters.

For the latter two cases, probability distributions were estimated for the regional hydraulic gradient and effective thickness. In general, there are fewer data available to determine the probability distributions for these inputs than are available for transmissivities. To compensate for this lack of data, the regional hydraulic gradient and effective thickness were assigned uniform probability distributions over plausible ranges. The assigned regional hydraulic gradient ranged between 10^{-4} and 10^{-3}. The assigned effective thickness was considered to be

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homogeneous within the model boundary, and ranged between 10^{-3} and 10^{-1} meters (3.28×10^{-3} and 3.28×10^{-1} feet). This range of effective thicknesses includes the two effective thicknesses determined within the deep basalts of the Cold Creek syncline (Leonhart et al., 1982).

Refer to Sections 3.3.2, 4.1, and Subsection 6.3.1.1.11.3 for discussions on data availability, uncertainty, and site characterization plans.

Principal results. Stochastic simulations of horizontal ground-water movement along a basalt flow top were conducted to examine the effects of hydraulic properties and their uncertainties on predicted ground-water travel times. As described in detail above, simulations for three cases were made:

(1) Ground-water transmissivity of the flow top is analyzed as a stochastic parameter (i.e., represented by a probability distribution) while the hydraulic gradient and effective thickness are held constant.

(2) Transmissivity and hydraulic gradient analyzed as stochastic parameters while effective thickness is held constant.

(3) Transmissivity, hydraulic gradient, and effective thickness are treated as stochastic parameters.

Probability curves for ground-water travel time from the repository to the accessible environment boundary at 10 kilometers (6.2 miles) were calculated and then graphically compared (Fig. 6-24). The median ground-water travel times for the three cases are:

Simulation case	Median ground-water travel time	Standard deviation of log-travel-time
1	17,000	0.71
2	86,000	0.77
3	81,000	0.96

The results of the first case show a shorter median travel time that reflects the conservative values assigned for hydraulic gradient and effective thickness. Results for the latter two cases show significantly longer median travel times. This reflects a lower mean gradient and higher mean effective thickness than was used in the deterministic analysis of case No. 1. As expected, case No. 3 shows a higher standard deviation than the first two cases because of the additive effects of the spread about the mean values. Overall, the results indicate that even though there is a relatively large variation in flow top hydraulic properties, the median ground-water travel times could be very long.

Under the conditions and assumptions of this analysis, the results indicate that for all three cases the probability of ground-water travel times exceeding 1,000 years could range from approximately 0.95 to more than 0.99. At these high confidence levels, the site subsystem would likely be considered in compliance with the U.S. Nuclear Regulatory Commission criterion for pre-waste-emplacement ground-water travel time.

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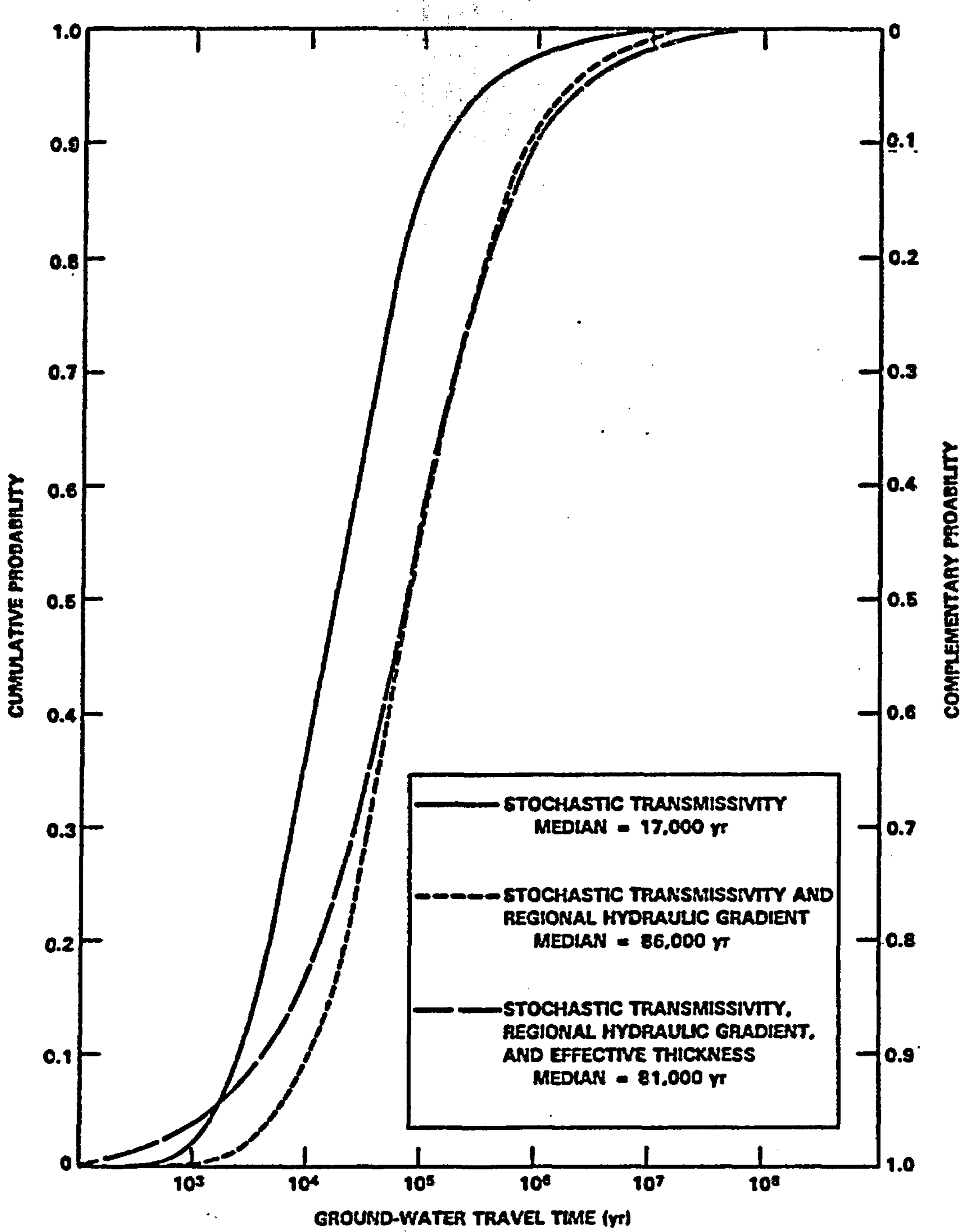

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FIGURE 6-24. PROBABILITY CURVES FOR GROUND WATER TRAVEL TIMES FROM THE REPOSITORY TO THE ACCESSIBLE ENVIRONMENT ALONG THE CANDIDATE HORIZON FLOW TOP

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These predicted ground-water travel times are particularly noteworthy in view of the fact that they: (1) consider large uncertainties in the hydraulic properties of the site subsystem, and (2) do not account for additional ground-water travel time through the emplacement horizon (flow interior). For a discussion of additional ground-water travel time afforded by the emplacement flow interior see Clifton (1984).

Radionuclide releases. The analysis of radionuclide releases from the site subsystem assumes that the spent fuel waste form is inserted directly into the dense interior of the basalt flow comprising the repository horizon. Thus, additional radionuclide containment afforded by the waste container and the zircaloy cladding, and restriction of release rate by packing material surrounding the container are assumed not to exist. The method, data, and results for preliminary analysis of releases from the site subsystem are presented in the following subsections.

Modeling approach. The basic premise of this site subsystem analysis is that physical and chemical barriers to radionuclide release and transport are provided only by the characteristics of the basalt formations beneath the Hanford Site. The approach used in this site subsystem analysis has four elements:

1. A conceptual model of the geologic setting that portrays features, conditions, and processes important to site subsystem behavior.

2. A mathematical model and submodels that represent the conceptual model and transport processes.

3. A data base that includes estimates of data uncertainty.

4. Identification and understanding of the nature, effects, and likelihood of disruptive events and processes that might significantly alter the undisturbed behavior of the subsystem.

The radionuclide release at the accessible environment boundary was calculated using the computer code EPASTAT (see Sonnichsen, 1984). The code is a one-dimensional calculation of radionuclide release from a point-source through a homogeneous pathway. The analysis is further simplified by excluding diffusion and dispersion effects, dead-end pore diffusion, and radionuclide daughter-product production--all of which are conservative assumptions. The principal input and output parameters are shown in Figure 6-25. The ground-water travel times were obtained from the analysis discussed in the previous subsection and in Clifton (1984). Uncertain parameters were represented by probability distributions, and a Monte Carlo sampling routine was used to select a data set for each simulation. The summation of values for the ratio of release contribution to allowable release provided a release term for each input vector. The release terms, when plotted in ascending order of release, display the fraction of samples for which release is less than a specified value.

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INPUTS

- GROUND-WATER TRAVEL TIME
- WATER (SOLVENT) FLOW RATE
- RADIONUCLIDE SOLUBILITIES
- RADIONUCLIDE RETARDATION FACTORS
- RADIONUCLIDE INVENTORIES
- TIME LIMIT (USUALLY 10,000 yr)
- U.S. ENVIRONMENTAL PROTECTION AGENCY ALLOWABLE LIMITS
- MATRIX DISSOLUTION DURATION

OUTPUT

- PROBABILITY CURVE FOR CUMULATIVE RELEASE (EXPRESSED IN MULTIPLES OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY ALLOWABLE LIMIT)

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Figure 6-25. Principal input/output model for analysis of radionuclide release from the site subsystem.

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Data set for radionuclide release analysis. Radionuclide data for the analysis are shown in Table 6-18. Hydrologic variables for the analysis are shown in Table 6-24. The indicated radionuclide solubility ranges encompass measured values and their uncertainties estimated from experiments relevant to the expected repository environment. The retardation factors for adsorbed radionuclides, also based on experimental data, are sufficiently high that such radionuclides have little or no impact on releases to the accessible environment (see discussion in Subsection 6.4.2.3.2).

Few experimental data describe solubility under appropriate environmental conditions; consequently, probability distributions were used to represent data estimates and uncertainties. The information shown in Table 6-18 is intended to reflect prudent interpretation of the available data. The assumed distributions of retardation factors for probabilistic analysis are based on the expected retardation factor as the mean, and one order of magnitude as the standard deviation. This results in the conservative estimate of retardation factor being approximately two standard deviations below the mean, which is a reasonable representation of the uncertainty distribution.

The ground-water travel time distribution used in this preliminary analysis of radionuclide releases is an approximation of results of the previous stochastic analysis of ground water leaving the downstream edge of a repository located in the Cohassett flow (Clifton et al., 1983; also see discussion of ground-water travel times in Subsection 6.4.2.3.5 and Clifton, 1984). Emphasis in defining the input for the EPASTAT analysis focused on matching computed travel times that are less than the median travel time, because higher values of travel time yield zero or very low releases for the duration of interest. A second distribution, representing only the flow-top portion of ground-water transport, was analyzed to assess the capability of the flow top alone as a barrier to radionuclide release.

The rate of ground-water flow through the repository was computed by Darcy's law, assuming a representative value of vertical hydraulic conductivity of 10^{-12} meter per second (10^{-7} feet per day) through the flow interior, a nominal gradient approximating the peak bouyant gradient (3×10^{-2}), and a waste-emplacement density per package typical of the current conceptual design (70 square meters (approximately 778 square feet) per package; i.e., 50 square meters (556 square feet) per metric ton (1.1 ton) of heavy metal). The resultant flow rate, assumed in subsequent calculations to be under saturated conditions, was approximately 50 liters (approximately 13 gallons) per 1,000 metric tons (1,100 tons) of heavy metal per year. Hydraulic conductivity is the principal source of uncertainty in the analysis; therefore, a lognormal distribution and a standard deviation of one were selected to reflect the dependence of flow rate on conductivity.

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Table 6-24. Hydrologic variables used for assessment of radionuclide releases from the site subsystem.

Parameters	Distribution type	Median	Standard deviation in log base 10
Ground-water travel time--composite pathway[a] (yr)	lognormal	74,000	0.570
Ground-water travel time--flow top (yr)	lognormal	17,000	0.643
Advective water flow rate, (liters/1,000 ~~metric tons~~ t of heavy metal/~~per year~~ yr)	lognormal	0.05	1.0

[a]For a discussion of ground-water travel time from the repository to the overlying flow top see Clifton (1984).

(L/1,000 t, of heavy metal/yr)
(____ tons)

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Results. The stochastic simulations of site subsystem performance provide results for two cases representing:

1. The flow top pathway by itself (see Subsection 6.4.2.3.5 on ground water travel times).

2. A composite flow path through the host-rock of the repository horizon and then through the flow top (Fig. 6-26, also see Clifton, 1984).

For each case, the cumulative radionuclide releases were computed for a 10,000-year time period.

The results, shown in Figures 6-27 and 6-28, indicate that releases are dominated by the nonadsorbed radionuclides, carbon-14 and iodine-129. Within the ranges of values ~~presently~~ currently expected for solubility, retardation coefficient, and ground-water travel time, other radionuclides are not likely to contribute significantly to releases.

The calculated radionuclide cumulative releases for the proposed repository in basalt, as shown in Figures 6-27 and 6-28, share three basic features:

1. For probabilities ranging from approximately 65 percent to as high as nearly 95 percent, travel time exceeds 10,000 years, and release is therefore zero. This result is reflected by the nearly horizontal portions of the curves.

2. The near-vertical portion of each curve shows the release of the total iodine-129 inventory.

3. Adsorbed (and relatively insoluble) radionuclides are either totally absent from releases at the accessible environment or are evident in only a few of the 5,000 Monte Carlo simulations.

Discussion. The analyses presented provide useful insights into bounding conditions and sensitivities for the site isolation subsystem behavior. These analyses must, however, be viewed in the context of their stated limitations in order to properly interpret the results. The representation of a physical system by a numerical model has two principal sources of uncertainty: (1) simplistic representation of the actual physical system, and (2) data. The computer code used in this analysis does not provide a detailed numerical representation of the complex hydrologic, chemical, and thermal processes involved in radionuclide transport. Instead, the inputs to the computer code are derived primarily from the outputs of other more detailed models. The results of the present analysis do, however, provide a good perspective on the potential isolation capability of the site subsystem and are believed to reasonably represent the potential isolation performance of the site subsystem.

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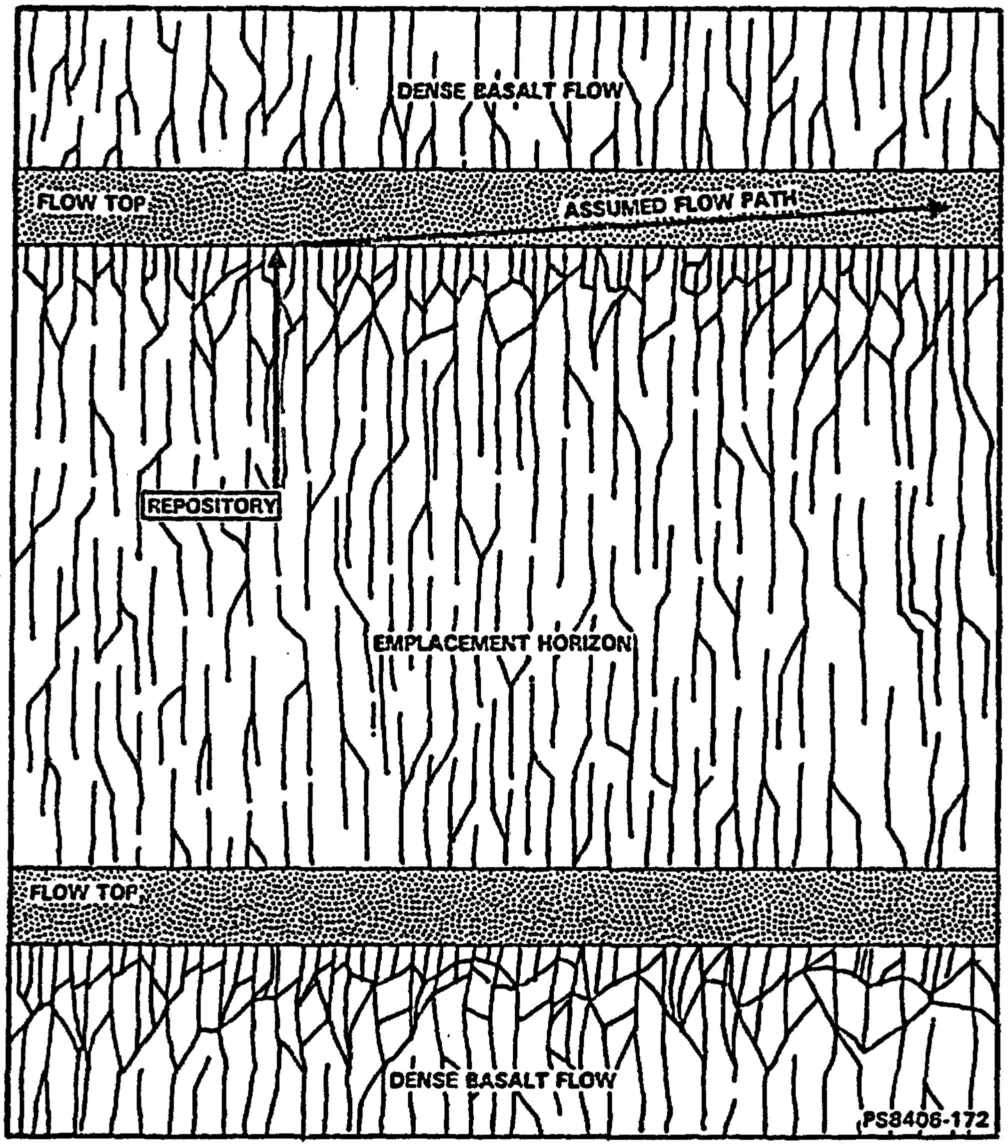

FIGURE 6-26. CONCEPTUAL MODEL OF GROUNDWATER FLOW PATHS USED IN SITE SUBSYSTEM PERFORMANCE ANALYSIS (NO SCALE)

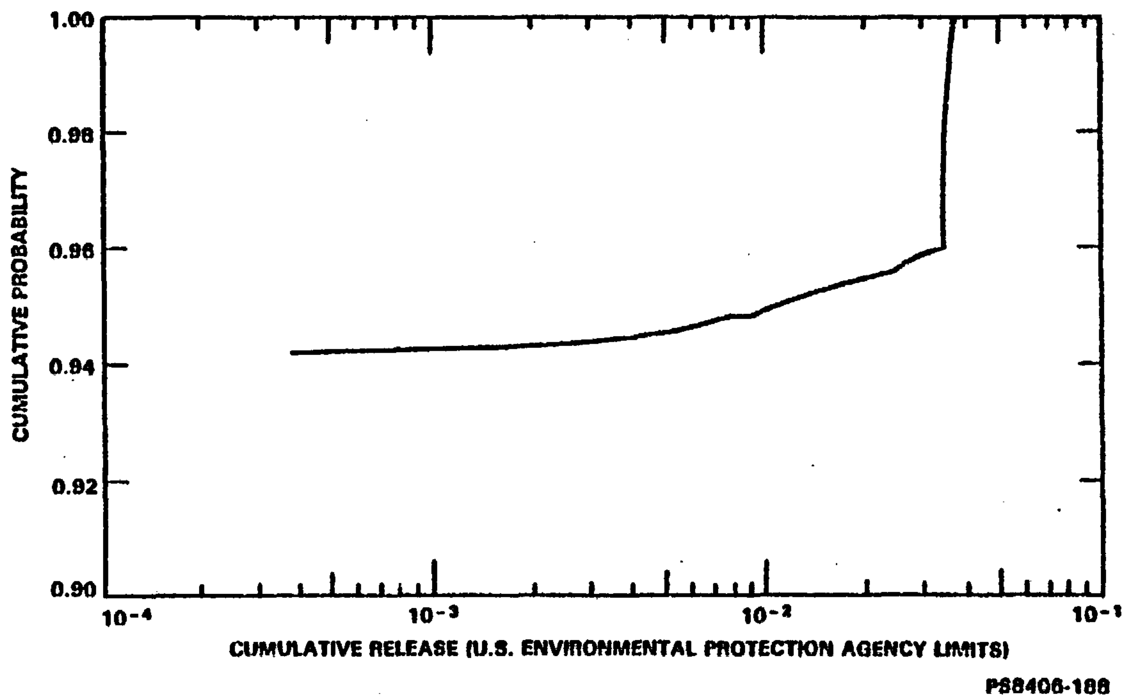

Figure 6-~~25~~27. ~~Site performance~~ --composite flow path.
Radionuclide releases from the site subsystem to the accessible environment

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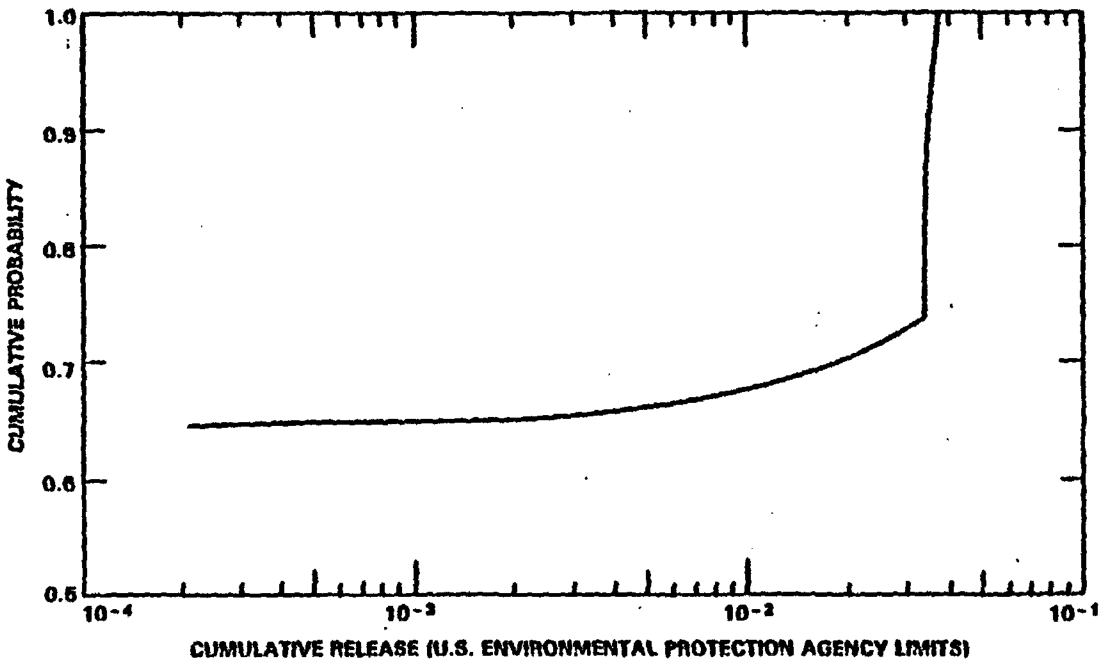

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Figure 6-~~26~~ 28. ~~Site performance~~ Radionuclide releases from the site subsystem to the accessible environment--flow tope pathway.

