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Site Characterization Report for the Basalt Waste Isolation Project

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U.S. Department of Energy
Assistant Secretary for Nuclear Energy
Office of Terminal Waste Disposal
and Remedial Action
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Prepared by Rockwell Hanford Operations
Under Contract DE-AC06-77RLO1030

Prepared For:
U.S. Department of Energy
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Washington, D.C. 20545

VOLUME III

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INTRODUCTION TO ISSUES AND PLANS CHAPTERS

Chapters 13, 14, 15, and 16 identify and describe elements of work needed to resolve the outstanding issues and satisfy proposed regulatory criteria. These chapters summarize the results of the investigations presently being conducted and planned to resolve outstanding issues.

Chapter 13 (Site Issues and Plans) uses information presented in Chapters 3, 5, 7, 8, 9, and 12. Chapter 14 (Geoengineering and Repository Design Issues and Plans) discusses information presented in Chapters 4 and 10, while Chapter 15 (Waste-Package and Site Geochemistry Issues and Plans) uses information from Chapters 6 and 11. Chapter 16 (Performance Assessment Issues and Plans) integrates the status and plans of the preclosure work elements and postclosure-related work elements and issues described in Chapters 13 through 15 that are performance oriented. Chapter 16 also summarizes information presented in Chapter 12.

Regulatory and technical requirements were analyzed by the Basalt Waste Isolation Project (BWIP) to identify the information needed to meet the criteria proposed in U.S. Nuclear Regulatory Commission (NRC, 1981) and other criteria documents (NWTS, 1981a; 1981b; 1981c; 1981d; draft EPA, 1981). The requirements were divided into work elements that address a specific portion of the criteria.

> A "work element" is defined as 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.

Work elements can be further broken down into the specific items of data needed and into specific analyses required to translate or interpret data. When there was some uncertainty or controversy as to whether a criterion, or portion thereof, could be clearly resolved or whether uncertainty surrounds the present state of knowledge, these items were described as issues in question form.

> An "issue" is defined as a technical question about which there is debate or controversy. Issues are technical questions that arise when the 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.

The existence of issues does not eliminate the development of a nuclear waste repository in basalt from consideration. Rather, the existence of an issue allows the results of planned work to be focused onto areas of controversy or uncertainty, thus providing assurance that the project's work will address these issues.

Those technical questions that could, depending of the BWIP's ability to resolve them, either confirm or eliminate the basalts underlying the Hanford Site as a potential repository site are designated as "key issues." Key issues are those technical questions where engineering cannot substantially and economically alter a negative finding. A generic logic diagram for the development of issues and work elements and the respective information needs as utilized in these chapters is shown in Figure 13.0-1.

CRITERIA ORGANIZATION

The proposed criteria and, therefore, the issues and planned work elements are organized into various subsections. These subsections were chosen to clarify the logic of relating the proposed criteria to ongoing work. Additional National Waste Terminal Storage Program and U.S. Nuclear Regulatory Commission proposed criteria that serve to clarify those cited in each chapter, but that do not add additional work elements and/or issues, have been entered as references in the criteria/issue/work element charts (Table 13.0-1). The process for the development of work elements and issues is described below.

The identification of work needed and issues requiring resolution to meet the criteria identified are tabulated in the criteria/issue/work element charts. Initially, a proposed 10 CFR 60 (NRC, 1981) and NWTS-33(1) through (4) (NWTS, 1981a; 1981b; 1981c; 1981d) were analyzed as part of the project technical planning to determine what work was needed to satisfy the individual criteria. Many of the National Waste Terminal Storage Program criteria and some of the proposed 10 CFR 60 criteria were found to be redundant and/or served only to clarify previously defined criteria. Redundancy has been minimized through the utilization of cross-referencing. If there appeared to be an element of controversy or debate about elements of work, an issue or key issue was defined.

CRITERIA/ISSUES/WORK ELEMENT NUMBERING SYSTEM

The issues and related work elements for each chapter (see Table 13.0-1) are preceded by a letter: S = Site (Chapter 13), R = Repository (Chapter 14), W = Waste Package (Chapter 15), and P = Performance Assessment (Chapter 16). Each "organization" Subsection is designated by a unique identification number. For example, the three subsections chosen for Chapter 15 are waste package design (W.1), site geochemistry and testing (W.2), and performance confirmation (W.3). Each work element required to satisfy a given criterion or grouping of criteria is numbered consecutively throughout a given section; i.e, all work elements related to design are numbered W.1.1 through W.1.n, where n is the last work element in the section. Where an issue has been identified, it

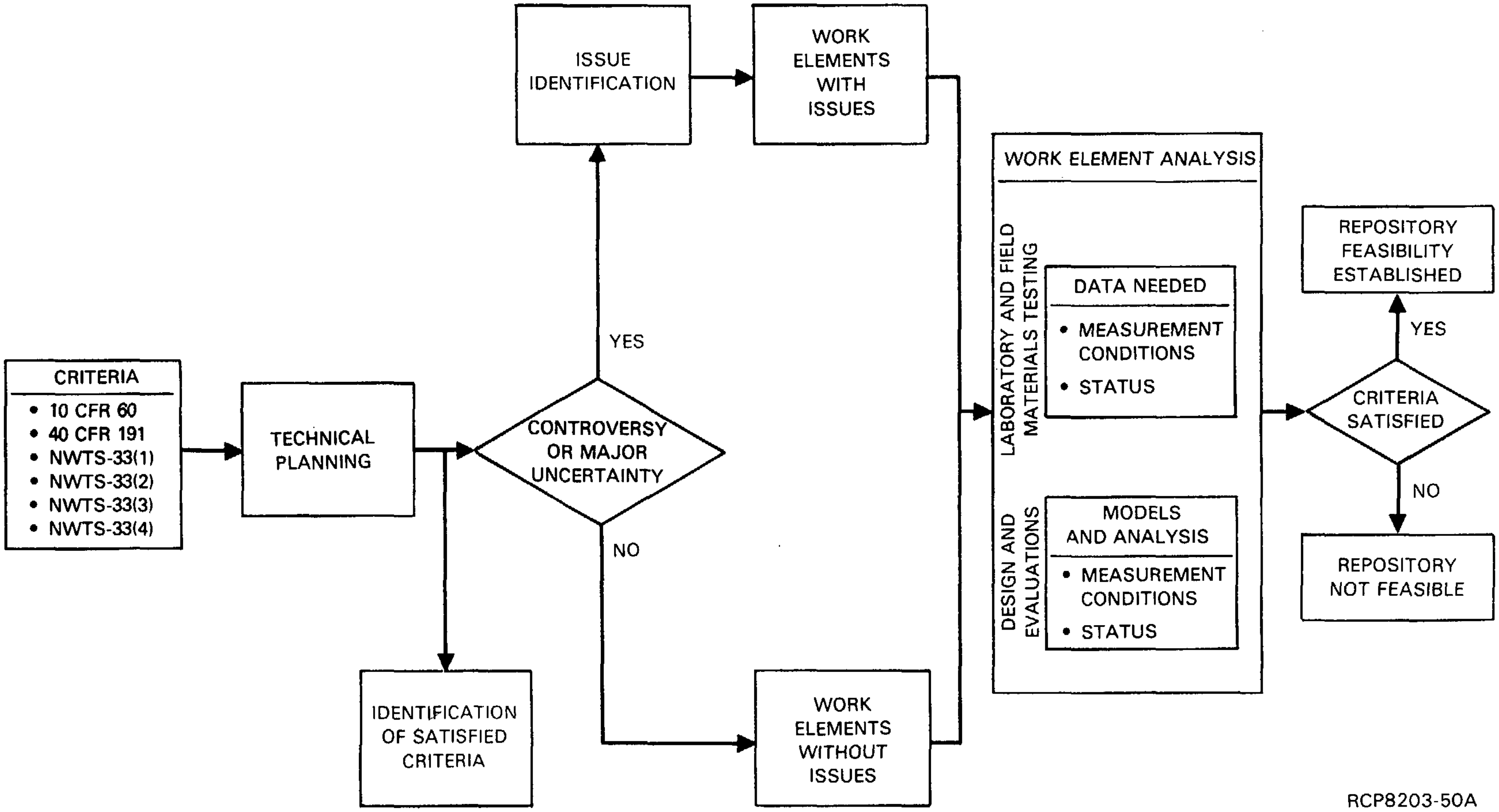

FIGURE 13.0-1. Logic for Definition of Basalt Waste Isolation Project Issues/Work Elements/Data Needs.

TABLE 13.0-1. Example of Criteria, Issues, and Work Elements for Site.

REFERENCE
ISSUE NUMBER
WORK ELEMENT NUMBER
SUPPLEMENTARY CRITERIA
CROSS REFERENCE

Technical criteria	Issues	Work element
S.1 - Geology and Hydrology		
<u>Areas Adjacent to the Geologic Repository Operations Area</u> (60.102(c)) Within the geologic setting (or site), particular attention must be given to the characteristics of the host rock as well as any rock units surrounding the host rock. For clarification see: NWTS 33(2), 3.1 NWTS 33(2), 3.2(1) NWTS 33(2), 3.2(4) NWTS 33(2), 3.4 NWTS 33(2), 3.4(1)	S.1.A What are the geologic, mineralogic, and petrographic characteristics of the candidate repository horizons and surrounding strata within the reference repository location?	S.1.1.A Determine the thickness and continuity of the candidate repository horizons within the reference repository location. S.1.2.A (Included in S.1.12.B) Determine the dip, strike, fold wavelength, and fold amplitude of the candidate repository horizons within the reference repository location. S.1.3.A (Included in S.1.12.B) Determine what deformational features are likely to intersect the candidate repository horizons within the reference repository location. S.1.4.A Determine the primary internal structure of the candidate repository horizons within the reference repository location. S.1.5.A (Related to S.1.9.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the orientation, distribution, aperture infilling (secondary mineralization), and origin of fractures, discontinuities, and heterogeneities within the candidate repository horizons.

is placed adjacent to the criterion it addresses and is given an identifying letter designator (A, B, C,...) within its section. For example, W.2.B is the second issue, B, in Site Geochemistry. The work required to meet a criterion and/or consequently resolve an issue has the issue identifier appended to the work element number. For example, S.1.2.A (see Table 13.0-1) is the unique element of work, no. 2, which addresses issue A in the Geology and Hydrology section, S.1. Each work element is further cross-referenced, if necessary, to define its relationship to other work elements in the criteria/issues/work element tables. These cross-references are as follows:

- Identical to: A specific element of work is used more than once as a means of satisfying more than one criterion.

- Related to: Details of work overlap and so are treated only once in work analysis tables to avoid redundancy.

- Included in: The work defined in the designated work element is a part of a larger piece of work discussed in another broader work element.

WORK ELEMENT ANALYSIS: PRIORITY, DATA NEEDS, AND STATUS

To define the work and to identify required resources, the BWIP has defined specific items of information needed to complete a work element. In general, information needed to support site characterization and performance assessment efforts is provided through a combination of field studies and surveys, drilling and testing operations, laboratory analyses, and data interpretation and modeling efforts. The work element analysis tables, a part of Sections 13.3, 14.3, and 15.3 (example shown in Table 13.0-2), provide a summary of status and information needed to complete work elements listed in the criteria/issues/work element tables (see Sections 13.5, 14.5, and 15.5).

Chapter 16, which serves to integrate the performance-oriented work elements in Chapters 13 through 15, does not require work element analysis tables. Each of the work elements cited in Chapter 16 which require the acquisition of data or its detailed analysis, will appear in Chapters 13 through 15. The unique performance-oriented work elements in Chapter 16 are those which deal primarily with performance planning, criteria definition, descriptions of relevant systems, documentation, verification, validation, benchmarking of codes, and identification of the specific assessments to be done by the BWIP. The work elements related to the above items are presented only in narrative form in Chapter 16. All other work elements in Chapter 16 have been cross-referenced to the Chapter (13 through 15) in which they originally appear.

TABLE 13.0-2. Sample of a Work Element Analysis Chart.

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.1.A Determine the thickness and continuity of the candidate repository horizons within the reference repository location.	Range of thickness variations for the candidate repository horizons within the reference repository location. Prediction of thickness of the candidate repository horizons to ±4 meters within the reference repository location. Nature and magnitude of short-range (less than tens of meters) variations in thickness of the candidate repository horizons.	Measurement of thickness of candidate repository horizons in boreholes RRL-2, -6, -14, and DC-16A (BWIP, 1982a; 1982b).	Presently, a thickness range of 64 to 88 meters has been determined for the Umtanum flow in the Cold Creek syncline. Thickness of the Umtanum flow can currently be predicted to ±4 meters at the exploratory shaft site and ±4 meters within the reference repository location. The middle Sentinel Bluffs flow in the Cold Creek syncline ranges in thickness from 85 to 47 meters. Its thickness can be predicted to accuracies similar to those for the Umtanum flow (Long and Landon, 1981; Long and Davidson, 1981; Section 3.5.4 of this document). Thickness of intraflow structures within the candidate repository horizons are considered under S.1.4.A.
	Areal extent of the candidate repository horizons within the Cold Creek syncline and region.	Locate and examine the candidate repository horizons in the Pasco Basin to determine the lateral extent and the conditions that control the lateral extent of of the flow; identify candidate repository horizons using X-ray fluorescence and paleomagnetic analyses.	Preliminary work indicates that the candidate repository horizons are continuous across the Cold Creek syncline, and as of yet, no conditions that could limit lateral extent of their total thickness within the reference repository location have been identified in either outcrops or boreholes (Myers/Price et al., 1979; Long and Landon, 1981; Long and Davidson, 1981; Section 3.5.4 of this document). There is near certainty that the margins of the two candidate repository horizons extend beyond the reference repository location. Variation or lateral extent of dense interior or flow top of the candidate repository horizons are considered under S.1.4.A.

To define the relative importance of the work elements presented in Chapters 13 through 16, three priority categories were established. The definitions are provided below:

PRIORITY 1: Most Important Activity

Any work element that is necessary to determining isolation and containment capability, or constructibility.

PRIORITY 2: Data Gathering Activity

A major/extended data gathering activity that provides significant support toward meeting performance-related criteria.

PRIORITY 3: Additional Tasks

(1) Any work element not directly related to site characterization, but needed to meet criteria at the time of a license application

(2) Narrowly defined characterization activities that provide specific supporting information to other characterization tasks.

These priorities are intended for guidance purposes only. They were developed to assist the BWIP in determining the relative importance of each work element to the site characterization effort.

ORGANIZATION OF THE ISSUE CHAPTERS

Section 0 provides a general description of the logic used in developing Chapters 13 through 16 and gives examples of tables that will be used in the remainder of each chapter. This section appears only in Chapter 13.

Section 1 provides a description of applicable proposed criteria and lists the issues that are specific to each chapter.

Section 2 deals with criteria fully satisfied by the BWIP, if any.

Section 3 contains in a tabular and/or narrative form, a description of the work needed to meet existing or proposed criteria. The narratives clarify the information contained in the work element analysis tables. The narratives are divided into status and planning sections.

Section 4 contains a summary of the overall work planned by the BWIP. The summary is accompanied by a network depicting the relationship among these activities. The summary and network were prepared by consolidating the work element analyses.

Section 5 contains the complete set of criteria/issues/work element tables that were used as the basis for identifying work needed.

Section 6 contains a brief summary description of the material presented in each chapter.

Section 7 contains the references to the literature cited in these chapters.

Thus, the information provided in these chapters summarizes how the BWIP will obtain the information required to resolve each issue or criterion. The information resulting from this work will serve, when completed and integrated, to demonstrate whether or not issues in the areas of site, repository, and waste package can be resolved, thus allowing an assessment of the suitability of the basalts beneath the Hanford Site as a site for a repository.

CHAPTER 13. SITE ISSUES AND PLANS

13.1 INTRODUCTION

This chapter summarizes the results of the investigations presently being conducted and those planned to resolve issues or data needs identified in Chapter 3 (Geologic Description of the Reference Repository Location and the Surrounding Site), Chapter 5 (Hydrogeology), Chapter 7 (Surface Hydrology), Chapter 8 (Climatology, Meteorology, and Air Quality), Chapter 9 (Environmental, Land-Use, and Socioeconomic Characteristics), and Chapter 12 (Performance Assessment). The subsections chosen for this chapter are geologic and hydrologic considerations (which include a discussion of issues and work elements identified in Chapters 3, 5, 7, and 12) and environmental and socioeconomic considerations (which include a discussion of work elements identified in Chapters 8 and 9) (Fig. 13-1). For purposes of organization, the term "environmental" has been expanded to include climatology, meteorology, and air-quality considerations; the term "socioeconomic" has been broadened to include land-use considerations (Fig. 13-1).

The U.S. Nuclear Regulatory Commission (NRC) has designated certain of its proposed criteria as performance objectives in 10 CFR 60 (NRC, 1981). For the area of site, the relevant objectives are those dealing with the preclosure and postclosure containment and release of waste as a function of the "environmental," geologic, and hydrologic characteristics of the repository setting (Fig. 13-1). "Environmental" work elements are keyed, for the most part, to performance criteria specifying that the release of radioactive materials to the unrestricted environment be maintained within designated limits until permanent closure of the repository. Geologic and hydrologic work elements (and issues) are keyed, for the most part, to postclosure performance criteria. These proposed criteria are primarily located in three sections of 10 CFR 60 (NRC, 1981): 60.112, "Required Characteristics of the Geologic Setting," 60.122, "Favorable Conditions," and 60.123, "Potentially Adverse Conditions." The emphasis of the proposed criteria contained in these sections is on geologic and hydrologic stability. A "stability assessment," by virtue of its definition in 10 CFR 60 (NRC, 1981), consists of two parts:

- Determination of the past (i.e., approximately 3 million years before present), present, and projected (up to 10,000 years after present) nature and rates of geologic and hydrologic processes (i.e., site characterization).

- Evaluation of the effect of the present and projected processes and rates on waste isolation (i.e., performance assessment).

The geologic and hydrologic issues and work elements discussed within Section 13.3 reflect these two basic data-gathering needs. The site issues discussed in Section 13.3 are tabulated in Table 13-1.

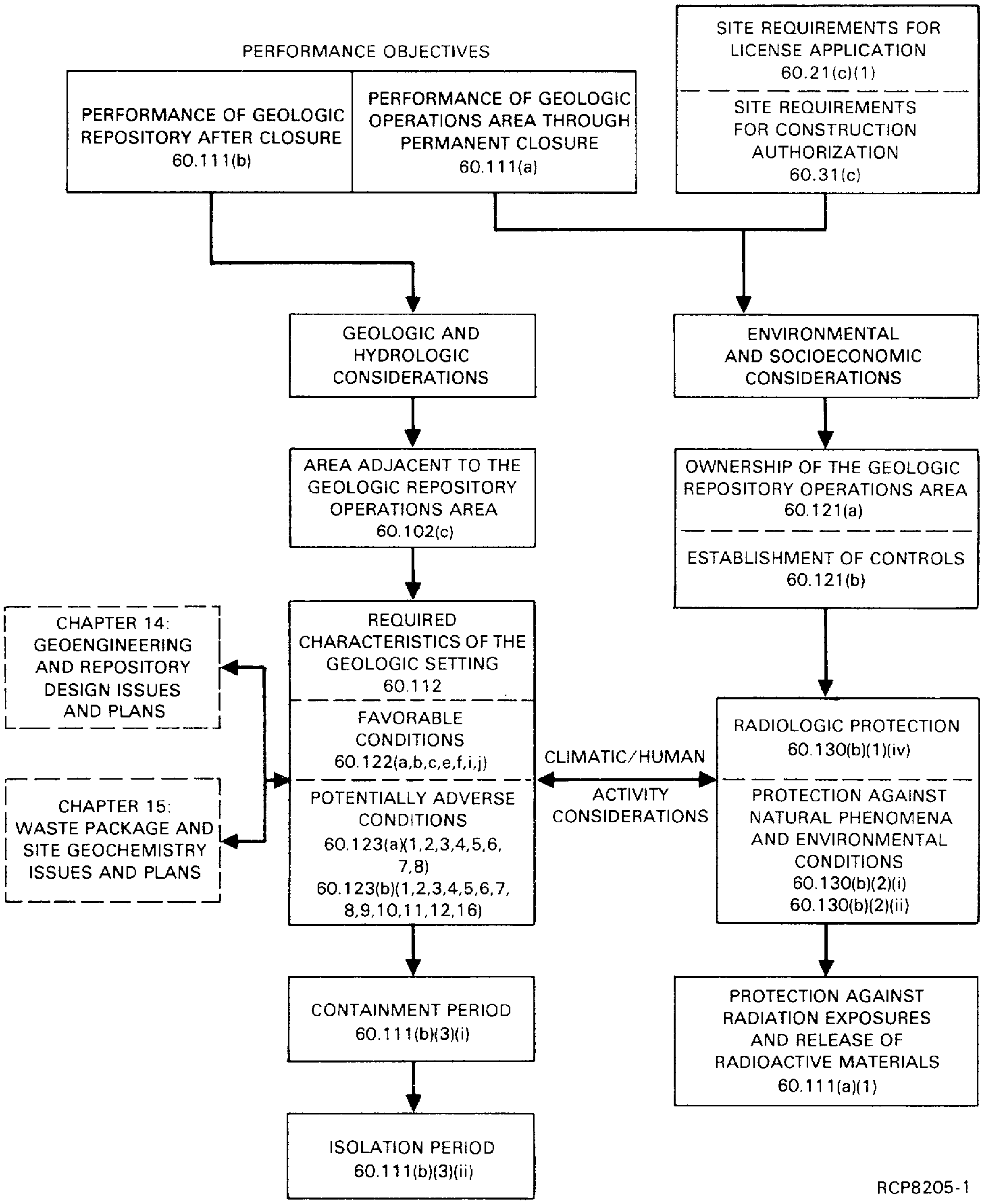

FIGURE 13-1. Key Proposed Criteria Governing the Site Issues and Work Elements (numbers/words in parentheses relate to 10 CFR 60 (NRC, 1981)).

TABLE 13-1. Issues for Site.

Issue	Issue number	Chapter
S.1 - Geologic and Hydrologic Considerations		
Key Issue		
What is the total amount (activity) of radionuclides potentially releasable to the accessible environment in a 10,000-year period, and is this amount in compliance with appropriate U.S. Environmental Protection Agency regulations?	S.1.D	3, 5, 12
Issue		
What are the geologic, mineralogic, and petrographic characteristics of the candidate repository horizons and surrounding strata within the reference repository location?	S.1.A	3
What are the nature and rates of past, present, and projected structural and tectonic processes within the geologic setting and reference repository location?	S.1.B	3
Are the pre-waste-emplacement groundwater travel times near the repository sufficient to assure compliance with U.S. Nuclear Regulatory Commission proposed technical criteria?	S.1.C	5, 12
S.2 - Environmental and Socioeconomic Considerations		
No issues have been identified.		

13.2 SUMMARY OF CRITERIA FULLY SATISFIED

Geologic and hydrologic studies thus far carried out under the Basalt Waste Isolation Project (BWIP) have included reconnaissance studies throughout much of the Columbia Plateau and detailed investigations within and in the vicinity of the Hanford Site (Myers/Price et al., 1979; Gephart et al., 1979a; Myers and Price, 1981). These studies have been aimed at gathering the data required for preliminary characterization of the Pasco Basin and for the identification of the reference repository location and principal borehole/exploratory shaft location (see Chapter 2). Investigations conducted in support of site identification have provided data considered sufficient to meet a number of NRC proposed criteria (NRC, 1981). These criteria are associated with Work Elements S.1.23.B, S.1.44.D, S.1.49.D, S.1.59.D, S.1.60.D, S.1.61.D. S.2.2, S.2.3, and S.2.4.

The four site issues identified in Table 13-1 relate to work elements that support repository or waste package and site geochemistry needs (see Chapters 14 and 15, respectively) or to those concerned with the development of a more complete understanding of the geohydrologic setting of the site. With regard to post-waste-emplacement repository performance, the groundwater pathway is considered the most likely avenue of transport from the repository to the accessible environment (see Chapters 12 and 16). A considerable volume of geohydrologic data has already been generated in support of site identification needs; newly acquired data, which can be used to more fully address NRC proposed criteria (NRC, 1981) relating to the four site issues, will be the focus of future BWIP semiannual progress reports.

13.3 UNRESOLVED ISSUES AND PLANS FOR THEIR RESOLUTION

This section contains a narrative and tabular analysis of the work needed to meet criteria outlined in Section 13.5. The work element analysis tables serve to summarize the information contained in the narratives. This section is organized into two subsections: (1) Geologic and Hydrologic Considerations, and (2) Environmental and Socioeconomic Considerations. Each subsection is further subdivided by individual issues. The narratives (status and plans) for each issue are presented by work element. A discussion of work elements not associated with issues is also included.

13.3.1 Geologic and Hydrologic Considerations: Issues and Work Elements

This section contains a discussion of issues and work elements related to geologic and hydrologic considerations. The text is accompanied by work element analysis tables summarizing the data needs and status of work supporting each of the four issues identified in Table 13-1.

ISSUE S.1.A

What are the geologic, mineralogic, and petrographic characteristics of the candidate repository horizons and surrounding strata within the reference repository location?

The stratigraphy of the reference repository location consists of a thick sequence of basalt flows; at least 70 flows are included in the Pasco Basin stratigraphic column down to a depth of at least 3.2 kilometers. The upper 20 or so flows are interbedded with thin sedimentary units that are, in turn, overlain by younger sedimentary rocks. The Umtanum flow, one of two candidate repository horizons, is a thick (approximately 70 meters thick) basalt flow in the sequence and lies approximately 1,100 meters below ground surface in the reference repository location. The middle Sentinel Bluffs flow is a second candidate repository horizon. It is thicker than the Umtanum flow (approximately 80 meters thick) but lies at a shallower depth (approximately 910 meters below ground surface). (See Section 3.5 for a discussion of the stratigraphy and lithology of the reference repository location.)

The stratigraphy and structure of the basalt flows dominantly control the deep groundwater flow within the reference repository location and the Columbia Basin. Consequently, the characteristics of the candidate repository horizons and surrounding strata determine their performance as geologic barriers to the migration of radionuclides to the accessible environment. Data concerning the geologic, mineralogic, chemical, and petrographic characteristics of the basalt section serve as input to rock mechanics models (see Chapter 14), radionuclide release models (see Chapter 15), and near- and far-field hydrologic models. Hence, the work

discussed within this subsection is an important part of both preclosure and postclosure repository performance assessment work. The work elements outlined below, and summarized in Table 13-2, are the subject areas in which information is needed to adequately describe the characteristics of the candidate repository horizons and surrounding strata. Individual work elements include both a brief discussion of the status of the subject area and plans to obtain the required information to complete the work element.

Work Element S.1.1.A (Priority 1)

> Determine the thickness and continuity of the candidate repository horizons within the reference repository location.

Status

An isopach map of one of the two candidate repository horizons, the Umtanum flow, was produced by Long et al. (1980, p. 18) and updated by Long and Landon (1981, p. 4-27). The current version is included in Chapter 3 (Section 3.5). Within the reference repository location, the thickness of the Umtanum flow is nearly constant at 64 to 71 meters and has an estimated predictive accuracy of ±4 meters for any thickness prediction made for a borehole in the reference repository location. The predictive accuracy value represents an estimated 1 standard deviation value and was obtained from predictions using the isopach map in Long et al. (1980, p. 18) compared to values observed in boreholes DC-12 and -15 (Fig. 13-2).

The thickness of the Umtanum flow, including its flow top, ranges from 64 to 88 meters within the Cold Creek syncline and 40 to 88 meters for the Pasco Basin (Long and Landon, 1981, p. 4-27) and has a predictive accuracy of ±9 meters. Values for predictions were taken from Long et al. (1980, p. 18) and from values observed in boreholes DC-12, -14, and -15 (Fig. 13-2) (BWIP, 1982a; 1982b). A preliminary isopach of the middle Sentinel Bluffs flow, indicates that its thickness ranges from approximately 85 to 77 meters in the reference repository location and from 85 to 47 meters in the Pasco Basin. Predictive accuracy for the middle Sentinel Bluffs flow is probably similar to that for the Umtanum flow.

The maximum distances from the center of the reference repository location to the farthest known extent of both of the most promising candidate repository horizons in each major compass direction are: north, 27.8 kilometers; east, 26.4 kilometers; south, 13.6 kilometers; and west, 21.4 kilometers. The area required by the conceptual design of the repository is less than 10 square kilometers. The reference repository location is 48 square kilometers and of sufficient size to meet the repository size requirements. There is near certainty that the margins of the candidate repository horizons are beyond the reference repository location.

TABLE 13-2. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.A. (Sheet 1 of 5)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.1.A Determine the thickness and continuity of the candidate repository horizons within the reference repository location.	Range of thickness variations for the candidate repository horizons within the reference repository location.	Measurement of thickness of candidate repository horizons in boreholes RRL-2, -6, -14, and DC-16A (BWIP, 1982a; 1982b).	Presently, a thickness range of 64 to 88 meters has been determined for the Umtanum flow in the Cold Creek syncline. Thickness of the Umtanum flow can currently be predicted to ±4 meters at the exploratory shaft site and ±4 meters within the reference repository location. The middle Sentinel Bluffs flow in the Cold Creek syncline ranges in thickness from 85 to 47 meters. Its thickness can be predicted to accuracies similar to those for the Umtanum flow (Long and Landon, 1981; Long and Davidson, 1981; Section 3.5.4 of this document). Thickness of intraflow structures within the candidate repository horizons are considered under S.1.4.A.
	Prediction of thickness of the candidate repository horizons to ±4 meters within the reference repository location.		
	Nature and magnitude of short-range (less than tens of meters) variations in thickness of the candidate repository horizons.		
	Areal extent of the candidate repository horizons within the Cold Creek syncline and region.	Locate and examine the candidate repository horizons in the Pasco Basin to determine the lateral extent and the conditions that control the lateral extent of of the flow; identify candidate repository horizons using X-ray fluorescence and paleomagnetic analyses.	Preliminary work indicates that the candidate repository horizons are continuous across the Cold Creek syncline, and as of yet, no conditions that could limit lateral extent of their total thickness within the reference repository location have been identified in either outcrops or boreholes (Myers/Price et al., 1979; Long and Landon, 1981; Long and Davidson, 1981; Section 3.5.4 of this document). There is near certainty that the margins of the two candidate repository horizons extend beyond the reference repository location. Variation or lateral extent of dense interior or flow top of the candidate repository horizons are considered under S.1.4.A.

TABLE 13-2. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.A. (Sheet 2 of 5)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.2.A (Included in S.1.12.B) Determine the dip, strike, fold wavelength, and fold amplitude of the candidate repository horizons within the reference repository location.	Included in S.1.12.B.	Included in S.1.12.B.	Included in S.1.12.B.
S.1.3.A (Included in S.1.12.B) Determine what deformational features are likely to intersect the candidate repository horizons within the reference repository location.	Included in S.1.12.B.	Included in S.1.12.B.	Included in S.1.12.B.
S.1.4.A Determine the primary internal structure of the candidate repository horizons within the reference repository location.	Estimate of spatial variation of thickness of the flow top, entablature, and colonnade in the candidate repository horizons. Identify areas in the candidate horizons where basalt flow emplacement conditions may have created extensive vesiculation or brecciation that could affect isolation capabilities or constructibility of a repository.	Conduct detailed logging, sampling, and petrographic analysis of core from additional boreholes penetrating the candidate repository horizons. Conduct detailed fracture and lithologic logging of exposures of the candidate repository horizons; conduct detailed petrographic analysis of samples from these exposures.	General relationships between petrographic textures and intraflow structures are known (Long, 1978; Long and Davidson, 1981). Broad-scale variations in intraflow structures of the Umtanum and middle Sentinel Bluffs flows across the Pasco Basin are known (see Chapter 3). These broad-scale variations provide constraints on variations of intraflow structures within the reference repository location (Long and Davidson, 1981; Section 3.5.4 of this document). An anomalous flow top 45 meters thick was encountered in the Umtanum flow in RRL-2. Additional boreholes are being drilled in order to assess the lateral extent of this anomaly. For the middle Sentinel Bluffs flow, general variations in flow top thickness are known to be minimal; flow top thickness in the reference repository location is less than 6 meters.

TABLE 13-2. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.A. (Sheet 3 of 5)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.5.A (Related to S.1.9.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the orientation, distribution, aperture infilling (secondary mineralization), and origin of fractures, discontinuities, and heterogeneities within the candidate repository horizons.	Data collection areas include: • Fracture orientation and spacing data from surface exposures of the candidate repository horizons • Quantitative petrographic data from surface exposures of the candidate repository horizons • Relationship between fractures and petrographic features • Aperture infilling data from core samples • Relative fracture orientation and spacing data from core samples.	Conduct detailed fracture and lithologic logging of exposures of the of the candidate repository horizons; conduct detailed petrographic analysis of samples from these exposures. Conduct detailed logging, sampling, and petrographic analysis of core from existing boreholes (DC-2, -4, -6, -8, -12, -14, and -15) and from new boreholes (RRL-2, -6, -14, and DC-16A) (BWIP, 1982a; 1982b) penetrating the candidate repository horizons.	Preliminary surface fracture and petrographic data are currently being collected for the candidate repository horizons. Data for other flows are reported in Long (1978) and can be generalized to the candidate repository horizons (also see Section 3.5.4 of this document). Orientation and distribution data for core samples of the candidate repository horizons in boreholes have been collected but have not yet been analyzed.
S.1.6.A (Related to S.1.5.A, S.1.8.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the mineralogic, petrographic, and chemical characteristics of the candidate repository horizons including the composition, texture, and abundance of both primary and secondary phases; apply data as appropriate to predict fracture distribution in Work Element S.1.5.A.	Information needs include: • Composition of primary and secondary phases • Abundance of primary and secondary phases • Establishment of relationship between above features and fractures or discontinuities in the candidate repository horizons. Prediction of mineralogic and petrographic characteristics of the candidate repository horizons within the repository site.	Conduct detailed mineralogic and petrographic analysis of samples from the candidate repository horizons.	General mineralogy and petrography of Grande Ronde Basalt is known; this knowledge can, in part, be applied to the Umtanum flow. Major- and trace-element bulk chemical composition of the candidate repository horizons are well known. Qualitative relationships between basalt textures and fracture abundance have been established (Myers/Price et al., 1979; Long and Davidson, 1981; Section 3.5.4 of this document). Detailed abundance and composition data for the minerals in the candidate repository horizons are currently being collected.