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6.4.2.4 System performance assessment

If it is assumed that the radionuclide transport pathways of the site subsystem are the only significant path for radionuclide transport to the accessible environment, the overall repository isolation system can be viewed as consisting of isolation barriers that function in series between the waste package and the accessible environment. Thus, the waste package can be represented mathematically by (1) a containment period prior to any radionuclide release, and (2) a release rate reflecting the diffusional control provided by packing material surrounding the container.

The transport pathways considered in site subsystem radionuclide release analysis (i.e., a composite pathway comprised of the emplacement flow interior plus the first flow top above the repository, and a pathway consisting of the flow top alone) were utilized in this preliminary analysis of system performance to illustrate the nominal effects of the waste package subsystem barriers. Two cases were analyzed to assess overall repository isolation system performance:

1. Reference case.
   - Waste package subsystem containment represented by a normal probability distribution of container lifetime, with a mean value of 6,500 years and a standard deviation of 2,000 years, prior to start of release.
   - Waste package subsystem release rates lower by a factor of 3 than the rates used in the site subsystem analysis (to approximate the results presented in Subsection 6.4.2.3.3).
2. Performance limits case.
   - Waste package subsystem containment of 300 years.
   - Waste package subsystem release rates of one part in 100,000 per year, of the radionuclide inventory at 1,000 years after emplacement.

For each set of stipulated conditions, cumulative releases during 10,000 years and 100,000 years were computed.

Results

Results of the preliminary performance analysis of the repository isolation system are presented in Figures 6-29 through 6-34. The results show that the additional travel time provided by the basalt of the dense flow interior of the emplacement horizon leads to a substantial increase in the probability that total release will be less than the total inventory of iodine-129 (0.033 times the U.S. Environmental Protection Agency standard). In Figures 6-33 and 6-34, results from assessment of site-subsystem performance, from Subsection 6.4.2.3.5 ,are superimposed on transport pathway cases in assessment of overall system performance.

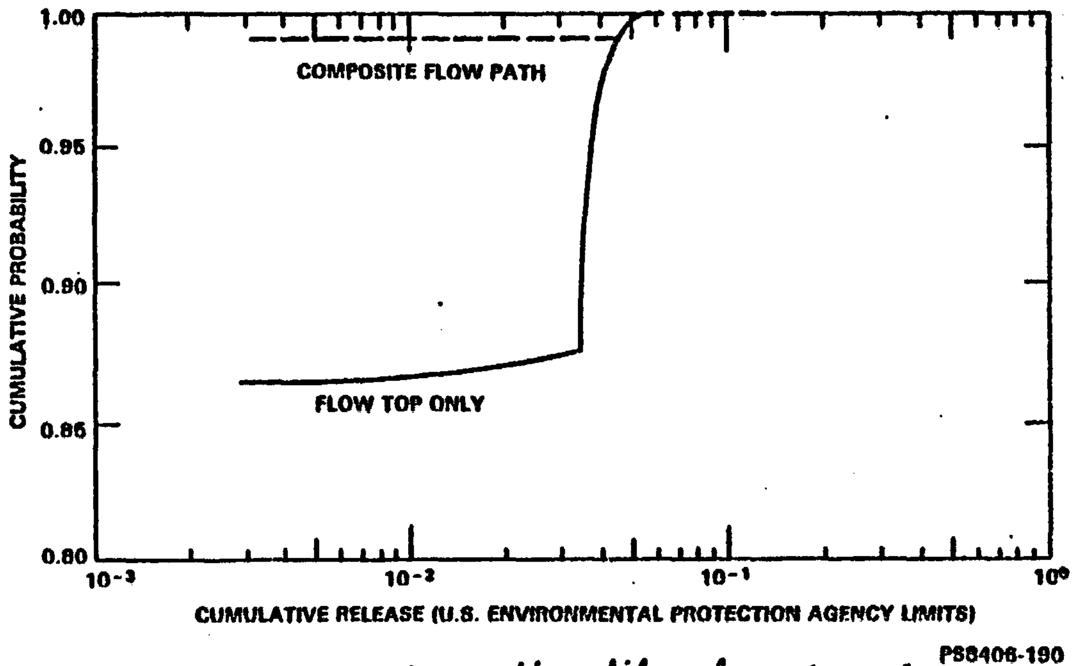

Figure 6-~~27~~ 29. ~~Cumulative release in 10,000 years—reference case~~ Cumulative radionuclide release from the repository isolation system to the accessible environment in 10,000 years--reference case.

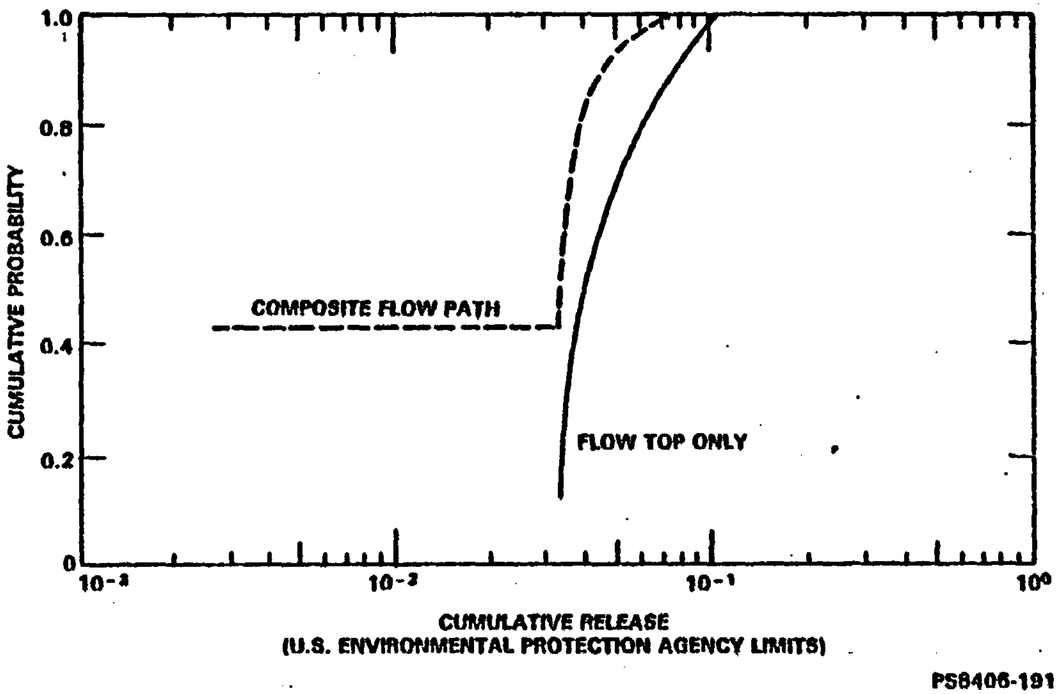

Figure 6-~~28~~30. ~~Cumulative release in 100,000 years - reference case.~~ Cumulative radionuclide release from the repository isolation system to the accessible environment in 100,000 years -- reference case.

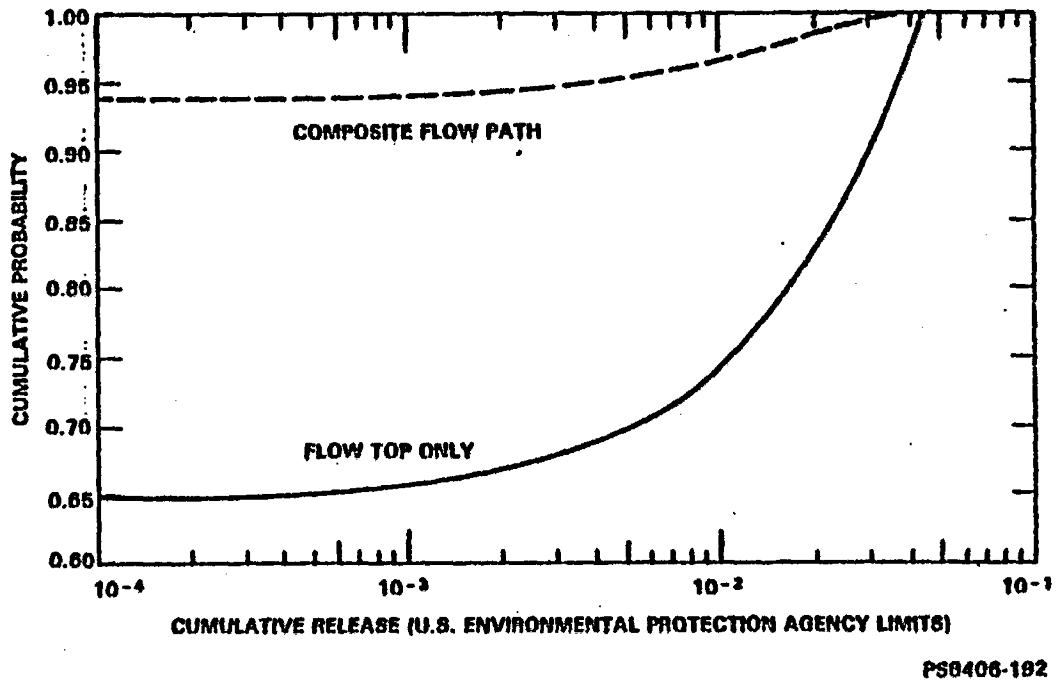

Figure 6-~~29~~31. ~~Cumulative release in 10,000 years—performance limits case~~ Cumulative radionuclide release from the repository isolation system to the accessible environment in 10,000 years--performance limits case.

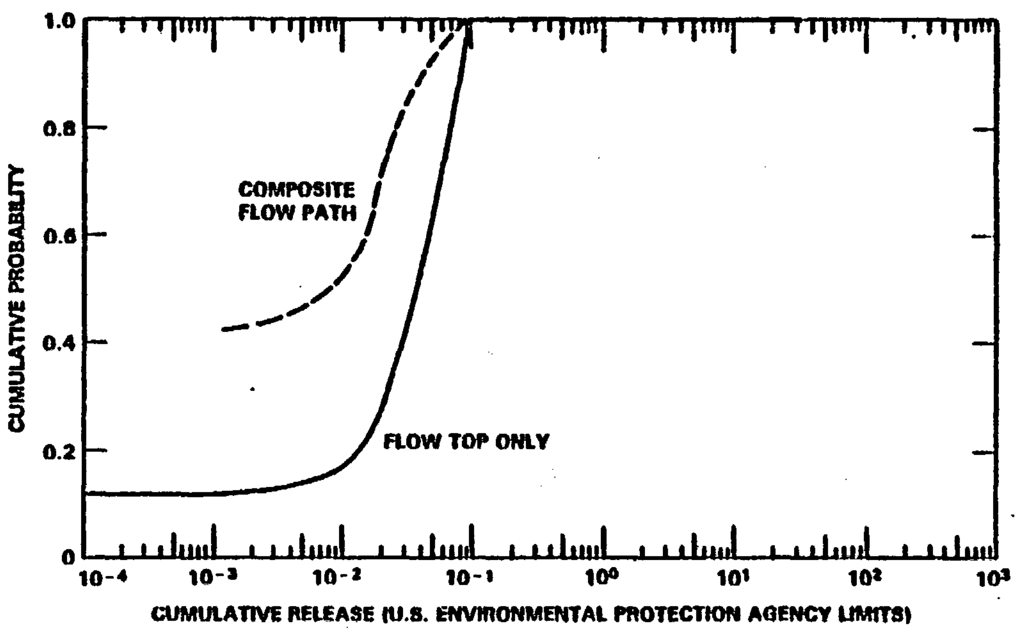

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Figure 6-~~30~~ 32. ~~Cumulative release in 100,000 years--performance limits case.~~
Cumulative radionuclide release from the repository isolation system to the accessible environment in 100,000 years-- performance limits case.

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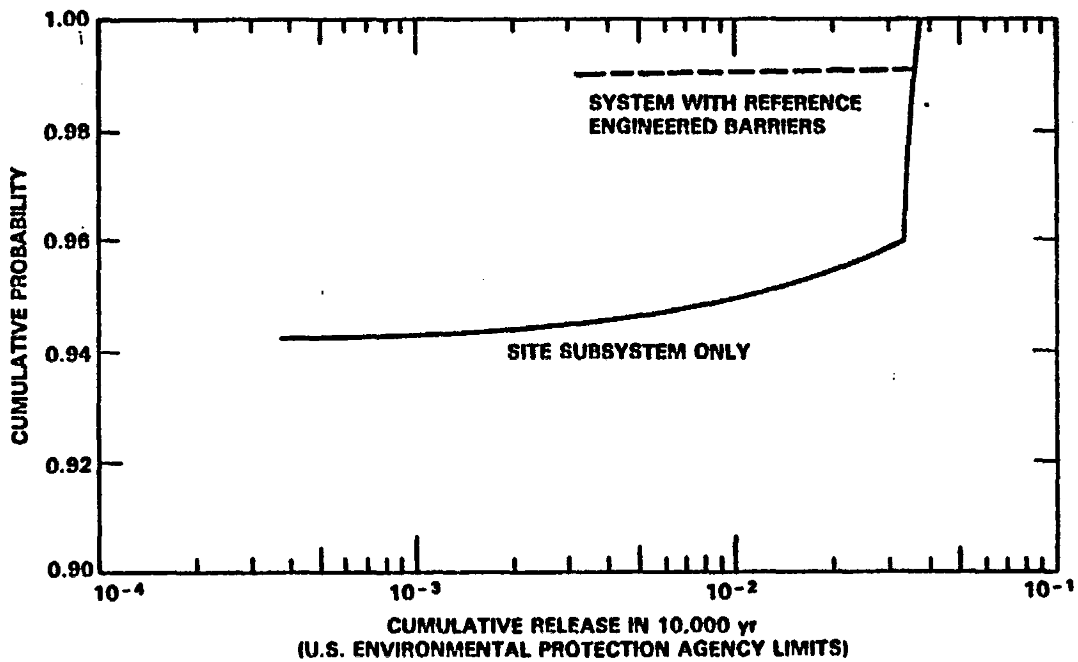

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FIGURE 6-33. COMPARISON OF ISOLATION PERFORMANCE DUE TO THE SITE SUBSYSTEM ALONE WITH ISOLATION PERFORMANCE OF THE SITE PLUS WASTE PACKAGE SUBSYSTEM ACTING TOGETHER -- COMPOSITE FLOW PATHWAY.

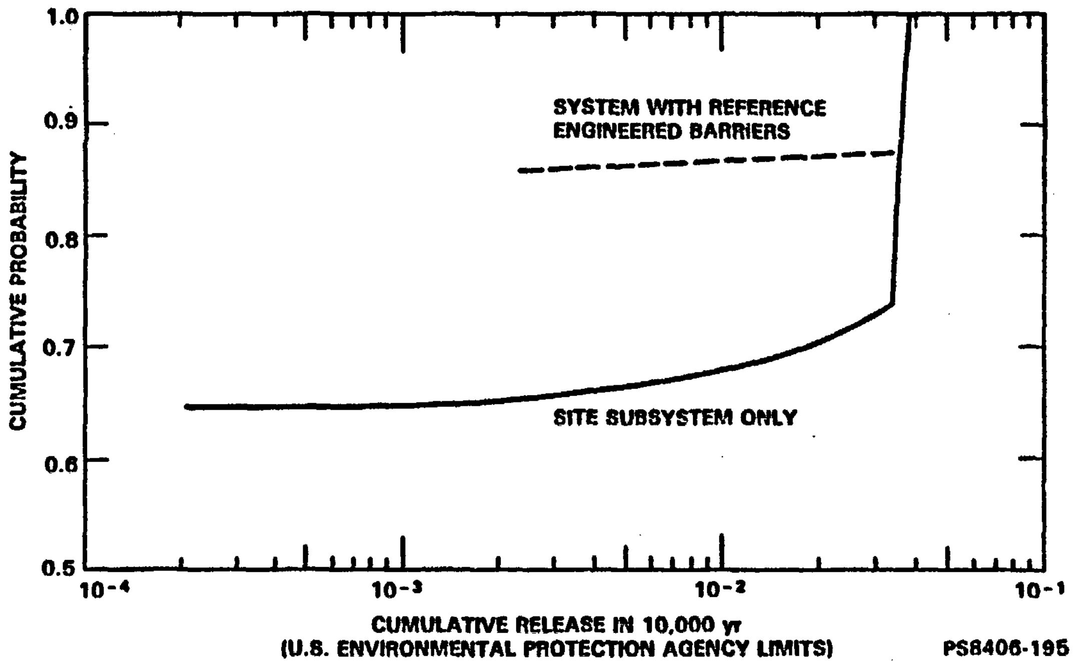

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FIGURE 6-34. COMPARISON OF ISOLATION PERFORMANCE DUE TO THE SITE SUBSYSTEM ALONE WITH ISOLATION PERFORMANCE OF THE SITE PLUS WASTE PACKAGE SUBSYSTEMS ACTING TOGETHER-- FLOW TOP PATHWAY.

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The superposition illustrates potential improvements in site subsystem isolation performance that are attributable to the containment and release-rate barriers provided by the waste package. The results for the reference and performance limits case indicate that cumulative releases during 10,000 and 100,000 years would likely meet U.S. Environental Protection Agency standard.

6.4.2.5 Summary of performance assessment results

In the foregoing subsections, preliminary performance assessments were presented for the proposed repository in basalt. The first assessment analyzed the isolation performance of the three major subsystems (waste package, repository seal, and site) for a 10,000-year period after repository closure. The second assessment analyzed the isolation performance of the total repository system for two time periods: the first 10,000 and the first 100,000 years after closure. For the latter assessment, two cases were considered and compared: (1) a reference case and (2) a performance limits case. A summary of the principal performance assessment results is presented below. The results are discussed in terms of the additional data and understanding that would be needed to conduct a detailed evaluation of compliance with the postclosure system guideline and the regulatory criteria and standards.

6.4.2.5.1 Performance of the waste package subsystem

The analysis of the waste package subsystem for the proposed repository in basalt examined the relationships between subsystem performance and its controlling processes. The performance of the waste package subsystem was expressed in terms of three basic measures: (1) container lifetime, (2) maximum fractional radionuclide release rate, and (3) cumulative radionuclide release. The latter two performance measures were computed at the boundary of the waste package subsystem (i.e., outer edge of the packing material). Physical and chemical processes accounted for in the analysis were uniform container corrosion, molecular diffusion, and radionuclide adsorption and decay. Computer simulations of container corrosion and radionuclide migration were carried out using a probabilistic approach. Statistical representations (i.e., probability distributions) were used to account for uncertainties in data, model parameters, and varying geochemical conditions.

On the basis of the cases considered, the computer simulations of waste package subsystem performance showed that:

- The expected lifetime (i.e., depletion of corrosion allowance) of the carbon steel containers, if dominated by uniformly distributed corrosion, would be on the order of 6,500 years, with a standard deviation of approximately 2,000 years. Moreover, the probability of container failure in less than 1,000 years is estimated to be smaller than one chance in 10,000. Additional research is needed to evaluate corrosion mechanisms other than uniform corrosion,

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such as pitting, that could potentially reduce container lifetime. Investigations of the expected lifetime and potential failure mechanisms of zircaloy cladding are also needed.

- Of the numerous radionuclides in the spent fuel, only a few are likely to contribute to potential release from the waste package. These radionuclides are: carbon-14, iodine-129, selenium-79, technetium-99, and tin-126. Consequently, future laboratory studies need to focus on these five radionuclides, as well as to reaffirm the validity of the solubility and adsorption values for the other radionuclides in the waste.

- Radionuclide release rates for these five radionuclides are strongly dependent on their solubilities and effects of adsorption on their retardation. Because molecular diffusion is likely to be the primary mechanism for transport of radionuclides from the waste package subsystem, laboratory determinations of diffusion coefficients of the five radionuclides are needed to reduce uncertainty in the release rate predictions.

- The computer simulations of radionuclide migration through the packing material indicate that fractional release rates for selenium-79 and iodine-99 are likely to exceed the U.S. Nuclear Regulatory Commission fractional release rate criterion. These results do not account for additional containment provided by the spent fuel cladding or container confinement provided during the time between depletion of the container corrosion allowance and actual container failure. In addition, these predictions may be an artifact of the conservative solubility estimates for these radionuclides. Additional laboratory determinations are needed for confirmation or refinement of the estimates.

- The simulations also indicate that the cumulative release of all radionuclides over 10,000 years would be very small. In particular, the results indicate a high probability (i.e., greater than 0.95) that the cumulative release at the waste package subsystem boundary would be less than the proposed U.S. Environmental Protection Agency limits. (The limits actually apply at the accessible environment boundary, i.e., 10 kilometers (6.2 miles) from the edge of the repository).

The preliminary performance assessment demonstrates that, although additional data and refinement of knowledge are needed, the isolation performance of the waste package subsystem can be analyzed in a systematic manner that accounts for uncertainties. Moreover, the assessment methodology provides a rigorous way of estimating the probabilities and, therefore, the degree of confidence in achieving compliance with the applicable criteria.

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6.4.2.5.2 Performance of the repository seal subsystem

A performance analysis of the repository seal subsystem was conducted to assess potential cumulative radionuclide releases and their dependence on the hydraulic properties of the subsystem. For simplicity and conservatism, the analysis was based on a conceptual model that treated the repository seal subsystem as the only pathway for radionuclide migration. The performance measure considered was the cumulative radionuclide release during a 10,000-year period. The release was calculated at a subsystem boundary designated as the point at which the vertical shafts intersect the Vantage interbed. The release at this boundary was computed as a function of: (1) the container lifetime and waste package subsystem release rates and (2) the rates of ground-water flow and radionuclide migration through the repository seal subsystem. The processes accounted for in the calculations were radionuclide transport by advection, retardation of radionuclide migration by adsorption, and radioactive decay. The probabilistic approach considered uncertainties in data, model parameters, and varying geochemical conditions.

The computer simulations of repository seal subsystem performance showed the following:

- Of the radionuclides considered, only two, carbon-14 and iodine-129, contribute significantly to the total release. The process of adsorption retards the movement of all other radionuclides considered in the analysis. Laboratory studies are needed to: (1) refine the current estimates of adsorption for the pertinent radionuclides and (2) examine the basic chemical properties of carbon and iodine in the basalt ground-water environment.

- Small releases would occur at the designated repository seal subsystem boundary during a 10,000-year period. There is a high probability that the cumulative release would be less than the U.S. Environmental Protection Agency limits that apply at the accessible environment boundary. The principal reasons for the low cumulative releases are the absence of hydraulic driving force along the pathway, the relatively long path lengths from the waste package to the repository seal subsystem boundary, and retardation of adsorbed radionuclides.

The preliminary performance assessment of the repository seal subsystem indicates that this subsystem is very unlikely to be a significant pathway for radionuclide migration. Moreover, it appears that a relatively simple approach can be used to assess the isolation performance of this subsystem.

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6.4.2.5.3 Performance of the site subsystem

To examine the potential isolation capability of the site subsystem (i.e., the host geology), an analysis was performed in which the potential cumulative releases (at the accessible environment boundary at 10 kilometers (6.2 miles)) were calculated as a function of the probabilistic ground-water travel time distributions. Two ground-water pathways were considered: (1) composite (emplacement horizon flow interior plus flow top) and (2) flow top only. The first case considers a flow path that starts at the waste package, is vertical through the emplacment horizon (i.e., dense basalt flow interior), and then horizontal along the overlying flow top. In contrast, the second case does not take credit for the isolation capability of the vertical part of the travel path. The two cases contrast isolation performance of the geologic barrier with and without the contribution of the emplacement horizon flow interior. The analysis assumes no containment or constraint of ground-water flow by the waste package.

The probabilistic computer simulations of radionuclide transport through the site subsystem indicate the following:

- The dense basalt flow interior of the emplacement horizon is likely to contribute significantly to the isolation performance of the site subsystem. The main reasons for this contribution are the long ground-water travel times through the dense basalt flow interior and the retardation of adsorbed radionuclides by the host-rock environment.

- The potential cumulative releases at the accessible environment boundary are dominated by two radionuclides: carbon-14 and iodine-129. Dominances of cumulative releases of these two radionuclides appear to be due to the fact that the rate of migration of other radionuclides are significantly reduced by adsorption.

- Cumulative releases calculated at the accessible environment boundary for the two pathways considered have a high probability (i.e., greater than 0.95) of meeting the U.S. Environmental Protection Agency limit.

Overall, this preliminary performance assessment for the site subsystem indicates that future site characterization needs to emphasize those data collection activities that are relevant to: (1) definition of the fastest flow paths from the repository to the accessible environment, (2) determination of hydraulic properties (e.g., hydraulic conductivity and effective porosity) of the host geology, and (3) measurement of pertinent solubility and adsorption properties of the radionuclides of most concern.

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6.4.2.5.4 Performance of the total isolation system

The long-term isolation performance of the total repository system ultimately depends on the combined performance of the engineered and natural barriers. To develop a quantitative perspective of the isolation capability of the total system, a parametric analysis was conducted for two basic cases: (1) a reference case and (2) a performance limits case. For each case, probabilistic computer simulations were made to compare the cumulative releases for two pathways: composite (flow interior and flow top) and flow top only. These analyses were made for two time periods: 10,000 and 100,000 years. For purposes of modeling, the total isolation system was represented as functioning in series between the waste package subsystem and the accessible environment.

The principal results of the total system performance assessment were:

- For the reference conditions, all of the cases simulated showed radionuclide releases less than the U.S. Environmental Protection Agency limit for both 10,000 and 100,000 years after closure.
- For the performance limits conditions, even the flow top pathway case for the 100,000-year time limit indicated that the standard would be met with a probability of 0.995.

6.4.2.6 Human intrusion and disruptive events

Assessment of long-term repository performance also requires consideration of potential disruptions to nominal repository performance during the 10,000-year period specified by regulatory standards (NRC, 1983a; EPA, 1984). The term disruption scenario is here defined as postulated events, processes, and conditions of human-induced or natural origin, that could adversely affect repository performance. The objective of ongoing scenario studies is to identify site-specific scenarios, to classify them according to probability categories, and to characterize them to a degree sufficient to permit assessment of their effect on repository performance.

Several types of methods can be used to assess disruption scenarios, including systems analysis, event/fault-tree analysis, geologic simulations, and a formal Delphi method of eliciting expert opinion. Because of the length of the required assessment period (10,000 years), incomplete comprehension of the mechanics that may lead to disruption scenarios, and only partial understanding of the geologic history of the site, all of the techniques mentioned above incorporate, to varying degrees, subjective expert judgment. At the present time, the Basalt Waste Isolation Project is in the process of reviewing and evaluating various methods to develop, implement, and refine a reasonable approach for selection, evaluation of probability of occurrence, and characterization of disruption scenarios.

As an initial step towards the study of disruption scenarios for the basalt site, the Basalt Waste Isolation Project conducted a formal Delphi survey of expert opinion. In the study, a panel of fifteen nationally recognized experts with site-specific and issue-specific experience, and independent of the Basalt Waste Isolation Project, from the disciplines of hydrology, geology, mining engineering, paleoclimatology, and geophysics, were iteratively administered a questionnaire. The objective was to obtain a majority consensus on probability of scenario occurrence and likely consequence. The Delphi methodology is widely considered to be a balanced, auditable means of eliciting expert opinion that can be structured to minimize biases (Dalkey and Helmer, 1963; Gordon and Helmer, 1964). This method has found widespread acceptance among the general public and the scientific community for guidance on important questions of public-policy decision-making. By this means, 45 disruption scenarios were initially identified (Table 6-25).

The 45 scenarios thus identified were also ranked by the fifteen experts according to likelihood of occurrence and relative adversity of consequence (see Davis et al., 1983). Although it is unlikely that an exact probability of occurrence can defensibly be assigned to most disruption scenarios, the classification of scenarios into broad occurrence probability categories (Davis et al., 1983) is desirable because of the scope of disruption scenario studies defined by the U.S. Environmental Protection Agency (EPA, 1982) and the U.S. Nuclear Regulatory Commission (1983). Three such categories have been defined by the U.S. Environmental Protection Agency (EPA, 1982, draft 40 CFR 191):

- o Reasonably foreseeable - occurrence probability of no less than 0.1 during the next 10,000 years.
- o Very unlikely - occurrence probability of less than 0.1 but greater than 0.00001 during the next 10,000 years.
- o Extremely unlikely - occurrence probability of less than 0.00001 during the next 10,000 years.

Two other categories are defined by the U.S. Nuclear Regulatory Commission (NRC, 1983a):

- o Anticipated - site-specific evidence of occurrence during Quaternary geologic time.
- o Unanticipated - site-specific evidence of occurrence during Quaternary geologic time is not found.

Both of the above occurrence probability nomenclatures were used in categorizing the 45 disruption scenarios identified. Delphi panelists categorized the disruptions into five occurrence probability categories: reasonably foreseeable-anticipated, reasonably foreseeable-unanticipated, very unlikely-anticipated, very unlikely-unanticipated, and extremely unlikely unanticipated. The definition of reasonably foreseeable-anticipated, for example, includes those scenarios whose occurrences are due to dynamics of the site subsystem, whose probability of occurrence is

Table 6-25. Site-specific disruption scenarios identified by means of a formal Delphi elicitation of expert opinion.

Item no.	Description	Item no.	Description	Item no.	Description	Item no.	Description
1.	Undetected flow breccia of areal extent less than 1/2 mi^2 that adversely affects ground-water travel times	13.	Latent seismic activity triggered by changes in hydraulic pressure and rock stress	24.	Collapse of repository waste into undetected voids, such as lava tubes	35.	Adverse effects on ground-water travel time due to adverse effects on recharge, because of severe changes in the local water budget (i.e., evaporation/precipitation ratio)
2	Undetected fault with movement periodicity greater than one per 10,000 yr	14.	Estimation uncertainty of greater than one order of magnitude in convective dispersion through fracture or interflow systems	25.	Diapirism of rock underlying repository host rock (e.g., shale, serpentine, evaporite)	36.	Criticality; assumes unreprocessed spent fuel in storage
3.	Premature shaft seal failure resulting from No. 2	15.	Fault movement with periodicity greater than one per 10,000 yr that could intersect the repository	26.	Change in transport properties causing a decrease of greater than 50% in ground-water travel times	37.	Shaft seal failure due to methane, hydrogen, or steam explosions
4	Undetected flow breccia of areal extent greater than 1/2 mi^2 that adversely affects ground water travel times	16	Seismicity of less than 6.7 magnitude, with faulting	27	Premature failure or omission of engineered repository systems	38.	Premature failure or omission of waste package engineered systems
5.	Undetected fault with movement periodicity less than one per 10,000 yr	17	Seismicity of greater than 6.7 magnitude, with faulting	28.	Latent seismicity triggered by changes in hydraulic pressure and rock stress as a result of repository heating	39	Estimation uncertainty of greater than 50% in extent of host rock fracturing induced by radiogenic heat
6	Premature shaft seal failure resulting from No. 5	18	Celestial impacts	29.	Estimation errors of fracture permeability of greater than 50% due to conditions changed from testing environment	40	Estimation uncertainty of greater than 50% in extent of host rock fracturing induced by shaft, tunnel, and emplacement hole boring or mining
7	Undetected major fault within the site	19	Seismicity induced failure of shaft seals due to faulting	30	Breakdown of shaft seals by chemical/mechanical aging	41.	Nuclear fuel recovery by deep mining methods
8	Estimation uncertainty of greater than one order of magnitude in hydraulic conductivity	20.	Ground-water chemistry changes with adverse effects on radionuclide flux	31.	Adverse effects on ground-water travel time due to adverse effects on recharge, because of severe changes in precipitation	42.	Irrigation or other human-induced perturbation of the hydrologic system, resulting in adverse ground-water system perturbation
9	Estimation uncertainty of greater than one order of magnitude in radionuclide-rock partition coefficient	21	Breach or premature failure due to net effects of surficial geologic processes	32.	Adverse effects on ground-water travel time due to adverse effects on recharge, because of, accelerated erosion or sedimentation	43	Inadvertent entry by deep drilling
10	Estimation uncertainty of greater than one order of magnitude in the state of fracturing of undisturbed rock	22	Intrusive igneous activity	33.	Change in the course of the Columbia River that adversely affects the hydrologic system of the site	44	A combination of human error during construction or commissioning of the repository, together with natural disasters, such as an earthquake, that may possibly result in a permanent state of disrepair and radioactive release that would be excessively hazardous to remedy
11	Glaciation	23	Microseismicity with host rock fracturing	34	Climatic change, development of glaciers and ice sheets in the region	45.	Breaching by nuclear weapons
12	Volcanism						

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not less than 0.1, and for which site-specific evidence of occurrence during Quaternary time exists. The 45 scenarios thus identified and categorized include disruptions due to natural systems dynamics, potential site characterization omissions and uncertainties, the presence of the repository, and other human-induced events and processes (Table 6-18; also see Davis et al., 1983; Davis and Runchal, 1983).

6.4.2.7 Conclusions of preliminary performance assessment

In this section, the results of the subsystem and system performance assessments are compared with the criteria of the General Siting Guidelines of 10 CFR 960 (DOE, 1984), criteria of 10 CFR 60 (NRC, 1983a), and proposed standards of Draft No. 4 of 40 CFR 191 (EPA, 1984). The comparisons are not intended to demonstrate compliance with the guidelines, criteria, or standards. Rather, the results provide a quantitative perspective on potential isolation performance by which the merits of further site characterization may be judged. The results are discussed in terms of the following criteria: containment time, release rate, ground-water travel time, ground-water protection, and cumulative release.

6.4.2.7.1 Containment time

The U.S. Nuclear Regulatory Commission technical criteria, as specified in 10 CFR 60.113 (NRC, 1983a), set a containment time objective for the waste package. The technical criterion specific to containment time states that:

> "Containment of HLW (high-level waste) within the waste packages will be substantially complete for a period to be determined by the Commission (Nuclear Regulatory Commission) taking into account the factors specified in 60.113(b) provided that such period shall be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository." ~~and. . . ."~~

The waste package for the proposed repository in basalt will be designed to have a high probability of meeting the containment time performance objective. The preliminary performance assessment presented herein (see Subsection 6.4.2.3.3) suggests that, based on the current design, the container could have an expected lifetime (i.e., time to depletion of corrosion allowance) of approximately 6,500 years, with a standard deviation of approximately 2,000 years. Moreover, the preliminary analysis of waste package performance suggests a high probability (i.e., greater than 0.99) of container lifetimes greater than 1,000 years.

The analysis of container lifetime is based on the assumption of uniformly distributed corrosion as the principal mechanism for container degradation. The data and assumptions used in the container lifetime calculations are believed to be of a conservative nature. Additional

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conservatism was provided by defining the container lifetime as the time required only to reach the corrosion-limit allowance and, therefore, not necessarily the time of actual container failure. In addition, no credit was taken for the added containment time potentially provided by zircaloy cladding of the spent fuel. However, additional research will be needed to develop an understanding of other corrosion mechanisms (e.g., pitting) that potentially could reduce the container lifetime.

6.4.2.7.2 Release rate

The U.S. Nuclear Regulatory Commission technical criteria, as stated in 10 CFR 60.113 (NRC, 1983a), established a radionuclide release criterion for the waste packages that applies 1,000 years after permanent closure. The technical criterion specifically states that:

> "The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission provided that this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay."

The technical criterion has been interpreted herein so that no radionuclide is exempted from consideration. In addition, to provide reasonable assurance that the waste package is an effective barrier, it will be designed to meet the U.S. Environmental Protection Agency standard at the outer boundary of the waste package, rather than at the accessible environment.

The preliminary performance assessment for the waste package presented herein (see Subsection 6.4.2.3.3) indicates that the current waste package design is unlikely to satisfy the fractional release rate criterion for iodine-129 and selenium-79. The reason for this finding is the apparently high solubility, nonsorptive property, long half-life of iodine, and the fact that the analysis does not take credit for the isolation capability of the zircaloy cladding. However, the initial inventory of iodine-129 and selenium-79 in the spent fuel is very small (for example, approximately 0.03 of the U.S. Environmental Protection Agency limit for iodine-129), and consequently, the cumulative release limit would not be exceeded. The technical criterion provides that other release rate limits may be specified. The U.S. Nuclear Regulatory Commission criterion in 10 CFR 60.113(b) states:

> "On a case-by-case basis, the Commission may approve or specify some other radionuclide release rate,. . ., provided that the overall system performance objective, as it relates to anticipated processes and events is satisfied."

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The overall system performance objective referred to here is the U.S. Environmental Protection Agency regulation (EPA, 1984). Consequently, several options will be considered: (1) confirmation or refinement of current estimates of solubility for iodine-129, (2) taking credit for the isolation capability of the spent fuel zircaloy cladding, (3) modification of the existing waste package design to enhance containment, and (4) requesting a variance in accordance with the provisions of the U.S. Nuclear Regulatory Commission criterion.

The probabilistic computer simulations of waste package performance indicate that there is a reasonable expectation that all other radionuclides in the waste inventory would comply with the fractional release rate criterion. The probabilistic calculations for cumulative releases (for all radionuclides analyzed) at the boundary of the waste package subsystem indicate a high probability (i.e., greater than 0.90) of meeting the U.S. Environmental Protection Agency limits. The preliminary analysis of waste package performance was conducted using data and assumptions that are considered to be of a conservative nature. However, additional research is needed to obtain data on radionuclide solubilities, and to confirm existing estimates of adsorption and diffusion coefficients for the radionuclides of concern.

6.4.2.7.3 Ground-water travel time

The General Siting Guidelines and the U.S. Nuclear Regulatory Commission technical criteria specify pre-waste-emplacment ground-water travel time as a site performance measure. The applicable criterion in 10 CFR 60.113 states:

> "The geologic repository shall be located so that pre-waste-groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission."

A precise definition of the disturbed zone that gives the location of this boundary has yet to be provided. For this assessment, the ground-water travel times were computed for a starting point located in the flow top overlying the emplacement horizon above the downstream edge of the repository. The location of the accessible environment was taken to be at 10 kilometers (6.2 miles) from the starting point. The pathway of likely radionuclide travel was assumed to be along the flow top.

For the conceptual model specified herein (no credit taken for travel time in the emplacement horizon flow interior), the preliminary performance assessment (see Subsection 6.4.2.3.5) indicates that the range of expected ground-water travel times may be on the order of 17,000 to 86,000 years. The probabilistic calculations indicate that there could be a high probability (i.e., greater than 0.95) that the pre-waste-emplacement ground-water travel times are greater than 1,000 years. The principal reason for these potential long ground-water travel times are the apparently low hydraulic gradients.

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Although this preliminary assessment of site performance indicates acceptably long ground-water travel times, additional hydrologic field studies are needed to provide the data for validation of conceptual models used in the computer model predictions. Piezometric baseline studies and large-scale pumping tests are planned to provide greater insight into the hydrogeologic characteristics of the basalts and data on key hydraulic properties (e.g., hydraulic conductivities, gradients and effective porosities; see Subsection 6.3.1.1.11.3). These tests will be directed, as a result of current performance assessment results, toward reducing uncertainties in computer model predictions. In addition to providing refined knowledge and understanding of the hydrogeology, the future characterization activities will be directed toward quantitative definition of a preferred hydrologic conceptual model for the basalts.