TABLE 13-2. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.A. (Sheet 4 of 5)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.7.A (Related to S.1.11.B) Determine the stratigraphic characteristics of the flows above and below the candidate repository horizons.	Information needs include: • Thickness, intraflow structure, magnetic polarity, mineralogy, and geochemistry of the flows above and below the candidate repository horizons • Lateral continuity of flows above and below the candidate repository horizons • Identity of additional flows that could serve as acceptable candidate repository horizons.	Obtain major- and trace-element chemical data and paleomagnetic data for core samples from additional boreholes within and near the reference repository location. Obtain major- and trace-element chemical data and paleomagnetic data for core samples above and below the Umtanum flow; analyze samples from nearby sections. Identify areas of possible flow pinch-outs or other significant stratigraphic discontinuities.	Most of the flows above the Umtanum flow, including the middle Sentinel Bluffs flow are stratigraphically well characterized and can be correlated on a flow-by-flow basis within the reference repository location. Flows below the Umtanum are more difficult to correlate, but marker flows that are paleomagnetically and chemically distinct have been recognized; additional boreholes should allow flow-by-flow correlations to be made (Long and Landon, 1981; see Section 3.5.4 of this document).
S.1.8.A (Related to S.1.6.A, S.1.7.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the structural, textural, mineralogic, and petrographic characteristics of the rocks above and below the candidate repository horizons.	Provide for Grande Ronde Basalt flows within and adjacent to the reference repository location (to a maximum depth of approximately 1,700 meters below the ground surface): • Qualitative description of intraflow structures • Reconnaissance petrographic data including quantitative mineral-abundance data • Mineralogic analyses of selected samples of both primary and secondary minerals. Ascertain the variability of structural, textural, and mineralogic characteristics of Grande Ronde Basalt flows.	Assess structural, textural, and mineralogic characteristics of the rocks above and below the candidate repository horizons in a minimum of two additional boreholes within or adjacent to the reference repository location (boreholes RRL-2 and DC-16A). Compare results obtained from new boreholes with data from existing boreholes.	General mineralogy and petrology of Columbia River basalts is known. However, site-specific spatial variations of textural and mineralogic characteristics have yet to be determined. Spatial variation of primary internal structures within the reference repository location is known in a very general way. A more specific interpretation will be made based on additional borehole information (Long and Davidson, 1981; Sections 3.5.4 and 6.1 of this document).

TABLE 13-2. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.A. (Sheet 5 of 5)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.9.A (Related to S.1.5.A, S.1.7.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the orientation, distribution, aperture infilling (secondary mineralization), and origin of fractures, discontinuities, and heterogeneities within rocks above and below the candidate repository horizons.	Provide for Grande Ronde Basalt flows within and adjacent to the reference repository location (to a maximum depth of approximately 1,700 meters below the ground surface): • Estimates of fractures, discontinuities, and heterogeneities emphasizing aperture infilling and fracture distribution data • Estimates of the types of discontinuities and heterogeneities that occur in the Grande Ronde Basalt and the distribution of these features in the reference repository location and Cold Creek syncline.	Collect lithologic logging, fracture orientation (relative) and spacing, and fracture-infilling data from DC-12, RRL-2, DC-16A, and RRL-14 (BWIP, 1982a; 1982b). Compare results obtained from new boreholes with data collected from existing boreholes.	Types of discontinuities and heterogeneities in Grande Ronde Basalt are reasonably well known. The distribution of features such as pillow zones and flow tops (which could have hydrologic importance) are known at point locations (boreholes). A general distribution within the Pasco Basin area can be interpreted from available data (Long and Davidson, 1981; Section 3.5.4 of this document).
S.1.10.A (Related to S.1.27.C, S.1.28.C, S.1.29.C, and S.1.30.C) Determine the presence and characteristics of other possible anomalies that could serve as zones of greater permeability.	Determine the characteristics, and potential for occurrence within the reference repository location of: • Spiracles • Vesicle cylinders and vesicle sheets • Pillow-palagonite zones • Localized increased thickness of flow-top breccia • Anomalous fractures or fissures in either flow tops or flow interiors.	Examine core from RRL-2, DC-16A, and RRL-14 and other deep boreholes, as available (BWIP, 1982a; 1982b). Conduct hydrologic tests in DC-16A,B,C "cluster" boreholes to determine if any anomalously permeable zones have a significant impact on flow paths within the reference repository location. Conduct hydrologic tests of fanning columns in entablatures associated with increased thicknesses of flow top (if encountered in planned boreholes). Conduct confirmation of hydrologic effect of cited features, through lateral borings and excavations within an underground facility.	The types of potential flow paths or permeable zones in basalt zones, beside those considered as part of other work elements have been recognized. These features are considered relatively insignificant in determining flow paths. Some of these features may occur in the near field of the repository. Their impact is anticipated to be small (Myers/Price et al., 1979; Long and Davidson, 1981), but this must be verified by in situ testing as noted under mandatory measurement conditions.

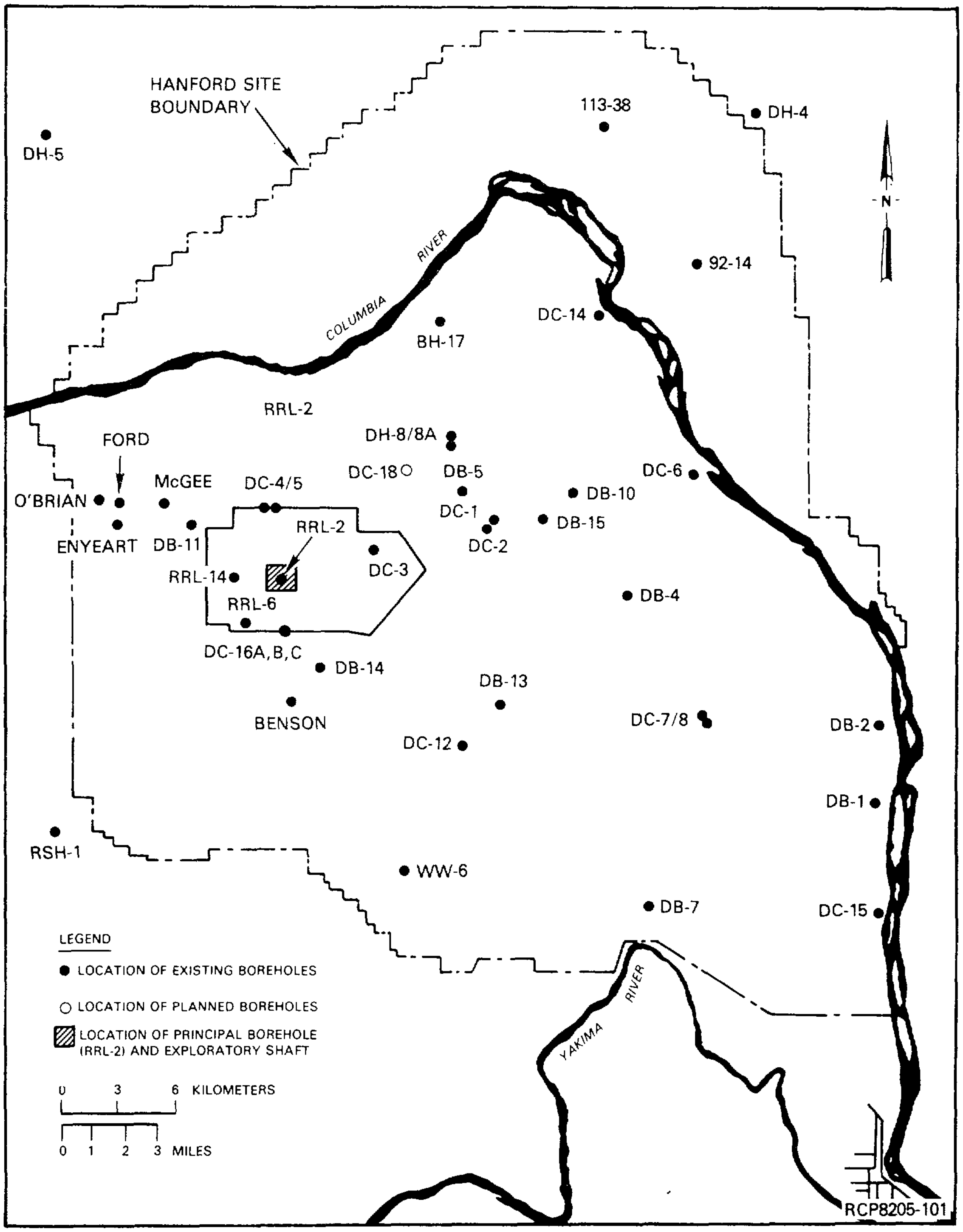

FIGURE 13-2. Existing and Planned Boreholes at the Hanford Site (see BWIP, 1982a; 1982b).

Plans

Predictive accuracy for the total thickness of the candidate repository horizons is ±4 meters in the reference repository location (BWIP, 1982a; 1982b). This value reflects design requirements and near-field rock mechanics (Chapters 14 and 17) and hydrologic modeling needs. Data from several core holes (Fig. 13-2) will be used to achieve the accuracy needed for thickness predictions. Verification of the presence of the candidate repository horizons within the core holes will be based on X-ray fluorescence chemical analyses and paleomagnetic analyses. Thickness values will be obtained from the direct measurement of core.

In addition to core hole data, study of field exposures of the candidate repository horizons will be continued to determine typical, short-range (tens of meters) variations in flow thickness. Although it has been shown (Reidel and Fecht, 1981; Long and Landon, 1981) that long-range variation of flow thickness is generally dependent on depositional, topographic, and structural controls, factors controlling short-range variations (approximately ±2 meters) are less well understood. Work will proceed to acquire such an understanding so that typical or expected short-range variations can be factored into near-field performance models. Completion of a study on lateral variation of basalt flows north of Vantage, Washington (Long and Landon, 1981) will provide a basis for predicting typical short-range thickness variations that could occur in Grande Ronde Basalt flows, including the candidate repository horizons. This study will be based on examination of photographs of actual cliff exposures wherein thickness variations can be measured. The results from this study will provide an improved understanding of the expected variation in total flow thickness and to a lesser extent variations in thickness of intraflow structures.

The currently available data are sufficient to ensure that the candidate repository horizons are present throughout the reference repository location, an area of sufficient size (approximately 48 square kilometers) to encompass a nuclear waste repository.

Work Element S.1.2.A (Included in S.1.12.B) (Priority 2)

Determine the dip, strike, fold wavelength, and fold amplitude of the candidate repository horizons within the reference repository location.

Status

Included in S.1.12.B.

Plans

Included in S.1.12.B.

Work Element S.1.3.A (Included in S.1.12.B) (Priority 1)

Determine what deformational features are likely to intersect the candidate repository horizons within the reference repository location.

Status

Included in S.1.12.B.

Plans

Included in S.1.12.B.

Work Element S.1.4.A (Priority 1)

Determine the primary internal structure of the candidate repository horizons within the reference repository location.

Status

Types of primary internal structures of the Umtanum flow are recognized and variations of these features across the Pasco Basin are known. Specific features of importance in the candidate repository horizons are flow top, entablature, and colonnade (see Section 3.5.4). The flow top of a basalt flow is the scoriaceous-to-brecciated zone between the top of the flow and the underlying dense flow interior (Long and Davidson, 1981, p. 5-4). Entablature is that portion of a flow that has smaller and less regular columns than the underlying colonnade. In some parts of the Umtanum flow, colonnade-like features occur within the entablature. It is also recognized that fanning arrays of columns occur within the entablature and that these features are, at least in part, codistributed with anomalous, locally thickened areas of flow top. The colonnade of the flow is that portion of the flow at its base that consists of relatively large, regular columns. These features are recognized in core samples by a combination of detailed core logging and petrographic textural determinations (Long, 1978).

Currently, the flow tops of the candidate repository horizons in the reference repository location range from 45 to 17 meters in thickness for the Umtanum flow and from 4 to 7 meters in thickness for the middle Sentinel Bluffs flow. The ranges given for flow tops are proportionately larger than the variation for the thickness of the entire flow because of the inherently greater variation of intraflow structures relative to total flow thickness.

Plans

In order to adequately define internal structures, additional core holes are being drilled through the candidate repository horizons. The boreholes will be located to effectively assess intraflow thicknesses within the reference repository location and, in particular, to assess

whether the anomalously thick flow-top breccia in the Umtanum flow exposed at the Emerson Nipple section (Umtanum Ridge) and encountered in RRL-2 occurs across most of the reference repository location or if it is limited to the vicinity of RRL-2. Intraflow structures in core from these boreholes will be determined by detailed core logging, petrographic analysis, and borehole geophysics. Data thus obtained will provide additional insight into the general trends of intraflow structure thickness variations. This information will be crucial input to the selection of a reference repository horizon by decision analysis (see Section 2.7). However, such data will provide only limited information regarding local variations in thicknesses in intraflow structures. Data needs related to a determination of such local variations are addressed under Work Elements S.1.1.A and S.1.4.A.

Work Element S.1.5.A (Related to S.1.9.A, W.2.1.A, W.2.4.A, and W.2.13.D) (Priority 2)

Determine the orientation, distribution, aperture infilling (secondary mineralization), and origin of fractures, discontinuities, and heterogeneities within the candidate repository horizons.

Status

Data on relative orientation and distribution of fractures have been collected from Umtanum flow core samples from existing boreholes (DC-2, -4, -6, -8, -12, -14, and -15). However, these data have not yet been fully analyzed. Orientations and distribution of fractures in a surface exposure of the Umtanum flow are currently being determined. Qualitative petrographic data show a strong correlation between fracture abundance and petrographic texture (Long and Davidson, 1981). Quantitative petrographic data are currently being collected. Types of minerals that form fracture infillings have been identified (Long and Davidson, 1981), but their relative proportions and absolute abundances in core samples from the Umtanum flow have not been firmly established.

The vast majority of fractures in relatively undeformed surface exposures and in core samples are cooling joints that result from contraction of the rock on cooling after solidification of the magma. The general origin of the fractures is thus well understood. The specific origin of features such as entablature and colonnade, however, is less obvious. Study of the textures of the Umtanum and other flows indicates that the entablatures are quenched by inundation with water from deranged drainages (Long and Davidson, 1981; Section 3.5.4 of this document). This process may be responsible for the occurrence of fan-like columns in the entablature of the Umtanum flow and thus may be an important control of the relative orientation of fractures in the entablature.

Plans

Fracture orientation and spacing data will be compared with petrographic data (quantitative modal analysis and qualitative textural analysis) from surface exposures of the candidate repository horizons. These data will determine the extent to which petrography can be used to predict fracture spacing at depth from core samples by utilizing known fracture characteristics in surface exposures and by fracture spacing from the core itself. This technique will be employed to predict likely fracture characteristics in the Umtanum flow in the reference repository location based on core holes DC-2, -4, -12, RRL-2, -6, -14, and DC-16A (BWIP, 1982a; 1982b). This prediction will provide constraints to very near-field hydrologic and geomechanical modeling prior to completion of Exploratory Shaft-Phase I.

Aperture infilling data will be obtained from detailed measurement of fracture widths and estimation of relative proportions of infilling minerals in core samples from DC-2, -4, -12, RRL-2, and DC-16A. These data will provide input important to near-field hydrologic, geomechanical, and radionuclide release models, in that fracture infillings affect hydrologic conductivity, mechanical stability (because of potential for loss of water in hydrated phases due to the thermal field of the repository), and the sorptive capacity of the rock. Both X-ray diffraction and analytical scanning-transmission electron microscopy will be used to identify unknown mineral phases (see S.1.5.A) and to estimate relative proportions of infilling (secondary) minerals.

As discussed in S.1.2.B, a small proportion of fractures in core are likely to be tectonic in origin (i.e., tectonic fractures). Work will include a determination as to whether infillings of such fractures differ significantly from those in cooling joints. This information will be collected jointly under Work Elements S.1.4.A and S.1.5.A.

Work Element S.1.6.A (Related to S.1.5.A, S.1.8.A, W.2.1.A, W.2.4.A, and W.2.13.D) (Priority 2)

Determine the mineralogic, petrographic, and chemical characteristics of the candidate repository horizons including the composition, texture, and abundance of both primary and secondary phases; apply data as appropriate to predict fracture distribution in Work Element S.1.5.A.

Status

The general mineralogy, petrography, and chemistry of the Grande Ronde Basalt is well known, and this knowledge can be applied in part to the candidate repository horizons. Major- and trace-element bulk chemical composition of the Umtanum flow are known to vary within relatively narrow limits, and hence a relatively constant mineralogical assemblage for the flow is anticipated. Details of mineral chemistry, however, reflect the

crystallization and cooling history of the flow and, hence, are subject to a wider compositional range than the bulk chemistry of the flow itself. This is particularly true of the residual glass composition. This composition reflects the extent of crystallization and is not stoichiometrically controlled. In order to complete this work element, detailed abundance and composition data for the minerals in the Umtanum flow are currently being collected. Although fewer data are available for the middle Sentinel Bluffs flow, it is expected to exhibit a similar restricted mineralogic assemblage. Because its bulk chemical composition differs slightly from that of the Umtanum flow, its mineral abundance and composition are expected to reflect that difference. Such differences are expected to have an insignificant impact on isolation capabilities of the flow.

A qualitative relationship between basalt textures and fracture abundance has been established (Long and Davidson, 1981), which shows that increases in mesostasis abundance are correlated with increases in fracture abundance. Collection of data to quantify this relationship is in progress.

Plans

The composition, abundance, and texture of primary and secondary phases will be determined in samples from existing and planned core holes. Techniques used to obtain these data will be electron microprobe analysis, analytical scanning-transmission electron microscopy, X-ray diffraction, modal analysis (point counting), and image analysis.

Similar data are currently being collected on samples from a surface outcrop of the Umtanum flow, located at McCoy Canyon on Umtanum Ridge. The approach used to analyze primary mineral phases will be the collection of compositional data for approximately 20 samples each from the Umtanum Ridge exposure and core hole RRL-2, followed by the collection of data for approximately four samples each from additional core holes near the reference repository location.

A similar approach will be utilized for samples of secondary minerals from RRL-2. These analyses will be compared with existing data from Benson and Teague (1979) and will be used to calibrate visual identification for mineral abundance estimates of Work Element S.1.4.A.

These data taken together will be used to predict the mineralogic and petrographic characteristics of the candidate repository horizons in the repository site. Results that can be correlated with fracture distribution will be used as part of Work Element S.1.4.A.

Work Element S.1.7.A (Related to S.1.11.B) (Priority 2)

Determine the stratigraphic characteristics of the flows above and below the candidate repository horizons.

Status

The stratigraphic characteristics of flows include lithology, chemical composition, intraflow structures, magnetic polarity, and mineralogy. These are properties that allow flows to be correlated throughout the Cold Creek syncline. Flow correlation forms the geologic basis of several facets of repository work, including hydrologic modeling, repository design, rock mechanics modeling, repository seals, borehole seals and shaft design.

The accuracy of data used to correlate flows is that sufficient to confirm stratigraphic correlations to within member status in the Cold Creek syncline and on a flow-by-flow basis in the reference repository location.

The ability currently exists to correlate the strata on a member basis within the Cold Creek syncline and on a flow-by-flow basis within the reference repository location. The data correlations to provide the level of accuracy selected for the exploratory shaft and reference repository location will be acquired from an analysis of core samples from additional deep boreholes in and around the reference repository location (Fig. 13-2).

Internal structures to be identified include both the flow tops and flow interiors. This is achieved by mesoscopic examination of core and petrographic examination of thin sections of core samples. These techniques are discussed in Long and Davidson (1981, pp. 5-1 to 5-55). Core holes for identification of these features in the site and reference repository location, however, are in progress or planned but have not yet been completed.

Plans

Data to determine the stratigraphic characteristics of flows above and below the candidate repository horizons in the reference repository location and exploratory shaft site will be acquired through analysis of a core hole located at the exploratory shaft site (RRL-2) (drilled to a depth of at least 1,189 meters (3,900 feet)) (Fig. 13-2).

A core hole located in the south or southwest portion of the reference repository location (DC-16A) (Fig. 13-2) will be used to provide information to characterize the strata for individual flows in the reference repository location. This core hole will extend to a depth of 1,675 meters (below ground surface) so as to meet 10 CFR 60 (NRC, 1981) proposed criteria for geologic characterization to 500 meters below the lowest repository excavation. Borehole DC-5 (Fig. 13-2) is planned to be deepened to 1,675 meters (below ground surface) (BWIP, 1982a; 1982b).

A core hole located along the extreme western portion of the reference repository location (RRL-14) will establish the presence or absence of flow pinchouts within the reference repository location, particularly for the very high magnesium flow (see Section 3.5.4). The core hole will extend to approximately 1,230 meters in depth. In addition, other new

core holes designed mainly to define intraflow structures of the candidate repository horizons will also be used for stratigraphic characterization (BWIP, 1982a; 1982b). Specific analyses that will be made on core samples from the above wells are major- and minor-element chemical analysis, trace-element chemical analysis, paleomagnetic analysis, and megascopic determination of lithologic, mineralogic, and intraflow structures as part of core logging procedures.

Work Element S.1.8.A (Related to S.1.6.A, S.1.7.A, W.2.1.A, W.2.4.A, and W.2.13.D) (Priority 2)

> Determine the structural, textural, mineralogic, and petrographic characteristics of the rocks above and below the candidate repository horizons.

Status

General internal structures, mineralogy, and petrology of Columbia River basalts are known. However, site-specific spatial variation of textural, mineralogical, and structural characteristics have yet to be determined for near- to intermediate-field hydrologic modeling. Information is required primarily in Grande Ronde Basalts to a depth of approximately 1,675 meters (below ground surface). Types of data needed are similar to those required for the Umtanum flow in Work Elements S.1.2.A, S.1.4.A, and S.1.5.A, except that less detail is required.

Plans

The following information will be collected for Grande Ronde Basalt flows penetrated by boreholes DC-2, -4, -5 (as deepened), -12, -16A, RRL-2, and -14 (Fig. 13-2): (1) qualitative description of intraflow structures, (2) reconnaissance petrographic data including quantitative modal analysis, and (3) mineralogic analysis of selected samples of both primary and secondary minerals.

The placement of these boreholes (see Fig. 13-2) will provide three-dimensional information on spatial variations of the structural, textural, and mineralogical characteristics of Grande Ronde Basalt in the reference repository location. Particular attention will be paid to variation in secondary mineral species and abundance with depth, as this could provide an important input to variation of sorptive properties of basalt as a function of depth. This information will be included in performance assessment models.

The general aspects of spatial variation of primary intraflow structures (flow top, entablature, and colonnade) are known in a general way. Data obtained from additional boreholes will permit a more site-specific interpretation, thus providing a refinement of input to near-field hydrologic models and geomechanical models.

Work Element S.1.9.A (Related to S.1.5.A, S.1.7.A, W.2.1.A, W.2.4.A, and W.2.13.D) (Priority 2)

Determine the orientation, distribution, aperture infilling (secondary mineralization), and origin of fractures, discontinuities, and heterogeneities within rocks above and below the candidate repository horizons.

Status

Types of discontinuities and heterogeneities that occur in Grande Ronde Basalt, and that may affect groundwater flow, are reasonably well known. The distribution of features such as pillow zones and flow tops are known at point locations (boreholes) and their general distribution can be interpreted from this information. Fractures in these rocks are dominantly cooling joints. Data needed to satisfy this work element are similar to those required for the candidate repository horizons (Work Element S.1.4.A) except that less detail is required; i.e., it will be sufficient to know, for example, that fracture abundance falls within expected ranges, rather than to know detailed fracture abundances, as is required for the Umtanum flow. Fracture orientation and distribution data have been obtained from core holes DC-2 and -4, but these data have yet to be fully analyzed.

Plans

The following data will be collected for Grande Ronde Basalt from boreholes DC-5 (as deepened), -12, -16A, RRL-2, and RRL-14 (Fig. 13-2) (BWIP, 1982a; 1982b): lithologic logging, fracture orientation (relative) and spacing, and reconnaissance sampling of fracture infillings. Based on these data, an interpretation will be made as to the distribution of discontinuities and heterogeneities within Grande Ronde Basalt flows in the reference repository location. Data from any additional deep boreholes will be utilized as available.

Work Element S.1.10.A (Related to S.1.27.C, S.1.28.C, S.1.29.C, and S.1.30.C) (Priority 1)

Determine the presence and characteristics of other possible anomalies that could serve as zones of greater permeability.

Status

Because of the highly insoluble nature of basalt, solution fractures and solution-related breccia pipes do not occur in basalt terranes. Other permeable anomalies must be considered, however. All potential flow paths in basalt not considered under Work Elements S.1.1.A, S.1.2.A, S.1.4.A, S.1.6.A, S.1.8.A, S.1.9.A, and S.1.12.B will be considered within this work element. Features in this category include spiracles, vesicle cylinders, vesicle sheets, pillow-palagonite zones, localized increased thickness of flow top, and anomalous fractures or fissures in either flow tops or flow interiors.

Plans

Drilling of DC-16A, RRL-6, and -14 in the reference repository location (Fig. 13-2) should further demonstrate the absence of pillow palagonite in Grande Ronde Basalt in the reference repository location, and the "cluster" hydrologic test to be conducted at DC-16A,B,C should reveal any major anomalies in flow paths that might be associated with any of the features discussed above (BWIP, 1982a; 1982b).

The relatively small scale of most of these features suggests that they could be significant only in the near field and thus, if encountered, should be explored at depth. Fanning entablature columns in the Umtanum flow, associated with an increased thickness of flow top, will be hydrologically tested if encountered in horizontal boreholes drilled from the exploratory shaft (Fig. 13-2).

ISSUE S.1.B

What are the nature and rates of past, present, and projected structural and tectonic processes within the geologic setting and reference repository location?

Work elements grouped under Issue S.1.B include studies to characterize and assess the tectonic setting of the Pasco Basin (location of the Hanford Site) and reference repository location. U.S. Nuclear Regulatory Commission proposed criteria (NRC, 1981) and other criteria (NWTS, 1981a; 1981b; 1981c; 1981d) recommend that a repository be located in a "tectonically stable" area (i.e., one that has exhibited, and will continue to exhibit a slow rate of deformation that will not adversely affect containment). As such, the geologic, geophysical, historic, and instrumental monitoring work described within this section is aimed at defining the past, present, and projected (over an anticipated 10,000-year time frame) structural and tectonic setting of the reference repository location. Such work supplements other tectonic studies under way in the Hanford area in support of commercial nuclear power plant licensing (WPPSS, 1981; PSPL, 1982). A review of such work by the U.S. Nuclear Regulatory Commission has recently been summarized in the Supplementary Safety Evaluation Report for Washington Public Power Supply, Inc. Plant No. 2 (NRC, 1982).

Studies discussed under the Issue S.1.B Work Elements (Table 13-3) are keyed to preclosure and postclosure proposed performance criteria (NRC, 1981) (Fig. 13-2). Work to estimate tectonic strain that could occur during the preclosure phase of the repository is being conducted in support of ongoing repository and waste package design efforts (see Chapters 14 and 15, respectively). Tectonic structures represent zones of fractures that might affect shallow and deep groundwater flow systems. Hence, an assessment of pre-waste-emplacement groundwater travel times requires an evaluation of (1) the location and characteristics of existing structures and (2) the potential for tectonic activity that could generate new structures or increase or decrease the fracture permeability associated with existing structures. Estimates of strain rate and possible tectonic effects are serving as input to computer models generated as part of an assessment of postclosure repository performance (see Chapters 5 and 12).

TABLE 13-3. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.B. (Sheet 1 of 7)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.11.B (Related to S.1.17.B) Evaluate the regional structural and tectonic setting of the Pasco Basin.	Integrated structural and tectonic interpretation of the Columbia Plateau, Pasco Basin, Cold Creek syncline, and reference repository location.	Review existing regional geologic work.	Columbia Plateau bibliography completed (Tucker and Rigby, 1978; Tucker and Rigby, 1979; Bela, 1979; Strowd, 1978).
		Evaluate geologic and remote sensing maps of the Columbia Plateau in conjunction with geologic maps of the Pasco Basin and top-of-basalt map of the Cold Creek syncline.	Reconnaissance geologic and photo-lineament maps of the Columbia Plateau completed (Swanson et al., 1979; 1980, 1981; Rigby and Othberg, 1979; Farooqui et al., 1981). Formulation of preliminary stratigraphic and structural model of the plateau (Myers/Price et al., 1979; Sections 3.5 and 3.7 of this document).
S.1.12.B (Related to S.1.11.B and S.1.29.C) Determine the location of folds and faults in the Pasco Basin area with emphasis on the reference repository location.	Within the Yakima fold belt (with emphasis on the Pasco Basin, Cold Creek syncline, and, in particular, the reference repository location) determine: • Definition of northwest-trending structures	Review and evaluate existing mapping.	Surface geologic map of Pasco Basin completed (Myers/Price et al., 1979); subsurface maps of Cold Creek syncline completed (Myers, 1981); structural interpretive map of Cold Creek syncline completed (Myers, 1981) (see Section 3.7.2 of this document).
		Implement local, shallow geophysical surveys.	Hog Ranch axis and Jackass monocline mapped (Myers/Price et al., 1979).
	• Nature of brachyanticlines (doubly plunging folds) within and to the southeast of the Pasco Basin	Determine extent of minor faulting and folding associated with Rattlesnake trend and Gable Mountain extension using ground geophysics, drill-core data, and surface mapping.	Rattlesnake trend surface mapping reported in Myers/Price et al. (1979); subsurface faults associated with Gable Mountain anticline reported by PSPL (1982).
	• Orientation and spacing of tectonic breccia and fractures in relatively undeformed areas	Analyze tectonic fractures in Grande Ronde Basalt north of Vantage and in synclinal exposures.	Field studies completed that have shown that faults are most numerous in steeply dipping strata where flows have experienced maximum strain (i.e., anticlines) (Price, 1982).

TABLE 13-3. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.B. (Sheet 2 of 7)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	• Analysis of geophysical anomalies in reference repository location	Conduct gridded gravity surveys; evaluate gridded gravity data, seismic refraction, and vertical seismic profile data to interpret geophysical anomalies. Conduct evaluation of existing geophysical data set.	Qualitatively interpreted groundwater barriers identified (Gephart et al., 1979a). Preliminary integration of aeromagnetic and seismic reflection anomalies used to identify potential structural trends within the Cold Creek syncline (Myers, 1981)
	• Strike, dip, fold amplitude, and wavelength within the reference repository location for the Umtanum flow.	Acquire data from boreholes RRL-2 and DC-16A; increase fold amplitude and wavelength estimates to $\pm$3 meters and $\pm$90 meters, respectively; improve strike and dip estimates accordingly as specified by exploratory shaft design requirements.	Strike is known to $\pm$5 degrees; dip to $\pm$2 degrees; fold amplitude to $\pm$21 meters; fold wavelength to $\pm$200 meters; dip is less than 5 degrees.
S.1.13.B Evaluate the type and amount of displacement, geometry (width and continuous length), and age of faults within the Pasco Basin.	Within the Yakima fold belt (with emphasis on the Pasco Basin) determine:		
	• Definition of fault displacement, geometry, and extent of brecciation	Conduct geologic field mapping, geophysical surveys, and possible trenching and shallow drilling to provide geometric and descriptive fault data.	Thrust and reverse faults parallel major ridges and steeply dipping faults strike at oblique angles to major fold axes (Myers/Price et al., 1979).
	• Age of faulting	From field mapping and geophysical studies obtain relative age of faulting from study of effects on Miocene and younger strata. Obtain radiometric dates on fault-related materials to determine slip-rate, recurrence, and age of faulting (also see Information needs and Mandatory measurement conditions under S.1.15.B).	Suprabasalt sediments are generally not offset by faults in basalt. Possible Quaternary movement has been interpreted at Gable Mountain (PSPL, 1982) and Toppenish Ridge (Campbell and Bentley, 1981).
	• Extent of continuity of faulting associated with Cle Elum-Wallula lineament.	Use general method of Cochran (1981b) to determine extent of faulting along selected sections of lineament between Rattlesnake Mountain and Wallula Gap.	Faulting is interpreted to be continuous between two brachyanticlines (doubly plunging folds) southeast of Rattlesnake Mountain (Cochran, 1981b).