6.4.2.7.4 Ground-water protection requirement

The proposed U.S. Environmental Protection Agency Regulation 40 CFR 191, Draft No. 4, sets a protection requirement for any major or sole-source aquifer outside the designated area of the repository. In particular, the proposed standard, 40 CFR 191.15 states:

"Disposal systems for spent fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, for 1,000 years after disposal, undisturbed performance of the disposal system shall not increase the radionuclide concentrations in any major source of ground water or any sole source aquifer (outside of the controlled area, which is assumed to exist for no more than 100 years after disposal) by more than: (a) 15 picocuries per liter of alpha-emitting radionuclides~~; or. . . .~~"

The proposed ground-water protection requirement can be met if the waste package can contain the radionuclides for 1,000 years, or if the ground-water travel times to the accessible environment are greater than 1,000 years. The preliminary performance assessments for the waste package indicate a high probability of container lifetimes greater than 1,000 years. Assessment of the site subsystem indicated ground-water travel times greater than 1,000 years. Therefore, there is reasonable expectation that the ground-water protection requirement could be met (see Subsection 6.4.2.3.5).

6.4.2.7.5 Cumulative release requirement

The U.S. Environmental Protection Agency is responsible for setting radiologic protection standards. The proposed regulation for mined geologic repositories sets numerical limits on potential releases to the accessible environment. The current version of the proposed standard states:

"Disposal systems for spent nuclear fuel or high-level or transuranic wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of waste to the accessible environment for

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> 10,000 years after disposal from all significant processes and events that may affect the disposal system shall: (1) have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1, and (2) have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (EPA, 40 CFR 191 draft, 1984)."

The first item requires that there be at least a 0.90 probability that the cumulative release is less than 1.0 release limit; whereas, the second part requires that there be at least a 0.999 probability that the cumulative release is less than 10.0 release limits.

In the preliminary performance assessments of major repository subsystems (see Subsection 6.4.2.3) and total system (see Subsection 6.4.2.4), analyses were conducted for the undisturbed condition (i.e., no disruptive events). For this condition, compliance with item (1) of the U.S. Environmental Protection Agency regulation is highly probable. Performance with respect to item (2), the criterion for disruption scenario conditions, was not addressed by the current analysis. The assessment for the subsystems indicated that the waste package, repository seals, and site subsystems each could meet the 1.0 release limit with greater than 0.90 probability. This means that the combined performances of all subsystems may have a higher probability of meeting the proposed regulation. This result was confirmed by the assessment results for the total system, which considered releases during both 10,000 and 100,000 years.

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Don Carroll need info. Also, are all of these terms really used?

GLOSSARY

abnormal occurrences -- those occurrences stemming from malfunctions of systems, operating conditions, or operator error that would not have a significant effect beyond the exclusion area.

~~absorption -- see sorption.~~

wrong term. should not be in EA.

accessible environment -- the atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere that is outside the controlled area.

accountability -- (as used in the nuclear industry) the material balance in the inventory of source and fissionable elements and isotopes, accounting for all significant amounts of incoming and outgoing materials.

Act -- the Nuclear Waste Policy Act of 1982.

actinide -- a chemical element in the series beginning with atomic number 89 and continuing through 103.

active fault -- a fault along which there is recurrent movement, which is usually indicated by small, periodic displacements or seismic activity.

adit -- a nearly horizontal passage from the surface by which a mine is entered.

adsorption -- see sorption.

aeromagnetic survey -- a determination of the magnetic field of the Earth through the use of electronic magnetometers suspended from an aircraft.

affected area -- either the area of socioeconomic impact or the area of environmental impact, each of which will vary in size among potential repository sites.

affected Indian tribe -- any Indian tribe (1) within whose reservation boundaries a repository for radioactive waste is proposed to be located or (2) whose federally defined possessory or usage rights to other lands outside the reservation's boundaries arising out of congressionally ratified treaties may be substantially and adversely affected by the locating of such a facility: provided that the Secretary of the Interior finds, upon the petition of the appropriate governmental officials of the tribe, that such effects are both substantial and adverse to the tribe.

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<u>affected State</u> -- any State that (1) has been notified by the DOE in accordance with Section 116(a) if the Act as encompassing a potentially acceptable site; (2) contains a candidate site for site characterization or repository development; or (3) contains a site selected for repository development.

<u>aggradation</u> -- the building up of the Earth's surface by deposition.

<u>airborne</u> -- supported by air. Airborne contamination applies to radioactive material suspended in the air.

<u>air change</u> -- the rate of change of ventilation air, usually in terms of air changes per hour.

<u>air monitor</u> -- air sampler with associated electronic circuitry for the continuous detection of radioactivity, to warn personnel of changes in airborne radioactivity.

<u>air sample</u> -- a sample of air for determining the amount of radioactive material present.

<u>ALARA</u> -- see as low as reasonably achievable.

<u>alkaline</u> -- containing sodium and (or) potassium in excess of the amount needed to form feldspar with the available silica.

<u>alluvial plain</u> -- a level of gently sloping surface adjacent to a stream, developed over time by the periodic flooding of and associated deposition by the stream (either existing today or active in the past).

<u>alluvium</u> -- clay silt, sand, gravel, or other rock materials transported by flowing water and deposited in fairly recent geologic time as sorted or semi-sorted sediments in riverbeds, estuaries, flood plains, lakes, shores, and in fans at the base of mountain slopes.

<u>alpha decay</u> -- a radioactive transformation in which an alpha particle is emitted by a nuclide thus changing the nuclide to another one with a smaller atomic number and weight.

<u>alpha particle</u> -- a positively charged particle emitted in the radioactive decay of certain nuclides. Made up of two protons and two neutrons bound together, it is identical to the nucleus of a helium atom. It is the least penetrating of the three common types of radiation, alpha, beta, and gamma.

<u>anoxic</u> -- a general term meaning in the absence of oxygen, usually implying reducing conditions.

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anticipated processes and events -- those natural processes and events that are reasonably likely to occur during the period the intended performance objective must be achieved. To the extent reasonable in the light of the geologic record, it shall be assumed that those processes operating in the geologic setting during the Quaternary Period continue to operate but with the perturbations caused by the presence of emplaced radioactive waste superimposed thereon.

anticline -- an up-arched fold composed of strata which dip outward from a common ridge or axis. The core of an anticline contains stratigraphically older rocks and is convex upward.

anticlinorium -- a series of anticlines and synclines so arranged structurally that together they form a general arch or anticline.

antithetic fault -- a fault that dips in the opposite direction from the direction in which the associated sediments dip. Opposite of synthetic fault.

aphanitic -- applied to a texture of rocks, the mineral constituents of which are so fine that the individual crystals or grains cannot be distinguished by the unaided eye.

aphyric -- an igneous rock texture showing two generations of the same mineral but without large crystals.

application -- in the Siting Guidelines means the act of making a finding of compliance or noncompliance with the ~~requirements of the~~ qualifying or disqualifying conditions specified in the guidelines of Subparts C and D, in accordance with the types of findings specified in Appendix ~~C.~~ III

aquiclude -- a saturated geologic unit that is incapable of transmitting significant quantities of water under ordinary hydraulic gradients ~~a hydrogeologic unit which has a distinctively low permeability by comparison with adjacent aquifers and which can serve to maintain artesian pressures within such aquifers. (Replaces the terms aquitard and aquifuge.)~~

aquifer -- a formation, a group of formations, or a part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

~~aquifuge -- see aquiclude.~~

~~aquitard -- see aquiclude.~~

not used

artesian well -- ~~ground water confined under hydrostatic pressure and is synonymous with "confined." The water level in an artesian well stands above the top of the artesian water body it taps.~~ a well in which the water level rises above the top of the aquifer penetrated. If the water level in an artesian well stands above the land surface, the well is a flowing artesian well.

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as low as reasonably achievable (ALARA) -- refers to limiting release and exposure and is used by the NRC (1980a; 1980c; 1981) in the context of "as low as reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety and other societal and socioeconomic considerations. . . ."

audit -- (as related to quality assurance) a planned and documented activity performed to determine by investigation, examination, or evaluation of objective evidence the adequacy of and compliance with established procedures, instructions, drawings, specifications, codes, and other applicable documents, and the effectiveness of implementation. An audit should not be confused with surveillance or inspection activities performed for the sole purpose of process control or product acceptance.

augite -- a common mineral of the clinopyroxene group. It is usually black, greenish black, or dark green, and occurs as an essential constituent in many basic igneous rocks and in certain metamorphic rocks.

back end of the fuel cycle -- includes spent fuel transportation and storage, fuel reprocessing, and waste management.

backfill -- (1) (as related to a waste package) barrier material surrounding the containment portions of the waste package, acting as a radionuclide sorptive medium, hydrologic intrusion barrier, heat transfer agent, and plastic stress adjustment medium. (2) (As related to a repository) a material placed into the shafts and tunnels of a repository which acts as an intrusion barrier, sorptive material, hydrologic intrusion barrier, and structure fill. It may differ in composition from the waste package backfill, but must be compatible and support the functions of this barrier. (3) The material used in restoring excavated cuts to natural contours.

background radiation -- the level of radioactivity in an area which is produced by sources other than the one of specific interest, such as naturally occurring radioactive materials in the biosphere, cosmic radiations, fallout from nuclear weapons tests, as well as naturally occurring radioisotopes in living organisms.

barrier -- any material or structure that prevents or substantially delays the movement of water or radionuclides.

basalt -- a dark- to medium-dark-colored mafic (iron-magnesium rich) extrusive igneous rock with small grains composed primarily of feldspar (calcic plagioclase), pyroxene, with or without olivine, and varying proportions of glass.

basalt flow -- includes the flowtop, entablature, colonnade, pillow zones, and lower contact zones. A basalt flow is the rock that is formed from liquid basalt flowing onto the surface of the ground and solidifying in place.

DRAFT

basalt interbed -- sedimentary unit occurring between or alternating with sequential basalt flows.

basement rock -- a complex of undifferentiated rocks underlying the oldest stratified rocks in the area.

basin (structural) -- a general term for a broad, depressed, sediment-filled area.

bedding -- (1) collective term signifying existence of beds or laminae. Planes dividing sedimentary rocks of the same or different lithology. Structure occurring in granite and similar rocks evident in a tendency to split more or less horizontally or parallel to the land surface. (2) As used in geology, the arrangement of rock in layers, strata, or beds.

bedrock -- solid rock that underlies all soil, sand, clay, gravel, and loose material on the Earth's surface.

benchmarking of computer codes -- code-to-code comparisons in which simulations obtained with BWIP codes are compared to those obtained with other available codes. The test cases used for benchmarking will use data representative of the actual repository setting. Benchmarking is complete when a reasonable consensus between independent code predictions is achieved.

bench-scale -- (as related to testing) a type of laboratory or, occasionally, field test; refers to the size of tests being performed. Bench-scale tests are run to determine the practicability of incorporating an observed phenomenon into a design or test procedure.

bentonite -- calcium or sodium montmorillonite clay or a mixture of both with variable magnesium and iron content formed by the alteration of volcanic ash. Bentonite, principally sodium montmorillonite, has the ability to absorb large quantities of water and to expand to several times its normal volume.

beta decay -- radioactive change by emission of beta particles.

beta particle -- an electron emitted from an atomic nucleus in the process of radioactive decay.

biosphere -- (1) the zone of the Earth which contains, or is theoretically capable of containing, living organisms including the lithosphere, hydrosphere, and atmosphere; living beings together with their environment. (2) The Earth's atmosphere, land surface, surface waters, and those ground waters utilized by man, plants, or animals. (See also accessible environment.)

biosphere transport (biotransport) -- in this document, movement of radionuclides through food chains. Used in contrast to geotransport.

DRAFT

block faulting -- a type of vertical faulting in which the crust is divided into structural or fault blocks of different elevations and orientations.

boomtown -- a community that experiences a sudden, rapid growth and expansion.

borehole jacking test -- this test measures in situ rock mass deformation through the application of unidirectional pressures to opposite sides of a borehole wall.

breccia -- rock composed of sharply angled fragments cemented in a fine matrix. A fragmental rock, the components of which are angular, and therefore, it is distinguished from a conglomerate in that its components are not waterworn. There are friction or fault breccias, talus breccias, and eruptive breccias.

bridge plug -- a downhole tool, composed primarily of slips, plug mandrell and rubber sealing elements that is run in and set in dense, nonfractured rock in a borehole to isolate a zone. Multiple bridge plugs may be set in a borehole to isolate numerous zones.

calcine -- material heated to a temperature below its melting point to reduce the water content and decompose soluble forms such as sulphate, nitrate, and carbonates by forming the less soluble oxide form.

caliche -- a limy material of low permeability commonly found in layers on or within the surface of stoney soils of arid or semiarid regions. It occurs as gravels, sands, silts, and clays cemented together by calcium carbonate (lime) or as crusts at the surface of the soil.

Cambrian -- the oldest of the periods of the Paleozoic Era, extending from 570 to 500 million years ago. (See also geologic time scale.)

candidate repository horizon -- a rock layer; e.g., a basalt flow with sufficient favorable properties to be designated as a potential host rock for a nuclear waste repository.

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candidate site -- an area, within a geohydrologic setting, that is recommended by the Secretary of Energy under Section 112 of the Act for site characterization, approved by the President under Section 112 of the Act for characterization, or undergoing site characterization under Section 113 of the Act.

canister -- the first material envelope surrounding a waste form (i.e., a processed waste form such as a glass, crystalline ceramic, etc., and possibly in some cases light water reactor spent fuel rods). The canister is installed by the waste form producer/shipper.

DRAFT

capable fault -- a fault which has exhibited one or more of the following characteristics, as described in 10 CFR 50 (NRC, 1980a): (a) movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years; (b) macroseismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault; or (c) a structural relationship to a capable fault according to characteristics (a) and (b) such that movement on one could be reasonably expected to be accompanied by movement on the other.

capillary fringe -- the ~~zone~~ Rock pores or fractures immediately above the water table in which all or some of the ~~interstices~~ are filled with water that is under less than atmospheric pressure and that is continuous with the water below the water table.

casing -- (1) a liner in a shaft or borehole to prevent entry of loose rock, gas, or liquid, or to prevent the loss of circulating liquid into porous, cavernous, or fractured ground. (2) The process of inserting casing into a borehole.

cask -- a shielded container used to transport radioactive material.

Cenozoic -- the latest of the eras into which geologic time, as recorded by the stratified rocks of the Earth's crust, is divided; it extends from the end of the Mesozoic Era to and including the present. (See also geologic time scale.)

chemical grouts -- are different from cement grouts in that chemical grouts contain silicates, acrylamides, bentonite, lignins, etc.

chilled contact -- that part of a mass of igneous rock, near its contact with older rocks, that is finer grained than the rest of the mass, because of its having cooled more rapidly.

chilled zone -- the border or marginal area of an igneous intrusion, characterized by a finer grain than the interior of the rock mass due to more rapid cooling.

cladding -- (as related to nuclear fuel) a metal or ceramic covering that contains the fuel material.

clast -- an individual constituent, grain, or fragment of a sediment or rock, produced by the physical disintegration of a larger rock mass.

clastic dike -- a tabular body of clastic material transecting the bedding of a sedimentary formation, representing extraneous material that has invaded the containing formation along a crack.

clastic rock -- any deposit which is composed of fragments of pre-existing rocks or of solid products formed during the chemical weathering of such older rocks and which have been transported mechanically to their places of deposition.

DRAFT

clay -- a fine-grained natural, earthy material, usually exhibiting plastic properties, composed primarily of hydrous aluminum silicates. It may be a mixture of clay minerals and small amounts of non-clay materials or it may be predominantly one clay mineral. The type of clay is determined by the predominant clay mineral present (that is, kaolin, montmorillonite, illite, halloysite, etc.).

closure -- final backfilling of the remaining open operational areas of the underground facility and boreholes after the termination of waste emplacement, culminating in the sealing of shafts.

coda -- the concluding part of a seismogram following the early identifiable waves.

coeval -- originating or existing over the same period of time.

collar -- (as related to boreholes) (1) (mining term) the mouth or opening of a borehole or shaft. (2) (shaft related) Surface area at the top of a shaft; the area is usually reinforced with concrete.

colloid -- a suspension of finely divided particles in a continuous medium, such as a liquid, gaseous, or solid substance containing suspended particles that range from 5 to 5,000 angstroms in diameter and are not easily filtered out.

colluvium -- a general term applied to the accumulation of loose incoherent soil and rock material at the base of a slope.

colonnade -- in columnar jointing, the lower portion of a basalt flow that structurally has thicker and better formed columns than the upper portion (or entablature). The colonnade may also occur in the upper third of a flow (directly below the flow top).

Columbia Plateau -- a region of approximately 202,000 square kilometers (78,000 square miles) occupying a major part of eastern Washington, a portion of northeastern Oregon, and a small part of western Idaho. It is underlain by a flood basalt province consisting of approximately 170,000 cubic kilometers (41,000 cubic miles) of basalt. This is called the Columbia River Basalt Group.

columnar fan -- a variation of the internal structure of a basalt flow in which the orientation of the columnar joints changes from generally parallel to make a fan-like pattern.

columnar jointing -- jointing that breaks the rock into columns. The joints, which usually form a fairly well-defined prism that is hexagonal in cross section, are found in basaltic flows as a result of contraction during cooling of the igneous mass in which they occur.

commercial waste -- radioactive wastes generated in private industrial and other nongovernment facilities; principally wastes generated in power reactors and chemical processing plants, but also including research laboratories and medical facilities. (See also defense wastes (nuclear).)

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complexes -- in chemistry, any combination of cations with molecules or anions containing free pairs of electrons. An organic complex is a complex in which the cation is combined with an organic ligand. An inorganic complex is formed when the cation is combined with an inorganic ligand.

concreting -- in tunneling, a method of support in which tunnel surfaces are coated with concrete and sometimes containing reinforcing bar patterns. (See also shotcrete.)

conductivity (hydraulic) - see hydraulic conductivity.

confined aquifer -- a subsurface water-bearing region having defined, relatively impermeable upper and lower boundaries and containing confined ground water whose pressure is usually greater than atmospheric pressure throughout.

confinement -- as pertains to radioactivity, to keep radioactive material within some specified bounds; differing from containment, in that no absolute physical barrier exists.

confining unit -- a body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.

conglomerate -- (as related to geology) a cemented clastic rock containing rounded or dissimilar fragments of gravel or pebble size.

constitutive model -- a mathematical model of a material or a process that expresses its essential quality or nature. A constitutive model is expressed by constitutive equations which mathematically express the nature of the relationship between quantities of interest. For example, a linear elastic constitutive material model may be expressed as a set of constitutive equations establishing a linear elastic relationship between stress and strain; a nonlinear elastic constitutive model would use a different set of constitutive equations to express a nonlinear elastic relationship between stress and strain.

contact-handled waste -- containerized waste, usually in canisters, whose surface dose rate (less than 0.2 rem per hour) is sufficiently low to permit direct handling. Such waste does not usually require shielding other than that provided by its container.

container -- the (metal or ceramic) envelope in the waste package that provides the primary containment function of the waste package to meet the containment requirements of 10 CFR 60 (NRC).

containerized waste -- container and contents including waste form and any liner or stabilizing material.

containment -- the confinement of radioactive waste within a designated boundary.

conceptual model -- a physical description of a system devised to show property variations as based upon field and laboratory measurements and best technical judgments.

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controlled area -- a surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be prohibited before and after permanent closure.

cooling (spent fuel) -- storage of fuel elements after discharge from reactors, usually under water, to allow for the decay of short-lived isotopes to acceptable radioactivity and heat emission levels.

cooling joints -- a joint that is formed as a result of contraction during cooling of a basalt flow (see joint).

core -- a cylindrical sample of rock obtained by use of a hollow drilling bit.

core discing -- drilling of highly stressed hard rock may result in the formation of discs or wafers of relatively uniform thickness with curved surfaces developed approximately normal to the axis of the core. The partings are independent of the rock structure with thickness of discs diminishing with increasing stress. Disc thickness has been observed varying from that equal to the core diameter to less than a fifth of the core diameter.

core drill -- a mechanism designed to rotate and cause an annular-shaped rock cutting bit to penetrate rock formations, produce cylindrical cores of the formations penetrated, and lift such cores to the surface where they may be collected and examined.

coulee -- a dry or intermittent stream valley of considerable extent. On the Columbia Plateau coulees are a long, steep-walled, trench-like gorge or valley which commonly is an abandoned overflow channel that temporarily carried meltwater from an ice sheet.

crib -- as used for nuclear waste, a linear excavation of approximately 15 feet in depth along the bottom of which is laid a perforated pipe, after which the ditch is backfilled with broken rock or other loose material and then covered by soil and a membrane which is impermeable to liquids; the pipe is then used to distribute intermediate-level liquid wastes along the crib.

crib -- as used in underground mining for roof support, a structure composed of frames of timber laid horizontally on one another, or of timbers built up as in the walls of a log cabin.

criterion -- a standard rule or test by which something can be judged.

criticality -- state of being critical; a self-sustaining neutron chain reaction.

DRAFT

crosscut -- (1) a small passageway driven at right angles to the main entry to connect it with a parallel entry or air course. (2) A level driven across the course of a vein or across the general direction of the workings.

crystalline rock -- an inexact but convenient term designating an igneous or metamorphic rock, as opposed to a sedimentary rock. Such rock consists almost wholly of mineral crystals or fragments of crystals.

cumulative releases of radionuclides -- the total number of curies of radionuclides entering the accessible environment in any 10,000-year period, normalized on the basis of radiotoxicity in accordance with 40 CFR Part 191. The peak cumulative release of radionuclides refers to the 10,000-year period during which any such release attains its maximum projected value.

curie -- a unit of radioactivity defined as the amount of a radioactive material that has an activity of 3.7×10^{10} disintegrations per second; millicurie = 10^{-3} curie; microcurie = 10^{-6} curie; nanocurie = 10^{-9} curie; picocurie = 10^{-12} curie.

decay (radioactive) -- (1) the process whereby radioactive materials undergo a change from one isotope, element, or state to another, releasing radiation in the process. This action ultimately results in a decrease in the number of radioactive nuclei present in the sample. (2) The spontaneous transformation of one nuclide into a different nuclide or into a different isotope of the same nuclide.

decay chain -- the sequence of radioactive disintegrations in succession from one nuclide to another until a stable daughter is reached.

decollement -- detachment structure of strata due to deformation, resulting in independent styles of deformation in the rocks above and below.

decommissioning -- the permanent removal from service of surface facilities and components necessary for preclosure operations only, after repository closure, in accordance with regulatory requirements and environmental policies.

defense wastes (nuclear) -- radioactive wastes generated in activities related to the national defense program, including the manufacture of nuclear weapons, the operation of naval reactors, and research and development at weapons laboratories. (See also commercial waste.)

dense interior -- see flow interior

density log -- a gamma-gamma log used to indicate the varying bulk densities of rocks penetrated in drilling by recording the amount of backscattering of gamma rays.

denudation -- the sum of the processes that result in the wearing away or progressive lowering of the Earth's surface by various natural agents including weather, erosion, mass-wasting, and transportation.

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deposition -- the constructive accumulation, through mechanical or chemical processes, of material, normally into parallel layers.

design basis accident -- that accident, from an exhaustive list of credible accidents, which is determined by analysis to be realistically the most consequential with respect to public health. The design basis accident is used to test the facility design and to evaluate site suitability against the criteria of NRC (1980b).

design basis earthquake -- that "realistic" earthquake which is the most severe design basis accident of this type (earthquake) and which produces the vibratory ground motion for which critical structures and systems important to safety are designed to remain functional. A detailed definition is presented in Appendix A of NRC (1980b). Design basis accident is equivalent to safe shutdown earthquake. (See also safe shutdown earthquake.)

design basis explosion -- the most severe design basis accident involving an explosion.

design basis fire -- the most severe fire that can be identified; it is used to evaluate the integrity of facility structures and fire barriers.

design basis tornado and windstorm -- a site-related tornado or other windstorm with windspeeds, pressure transients, and the standard set of associated missiles, that is the most severe, but realistic, design basis accident of that type.

determination -- as used in the Siting Guidelines, means a decision made by the Secretary of Energy that a site is suitable for site characterization, for selection of a repository site, or that a site is suitable for the development of a repository, consistent with applications of the guidelines of Subparts C and D in accordance with the provisions set forth in Subpart B.

deviation -- (as related to quality assurance) a departure from specified requirements or procedures.

devitrification -- the process by which glassy substances lose their vitreous nature and become crystalline.

dextral shear -- (tectonic term) a shear in which the portion on the far side appears to be offset to the right. (See also right-lateral offset.)

diagenesis -- (1) the process involving physical and chemical changes at low temperatures and pressures in sediment after deposition that converts it to a consolidated rock. (2) Recombination or rearrangement of a mineral resulting in a new mineral.

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diapir -- either a dome or an anticline fold in which overlying rocks have been ruptured by the flow upwards of a plastic core material such as salt.

diastrophism -- a general term for all movement of the crust produced by Earth forces including the formation of continents and ocean basins, plateaus and mountains, folds of strata, and faults.

diatomaceous earth -- a fossil accumulation of diatoms, usually with some radiolaria and smaller amounts of foraminifera. It is used as a filter medium, as industrial filler, for insulation, in ceramics, etc.

diffusion -- a solute spreading phenomena important only at low groundwater velocities.

dike -- a tabular igneous or other intrusion that cuts across the planar structures of the surrounding rock.

diktytaxitic -- a rock texture characterized by numerous jagged, irregular vesicles bounded by crystals, some of which protude into the cavities.

dip -- the angle at which a bed, stratum, vein, or any planar feature is inclined from the horizontal. The dip is at a right angle to the strike.

dip-slip fault -- a fault in which the Earth displacement is parallel to the dip of the fault, and there is no horizontal component parallel to the strike. (See also strike-slip fault.)

Dirichlet boundary conditions -- this phrase means that the value of the mathematical function is assigned definite values at the boundary.

discharge point (or area) -- in ground-water hydraulics, the point (or area) where water comes out of an aquifer onto the surface.

discing -- see core discing.

dispers~~ivity~~ion -- ~~the coefficient of molecular diffusion for the solute in a porous medium. Diffusion in solutions is the process by which ionic or molecular constituents move by their kinetic activity in the direction of their concentration gradient.~~ a solute spreading or dilution phenomena caused by mechanical mixing during groundwater movement and molecular diffusion.

disposal -- the emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste, and the isolation of such waste from the accessible environment.

disqualifying condition -- a condition that, if present at a site, would eliminate that site from further consideration.

dissolution -- the taking up of a substance by a liquid (i.e., water) with the formation of a homogeneous solution (liquid phase).

DRAFT

<u>distribution coefficient</u> -- the ratio of the concentration of a solute sorbed by ion exchange substances such as Earth materials, particularly clays, to the concentration of the solute remaining in solution. A large distribution coefficient implies that the substance is readily sorbed and is redissolved slowly. The concentration of a material in the solid phase (i.e., rock or sediment) (moles per gram) divided by the concentration of material in the aqueous phase (moles per liter).

<u>disturbed zone</u> -- that portion of the controlled area, whose physical or chemical properties are projected to change as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change of properties could have a significant affect on the performance of the geologic repository.

<u>DOE</u> -- the U.S. Department of Energy or its duly authorized representatives.

<u>dome (general)</u> -- a dome-shaped landform or rock mass; a large igneous intrusion whose surface is convex upward with sides sloping away at low but gradually increasing angles; an uplift or an anticlinal structure, either circular or elliptical in outline, in which the rock dips gently away in all directions.

<u>dome (salt)</u> -- a diapiric or piercement structure with a central, nearly circular salt plug, generally 1 to 2 kilometers (0.67 to 1.34 miles) in diameter, that has risen through the enclosing sediments from a deep mother bed of salt.

<u>dose commitment</u> -- the integrated dose that results from an intake of radioactive material when the dose is evaluated from the beginning of intake to a later time; also used for the long-term integrated dose to which people are considered committed because radioactive material has been released to the environment.

<u>dose rate</u> -- radiation dose received per unit of time.

<u>drift</u> -- (as related to mining) horizontal, or nearly horizontal, mined passageway.

<u>drift</u> -- (as related to geology) a general term for all rock material transported either by a glacier or by proglacial meltwater.

<u>drum</u> -- a metal or composition (fiberglass) cylindrical container used for the transportation, storage, and disposal of waste materials.

<u>ductile</u> -- capable of being easily molded or shaped.

<u>earthquake swarm</u> -- a series of minor earthquakes, none of which may be identified as the main shock, occurring in a limited area and time.

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<u>eddy bar</u> -- an accumulation of sand and gravel in an eddying current marginal to a main catastrophic flood channel.

<u>effective porosity</u> -- the amount of interconnected pore space and fracture openings available for the transmission of fluids, expressed as the ratio of the volume of interconnected pores and openings to the volume of rock.

<u>Eh</u> -- a measure of the oxidation reduction potential (volts); the difference in potential measured in a cell having both oxidized and reduced form of an element (measured) and the standard hydrogen electrode potential.

<u>emplacement</u> -- (as related to waste management) the act of placing containerized waste in a prepared position.

<u>emplacement medium</u> -- the material in which a repository is built and into which the waste will be placed. (See also host rock.)

<u>emplacement site</u> -- (as related to waste management) the prepared position where the assembled waste package resides.

<u>engineered barrier system</u> -- the manmade components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. Such term includes the radioactive-waste form, radioactive-waste canisters, materials placed over and around such canisters, any other components of the waste package, and barriers used to seal penetrations into the underground facility.

<u>engineering scale</u> -- refers to the size of tests being performed. Engineering-scale tests are conducted as an intermediate step between small- (bench-) scale laboratory tests and semi- or full-scale tests that are conducted at field test facilities or at a repository site.

<u>entablature</u> -- the upper to the middle portion of a basalt flow that has thinner and less regular columns than the lower portion or colonnade.

<u>Environmental Assessment</u> -- the document required by Section 112(b)(1)(E) of the Nuclear Waste Policy Act of 1982.

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

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<u>Environmental Report</u> -- a detailed document that is submitted to the NRC as part of the license application. The document provides a detailed description of the expected environmental impacts associated with a proposed construction project, in this case a nuclear waste repository in basalt.

<u>eolian</u> -- of, related to, formed by, or deposited from the wind or currents of air. Often applied to sand dunes which have been accumulated by the wind.

<u>EPA</u> -- the U.S. Environmental Protection Agency or its duly authorized representatives.

<u>ephemeral stream</u> -- a stream that flows in direct response to precipitation and is dry at some or most of the time during the year.

<u>epicenter</u> -- the point on the Earth's surface directly above the focus or place of origin of an earthquake.

<u>erosion</u> -- the general natural process by which materials at the surface of the Earth are loosened, worn down, and transported from their original locations.

<u>eustatic</u> -- pertaining to world wide changes of sea level that affect all the oceans (see glacio-eustatic).

<u>evaluation</u> -- as used in the Siting Guidelines means the act of carefully examining the characteristics of a site in relation to the requirements of the qualifying or disqualifying conditions specified in the guidelines of Subparts C and D. Evaluation includes the consideration of favorable and potentially adverse conditions.

<u>evapotranspiration</u> -- the mechanism whereby moisture is removed from the soil by transpiration through plants and subsequent evaporation.

<u>exclusion area</u> -- that area surrounding an individual nuclear facility in which the licensee has the authority to determine all activities including exclusion or removal of personnel and property from the area. The BWIP has defined this as the outer fence of the surface workings.

<u>expected</u> -- assumed to be probable or certain on the basis of existing evidence and in the absence of significant evidence to the contrary.

<u>expected repository performance</u> -- the manner in which the repository is projected to function, considering those conditions, processes, and events that are most likely to prevail or occur during the time period of interest.

<u>extensometer</u> -- an instrument used in measuring strain.

<u>facies</u> -- part of a rock body as differentiated from other parts by origin, appearance, and composition.

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facility -- any structure, system, or system component, including engineered barriers, created by the DOE to meet repository performance or functional objectives.

fanglomerate -- a sedimentary rock consisting of slightly waterworn, heterogeneous fragments of all sizes, originally deposited in an alluvial fan and subsequently cemented into a firm rock.

fault (geologic) -- a fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture or zone of fractures.

fault block -- a mass bounded on at least two opposite sides by faults. It may be elevated or depressed relative to the adjoining region, or it may be elevated relative to the region on one side and depressed relative to that on the other side.

fault gouge -- a soft, uncemented pulverized clayey or claylike material, commonly a mixture of minerals in finely divided form, found along some faults or between the walls of a fault, and filling or partly filling a fault zone; a slippery mud that coats the fault surface or cements the fault breccia. It is formed by the crushing and grinding of rock material as the fault developed, as well as by subsequent decomposition and alteration caused by underground circulating solutions.

fault system -- a system of parallel or nearly parallel faults that are related to a particular deformational episode.

faulting -- the process of fracturing and displacement that produces a fault.

favorable condition -- a condition that, though not necessary to qualify a site, is presumed, if present, to enhance confidence that the qualifying condition of a particular guideline can be met.

filler -- the nonradioactive portion of the waste form which chemically or mechanically limits the mobility of radionuclides by dispersion or leaching. Also called binder, matrix, or immobilizing agent.

Final Environmental Impact Statement -- an Environmental Impact Statement that has completed the public hearing process and has been issued by the responsible governmental agency.

Final Safety Analysis Report -- a detailed safety document issued by the NRC to discuss and resolve safety questions pertaining to a nuclear project. The document is considered final after public hearings have been completed and NRC issues the document.

Finding -- a conclusion that is reached after evaluation.

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finite-element computer code -- a computer code which uses the finite-element method. The finite-element method is a method of numerical analysis which divides a region of interest into discrete elements and represents the behavior of the elements with a set of simultaneous equations. Solution of the set of equations yields the behavior at discrete points within the region of interest.

first-order fold -- an original stage fold larger than subsequent folds that may occur on it. (See also second-order fold.)

fission (nuclear) -- the division of nucleus into nuclides of lower mass, roughly one-half the original mass, usually accompanied by the expulsion of gamma rays, neutrons, heat, and other subatomic particles.

fission product -- a nuclide produced by the fission of a heavier element.

fissure -- a fracture or a crack in the Earth's surface, along which there is a distinct separation.

flat jack test -- testing apparatus used for determination of in situ stresses or rock mass deformability. The apparatus consists of two thin metal plates welded together at the edges that expands when pressurized with hydraulic fluid. The flat jack is placed into a slot cut into the rock which is oriented normal to two preinstalled reference pins. The deformability test is conducted by measuring the change in distance between the pins for incremental changes in flat jack pressure. In situ stresses in one direction perpendicular to the plane of the flat jack are determined when the flat jack pressure produces pin separation equal to that which existed prior to slot cutting and rock mass relaxation into the slot. Three tests at mutually perpendicular orientations are, at a minimum, required for the complete in situ stress condition.

flexure-flow fold -- a fold in which the mechanism of folding is flow within layers, resulting in thickening of hinge areas and thinning of limbs.

flooding potential -- areas susceptible to flooding by precipitation, wind, or seismically induced floods (i.e., those resulting from dam failure, river blockage or diversion, or distantly or locally generated waves) are considered to have a flooding potential.

flood plain -- (as defined in 10 CFR 60 (NRC, 1983)) the lowland and relatively flat areas adjoining inland and coastal waters, including flood-prone areas of offshore islands and including, at a minimum, that area subject to a 1 percent or greater chance of flooding in any given year.

flow -- (geological in terms of this document) a basalt layer.

flow contact -- a planar or irregular surface where two different types or ages of rock meet (i.e., between two basalt flows).

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finite-element computer code -- a computer code which uses the finite-element method. The finite-element method is a method of numerical analysis which divides a region of interest into discrete elements and represents the behavior of the elements with a set of simultaneous equations. Solution of the set of equations yields the behavior at discrete points within the region of interest.

first-order fold -- an original stage fold larger than subsequent folds that may occur on it. (See also second-order fold.)

fission (nuclear) -- the division of nucleus into nuclides of lower mass, roughly one-half the original mass, usually accompanied by the expulsion of gamma rays, neutrons, heat, and other subatomic particles.

fission product -- a nuclide produced by the fission of a heavier element.

fissure -- a fracture or a crack in the Earth's surface, along which there is a distinct separation.

flat jack test -- testing apparatus used for determination of in situ stresses or rock mass deformability. The apparatus consists of two thin metal plates welded together at the edges that expands when pressurized with hydraulic fluid. The flat jack is placed into a slot cut into the rock which is oriented normal to two preinstalled reference pins. The deformability test is conducted by measuring the change in distance between the pins for incremental changes in flat jack pressure. In situ stresses in one direction perpendicular to the plane of the flat jack are determined when the flat jack pressure produces pin separation equal to that which existed prior to slot cutting and rock mass relaxation into the slot. Three tests at mutually perpendicular orientations are, at a minimum, required for the complete in situ stress condition.

flexure-flow fold -- a fold in which the mechanism of folding is flow within layers, resulting in thickening of hinge areas and thinning of limbs.

flooding potential -- areas susceptible to flooding by precipitation, wind, or seismically induced floods (i.e., those resulting from dam failure, river blockage or diversion, or distantly or locally generated waves) are considered to have a flooding potential.

flood plain -- (as defined in 10 CFR 60 (NRC, 1983)) the lowland and relatively flat areas adjoining inland and coastal waters, including flood-prone areas of offshore islands and including, at a minimum, that area subject to a 1 percent or greater chance of flooding in any given year.

flow -- (geological in terms of this document) a basalt layer.

flow contact -- a planar or irregular surface where two different types or ages of rock meet (i.e., between two basalt flows).

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flow interior -- the zone within a basalt flow that includes both the entablature and colonnade.

flow structure -- the structure of igneous rocks, generally but not necessarily restricted to volcanic rocks, in which the stream or flow lines of the magma (as evidenced by the orientation of the rock crystals) are revealed by alternating bands or layers of differing composition, crystallinity, or texture.

flow top -- the uppermost portion of a basalt flow, which consists of vesicular and rubbly-to-brecciated basalt.

fluid content -- the degree of saturation of the intergranular space in rocks by organic fluids, gases, or water; the state of hydration of the rock minerals.

fluvial -- of or pertaining to streams and rivers; produced by stream or river action.

flux -- rate of flow over a surface (quantity per unit area per unit time).

focal-mechanism solution -- a double-couple solution obtained using first motion of arrival of P waves at a particular seismic-recording station.

fold (geological) -- a bend or flexure in a layer or layers of rock. Usually applies to a single strong flexure with steeply inclined sides.

foldbelt -- a linear region that has been subjected to folding and deformation.

formation (geologic) -- the basic rock-stratigraphic unit in the local classification of rocks. It consists of a body of rock generally characterized by some degree of internal lithologic homogeneity or distinctive features.

fracture -- a general term for any break or discontinuity in a rock caused by mechanical failure resulting from stress, whether or not it causes displacement on either side large enough to be visible to the unaided eye. It may be a joint, fault, or fissure caused by geological or mechanical process and can range from microscopic to macro- and megascopic scales.

fuel (nuclear reactor) -- fissionable material used as the source of power when placed in a critical arrangement in a nuclear reactor.

fuel assembly -- a unit of nuclear reactor fuel, assembled of fuel rods, ends, and supports.

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fuel cycle -- the complete series of steps involved in supplying fuel for nuclear reactors. It includes mining, refining, the original fabrication of fuel elements, their use in a reactor, chemical processing to recover the fissionable material remaining in the spent fuel, re-enrichment of the fuel material, refabrication into new fuel elements, and management of radioactive waste.

fuel reprocessing (fuel separation) -- processing of irradiated (spent) nuclear reactor fuel to recover useful materials as separate products, usually includes separation into plutonium, uranium, neptunium, and fission products.

fuel rod -- a tube form into which fissionable material is fabricated for use in a reactor.

gallery (geology) -- (1) a horizontal or nearly horizontal underground passage, either natural or artificial. (2) A subsidiary passage in a cave at a higher level than the main passage.

geochemistry -- study of the quantity, distribution, and origin of chemical elements in minerals, rocks, spoils, water, and the atmosphere.

geodetic survey -- a survey of a large land area in which account is taken of the figure and size of the Earth and corrections are made for Earth curvature.

geodolite -- an electro-optical distance-measuring instrument in which a modulated laser beam is projected from the instrument to a remote reflector from which it is returned to the instrument. Geodolite is a trade name.

geoelectric layer -- one particular layer in a vertical distribution of layer thicknesses, electrical conductivities, dielectric permissivities, and magnetic permeabilities that are descriptive of the subsurface.

geoengineering -- The application of geologic data, principals, and techniques to the study of naturally occurring rock and soil materials or ground-water for the purpose of assurring that geologic factors affecting the location, planning, design, construction, operation, and maintenance of engineering structures and the development of ground-water resources are properly recognized and adequately interpreted, utilized, and presented for use in engineering practice.

geohydrologic setting -- the system of geohydrologic units that is located within a given geologic setting.

geohydrologic system -- the geohydrologic units within a geologic setting, including any recharge, discharge, interconnections between units, and any natural or man-induced processes or events that could affect ground-water flow within or among those units.

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geohydrologic unit -- an aquifer, a confining unit, or a combination of aquifers and confining units comprising a framework for a reasonably distinct geohydrologic system.

geologic repository -- the portion of the total disposal system that consists of the underground structures and components, including engineered barriers not associated with the waste package, notably seals, and; the host rock that supports them. The repository will be designed to mitigate the effects exerted on the natural system by repository construction and waste emplacement.

geologic-repository operations area -- a radioactive-waste facility that is part of the geologic repository, including both surface and subsurface areas and facilities where waste-handling activities are conducted.