TABLE 13-3. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.B. (Sheet 3 of 7)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.14.B Evaluate the relationship of folding and faulting in the Yakima fold belt; evaluate the relationship of Yakima folds to structures that may be present in rocks beneath the Columbia River basalt within the Pasco Basin.	Within the Yakima fold belt (with emphasis on the Pasco Basin) define:		
	• Appropriate model of Yakima fold belt deformation that can be applied to a determination of the style of deformation; to include characterization of tectonic breccia and fractures.	Perform kinematic analysis following method of Price (1982) at Sentinel Gap, Smyrna Bench, Snively Basin, Wallula Gap, and Horse Heaven Hills.	Detailed kinematic and cross-sectional analysis at Umtanum Ridge completed by Price (1982). Various deformation models of the Yakima fold belt proposed by Laubscher (1981), Davis (1981), Bentley (1982), and others. (See Section 3.8.2 of this document.)
		Use paleomagnetic analysis to define extent of horizontal rotation.	Models that involve tectonic rotation within the Pacific Northwest have been proposed by Beck (1976) and Simpson and Cox (1977).
	• Extent of influence of hypothesized basement structures on basalt deformation	Detailed interpretation of existing magnetotelluric data and integration with all available gravity data.	Available magnetotelluric data for Pasco Basin suggest thickening and thinning of the basalt sequence over sedimentary basement with significant relief, indicating some pre-basalt structures may be present (Myers/Price et al., 1979; Section 3.6.4 of this document).
	• Geologic data from S.1.11.B through S.1.13.B, S.1.15.B, and S.1.16.B.	See Information needs and mandatory measurement conditions under S.1.11.B through S.1.13.B, S.1.15.B, and S.1.16.B.	See Status achieved under S.1.11.B through S.1.13.B, S.1.15.B, and S.1.16.B.
	• Theoretical mechanical analysis of basalt deformation.	(1) Rheological properties of basalt and interbeds	(1) Largely undetermined.
		(2) Thickness and number of basalt flows and nature of intraflow structures.	(2) Well known (Myers/Price et al., 1979; Myers and Price, 1981).

TABLE 13-3. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.B. (Sheet 4 of 7)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.15.B (Related to S.1.13.B, R.1.3.A, and R.1.6.A) Evaluate the geologic (long-term) and contemporary rate of deformation and stress field in the Pasco Basin and reference repository location.	Within the Yakima fold belt (with emphasis on the Pasco Basin and reference repository location) determine:		
	• Variation in the rate of vertical and horizontal deformation temporally (over the past 10 million years) and spatially (across the Pasco Basin)	Obtain thickness, depth, and continuity data on Miocene basalts and Miocene and younger suprabasalt sediments from borehole and outcrop measurements. Supplement stratigraphy data with estimates of fault slip rate (also see Information needs and Mandatory measurement conditions under S.1.13.B).	Vertical strain rate during Miocene estimated at 0.03 to 0.05 millimeter per year (Reidel et al., 1980). Displacement rate on central Gable Mountain fault estimated at 0.01 millimeter per year (PSPL, 1982). Deformation rates in Pliocene and Quaternary remain to be confirmed (Reidel and Fecht, 1981; PSPL, 1982).
	• Contemporary spatial stress and strain relationships in the Pasco Basin and reference repository location.	Determine changes in lengths of lines of Hanford trilateration network.	Six surveys suggest horizontal strain of less than 0.04 millimeter per year (Savage et al., 1981).
		Determine changes in elevation of leveling lines across the reference repository location.	
		Determine seismic moment and focal mechanism solutions from digitally recorded earthquake data (see Information needs and Mandatory measurement conditions under S.1.16.B).	Available data indicate a north-south compressional stress axis (WPPSS, 1981).
		Perform in situ stress measurements (see Chapter 14).	See Section 4.6.2 of this document for status of in situ stress measurements.
S.1.16.B (Related to R.1.29 and R.1.30) Determine the seismicity of the Pasco Basin and reference repository location.	Confirmation of regional pattern of stress release and the relationship of known and postulated structures to seismicity within the Pasco Basin area. Information needs include: • Velocity model • Determination of size and frequency of earthquakes	Continue seismic monitoring of Columbia Plateau, Pasco Basin, and reference repository location: • Operate regional University of Washington network • Maintain portable network to monitor earthquake swarm activity within the Pasco Basin	Pasco Basin is an area of low seismicity, characterized by shallow swarms of low magnitude. No correlation of seismicity with known structures is indicated (Malone, 1979; WPPSS, 1981; Section 3.7.3 of this document).

TABLE 13-3. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.B. (Sheet 5 of 7)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	• Proximity of seismic events • Attendant ground motion (at surface and repository depths) • Characteristics of swarm activity (causative fault, stress released, amount of displacement).	• Operate borehole seismometer • Operate fixed baseline network within vicinity of reference repository location.	
S.1.17.B (Related to S.1.11.B through S.1.16.B, and S.1.23.B) Develop a conceptual model that can be used to evaluate the past, present, and projected tectonic setting of the reference repository location.	Development of conceptual tectonic model for the Yakima fold belt (with emphasis on Pasco Basin and reference repository location). Provide: • Geologic, geophysical, seismologic, and geodetic data outlined in S.1.11.B through S.1.16.B. • Integration of BWIP data with results of investigations conducted by others in the Columbia Plateau		Conceptual tectonic models concerned with fold and fault development within the Pasco Basin have been developed by Price (1982), Laubscher (1981), Davis (1981), and others (See Section 3.8.2 of this document).
	• Evaluation of models in terms of available data and in terms of their impact on preclosure and postclosure repository performance.	Conduct evaluation of applicability of existing models and their impact on preclosure and postclosure repository performance.	Evaluation under way.
S.1.18.B (Included in S.1.12.B, S.1.13.B, and S.1.14.B) Determine the presence of active faults within the geologic setting; evaluate their rupture length.	Included in S.1.12.B, S.1.13.B, and S.1.14.B.	Included in S.1.12.B, S.1.13.B, and S.1.14.B.	Included in S.1.12.B, S.1.13.B, and S.1.14.B.

TABLE 13-3. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.B. (Sheet 6 of 7)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.19.B (Included in S.1.12.B and S.1.13.B) Determine if Quaternary faulting is present within the disturbed zone.	Included in S.1.12.B and S.1.13.B.	Included in S.1.12.B and S.1.13.B.	Included in S.1.12.B and S.1.13.B.
S.1.20.B (Included in S.1.12.B through S.1.16.B) Determine the presence of faults of any age within the disturbed zone; determine the potential for movement along existing faults and fractures within the disturbed zone; determine the potential for generation of new faults and fractures within the disturbed zone.	Included in S.1.12.B, S.1.13.B, S.1.14.B, S.1.15.B, and S.1.16.B.	Included in S.1.12.B, S.1.13.B, S.1.14.B, S.1.15.B, and S.1.16.B.	Included in S.1.12.B, S.1.13.B, S.1.14.B, S.1.15.B, and S.1.16.B.
S.1.21.B (Included in S.1.11.B, S.1.12.B, and S.1.15.B) Evaluate the nature of structural deformation such as uplift, subsidence, folding, and fracturing during the Quaternary Period.	Included in S.1.11.B, S.1.12.B, and S.1.15.B.	Included in S.1.11.B, S.1.12.B, and S.1.15.B.	Included in S.1.11.B, S.1.12.B, and S.1.15.B.
S.1.22.B (Included in S.1.16.B) Determine if earthquakes are correlatable with tectonic processes and/or features within the reference repository location; if correlatable, predict the frequency and magnitude of future events.	Included in S.1.16.B.	Included in S.1.16.B.	Included in S.1.16.B.

TABLE 13-3. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.B. (Sheet 7 of 7)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.23.B (Related to S.1.17.B)	Information needs include:		See Section 3.7.2 of this document.
Determine the nature of igneous activity within the Pasco Basin area.	• Knowledge of distribution of volcanic units and structures	Obtain structural and stratigraphic geologic mapping; compile existing geologic mapping of the Pasco Basin and Columbia Plateau.	Mapping and map compilation completed (Myers/Price et al., 1979; Myers and Price, 1981; Reidel et al., 1980).
	• Knowledge of trace- and major-element geochemistry, petrofabric, and mineralogy of mapped volcanic units of the Pasco Basin	Apply standard methods of chemical analysis, optical petrography, and electron microprobe analysis.	Information contained in Myers/Price et al. (1979) and Reidel et al. (1980).
	• Absolute and relative age determinations of mappable volcanic units and structures	Obtain radiometrically absolute ages of mapped volcanic units within the Pasco Basin.	Information contained in Myers/Price et al. (1979) and Reidel et al. (1980).
	• Knowledge of regional Columbia Plateau and Pasco Basin geothermal gradient and heat flow	Obtain geothermal gradient data from borehole measurements. Obtain laboratory determinations of thermal conductivities.	See Johnpeer et al. (1981); Murphy and Johnpeer (1981); borehole measurements ongoing.
	• Interpretation of tectonic setting of Pasco Basin (see Information needs under S.1.17.B).	See Mandatory measurement conditions under S.1.17.B.	See Status achieved under S.1.17.B.

Work Element S.1.11.B (Related to S.1.17.B) (Priority 2)

Evaluate the regional structural and tectonic setting of the Pasco Basin.

Status

Regional geologic studies conducted in support of the BWIP have included a literature search (Tucker and Rigby, 1978; 1979; Bela, 1979; Strowd, 1978), surface geologic mapping (Swanson et al., 1979; 1980, 1981; Rigby and Othberg, 1979; Farooqui et al., 1981), and a photolineament analysis (Sandness et al., 1981). Surface geologic mapping, and the complementary photolineament analysis of the Columbia Plateau, are primarily of a reconnaissance nature (i.e., scale of 1:250,000) and were designed to augment more detailed work conducted concurrently within the Pasco Basin.

Data generated under the regional geologic studies work element have been utilized to formulate a preliminary regional stratigraphic and structural interpretation of the Columbia River Basalt Group, overlying late Cenozoic sediments and volcanics, and older rocks bounding the plateau margin. Structurally, the reference repository location, and most of the Pasco Basin, is located within the Yakima Fold Belt subprovince, which covers the central and western parts of the Columbia Plateau. Anticlinal and synclinal folds that comprise this subprovince began to form as early as late Grande Ronde Basalt time; although some suprabasalt sediments were involved in the folding process, younger Quaternary sediments generally appear to be undeformed. More detailed discussions of the findings of the regional geologic studies effort are contained in Chapter 3 of this document.

Plans

Current plans include a more thorough evaluation of recently completed geologic and photolineament maps of the Columbia Plateau. Such an analysis will be carried out in conjunction with data available for the Pasco Basin and Cold Creek syncline to provide an integrated structural and tectonic interpretation of the reference repository location. This evaluation may include further study of selected areas within the region, as needed, to enhance and to support interpretations of more site-specific findings.

Work Element S.1.12.B (Related to S.1.11.B and S.1.29.C) (Priority 2)

Determine the location of folds and faults in the Pasco Basin area with emphasis on the reference repository location.

Status

East-west-trending, asymmetrical, anticlinal ridges of the Yakima fold belt bound the Pasco Basin on the north and south and plunge into the basin from the west. The east-west-trending anticlines of the basin and surrounding area have been characterized through geologic mapping (Myers/Price et al., 1979; Price, 1982; Section 3.7.2 of this document). Fold structures and possible fold structures within the sediment-filled synclines of the Pasco Basin have been largely interpreted from geophysical investigations and drill hole data (Myers, 1981; Section 3.7.2 of this document). The results of surface and subsurface work have shown that more subtle second- and third-order folds, with axes subparallel to the main first-order folds, are present as well as first-order northwest-trending folds. Studies by Price (1982) suggest that faults are most numerous in steeply dipping strata where flows have experienced maximum strain (i.e., anticlines). Thus, faults of major displacement are not anticipated in shallow-dipping synclinal strata, although faults of small displacement may be present. Few tectonic fractures have been found in the thousands of meters of core drilled within Pasco Basin synclines (Moak, 1981).

The Cold Creek syncline lies between the Umtanum Ridge anticlinal structure on the north and the Yakima Ridge and Rattlesnake Mountain anticlinal structures on the south (Fig. 13-3). Two subtle, subsurface depressions are present along the troughline of the syncline: (1) the Cold Creek Valley depression, located within the area of the reference repository location and (2) the Wye Barricade depression, located approximately 25 kilometers to the east (Fig. 13-3). The central and eastern parts of the Cold Creek syncline appear to be free of potentially adverse bedrock structures relative to other parts of the Cold Creek syncline and Hanford Site. Within this area, the structure of the top of basalt and the structure of deeper horizons (such as the Umtanum and middle Sentinel Bluffs flows) are interpreted to be nearly flat-lying (Myers, 1981; Section 3.7.2 of this document).

Plans

Additional work will be focused on defining the pattern of subtle deformation within the Cold Creek syncline and reference repository location. Interpretation of geophysical anomalies and borehole data have led to the mapping of minor features in the Cold Creek syncline (Myers, 1981), but it is not clear whether the anomalies represent structures and, if so, whether the structures are folds or faults. The emphasis of additional work will be toward the evaluation of these anomalies and known structures within the vicinity of the reference repository location so that their potential influence on groundwater travel times can be more fully assessed.

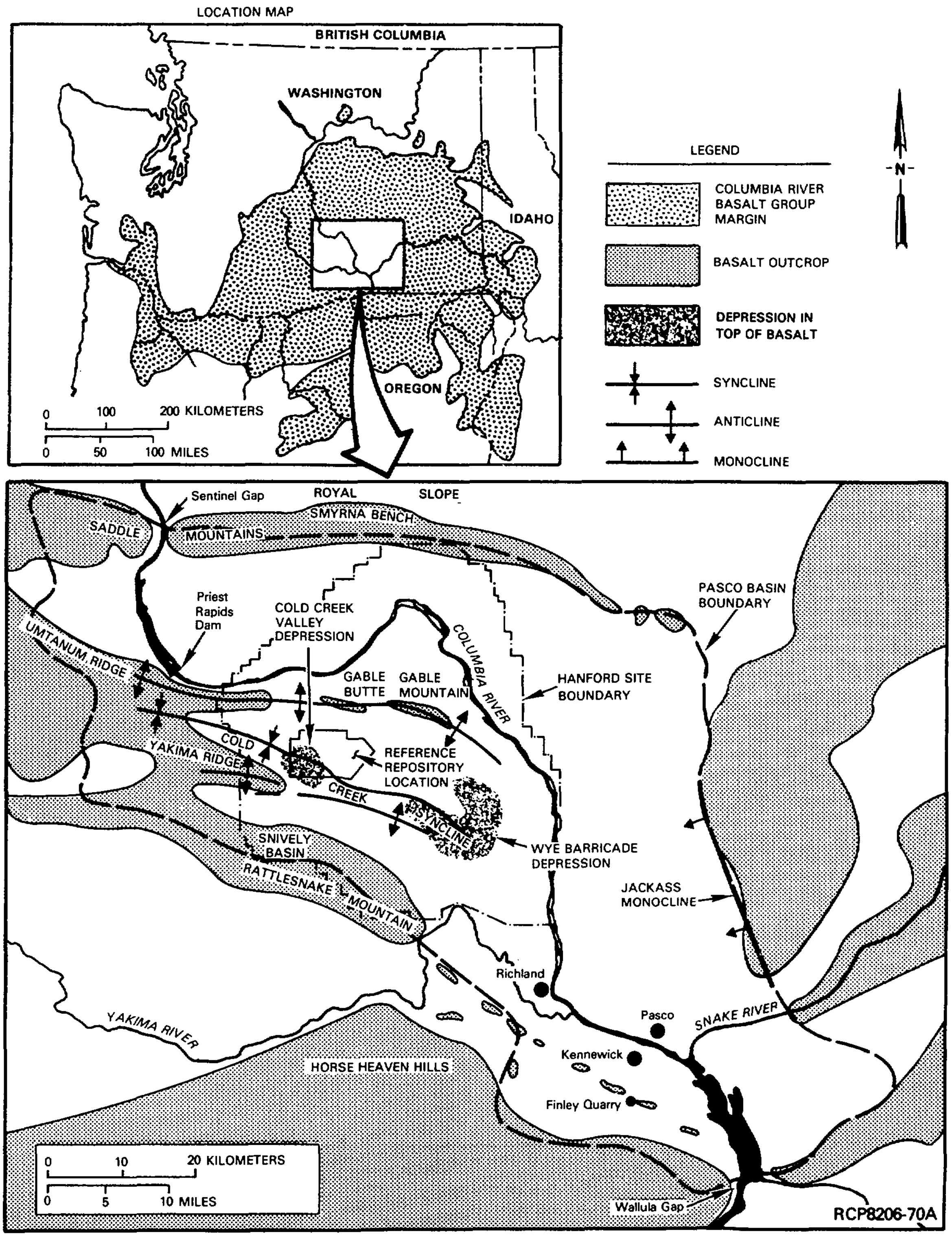

FIGURE 13-3. Location Index Map.

Previous studies of folding have concentrated on east-west-trending folds. Northwest-trending structures are also present within the Pasco Basin. Whereas the eastern and western borders of the Cold Creek syncline (and the basin) are defined by northwest-trending folds, additional work will be focused on determining the geologic properties of these structures (the Hog Ranch and the Jackass monocline) as well as a possible third northwest-trending structure (Snively Basin) outcropping to the south of the reference repository location (Fig. 13-3). Work will include a review and field evaluation of existing mapping and the possible implementation of localized, shallow geophysical surveys. Results of these studies will also be used to assess the possible hydrologic significance and characteristics of the "structural high" that subdivides the Cold Creek syncline into the Cold Creek Valley depression and the Wye Barricade depression (Fig. 13-3).

In addition, the nature of doubly plunging folds exposed southeast of the Pasco Basin will be investigated to provide data regarding the geologic characteristics of small subsurface folds associated with Gable Mountain and Gable Butte (Fig. 13-3) (Cochran, 1981a). The Gable Mountain-Gable Butte structure is currently interpreted to have an effect on groundwater circulation within the Pasco Basin, especially in providing a possible avenue of interconnection between the unconfined and the upper confined aquifer (Gephart et al., 1979a).

A determination of the orientation and spacing of tectonic fractures will be carried out in the Grande Ronde Basalt north of Vantage (Fig. 13-3). The results of this study will provide a semiquantitative basis for assessing the possible impact of such features on near-field repository performance, should they be found in an underground repository. In addition, Yakima fold-belt exposures to the west of the Pasco Basin will be examined to provide additional insight into the possible distribution of strain features within synclinal areas.

Within the reference repository location, geophysical anomalies identified by aeromagnetic and reflection seismic surveys will be assessed. This will include a quantitative interpretation of existing aeromagnetic data and a thorough review of existing seismic reflection surveys. A gridded gravity survey is currently under way. Newly acquired seismic refraction and downhole vertical seismic profile data collected from within the reference repository location will also be used to further evaluate the sources of previously identified geophysical anomalies. Work will include a thorough evaluation of the entire data set to determine whether additional geophysical surveys are required.

To calculate and verify the strike and dip of candidate repository horizons, in support of design specification needs (Kaiser Engineers, Inc./Parsons Brinckerhoff Quade & Douglas, Inc.), borehole RRL-2 was drilled and drilling of DC-16A is in progress (Fig. 13-2). Borehole RRL-2 has increased the predictive accuracy of the structural surface of the reference repository horizon and additionally increased the accuracy of determining fold amplitudes (±3 meters). Boreholes DC-16A, RRL-6, and -14, (Fig. 13-2) have increased predictive accuracy for fold wavelengths to about ±90 meters for folds with limbs dipping greater than 5 degrees.

Work Element S.1.13.B (Priority 1)

Evaluate the type and amount of displacement, geometry (width and continuous length), and age of faults within the Pasco Basin.

Status

Faults mapped in exposed anticlines of the Yakima fold belt include: (1) thrust and reverse faults that strike subparallel to fold axes; and (2) steeply dipping faults that strike oblique to fold axes (Myers/Price et al., 1979). The latter category includes both northwest- and northeast-trending faults that in some places segment anticlines into sections with different cross-sectional geometries. In an area approximately 75 kilometers to the west of the Pasco Basin (Swanson et al., 1979), collective strike/slip displacement (of up to 5 kilometers) has been interpreted for some northwest-trending faults which cross cut the Columbia River Gorge. Based on geometric constraints, basalt offsets of up to 1 kilometer have been estimated along thrust and reverse faults that subparallel anticlinal fold axes (Price, 1982).

Studies to evaluate fault geometries have been limited by the general lack of continuous bedrock exposure. Geophysical surveys conducted within areas of sediment cover have not always been able to distinguish between deformation that could be attributed to faulting and deformation that could be attributed to folding. Hence, fault lengths have been variously interpreted to range from less than 1 kilometer up to several tens of kilometers. Reported widths of fault zones range from less than 1 meter to several tens of meters.

Suprabasalt sediments and volcanics overlying most faults associated with Yakima fold-belt anticlines do not appear to be offset. However, faults that have been interpreted to offset sediments as young as 13,000 years before present (i.e., Quaternary in age) have been located at Toppenish Ridge (located approximately 65 kilometers southwest of the reference repository location) and at Gable Mountain (located approximately 8 kilometers northeast of the reference repository location) (Fig. 13-3). Other faults exposed at Finley Quarry, along the trend of the Cle Elum-Wallula lineament (see Chapter 3), and at Smyrna Bench (Fig. 13-3), have also been interpreted to offset suprabasalt sediments; the age of these sediments is currently being evaluated. A more detailed discussion of faulting within the Pasco Basin area is contained in Section 3.7.2 of this document (also see Table 3-8) and in WPPSS (1981), PSPL (1982), and NRC (1982).

Plans

Additional work will be focused on refining fault parameters supportive of seismic design specifications and preclosure and postclosure performance assessment modeling (including tectonic model development). Such parameters include fault geometry, extent and physical properties of brecciation, and any apparent relationship between width of the fault zone and amount of displacement, age, and slip rate. Fault parameters will be

further evaluated by examining fault exposures at Sentinel Gap, Smyrna Bench, Rattlesnake Mountain, and Snively Basin (Fig. 13-3). An assessment as to whether further insight into fault parameters influencing design could be gained by trenching, geophysical surveys, and shallow drilling will be made following such studies.

A part of the Cle Elum-Wallula lineament, known as the Rattlesnake-Wallula lineament, has been variously interpreted as a through-going fault and as discontinuous faults extending from Rattlesnake Mountain, beneath brachyanticlines (doubly plunging anticlines) to Wallula Gap (Davis, 1981). A recent study by Cochran (1981b), using ground magnetic and gravity techniques, suggests a subsurface structural continuance between two of the brachyanticlines west of Finley Quarry (Fig. 13-3). Further study, following the general method of Cochran (1981b), will be conducted to assess the continuity of faulting associated with this section of the Cle Elum-Wallula lineament (Fig. 13-3). The results of this work, as well as studies discussed in Work Elements S.1.2.B and S.1.4.B, will be factored into an assessment of whether seismic design models for a repository should consider the Cle Elum-Wallula lineament as one continuous fault or as a number of discontinuous faults.

Work Element S.1.14.B (Priority 2)

> Evaluate the relationship of folding and faulting in the Yakima fold belt; evaluate the relationship of Yakima folds to structures that may be present in rocks beneath the Columbia River basalt within the Pasco Basin.

Status

Faults and folds within the Yakima fold belt are assumed to have formed under north-south compression and to be genetically related. However, the causal relationship between folding and faulting is currently the subject of alternate interpretations. Laubscher (1981) has proposed that Yakima folds developed sequentially, as a result of thrust faults ramping upward from a deep-seated décollement. In contrast, Davis (1981) and Price (1982) have contended that folds developed initially and that faults developed as folds began to "lock up." Strike/slip along northwest-trending faults is a key element of models by Bentley (1982), Davis (1981), and Kienle et al. (1977). The geometry of Yakima folds, as well as regional paleomagnetic studies, have also been used to support deformation models that involve tectonic rotation (Beck, 1976; Simpson and Cox, 1977). Further discussion of such models is contained in Section 3.8.2 of this document.

A possible relationship between Yakima fold-belt structures and structures in rocks beneath the Columbia River basalt has been hypothesized by Bentley (1977; 1980), Davis (1977; 1981), and Laubscher (1981). These hypotheses are based primarily on an analysis of the spatial geometry and distribution of surface structures, including those that trend into the plateau from its margins (Swanson et al., 1979; 1980; 1981). Preliminary magnetotelluric data collected within the Pasco Basin suggest

thickening and thinning of the basalt sequence over sedimentary basement with significant relief, indicating that some prebasalt structures may possibly be present (see Section 3.6.4). Additional magnetotelluric data collected within the Pasco Basin is currently being evaluated.

Plans

Studies carried out under this work element will be focused toward distinguishing between the proposed models of Yakima fold-belt deformation and toward evaluating the potential effects such models could have on the pattern of deformation within the Cold Creek syncline and reference repository location over a projected 10,000-year period. A kinematic analysis of the distribution and orientation of strain features in folds, following the general method of Price (1982), will continue (see Chapter 3) along the east and west sides of Sentinel Gap, the west side of Smyrna Bench, Snively Basin, Wallula Gap, and the Horse Heaven Hills area (Fig. 13-3). The results of such work will be used to assess how representative the relationships observed by Price (1982) on Umtanum Ridge are of Yakima fold-belt deformation with the Pasco Basin area. Selected Yakima fold-belt exposures to the west of the Pasco Basin may also be studied.

Kinematic data, in conjunction with paleomagnetic data, will be used to constrain the age of the growth of folds in relation to regional rotation and to assess the role of northeast- and northwest-trending faults (see Work Element S.1.13.B). Such work will be coordinated with similar ongoing studies currently under way by others throughout the Columbia Plateau.

To further evaluate the influence of possible basement structures on basalt deformation, existing magnetotelluric data will be interpreted in conjunction with other geophysical and geologic data. Based on results of these interpretations, additional magnetotelluric data will be obtained, if required, to refine interpretations of previously delineated anomalies.

All available gravity data for the Pasco Basin will be obtained and entered into the BWIP data base, so that areas where additional gravity data may be needed can be defined. Work within the Pasco Basin area will also be compared with data available for structures that trend into the basalt from plateau margins.

Mechanical modeling will be undertaken, as required, to determine the theoretical behavior of the basalt and subbasalt rocks under regional horizontal compression. The theoretical strain style resulting from horizontal compression can be compared with that observed in the field to gain insight into the actual style of deformation. Such a mechanical model has the potential to provide additional information regarding both the relationship of folding to faulting and the extent of basement involvement in Yakima fold formation. Such a model could also be used to predict the style of deformation within synclinal areas under a preselected range of possible future stress regimes. Data provided from

studies conducted under this work element, and Work Elements S.1.11.B, S.1.12.B, and S.1.13.B, will serve as input to the conceptual tectonic model (see Work Element S.1.17.B) and other models that support seismic design and post-waste-emplacement performance assessment efforts.

Work Element S.1.15.B (Related to S.1.13.B, R.1.3.A, and R.1.6.A) (Priority 1)

Evaluate the geologic (long-term) and contemporary rate of deformation and stress field in the Pasco Basin and reference repository location.

Status

Proposed criteria (NRC, 1981) recommend that a repository be located in a tectonically stable area. Because the earth is not static, stability is a function of the tectonic environment and, especially, the rate and location of deformation. Deformation is a vector quantity consisting of both vertical and horizontal components. Within the Pasco Basin, the vertical rate of Miocene strain (deformation) has been approximated using the thickness and distribution of radiometrically dated Saddle Mountains Basalt flows (see Section 3.7.2). The development of structurally controlled topography from 14.5 to 10.5 million years ago suggests that the Saddle Mountains and Rattlesnake Ridge were uplifting at an average rate of 0.03 to 0.05 millimeter per year (Reidel et al., 1980). (Deformation rates along plate boundaries, for comparison, may be several centimeters per year, or approximately 10^2 to 10^3 times greater than those for the Pasco Basin.)

Trenching across the central fault on Gable Mountain (Fig. 13-3) and drilling from the hanging wall through the fault zone indicates decreasing displacement with decreasing age of the strata (PSPL, 1982). Using the age and displacement data, an average displacement of less than 0.01 millimeter per year (horizontal strain) was calculated.

Six surveys of the Hanford trilateration array suggest that nonuniform compression (i.e., horizontal strain) is continuing at contemporary rates of about 0.04 and 0.02 millimeter per year along northeast and northwest axes (Savage et al., 1981). While these survey results barely exceed the limits of resolution of the technique, shortening of most lines indicates horizontal strain at a rate that is in agreement with rates determined on the basis of geologic data. Together with instrumental seismic data, both "geologic" and "contemporary" data sources suggest that deformation has been proceeding at an average low rate of strain over the past 15 million years (Caggiano et al., 1980).

Plans

Further work will be focused on assessing whether deformation has been continuous from 14.5 million years to the present or has occurred in periodic pulses; this work will also include an assessment as to whether such deformation has been basinwide or localized in certain structures

that average to a basinwide low rate of strain. Current estimates of strain rate from 14.5 to 10.5 million years will be supplemented by further examination of basalt flow thickness distributions. The pattern and rate of deformation from 10.5 million years to the present will be estimated from an examination of the distribution and deformation of late Miocene and younger strata, using both outcrop and borehole data. Paleomagnetic analysis of sediments will be continued, particularly of core samples of the Ringold Formation obtained from boreholes drilled within the Cold Creek syncline (see Section 3.5.4) to aid in time-stratigraphic correlations.

Vertical deformation rates obtained from stratigraphic studies will be assessed by further study of fault exposures within and in the vicinity of the Pasco Basin (see Work Element S.1.13.B). Such studies may involve trenching and shallow boreholes across selected faults to provide slip rate data.

Geodetic monitoring will be continued to assess whether deformation is localized, the volume of rock that is deforming, and the stress to which the crust is currently responding. Periodic resurveys of the Hanford trilateration array and newly established triangulation arrays (see Section 3.7.2) will be used to determine the current rate of deformation and whether it is localized along specific structures. Leveling surveys of the Cold Creek syncline will also be run, as required, to determine whether subsidence or uplift is occurring. Geodetic data work will be evaluated with seismic monitoring data (see Work Element S.1.16.B) to further assess the nature of stress and strain within the area. These results will also be evaluated with in situ stress data being gathered under the Repository program (see Chapter 14). All available geologic and geodetic data will be further examined to assess the magnitude and orientation of stress in the reference repository location.

Work Element S.1.16.B (Related to R.1.29 and R.1.30) (Priority 2)

Determine the seismicity of the Pasco Basin and reference repository location.

Status

Seismicity data collected in support of repository design and preclosure and postclosure performance assessment modeling efforts (see Sections 4.2, 4.6, and 12.2.1) include size and frequency of earthquakes, proximity of seismic events, and attendant ground motion. Historic and instrumental monitoring data indicate that the Pasco Basin, which includes the reference repository location, is an area of low seismicity. Historically, few earthquakes have been felt in the Pasco Basin and most of these occurred beyond the margins of the basin (Rasmussen, 1967; WPPSS, 1974). The largest known historic earthquake in the Columbia Plateau is the 1936 Milton-Freewater event, which has been used to develop seismic design for nuclear plants on the Hanford Site (WPPSS, 1981; PSPL, 1982). Recent analysis of sparse records suggests this earthquake was of a 6.1 magnitude, located near Waitsburg, Washington (about 100 kilometers east of the reference repository location) (NRC, 1982).

Instrumental monitoring since 1969 indicates that the area is characterized by low-magnitude earthquakes confined to a thin crust (less than or equal to 30 kilometers) (Malone, 1979). Areas within and along the margins of the Pasco Basin are characterized by apparently diffuse, low-magnitude and moderately deep earthquakes (greater than 8 kilometers in depth) and swarms of shallow (less than 8 kilometers in depth), low-magnitude earthquakes that are spatially and temporally limited. Swarms of microearthquakes (most are less than a magnitude of 2.0) consist of several to several hundred events that occur in limited volumes of rock (less than or equal to 50 cubic kilometers) at depths of up to 3 kilometers over a period of a few days to several months (Malone et al., 1975; Rothe, 1978; Malone, 1979). There is no increase or reduction in size or frequency of events centered about a mainshock. Earthquakes are not known to be associated with mapped geologic structures. The largest earthquake recorded during 12 years of monitoring was a 4.4 magnitude event that occurred on Royal Slope (Fig. 13-3), the limb of a Yakima fold north of the Pasco Basin. Further details of the seismicity of the Columbia Plateau and Hanford Site are contained in Section 3.7.3.

The regional network has been operated for the U.S. Department of Energy by the University of Washington Geophysics Program since 1975. Recently, a downhole seismometer was deployed at the bottom of borehole DC-3 (Fig. 13-2) in the Umtanum flow and a network of 6 three-component seismometers has been deployed at ground surface to supplement the regional monitoring network.

Plans

Regional seismic monitoring by the University of Washington will be continued to confirm the pattern of regional stress release and to ascertain any relationship between geologic structures and seismicity. The extent of monitoring required in the reference repository location to supplement regional monitoring, to support development of seismic design criteria, and to carry out preclosure and postclosure performance assessment modeling is currently being evaluated.

At present, the operation of two supplementary networks within the Pasco Basin will be continued. A fixed baseline network of four stations has been installed at culturally quiet bedrock sites surrounding the reference repository location to improve the location accuracy for proximate events. Additional coverage is being provided by a portable network of six component stations. This network is designed for rapid deployment in the event of significant earthquake swarm activity in other regions of the Pasco Basin and to determine selected parameters of these events. Swarm parameters to be determined with this network include the area of the causative fault, the stress released, and the amount of displacement of the fault surface.

The University of Washington and the BWIP will continue to jointly operate a borehole seismometer as long as deemed appropriate. This instrument is currently deployed in the uncased portion of borehole DC-3 (Fig. 13-2) in the Umtanum flow at a depth of 1,100 meters beneath the

surface. It is designed to provide underground data on ground vibration at repository depths from local earthquakes. These data, in conjunction with surface monitoring data, will be used as input to repository design and preclosure and postclosure performance assessment modeling efforts (see Chapters 14 and 16).