(Columbia Plateau)

geologic setting -- the geologic, hydrologic, and geochemical systems of the region in which a geologic-repository operations area is or may be located.

geologic time scale -- a system of subdividing geologic time, usually presented in the form of a chart showing the names of the various divisions of time, stratigraphy, or rock as currently understood (Table 1).

geomechanics -- a branch of geology that embraces the fundamentals of structural geology and a knowledge of the response, or strain, of natural materials to deformation, or changes caused by the application of stress and (or) strain energy.

geomorphic processes -- geologic processes that are responsible for the general configuration of the Earth's surface, including the development of present landforms and their relationships to underlying structures, and are responsible for the geologic changes recorded by these surface features.

geophysical anomaly -- an area or restricted portion of information derived from a geophysical survey that is different in appearance from the general pattern of the information.

geophysical log -- a graphic record of measured or computed geophysical data. Types of geophysical logs include sonic, density, natural gamma, neutron, and porosity logs.

geophysical survey -- the use of one or more geophysical techniques such as Earth currents, electrical, gravity, magnetic, and seismic to gather information on the subsurface geology.

geothermal gradient -- the rate of increase of temperature of the Earth with depth.

Geologic repository -- [redacted] a system, requiring licensing by the NRC, that is intended to be used, or may be used, for the disposal of radioactive waste in excavated geologic media. A geologic repository includes (1) the geologic-repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.

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Table 1. Geologic column and scale of time.

Periods of time/ systems of rocks	Epochs of time/ series of rocks	Age (years x 106 before present)
	CENOZOIC ERA	
Quaternary	Holocene (Recent)	0.1
	Pleistocene	1.8
Tertiary	Pliocene	5.0
	Miocene	22.0
	Oligocene	38.0
	Eocene	54.0
	Paleocene	65.0
	MESOZOIC ERA	
Cretaceous		
Jurassic		65 - 225
Triassic		
	PALEOZOIC ERA	
Permian		
Carboniferous periods		
Upper (Pennsylvanian)		
Lower (Mississippian)		
Devonian		225 - 570
Silurian		
Ordovician		
Cambrian		
	PRECAMBRIAN TIME	
No basis for worldwide subdivisions		570 - 5,000

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geotransport -- in this document, movement of radionuclides through subsurface soils and rocks, especially movement with the ground water. Used in contrast to biotransport.

getter -- a material that selectively sorbs and holds particular elements; i.e., an Eh buffer is an oxygen getter. This term is particularly applicable to engineered barrier systems. (Adapted from metallurgical processes wherein a getter is used to remove impurities.)

glacio-eustatic -- pertaining to worldwide changes in sea level resulting from successive withdrawal and return of water to the oceans, which occurs during the growth and melting of ice sheets (see eustatic).

glaciofluvial -- of, pertaining to, produced by, or resulting from combined glacial meltwaters.

gouge -- the clay or clayey material in a fault zone. Also crushed rock along a fault slip.

Governor -- the chief executive officer of a State.

granite -- a medium to coarse grained intrusive igneous rock consisting primarily of feldspar and quartz.

gravity survey -- the systematic measurement of the Earth's gravitational field in a specified area.

ground magnetic survey -- a determination of the magnetic field at the surface of the Earth by means of ground-based instruments.

ground motion -- vibration of the Earth's crust caused by earthquakes. Ground motion has both horizontal and vertical components. Also called vibratory ground motion and measured as a decimal fraction of the acceleration due to gravity.

ground water -- ~~all subsurface water as distinct from surface water.~~ water that exists below the land surface.

ground-water flux -- the rate of ground-water flow per unit area of porous or fractured media measured perpendicular to the direction of flow.

ground-water recharge rate -- the rate at which water is added to the zone of saturation, either directly into a formation or indirectly by way of another formation.

ground-water residence time -- the time that ground water remains in an aquifer or aquifer system.

ground-water sources -- aquifers that have been or could be economically and technologically developed as a source of water in the foreseeable future.

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ground-water travel time -- the time required for a unit volume of ground water to travel between two locations. The travel time is the length of the flow path divided by the ~~mean~~ velocity, where ~~mean~~ velocity is the average ground-water flux passing through the cross-sectional area of the geologic medium through which flow occurs, perpendicular to the flow direction, divided by the mean effective porosity along the flow path. If discrete segments of the flow path have different hydrologic properties, the total travel time will be the sum of the travel times for each discrete segment.

grout (grouting) -- (structural) a neat cement, mixture of cement and sand, or cement admixed with bentonite or other clay. It is usually injected under pressure into foundations through specially drilled holes for the purpose of sealing off or filling joint seams, fissures, or other openings.

grout, isolation -- (as used in a repository) a mortar or cement-water-additive mixture used to seal boreholes. In radioactive waste processing it may be combined with liquid waste to provide a matrix for isolation of the waste and to seal the waste from the environment.

guideline -- a statement of policy or procedure that may include, when appropriate, qualifying, disqualifying, favorable, or potentially adverse conditions as specified in the "guidelines."

guidelines -- Part 960 of Title 10 of the Code of Federal Regulations--General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories.

half-life -- (1) the time required for a radioactive substance to decay to half its original concentration. Each radionuclide has a characteristic, but constant half-life. (2) Biological half-life: time required for half of an ingested (or inhaled) substance to be eliminated by natural processes.

hanging wall -- the overlying side of a fault or other structure.

head, hydraulic -- see hydraulic potential (or hydraulic head).

headframe -- the steel or timber frame at the top of a shaft which carries the sheave or pulley for the hoisting rope and serves various other purposes.

heat emission -- for the purpose of establishing waste package acceptance criteria, the total amount of heat dissipated from a radioactive waste package.

heavy metal -- (as used by the EPA) all uranium, plutonium, or thorium placed into a nuclear reactor.

hinge zone -- a zone along the boundary between a tectonically stable region and a region moving upward or downward.

replacement

"High-level radioactive waste" means (1) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations and (2) other highly radioactive material that the NRC, consistent with existing law, determines by rule requires permanent isolation.

new

"Highly populated area" means any incorporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2,500 or more persons, or any census designated place (as defined and delineated by the Bureau) of 2,500 or more persons, unless it can be demonstrated that any such place has a lower population density than the mean value for the continental United States. Counties or county equivalents, whether incorporated or not, are specifically excluded from the definition of "place" as used herein.

historical seismicity -- earthquake activity that occurred during man's recorded history, including those reported before seismographs existed (pre-instrumental) and those recorded by seismographs (instrumental).

Holocene -- an epoch of the Quaternary Period, from the end of the Pleistocene to the present time. (See also geologic time scale.)

horizon -- (1) in geology, a given definite position or interval in the stratigraphic column. (2) In this document, a specific underground level, altitude, or elevation.

host rock -- means the geologic medium in which the waste is emplaced, specifically the geologic materials that directly encompass and are in close proximity to the underground facility.

hot cell -- facility with remote-handling capabilities and adequate shielding for handling highly radioactive substances.

hyalocrystalline -- a textural term referring to an igneous rock in which glass groundmass constitutes approximately three-eighths to five-eighths volume proportion of the rock.

hydraulic conductivity -- the ~~volume of~~ rate of water flow ~~that will move~~ through a given cross section of rock ~~a medium~~ in a unit time under a unit hydraulic gradient ~~through a unit area~~ measured perpendicular to the direction of flow. Synonymous with the case of groundwater movement.

hydraulic gradient -- a change in the static pressure of ground water, expressed in terms of the height of water above a datum, per unit of distance in a given direction.

~~hydraulic potential (or~~ hydraulic head~~)~~ -- a measure of the mechanical energy per unit mass of fluid present at a given point within a porous medium. For ground-water flow systems the parameter is generally determined in the field by measuring the elevation of water within tightly cased wells or by measuring the pressure within a hydraulically isolated portion of a borehole or well. ~~Generally expressed in units of length.~~

hydrofracturing -- (as used in rock mechanics) a technique for measuring in situ stress by artificially inducing fractures hydraulically in a rock mass.

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hydrogeologic unit -- any soil or rock unit or subsurface zone that has a distinct influence on the storage or movement of ground water by virtue of its porosity or permeability.

hydrologic process -- any hydrologic phenomenon that exhibits a continuous change in time, whether slow or rapid.

hydrologic properties -- those properties of a rock that govern the entrance of water and the capacity to hold, transmit, and deliver water, such as porosity, effective porosity, ~~specific retention,~~ permeability, and the directions of maximum and minimum permeabilities.

hydrological regime -- the distribution, characteristics, and interrelationships of the aqueous components of the geologic environment.

hydrologic modeling -- the process of using a mathematical representation of a hydrologic system (as embodied in a computer code) to predict the flow of ground water and the movement of dissolved substances.

hydrologic transport -- transport of solutes through a geologic formation due to movement of ground water.

hydrology -- ~~hydrology is~~ the science of hydraulics as it pertains to ground water, its properties, circulation, and distribution, from the time it falls as rainwater until it is returned to the atmosphere through evapotranspiration or flows into the ocean.

hydrostatic equilibrium -- the static head is the height above a standard datum (such as sea level) of the surface of a column of water ~~(or other liquid)~~ that can be supported by the static pressure at a given point. When fluid bodies of equal head are connected, the result is a condition where there is no relative movement of liquid between the fluid elements. Such a system is said to be in hydrostatic equilibrium.

hydrostatic pressure -- the pressure of, or corresponding to, the weight of a column of water at rest.

hydrothermal reactions -- the reaction of materials under aqueous conditions at elevated temperatures and pressures. A component of hydrothermal test mixtures is usually the host rock, but such mixtures may contain any or all waste package components.

hypocenter -- the focus or specific point at which initial rupture occurs in an earthquake.

igneous -- formed by volcanic action or intense heat (crystallized from an original melt).

The science that treats the occurrence, circulation, distribution, and properties of the waters of the earth and their reaction with the environment.

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igneous activity -- the emplacement (intrusion) of molten rock material (magma) into material in the Earth's crust or the expulsion (extrusion) of such material onto the Earth's surface or into its atmosphere or surface water.

igneous rock -- rock formed by solidification of a molten material that originated within the Earth.

image analysis -- the quantiative analyis of a specimen, using the optical counterpart of the specimen, produced by the enhanced reflection or refraction of light when focused by an electronic optical system.

imbricate faulting -- a zone of closely spaced faults exhibiting a structure of tabular masses that overlap one another as shingles on a roof.

immobilization -- treatment and/or positioning of nuclear wastes so as to impede the movement of radioactive isotopes.

important to safety -- (NRC, 1983) with reference to structures, systems, and components, means those engineered structures, systems, and components essential to the prevention or mitigation of any accident that could result in a radiation dose to the whole body, or an organ, of 0.5 rem or greater at or beyond the nearest boundary of the controlled area at any time until the completion of permanent closure.

in situ -- in the natural or original position. The phrase is used in this document to distinguish in-place experiments, rock properties, and so on, from those in the laboratory. Derived from the Latin for "in its original place."

in situ stress -- the magnitude and state of ground stress in a rock mass. The inherent stress in a rock mass at depth.

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

institutional control -- activities, devices, and combinations thereof which involve the performance of functions by human beings to limit contact between the waste and humans or the biosphere. Requires maintaining an institutional capability to (a) restrict or deny access; (b) monitor, terminate, or clean up releases to the accessible environment; or (c) preserve knowledge about the location, design, or inventory of a disposal site.

instrumental seismicity -- earthquakes recorded on a seismograph (an instrument designed to detect and record earthquakes).

intensity (earthquake) -- measure of the effects of an earthquake on man, on man-built structures, and on the Earth's surface at a particular location. Quantified by a numerical value on the modified Mercalli scale. (See also magnitude (earthquake), modified Mercalli scale, and Richter scale.)

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<u>intercalated</u> -- occurring between two rock layers or within a series of layers.

<u>interbed</u> -- see basalt interbed.

<u>interflow</u> -- occurring between basalt flows, as in interflow zone.

<u>intergranular</u> -- refers to the ophitic texture of an igneous rock in which the augite occurs as an aggregation of grains, not in optical continuity, in the interstices of a network of feldspar laths which may be diverse, subradial, or subparallel. The interstitial augite forms a relatively small proportion of the rock.

<u>interim storage</u> -- short-term, temporary storage operations for which (a) surveillance and human control are provided and (b) subsequent action involving treatment, transportation, or final disposition is expected. The time scale encompassed in this definition is typically a few decades.

<u>internal structures</u> -- as pertains to internal characteristics of basalt flows this phrase includes: flow top breccias, visicular zones, pillow zones and cooling joint structures (patterns) such as entablature and colonnade.

<u>intersertal</u> -- a textural term applied to porphyritic igneous rock in which the groundmass occupies the interstices between unoriented feldspar laths, with the groundmass forming a relatively small proportion of the rock.

<u>interstitial compounds</u> -- interstitial deposits formed subsequently to the rock formations whose pores they have filled by impregnation.

<u>intracanyon</u> -- occurring within a canyon.

<u>intraflow structures</u> -- see internal structures.

<u>ion exchange</u> -- (1) a phenomenon in which chemical species in one phase or material exchange with a species in another phase. In this report, ion exchange usually refers to a particular process in an aquifer: the exchange of ions in the water for ions in or on the minerals. (2) Process for selectively removing a solute from a waste stream by reversibly transferring ions between an insoluble solid and a solute in the waste stream; the exchange medium (usually a column of resin or soil) can then be washed to collect the waste or taken directly to disposal; for example, a water softener.

<u>isolation</u> -- 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.

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isolation -- (as defined in 10 CFR 60 (NRC, 1983)) inhibiting the transport of radioactive material so that amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.

isolation barrier (natural) -- as pertains to nuclear waste storage in a geologic repository, the Earth material around the subsurface chambers which acts in a manner to prevent radioactivity from entering the biosphere.

isopach map -- a map that shows the thickness of a geologic unit throughout a geographic area by means of isopach lines at regular intervals.

isoperemetric -- as pertaining to maps, isoperemetric lines are lines along which there is no variation from exact scale.

isopleth -- a line connecting all points of equal value of concentrations, head, etc.

isotherm -- a line joining data points on a map or chart having the same temperature.

issue -- a technical question about which there is debate or controversy. Issues are technical questions that arise when available information or technology is insufficient to make a specific decision or come to a specific conclusion about some aspect of repository siting or development. (See also work element.)

joint -- a surface of fracture or parting in a rock without displacement that cuts through and abruptly interrupts the physical continuity of a rockmass.

jointing, columnar -- see columnar jointing.

K_d -- see distribution coefficient

kinematic analysis -- the analysis of motion, exclusive of the influences of mass and force. Kinematic analysis is the analysis of displacements and strains, based on geometric analysis plus a number of assumptions regarding the manner in which geometrical relationships serve to indicate displacements. After the recording and evaluating of geometric data, an inventory must be made of all observable and deducible traces of movement and indications of strain.

kriging -- an interpolation technique that can provide unbiased estimates of a spatially distributed quantity at points, or in regions, where data are lacking. The kriging algorithm is designed to minimize the error of each estimate.

lacustrine -- pertaining to, produced by, or formed in a lake or lakes.

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lahar -- a type of mudflow composed chiefly of volcaniclastic materials on the flank of a volcano.

leakage -- refers to ~~vertical~~ ground-water ~~movement~~ ~~across basalt flows.~~ flow across or through a rock zone of low permeability

license application -- an application for permits and authorization from responsible Federal, State and local regulatory agencies to site, construct, operate, and decommission a repository. Such an application is usually accompanied by required documentation showing that the nuclear facility and its safety-related systems, with reasonable assurance, can be operated without undue risk to the health and safety of the public and with adequate provisions for the protection of property and the environment.

licensing -- the process of obtaining the permits and authorizations from responsible federal, state, and local regulatory agencies required to site, construct, operate, and decommission a repository. Includes preparing required documentation, submitting it to the appropriate agencies, responding to agency requests for additional information, and testifying as necessary at public hearings. Within the licensing framework, as defined in statutory requirements, approved permits or licenses must be available prior to the commencement of the activity involved.

ligand -- the anion or molecule with which a cation forms a complex.

lignite -- a brownish-black coal in which the alteration of vegetable material has proceeded further than in peat, but not so far as subbituminous coal.

"Likely" ~~means~~ possessing or displaying the qualities, characteristics, or attributes that provide a reasonable basis for confidence that what is expected indeed exists or will occur.

Changed

lineament -- a significant line of landscape that reveals the hidden structure of the rock.

lithology -- the study of rocks. Also the description of a rock on the basis of such characteristics as structure, color, mineral composition, grain size, and arrangement of its component parts.

lithosphere -- the solid part of the Earth, including any ground water contained within it.

lithostatic pressure -- the confining pressure at depth in the crust of the Earth due to the weight of the overlying rocks.

loess -- a homogeneous unstratified deposit of windblown dust composed predominantly of sand and silt.

logging -- recording observations, conditions, activities, or measurements.

long-lived isotope -- a radioactive nuclide which decays at such a slow rate that a quantity of it will exist for an extended period.

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low-level transuranic waste -- transuranic waste packages whose surface dose rate is sufficiently low to permit direct contact handling; also referred to as contact-handled transuranic waste.

macroearthquake -- for the purposes of this study, an earthquake that is felt by people or an earthquake having a magnitude of 3 or greater on the Richter scale.

magma -- a comprehensive term for the molten fluids generated within the Earth from which igneous rocks are believed to have been derived by crystallization or by other processes of consolidation.

magnetic survey -- as pertains to geophysical survey, a measurement of a component of the Earth's geomagnetic field at several locations in order to produce a map of local anomalies caused by variation in rock magnetization.

magnetometer survey -- a magnetometer is an instrument that measures the Earth's field or the magnetic field of a particular rock (see magnetic survey).

magnetostratigraphy -- stratigraphy based on paleomagnetic signatures (remanent magnetization).

magnetotelluric method -- a geophysical surveying method which measures the natural electric and magnetic fields of the Earth.

magnitude (earthquake) -- the measure of the strength of an earthquake; related to the energy released in the form of seismic waves, as determined by seismographic observation. Magnitude is quantified by numerical value on the Richter scale. (See also intensity, modified Mercalli scale, and Richter scale.)

management and storage -- (as used by the EPA (1981)) any activity, operation, or process, except for transportation, conducted to prepare spent nuclear fuel, high-level, or transuranic radioactive wastes for storage or disposal, the storage of any of these materials, or activities associated with the disposal of these materials.

man-rem -- used as a unit of population dose; often the average dose per individual expressed in rems times the population affected.

matrix, waste -- the material in which radioactive nuclear waste is encapsulated. As used frequently in this document, the term refers to the material, likely to be a glass, encapsulating reprocessed high-level waste.

maximum credible earthquake -- the highest magnitude earthquake, considering the known earthquake history and the tectonic setting of an area, which could be expected to occur during the life of an engineered facility such as a repository.

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maximum individual -- characterized as "maximum" with regard to food consumption, occupancy, and other usage of the region in the vicinity of the facility site and as such represents an individual with habits representing reasonable deviations from the average for the population in general. The maximum individual for this study is assumed to reside in a zone where all food from irrigated sources is grown with irrigation water drawn from the Columbia River downstream from the radionuclide discharge point. In addition, this individual is assumed to drill a well for drinking water which intercepts the contaminated ground-water plume at a point where the plume reaches the reasonable depth for such a well. For the base case, the ground-water pathline is in deep basalts until the vicinity of the river is reached. The assumed location of the well is the fourth of five calculation points used for the ground-water transport calculation or a distance of 7 kilometers from the center of the repository. It is not reasonable to assume that irrigation water would be drawn from the plume. If it were, the ground-water flow field would be altered considerably and the bulk of irrigation water would flow in from uncontaminated areas.

maximum permissible concentration -- the average concentration of a radionuclide in air or water to which a worker or member of the general population may be continuously exposed, thus limiting external and/or internal doses to within established values.

member of the public -- any individual who is not engaged in operations involving the management, storage, and disposal of radioactive waste. A worker so engaged is a member of the public except when on duty at the geologic-repository operations area.

Mercalli instensity -- a scale measurement of earthquake intensity. Primarily defined in terms of effects perceived by those near the earthquake. An intensity of 3 to 4 would not normally be felt by a casual observer. See also intensity.

mesostasis -- the last-formed interstitial material of an igneous rock.

Mesozoic -- an era of geologic time, from the end of the Paleozoic to the beginning of the Cenozoic. (See also geologic time scale.)

metamorphic rock -- includes all those rocks which have formed in the solid state in response to pronounced changes of temperature, pressure, and chemical environment, which take place, in general, below the surface zones of weathering and cementation.

metasedimentary -- sedimentary rocks altered by the effects of heat or pressure or both.

metavolcanic -- volcanic rocks altered by the effects of heat or pressure or both.

microearthquake -- for the purposes of this study, an earthquake which is not felt or has a magnitude of less than 3 on the Richter scale.

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microseismic region -- the area in which an earthquake is recorded by instruments only.

microsilica shotcrete -- this type of shotcrete contains more finely ground silica sand than ordinary shotcrete.

millirem -- 1 millirem is 1/1000 of a rem.

Miocene -- an epoch of geologic time within the upper Tertiary Period, after the Oligocene, and before the Pliocene. (See also geologic time scale.)

missile -- any object flying through the air with sufficient mass and velocity to present a significant hazard to persons or structures (WCC, 1981).

mitigation -- (1) avoiding the impact altogether by not taking a certain action or parts of an action; (2) minimizing impacts by limiting the degree or magnitude of the action and its implementation; (3) rectifying the impact by repairing, rehabilitating, or restoring the affected environment; (4) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; or (5) compensating for the impact by replacing or providing substitute resources or environments.

modal analysis -- the analysis of the actual mineral composition of a rock, usually expressed in weight or volume percentages.

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

model (tectonic or seismic) -- a non-numerical, descriptive theory or concept that incorporates geological, geophysical, and geodetic data into a satisfactory explanation of the evolution of stress and strain in the Earth's crust. Such a conceptual simulation that satisfactorily explains past crustal evolution can be used to make predictive estimates of future crustal processes. A tectonic model is useful in predicting potential effects of crustal deformation on a repository during operational and postclosure (containment) periods.

modeling, hydrologic -- see hydrologic modeling.

modified Mercalli scale -- an earthquake intensity scale having 12 divisions ranging from I (not felt by people) to XII (damage nearly total). (See also magnitude (earthquake) and intensity (earthquake).)

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monitoring -- routine measuring of the quantity and type of discharges or migration of radioactive waste from a waste management facility, or measuring changes in physical, chemical, or biological characteristics of the site and the surrounding site area.

monocline -- a downward flexure in otherwise horizontal strata without any corresponding upfold to form a syncline or anticline. Generally a large feature of gentle dip.

moraine -- a mound, ridge, or other distinct accumulation of unsorted, unstratified rock material left at the margins of a retreating glacier.

muck -- broken rock or ore that results from excavation during mining operations.

mucking pocket -- for the Exploratory Shaft test facility, the pocket will be a portion of the shaft below the breakout horizon where muck is collected and loaded for transport to the surface.

mucking (and/or settling) ponds -- ponds next to drilling operations where the excavated mud or slurry is placed; the sediment that settles at the bottom of these ponds is also called muck. Pond muck is very fine grained.

multibarrier system -- concept of using the waste form, the container (canister), the overpack, the emplacement medium, and surrounding geologic media as multiple barriers to isolate the waste from the biosphere. A multi-barrier system is a system of barriers, operating independently or relatively independently, which acts to contain and/or isolate nuclear waste.

natural background radiation -- radiation in the environment from naturally occurring elements and from cosmic radiation.

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

natural gamma log -- a radioactivity log obtained by recording the natural radioactivity of the rocks traversed in a borehole or well and expressed by measuring the intensity of naturally emitted gamma rays and plotting the data as a function of depth.

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

DRAFT

Near-Surface Test Facility -- a full-scale demonstration facility to examine how basalt is affected by heat and radiation-induced stresses from the emplacement of nuclear waste. The objective is to assess the thermomechanical behavior of basalt in response to a heat source simulating the shape, thermal energy, and other characteristics of proposed nuclear waste packages emplaced as intended in a repository.

neutron log -- a radioactivity log that measures the intensity of radiation (neutrons or gamma rays) artificially produced when the rocks around a borehole or well are bombarded by neutrons from a synthetic source.

Nevada Test Site (NTS) -- an area in Clark and Nye Counties in southern Nevada dedicated to the underground testing of nuclear weapons.

NRC -- the U.S. Nuclear Regulatory Commission or its duly authorized representatives.

operating basis earthquake -- that earthquake which, considering the regional and local geology, seismology, and specific characteristics of local subsurface material, could reasonably be expected to affect the plant site during the operating life of the plant. It is that earthquake which produces the vibratory ground motion for which those features of the repository necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional. (See also safe shutdown earthquake.)

operational phase -- that time span of the repository's existence during which radioactive material may be stored or retrieved and prior to decommissioning of the surface facilities. This may include the storage room backfill period. Also called the demonstration phase or period.

ophitic texture -- said of the texture of an igneous rock in which lath-shaped plagioclase crystals are partially or completely included in pyroxene crystals, typically augite.

outcrop -- a part of a body of rock formation that appears bare and exposed at the surface of the ground.

outwash -- sorted and stratified rock material deposited by proglacial meltwater streams.

overburden -- loose soil, sand, gravel, etc., that lies above the bedrock. The term should not be used without specific definition. Also called burden, cover, drift, mantle, surface. (See also regolith.)

overcoring test -- (1) (as related to retrieval) a process for removing waste from its burial in basalt by extracting a cylinder of rock that surrounds and contains the waste. (2) (As related to rock mechanics) a method of measuring in situ stress. The method involves installation of multidirectional strain recording devices in small boreholes and removing the devices by coring and enclosing wall rock while recording the resulting strain relief.

DRAFT

overpack -- a material envelope surrounding an as-canisterized waste form in which the specific canister is not in compliance with the acceptance specifications of the repository, but is in compliance when housed within the envelope provided by the overpack. The overpack is not intended for routine application.

overthrust -- a low-angle thrust fault of large scale, with displacement generally measured in kilometers.

oxidize -- to combine oxygen with some substance, or to raise the valence state of a substance by removing electrons from it.

oxygen chemical potential -- see Eh.

packaging -- the container, any overpacks, and their contents, excluding radioactive materials and their encapsulating matrix but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for absorbing mechanical shock, external fittings or handling devices, neutron absorbers or moderators, and other supplementary equipment that surrounds the radioactive material.

packer -- a device used in drilled holes to isolate one part of a borehole from another in order to carry out studies (e.g., hydrologic) of particular formations or parts thereof.

packing -- the part of the waste package that contributes to the performance of the total waste package by minimizing ground-water interaction with the container and waste form materials, limiting radionuclide transport, and (or) altering ground-water chemistry to minimize waste form/canister/container degradation and radionuclide solubility.

palagonite -- a weathered hydrated basaltic glass commonly formed when molten basalt that entered water has become weathered; indicative of an aqueous environment, often associated with pillow lava.

paleo -- a combining form denoting the attribute of great age or remoteness in the past.

paleomagnetism -- the study of the natural remanent magnetization to determine the intensity and direction of the Earth's magnetic field in the geologic past.

paleontology -- the study of life in the geologic past, based on fossilized plant and animal remains.

palynology -- the study of spores, pollen, and micro-organisms that occur in sediments.

paludal -- pertaining to a marsh or swamp.

panel -- separate series of storage rooms designed for the storage of 1 year's (nominal) waste receipts.

DRAFT

Paradox basin -- a 25,900-square-kilometer (10,000-square-mile) area in southeastern Utah and southwestern Colorado underlain by bedded salt and a series of salt-core anticlines.

paragenesis -- a general term for the order of formation of associated minerals in time succession, one after another. To study the paragenesis is to trace out in a rock or vein the succession in which the minerals have developed.

parasitic anticline -- an anticlinal fold occurring on one of the flanks of a larger anticline.

Pasco Basin -- a structural and topographic basin within the western Columbia Plateau. The Hanford Site is located within the Pasco Basin.

pathway -- (as related to waste management) possible or potential routes by which wastes might reach the accessible environment.

penecontemporaneous -- said of a geologic process, or resultant structure or mineral, occurring immediately after deposition but before consolidation of the enclosing rock.

perched ground water -- unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Its water table is a perched water table. Perched ground water is held up by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.

percolate -- in hydrology, the passage of a liquid through a porous substance; e.g., the movement of water, under hydrostatic pressure developed naturally underground, through the interstices and pores of the rock or soil; i.e., the slow seepage of water through soils or porous deposits.

performance assessment -- any analysis that predicts the behavior of a system or system component under a given set of constant and (or) transient conditions. Performance assessments will include estimates of the effects of uncertainties in data and modeling.

performance confirmation -- (NRC, 1983) the program of tests, experiments, and analyses which is conducted to evaluate the accuracy and adequacy of the information used to determine reasonable assurance that the performance objectives for the period after permanent closure can be met.

periglacial -- pertaining to the areas, conditions, processes, and deposits marginal to an ice sheet or glacier.

permanent closure -- is synonymous with closure.

permeability (permeable) ~~(K)~~ -- a material's or rock's capacity for transmitting a fluid under a hydraulic gradient. It is approximately equivalent to hydraulic conductivity in water saturated systems. ~~(See also hydraulic gradient.)~~

DRAFT

petrocalcic -- a diagnostic subsurface soil horizon that is characterized by an induration with calcium carbonate.

petrography -- the microscopic study of rocks in thin sections.

pH -- a measure of the relative acidity or alkalinity of solution; a neutral solution has pH of 7, acids have pH's of less than 7, and alkalies have pH's of greater than 7. $pH = -\log H^+$ where H^+ is the hydrogen ion activity in solution.

phaneritic -- a textural term pertaining to crystals or grains in igneous rocks that are visible to the unaided eye; as opposed to aphanitic.

phenocryst -- a textural term applied to any relatively large conspicuous crystal in an igneous rock.

photolineament -- a lineament observed in photographic image that is a mappable, simple or composite linear feature (both geologic and non-geologic) of a surface, whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differs distinctly from the patterns of adjacent features.

physiography -- the descriptive study of land forms as opposed to geomorphology, which is the interpretive study of land forms.

piezometer -- a tube or pipe in which normally the elevation of a water level can be determined. A piezometer is sealed along its length, open to water flow at the bottom, and open to the atmosphere at the top.

piezometric surface -- in hydrology, ~~an imaginary~~ a contoured mapped surface that coincides everywhere with the static level of the water in an aquifer. (See ~~also~~ potentiometric surface). ~~which is more commonly used.)~~

pillow lava -- basaltic material congealed in rounded masses, indicative of subaqueous flows or eruptions, occurring mostly in basalts.

plagioclase -- an isomorphous series of (solid solution) triclinic feldspar minerals which form the group of common rock-forming minerals; the silicates of varying mixtures of sodium, calcium, and aluminum, ranging from albite, $NaAlSi_3O_8$, to anorthite, $CaAl_2Si_2O_8$.

plate bearing test -- a procedure performed in small tunnels or adits to measure the deformation characteristics of a rock mass. Typically two areas, each generally on the order of 1 meter in diameter, are loaded simultaneously using hydraulic jacks positioned across the tunnel. Rock mass deformations are measured in boreholes behind each area and across the tunnel.

Pleistocene -- the first epoch before the Holocene (or present time) of the Quaternary Period. (See also geologic time scale.)

DRAFT

<u>Pliocene</u> -- the latest epoch of geologic time within the Tertiary Period, preceded by the Miocene, and followed by the Pleistocene Epochs. (See also geologic time scale.)

<u>plug (geology)</u> -- (1) the vertical pipe-like magmatic body representing the conduit of a former volcanic vent. (2) A crater filling of lava, the surrounding material of which has been removed by erosion. (3) A mass of clay, sand, or other sediment filling the part of a stream channel abandoned by the formation of a cutoff.

<u>plug (scientific technology)</u> -- (1) a piece of material to fill a hole. (2) A small segment of material removed from a larger object.

<u>plug (shaft or borehole)</u> -- a watertight seal in a shaft formed by removing the lining and inserting a concrete and/or metal dam, or by placing a plug of clay over ordinary debris used to fill the shaft up to the location of the plug.

<u>population dose (population exposure)</u> -- the summation of individual radiation doses received by all those exposed to the sources or event being considered.

<u>pore</u> -- as applied to stone, soil, etc., any small open space, generally one that admits the passage or absorption of liquid, within the rock or soil.

<u>porosity</u> -- usually expressed as a percentage of the volume, Vp, of the pore space in a rock to the volume, Vr, of the rock, the latter volume including rock material plus void space.

~~porosity = n = $\frac{V_v}{V_T}$, where V_v = volume of voids and V_T = total volume.~~

Effective porosity is interconnected pore space.

<u>porosity log</u> -- a determination of pore volume per unit volume of formation made from a sonic log, density log, neutron log, or resistivity log.

<u>postclosure</u> -- the period of time after the closure of the geologic repository.

<u>potentially acceptable site</u> -- any site at which, after geologic studies and field mapping but before detailed geologic data gathering, the DOE undertakes preliminary drilling and geophysical testing for the definition of site location.

<u>potentially adverse condition</u> -- a condition that is presumed to detract from expected system performance ~~unless~~ but further evaluation, additional data, or the identification of compensating or mitigating factors indicates that its effect on the expected system performance is acceptable.

DRAFT

contour a map of the hydraulic heads in an aquifer

potentiometric surface -- the surface of the hydraulic potentials of an aquifer. It is usually represented as a contour map, each point in which tells how high the water would rise in a well tapping that aquifer at that point. (See also piezometric.) surface

Precambrian -- the first of the eras of geologic time. (See also geologic time scale.)

preclosure -- the period of time before and during the closure of the geologic repository.

pre-waste-emplacement -- before the authorization of repository construction by the NRC.

principal borehole -- borehole RRL-2 was designated the principal borehole because it is the most important borehole for drilling the Exploratory Shaft. Drilling of the principal borehole determined the location of the Exploratory Shaft, because they need to be close to each other.

protected or endangered species -- those plants and animals officially listed in U.S. Fish and Wildlife Service (1973) and National Environmental Policy Act (1970). However, species listed by the states as rare, threatened, or endangered are not included (unless they also are on the federal list) because they are not officially recognized by the NRC.

pyrite -- a common, brass-yellow mineral with a chemical composition of iron sulfide (FeS_2).

pyroxene -- a group of dark colored rock-forming silicate minerals that are closely related in crystal form and composition. The general chemical formula is $A\ B\ Si_2\ O_6$, where A = Ca, Na, Mg, or Fe^{+2} and B = Mg, Fe^{+2}, Fe^{+3}, Fe, Cr, Mn, or Al with silicone, sometimes replaced in part by aluminum.

qualification (personnel) -- the characteristics of abilities gained through education, training, or experience, as measured against established requirements, such as standards or tests, that qualify an individual to perform a required function.

qualified site -- a site which, having been characterized in detail, is considered to be technically suitable for location of a repository and may be offered for formal licensing by the DOE.

qualifying condition -- a condition that must be satisfied for a site to be considered acceptable with respect to a specific guideline.

quality assurance -- all those planned and systematic actions necessary to provide adequate confidence that a structure, system, or component is constructed to plans and specifications and will perform satisfactorily in service.

DRAFT

<u>quality control</u> -- those quality assurance actions which provide a means to control and measure the characteristics of an item, process, or facility to established requirements.

<u>Quaternary faults</u> -- faults that have formed or experienced movement during the Quaternary Period.

<u>Quaternary igneous activity</u> -- intrusion or extrusion of molten rock material into or onto the Earth's crust during the Quaternary Period.

<u>Quaternary Period</u> -- the second period of the Cenozoic Era, following the Tertiary, beginning 2 to 3 million years ago and extending to the present.

<u>rad</u> -- radiation absorbed dose, the basic unit of absorbed dose of ionizing radiation. A dose of 1 rad means the absorption of 100 ergs of radiation energy per gram of absorbing material.

<u>radiation (ionizing)</u> -- particles and electromagnetic energy emitted by nuclear transformations that are capable of producing ions when interacting with matter; gamma rays and alpha and beta particles are primary examples.

<u>radiation zone</u> -- an area that contains radioactive materials or radiation field in quantities significant enough to require control of personnel entry to the area.

<u>radioactive decay</u> -- property of undergoing spontaneous nuclear transformation (disintegration) in which nuclear particles or electromagnetic energy (alpha particles, beta particles or gamma photons) are emitted.

<u>radioactive material</u> -- in general, any material which spontaneously emits atomic particles or rays from the nuclei of its atoms.

"Radioactive waste" or "waste" ~~means~~ -- high-level radioactive waste and other radioactive materials, including spent nuclear fuel, that are received for emplacement in a geologic repository.

NEW

<u>radioactive waste facility</u> -- a facility subject to the licensing and related regulatory authority of the NRC pursuant to Sections 202(3) and 202(4) of the Energy Reorganization Act of 1974 (88 Stat 1244).

<u>radiolysis</u> -- decomposition (splitting) of chemical molecules (often water) due to interactions with radiation.

<u>radiometric dating</u> -- the calculation of age in years of a material, based on the decay of naturally occurring radioactive isotopes.

<u>radionuclide</u> -- an unstable, radioactive isotope which decays toward a stable state at a characteristic rate by the emission of ionizing radiation(s).

DRAFT

radionuclide retardation -- the process or processes that cause the time required for a given radionuclide to move between two locations to be greater than the ground-water travel time, because of physical and chemical interactions between the radionuclide and the geohydrologic unit through which the radionuclide travels.

radwaste -- short form of radioactive waste.

reasonably achievable (to the extent) -- that which is shown to be reasonable considering the costs and benefits of potential mitigative measures or reasonable courses of action in accordance with requirements of National Environmental Policy Act (1970) and Council of Environmental Quality (1978). (See also as low as reasonably achievable (ALARA).)

reasonably available technology -- technology that exists and has been demonstrated, or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time periods.

reasonably foreseeable releases -- (as used by the EPA (1981)) releases of radioactive wastes to the accessible environment that are estimated to have more than one chance in 100 of occurring within 10,000 years.

recharge -- the process by which water is absorbed and added to the zone of saturation, either directly into a formation, indirectly by way of another formation, or indirectly through unconsolidated sediments.

recharge area -- in ground-water hydraulics, the area where surface water enters an aquifer.

reference repository location -- the highest ranking candidate site determined by the screening process.

regolith -- the superficial mantle of unconsolidated debris that nearly everywhere covers the solid or "bed" rock and forms the surface of the land. It comprises rock waste of all sorts, volcanic ash, glacial drift, alluvium, windblown deposits, vegetal accumulations, and soils. In the Pasco Basin, the basin-filled sediments that overlie the basalt. (See also overburden.)

regulated area -- a radiation area, or otherwise controlled area, access to which is limited and controlled.

regulatory guide -- one of a series of official NRC guides prescribing standards and recommendations for nuclear facilities. They cover a variety of subjects, such as what constitutes acceptable meteorological data or acceptable methods for calculating radiation dose, and serve to guide the license applicant on the content and format of materials that support the license application.

DRAFT

release -- the process by which contaminants leave human direct control and are dispersed to the environment. Releases may be scheduled, controlled, intentional, or accidental.

release guide -- a directive which sets the maximum concentration or amount of radioactive material or toxic chemical that can be released to the environment.

release limit -- a control number established as a regulatory limit for the concentration or amount of radioactive material released to the environment in an industrial situation; usually dose to persons in the environment derived from environmental behavior of the released material so that the dose is kept below a selected control value.

rem -- a unit dose of ionizing radiation which has the same biological effect as 1 roentgen of X-rays; 1 rem approximately equals 1 rad for X, gamma, or beta radiation. Thus, a rem is a unit of individual dose that allows comparison of effects of various radiation types, as well as quantities.

remotely handled waste -- waste that requires shielding in addition to that provided by its container in order to protect people nearby, because its surface dose rate precludes safe direct handling. May be transuranic or nontransuranic waste.

repository -- is synonymous with geologic repository.

repository closure -- is synonymous with closure.

repository construction -- all excavation and mining activities associated with the construction of shafts, shaft stations, rooms, and necessary openings in the underground facility, preparatory to radioactive-waste emplacement, as well as the construction of necessary surface facilities, but excluding site characterization activities.

repository operation -- all of the functions at the site leading to and involving radioactive-waste emplacement in the underground facility, including receiving, transportation, handling, emplacement, and, if necessary, retrieval.

repository support facilities -- all permanent facilities constructed in support of site-characterization activities and repository construction, operation, and closure activities, including surface structures, utility lines, roads, railroads, and similar facilities, but excluding the underground facility.

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

DRAFT

<u>residual uncertainty</u> -- those inherent uncertainties in data, modeling, and assumed future conditions that cannot be eliminated.

<u>restricted area</u> -- any area access to which is controlled by the DOE for purposes of protection of individuals from exposure to radiation and radioactive materials before repository closure, but not including any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

<u>retrieval</u> -- the act of intentionally removing radioactive waste before repository closure from the underground location at which the waste had been previously emplaced for disposal.

<u>reverse fault</u> -- a fault in which the hanging wall appears to have moved upward relative to the foot wall.

<u>Richter scale</u> -- the range of numerical values of earthquake magnitude, as measured on an instrument such as a seismometer which transforms the mechanical effects of Earth shocks into electrical signals. It was devised in 1935 by the seismologist C. F. Richter. Very small earthquakes, or microearthquakes, can have negative magnitude values. (See also intensity (earthquake), magnitude (earthquake), and modified Mercalli scale.)