Work Element S.1.17.B (Related to S.1.11.B through S.1.16.B and S.1.23.B) (Priority 1)

Develop a conceptual model that can be used to evaluate the past, present, and projected tectonic setting of the reference repository location.

Status

A tectonically stable area is one in which the present and projected rates of tectonic processes are considered not to pose a hazard to repository construction and operation or to the long-term isolation of radioactive waste. Adequate definition of tectonic processes and their rates of operation requires development of a conceptual tectonic model. A tectonic model is a nonnumerical descriptive theory that incorporates geologic, geophysical, seismologic, and geodetic data into a satisfactory explanation of the dynamic development of geologic structures. For the Pasco Basin region, such a model must be compatible with the plate tectonic setting of the Pacific Northwest, which assumes an eastward-directed subduction of the Juan de Fuca Plate beneath the North American Plate (Riddihough and Hyndman, 1976). Current tectonic models with specific application to the Pasco Basin and the reference repository location are summarized in Section 3.8.2. The applicability of the several models proposed for Yakima fold-belt deformation is currently under evaluation.

Plans

Investigations that may provide a basis for model distinction have been discussed under Work Elements S.1.11.B through S.1.16.B. Results of these investigations, as well as the results of investigations conducted by others in the Columbia Plateau, will be continually assessed and integrated.

Available models will be evaluated in terms of their impact on preclosure and postclosure repository performance. If the anticipated effects of all or a number of models can be shown not to jeopardize repository performance, then it may not be necessary to distinguish between model applicability.

Work Element S.1.18.B (Included in S.1.12.B, S.1.13.B, and S.1.14.B) (Priority 1)

Determine the presence of active faults within the geologic setting; evaluate their rupture length.

Status

Included in Work Elements S.1.12.B, S.1.13.B, and S.1.14.B.

Plans

Included in Work Elements S.1.12.B, S.1.13.B, and S.1.14.B.

Work Element S.1.19.B (Included in S.1.12.B and S.1.13.B) (Priority 1)

Determine if Quaternary faulting is present within the disturbed zone.

Status

Included in Work Elements S.1.12.B and S.1.13.B.

Plans

Included in Work Elements S.1.12.B and S.1.13.B.

Work Element S.1.20.B (Included in S.1.12.B through S.1.16.B) (Priority 1)

Determine the presence of faults of any age within the disturbed zone; determine the potential for movement along existing faults and fractures within the disturbed zone; determine the potential for generation of new faults and fractures within the disturbed zone.

Status

Included in Work Elements S.1.12.B, S.1.13.B, S.1.14.B, S.1.15.B, and S.1.16.B.

Plans

Included in Work Elements S.1.12.B, S.1.13.B, S.1.14.B, S.1.15.B, and S.1.16.B.

Work Element S.1.21.B (Included in S.1.11.B, S.1.12.B, and S.1.15.B) (Priority 1)

Evaluate the nature of structural deformation such as uplift, subsidence, folding, and fracturing during the Quaternary Period.

Status

Included in Work Elements S.1.11.B, S.1.12.B, and S.1.15.B.

Plans

Included in Work Elements S.1.11.B, S.1.12.B, and S.1.15.B.

Work Element S.1.22.B (Included in S.1.16.B) (Priority 1)

Determine if earthquakes are correlatable with tectonic processes and/or features within the reference repository location; if correlatable, predict the frequency and magnitude of future events.

Status

Included in Work Element S.1.16.B.

Plans

Included in Work Element S.1.16.B.

Work Element S.1.23.B (Related to S.1.17.B) (Priority 3)

Determine the nature of igneous activity within the Pasco Basin area.

Status

Surface and subsurface geologic mapping have delineated to a high degree of confidence the surface distribution of volcanic units and structures in the site area and the Columbia Plateau. Subsurface distributions and continuity of volcanic structures and strata are known, based on geologic inference from surface exposures and drill hole logs.

Characterization of the Saddle Mountains and Wanapum Basalts by means of trace- and major-element chemical analyses, optical petrography, electron microprobe, and radiometric geochronology (Reidel et al., 1980; Asaro et al., 1978) has provided extensive information for utilization in analysis of the nature and origin of Columbia Plateau volcanism. Analogous data for Grande Ronde Basalts currently is appreciably more limited. Present knowledge of terrestrial heat flow in the Columbia Plateau and site area is based on published data (Blackwell, 1978; Korosec and Schuster, 1980) and thermal measurements made in conjunction with hydrologic testing of Hanford Site wells by subcontractors to Rockwell.

Based on the information outlined above, plus published eruptive-history data for volcanism in the adjacent Cascade Range and Basin and Range provinces, the means exist to predict occurrence potential for future igneous events that may affect the Pasco Basin (Johnpeer et al., 1981; Murphy and Johnpeer, 1981). Future time intervals equivalent to prerepository closure (100 years) and postclosure (10,000 years) have been considered. See Section 3.7.2, for a more detailed discussion of an evaluation of the volcanic setting of the Pasco Basin.

Plans

Measurements of geothermal gradients in hydrologic test wells and laboratory determination of thermal conductivity of formational-rank site area basalt units will be used to better assess heat flow within the Pasco Basin.

ISSUE S.1.C

Are the pre-waste-emplacement groundwater travel times near the repository sufficient to assure compliance with the U.S. Nuclear Regulatory Commission proposed technical criteria?

Following the thermal loading period of the repository, groundwater movement in the general vicinity of the repository is expected to return to near pre-waste-emplacement conditions. These conditions will prevail for the life of the repository and its contents, providing no geologic disruptions take place to significantly alter the groundwater flow paths or travel times. Therefore, a reasonable understanding of the present groundwater system and that which can be postulated to occur is needed to model long-term groundwater movement. Hydrologic information requiring definition includes the flow system's physical properties (e.g., hydraulic conductivity and effective porosity), hydraulic heads, and the groundwater's hydrochemistry.

While hydrologic characteristics determine the amount of groundwater present, the geologic setting defines the occurrence and distribution of this groundwater. Geologic information needed for understanding groundwater movement includes the location and physical character of major structures, stratigraphy, and intraflow lithology.

Numerical models are developed for predicting groundwater movement and for refining the conceptual groundwater model and identifying additional data needs. An iterative process exists between data collection and numerical modeling to assure that sufficient data are available for confidence in the modeling results.

Work elements that relate to Issue S.1.C are discussed below; a tabulation of the contents of this discussion is contained in Table 13-4.

Work Element S.1.24.C (Related to S.1.30.C, S.1.33.C, S.1.34.C, S.1.38.D, S.1.39.D, S.1.40.D, and S.1.51.D) (Priority 1)

Determine the hydraulic properties of the groundwater flow system.

TABLE 13-4. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.C. (Sheet 1 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.24.C (Related to S.1.30.C, S.1.33.C, S.1.34.C, S.1.38.D, S.1.39.D, S.1.40.D, and S.1.51.D) Determine the hydraulic properties of the groundwater flow system.	Hydraulic properties across selected interbeds, flow tops, and columnar zones. Properties include: • Hydraulic conductivity (horizontal in interbeds and flow tops and horizontal plus vertical in columnar zones) • Storativity (principally in interbeds and flow tops) • Effective porosity (flow tops and columnar zones) • Dispersivity (flow tops).	Hydraulic tests will be conducted in selected intervals of Saddle Mountains, Wanapum, and Grande Ronde Basalts in the following combination of existing and new boreholes: • Single, dual, and cluster borehole testing within and immediately surrounding the reference repository location boreholes DC-5, -16A,B,C, RRL-2, -6, and -14) • Single and dual borehole testing within the Cold Creek syncline either near the reference repository location or along the groundwater flow paths (DC-1/2, -7/8, -12, -15, DB-1, -2, -4, -5, -7, -10, -11, -13, -14, -15, -18, O'Brian, Ford, Enyeart, McGee, DH-8/8A, WW-6, and Benson) • Single borehole testing in areas surrounding the Cold Creek syncline (DC-6, -14, DH-4, -5, RSH-1, 699-92-14, and 699-113-33). Specific property to be tested depends on the test interval's stratigraphic location and the age and areal location of boreholes. Portholes and possible room-scale testing within the exploratory shaft.	Measurements of horizontal hydraulic conductivity and storativity are specified in Gephart et al. (1979a; 1979b) and Sections 5.1.3 and 5.2.1 of this document. Presently, estimates are used for vertical hydraulic conductivity, effective porosity, and dispersivity.
S.1.25.C (Related to S.1.27.C, S.1.28.C, S.1.29.C, S.1.30.C, S.1.33.C, S.1.36.C, S.1.39.C, S.1.40.D, S.1.41.D, S.1.45.D, and S.1.51.D) Determine the hydraulic heads of the groundwater flow systems.	Potentiometric maps for selected sedimentary interbeds and flow tops in the Columbia River basalts. (Emphasis will be on constructing detailed potentiometric maps for the area of and immediately surrounding the reference repository location; more generalized maps will be developed for the Cold Creek syncline and adjacent areas.)	Fixed point-in-time as well as time variant measurement of hydraulic heads will be taken across selected sedimentary interbeds and flow tops in the Columbia River basalts in the following combination of existing and new boreholes:	Available potentiometric maps and vertical head patterns are specified in Gephart et al. (1979a) and Sections 5.1.4 and 5.2.2 of this document.

TABLE 13-4. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.C. (Sheet 2 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
		• Boreholes within and immediately surrounding the reference repository location (DC-4/5, -16A,B,C, RRL-2, -6, and -14) • Boreholes within the Cold Creek syncline either near the reference repository location or along the groundwater flow path (DC-1/2, -7/8, -12, -15, DB-1, -2, -4, -5, -7, -10, -11, -13, -14, -15, DC-18, BH-17, McGee, DH-8/8A, WW-6, and Benson) • Boreholes in areas surrounding the Cold Creek syncline (DC-6, -14, DH-4/5, RSH-1, 699-92-14, and 699-133-33). Specific horizons for head measurements depend on rock hydraulic conductivity and borehole conditions. Portholes within the exploratory shaft.	
S.1.26.C (Related to S.1.27.C, S.1.28.C, S.1.29.C, S.1.30.C, S.1.33.C, S.1.34.C, S.1.39.D, S.1.40.D, R.1.34, R.1.36, R.1.63, R.1.64, R.1.65, W.2.1.A, W.2.2.A, W.2.4.A, W.2.5.A, and W.2.13.D) Determine the hydrochemistry of the basalt groundwater system.	Fixed-point as well as time-variant characteristics of groundwater chemistries of selected sedimentary interbeds and flow tops in the Columbia River basalts. (Emphasis will be placed on evaluating groundwater hydrochemistry within and adjacent to the reference repository location; hydrochemical data for areas more distant will support evaluation of the overall hydrology of the reference repository location). Determinations include: • Mass chemistry • Trace elements • Dissolved gases • Stable isotopes • Radioactive isotopes.	Groundwater samples collected from selected zones in the Saddle Mountains, Wanapum, and Grande Ronde Basalts, from existing and new boreholes listed under Work Element S.1.25.C. Suite of analyses possible will be dependent upon borehole conditions. Sampling from portholes drilled from the exploratory shaft. Reasonable technical consensus on groundwater chemistry data and models through peer review.	Summary of available hydrochemical data is included in Gephart et al. (1979a) and Sections 5.1.5, 5.1.6, and 5.2.3 of this document. Detailed hydrochemical information for each of the principal basalt formations is in preparation.

TABLE 13-4. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.C. (Sheet 3 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.27.C (Related to S.1.7.A, S.1.9.A, S.1.12.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.30.C, and S.1.33.C) Determine the geometry of and interaction between the confined flow systems.	Information needs on hydraulic interactions: • Hydraulic heads • Hydraulic interactions • Hydrochemistry	See Mandatory measurement conditions under Work Elements S.1.24.C, S.1.25.C, and S.1.26.C.	Summary references on the geologic setting of the Hanford Site and area are found in Myers/Price et al. (1979), Myers and Price, (1981), and Chapter 3 of this document. Information on the hydraulic interaction between flow systems is contained in Gephart et al. (1979a) and Section 5.1.7 of this document.
	• Geometry of flow system as defined by the geologic setting (i.e., structure, stratigraphy basalt intraflow characteristics).	See Mandatory measurement conditions under Work Elements S.1.7.A, S.1.9.A, and S.1.11.B.	
	Integration of combined hydrogeologic data base and quantification of the geometry and hydraulic interaction between flow systems using numerical modeling.	Determine pre-waste-emplacement travel times from the repository location to the accessible environment.	
S.1.28.C (Related to S.1.4.A, S.1.7.A, S.1.8.A, S.1.10.A, S.1.11.B, S.1.12.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.30.C, S.1.31.C, and S.1.51.D) Determine the extent of vertical groundwater movement between the confined, unconfined, and surface water systems.	Vertical hydraulic conductivity values.	Ratio-type tests in boreholes DC-1/2, -4/5, -7/8, and -16A,B,C.	Hydrologic data addressing suspected or known areas of vertical groundwater movement are summarized in Gephart et al. (1979a) and Section 5.1.7 of this document. Information regarding intraflow structures and structurally complex areas is contained in Myers/Price et al. (1979), Myers and Price (1981), and Section 3.7.2 of this document.
	Location of structures (folds, faults, and fractures) intraflow structures and other potentially permeable zones within and adjacent to the reference repository location.	See Mandatory measurement conditions under S.1.4.A, S.1.7.A, S.1.8.A, S.1.10.A, and S.1.11.B.	
	Comparisons of geologic data with hydraulic properties, hydraulic heads, and hydrochemistries of flow systems.	See Mandatory measurement conditions under S.1.24.C, S.1.25.C, and S.1.26.C.	
	Evaluation of the extent and possible locations of vertical groundwater exchange between groundwater systems, based on numerical modeling.	See Mandatory measurement conditions under S.1.33.C.	

TABLE 13-4. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.C. (Sheet 4 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.29.C (Related to S.1.7.A, S.1.11.B, S.1.12.B, S.1.17.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, S.1.33.D, and S.1.41.D) Determine the hydrologic characteristics and influences of structure and stratigraphic discontinuities that may shorten groundwater flow paths and solute transport times.	Characterization of the reference repository location and vicinity including: • Assessment of the influence of known and suspected structures • Definition of far-field boundary conditions along the Saddle Mountains • Location and geologic characteristics of structures and stratigraphic discontinuities • Evaluation of groundwater-flow paths and solute transport times based on numerical modeling.	Testing of McGee well and boreholes RRL-14, BH-17, 699-92-14, and 699-113-33. Testing of rehabilitated boreholes DH-4 and -5. For description of above tests, see Information needs and Mandatory measurement conditions under S.1.24.C, S.1.25.C, and S.1.26.C. See Information needs and Mandatory measurement conditions under S.1.7.A and S.1.11.B. See Information needs and Mandatory measurement conditions under S.1.33.C and S.1.41.D.	Hydrologic data pertaining to local structure and stratigraphic discontinuities is included in Myers/Price et al. (1979), Myers and Price (1981), Gephart et al. (1979a), and Sections 3.7.2 and 5.1.7 of this document.
S.1.30.C (Related to S.1.7.A, S.1.9.A, S.1.11.B, S.1.12.B, S.1.17.B, S.1.24.C through S.1.29.C, and S.1.31.C) Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models.	Basin hydrogeologic elements that serve as input to conceptually model the groundwater flow system (with emphasis directed at understanding the groundwater system within and surrounding the reference repository location, particularly near the candidate repository horizons). These elements are: • Physical hydraulic characteristics • Flow system geometry • Groundwater budget (water content)	Hydrologic testing; for description of testing see Information needs and Mandatory measurement conditions under Work Elements S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, and S.1.29.C.	Conceptual models have been developed as presented in Section 5.1.10 of this document. Models developed for the Hanford Site and surrounding area are also reported in La Sala et al. (1972), Summers et al. (1978), and Dove et al. (1981).

TABLE 13-4. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.C. (Sheet 5 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	• Surface/groundwater interactions • Groundwater circulation within and between flow systems • Influence of structure and stratigraphic discontinuities • Flow directions • Recharge/discharge areas		
	• Geologic characteristics of the Pasco Basin, particularly of the reference repository location and candidate repository horizons	See Information needs and Mandatory measurement conditions under Work Elements S.1.7.A, S.1.9.A, S.1.11.B, and S.1.17.B.	
	• Identification of areas of additional or refined data needs using numerical modeling results.	See Information needs and Mandatory measurement conditions under Work Element S.1.31.C.	
S.1.31.C (Related to S.1.30.C, S.1.33.C, S.1.34.C, S.1.38.D, and S.1.39.D) Develop and/or modify numerical codes that adequately simulate groundwater flow, natural hydrochemical species transport, and travel times under pre-waste-emplacement conditions.	Porous-media groundwater flow codes that exhibit the following characteristics: • Isothermal • Up to three-dimensional • Both flux and head boundary conditions • Heterogeneous and anisotropic • Complex geometry • Transient and steady state. Pathline/streamline code that receives input from groundwater flow model to calculate groundwater velocity, pathlines (transient conditions), streamlines (steady-state conditions), and travel times. Verification and benchmarking of major codes.	Not applicable.	Several codes are available that collectively satisfy requirements (see Section 12.3.2 of this document). Verification and benchmarking of codes are under way.

TABLE 13-4. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.C. (Sheet 6 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.32.C (Included in S.1.41.D) Evaluate the ranges of relevant hydrogeologic conditions since the start of the Quaternary Period.	Included in S.1.41.D.	Included in S.1.41.D.	Included in S.1.41.D.
S.1.33.C (Related to S.1.30.C, S.1.31.C, S.1.34.C, S.1.37.D, S.1.39.D, and S.1.41.D) Using selected models, predict groundwater travel time from the repository location to the accessible environment under pre-waste-emplacement conditions.	Adequate conceptual hydrologic model (see Information needs under S.1.30.C). Adequate numerical codes (see Information needs under S.1.31.C). Definition and establishment of model scale consistent with U.S. Environmental Protection Agency's (EPA, 1981) draft definition of the accessible environment.	See Information needs and Mandatory measurements conditions under S.1.24.C, S.1.25.C, and S.1.26.C.	Several preliminary studies of groundwater travel time within the Hanford Site have been completed (see Section 12.4 of this document). All analyses to date show that pre-waste-emplacement groundwater travel times to the accessible environment exceed 1,000 years (i.e., meet the proposed criteria specified by 10 CFR 60 (NRC, 1981)).
	Calculation of groundwater travel time through application of data and models.	Reasonable technical consensus of groundwater travel time determinations through peer review of data and models.	Full technical consensus on flow paths and travel times has not yet been reached.
S.1.34.C (Related to S.1.24.C, S.1.25.C, S.1.26.C, S.1.30.C, S.1.31.C, and S.1.33.C) Determine the bounds of uncertainty in model predictions of pre-waste-emplacement groundwater travel time.	Adequate conceptual hydrologic model (see Information needs under S.1.30.C). Identification of important parameters from a waste isolation standpoint through a model parameter and sensitivity analysis.	See Information needs and Mandatory measurement conditions under S.1.24.C, S.1.25.C, and S.1.26.C.	Preliminary conceptual hydrologic model available (see S.1.30.C and Section 5.1.10 of this document). Parameter and sensitivity study under way (see Section 12.4 of this document); preliminary Kriging analysis completed (Oston and Hunt, 1982).
	Stochastic analysis of the groundwater flow system and travel times.	Reasonable technical consensus of groundwater travel time determinations through peer review of data and models (see S.1.33.C).	Technical consensus on flow paths and travel times has not yet been fully attained.
S.1.35.C (Included in S.1.30.C) Determine the groundwater content of the host rock.	Included in S.1.30.C.	Included in S.1.30.C.	Included in S.1.30.C.
S.1.36.C (Included in S.1.30.C) Determine the nature of groundwater circulation in the host rock.	Included in S.1.30.C.	Included in S.1.30.C.	Included in S.1.30.C.

Status

Currently, approximately 140 measurements of equivalent hydraulic conductivity across individual sedimentary interbeds and flow tops are available from testing in boreholes on the Hanford Site. The number of measurements is approximately evenly divided between the Saddle Mountains, Wanapum, and Grande Ronde Basalts. Most of these tests are from small-diameter (approximately 7.6 centimeters) single boreholes. In addition, a number of measurements of equivalent hydraulic conductivity have been conducted in columnar basalts, mostly within the Grande Ronde Basalt. Some 20 estimates of storativity are available. The most reliable of these values are from dual borehole testing. Tracer tests within boreholes are now under way to calculate effective porosities and dispersivities.

The above data are principally concentrated within the Cold Creek syncline, with some information available along or north of the Umtanum Ridge-Gable Mountain anticline. A limited number of hydraulic properties within the Columbia River basalts are presently available in the reference repository location.

Plans

The primary emphasis in data gathering will be to obtain representative values of hydraulic conductivity, principally values within individual flow tops of the Grande Ronde and Wanapum Basalts, in addition to vertical values within the repository horizon and surrounding flows. Hydraulic conductivity is a critical measurement because it is a primary input parameter for calculations of groundwater velocity and is known to vary stratigraphically over several orders of magnitude.

Interstitial groundwater velocity is also inversely proportional to the rock's effective porosity. No in situ effective porosity measurements are currently available. Values are expected to range, however, between 10 to less than 1 percent. Because dispersivity enters only into transport modeling and has an apparently smaller variability compared to other field parameters, its determination is, at this time, less critical than hydraulic conductivity or effective porosity. Typical dispersivity values reported in the literature are 1 to 100 meters.

Storativity does not enter into steady-state flow or transport calculations. Therefore, it is assigned a greater importance than dispersivity but less than the hydraulic conductivity or effecrive porosity. Storativity is calculated form data collected during hydraulic conductivity testing. Field data indicate that Grande Ronde storativity varies between 3 orders of magnitude (i.e., 10^{-3} to 10^{-6}).

Determinations of hydraulic properties needed for site characterization will be accomplished using the following approach (BWIP, 1982a; 1982c); this approach will rely on both single and multiple borehole testing under both high- and low-induced stresses:

(1) Single, dual, and cluster borehole testing within and immediately surrounding the reference repository location (Fig. 13-2):

- DC-4/5 (deepen existing DC-5 hole in Grande Ronde Basalt)
- DC-16A, B, and C (new holes in Saddle Mountains, Wanapum, and Grande Ronde Basalts)
- RRL-2
- RRL-6 (new hole into Grande Ronde Basalt)
- RRL-14 (new hole into Grande Ronde Basalt)
- Portholes and possible room-scale testing within the exploratory shaft.

(2) Single and dual borehole testing within the Cold Creek syncline either near the reference repository location or along the groundwater flow path (Fig. 13-2).

- DC-1/2, -7/8, -12, and -15 (existing holes in Grande Ronde Basalt)
- DB-1, -2, -4, -5, -7, -10, -11, -13, -14, and -15 (existing holes in lower Saddle Mountains and Wanapum Basalts)
- DC-18 (planned hole in Saddle Mountains, Wanapum, and Grande Ronde Basalts)
- BH-17 (deepen existing hole through Saddle Mountains and into upper Wanapum)
- O'Brian, Ford, and Enyeart wells (existing holes in upper Wanapum Basalt)
- McGee well (deepen existing hole through Wanapum Basalt into Grande Ronde Basalt)
- DH-8/8A* (lower Saddle Mountains Basalt)
- WW-6* (Saddle Mountains, Wanapum, and Grande Ronde Basalts)
- Benson well* (Wanapum and Grande Ronde Basalts).

*Testing if rehabilitation of existing hole is possible.

(3) Single borehole testing in areas surrounding the Cold Creek syncline (Fig. 13-2):

- DC-6 and -14 (existing holes in Wanapum (DC-14) and Grande Ronde (DC-6 and DC-14) Basalts)
- DH-4 and -5* (existing holes cased deep into Grande Ronde Basalt; rehabilitate that portion in the Wanapum and Grande Ronde Basalts)
- RSH-1* (existing hole open to Wanapum and Grande Ronde Basalts; rehabilitate)
- 699-92-14* (existing hole into upper Wanapum Basalt; rehabilitate)
- 699-113-38* (existing hole into upper Wanapum Basalt; rehabilitate).

The primary locations for tracer testing in the determination of effective porosity and dispersivity are at the dual or cluster borehole sites and also within the exploratory shaft.

The depth of testing in the above boreholes is site specific; testing depths will vary from a few hundred to about 1,500 meters below ground level (BWIP, 1982a; 1982c).

The results from these testing activities will be continuously input to the modeling studies of groundwater flow and solute transport. Any additional data needs will be established by an iterative process between data collection and modeling confidence.

Work Element S.1.25.C (Related to S.1.27.C, S.1.28.C, S.1.29.C, S.1.30.C, S.1.33.C, S.1.36.C, S.1.39.D, S.1.40.D, S.1.41.D, S.1.45.D, and S.1.51.D) (Priority 1)

Determine the hydraulic heads of the groundwater flow systems.

Status

A potentiometric map has been constructed for the Mabton interbed within the Cold Creek syncline and surrounding area. These head data suggest that groundwater flow from the reference repository location in the upper basalts may be north toward a hydraulic low near the Umtanum Ridge-Gable Mountain anticline or southeast along the Cold Creek syncline (Fig. 13-3). Additional head data within and adjacent to the reference repository location will resolve this question. Since data are presently

*Testing if rehabilitation of existing hole is possible.

too sparse to develop potentiometric maps for the Wanapum or Grande Ronde Basalts, it is unknown whether or not the above-mentioned hydraulic low extends into the deeper basalts or what the specific direction of groundwater movement is in the deep basalts. Evidence suggests an easterly to southeasterly flow direction, although this conclusion needs further confirmation.

Vertical head profiles are available from eight boreholes in the Saddle Mountains Basalt and four boreholes in both the Wanapum and Grande Ronde Basalts. These data suggest that the shallow basalts are locally recharged; essentially, no head gradient exists in the Wanapum Basalt and a slight upward gradient characterizes the Grande Ronde. However, the areal and vertical heads within and immediately adjacent to the reference repository location are extrapolated from boreholes farther away. In addition, the areal and stratigraphic extent of the high artesian pressures existing in the Cold Creek Valley (seen in the McGee, O'Brian, Ford, and Enyeart wells in Fig. 13-2), just west of the reference repository location, is not yet known.

Plans

Measurement of additional hydraulic heads for site characterization will take place using three sets of new and existing boreholes outlined below (BWIP, 1982a; 1982c).

(1) Boreholes within and immediately surrounding the reference repository location (Fig. 13-2):

- DC-4/5 (deepen existing DC-5 hole in Grande Ronde Basalt)
- DC-16A, B, and C (new holes in Saddle Mountains, Wanapum, and Grande Ronde Basalts)
- RRL-2
- RRL-6 (new hole into Grande Ronde Basalt)
- RRL-14 (new hole into Grande Ronde Basalt)
- Portholes within the exploratory shaft.

(2) Boreholes within the Cold Creek syncline either near the reference repository location or along the groundwater flow path (Fig. 13-2):

- DC-1/2, -7/8, -12, and -15 (existing holes in Grande Ronde Basalt)
- DB-1, -2, -4, -5, -7, -10, -11, -13, -14, and -15 (existing holes in lower Saddle Mountains and Wanapum Basalts)

- DC-18 (planned hole in Saddle Mountains, Wanapum, and Grande Ronde Basalts)

- BH-17 (deepen existing hole through Saddle Mountains and into upper Wanapum Basalts)

- McGee well (deepen existing hole through Wanapum Basalt into Grande Ronde Basalt)

- DH-8/8A (existing hole to lower Saddle Mountains Basalt; rehabilitate)

- WW-6 (existing hole open from lower Saddle Mountains Basalt into Grande Ronde Basalt; rehabilitate)

- Benson well (existing hole open from Wanapum Basalt to upper Grande Ronde Basalt; rehabilitate).

(3) Boreholes in areas surrounding the Cold Creek syncline (Fig. 13-2):

- DC-6 and -14 (existing holes in Wanapum (DC-14) and Grande Ronde (DC-6 and -14) Basalts)

- DH-4, and -5 (existing holes cased deep into Grande Ronde Basalt; rehabilitate that portion in the Wanapum and Grande Ronde Basalts)

- RSH-1 (existing hole open to Wanapum and Grande Ronde Basalts; rehabilitate)

- 699-92-14 (existing hole into lower Wanapum Basalt; rehabilitate)

- 699-113-38 (existing hole into lower Wanapum Basalt; rehabilitate).

It is recognized that head measurements in existing holes or those identified for rehabilitation will have an associated higher uncertainty as opposed to measurements acquired in new holes. Nonetheless, these data can be very valuable to the overall hydrologic assessment.

Head measurements will be input to the modeling studies of groundwater flow and solute transport. Any additional data needs or refinement will be established through an iterative process of data collection and modeling.

Additionally, an assessment of the need to measure the time variant behavior of hydraulic head in each of the principal hydrogeologic units is currently being made.

Work Element S.1.26.C (Related to S.1.27.C, S.1.28.C, S.1.29.C, S.1.30.C, S.1.33.C, S.1.34.C, S.1.39.D, S.1.40.D, R.1.34, R.1.63, R.1.64, R.1.65, W.2.1.A, W.2.2.A, W.2.4.A, W.2.5.A, and W.2.13.D) (Priority 1)

Determine the hydrochemistry of the basalt groundwater system.

Status

Hydrochemical data can be utilized to provide a wide range of hydrologic information. This includes rock/water interactions, groundwater travel times and ages, origin and source of groundwater, flow patterns, aquifer intercommunication flow system geometry, and groundwater/surface water relationships. Hydrochemical data analyzed include the principal cations and anions, trace elements, dissolved gases, and stable and radioactive isotopes. These data are valuable in understanding the groundwater system because they preserve the only long-term evidence of groundwater movement, occurrence, and history. The dissolved gas data, particularly methane analyses, can also be used to estimate ventilation needs within a repository. Additional hydrochemical analyses (e.g., potential complexing agents and Eh or indicators of Eh) are discussed in Chapter 15.

Approximately 80 representative groundwater samples from the Columbia River basalts have been collected and analyzed. The data collection points and overall analysis results are reported in Sections 5.1.5 and 5.2.3. The most reliable data have been gathered from new boreholes as samples were obtained during coring operations. Areal hydrochemistry is available for the Mabton interbed of the lower Saddle Mountains Basalt and to a lesser extent the Priest Rapids Member of the upper Wanapum Basalt. A vertical definition of hydrochemistry is completed in eight Saddle Mountains, four Wanapum, and four Grande Ronde Basalt boreholes. These data suggest that with increasing depth, the groundwater system contains distinct chemical and isotopic breaks, is progressively older, and is characterized by longer flow paths with no apparent significant vertical mixing except possibly near highly folded or faulted areas such as the Umtanum Ridge-Gable Mountain anticline (Fig. 13-3). Vertical groundwater leakage across basalt layers is recognized. The extent of such leakage depends on the vertical transmissivity of the dense interiors of individual basalt layers, which has not yet been quantified. This information is principally concentrated in the Cold Creek syncline with limited data from the surrounding area.

Plans

Groundwater sampling supporting site characterization will take place using three sets of new and existing boreholes plus sampling from portholes drilled from the exploratory shaft. The details regarding these boreholes are included in Work Element S.1.1.C.

Acquiring representative groundwater samples from existing boreholes can be difficult because of previous groundwater mixing. Therefore, it is recognized that water samples from existing holes will have more uncertainty associated with their analyses, especially those chemical constituents present in trace quantities (e.g., isotopes). However, these data are still valuable. As hydrochemical data are acquired in the abovementioned boreholes and modeled, they will be used to refine the conceptual model of the groundwater system, particularly as related to the hydrology and hydrologic setting of the reference repository location. Additional data needs such as sampling for potential complexing agents and Eh or Eh indicators will be satisfied so as to understand the groundwater system within the confidence limits needed for assuring waste isolation. A peer review of hydrochemical data and modeling results will be used to obtain a reasonable technical consensus on the nature of the groundwater chemistry and its input into conceptual model development.

Work Element S.1.27.C (Related to S.1.7.A, S.1.9.A, S.1.12.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.30.C, and S.1.33.C) (Priority 1)

Determine the geometry of and interaction between the confined flow systems.

Status

The geologic framework of the basalts in which the confined groundwater systems exist is described under Work Elements S.1.1.A through S.1.10.A and S.1.11.B through S.1.17.B. The principal groundwater flow paths are in sedimentary interbeds and flow tops. The high density, low porosity, and low transmissivity columnar zones of individual flows act as aquitards. Separate flow systems appear to occur in the basalts. The upper system recharges and discharges locally and contains relatively young and isotopically light groundwaters. The deep groundwater system contains isotopically heavier and older groundwater, has high total-dissolved solids, and has an overall chemistry distinct from the overlying groundwater system(s).

No directly detectable hydraulic interactions appear to take place between these systems, even adjacent to the Columbia River. Hydraulic communication may occur along the Umtanum Ridge-Gable Mountain anticline (Fig. 13-3). Groundwater mixing between different flow systems may occur near such anticlines where tight folding and/or faulting has likely resulted in increased vertical fracturing compared to a nondeformed area.

Plans

Some of the primary input into further defining the geometry and hydraulic interactions of the flow systems will be through a drilling and testing program. This plan calls for hydrologic data gathering (hydraulic properties, heads, and hydrochemistry) in new and existing boreholes within and near the reference repository location and within and surrounding the Cold Creek syncline. These data, combined with the stratigraphic

and structural mapping identified in Work Elements S.1.11.B through S.1.17.B, should permit a reasonable understanding of the geometry and hydraulic interaction between flow systems as required for waste isolation.

Results from these studies will be input to the modeling studies (Work Elements S.1.30.C through S.1.34.C). Any additional data needs will be established through an iterative process of data collection and modeling.

Work Element S.1.28.C (Related to S.1.4.A, S.1.7.A, S.1.8.A, S.1.10.A, S.1.11.B, S.1.12.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.30.C, S.1.31.C, and S.1.51.D) (Priority 1)

Determine the extent of vertical groundwater movement between the confined, unconfined, and surface water systems.

Status

Vertical groundwater movement preferentially takes place in areas having higher vertical transmissivities, where tight folding and faulting have likely fractured the basalt, creating vertical flow paths (conduits) (see Work Element S.1.11.B). These fractures are in addition to the primary fractures formed in the basalts from cooling and shrinkage of the original molten rock (see Work Elements S.1.4.A and S.1.8.A).

Existing hydrochemical evidence suggests that separate groundwater systems appear to exist beneath the Hanford Site with minimal groundwater mixing except along localized areas even though artesian conditions are known to exist in portions of the Pasco Basin.

Plans

The quantification of vertical mixing will be addressed through both data gathering and numerical modeling. Ratio-type tests for determining vertical hydraulic conductivity are planned in DC-1/2, -4/5, -7/8, and DC-16A,B,C (Fig. 13-2). At these sites, borehole separations vary from about 10 meters to several hundred meters. In addition, large-scale (covering several square kilometers) determinations of vertical hydraulic conductivity will be attempted in the Cold Creek Valley (Fig. 13-3). Groundwater samples will be collected in selected boreholes (see Work Element S.1.26.C). In addition, vertical hydraulic conductivity testing will be undertaken within the exploratory shaft. Hydrochemical data can also provide direct evidence of groundwater mixing.

Estimates of vertical conductivities will be input to the modeling studies to simulate and refine groundwater flow directions and rates. Hydrochemical modeling will also be performed to better define the interaction between shallow and deep flow systems. Data needs will be continuously updated through an iterative process of data collection and numerical modeling.

Work Element S.1.29.C (Related to S.1.7.A, S.1.11.B, S.1.12.B, S.1.17.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, S.1.33.D, and S.1.41.D) (Priority 1)

Determine the hydrologic characteristics and influences of structure and stratigraphic discontinuities that may shorten groundwater flow paths and solute transport times.

Status

The status of this work element is principally included in the above-referenced work elements. Evidence suggests that a hydraulic low may exist along the axis of the Umtanum Ridge-Gable Mountain anticline with a large difference in head gradient north of the anticline as compared to south. There is also an indication from hydrochemical data of possible shallow and deep groundwater mixing near this anticline. In addition, a 150-meter head decrease occurs in the upper Wanapum Basalt across the Cold Creek Valley structure. Geophysical data suggest that a north-south-trending structure crosses the Cold Creek Valley. The drop in hydraulic head occurs across this structure.

Stratigraphic discontinuities, such as flow pinchouts, could also disrupt or change local groundwater patterns by creating a vertical conduit or barrier along the flow front. Over large areas, the hydraulic influence of a single flow front would probably be inconsequential, but multiple fronts may permit some vertical groundwater movement. No known hydrologic influence from stratigraphic discontinuities has been detected to date.

Plans

Structural influences will be evaluated through the use of new or existing boreholes. Such work includes deepening of the existing McGee well and drilling a new borehole, RRL-14 (under construction). These wells are located on the west and east side, respectively, of the Cold Creek Valley structure (Fig. 13-2). Borehole DC-18 is sited near the axis of the Umtanum Ridge-Gable Mountain anticline (Fig. 13-2). Information from this borehole will help evaluate the potential of vertical groundwater mixing. North of this anticline and near the Columbia River, deepening of BH-17 and the rehabilitation of boreholes 699-92-14 and -113-38 will assist in further refining hydraulic heads just north of the Umtanum Ridge-Gable Mountain anticline (see Fig. 13-2 for borehole locations). Rehabilitation of boreholes DH-4 and -5 (Fig. 13-2) will better define the far-field boundary conditions along the Saddle Mountains anticline. Hydraulic heads and groundwater hydrochemistry from all of these holes will be used to conceptually define the hydraulic characteristics and influences of these structures. This information, in turn, will be input to the numerical modeling studies of groundwater flow and solute transport.

Work Element S.1.30.C (Related to S.1.7.A, S.1.9.A, S.1.11.B, S.1.12.B, S.1.17.B, S.1.24.C through S.1.29.C, and S.1.31.C) (Priority 1)

Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models.

Status

The conceptual model of the Cold Creek syncline and surrounding area is considered preliminary. Data needs remain concerning the groundwater circulation within and between flow systems, distribution of hydraulic properties, boundary conditions, and the water budget (i.e., water content) of the basalt flow systems, etc.

Gephart et al. (1979a) devised an integrated model for groundwater movement from recharge to discharge areas in both the shallow and deep basalts beneath the Hanford Site, in particular, and the surrounding Columbia Plateau, in general. La Sala et al. (1972) basically examined only groundwater flow directions in the shallow basalts in south-central Washington. They concluded that flow directions appear directed away from topographic highs and that groundwater movement beneath the Hanford Site was east to southeast. Summers et al. (1978) developed a model consisting of local, intermediate, and regional flow systems while Dove et al. (1981) considered a large-scale model for the Columbia Plateau with line discharge into the major rivers.

Available evidence suggests that within the Cold Creek syncline and vicinity the columnar zones of a basalt flow possess very low hydraulic conductivities and distinct groundwater systems exist. Vertical and areal gradients are small. Geologic structures (e.g., the Umtanum Ridge-Gable Mountain anticline) may play an important role in controlling local groundwater flow patterns.

The conceptual model of the Cold Creek syncline area has been developed from hydrogeologic studies based on data collected in boreholes. The conceptual model has also been refined by the application of numerical models. Several preliminary model calibration efforts have been conducted to date and are summarized in Chapter 12 of this document. To date, the process of preliminary model calibration has pointed out specific areas of the conceptual model that require refinement relative to groundwater flow paths and travel times.

Plans

As noted under Work Elements S.1.24.C, S.1.25.C and S.1.26.C, determinations of hydraulic properties, hydraulic heads, and groundwater hydrochemistry for site characterization will be accomplished through an array

of existing and new boreholes. These boreholes are distributed to evaluate the hydrogeology both within and near the reference repository location, as well as the surrounding hydrogeologic setting significant to understanding the waste isolation potential of the location.

Results from the above test activities will be input to modeling studies of groundwater flow and solute transport. Any additional data needs will be established by an iterative process between data collection and modeling.

Work Element S.1.31.C (Related to S.1.30.C, S.1.33.C, S.1.34.C, and S.1.38.D and S.1.39.D) (Priority 1)

Develop and/or modify numerical codes that adequately simulate groundwater flow, natural hydrochemical species transport, and travel times under pre-waste-emplacement conditions.

Status

A set of computer codes that model groundwater flow and travel times has been assembled and applied to basalt. Some of the models being applied within the BWIP are MAGNUM 3D, PATH 3D, MAGNUM, PATH, PORFLO, and FECTRA (see Section 12.3.2). At present, MAGNUM 3D and PATH 3D are being used by the BWIP to simulate the pre-waste-emplacement groundwater system. A version of FECTRA is being considered for simulating the movement and mixing of natural hydrochemical species in order to improve the understanding of the flow system.

Plans

The MAGNUM 3D, PATH 3D, and FECTRA codes have been successfully compared to some analytical solutions. The process of fully demonstrating the value and correctness of a computer code involves:

- Verification - demonstrating that the numerical operations performed by a computer code are correct
- Benchmarking - comparing the solutions obtained with one computer code to solutions obtained with other codes or with a closed-form solution to a specific problem.

Work is under way to fully verify, benchmark, and document MAGNUM 3D, PATH 3D, and FECTRA as well as the other BWIP codes. The MAGNUM 3D code will likely be modified to simulate unconfined aquifer characteristics to the extent needed to assure meeting waste isolation criteria.

Work Element S.1.32.C (Included in S.1.41.D) (Priority 3)

Evaluate the ranges of relevant hydrogeologic conditions since the start of the Quaternary Period.

Status

Status included in Work Element S.1.41.D.

Plans

Plans included in Work Element S.1.41.D.

Work Element S.1.33.C (Related to S.1.30.C, S.1.31.C, S.1.34.C, S.1.37.D, S.1.39.D, and S.1.41.D) (Priority 1)

Using selected models, predict groundwater travel time from the repository location to the accessible environment under pre-waste-emplacement conditions.

Status

Far-field hydrologic modeling studies of the groundwater system in the basalts have been performed over the past several years by a number of independent organizations, using the hydrologic data sets available at the time. The emphasis of some of these studies was to simulate the three-dimensional groundwater head patterns and to estimate flow paths and travel times from a hypothetical repository location to the biosphere. Other studies emphasized one-dimensional radionuclide transport but also provided estimates of groundwater travel time. In each of the studies, substantial interpolation and subjective judgment were required to prepare the model inputs. This is because models require quantitative definition of geometry, material properties, and boundary conditions, whether this information is well known or not. These studies are discussed and summarized in Chapter 12.

There are differences in the orientation of the streamlines and the travel times among the various studies. The important reasons for these differences are, for the most part, related to different data sets and varying interpretations of conditions where insufficient data existed. In spite of the differences, each study concluded that under pre-waste-emplacement conditions the predicted groundwater travel times from the hypothetical repository location to the accessible environment exceeded the 1,000-year proposed criteria (NRC, 1981).

Plans

In order to demonstrate a satisfactory understanding of the groundwater flow path orientation and travel times and to achieve a reasonable consensus of both the conceptual and numerical model results within the technical community, the following items are needed:

(1) Additional hydrologic data from existing and new boreholes (Work Elements S.1.24.C through S.1.26.C).

(2) Refinements to the conceptual model (Work Element S.1.30.C).

(3) Establishment of the far-field model scale such that it is consistent in scale with the definition of the accessible environment as drafted by the U.S. Environmental Protection Agency (EPA, 1981). This will allow more complete and quantitative definition of model parameters.

(4) Formation of a technical task force to carefully review data and assumptions, to resolve significant differences, where possible, and to make recommendations for resolving remaining differences.

Work Element S.1.34.C (Related to S.1.24.C, S.1.25.C, S.1.26.C, S.1.30.C, S.1.31.C, and S.1.33.C) (Priority 2)

Determine the bounds of uncertainty in model predictions of pre-waste-emplacement groundwater travel time.

Status

Confidence in the site performance assessment will rely heavily on the degree of model validity. Model validation is defined as the process of demonstrating that the model adequately represents physical reality. Because the time period of interest in a nuclear waste repository is long, precise validation through direct experiment prior to full-scale construction is not feasible. However, from the perspective of nuclear waste isolation criteria, "adequate representation" allows for substantial uncertainty. Consequently, it is expected that determination of the bounds of uncertainty in the travel time will be the key to model validation.

Uncertainty in the groundwater travel time estimates is a function of the basic data, the conceptual model, the numerical models, and how the uncertainty propagates from each of these model levels to the next higher one. The degree of approximation or error in the numerical codes can be checked in the process of code verification and benchmarking and will be (or can be made to be) relatively low. Consequently, the final overall uncertainty in the modeling results will derive largely from data and conceptual model uncertainties.

The ranges of hydrologic properties are discussed in Sections 5.1.3 through 5.1.6 and 5.2.1 through 5.2.3. The nature of the assumptions and extrapolations that significantly influence the conceptual model is discussed in Sections 5.1.10 and 12.4. Also summarized in Section 12.4 is a preliminary statistical analysis (Kriging) of the Hanford basalt hydraulic conductivity, which provided calculated distributions of conductivity for two stratigraphic horizons at 90- and 97.5-percent confidence limits.

Plans

Reduction in the data and conceptual model uncertainties are planned (Work Elements S.1.24.C through S.1.26.C and S.1.30.C) as well as verification and benchmarking of the numerical codes (Work Element S.1.31.C).

A comprehensive far-field model parameter and sensitivity analysis for the far-field groundwater flow is under way that will identify the key parameters (and parameter distributions) and model inputs (including geometry) in terms of their impact on groundwater travel times.

Unless a very conservative analysis demonstrates compliance with the regulatory criteria to the point where a reasonable consensus can be expected, a stochastic modeling approach will be needed. Although deterministic models are generally more feasible for use in performance analyses, stochastic models may be a more rigorous approach to bounding predictive uncertainty. A Monte Carlo-type analysis is the stochastic approach planned for addressing the uncertainty in the predictions of the pre-waste-emplacement groundwater travel time. This will likely be conducted after completion of the parameter and sensitivity analysis now under way, which is expected to allow a substantial reduction in the number of runs required.

As mentioned under Work Element S.1.33.C, a task force of technical personnel has been organized to address the assumptions used in the various modeling efforts. One objective of this task force is to reduce the range of uncertainty in the model results.

Work Element S.1.35.C (Included in S.1.30.C) (Priority 3)

Determine the groundwater content of the host rock.

Status

Included in Work Element S.1.30.C.

Plans

Included in Work Element S.1.30.C.

Work Element S.1.36.C (Included in S.1.30.C) (Priority 3)

Determine the nature of groundwater circulation in the host rock.

Status

Included in Work Element S.1.30.C.

Plans

Included in Work Element S.1.30.C.

KEY ISSUE S.1.D

> What is the total amount (activity) of radionuclides potentially releasable to the accessible environment in a 10,000-year period, and is this amount in compliance with appropriate U.S. Environmental Protection Agency regulations?

Technical criteria proposed by the U.S. Nuclear Regulatory Commission require a minimum containment period of 1,000 years and a maximum annual release rate of 1 part in 100,000 for any radionuclide released from the engineered system, assuming anticipated geologic processes and events (NRC, 1981). In addition, the U.S. Environmental Protection Agency draft regulations have proposed a 10-kilometer distance to the accessible environment.

The long-term isolation potential of the repository setting will require a detailed risk assessment that identifies plausible natural and man-induced release modes, estimates the probabilities of the release modes, and conservatively bounds the uncertainty of these release analyses. The planned performance assessment for evaluating compliance with proposed U.S. Nuclear Regulatory Commission and draft U.S. Environmental Protection Agency regulations will consider a broad range of potential radionuclide release conditions. An evaluation of groundwater flow and solute transport under nondisturbed and plausible disruptive-release conditions will quantify the radiologic risk of the repository system.

The emphasis of work elements keyed to this issue is to provide data that can be used to reach a technical consensus that the repository system meets regulatory guidelines and poses no significant short- or long-term hazard to man. The contents of these work elements are summarized in tabular form in Table 13-5.

Work Element S.1.37.D (Related to S.1.30.C, S.1.31.C, S.1.33.C, S.1.34.C, and S.1.39.D) (Priority 1)

> Develop and/or modify numerical codes that can reliably predict the changes in the processes determining the rate and extent of radionuclide transport under post-waste-emplacement conditions.

Status

A set of numerical codes has been developed and interfaced for use in repository analysis at three space scales: (1) very near field (canister to room scale), (2) near field (repository scale), and (3) far field (area between the near field and the accessible environment). The numerical codes are designed to simulate the response of the repository system (engineered facility and geohydrologic system) in the postclosure period. The very near-field models will be used in conjunction with the waste package performance models to predict the radionuclide release rate from the engineered facility and emplacement horizon. This information will be used by the near-field models to predict radionuclide releases to the far field. The far-field models will be used to predict radionuclide releases to the accessible environment.

TABLE 13-5. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.D. (Sheet 1 of 9)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.37.D (Related to S.1.30.C, S.1.31.C, S.1.33.C, S.1.34.C, and S.1.39.D) Develop and/or modify numerical codes that can reliably predict the changes in the processes determining the rate and extent of radionuclide transport under post-waste-emplacement conditions.	Models that simulate: • Near field and very near field (1) Coupled groundwater flow and heat transport (2) Rock stress/strain coupling with hydraulic conductivity (3) Radionuclide transport including convection/dispersion, sorption, decay, and chain decay • Far Field (1) Three-dimensional groundwater flow (2) Radionuclide transport including convection/dispersion, sorption, and decay • Coordination of far-field, near-field, and very near-field models.	Not applicable.	Codes that meet requirements have been assembled and are operational (see Section 12.3.2 of this document).
	Verification and benchmarking of: • Near-field and very near-field codes; validation with laboratory data		Verification, benchmarking, and validation under way (see Section 12.3.3 of this document).
	• Far-field codes.		See Work Element S.1.31.C for Status of MAGNUM 3D and PATH 3D. FECTRA being brought into operational status.
S.1.38.D (Related to S.1.24.C, R.1.3.A, R.1.12.B, R.1.67, W.1.4.A, W.1.10.A, W.1.12.A, W.1.19.B, W.2.1.A, W.2.2.A, W.2.5.A, and W.2.9.B) Determine the radionuclide transport, thermal, and mechanical properties of the geohydrologic system.	Principal information needs include:		
	• Dispersivities (see Information needs under S.1.24.C)	See Mandatory measurement conditions under S.1.24.C.	See Status achieved under S.1.24.C.
	• Radionuclide solubility constants (see Information needs under related Chapter 15 work elements).	See Mandatory measurement conditions under related Chapter 15 work elements.	See Status achieved under related Chapter 15 work elements.

TABLE 13-5. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.D. (Sheet 2 of 9)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	• Radionuclide distribution coefficients (see Information needs under related Chapter 15 work elements)	See Mandatory measurement conditions under related Chapter 15 work elements.	See Status achieved under related Chapter 15 work elements.
	• Rock thermal conductivity (see Information needs under related work elements)	See Mandatory measurement conditions under related Chapter 14 work elements.	See Status achieved under related Chapter 14 work elements.
	• Specific heat capacity of rock (see Information needs under related Chapter 14 work elements)	See Mandatory measurement conditions under related Chapter 14 work elements.	See Status achieved under related Chapter 14 work elements.
	• Deformational modulus and Poisson's ratio (see related Chapter 14 work elements).	See Mandatory measurement conditions under related Chapter 14 work elements.	See Status achieved under related Chapter 14 work elements.
S.1.39.D (Related to S.1.24.C through S.1.30,C, S.1.37.D, S.1.38.D, S.1.40.D, R.1.13.B, R.1.20.D, W.2.4.A, W.2.8.A, W.2.11.D, and W.2.13.D) Using selected models, predict radionuclide mass fluxes to the accessible environment.	Information needs include: • Adequate conceptual model, particularly in the near field (see Information needs under S.1.30.C) • Adequate determination of radionuclide mass transport and thermal properties in the near field (see Information needs under S.1.38.D) • Adequate numerical models (see Information needs under S.1.33.C and S.1.37.D).	See Mandatory measurement conditions under S.1.30.C. See Mandatory measurement conditions under S.1.38.D. See Mandatory measurement conditions under S.1.33.C and S.1.37.D.	Several preliminary studies have been completed (see Section 12.4 of this document and Dove et al., 1981). Application of PORFLO model for the release scenarios analyzed (see Section 12.4 of this document) has shown that the predicted radionuclide fluxes to the far field are consistent with meeting the limit proposed by the U.S. Environmental Protection Agency at the accessibale-environment boundary (10 kilometers from the center of the repository).
S.1.40.D (Related to S.1.39.D) Determine the bounds of uncertainty in the model predictions of radionuclide fluxes to the accessible environment.	Information needs include: • Identification of the most important hydrologic properties influencing radionuclide transport	Not applicable.	Preliminary parametric and sensitivity modeling analysis completed (King et al., 1981); most important properties are hydraulic conductivities, sorption contents (or retardation factors), and mass dispersivities.

TABLE 13-5. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.D. (Sheet 3 of 9)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	• Calculation of the bounds of radionuclide fluxes using deterministic models.	Technical peer group review and concurrence.	Work under way (see Section 12.4 of this document).
	• Calculation of probability-density functions for radionuclide flux predictions using probabilistic transport models.	Technical peer group review and concurrence.	Work under way (see Section 12.4 of this document).
S.1.41.D (Related to S.1.1.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.23.B, S.1.24.C through S.1.26.C, and S.1.30.C) Identify credible disruptive events and potentially unfavorable process scenarios and estimate the associated properties and conditions of the host basalt near the repository site; develop bounding estimates for probabilities of occurrence for each event, as needed.	Information needs include: • Past, present, and projected geologic and hydrologic characteristics of the reference repository location and surrounding area (see Information needs under S.1.A through S.1.10,A, S.1.11.B through S.1.17.B, S.1.23.B, S.1.24.C through S.1.26.C, and S.1.30.C). • Analysis of altered properties and conditions associated with: (1) Geologic and hydrologic phenomena (2) Potential repository phenomena (3) Man-induced phenomena (4) Climatic variations • Determination of event consequences • Determination of probability of event occurrence.	See Mandatory measurement conditions under S.1.1.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.23.B, S.1.24.C through S.1.26.C, and S.1.30.C.	Geologic and hydrologic characteristics of the reference repository location and surrounding area are summarized in Myers/Price et al. (1979); Gephart et al. (1979a); and Chapters 3, 5, 7, and 8 of this document. Also see Status achieved under S.1.1.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.23.B, S.1.24.C through S.1.26.C, and S.1.30.C. Results of scenario analysis of an interconnecting fault, shaft seal degradation or failure, microearthquake swarm, penetration by borehole, and dike intrusion are summarized in Arnett et al. (1980) and Section 12.4 of this document. Analysis to date shows compliance with all U.S. Nuclear Regulatory Commission (NRC, 1981) proposed criteria and U.S. Environmental Protection Agency (EPA, 1981) draft regulations. Probability of breach of a repository by a dike intrusion has been determined by Johnpeer et al. (1981). (See S.1.59.C and Section 3.7.2 of this document).

TABLE 13-5. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.D. (Sheet 4 of 9)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.42.D (Related to S.1.6.A, S.1.9.A, S.1.26.C, S.1.39.D, S.1.40.D, S.1.41.D, and W.2.13.D) Determine whether the range of geochemical conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.	Information needs include those defined under S.1.6.A, S.1.9.A, S.1.26.C, S.1.39.D, S.1.40.D, S.1.41.D, and related work elements in Chapter 15.	See Mandatory measurement conditions under S.1.6.A, S.1.9.A, S.1.26.C, S.1.39.D, S.1.40.D, S.1.41.D, and related work elements in Chapter 15.	See Status achieved under S.1.6.A, S.1.9.A, S.1.26.C, S.1.39.D, S.1.40.D, and S.1.41.D. A discussion of the present geochemical setting of reference repository location is contained in Chapter 6 of this document; geochemical conditions related to waste package are discussed in Chapters 6 and 11 of this document.
S.1.43.D (Related to S.1.30.C, S.1.33.C, S.1.39.D, S.1.40.D, S.1.41.D, W.2.4.A, W.2.8.A, W.2.11.D, and W.2.13.D) Determine whether the range of hydrogeologic conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.	Information needs include those defined under S.1.30.C, S.1.33.C, S.1.39.D, S.1.40.D, S.1.41.D, and related work elements in Chapter 15.	See Mandatory measurement conditions under S.1.30.C, S.1.33.C, S.1.39.D, S.1.40.D, S.1.41.D, and related work elements in Chapter 15.	See Status achieved under S.1.30.C, S.1.33.C, S.1.39.D, S.1.40.D, S.1.41.D, and related work elements in Chapter 15. (Also see information contained in Chapters 3, 5, 6, and 7 of this document). Work to integrate present hydrologic results with waste package needs is under way.
S.1.44.D (Related to S.1.45.D, S.1.48.D, and S.1.49.D) Determine the potential for, and effect of, failure of existing or planned man-made surface water impoundments.	Information needs include: • Numerical simulation of dam-break flood scenarios for the Columbia River.	Not applicable.	Numerical models and guidelines are included in Fread (1977), Gundlach and Thomas (1977), Druffel et al. (1979), and Land (1981). The flood release from a 50-percent breach of Grand Coulee Dam has been determined by the U.S. Army Corps of Engineers (COE, 1951). For additional discussion see U.S. Energy Research and Development Administration (ERDA, 1976), Leonhart (1980), and Section 7.1.5 of this document.

TABLE 13-5. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.D. (Sheet 5 of 9)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.45.D (Related to S.1.16.B, S.1.41.D, S.1.46.D, and S.1.49.D) Determine the effect of potential impoundments on the groundwater flow system.	Information needs include: • Numerical simulation of vertical groundwater movement induced by increased hydraulic head near the land surface (as would be associated with impoundment) (see Information needs under S.1.41.D) • Estimation of the magnitude, frequency, and duration of catastrophic flooding events events (see Information needs under S.1.49.D).	Not applicable.	An analysis of the effects of the proposed Ben Franklin Dam on Hanford Site activities has been prepared by Harty (1979). Leonhart (1980) has concluded that man-made impoundments should have no significant effect upon seismicity.
S.1.46.D (Related to S.1.41.D, S.2.1, and S.2.4) Determine the potential for human activity to cause significant changes in the surface and groundwater hydrology.	Information needs include: • Identification of the most-likely human activity scenarios based on present and foreseeable trends in regional socioeconomics (see Information needs under S.2.1 and S.2.4) • Analysis of the probable hydrologic consequences of appropriate scenarios by means of numerical simulation (see Information needs under S.1.41.D).	Not applicable.	The most-likely scenario identified to date involves encroachment of irrigated agriculture toward the site. For additional information see Stephan et al. (1979), Wukelic et al. (1981), Leaming (1981), Pacific Northwest River Basins Commission (1980), and Johnson et al. (1981). Also see Sections 5.1.9 and 7.3.2 of this document. See Status achieved under S.1.41.D.
S.1.47.D (Related to R.1.34) Determine the potential for and the effect of occupancy and modification of the Columbia River flood plain.	Information needs include: • Limits of 100-year and probable-maximum flood plains as determined by historic records and/or geomorphic evidence • Depth of inundation associated with 100-year and probable-maximum floods.	Not applicable.	The 100-year flood for the Columbia River has been determined (Leonhart, 1979; 1980; Sections 7.2.1 and 7.2.2 of this document).

TABLE 13-5. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.D. (Sheet 6 of 9)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.48.D (Included in S.1.45.D) Determine the potential for and magnitude of impoundment that could affect a change in the regional groundwater flow.	Included in S.1.45.D.	Not applicable.	Included in S.1.45.D.
S.1.49.D (Related to S.1.41.D, S.1.44.D, S.1.45.D, S.1.60.D, and S.2.5) Evaluate the effect of possible climatic changes.	*Information needs include:* • Quaternary paleoclimate data for use in determining probable range of climatic conditions that could occur within the Columbia Plateau	Not applicable.	Evaluation of possible climatic changes has shown that catastrophic flooding, associated with renewal of continental glaciation, represents the most significant potential impact. See Myers/Price et al. (1979); Foley et al. (1981); Bull (1979; 1980); and Sections 3.3, 3.4, and 8.3.1 of this document for summary of related work.
	• Analysis of geologic, hydrologic, and geochemical consequences of catastrophic flooding by means of numerical simulation (see Information needs under S.1.41.D).		See Status achieved under S.1.41.D.
S.1.50.D (Related to S.1.41.D, R.1.18.D, and R.1.20.D) Determine the potential effect of boreholes on repository performance.	Information needs include: • Inventory of the locations and depths of boreholes within the Hanford Site, particularly within the reference repository location	Not applicable.	Borehole locations and depths within the Hanford Site have been documented by Jenkins (1922), Walters and Grolier (1960), Newcomb et al. (1972), McGhan and Damschen (1979), and Fecht and Lillie (1981). A high degree of certainty exists that the location and depths of all boreholes within the reference repository location are known (also see Section 3.2 of this document).
	• Analysis of probable consequences of borehole penetration of the repository by means of numerical simulation (see Information needs under S.1.41.D).		See Status achieved under S.1.41.D.

TABLE 13-5. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.D. (Sheet 7 of 9)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.51.D (Included in S.1.41.D) Determine the effect on waste isolation of potential changes in such hydrologic conditions as hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.	Included in S.1.41.D.	Included in S.1.41.D.	Included in S.1.41.D.
S.1.52.D (Related to S.1.17.B, S.1.39.D, S.1.40.D, S.1.41.D, R.1.3.A, R.1.29, R.1.30, and W.1.2.A) Determine whether the range in tectonic and structural conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.	Information needs include those defined under S.1.17.B, S.1.39.D, S.1.40.D, S.1.41.D, and related work elements in Chapters 14 and 15.	See Mandatory measurement conditions under S.1.17.B, S.1.39.D, S.1.40.D, S.1.41.D, and related work elements in Chapters 14 and 15.	See Status achieved under S.1.17.B, S.1.39.D, S.1.40.D, S.1.41.D, and related work elements in Chapters 14 and 15. Work to integrate present tectonic results with seismic design and waste package needs is under way.
S.1.53.D (Included in S.1.16.B, S.1.17.B, and S.1.52.D) Determine the historical seismicity of the geologic setting and if there are any historical earthquakes that could adversely affect the repository.	Included in S.1.16.B, S.1.17.B, and S.1.52.D.	Included in S.1.16.B, S.1.17.B, and S.1.52.D.	Included in S.1.16.B, S.1.17.B, and S.1.52.D.
S.1.54.D (Included in S.1.11.B through S.1.17.B and S.1.52.D) Determine the effect of an active fault within the geologic setting on repository performance.	Included in S.1.11.B through S.1.17.B and S.1.52.D.	Included in S.1.11.B through S.1.17.B and S.1.52.D.	Included in S.1.11.B through S.1.17.B and S.1.52.D.
S.1.55.D (Included in S.1.11.B through S.1.17.B and S.1.52.D) Determine the effect of an active fault within the disturbed zone on repository performance.	Included in S.1.11.B through S.1.17.B and S.1.52.D.	Included in S.1.11.B through S.1.17.B and S.1.52.D.	Included in S.1.11.B through S.1.17.B and S.1.52.D.

TABLE 13-5. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.D. (Sheet 8 of 9)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.56.D (Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B and S.1.52.D) Determine the effect of faults and fractures on repository performance.	Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, and S.1.52.D.	Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, and S.1.52.D.	Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, and S.1.52.D.
S.1.57.D (Included in S.1.16.B, S.1.17.B, and S.1.52.D) Determine the effect of seismicity on repository performance.	Included in S.1.16.B, S.1.17.B, and S.1.52.D.	Included in S.1.16.B, S.1.17.B, and S.1.52.D.	Included in S.1.16.B, S.1.17.B, and S.1.52.D.
S.1.58.D (Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.52.D, and S.1.60.D) Determine the effect of structural deformation such as uplift, subsidence, folding, and fracturing on repository performance.	Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.52.D, and S.1.60.D.	Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.52.D, and S.1.60.D.	Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.52.D, and S.1.60.D.
S.1.59.D (Related to S.1.17.B, S.1.23.B, S.1.41.D, and R.1.34) Determine the potential for breach of a repository by future fissure eruptions of Columbia River basalt; determine the effect of other types of igneous activity within and in the vicinity of the Pasco Basin.	Information needs include: • Analysis of future volcanic event-occurrence probability based upon past frequencies (see Information needs under S.1.23.B)	Conduct statistical analysis of occurrence probabilities of geologic events predicated on results of S.1.23.B (see Mandatory measurement conditions under S.1.23.B).	Analysis completed (PGE, 1978; Johnpeer et al., 1981; Section 3.7.2 of this document). Consequent events considered include volcanically induced flooding, covering of the repository site by tephra, ash flows, or lava flows, and breach of a repository by a dike.
	• Probability determination of consequences of volcanic events.	Conduct statistical analysis of event/consequence network probabilities as determined by above Mandatory measurement condition.	Analysis completed (Johnpeer et al., 1981; Section 3.7.2 of this document). The probability of intrusive igneous events disturbing the integrity of a repository was found to be 0.053 in 10^6 years.

TABLE 13-5. Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.D. (Sheet 9 of 9)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.1.60.D (Related to S.1.15.B, S.1.17.B, S.1.45.D, S.1.49.D, and S.1.51.D) Determine whether the range of geomorphic conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.	Information needs include: • Characterization and classification of the physiography of the Pasco Basin • Identification of surficial geologic and tectonic processes that have operated during Quaternary time in the Pasco Basin • Identification and evaluation of geomorphic variables such as climate, tectonism, and lithology that influence erosional and depositional processes • Quantification of ranges and most likely rates of denudation, sedimentation, uplift, and subsidence in the Pasco Basin • Evaluation of net effect of rates of surficial geologic processes on surface elevation of the Pasco Basin for a future time, equal in duration to that portion of Quaternary time for which documentable geologic evidence is available.	Not applicable.	Surface mapping and Quaternary stratigraphy presented in Myers/Price et al. (1979), Tallman et al. (1981), and WCC (1980). Information included in Myers/Price et al. (1979), Reidel et al. (1980), and Myers and Price (1981). Information and evaluation of variables included in Myers/Price et al. (1979), Reidel et al. (1980), and WCC (1980). Information included in references listed above. Based on an assessment of long-term rates of uplift, denudation, and channel incision, WCC (1980) concluded that it was unlikely that more than 100 meters of downcutting will occur within the Pasco Basin during the next 1 million years; hence geomorphic effects on waste isolation are concluded to be inconsequential.
S.1.61.D (Included in S.1.60.D) Determine the likelihood of repository exhumation due to extreme erosion over the next 10,000 years.	Included in S.1.60.D.	Included in S.1.60.D.	Included in S.1.60.D.

The principal codes for the very near-field scale consist of MAGNUM 2D, CHAINT, BETA, and WOOD/SALTER. These codes taken together simulate the processes of heat transfer, groundwater flow, radionuclide transport, or rock stress/strain. The work completed to date on the very near-field models includes: (1) verification of computer codes using analytical solutions, (2) comparison testing against other codes, and (3) limited validation with laboratory experimental data (see Section 12.3.3).