<u>right-lateral offset</u> -- an offset or fault, the displacement of which is right-lateral separation. (See also dextral shear.)

<u>risk</u> -- the product of probability and consequence of an event.

<u>rock bolt</u> -- a bar, usually constructed of steel, which is anchored into predrilled holes in rock as a structure support device.

<u>rock burst</u> -- a sudden yielding that occurs when a volume of rock is strained beyond its elastic limit and the accompanying failure is such that the accumulated energy is released instantaneously. Types of failures vary from splitting off of small slabs of rock from a mine wall to the collapse of large pillars, roofs, or other massive portions of the mine structure.

<u>rock mass quality</u> -- a description of the rock mass physical characteristics and mechanical behavior. Rock mass quality classifications are applied empirically to estimate expected underground excavation support requirements and rock mass mechanical properties such as strength and deformation modulus.

<u>rubble</u> -- loose, unconsolidated rock consisting mostly of large, angular rocks intermixed with a small amount of soil or earthy material.

<u>rupture</u> -- as relates to radioactive packaging, a breach of the barrier provided by the radioactive material container.

DRAFT

safe shutdown earthquake -- the earthquake producing the maximum vibratory ground motion for which structures, systems, and components are designed to remain functional. (See also design basis earthquake.)

Safety Analysis Report -- a safety document showing that the facility and its safety-related systems can be operated with reasonable assurance of no undue risk to the health and safety of the public and with adequate provisions for the protection of property and the environment.

Safety Assessment Document -- a brief, factual, and objective document which provides a general assessment of the potential environmental, safety, and health risks or consequences, determined upon the identification and analysis of the hazards involved in the operations of the nuclear facility.

saturated zone -- that part of the Earth's crust beneath the water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

scabland -- an elevated area, underlain by flat-lying basalt flows, with a thin soil cover and sparse vegetation that is crossed by coulees.

scalar -- a quantity that has magnitude only and no direction, in contrast to a vector.

scanning-transmission electron microscope -- a type of electron microscope that scans with an extremely narrow beam of electrons transmitted through the sample; the detection apparatus produces an image whose brightness depends on the atomic number of the sample.

scenario -- a particular chain of hypothetical circumstances often used in performance analysis to model possible events.

scenario analysis -- analytical process that attempts to quantify probabilities of occurrence and consequences of a postulated sequence of events.

scoria -- vesicular, cindery crust on the surface of andesite or basaltic lava, the vesicular nature of which is due to the escape of volcanic gases before solidification.

screening (for site selection) -- the process of evaluating an area, on the basis of criteria, to identify places which best fulfill the criteria.

screening area -- for the purposes of the BWIP siting study, it was the Pasco Basin.

second-order fold -- a fold that occurs on the limbs or in the closure of a larger fold. Also referred to as a parasitic fold. (See also first-order fold.)

Secretary -- the Secretary of Energy.

DRAFT

<u>sedimentary</u> -- descriptive term for rock formed of sediment, especially (a) clastic rocks, as conglomerates, sandstone, and shales, formed of fragments of other rock transported from their sources and deposited in water and (b) rocks formed by precipitation from solution, as rock salt and gypsum, or from secretions of organisms, as most limestones.

<u>seismic</u> -- pertaining to, characteristic of, or produced by earthquakes or Earth vibrations.

<u>seismic refraction method</u> -- a seismic exploration technique used for determining the depths to various rock formations; based on variations in the velocity at which artificially generated seismic waves travel through the subsurface.

<u>seismicity</u> -- (1) the tendency for the occurrence of earthquakes. (2) the spatial distribution of earthquake activity.

<u>seismometer</u> -- an instrument that detects Earth motion.

<u>shaft</u> -- with regard to a geologic repository, the penetration of the natural isolation barrier to provide access to the subsurface facility; it is usually of limited cross-sectional area compared to its depth. A more common definition is a man-made hole, either vertical or steeply inclined, that connects the surface with the underground workings of a mine or excavation. The difference between a shaft and a borehole is primarily in size and use.

<u>shear</u> -- (1) a strain that causes contiguous parts of a body to slide relative to each other in a direction parallel to their plane of contact. (2) Surfaces and zones of failure by shear, or surfaces along which differential movement has taken place.

<u>shielding</u> -- the material interposed between a source of radiation and personnel for protection against danger of radiation; commonly used shielding materials are concrete, water, and lead.

<u>shipping cask</u> -- a specially designed container used for shipping radioactive materials.

<u>shotcrete</u> -- cement-based compounds sprayed onto mine timbers to make them fire resistant, onto mine surfaces to prevent erosion by air and moisture, and onto rock surfaces to stabilize against minor rock falls. Also used to prevent dehydration and rock decrepitation.

<u>shrub-steppe</u> -- distinguished from a true steppe by the presence of forbes, shrubs, and a few trees in an extensive grassland area. Generally not as dry as a steppe.

<u>silica</u> -- a chemically resistant dioxide of silicon: SiO_2.

<u>site</u> -- a potentially acceptable site or a candidate site, as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same.

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silica -- a chemically resistant dioxide of silicon: SiO_2.

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DRAFT

site characterization -- activities, whether in the laboratory or in the field, undertaken to establish the geologic condition and the ranges of the parameters of a candidate site relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken.

siting -- the collection of exploration, testing, evaluation, and decision-making activities associated with the process of site screening, site nomination, site recommendation, and site approval for characterization or repository development.

sleeve -- (as related to waste package) a metallic or nonmetallic liner that may be located in the emplacement hole to aid in emplacement and possible retrieval of the waste package.

slickensides -- polished and smoothly striated surfaces that result from friction along a fault plane.

slip -- the relative displacement of formerly adjacent points on opposite sides of a fault, measured in the fault surface.

slump (geological) -- the downward slipping of a mass of rock or unconsolidated material of any size, moving as a unit or as several subsidiary units, usually with backward rotation on a more or less horizontal axis parallel to the cliff or slope from which it descends.

solubility -- the amount of substance that can be dissolved in a given amount of solvent.

solute -- the substance dissolved in a solvent.

sonic log -- a geophysical log made by an instrument, lowered and raised in a borehole or well, that continuously records, as a function of depth, the velocity of sound waves as they travel over short distances in the adjacent rocks. The log reflects lithologic changes.

sorb -- to take and hold by either absorption or adsorption.

sorption -- the binding, on a microscopic scale, of one substance to another, such as by adsorption or ion exchange. In this document, the word is especially used in the sorption of solutes, such as dissolved radionuclides, onto ~~aquifer solids~~ mineral surfaces or waste package materials. This occurs by means of close-range chemical or physical forces. Absorption -- taking up of matter or energy or penetration by a specific medium. Adsorption -- surface retention of solid, liquid, or gas atoms, molecules, or ions by a solid or a liquid.

sorptive capacity -- the measure of a material's ability to sorb specific constituents from a liquid as it passes through the material.

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<u>source term</u> -- this term is often used in mathematical modeling to describe the input to a system. A special case application is the quantity of radioactive material released by an accident or operation which subsequently causes exposure through some mechanism of transmission or deposition. The kinds and amounts of radionuclides that make up the source of a potential release of radioactivity ©

<u>spalling</u> -- the chipping, fracturing, or fragmentation of a rock by weathering or by interaction of a shock (compressional) wave at a free surface.

<u>specification</u> -- a concise statement of a set of requirements prescribing materials, dimensions, or workmanship for something to be built or manufactured. This is a quantitative statement that meets a criterion or criteria. Specifications are prepared during the design process. Alternatively, a performance criterion or criteria for a selected design or siting option--often quantitative.

<u>specific heat</u> -- ratio of the thermal capacity of a substance compared to the thermal capacity of water (number of calories required to raise the temperature of a unit mass of a substance by 1 degree).

<u>spent fuel waste</u> -- the final form of spent fuel as waste which could include the fuel in some mechanically processed or disassembled form.

<u>spent nuclear fuel</u> -- fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

<u>spiracle</u> -- a fume or vapor vent in a lava flow, formed by a gaseous explosion in lava that is still fluid, probably due to generation of steam from underlying wet material.

<u>spoils</u> -- the debris or waste material from a mine. The rock and other natural materials brought up to the ground surface during mining. Also called mined materials.

<u>stability</u> -- (relative to a repository) (1) a statement that the nature and rates of natural processes affecting the site during the recent geologic past are projected to be relatively slow and will not significantly change during the next 10,000 years or jeopardize isolation of the radioactive waste. (2) Stability of a rock structure is the capability of an opening at depth to retain its original shape for a length of time. Stability is related to quality of rock mass around the opening including slabbing and fracturing.

<u>stability</u> -- (as defined in 10 CFR 60 (NRC, 1983)) the nature and rates of natural processes such as erosion and faulting have been and are projected to be such that their effects will not jeopardize isolation of the radioactive waste.

<u>steel sets</u> -- with regard to mining, used to support roof and wall of mines. Steel "I" beams are used for caps and "H" beams are used for posts.

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<u>steppe</u> -- an extensive, treeless, grassland area in southeastern Europe and Asia that is developing in semiarid mid-latitudes of that region. Often used as a general term to describe similar areas in other parts of the world.

<u>stochastic</u> -- random.

<u>storage coefficient</u> -- the volume of water an aquifer releases from, or takes into storage, per unit surface area of the aquifer, and per unit change in head. In a confined water body the water derived from storage with decline in head comes from expansion of the water and compression of the aquifer; similarly, water added to storage with a rise in head is accommodated partly by compression of the water and partly by expansion of the aquifer.

<u>stratigraphic setting</u> -- the characteristics of the rock layers or other units in the geologic environment.

<u>stratigraphy</u> -- the branch of geology that deals with the definition and interpretation of the rock strata, the conditions of their formation, their character, arrangement, sequence, age, distribution, and, especially, their correlation by the use of fossils and other means of identification.

<u>strike</u> -- the course or bearing of the outcrop of an inclined bed or structure on a level surface; the direction or bearing of a horizontal line in the plane of an inclined stratum, joint, fault, cleavage plane, or other structural plane. It is perpendicular to the direction of the dip.

<u>strike-slip fault</u> -- a fault in which the net slip is horizontal or parallel to the fault's strike. (See also dip-slip fault.)

<u>subsidence</u> -- sinking of a part of the Earth's crust relative to adjacent parts.

<u>subsurface facility</u> -- the underground portions of the geologic repository operations area including openings, backfill materials, shafts, tunnels, and boreholes, as well as shaft, tunnel, and borehole seals until the time of preliminary closure.

<u>subsurface facility</u> -- (as defined in 10 CFR 60 (NRC, 1983)) the underground portions of the geologic repository operations area including openings, backfill materials, shafts, and boreholes as well as shaft and borehole seals.

<u>surface facilities</u> -- repository support facilities within the restricted area.

<u>surface water</u> -- any waters on the surface of the Earth, including fresh and salt water, ice, and snow.

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syncline -- downfolded strata that form a trough. Beds dip toward the center of a syncline.

new def "System" ~~means~~ the geologic setting at the site, the waste package, and the repository, all acting together to contain and isolate the waste.

new def "System performance" means the complete behavior of a repository system in response to the conditions, processes, and events that may affect it.

talus -- loose rock fragments of any size or shape derived from and lying at the base of a steep slope.

technical conservatism -- a policy applied throughout the BWIP to ensure that the final repository system will be sufficiently and conservatively safe. The mined geologic disposal system design and the analytical methods used to develop and demonstrate system effectiveness should be sufficiently conservative to compensate for residual design, operational, and long-term predictive uncertainties of potential importance to system effectiveness and should provide reasonable assurance that regulatory standards will be met.

tectonic -- of, or pertaining to, the forces involved in, or the resulting structures or features of, "tectonics."

tectonic activity -- movement of the Earth's crust, such as uplift and subsidence and the associated folding, faulting, and seismicity.

tectonic breccia -- a breccia formed as the result of crustal movements, usually developed in brittle rocks. Slickensides are commonly associated with tectonic breccia and varying amounts of clay-like gouge may be present.

tectonic features -- include fault gouge, fault displacement and folded rock. Shear zones are tectonic features that include fault gouge, fault displacement, brecciated zones, and increased fracture frequency. Tectonic features indicate that the rock has been moved since its original placement.

tectonic fracture -- a fracture formed as a result of crustal stresses. Tectonic fractures may or may not have slickensides on their joining surfaces and are commonly associated with tectonic breccias. Includes fractures across which no measurable movement has occurred.

tectonic province -- a region of the Earth's crust characterized by a relative consistency of the geologic structural features contained therein.

tectonics -- the branch of geology dealing with the broad architecture of the outer part of the Earth, that is, the regional assembling of structural or deformational features and the study of their mutual relations, origin, and historical evolution.

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tectonism (diastrophism) -- crustal movement produced by Earth forces such as the formation of plateaus and mountain ranges; the structural behavior of an element of the Earth's crust.

tensor -- a set of functions that relates different vector fields, such as might involve a change in coordinate system.

tephra -- a general term for all clastic volcanic materials that, during an eruption, are ejected and transported through the air.

terminal storage -- isolation and storage of radioactive waste operations for which no subsequent waste treatment or transportation operations are anticipated.

Tertiary -- the earlier of the two geologic periods comprising the Cenzoic Era, extending from 65 to 1.8 million years ago. (See geologic time scale.)

thermal conductivity -- the quantity of heat that will pass between faces of a unit area of a material of unit thickness in unit time when a unit differential of temperature is established between the faces.

thermal expansion -- the increase in linear dimensions which occurs when materials are heated.

thermal gradient -- the rate of change of temperature with distance.

thermal loading -- the application of heat to a system. Usually measured in terms of watt density. The thermal loading for a repository is the watts per acre produced by the nuclear waste in the active storage area.

thermodynamic -- for geology and rock mechanics, the interacting properties of a geologic system as they are affected by heat and react physically to the stress. For chemistry, thermodynamics refers to the energy evolved and consumed in chemical reactions and the relationship of this energy to equilibrium. The "thermodynamic data base" refers to a compilation of specific thermal properties (e.g., enthalpy, entropy, and free energy) of different chemical species that can be quantified.

thermomechanical -- related to the transformation of heat energy into mechanical work (see thermodynamic).

third-order fold -- a fold that occurs on the limbs or in the closure of a second-order fold. (See also second-order fold.)

tholeiitic -- a type of basalt characterized by its lack of olivine.

thrust fault -- a fault with a dip of 45 degrees or less in which the hanging wall appears to have moved upward relative to the foot wall.

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till -- an unsorted and unstratified mixture of glacial debris having a wide range of clast sizes.

to the extent practicable -- the degree to which an intended course of action is capable of being affected in a manner that is reasonable and feasible within a framework of constraints.

topography -- the general configuration of a land surface, including its relief, the position of its man-made features.

total field -- the vector sum or combination of all components of a field under consideration, such as a magnetic or gravitation field.

traceability -- (1) the ability to trace the history, application, or location of an item and like items or activities by means of recorded identification. (2) The capability to recover specific configuration information or documentation (i.e, inspection data, certification data, etc., via markings and an auditable trail). For a repository, the ability to trace the conclusion of a site characterization study through the data interpretation and analyses to the original field and/or laboratory work.

tracer testing -- a procedure in which a soluble substance (tracer) is added to a ground-water system at one location ~~to observe the tracer~~ and its movement to another location is observed. Tracer testing is a technique by which ground-water flow directions, velocities, and other hydrologic properties of rocks can be estimated.

transfer cask -- a shielded (unlicensed) enclosure for the movement of highly radioactive material within a facility.

transmissivity -- a coefficient relating the volumetric flow through a unit width of material to the driving force (hydraulic ~~potential~~ head); a function of both the porous medium, fluid properties (including viscosity), and saturated thickness of the aquifer. Mathematically, it is the product of hydraulic conductivity and the thickness of the zone of the aquifer being measured. ~~It is measured in square feet per day or equivalent units.~~

transport path -- a route along or through which radionuclides could migrate.

transuranic elements -- those elements which have an atomic number higher than 92. They do not normally occur in nature and have to be produced artificially from uranium, either directly or indirectly by successive steps of transmutations.

trellis drainage -- a drainage pattern characterized by parallel main streams intersected at, or nearly at, right angles by their tributaries.

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trilateration -- land survey based on triangulation in which sides of the triangle are measured directly by use of an interferometer.

tubbing -- cast-iron liner plates for shafts, fabricated to specification, which bolt together to give rock support.

tuff -- a rock formed of compacted volcanic ash and dust.

tunnel -- a long, narrow subterranean passageway.

unconfined aquifer -- an aquifer containing ground water that has a water table or upper surface at atmospheric pressure.

underground facility -- the underground structure and the rock required to support, including mined openings and backfill materials, but excluding shafts, boreholes, and their seals.

unsaturated zone -- the zone between the land surface and the water table. ~~It includes the "capillary fringe."~~ Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric.

uplift -- (1) the process that results in elevation of a portion of the Earth's crust relative to an adjacent portion. (2) A structurally high area in the crust, produced by movements that have raised or upthrust the rocks, as in a dome or arch.

vadose zone -- the unsaturated region of soil or the zone of aeration between the ground surface and the water table.

validation of computer codes -- the method of assessing that the code indeed reflects the behavior of the real world (i.e., that the map is an adequate accurate description of the territory).

vent system -- a group of generally parallel fissures from which lava came to the surface.

verification of computer codes/models -- testing a code with analytical solutions for idealized boundary value problems. A computer code will be considered verified when it has been shown to solve the boundary value problems with sufficient accuracy. This testing process provides a check on both the computer coding and the numerical approximations to the mathematical model.

vesicle -- a small cavity in an igneous rock, formed by the expansion of a bubble of gas or steam during the solidification of the rock.

vesicle cylinder -- a cylindrical zone in a lava, in which there are abundant vesicles, probably formed by the generation of steam from underlying wet material.

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vesicle sheets -- a planar or near horizontally emplaced zone in a lava in which there are abundant vesicles.

vesicular -- a texture characterized by abundant vesicles.

vitrify -- to solidify the waste in a glass form.

vitrinite reflectance -- an index of the amount of light reflected from a polished surface of the vitrain component of coal. The index indicates the relative rank (lignite-semibituminous-bituminous-anthracite) of the coal which, in turn, is indicative of the relative temperature and pressure conditions under which the coal formed (depth of burial). The higher the reflectance, the higher the rank, hence, temperature, and pressure under which the coal formed.

volcaniclastic sediment -- a deposit dominated by transported fragments of volcanic origin.

volcanism -- the processes by which magma and its associated gases rise into the crust and are extruded onto the Earth's surface and into the atmosphere.

vug -- a cavity, often with a mineral lining of different composition from that of the surrounding rock.

waste, cladding -- cladding fragments and other structural materials from the spent fuel remaining in the dissolving vessel in chemical reprocessing. Usually a transuranic waste.

waste, commercial -- waste generated by private industry and other nongovernmental facilities.

waste, contact-handled -- containerized waste that has a surface dose rate which is sufficiently low to permit direct handling. May be transuranic or nontransuranic waste.

waste, containerized -- the container and its contents.

waste, defense -- waste generated by the Federal Government and/or federal programs in nongovernment facilities.

waste form -- the radioactive waste materials and any encapsulating or stabilizing matrix.

waste, high-level -- see high-level radioactive wastes.

waste management -- the planning, execution, and surveillance of essential functions related to the control of radioactive (and nonradioactive) waste, including treatment, solidification, packaging, transportation, initial or long-term storage, surveillance, disposal, and isolation.

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waste matrix -- the material that surrounds and contains the waste and to some extent protects it from being released into the surrounding rock and ground water. Only material within the canister (or drum or box) that contains the waste is considered part of the waste matrix.

waste package -- the waste form and other engineered barriers that separate the waste form from the host rock. The waste package contributes to long term isolation by (1) hindering the dissolution of the waste by any ground water that may reach it, and (2) controlling the release and migration of radionuclides into the host rock.

water budget -- the quantification of the amount of water entering, moving through, and leaving a flow system; sometimes called water balance.

water table -- that surface in a body of ground water at which the water pressure is atmospheric.

Werner deconvolution method -- the solutions obtained in terms of thin magnetic layers by a mathematical process in which the depth points, dip directions, and susceptibility values are automatically calculated from the profile magnetic data.

work element -- a technical activity required to satisfy all or part of a criterion and/or to resolve an issue identified for siting and/or developing a nuclear waste repository in basalt. (See also issue.)

WPPSS -- Washington Public Power Supply System.

X-ray diffraction analysis -- analysis of the crystal structure of materials by passing X-rays through them and registering the diffraction (scattering) image of the rays.

zeolites -- any of the various silicates analogous in composition to the feldspars, which occur as secondary minerals in cavities of lavas, or as minerals produced by alteration or lavas, and which can act as ion exchangers.

"Waste package ~~" means~~ the waste form and any containers, shielding, packing, and other sorbent materials immediately surrounding an individual waste container.

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