The major near-field codes model the processes of heat transport, groundwater flow, and/or radionuclide transport. The PORFLO code is a general code that simulates all three fluid-flow and transport processes. The MAGNUM 2D and CHAINT codes simulate fluid flow/heat transport and radionuclide transport, respectively, and may also be used in the near field as well as the very near field. The PATH 2D code is interfaced with PORFLO and computes pathlines and travel times in the near field. To date, the PORFLO code has been applied to evaluate the near-field performance of the reference repository location (see Section 12.3.2). A comprehensive benchmarking effort has been initiated with the PORFLO code.

The major post-waste-emplacement far-field codes consist of MAGNUM 3D, PATH 3D, FECTRA, and NUTRAN. The MAGNUM 3D, PATH 3D, and FECTRA codes simulate three-dimensional groundwater flow, pathline travel time, and radionuclide transport, respectively. The NUTRAN code simulates one-dimensional radionuclide transport. The far-field codes are discussed in more detail in Section 12.3.2.

Plans

The planned work with the post-waste-emplacement numerical models will be directed to two particular areas: (1) code verification, benchmarking, and limited validation, and (2) preparation of technical reports and user's manuals for the major codes. In addition, the existing waste-package models will be adapted and modified to apply to basalt. These models will be interfaced with the very near-field flow and transport models that will be used to calculate repository release rates.

The modeling of different scales (far field, near field, very near field) will be coordinated to achieve maximum understanding and consistency. Regional (Columbia Plateau) modeling has been performed using regional recharge/discharge relationships. The regional model will be improved and calibrated to the extent possible using regional data. The output of the regional model together with field data will be used to establish boundary conditions for the Pasco Basin. The Pasco Basin model will be calibrated and validated with field measurements and interpretation of the basin geohydrochemical system (aquifer interactions/mixing). A solute transport/mixing model will be used to assist in the geohydrochemical interpretations. The boundary conditions at the edge of the site models will be obtained from the Pasco Basin model and field measurements. The starting locations of the pathlines and the radionuclide

fluxes and concentrations (source terms) for the far-field models will be provided by the near-field model. Coordination of the various models will provide a practical method of addressing phenomena and conditions that are significant at different scales. It will also assure consistency between the different scaled analyses.

Work Element S.1.38.D (Related in S.1.24.C, R.1.3.A, R.1.12.B, R.1.67, W.1.4.A, W.1.10.A, W.1.12.A, W.1.19.B W.2.1.A, W.2.2.A, W.2.5.A, and W.2.9.B) (Priority 1)

Determine the radionuclide transport, thermal, and mechanical properties of the geohydrologic system.

Status

The prediction of radionuclide movement through basaltic rock is dependent on an adequate characterization of the mass transport, thermal, and mechanical properties of the basalt. The properties of principal importance are: (1) longitudinal and transverse dispersivities, (2) solubility constants and distribution coefficients for the key radionuclides, (3) thermal conductivity and specific heat of the rock, and (4) deformational modulus and Poisson's ratio for the rock mass.

At the present time, there are no field data for mass dispersivities for either the flow contacts or columnar basalts. Consequently, estimates based on literature values are currently used.

Measurements of distribution or sorption coefficients are now available for the major radionuclides, whereas only limited information is available on solubility constants. Solubilities for key radionuclides are needed because of their importance in calculating radionuclide release rates. Data reported in the technical literature have been assumed for the performance assessment analysis reported in Section 12.4.

Measurements of deformational modulus and Poisson's ratio for basalt have recently been obtained in the laboratory.

Plans

See Work Element S.1.24.C and related work elements in Chapters 14 and 15.

Work Element S.1.39.D (Related to S.1.24.C through S.1.30.C, S.1.37.D, S.1.38.D, S.1.40.D, R.1.13.B, R.1.20.D, W.2.4.A, W.2.8.A, W.2.11.D, and W.2.13.D) (Priority 1)

Using selected models, predict radionuclide mass fluxes to the accessible environment.

Status

A preliminary analysis of the reference repository location has been initiated to evaluate compliance with U.S. Environmental Protection Agency (EPA, 1981) draft regulations for releases to the accessible environment. The analysis performed to date is at the near-field scale and considers releases under current geohydrologic conditions and postulated disruptive-event conditions. The PORFLO model has been applied to calculate the transport of key radionuclides and, in turn, to calculate the total activity of these radionuclides entering the accessible environment over a 10,000-year period. For the release scenarios analyzed (see Section 12.4.3), the predicted radionuclide fluxes to the accessible environment are consistent with meeting the limit proposed by the U.S. Environmental Protection Agency at the accessible environment boundary (10 kilometers from the center of the repository).

Plans

For this work element, performance assessments will be carried out in three areas: (1) canister- and room-scale modeling taking into account rock stress/strain, heat transport, fracture flow, and radionuclide transport; (2) repository scale modeling taking into account heat transport, groundwater flow, and radionuclide transport, and (3) far-field scale modeling taking into account groundwater flow and radionuclide transport. These performance assessments will focus on the following aspects:

- Evaluating compliance with the proposed criteria (NRC, 1981) and draft regulations (EPA, 1981)
- Quantifying the waste isolation capability of the candidate repository horizons (e.g., Umtanum and middle Sentinel Bluffs flows)
- Establishing engineered barriers and borehole sealing requirements
- Evaluating the feasibility of alternative repository designs.

Performance assessment reports will be prepared and issued on a periodic basis. The reports will incorporate additional geohydrologic data and updated waste package and repository design specifications.

Hydrogeologic characterization of the zone between the repository and the accessible environment and surrounding area is critical input to performance assessment. Refer to Work Elements S.1.24.C through S.1.30.C for an outline of site characterization plans.

Work Element S.1.40.D (Related to S.1.39.D) (Priority 2)

Determine the bounds of uncertainty in the model predictions of radionuclide fluxes to the accessible environment.

Status

The regulations drafted by the U.S. Environmental Protection Agency (limiting radionuclide releases to accessible environment) (EPA, 1981) indicate that the final repository performance analysis must properly establish the "likelihood of compliance." This draft requirement is interpreted to mean that the radionuclide transport analysis carried out to estimate the fluxes should incorporate some bounding of the predictive uncertainty. Recognizing that the principal source of predictive uncertainty is associated with the estimates of the hydrologic properties of the basalt, the first task is to determine which properties contribute the most to the predictive uncertainty and to evaluate the propagation of uncertainty in the modeling process.

A preliminary near-field parametric and sensitivity analysis was conducted (King et al., 1981) for the purpose of identifying and ranking the important hydrologic and transport properties. This parametric study clearly showed that the more important properties are: (1) hydraulic conductivities, (2) sorption (or retardation factors), and (3) mass dispersivities; other properties such as porosities, thermal conductivities, etc. are less important because of their low variability and/or because they have less effect on the rate and extent of waste migration.

Plans

The effort planned under this work element will consist of two separate modeling efforts involving: (1) predictions of radionuclide transport using deterministic models and conservative data values and (2) application of probabilistic transport models that estimate the partial model validation using distribution of mass flux values. The objective of the first effort is to provide upper and lower bound values for the radionuclide fluxes. These calculations will be documented in performance assessment reports. The second effort will involve the use of existing probabilistic models to develop approximate probability density functions for the fluxes assuming various hydrologic conditions (i.e., flow paths and travel times). These probabilistic calculations will be used as an independent check of the deterministic predictions, as well as a basis for quantifying likelihood of compliance.

Work Element S.1.41.D (Related to S.1.1.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.23.B, S.1.24.C through S.1.26.C, and S.1.30.C) (Priority 1)

Identify credible disruptive events and potentially unfavorable process scenarios and estimate the associated properties and conditions of the host basalt near the repository site; develop bounding estimates for probabilities of occurrence for each event, as needed.

Status

Several non-site-specific credible scenarios for disruptive event occurrence have been proposed in the technical literature (see Arnett et al., 1980). These generic scenarios have been screened and evaluated on the basis of credibility, consistency with site-specific geologic and hydrologic knowledge, event likelihood, and release potential to preliminarily define scenarios relevant to disruption of a repository in Columbia River basalt. Scenarios initially considered applicable (Arnett et al., 1980) consisted of the following natural, man-induced, and repository-induced events for the first 10,000 years following repository decommissioning:

- Fault zone directly or indirectly connecting repository with biosphere
- Shaft seal degradation or failure
- Intrusion by borehole
- Loss of integrity due to microearthquake swarm zone
- Intrusion by basaltic dike.

Dike intrusion was eliminated from consideration based on a close examination of the nature and conditions of historic basaltic extrusions (see Work Element S.1.59.D). Preliminary analysis of the consequences of a microearthquake event centered at the repository indicates no significant effects over the 10,000-year period of interest. No definitive evidence was found that either magmatic intrusion by basaltic dike or a microearthquake event would have significant hydrologic effects. Additional information on the above scenarios may be found in Arnett et al. (1980).

Currently, no attempt has been made to estimate the probabilities of occurrence of such events. Johnpeer et al. (1981) have calculated the probability of volcanic events within the Pasco Basin (see Work Element S.1.59.D). Instead, consequence analyses have been undertaken to determine their potential for disruption of a repository in basalt. In many instances, the consequences of a particular event are sufficiently small to cause the issue of probability of occurrence to be of limited or no interest; i.e., even if the probability of occurrence of an event is 1, the radionuclides would be contained in the deep basalt away from the accessible environment.

Plans

The current list of plausible scenarios will be expanded to include other postulated events potentially associated with: (1) repository-induced phenomena, (2) man-induced phenomena, and (3) effects of climatic variation. If it is determined that an event or process has a potentially significant consequence, the overall risk will be calculated from the consequence and the probability of occurrence.

Considerations of the occurrence and consequences of disruptive events during the repository preclosure phase are addressed in Chapter 14.

Work Element S.1.42.D (Related to S.1.6.A, S.1.9.A, S.1.26.C, S.1.39.D, S.1.40.D, S.1.41.D, and W.2.13.D) (Priority 3)

Determine whether the range of geochemical conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.

Status

The geochemistry of the groundwater in the reference repository location and surrounding area tends to be buffered by reaction with basalts that constitute the bulk of the rocks at depth (see Sections 5.2.3, 6.1, and 6.2). Because of the relatively high rock-to-water ratios, and because the rock compositions do not change appreciably with time, the groundwater compositions will tend to be constant as long as the geothermal gradient remains constant. Changes in groundwater geochemistries would most likely result from an influx of oxygenated surface waters. Such an influx is likely to be very slow; both theoretical considerations and experimental results indicate that such water would react with basalt and become strongly reducing (see Chapter 6). Thus, conditions that would result in geochemical instability, particularly with respect to Eh, are unlikely to develop.

Determination of actual geochemical conditions during the last 1 million years is difficult, because it hinges on a knowledge of groundwater age and on an interpretation of secondary-mineral assemblages. Secondary-mineral assemblages are present within the basalt that have wide stability ranges in pressure-temperature composition space and whose ages of deposition are not known. The dominant secondary minerals, however, are compatible with a reducing environment and the ages of the oldest secondary minerals are almost certainly greater than 1 million years. Thus, there is no physical evidence to refute the conclusion that the basalt will buffer groundwaters to low Eh.

Plans

Data and interpretations that are part of other work elements will contribute to an evaluation of the conclusions discussed above. Specifically, the results of Work Elements S.1.6.A and S.1.9.A will provide more complete and detailed data on secondary minerals. Attempts will also be made to date secondary minerals by the uranium-thorium disequilibrium method and to apply groundwater dating techniques that can extend the present age limitation. The results of this work will be integrated with data gathered under related work elements in Chapter 15. Additional data needs will be established by an iterative process between data collection and modeling.

Work Element S.1.43.D (Related to S.1.30.C, S.1.33.C, S.1.39.D, S.1.40.D, S.1.41.D, W.2.4.A, W.2.8.A, W.2.11.D, and W.2.13.D) (Priority 3)

Determine whether the range of hydrogeologic conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.

Status

The status of work related to an assessment of the hydrogeologic stability of the reference repository location is discussed under Work Elements S.1.30.C (conceptual hydrologic models), S.1.33.C (numerical hydrologic modeling), S.1.39.D (radionuclide transport modeling), S.1.40.D (bounds of uncertainty), S.1.41.D (scenario analysis), and related work elements in Chapter 15 concerned with site geochemistry and waste package design.

Plans

Planned work entails an integration of data gathered under Work Elements S.1.30.C, S.1.33.C, S.1.39.D, S.1.40.D, and S.1.41.D, and related work elements in Chapter 15. Additional data needs will be established by an iterative process between data collection and modeling.

Work Element S.1.44.D (Related to S.1.45.D, S.1.48.D, and S.1.49.D) (Priority 3)

Determine the potential for, and effect of, failure of existing or planned man-made surface water impoundments.

Status

A number of dam failure scenarios have been evaluated by the U.S. Army Corps of Engineers (COE, 1951) involving failure of Grand Coulee Dam. These scenarios account for flow augmentation due to failure of earthen portions of dams downstream from Grand Coulee Dam and consequent releases of their respective storage volumes. The most extreme scenario evaluated was that of a 50-percent breach of Grand Coulee Dam.

Plans

The results of the analysis of transient hydrologic adjustments obtained with Work Element S.1.49.D will be used to determine if analysis of the transient groundwater hydraulics of dam failure scenarios will be required.

Work Element S.1.45.D (Related to S.1.16.B, S.1.41.D, S.1.46.D, and S.1.49.D) (Priority 3)

Determine the effect of potential impoundments on the groundwater flow system.

Status

Man-Made Impoundments. The only remaining site for a potential dam on the Columbia River in the United States is approximately at river kilometer 560 (proposed Ben Franklin Dam). Harty (1979) has provided a detailed analysis of the possible effects of the proposed Ben Franklin Dam and reservoir on the Hanford Site activities. In particular, his study addresses transient adjustments of the shallow groundwater system. No analysis was made of the potential impact on groundwater systems deeper than the unconfined system. The results of a study by Leonhart (1980) indicate that man-made impoundments will probably have no significant effect on seismicity.

Natural Impoundments. The most notable possibility with respect to probable natural impoundments that could affect regional groundwater flow would be related to catastrophic flooding such as might be associated with glacial activity. This scenario is discussed within Work Element S.1.49.D.

Plans

Man-made Impoundments. Using the numerical output from Harty's (1979) study, the potential for vertical movement of groundwater resulting from an elevated groundwater table will be assessed via selected groundwater-flow models.

Natural Impoundments. See Work Element S.1.49.D.

Work Element S.1.46.D (Related to S.1.41.D, S.2.1, and S.2.4) (Priority 3)

Determine the potential for human activity to cause significant changes in the surface and groundwater hydrology.

Status

The most likely scenario associated with potential anthropogenic impacts on regional hydrologic conditions at the site involves progressive encroachment of irrigated agricultural land use onto the reference repository location. This, of course, would involve relinquishment of current land-use controls over the Hanford Site by the U.S. Department of Energy.

To date, a great deal of information has been gathered that can be used to evaluate growth trends in irrigated agriculture (Stephan et al., 1979; Wukelic et al., 1981; Pacific Northwest River Basins Commission, 1980; Johnson et al., 1981). These reports involve inventorying and assessing regional land-use trends using various survey methods and/or remote sensing. Additionally, Leaming (1981) provided an assessment of water resource economics within the Pasco Basin. This report addressed the economic likelihood of various scenarios of conjunctive surface/groundwater use. To date, no formal numerical analysis of the consequences of such a scenario has been performed.

Plans

A formal description of a credible scenario involving agricultural activities near the reference repository location will be documented and a consequence analysis will be performed using appropriate numerical models. Most likely, the scenario will involve supplemental irrigation from groundwater withdrawals for maximum agricultural development (accounting for soil arability, water supply, crop tolerances, etc.). Additionally, monitoring of water level declines in the upper Cold Creek Valley will continue. A similar treatment will be applied to any other significant scenarios identified.

Work Element S.1.47.D (Related to R.1.34) (Priority 3)

Determine the potential for and the effect of occupancy and modification of the Columbia River flood plain.

Status

The reference repository location is situated outside and above the limits of the Columbia River flood plain. However, it is possible that the location could be subjected to flash flooding from the ephemeral Cold Creek during the anticipated 100-year-long preclosure phase of a repository.

Plans

The inundation at the reference repository location that would be associated with a 100-year flash flood event in the Cold Creek watershed is known to be of limited areal extent. Further studies including topographic surveys and analyses will be undertaken to quantify the areal extent and depth of such an event. These studies will be performed with topographic resolution that is detailed enough to support engineering decisions with respect to mitigation measures, should they be determined to be appropriate.

Work Element S.1.48.D (Included in S.1.45.D) (Priority 3)

Determine the potential for and magnitude of impoundment that could affect a change in the regional groundwater flow.

Status

Included in Work Element S.1.45.D.

Plans

Included in Work Element S.1.45.D.

Work Element S.1.49.D (Related to S.1.41.D, S.1.44.D, S.1.45.D, S.1.60.D, and S.2.5) (Priority 3)

Evaluate the effect of possible climatic changes.

Status

Within the range of climatic conditions probable at the reference repository location within the next 10,000 years, catastrophic flooding (as was associated with the last period of continental glaciation) represents the most significant potential impact. Geologic field data (Myers/Price et al., 1979) indicate that the maximum flood level achieved within the Pasco Basin from Pleistocene flooding was on the order of 370 meters. The duration and number of floods is not known, but each probably consisted of short-lived crests. Floodwaters within the basin are believed to have subsided over a period of weeks. The net residual effect of this event on conditions at the repository location was that of sediment deposition. A more detailed description of the geologic effects of catastrophic flooding is included in Sections 3.4 and 3.5 of this document.

Average annual temperatures within the Columbia Plateau region are believed to have varied over a range of 10°C during the Quaternary, based on palynological data (see Section 8.3.1). The net effect of such variations would probably be a change in the ratio of snow to rainfall. This may have an effect on recharge to regional groundwater systems.

A number of studies have been conducted to predict future ice ages (see Section 8.3.1). One model predicts that glaciation may advance into northern Washington within 10,000 years (Foley et al., 1981), while another estimates that the probability of ice cover at Hanford in the next million years is 50 percent (Bull, 1979; 1980).

Plans

The potential for vertical movement of groundwater resulting from standing floodwaters within the Pasco Basin will be assessed using numerical simulation. The sensitivity of regional groundwater flow models to adjustment of recharge parameters will be evaluated.

Work Element S.1.50.D (Related to S.1.41.D, R.1.18.D, and R.1.20.D) (Priority 3)

Determine the potential effect of boreholes on repository performance.

Status

The approximately 2,200 boreholes drilled prior to and after the establishment of the Hanford Site have been documented by Jenkins (1922), Walters and Grolier (1960), Newcomb et al. (1972), McGhan and Damschen (1979), and Fecht and Lillie (1981). The boreholes are of five general types: (1) water supply, (2) gas exploration and production, (3) surveillance, (4) nuclear power plant siting, and (5) repository feasibility and siting. Relatively few of these boreholes penetrate the basalt section.

Plans

Currently, regulations and standard operating procedures for the Hanford Site dictate that the location and depth of any borehole be known and approved by representatives of the U.S. Department of Energy. This ensures that future potential drilling activities within the reference repository location can be controlled, at least during the preclosure phase of the repository. Work to assess the potential consequences of a borehole on postclosure repository performance is discussed under Work Element S.1.41.D and in Chapter 14 (i.e., borehole/shaft sealing).

Work Element S.1.51.D (Included in S.1.41.D) (Priority 1)

Determine the effect on waste isolation of potential changes in such hydrologic conditions as hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.

Status

Included in Work Element S.1.41.D.

Plans

Included in Work Element S.1.41.D.

Work Element S.1.52.D (Related to S.1.17.B, S.1.39.D, S.1.40.D, S.1.41.D, R.1.3.A, R.1.29, R.1.30, and W.1.2.A) (Priority 2)

Determine whether the range in tectonic and structural conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.

Status

The status of work related to an assessment of the tectonic stability of the reference repository location is discussed under Work Elements S.1.17.B (development of a conceptual tectonic model), S.1.37.D (radionuclide transport modeling), S.1.40.D (bounds of uncertainty), S.1.41.D (scenario analysis), and related work elements in Chapters 14 and 15 concerned with in situ stress and seismic design of the repository and waste package.

Plans

Planned work entails an integration of data gathered under Work Elements S.1.17.D, S.1.37.D, S.1.40.D, and S.1.41.D, and related work elements within Chapters 14 and 15. Additional data needs will be established by an iterative process between data collection and modeling.

Work Element S.1.53.D (Included in S.1.16.B, S.1.17.B, and S.1.52.D) (Priority 2)

Determine the historical seismicity of the geologic setting and if there are any historical earthquakes that could adversely affect the repository.

Status

Included in Work Elements S.1.16.B, S.1.17.B, and S.1.52.D.

Plans

Included in Work Elements S.1.16.B, S.1.17.B, and S.1.52.D.

Work Element S.1.54.D (Included in S.1.11.B through S.1.17.B and S.1.52.D.) (Priority 1)

Determine the effect of an active fault within the geologic setting on repository performance.

Status

Included in Work Elements S.1.11.B through S.1.17.B and S.1.52.D.

Plans

Included in Work Elements S.1.11.B through S.1.17.B and S.1.52.D.

Work Element S.1.55.D (Included in S.1.11.B through S.1.17.B and S.1.52.D) (Priority 1)

Determine the effect of an active fault within the disturbed zone on repository performance.

Status

Included in Work Elements S.1.11.B through S.1.17.B and S.1.52.D.

Plans

Included in Work Elements S.1.11.B through S.1.17.B and S.1.52.D.

Work Element S.1.56.D (Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, and S.1.52.D. (Priority 1)

Determine the effect of faults and fractures on repository performance.

Status

Included in Work Elements S.1.1.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, and S.1.52.D.

Plans

Included in Work Elements S.1.1.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, and S.1.52.D.

Work Element S.1.57.D (Included in S.1.16.B, S.1.17.B, and S.1.52.D) (Priority 1)

Determine the effect of seismicity on repository performance.

Status

Included in Work Elements S.1.16.B, S.1.17.B, and S.1.52.D.

Plans

Included in Work Elements S.1.16.B, S.1.17.B, and S.1.52.D.

Work Element S.1.58.D (Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.52.D, and S.1.60.D) (Priority 1)

Determine the effect of structural deformation such as uplift, subsidence, folding, and fracturing on repository performance.

Status

Included in Work Elements S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.52.D, and S.1.60.D.

Plans

Included in Work Elements S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.52.D, and S.1.60.D.

Work Element S.1.59.D (Related to S.1.17.B, S.1.23.B S.1.41.D, and R.1.34) (Priority 3)

Determine the potential for breach of a repository by future fissure eruptions of Columbia River basalt; determine the effect of other types of igneous activity within and in the vicinity of the Pasco Basin.

Status

Potential for occurrence of future igneous activity within the site area, as well as potential impact to the site due to volcanic activity elsewhere, is a function of magma origins, eruptive histories, and tectonic setting. Event occurrence and consequence probability analyses based on the current state of geologic knowledge have been made and documented by Johnpeer et al. (1981). The predictive approach employed (see Section 3.7.2) utilized development of event and consequence networks for preclosure and postclosure repository periods.

Assuming a Poisson distribution of events and consequences based on frequency of past occurrences, probabilities were calculated for important consequences of future eruptive events. Consequent events considered include volcanically induced flooding, covering of the site area by thick, air-fall tephra, ash flows, or lava flows, breach of the repository by a dike or fissure, and disturbance of the near-field groundwater system by igneous activity. Based on such calculations, the probability of volcanically induced events disturbing the integrity of a repository was found to be exceedingly low (see Section 3.7.2).

Plans

Future work will consist of periodic reviews and updates of the present data base. Such reviews will consider additional geothermal gradient and heat flow data (see Work Element S.1.23.B) and will be conducted as part of the development of a refined model of the tectonic setting of the reference repository location (see Work Element S.1.17.B).

Work Element S.1.60.D (Related to S.1.15.B, S.1.17.B, S.1.45.D, S.1.49.D, and S.1.51.D) (Priority 3)

Determine whether the range of geomorphic conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.

Status

Work to assess the range of geomorphic conditions within the Pasco Basin since the start of the Quaternary Period has been conducted by Woodward-Clyde Consultants (WCC, 1980). Landscape modification of the Pasco Basin during the past 1 million years has been dominated by degradational processes. During catastrophic floods, rates of both aggradation and erosion were briefly accelerated (see Section 3.4.2). However, long-term rates of denudation and aggradation have been relatively low. These rates probably reflect dry climate and, perhaps more importantly, relatively low rates of uplift and subsidence.

Based on review of available geologic data regarding surficial processes that shaped the landscape in the Pasco Basin during Quaternary time, Woodward-Clyde Consultants (WCC, 1980) concluded that the net effect of surficial processes during the next 1 million years probably will not be significantly different. Data on rates of surficial geologic processes, particularly rates of uplift and subsidence, are insufficient to accurately predict where the land surface will be in 1 million years. However, based on an assessment of long-term rates of uplift, denudation, and channel incision, Woodward-Clyde Consultants (WCC, 1980) concluded that it was unlikely that more than 100 meters of downcutting will occur anywhere within the Pasco Basin during the next 1 million years. Hence, geomorphic effects on waste isolation are concluded to be inconsequential.

Plans

Rates of tectonic processes are the dominant factor affecting the evolution of the landscape in the Pasco Basin. The existing data base for deformation rates during the Quaternary is limited. Additional geologic studies of surficial Pliocene and Quaternary sediments will be completed to better constrain rates of tectonic uplift, subsidence, and folding within the Pasco Basin (see Work Element S.1.15.B).

Work Element S.1.61.D (Included in S.1.60.D) (Priority 3)

Determine the likelihood of repository exhumation due to extreme erosion over the next 10,000 years.

Status

Included in Work Element S.1.60.D.

Plans

Included in Work Element S.1.60.D.

13.3.2 Environmental and Socioeconomic Considerations

There are no unresolved issues in the work elements related to environmental and socioeconomic considerations. The analysis of data needs and status of work supporting work elements in this area are contained in Table 13-6. Although the following work elements do not relate to any issue, they are required to satisfy the criteria listed in Section 13.4.

Work Element S.2.1. (Related to S.1.46.D, S.2.3, and S.2.4) (Priority 2)

Establish baseline ecologic, radiologic, sociopolitical, and economic conditions against which impacts can be assessed and mitigation measures proposed.

Status

As part of the studies leading to the identification of a potential repository site at Hanford (Section 2.4), careful consideration has been given to environmental impacts. By avoiding areas of sensitive wildlife habitat, archaeological sites, important water resources, and significant population centers, the first step has been taken in reducing any environmental impacts. The remoteness of the reference repository location from urban centers helps to minimize the effects of noise or visual impact on members of the public.

TABLE 13-6. Work Element Analysis: Data Needs and Status Supporting Environmental and Socioeconomic Considerations. (Sheet 1 of 3)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
WORK ELEMENTS NOT RELATED TO ISSUES			
S.2.1 (Related to S.1.46.D, S.2.3, and S.2.4) Establish baseline ecologic, radiologic, sociopolitical, and economic conditions against which impacts can be assessed and mitigation measures proposed.	All requirements of the National Environmental Policy Act (CEQ, 1978) and other local, state, and federal regulations will be integrated into data collection and analysis plans. Information needs include:	Not applicable.	
	• Identification of major habitat types and important species within the reference repository location		Preliminary identification has been made (see Section 9.1 of this document).
	• Determination of radionuclide-concentration levels in the biotic and abiotic components of the reference repository location		Preliminary radiologic conditions have been established (see Section 9.1 of this document).
	• Identification of potential impacts of construction and operation of a repository on the environment and socioeconomic factors		Preliminary environmental conditions have been established (see Section 9.1 of this document). Baseline socioeconomic conditions have been established (see Section 9.3 of this document).
	• Citizen input to impact assessment and mitigation strategies		Public information meetings and periodic briefing sessions with state, local, and Indian reservation officials have been held during the siting process (see Section 2.5.3 of this document).
	• Development of mitigation plans		No data available.
	• Determination of the extent and radionuclide concentration of the existing 200 West Area contaminated groundwater plume.		A comprehensive groundwater-monitoring program is being routinely carried out (Eddy and Wilbur, 1980; Graham, 1981; Graham et al., 1981).

TABLE 13-6. Work Element Analysis: Data Needs and Status Supporting Environmental and Socioeconomic Considerations. (Sheet 2 of 3)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.2.2 (Related to S.2.3) Determine if subsurface mining is present within the disturbed zone.	None.	Not applicable.	A survey of the site has shown that no subsurface mining is present within the proposed repository and buffer zone (see Chapter 3 of this document; GG/GLA, 1981).
S.2.3 (Related to S.2.1, S.2.2, and R.1.34) Determine the gross value, net value, and commercial potential of resources within the disturbed zone and within similar-size areas that are representative of and located within the geologic setting.	Information needs include:	Not applicable.	
	• Compilation of available resource exploration and production data		Compilation completed (see GG/GLA, 1981; Section 3.9 of this document).
	• Compilation and analysis of available geologic maps		Compilation completed (see GG/GLA, 1981; Section 3.9 of this document).
	• Analysis of petrogenic and metallogenic attributes of the Hanford Site and Columbia Plateau in the context of their tectonic and petrogenic characteristics and setting		Completed for Columbia River Basalt Group and surficial sediments; incomplete for subbasalt lithologies (see GG/GLA, 1981; Section 3.9 of this document).
	• Compilation and analysis of population, land area, personal income, tax revenue, labor statistics, and mineral gross value, costs, net value, and net-present values. Analysis of potential values from possible future production		Current data base on Columbia River Basalt Group and surficial sediments indicates that the gross and net value and commercial potential of resources appear to be minimal compared to the remainder of the Columbia Plateau and the western United States; data that could be used to assess subbasalt lithologies is currently unavailable (see GG/GLA, 1981; Section 3.9 of this document).
	• Knowledge of current leasing and exploration activity.		Ongoing.

TABLE 13-6. Work Element Analysis: Data Needs and Status Supporting Environmental and Socioeconomic Considerations. (Sheet 3 of 3)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
S.2.4 Identify the distribution of land ownership, use, and control of the repository area.	None.	Not applicable.	The Hanford lands have been under federal jurisdiction since 1943.
S.2.5 (Related to S.1.49.D) Determine the meteorologic, climatologic, and air-quality conditions to be used as design and operating bases and assess future climatic changes that may affect repository performance.	Joint frequency distribution tables of windspeed, wind direction, and stability at the effluent release height for characterization of off-site dispersion acquired in accordance with guidelines proposed by the NRC (1972; 1980).	Not applicable.	Hanford Meteorological Station tower data have been the historical basis for the evaluation of dispersion for Hanford operations (Stone et al., 1972; Section 8.4.1 of this document). Meteorological conditions for repository design bases have been identified and include, among others, high wind, extreme temperatures, severe duststorms, and lightning (see Section 8.3.2 of this document). Future climatic variations have been projected and it is likely that the largest climate changes will be toward continued cooling (see Chapter 8 of this document).

A preliminary socioeconomic survey of the potential impact area has been undertaken. Baseline conditions have been identified and summarized (Section 9.3). Initial contacts have been made with government officials to establish two-way information exchange.

Plans

All major habitat types within the reference repository location will be identified. Upon identification of major habitat types and important species, detailed ecologic surveys will be undertaken. These surveys will include fieldwork and review of pertinent literature to establish baseline ecologic conditions. Major parameters within the reference repository location that could be affected by construction, operation, and decommissioning of a repository will be identified (e.g., critical habitat, threatened or endangered species, etc.).

Baseline radiologic inventories will include type, levels, location, and associations of radionuclides with respect to important biotic and abiotic components of the area. The radiologic inventory will also provide data relevant to radionuclide transport pathways, identification of potential problem areas, and identification of future monitoring requirements. Monitoring of the contaminated plume of groundwater to the southwest of the 200 West Area will continue. This data will be used to assure that all sources of groundwater contamination are known and any necessary preventive measures associated with construction and operation of a repository can be taken. Sampling procedures and field methodologies will be provided for both radiologic and ecologic surveys. All requirements of the National Environmental Policy Act and other local, state, and federal regulations will be integrated into data collection and analysis plans.

After determining the baseline environmental and radiological conditions at the reference repository location, impacts from the construction, operation, and decommissioning of a repository will be projected. These projections will be used to develop and implement plans to mitigate those impacts to the extent required.

The socioeconomic evaluation will encompass those activities required to evaluate the potential impact of the construction, operation, and decommissioning of a repository at the Hanford Site. These impacts can be both beneficial (e.g., create new jobs) and adverse (e.g., increased demands on transportation). Socioeconomic impact assessment and program plans for mitigation will evaluate current socioeconomic impacts of a repository and propose mitigation measurements. As new information becomes available from progressive stages of repository design (i.e., Title I (preliminary) and Title II (detailed)) the sociopolitical baseline as well as the impact assessment and program plan for mitigation will be revised.

An information program will serve to give the community a better understanding of how a repository will impact them. Community input to impact assessment and mitigation strategies will be sought.

Work Element S.2.2 (Related to S.2.3) (Priority 3)

Determine if subsurface mining is present within the disturbed zone.

Status

No subsurface mining is present within the disturbed zone (see Sections 3.2 and 3.9 of this document).

Plans

Currently, regulations and standard operating procedures for the Hanford Site dictate that the location and depth of any excavation be known and approved by representatives of the U.S. Department of Energy. This ensures that future potential mining activities, at least during the preclosure phase of the repository, can be controlled.

Work Element S.2.3 (Related to S.2.1, S.2.2, and R.1.34) (Priority 3)

Determine the gross value, net value, and commercial potential of resources within the disturbed zone and within similar-size areas that are representative of and located within the geologic setting.

Status

An inventory has been made of known occurrences of mineral and fossil fuel resources within a 100-kilometer radius of the proposed site. A geologic analysis of resource occurrence potential of the same area has been made based on known mineral occurrences, stratigraphic and structural features of the area, and known geologic associations of resources with particular lithologies, structures, and tectonic settings.

An economic study (GG/GLA, 1981) based on the geologic analysis was made to determine probable value of mineral and fossil fuel resource production from known and potential resources within 100 kilometers of the site. Economic data were projected for a period of 25 years--a period considered to be the maximum foreseeable forecast period for the economic data analyzed (see Section 3.9). The analysis considers only those resources that are known to occur or that potentially occur within surficial sediments and the Columbia River Basalt Group.

Values determined for gross, net, and net-present value of resources within 100 kilometers of the site have been compared to analogous values for the remainder of the Columbia Plateau and other areas of the western United States. A comparison basis of resource value per unit area and per capita income derivable from resources was utilized. The gross and net value and commercial potential of such resources appear to be minimal, based on current data, compared to the remainder of the Columbia Plateau and the western United States (GG/GLA, 1981).

Plans

Collection of additional methane gas samples from hydrologic test wells and their isotopic analysis is planned to establish a data base adequate to help evaluate the presence of natural gas within the Columbia River Basalt Group. Monitoring of resource exploration leasing and drilling activity on the Columbia Plateau will continue. Analysis of organic matter content of interbed and subbasalt sediments sampled by drill core (if available from the deepening of an existing borehole within the Pasco Basin, see Work Element S.1.14.B) will be carried out to evaluate their potential as sources of oil or gas. Geologic logging and gas content monitoring of exploration boreholes to be drilled in conjunction with hydrologic testing will be conducted both for evaluation of economic potential of possible natural gas resources and for analysis of its potential impact on underground construction (see Chapter 14).

Work Element S.2.4 (Priority 3)

Identify the distribution of land ownership, use, and control of the repository area.

Status

The Hanford lands were placed under federal jurisdiction in 1943 (see Section 9.2). Since federal jurisdiction predates local, regional, and state planning for the area, Hanford lands are designated as an existing special use in all land-use plans. Compatibility of the repository with other land-use plans at the Hanford Site is assured by the integration of the project into overall Hanford land-use planning activities.

Plans

No additional plans needed.

Work Element S.2.5 (Related to S.1.49.D) (Priority 3)

Determine meteorologic, climatological, and air-quality conditions to be used as design and operating bases and assess future climatic changes that may affect repository performance.

Status

Meteorologic data have been collected in the Hanford area since 1912. Climatology records from 1945 to 1980 have been evaluated at the Hanford Meteorological Station, located within the reference repository location. The data include standard 24-hour surface observations as well as other measurements specifically taken to describe atmospheric dispersion climatology of the Hanford area (Section 8.4.1).

Severe and extreme meteorologic phenomena that will be considered for design and operating bases of the reference repository location have been identified and include, among others, high winds, extreme temperatures, severe duststorms, and lightning. Future climatic variations that may affect repository performance have been projected and it is likely that the largest climatic changes will be toward continued cooling (Section 8.3.2).

Plans

Due to local variations in climatic elements within the reference repository location, a meteorology tower may be erected in the vicinity of the proposed surface facilities and incorporated into the Hanford meteorologic network. The onsite meteorologic monitoring program will be conducted in accordance with guidelines set forth by the U.S. Nuclear Regulatory Commission for commercial nuclear facilities. The meteorologic data collection systems will meet U.S. Nuclear Regulatory Commission guidelines proposed for installation, recording, display, and accuracy of meteorologic variables (NRC, 1972; 1980). Instrument maintenance, servicing schedules, and data availability will meet U.S. Nuclear Regulatory Commission requirements. In general, this will require better than 90-percent data recovery to generate joint frequency distribution tables of windspeed, wind direction, and stability at the effluent-release height. Data reduction and compilation will proceed in accordance with published U.S. Nuclear Regulatory Commission guidelines in a format compatible with the application of the Hanford dispersion models.

13.4 SUMMARY OF BASALT WASTE ISOLATION PROJECT SITE ACTIVITIES

The status and plans for each of the work elements associated with geologic and hydrologic considerations and environmental and socioeconomic considerations were presented in Section 13.3. In this section, a brief description of all the technical work being undertaken by the BWIP on these tasks is provided in summary narrative form. These narratives are accompanied by a logic diagram (Fig. 13-4) that describes, in general form, the main activities to accomplish the work and those points at which the issues presented in Section 13.3 will be resolved. Schedules and milestones for the work described in this chapter are presented in Chapter 17. Each box on the logic diagram is keyed to the narrative material. Each section of the narrative also contains a list of the work elements that support the tasks designated.

As noted in Section 13.1, much of the site work is oriented toward an evaluation of the geologic and hydrologic stability of the reference repository location. As such, most of the activities identified in the logic chart (Fig. 13-4) involve characterization and modeling work that can be used to assess the postclosure performance of a repository in basalt.

Summary Activity Narratives

1. Prepare Input to Basalt Waste Isolation Project Plan

   The site input to the BWIP plan describes geologic, hydrologic, environmental, socioeconomic, and performance assessment activities necessary to identify, characterize, and evaluate a site for a licensed repository within basalt at the Hanford Site. It also includes activities that relate to the exploratory shaft. Site activities shown in the logic diagram (Fig. 13-4) include those that directly or indirectly support all phases of the BWIP leading up to, and including, the license application for repository construction.

   Applicable Work Elements

   Initial work completed. The BWIP updates technical plans on a continuing basis. The definition (technical planning) of the work required to meet proposed criteria and draft regulations, covered in Chapter 13, forms the basis for this planning.

2. Conduct Preliminary Geologic Characterization and Integration

   Initial geologic characterization work of the BWIP consisted of the collection and interpretation of basic geologic data for the Washington State portion of the Columbia Plateau. On the basis of this data, a preliminary interpretation of the stratigraphic, structural, and tectonic setting of the Pasco Basin was formulated.

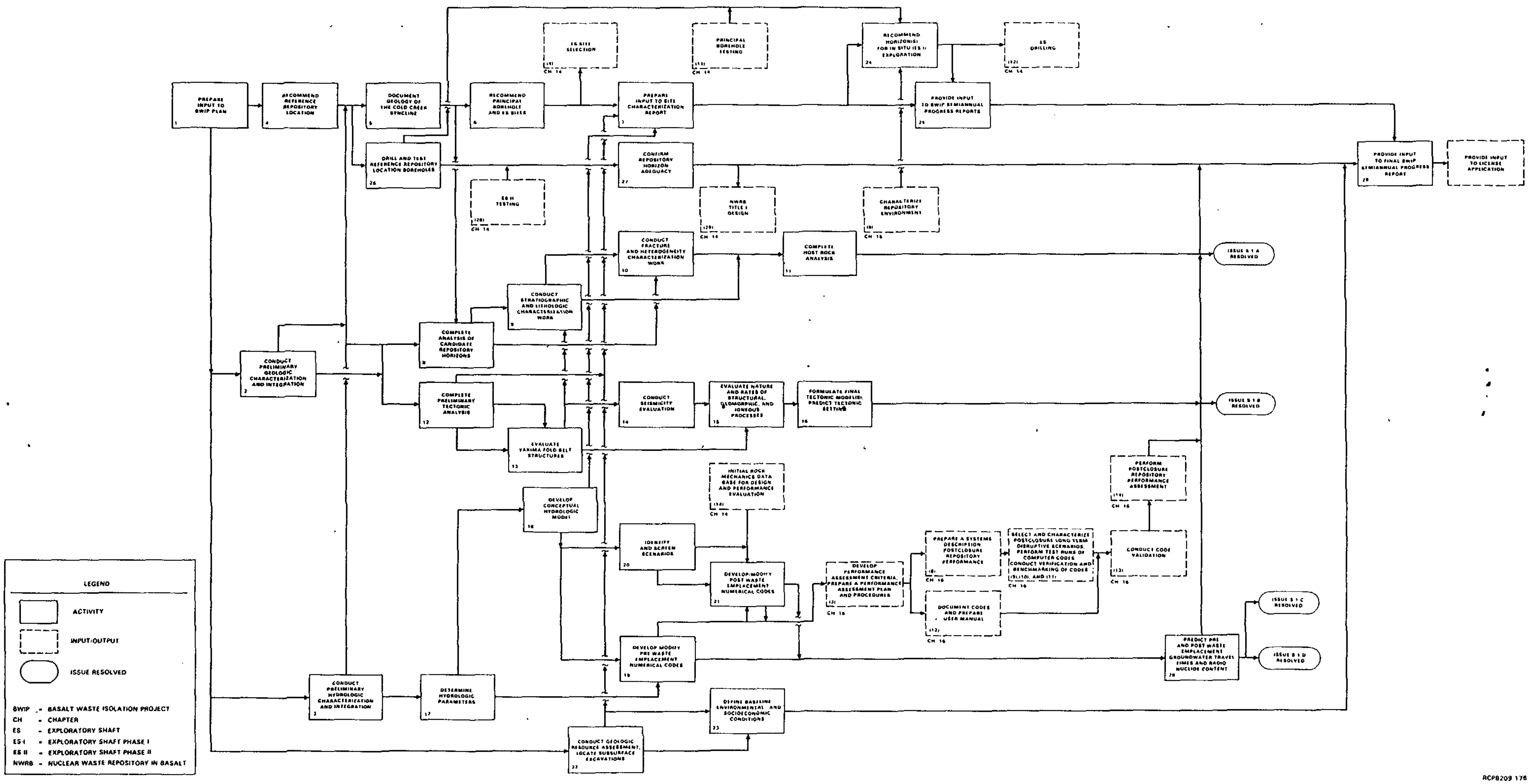

FIGURE 13-4. Logic Diagram for Site.

The results of this work are documented in a geologic data integration report (Myers/Price et al., 1979). Information contained in this report provided geologic input to the site identification process (see Fig. 13-4, Logic Node No. 4).

Applicable Work Elements

Work completed. See Myers/Price et al. (1979).

3. Conduct Preliminary Hydrologic Characterization and Integration

Initial hydrologic characterization work of the BWIP consisted of the collection and interpretation of basic hydrologic data for the Washington State portion of the Columbia Plateau. On the basis of this data, preliminary conceptual and numerical models were formulated for the Pasco Basin. The results of these hydrologic investigations are documented in a hydrologic data integration report (Gephart et al., 1979a). Information contained in this report provided hydrologic input to the site identification process (see Fig. 13-4, Logic Node No. 4).

Applicable Work Elements

Work completed. See Gephart et al. (1979a).

4. Recommend Reference Repository Location

A methodology was developed, structured, and implemented to identify candidate repository sites within the Pasco Basin and Hanford Site. The steps in the siting process included: identification of prospective candidate sites using a screening process, determination of a limited number of candidate sites, and determination of their relative adequacy. These steps resulted, ultimately, in the selection of the reference repository location and alternate within the Cold Creek syncline.

Applicable Work Elements

Work completed. See Chapter 2 of this document and WCC (1981) for a detailed discussion of the geologic, hydrologic, environmental, and socioeconomic input to the site identification process.

5. Document Geology of the Cold Creek Syncline

The status of current knowledge of stratigraphic, lithologic, and structural factors that relate specifically to the suitability of basalt flows within the Cold Creek syncline as host rock for a nuclear waste repository has been documented by Myers and Price (1981). The studies discussed concentrated on geologic factors that could potentially affect groundwater transport of radionuclides. These factors included: (1) intraflow structures, (2) interflow horizons and flow fronts, and (3) bedrock structures.

Applicable Work Elements

Work completed. See Myers and Price (1981).

6. Recommend Principal Borehole and Exploratory Shaft Sites

Geologic data contained in Myers and Price (1981), in conjunction with engineering and land-use data, were evaluated as part of an effort to identify the location of a principal borehole (i.e., pilot borehole for an exploratory shaft). The borehole (RRL-2, Fig. 13-2), and the nearby shaft site, are located 2.5 kilometers west of the 200 West Area within the Hanford Site.

Applicable Work Elements

Work completed. See Section 2.6 of this document.

7. Prepare Input to Site Characterization Report

Available geologic, hydrologic, environmental, and socioeconomic information was reviewed to prepare input to this document. The results of this review, and a review of repository criteria documents (NRC, 1981; NWTS, 1981a; 1981b; 1981c; 1981d; EPA, 1981), were used to identify site issues (see Table 13-1) and to prepare a plan for addressing these issues.

Applicable Work Elements

Work completed. See Chapters 2, 3, 5, 7, 8, 9, and 12 of this document.

8. Complete Analysis of Candidate Repository Horizons

The status of current knowledge of the geochemistry, petrology, mineralogy, and nature of intraflow structures of candidate repository horizons within the Cold Creek syncline (based on an analysis of available borehole and outcrop data) will be documented. The results of stratigraphic, host rock lithologic, and host rock geometric studies will be integrated to generate geologic maps and fence diagrams of these horizons in the reference repository location and adjacent area. The status of knowledge regarding the hydrologic setting of candidate repository horizons will also be reported. Information to be documented will serve as a basis for: (1) predicting the variability of lithologic and mineralogic properties of candidate repository horizons within the reference repository location (see Logic Node No. 9, 10, and 11) and (2) conducting near- and far-field performance assessment modeling work (see Chapter 16).

Applicable Work Elements

S.1.1.A through S.1.10.A, S.1.12.B, S.1.24.C through S.1.34.C, S.1.39.D, and S.1.40.D.

9. Conduct Stratigraphic and Lithologic Characterization Work

Additional stratigraphic, structural, textural, mineralogic, and petrographic data will be obtained from new and existing boreholes within and in the vicinity of the reference repository location and from further analysis of outcrops. An evaluation of these data will be used to acquire an understanding of factors controlling short-range variations in flow thicknesses and intraflow structures, so that such variations can be factored into repository design considerations and into near- and far-field performance assessment models. A series of isopach maps of candidate repository horizons and other basalt flows above and below these horizons will be produced as part of this work. These maps will emphasize the locations of potential flow fronts, thickness variations, and other stratigraphic variations.

Applicable Work Elements

S.1.1.A, S.1.4.A, S.1.7.A, S.1.8.A, and S.1.10.A.

10. Conduct Fracture and Heterogeneity Characterization Work

Additional data will be obtained from detailed fracture and lithologic logging of core from new and existing boreholes within and in the vicinity of the reference repository location. Work will also include a detailed petrographic analysis of both surface and subsurface samples to determine the extent to which petrography can be used to predict fracture spacing at depth. The emphasis of these studies will be to determine the orientation, distribution, aperture infilling (secondary mineralization) and origin of fractures, discontinuities, and heterogeneities within the candidate repository horizons and surrounding strata. Maps and written descriptions of the candidate repository horizons and adjacent flows will be produced to show variation of fractures and other discontinuity patterns, their distributions, and occurrence frequencies. The results of these studies will be used as input to hydrologic, geomechanical, and radionuclide release models.

Applicable Work Elements

S.1.5.A, S.1.6.A, S.1.8.A, S.1.9.A, S.1.10.A, S.1.27.C, S.1.28.C, S.1.29.C, S.1.30.C, W.2.1.A, W.2.4.A, and W.2.13.D.

11. Complete Host Rock Analysis

The results of work carried out under Logic Node No. 8 through 10 (Fig. 13-4) will be documented in technical reports, publications in the open literature, and semiannual progress reports (see Logic Node No. 25). A summary of the final results of host rock analysis work will be prepared as input to the environmental report and License Application (see Logic Node No. 28 and 29, respectively).

Applicable Work Elements

S.1.1.A through S.1.10.A.

12. Complete Preliminary Tectonic Analysis

A preliminary interpretation of the tectonic stability of the Columbia Plateau, Pasco Basin, and reference repository location will be documented. This interpretation will be based on a review of available geologic, geophysical, geodetic, and seismologic information. Included in the report will be a discussion of the tectonic history of the study area, the mechanics of Yakima fold-belt deformation, and geologic and contemporary rates of deformation. Available tectonic models will be evaluated with respect to how well they will be in agreement with existing data and how they could affect the preclosure and postclosure performance of a repository constructed within the reference repository location.

Applicable Work Elements

S.1.11.B through S.1.23.B.

13. Evaluate Yakima Fold-Belt Structures

Work will continue to define the pattern of subtle deformation within the Cold Creek syncline and reference repository location. Geophysical anomalies and known structures will be evaluated to determine the geometry and volume of intact basalt host rock available for repository construction and to locate bedrock structures that might affect hydrologic flow paths. Data from new boreholes within and in the vicinity of the reference repository location will be utilized to calculate and verify the strike and dip of candidate repository horizons. Additional work will also be focused on defining fault parameters supportive of seismic design specifications and preclosure and postclosure performance assessment modeling (including tectonic model development). Such parameters, which include fault geometry, amount of displacement, and age, will be evaluated through field studies and shallow geophysical surveys (and possibly trenching and shallow drilling as appropriate). The hypothesized relationship between Yakima fold-belt structures and structures in rocks beneath the Columbia River basalt will be investigated through the use of geophysical surveys (primarily gravity and magnetotellurics), kinematic analysis, and mechanical modeling. Studies will be focused toward distinguishing between the proposed models of Yakima fold-belt deformation and toward evaluating the potential effects such models could have on the pattern of deformation within the reference repository location.

Applicable Work Elements

S.1.2.A, S.1.3.A, S.1.12.B, S.1.13.B, S.1.14.B, S.1.17.B, S.1.18.B, S.1.19.B, S.1.20.B, and S.1.29.C.

14. Conduct Seismicity Evaluation

Work will include a continuation of regional seismic monitoring by a network of surface seismometers already established in eastern Washington. This regional network is being supplemented, as required, with the addition of portable and permanent surface seismometers. These instruments will be used to gather detailed data on microseismic activity within the Pasco Basin, Cold Creek syncline, and reference repository location. Instrumentation in at least one borehole will be used to monitor the nature of seismicity within candidate repository horizons. Analysis of the results of seismic monitoring, in conjunction with a geologic analysis of the Yakima fold system (see Logic Node No. 13), will provide data that will be used to assess the current and projected nature and rates of deformation within and in the vicinity of the reference repository location (see Logic Node No. 15). Such data will also be utilized to support seismic design work and to assess the effects of seismicity on the postclosure performance of a repository in basalt (see Chapter 16).

Applicable Work Elements

S.1.15.B, S.1.16.B, S.1.17.B, S.1.22.B, S.1.41.D, S.1.53.D, S.1.57.D, R.1.22.B, R.1.29, and R.1.30.

15. Evaluate Nature and Rates of Structural, Geomorphic, and Igneous Processes

Work will entail the use of stratigraphic, structural, geomorphic, geodetic, and seismic data to determine past and contemporary rates of deformation within and in the vicinity of the reference repository location. Determinations include rates of uplift, subsidence, folding, faulting, and tectonically induced strain. Geologic data will be obtained primarily through an examination of the distribution and deformation of basalt flows and suprabasalt sediments. Data on contemporary deformation rates will be provided through the periodic resurveys of the Hanford trilateration network and the reoccupation of leveling stations. Geodetic data will be evaluated with seismic monitoring data to further assess the nature of stress and strain within the area. Studies to evaluate the nature and rates of geomorphic and igneous processes within the Pasco Basin are essentially complete (WCC, 1980; Johnpeer et al., 1981; Murphy and Johnpeer, 1981).

Applicable Work Elements

S.1.15.B, S.1.17.B, S.1.21.B, S.1.23.B, and S.1.60.D.

16. Formulate Final Tectonic Model(s); Predict Tectonic Setting

A tectonically stable area is one in which the present and projected rates of tectonic processes are considered not to pose a hazard to repository construction and operation or to the long-term isolation of radioactive waste. Work will be undertaken to develop a tectonic model that can be used to predict the tectonic setting of a repository over the next 10,000 years. This model will be a nonnumerical descriptive theory that incorporates geologic, geophysical, seismologic, and geodetic data into a satisfactory explanation of the dynamic development of geologic structures. Currently, a number of tectonic models have been proposed for the Columbia Plateau. Work will be conducted to evaluate available models in terms of their impact on preclosure and postclosure repository performance. Investigations that may provide a basis for model distinction are discussed under Logic Nodes No. 12 through 15 (Fig. 13-4).

Applicable Work Elements

S.1.11.B through S.1.23.B.

17. Determine Hydrologic Parameters

Establishment of a data base of hydrologic parameters will continue in support of developing a reasonable understanding of the present groundwater system and of that which can be postulated to occur in the future. Hydrologic parameters requiring definition include hydraulic properties (hydraulic conductivity, storativity, effective porosity, dispersivity), hydraulic heads (fixed and time variant), and hydrochemical properties. Data will be obtained primarily from: (1) single, dual, and cluster borehole testing within and immediately surrounding the reference repository location, (2) single and dual borehole testing within the Cold Creek syncline either near the reference repository location or along the groundwater flow paths, and (3) single borehole testing in areas surrounding the Cold Creek syncline. The results of these testing activities and the results of applicable geologic work will be continuously input to the modeling studies of the near-field and far-field hydrologic system. Any additional data needs will be established through an iterative process of data collection and modeling.

Applicable Work Elements

S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, S.1.29.C, S.1.35.C, and S.1.36.C.

18. Develop Conceptual Hydrologic Model

The conceptual hydrologic model represents the organization of acquired data on the hydrologic regime into a system-type description that can be used for numerical simulation and prediction. As such, the conceptual hydrologic model forms the basis for determinations of

both pre- and post-waste-emplacement groundwater travel times in support of performance assessment work. Initial BWIP work (see Logic Node No. 3) was used to formulate a preliminary conceptual model of the Hanford Site, in particular, and the surrounding Columbia Plateau, in general. This model provided a substantial basis for the planning of further hydrologic investigations and the development of mathematical representations. Subsequent conceptual modeling, numerical modeling, and field testing has been and will continue to be performed in an iterative fashion as data is generated from hydrologic parameter work (see Logic Node No. 17) and geologic work. At the completion of such work, the conceptual hydrologic model will be finalized and final numerical models formulated.

Applicable Work Elements

S.1.30.C and S.1.32.C.

19. Develop/Modify Pre-Waste-Emplacement Numerical Codes

Numerical codes that are directly applicable to hydrologic simulations in a basaltic rock environment have been assembled and applied. These codes were identified on the basis of a review and evaluation of existing numerical codes, including those available through the Office of Nuclear Waste Isolation. As part of this work, recommendations will be developed for improvement of the numerical codes, as well as for the collection of additional data needed to refine the conceptual model.

Applicable Work Element

S.1.31.C.

20. Identify and Screen Scenarios

The planned performance assessment for evaluating compliance with U.S. Nuclear Regulatory Commission proposed criteria and U.S. Environmental Protection Agency draft regulations must consider a broad range of potential radionuclide release conditions. To date, a number of generic scenarios have been screened and evaluated on the basis of credibility, consistency with site-specific geologic and hydrologic knowledge, event likelihood, and release potential to preliminarily define scenarios relevant to disruption of a repository in Columbia River basalt. As discussed in Chapter 16, the current list of plausible scenarios will be expanded to include other postulated events potentially associated with preclosure and postclosure conditions.

Applicable Work Elements

S.1.41.D through S.1.61.D, S.2.1, S.2.3, and S.2.5.

21. Develop/Modify Post-Waste-Emplacement Numerical Codes

A set of numerical codes has been developed and interfaced for use in repository analysis. The numerical codes are designed to simulate the response of the repository system (engineered facility and geohydrologic system) in the postclosure period. Numerical model application (see Chapter 16) will be used to provide an information base for judging the adequacy of these codes. As part of this work, recommendations will be developed for improvement of the codes, as well as for the collection of additional data needed to refine the modeling effort.

Applicable Work Element

S.1.37.D.

22. Conduct Geologic Resource Assessment; Locate Subsurface Excavations

An evaluation of the geologic resource potential within a 100-kilometer radius of the reference repository location has been completed (GG/GLA, 1981). This evaluation included a determination of the gross value, net value, and commercial potential of mineral resources and documentation of subsurface mining or drilling for resources. This geologic and economic analysis of resource occurrence provides data that will also be utilized in a disruptive event scenario analysis (see Logic Node No. 20, Chapter 16). Geologic logging and gas content monitoring of exploration boreholes to be drilled in conjunction with hydrologic testing (see Logic Node No. 17) will be continued. Such work will be conducted to provide an evaluation of economic potential of possible natural-gas resources and for analysis of its potential impact on underground construction. Monitoring of resource exploration leasing and drilling activity on the Columbia Plateau will also continue.

Applicable Work Elements

S.1.41.D, S.1.46.D, S.1.50.D, S.2.2, and S.2.3.

23. Define Baseline "Environmental" and "Socioeconomic" Conditions

Requirements of the National Environmental Policy Act (CEQ, 1978) and other applicable local, state, and federal regulations will be integrated into data collection and analysis plans for the establishment of baseline ecologic and radiologic conditions. Work to determine baseline ecologic conditions will include the identification of major habitat types within the reference repository location. Upon identification of major habitat types (the important species), detailed ecologic surveys will be undertaken. Baseline radiologic inventories will be conducted with respect to important biotic and abiotic components of the area. The radiologic inventory will be used to provide data relevant to radionuclide transport pathways, identification

of potential problem areas, and establishment of future monitoring requirements. Using baseline data, impacts from the construction, operation, and decommissioning of a repository will be projected. These projections will be used to develop and implement plans to mitigate those impacts to the extent required.

Economic work will include an evaluation of current socioeconomic impacts of a repository and formulation of mitigation measurements. As new information becomes available from progressive stages of repository design (i.e., Title I and Title II), the sociopolitical baseline as well as the impact assessment and program plan for mitigation will be revised. A program will be continued to give the community a better understanding of how a repository will affect them. Community input to impact assessment and mitigation strategies will be sought.

Compatibility of the repository with other land-use plans at the federally owned Hanford Site is assured by the integration of the project into overall planning activities.

Severe and extreme meteorologic phenomena that will be considered for design and operating bases of the reference repository have been identified. Onsite meteorologic monitoring will be continued in accordance with guidelines proposed by the U.S. Nuclear Regulatory Commission (NRC, 1972; 1980) for commercial facilities. Data reduction and compilation will be in a format compatible with the application of the Hanford dispersion models. Projected climatic conditions have been established and have been used as input to postclosure performance assessment work (see Logic Node No. 20, Chapter 16).

Applicable Work Elements

S.2.1, S.2.3, S.2.4, and S.2.5.

24. Recommend Horizon(s) for In Situ (Exploratory Shaft-Phase I) Exploration

Geologic and hydrologic data, in conjunction with related geochemical and engineering data (see Chapters 14, 15, and 16), will be evaluated in order to recommend candidate repository horizon(s), which will be subject to in situ testing and exploration within the exploratory shaft (Phase I). Logic Node No. 24 will include activities associated with the documentation of the recommendation and selection process and supporting data.

Applicable Work Elements

S.1.1.A through S.1.10.A, S.1.12.B, S.1.11.C through S.1.34.C, S.1.39.D, S.1.40.D, R.1.11.B, R.1.12.B, W.1.2.A, W.1.7.A, W.1.10.A, W.1.12.A, W.2.1.A, and W.2.3.A.

25. Provide Input to BWIP Semiannual Progress Reports

Newly available site characterization data and data from the exploratory shaft testing program will be included in semiannual progress reports.

Applicable Work Elements

Work elements applied to this task are those that contribute to the resolution of Issues S.1.A, S.1.B, S.1.C, and S.1.D, and pertinent environmental and socioeconomic work elements (Fig. 13-4).

26. Drill and Test Reference Repository Location Boreholes

Boreholes located in the reference repository location will be drilled and tested to obtain geologic, hydrologic, and geochemical data. Some of the data was used to select the principal borehole and exploratory shaft location. Data available at a later time will be used as input to the BWIP semiannual progress reports and confirmation of the adequacy of the candidate repository horizon.

Applicable Work Elements

Work elements applied to this task are those that contribute to the resolution of Issues S.1.A and S.1.C.

27. Confirm Repository Horizon Adequacy

Geologic and hydrologic data, in conjunction with related geochemical and engineering data (see Chapters 14, 15, and 17), will be evaluated in order to recommend the candidate repository horizon most suitable for repository construction. Logic Node No. 27 will include activities associated with the documentation of the recommendation and selection process and supporting data.

Applicable Work Elements

Work elements applied to this task are those that contribute to the resolution of Issues S.1.A, S.1.C, and S.1.D, R.1.A, W.1.A, W.2.A, and W.2.B.

28. Predict Pre- and Post-Waste-Emplacement Groundwater Travel Times and Radionuclide Content

The results of hydrologic testing activities and the results of applicable geologic work will be continuously input to the modeling studies of the near- and far-field hydrologic system. An assessment of long-term isolation potential of the repository setting will require a detailed risk assessment that identifies plausible natural and man-induced release modes, estimates the probabilities of

the release modes, and conservatively bounds the uncertainty of these release analyses. Documents covering the progress of work relating to such an assessment will be prepared and issued on a periodic basis. Final documentation will be issued when a technical consensus is reached that the available data base and modeling are adequate to evaluate whether the repository system meets regulatory guidelines and poses no significant long-term hazard to man. A summary of this documentation will be included as input to the environmental report and License Application.

Applicable Work Elements

S.1.1.A through S.1.10.A, S.1.11.B through S.1.36.C, S.1.37.D through S.1.61.D, S.2.1, S.2.3, and S.2.5.

29. Provide Input to Final BWIP Semiannual Progress Report

The final BWIP semiannual progress report will contain the site-related information necessary to support the preparation of the draft environmental assessment report for the repository and the License Application for repository construction.

Applicable Work Elements

Work elements applied to this task are those that contribute to the resolution of Issues S.1.A, S.1.B, S.1.C, and S.1.D, and pertinent environmental and socioeconomic work elements (Fig. 13-4).

13.5 SITE CRITERIA/ISSUES/WORK ELEMENTS

The criteria, issues, and work elements utilized in the narratives in Section 13.3 are presented here (Table 13-7). Introductory comments concerning the development and organization of this table are contained in Section 13.0.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 1 of 20)

Technical criteria	Issues	Work element
S.1 - Geology and Hydrology		
Areas Adjacent to the Geologic Repository Operations Area (60.102(c)) Within the geologic setting (or site), particular attention must be given to the characteristics of the host rock as well as any rock units surrounding the host rock. For clarification see: NWTS 33(2), 3.1 NWTS 33(2), 3.2(1) NWTS 33(2), 3.2(4) NWTS 33(2), 3.4 NWTS 33(2), 3.4(1)	S.1.A What are the geologic, mineralogic, and petrographic characteristics of the candidate repository horizons and surrounding strata within the reference repository location?	S.1.1.A Determine the thickness and continuity of the candidate repository horizons within the reference repository location. S.1.2.A (Included in S.1.12.B) Determine the dip, strike, fold wavelength, and fold amplitude of the candidate repository horizons within the reference repository location. S.1.3.A (Included in S.1.12.B) Determine what deformational features are likely to intersect the candidate repository horizons within the reference repository location. S.1.4.A Determine the primary internal structure of the candidate repository horizons within the reference repository location. S.1.5.A (Related to S.1.9.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the orientation, distribution, aperture infilling (secondary mineralization), and origin of fractures, discontinuities, and heterogeneities within the candidate repository horizons.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 2 of 20)

Technical criteria	Issues	Work element
		S.1.6.A (Related to S.1.5.A, S.1.8.A, W.2.1.A., W.2.4.A, and W.2.13.D) Determine the mineralogic, petrographic, and chemical characteristics of the candidate repository horizons including the composition, texture, and abundance of both primary and secondary phases; apply data as appropriate to predict fracture distribution in Work Element S.1.5.A. S.1.7.A (Related to S.1.11.B) Determine the stratigraphic characteristics of the flows above and below the candidate repository horizons. S.1.8.A (Related to S.1.6.A, S.1.7.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the structural, textural, mineralogic, and petrographic characteristics of the rocks above and below the candidate repository horizons. S.1.9.A (Related to S.1.5.A, S.1.7.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the orientation, distribution, aperature infilling (secondary mineralization), and origin of fractures, discontinuities, and heterogeneities within rocks above and below the candidate repository horizons.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 3 of 20)

Technical criteria	Issues	Work element
		S.1.10.A (Related to S.1.27.C, S.1.28.C, S.1.29.C, and S.1.30.C) Determine the presence and characteristics of other possible anomalies that could serve as zones of greater permeability.
Required Characteristics of the Geologic Setting (60.112(a)) The geologic setting shall have exhibited structural and tectonic stability since the start of the Quaternary Period. Favorable Conditions (60.122(a)) The nature and rates of tectonic processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste. Favorable Conditions (60.122(b)) The nature and rates of structural processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste.	S.1.B What are the nature and rates of past, present, and projected structural and tectonic processes within the geologic setting and reference repository location?	S.1.11.B (Related to S.1.17.B) Evaluate the regional structural and tectonic setting of the Pasco Basin. S.1.12.B (Related to S.1.11.B and S.1.29.C) Determine the location of folds and faults in the Pasco Basin area with emphasis on the reference repository location. S.1.13.B Evaluate the type and amount of displacement, geometry (width and continuous length), and age of faults within the Pasco Basin. S.1.14.B Evaluate the relationship of folding and faulting in the Yakima fold belt; evaluate the relationship of Yakima folds to structures that may be present in rocks beneath the Columbia River basalt within the Pasco Basin.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 4 of 20)

Technical criteria	Issues	Work element
		S.1.15.B (Related to S.1.13.B, R.1.3.A, and R.1.6.A) Evaluate the geologic (long-term) and contemporary rate of deformation and stress field in the Pasco Basin and reference repository location.
		S.1.16.B (Related to R.1.29 and R.1.30) Determine the seismicity of the Pasco Basin and reference repository location.
		S.1.17.B (Related to S.1.11.B through S.1.16.B, and S.1.23.B) Develop a conceptual model that can be used to evaluate the past, present, and projected tectonic setting of the reference repository location.
<u>Potentially Adverse Conditions (60.123)</u>		
(a) Adverse conditions in the geologic setting.		
(5) A fault in the geologic setting that has been active since the start of the Quaternary Period and which is within a distance of the disturbed zone that is less than the smallest dimension of the fault rupture surface.		S.1.18.B (Included in S.1.12.B, S.1.13.B, and S.1.14.B) Determine the presence of active faults within the geologic setting; evaluate their rupture length.
(b) Adverse conditions in the disturbed zone.		S.1.19.B (Included in S.1.12.B and S.1.13.B) Determine if Quaternary faulting is present within the disturbed zone.
(6) The existence of a fault that has been active during the Quaternary Period.		

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 5 of 20)

Technical criteria	Issues	Work element
(7) Potential for creating new pathways for radionuclide migration due to presence of a fault or fracture zone irrespective of the age of last movement.		S.1.20.B (Included in S.1.12.B through S.1.16.B) Determine the presence of faults of any age within the disturbed zone; determine the potential for movement along existing faults and fractures within the disturbed zone; determine the potential for generation of new faults and fractures within the disturbed zone.
(8) Structural deformation such as uplift, subsidence, folding, and fracturing during the Quaternary Period.		S.1.21.B (Included in S.1.11.B, S.1.12.B, and S.1.15.B) Evaluate the nature of structural deformation such as uplift, subsidence, folding, and fracturing during the Quaternary Period.
(9) More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located.		S.1.22.B (Included in S.1.16.B) Determine if earthquakes are correlatable with tectonic processes and/or features within the reference repository location; if correlatable, predict the frequency and magnitude of future events.
(10) Indications, based on correlations of earthquakes with tectonic processes and features, that either frequency of occurrence or magnitude of earthquakes may increase.		
(11) Evidence of igneous activity since the start of the Quaternary Period.		S.1.23.B (Related to S.1.17.B) Determine the nature of igneous activity within the Pasco Basin.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 6 of 20)

Technical criteria	Issues	Work element
For clarification see: 10 CFR 60.111(b)(3)(ii) 10 CFR 60.122(a) 10 CFR 60.122(b) NWTS 33(2), 3.5 NWTS 33(2), 3.5(1) NWTS 33(2), 3.5(2) NWTS 33(2), 3.5(3) NWTS 33(2), 3.5(4) NWTS 33(2), 3.5(5)		
<u>Required Characteristics of the Geologic Setting</u> (60.112(c)) The geologic repository shall be located so that pre-waste-emplacement groundwater travel times through the far-field to the accessible environment are at least 1,000 years.	S.1.C Are the pre-waste-emplacement groundwater travel times near the repository sufficient to assure compliance with U.S. Nuclear Regulatory Commission proposed technical criteria?	S.1.24.C (Related to S.1.30.C, S.1.33.C, S.1.34.C, S.1.38.D, S.1.39.D, S.1.40.D, and S.1.51.D) Determine the hydraulic properties of the groundwater flow systems.
<u>Favorable Conditions</u> (60.122(f)(4)) Groundwater travel times under pre-waste-emplacement conditions between the underground facility and the accessible environment that substantially exceed 1,000 years.		S.1.25.C (Related to S.1.27.C, S.1.28.C, S.1.29.C, S.1.30.C, S.1.33.C, S.1.36.C, S.1.39.C, S.1.40.D, S.1.41.D, S.1.45.D, and S.1.51.D) Determine the hydraulic heads of the groundwater flow systems.
<u>Required Characteristics of the Geologic Setting</u> (60.112(b)) The geologic setting shall have exhibited hydrogeologic, geochemical, and geomorphic stability since the start of the Quaternary Period.		S.1.26.C (Related to S.1.27.C, S.1.28.C, S.1.29.C, S.1.30.C, S.1.33.C, S.1.34.C, S.1.39.D, S.1.40.D, R.1.34, R.1.63, R.1.64, R.1.65, W.2.1.A, W.2.2.A, W.2.4.A, W.2.5.A, and W.2.13.D) Determine the hydrochemistry of the basalt groundwater system.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 7 of 20)

Technical criteria	Issues	Work element
Favorable Conditions (60.122(c)) The nature and rates of hydrogeological processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste.		S.1.27.C (Related to S.1.7.A, S.1.9.A, S.1.12.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.30.C, and S.1.33.C) Determine the geometry of and interaction between the confined flow systems. S.1.28.C (Related to S.1.4.A, S.1.7.A, S.1.8.A, S.1.10.A, S.1.11.B, S.1.12.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.30.C, S.1.31.C, and S.1.51.D) Determine the extent of vertical groundwater movement between the confined, unconfined, and surface water systems. S.1.29.C (Related to S.1.7.A, S.1.11.B, S.1.12.B, S.1.17.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, S.1.33.D, and S.1.41.D) Determine the hydrologic characteristics and influences of structure and stratigraphic discontinuities that may shorten groundwater flow paths and solute transport times.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 8 of 20)

Technical criteria	Issues	Work element
		S.1.30.C (Related to S.1.7.A, S.1.9.A, S.1.11.B, S.1.12.B, S.1.17.B, S.1.24.C through S.1.29.C, and S.1.31.C) Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models.
		S.1.31.C (Related to S.1.30.C, S.1.33.C, S.1.34.C, S.1.38.D, and S.1.39.D) Develop and/or modify numerical codes that adequately simulate groundwater flow, natural hydro-chemical species transport, and travel times under pre-waste-emplacement conditions.
		S.1.32.C (Included in S.1.41.D) Evaluate the ranges of relevant hydrogeologic conditions since the start of the Quaternary Period.
		S.1.33.C (Related to S.1.30.C, S.1.31.C, S.1.34.C, S.1.37.D, S.1.39.D, and S.1.41.D) Using selected models, predict groundwater travel time from the repository location to the accessible environment under pre-waste-emplacement conditions.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 9 of 20)

Technical criteria	Issues	Work element
		S.1.34.C (Related to S.1.24.C, S.1.25.C, S.1.26.C, S.1.30.C, S.1.31.C, and S.1.33.C) Determine the bounds of uncertainty in model predictions of pre-waste-emplacement groundwater travel time.
Favorable Conditions (60.122) (f) A host rock that provides the following groundwater characteristics: (1) Low groundwater content		S.1.35.C (Included in S.1.30.C) Determine the groundwater content of the host rock.
(2) Inhibition of groundwater circulation in the host rock.		S.1.36.C (Included in S.1.30.C) Determine the nature of groundwater circulation in the host rock.
Overall System Performance (60.111(b)(1) The geologic setting shall be selected and the subsurface facility designed so as to assure that releases of radioactive materials from the geologic repository following permanent closure conform to such generally applicable environmental radiation protection standards as may have been established by the U.S. Environmental Protection Agency.	Issue S.1.D What is the total amount (activity) of radionuclides potentially releasable to the accessible environment in a 10,000-year period, and is this amount in compliance with appropriate U.S. Environmental Protection Agency regulations?	

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 10 of 20)

Technical criteria	Issues	Work element
Isolation (60.111(b)(3)(ii)) Following the containment period, the geologic setting, in conjunction with the engineered system as long as that system is expected to function, and alone thereafter, shall be capable of isolating radioactive waste so that transport of radionuclides to the accessible environment shall be in amounts and concentrations that conform to such generally applicable environmental standards as may have been established by the U.S. Environmental Protection Agency. For clarification see: NWTS 33(1), 2.2 NWTS 33(1), 2.1 NWTS 33(4), 2.1 NWTS 33(4), 3.1 NWTS 33(1), 3.3.2 NWTS 33(2), 3.2 NWTS 33(2), 3.2(1) NWTS 33(2), 3.2(2) NWTS 33(2), 3.2(3) NWTS 33(2), 3.2(4) NWTS 33(2), 3.5(2) NWTS 33(2), 3.5(3) NWTS 33(2), 3.5(5) NWTS 33(2), 3.7(1) EPA 40 CFR 191		S.1.37.D (Related to S.1.30.C, S.1.31.C, S.1.33.C, S.1.34.C, and S.1.39.D) Develop and/or modify numerical codes that can reliably predict the changes in the processes determining the rate and extent of radionuclide transport under post-waste-emplacement conditions. S.1.38.D (Related to S.1.24.C, R.1.3.A, R.1.12.B, R.1.67, W.1.4.A, W.1.10.A, W.1.12.A, W.1.19.B, W.2.1.A, W.2.2.A, W.2.5.A, and W.2.9.B) Determine the radionuclide transport, thermal, and mechanical properties of the geohydrologic system. S.1.39.D (Related to S.1.24.C through S.1.30.C, S.1.37.D, S.1.38.D, S.1.40.D, R.1.13.D, R.1.20.D, W.2.4.A, W.2.8.A, W.2.11.D, and W.2.13.D) Using selected models, predict radionuclide mass fluxes to the accessible environment. S.1.40.D (Related to S.1.39.D) Determine the bounds of uncertainty in the model predictions of radionuclide fluxes to the accessible environment.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 11 of 20)

Technical criteria	Issues	Work element
		S.1.41.D (Related to S.1.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.23.B, S.1.24.C through S.1.26.C, and S.1.30.C) Identify credible disruptive events and potentially unfavorable process scenarios and estimate the associated properties and conditions of the host basalt near the repository site; develop bounding estimates for probabilities of occurrence for each event, as needed.
Favorable Conditions (60.122) In addition to meeting the mandatory requirements of 60.112, a geologic setting shall exhibit an appropriate combination of these conditions so that, together with the engineered system, the favorable conditions present are sufficient to provide reasonable assurance that performance objectives will be met.		
Favorable Conditions (60.122) (d) The nature and rates of geochemical processes that have occurred since the start of the Quaternary Period are such that when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste.		S.1.42.D (Related to S.1.6.A, S.1.9.A, S.1.26.D, S.1.39.D, S.1.40.D, S.1.41.D, and W.2.13.D) Determine whether the range of geochemical conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 12 of 20)

Technical criteria	Issues	Work element
Favorable Conditions (60.122) (c) The nature and rates of hydrogeological processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste.		S.1.43.D (Related to S.1.30.C, S.1.33.C, S.1.39.D, S.1.40.D, S.1.41.D, W.2.4.A, W.2.8.A, W.2.11.D, and W.2.13.D) Determine whether the range of hydrogeologic conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.
Potentially Adverse Conditions (60.123) (a) Adverse conditions in the geologic setting. (1) Potential for failure of existing or planned man-made surface water impoundments that could cause flooding of the geologic repository operations area.		S.1.44.D (Related to S.1.45.D, S.1.48.D and S.1.49.D) Determine the potential for, and effect of, failure of existing or planned man-made surface water impoundments.
(2) Potential, based on existing geologic and hydrologic conditions, that planned construction of large-scale surface water impoundments may significantly affect the geologic repository through changes in the regional groundwater flow system.		S.1.45.D (Related to S.1.16.B, S.1.41.D, S.1.46.D, and S.1.49.D) Determine the effect of potential impoundments on the groundwater flow system.
(3) Potential for human activity to affect significantly the geologic repository through changes in the hydrology.		S.1.46.D (Related to S.1.41.D, S.2.1, and S.2.4) Determine the potential for human activity to cause significant changes in the surface and groundwater hydrology.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 13 of 20)

Technical criteria	Issues	Work element
(6) Potential for adverse impacts on the geologic repository resulting from the occupancy and modification of flood plains.		S.1.47.D (Related to R.1.34) Determine the potential for and the effect of occupancy and modification of the Columbia River flood plain.
(7) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such a magnitude that large-scale surface water impoundments could be created that could affect the performance of the geologic repository through changes in the regional groundwater flow.		S.1.48.D (Included in S.1.45.D) Determine the potential for and magnitude of impoundment that could affect a change in the regional groundwater flow.
(8) Expected climatic changes that would have an adverse effect on the geologic, geochemical, or hydrologic characteristics.		S.1.49.D (Related to S.1.41.D, S.1.44.D, S.1.45.D, S.1.60.D, and S.2.5) Evaluate the effect of possible climatic changes.
(b) Adverse conditions in the disturbed zone.		
(2) Evidence of drilling for any purpose.		S.1.50.D (Related to S.1.41.D, R.1.18.D, and R.1.20.D) Determine the potential effect of boreholes on repository performance.
(12) Potential for changes in hydrologic conditions that would significantly affect the migration of radionuclides to the accessible environment including but		S.1.51.D (Included in S.1.41.D) Determine the effect on waste isolation of potential changes in such hydrologic conditions as hydraulic gradient, average interstitial

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 14 of 20)

Technical criteria	Issues	Work element
not limited to changes in hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.		velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.
<u>Favorable Conditions (60.122)</u> (a) The nature and rates of tectonic processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste.		S.1.52.D (Related to S.1.17.B, S.1.39.D, S.1.40.D, S.1.41.D, R.1.3.A, R.1.29, R.1.30, W.1.2.A) Determine whether the range in tectonic and structural conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.
<u>Potentially Adverse Conditions (60.123)</u> (a) Adverse conditions in the geologic setting.		
(4) Earthquakes which have occurred historically that if they were to be repeated could affect the geologic repository significantly.		S.1.53.D (Included in S.1.16.B, S.1.17.B, and S.1.52.D) Determine the historical seismicity of the geologic setting and if there are any historical earthquakes that could adversely affect the repository.
(5) A fault in the geologic setting that has been active since the start of the Quaternary Period and which is within a distance of the disturbed zone that is less than the smallest dimension of the fault rupture surface.		S.1.54.D (Included in S.1.11.B through S.1.17.B, and S.1.52.D) Determine the effect of an active fault within the geologic setting on repository performance.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 15 of 20)

Technical criteria	Issues	Work element
(b) Adverse conditions in the disturbed zone.		
(6) The existence of a fault that has been active during the Quaternary Period.		S.1.55.D. (Included in S.1.11.B through S.1.17.B, and S.1.52.D) Determine the effect of an active fault within the disturbed zone on repository performance.
(7) Potential for creating new pathways for radionuclide migration due to the presence of a fault or fracture zone irrespective of the age of last movement.		S.1.56.D (Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, and S.1.52.D) Determine the effect of faults and fractures on repository performance.
(9) More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located.		S.1.57.D (Included in S.1.16.B, S.1.17.B, and S.1.52.D) Determine the effect of seismicity on repository performance.
(8) Structural deformation such as uplift, subsidence, folding, and fracturing during the Quaternary Period.		S.1.58.D (Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.52.D, and S.1.60.D) Determine the effect of structural deformation such as uplift, subsidence, folding, and fracturing on repository performance.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 16 of 20)

Technical criteria	Issues	Work element
(11) Evidence of igneous activity since the start of the Quaternary Period.		S.1.59.D (Related to S.1.17.B, S.1.23.B, S.1.41.D, and R.1.34) Determine the potential for breach of a repository by future fissure eruptions of Columbia River basalt; determine the effect of other types of igneous activity within and in the vicinity of the Pasco Basin.
<u>Favorable Conditions (60.122)</u> (e) The nature and rates of geomorphic processes that have occurred since the start of the Quaternary Period are such that, when projected they would not affect the ability of the geologic repository to isolate the waste.		S.1.60.D (Related to S.1.15.B, S.1.17.B, S.1.45.D, S.1.49.D, and S.1.51.D) Determine whether the range of geomorphic conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.
<u>Potentially Adverse Conditions (60.123)</u> (b) Adverse conditions in the disturbed zone. (4) Evidence of extreme erosion during the Quaternary Period.		S.1.61.D (Included in S.1.60.D) Determine the likelihood of repository exhumation due to extreme erosion over the next 10,000 years.
	S.2 - Environment and Socioeconomics	
<u>Environmental (60.31(c))</u> Upon review and consideration of an application and environmental report submitted under this part, the commission may authorize construction if it determines:	None.	S.2.1 (Related to S.1.46.D, S.2.3, and S.2.4) Establish baseline ecologic, radiologic, sociopolitical, and economic conditions against which impacts can be assessed and mitigation measures proposed.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 17 of 20)

Technical criteria	Issues	Work element
That after weighing the environmental, economic, technical, and other benefits against environmental costs and considering available alternatives, the action called for is issuance of the construction authorization, with any appropriate conditions to protect environmental values.		
Potentially Adverse Conditions (60.123)	None.	
(b) Adverse conditions in the disturbed zone.		S.2.2 (Related to S.2.3)
(1) Evidence of subsurface mining for resources.		Determine if subsurface mining is present within the disturbed zone.
(3) Resources that have either greater gross value, net value, or commercial potential than the average for other representative areas of similar size that are representative of and located in the geologic setting.		S.2.3 (Related to S.2.1, S.2.2, and R.1.34) Determine the gross value, net value, and commercial potential of resources within the disturbed zone and within similar-size areas that are representative of and located within the geologic setting.
Ownership of the Geologic Repository Operations Area (60.121(a)) The geologic repository operations area shall be located in and on lands that are either acquired lands under the jurisdiction and control of U.S. Department of Energy or lands permanently withdrawn and reserved for its use.	None.	S.2.4 Identify the distribution of land ownership, use, and control of the repository area.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 18 of 20)

Technical criteria	Issues	Work element
Establishment of Controls (60.121(b)) Appropriate controls shall be established outside of the geology repository operations area.		
Contents of Application (60.21(c)(1)) The Safety Analysis report shall include: A description and analysis of the site at which the proposed geologic repository operations area is to be located with appropriate attention to those features that might affect facility design and performance. The assessment shall contain an analysis of the geology, geophysics, hydrology, geochemistry, and meteorology of the site and the major design structures, systems, and components, both surface and subsurface, that bear significantly on the suitability of the geologic repository for disposal of radioactive waste. Radiological Protection (60.130(b)(1)(iv)) The structures, systems, and components located within restricted areas shall be designed to maintain radiation doses, levels, and concentrations of radioactive material in air in those restricted areas within the limits specified in Part 20 of this chapter. These structures, systems, and components shall be designed to include:	None.	S.2.5 (Related to S.1.49.D) Determine the meteorologic, climatologic, and air-quality conditions to be used as design and operating bases and assess future climatic changes that may affect repository performance.

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 19 of 20)

Technical criteria	Issues	Work element
(iv) Means to monitor and control the disposal of radioactive contamination.		
<u>Protection Against Natural Phenomena and Environmental Conditions</u> (60.130(b)(2)(i))		
The structures, systems, and components important to safety shall be designed to be compatible with anticipated site characteristics and to accommodate the effects of environmental conditions, so as to prevent interference with normal operation, maintenance and testing during the entire period of construction and operations.		
<u>Protection Against Natural Phenomena and Environmental Conditions</u> (60.130(b)(2)(ii))		
The structures, systems, and components important to safety shall be designed so that natural phenomena and environmental conditions anticipated at the site will not result, in any relevant time period, in failure to achieve the performance objectives.		
<u>Protection Against Radiation Exposures and Releases of Radioactive Material</u> (60.111(a)(1))		
The geologic repository operations area shall be designed so that until permanent closure has been completed, radiation exposures and radiation levels, and releases of radioactive		

TABLE 13-7. Criteria, Issues, and Work Elements for Site. (Sheet 20 of 20)

Technical criteria	Issues	Work element
materials to unrestricted areas, will at all times be maintained within the limits specified in Part 20 of this chapter and any generally applicable environmental standards established by the U.S. Environmental Protection Agency. For clarification see: NWTS 33(2), 2.2 NWTS 33(2), 3.7(4) NWTS 33(2), 3.8 NWTS 33(2), 3.8(1) NWTS 33(2), 3.10 NWTS 33(2), 3.10(1) NWTS 33(2), 3.10(2) NWTS 33(2), 4.3		

13.6 SUMMARY

A methodology for defining the work required to satisfy applicable regulatory and programmatic technical criteria relating to the site activities was presented in Section 13.1. The approach used to define work is a key part of the BWIP technical planning process. The details of the work needed to meet the criteria were presented initially as generalized work elements (statements of work). These specific work elements were further analyzed to identify in detail the data required and the analysis needed to complete each work element. A detailed description of the work needed to satisfy any specific applicable technical criteria was provided in tabular and narrative form in Section 13.3. These descriptions allow the reader to gain an understanding of the present status and future plans for each item of work proposed. A tabulation of all the criteria, work elements, and issues for Site was presented in Section 13.5.

A summary of criteria considered fully satisfied was presented in Section 13.2. Where debate or controversy about the available information or technology existed, issues were defined to highlight this fact. The resolution of these issues, as work progresses, will be highlighted in the BWIP semiannual progress reports.

A logic diagram of the work described in this chapter was presented in Section 13.4. The logic diagram was accompanied by a brief narrative describing each element of the diagram and served to present in summary form the overall and generalized scope of work described in this chapter. By consolidating the detailed elements of work into more concise form, the flow and direction of site activities can be more readily depicted. The logic diagram also identified points at which the issues presented in this chapter will be resolved. Each narrative accompanying the logic diagram contained a listing of applicable work elements. Although individual activities were not called out in the logic diagram (Fig. 13-4), the reader can ascertain the depth and scope of the activities by reading the individual status and plans descriptions in Section 13.2.

Finally, Chapter 17 of this document contains schedules for the resolution of the issues presented in Section 13.2 and a listing of technical milestones associated with the work described in this chapter, as well as from the other issue chapters (Chapters 14, 15, and 16). Chapter 17 thus ties all of the plans for the entire project into one integrated description, with schedules and milestones, to provide a capsule summary of the direction and scope of work being planned by the BWIP to complete site characterization.

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CHAPTER 14. GEOENGINEERING AND REPOSITORY-DESIGN ISSUES AND PLANS

14.1 INTRODUCTION

This chapter summarizes the results of the investigations presently being conducted and those planned to resolve the issues identified in Chapter 4 (Geoengineering) and Chapter 10 (Repository Design). The subsections chosen for this chapter are (1) design, construction, and operations, and (2) performance confirmation (Fig. 14-1). The U.S. Nuclear Regulatory Commission has designated certain of its proposed criteria as performance objectives in 10 CFR 60 (NRC, 1981). For the areas of geoengineering and repository design, the relevant proposed criteria are those dealing with the containment and release of wastes. Although listed in 10 CFR 60 as performance objectives, these proposed criteria have been incorporated in the criteria/issues/work elements under repository design, construction, and operations. These performance criteria also affect the requirement for performance confirmation work and, therefore, must be factored into the performance confirmation process, but their initial and primary impact is on the design process. Another reason for this "organization" is that the release and containment criteria form the bases for the work in geoengineering and repository design. Dealing with them separately would have led to a set of redundant issues and work elements. The geoengineering and repository design issues discussed in Section 14.3 are tabulated in Table 14-1.

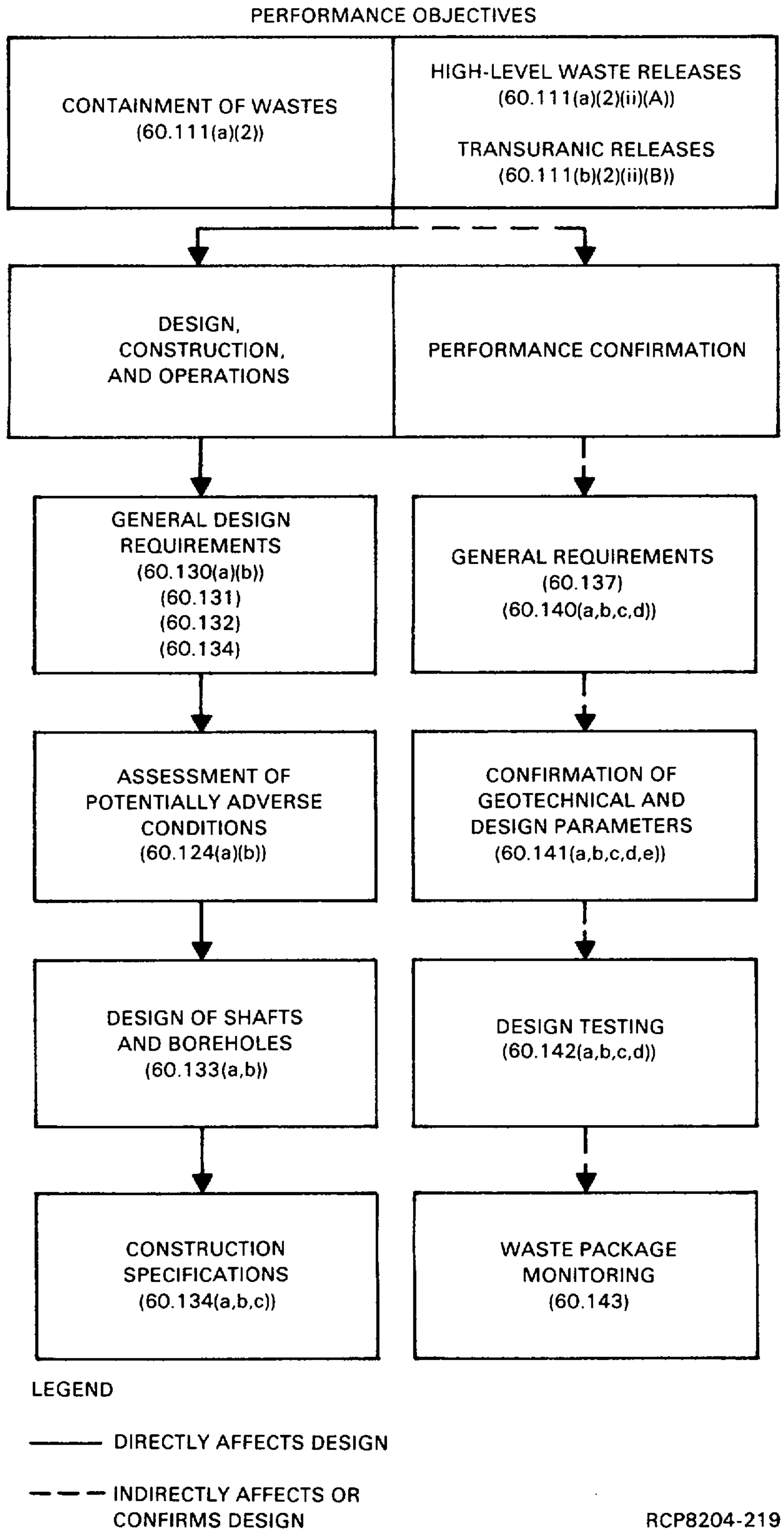

FIGURE 14-1. Key Proposed Criteria Governing the Geoengineering and Repository Design Issues and Work Elements (numbers/words in parentheses relate to 10 CFR 60 (NRC, 1981)).

TABLE 14-1. Issues for Geoengineering and Repository Design.

Issue	Issue number	Chapter
R.1 - Design and Construction		
Key Issues		
Can stability and isolation capability of the repository be maintained in the presence of coupled in situ, excavation-induced, and thermal-induced stresses?	R.1.A	4, 10
Can repository shafts, tunnels, and exploratory boreholes be constructed and sealed without causing preferential pathways for groundwater or increasing the potential for radionuclide migration from a nuclear waste repository such that compliance with appropriate U.S. Environmental Protection Agency regulations is not possible?	R.1.D	10
Issues		
Can satisfactory representative measurements or estimates of rock-mass strength be obtained?	R.1.B	4
Are current methods of in situ stress measurement used at depth reliable enough to provide satisfactory data for design requirements?	R.1.C	4
R.2 - Performance Confirmation		
No issues have been identified.		

14.2 SUMMARY OF CRITERIA FULLY SATISFIED

14.2.1 Issues

Studies are in progress in the areas of repository design and construction and performance confirmation to support characterization of the reference repository location within the Hanford Site for a nuclear waste repository in basalt. These studies are in the data-gathering and -analysis stage in support of gaining an understanding of what is needed to design and construct a nuclear waste repository in basalt. The Basalt Waste Isolation Project (BWIP) staff has raised a number of issues in Chapters 4 and 10 that have not been resolved. Although much is known about the conceptual design of a repository and its interactions with the site, information on issue resolutions, as requested by the U.S. Nuclear Regulatory Commission will, of necessity, be part of the BWIP semiannual progress reports.

14.2.2 Criteria

The present investigations into the repository design by the BWIP have not yet fully addressed all of the U.S. Nuclear Regulatory Commission criteria. As these are fully addressed, they will be reported in the BWIP semiannual progress reports.

14.3 UNRESOLVED ISSUES AND PLANS FOR THEIR RESOLUTION

This section contains an analysis of the work needed to meet the U.S. Nuclear Regulatory Commission proposed criteria. The work element analysis tables serve to summarize the information contained in the narratives. This section is organized into two subsections: Repository Design, Construction, and Operations and Performance Confirmation. Each subsection is further subdivided by individual issues. The narratives (status and plans) for each issue are presented by work element. A discussion of work elements that are not associated with issues is also included.

14.3.1 Repository Design, Construction, and Operations Issues and Work Elements

The analysis of data needs and status of work supporting repository design, construction, and operations issues and work elements are summarized in Table 14-2.

KEY ISSUE R.1.A

Can stability and isolation capability of the repository be maintained in the presence of coupled in situ, excavation-induced, and thermal-induced stresses?

Work Element R.1.1.A (Priority 1)

Determine the methodology for design and analysis of subsurface openings and their support systems.

Status

Work to be performed.

Plans

The conceptual repository design is based on analysis utilizing linear elastic theory and an empirical rock-mass strength relationship derived from laboratory testing results. The failure mode analysis also assumed a homogeneous linear elastic material. Although these assumptions are sufficient for a conceptual design, they do not adequately reflect the actual rock-mass response and must be improved prior to the Title I (preliminary) design. This will require the development of a failure criterion for the repository rock mass. A failure criterion is defined as a definite stress state or relation, characteristic of the material, that, when satisfied, will result in failure, or irreversible loss of peak load carrying capacity.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 1 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.1.A Determine the methodology for design and analysis of subsurface openings and their support systems.	Selection of rock-mass strength and deformation properties and failure criteria.	Not applicable.	Conceptual design contains initial analysis utilizing linear elastic theory and an empirical rock-mass strength relationship.
	Estimation of failure modes and sequence.	Not applicable.	Conceptual design contains initial analysis assuming failure consistent with a homogeneous linear elastic medium.
	Selection of methods and models for analyzing rock support system interaction and its effect on strength and deformation parameters.	Not applicable.	Work to be performed.
	Selection of details for incorporation of pore pressures and time effects in failure analysis.	Not applicable.	Work to be performed.
	Selection of models representing constitutive behavior of the rock mass and how that behavior varies in the region of interest.	Not applicable.	Initial model selection and evaluation on a canister scale is in progress.
R.1.2.A Evaluate the effect of underground construction sequence on the stability of openings.	Volumetric stress/strain related parameters (potential energy, strain energy) of rock mass for anticipated construction rates and sequences.	Calculation by analytical or numerical modeling techniques.	Work to be performed.
	Numerical models describing mechanical behavior of rock mass under stress (see Work Element R.1.13.B).	Identical to Work Element R.1.13.B.	Identical to Work Element R.1.13.B.
	Case history data on mining methods, rates, geometries, conditions associated with rock bursts (see Work Element R.1.6.A).	Not applicable.	Literature search under way.
	Analysis to determine construction sequences best suited to simultaneous construction materials handling, ventilation, and waste emplacement activities.	Not applicable.	Preliminary consideration of construction sequence has been addressed in the conceptual design.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 2 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.3.A Determine the magnitude and the rate of deformation of tunnels and canister boreholes resulting from in situ, excavation-induced, and thermal-induced stresses, and how deformation is affected by backfill.	Engineering characteristics of backfill materials in place, including deformation and time-dependent properties.	Full-scale in situ backfill test section at temperatures of 20^{o} to $300^{o}C$, moisture conditions from dry to saturated, and prevailing stress conditions.	No data presently available.
	Swelling pressures developed upon saturation.	Same as above.	No data presently available.
	Stress distribution around tunnels and canister boreholes at peak temperatures (identical to R.1.4.A and R.1.5.A).	Identical to R.1.4.A and R.1.5.A.	Identical to R.1.4.A and R.1.5.A.
	Time-dependent deformation characteristics of rock mass (identical to R.1.11.B).	Identical to R.1.11.B.	Identical to R.1.11.B.
	Stiffness of rock-support system and/or increase in rock-mass modulus provided by support (see Work Element R.1.61).	See Work Element R.1.61.	See Work Element R.1.61.
	Numerical model to determine long-term wall and borehole deformation (identical to R.1.13.B).	Identical to R.1.13.B.	Identical to R.1.13.B.
	Deformation measurements in situ.	Repository test section under anticipated repository conditions: • Temperature: 20^{o} to $300^{o}C$ • Pressure: 0 to 100 MPa • Moisture: Saturated.	Work to be performed.
	Analysis to determine effect of tunnel or backfill deformation on retrieval.	Numerical model using anticipated repository conditions: • Temperature: 20^{o} to $300^{o}C$ • Pressure: 0 to 100 MPa • Moisture: Saturated. By observation in test section of repository.	Work to be performed.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 3 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.4.A Determine the magnitude and distribution of excavation-induced stresses for single and multiple openings.	Effect of disturbed rock zone on the stress distribution.	Around openings of various shapes at the candidate repository horizons.	Work to be performed.
	Radial and tangential stress profile measurements around single tunnel.	Both in situ and Near-Surface Test Facilities.	Work to be performed.
	Numerical model analysis of radial and tangential stress profile around a single tunnel.	Conditions at Near-Surface Test Facility to allow correlation with in situ tests.	Work to be performed.
	Measured values of in situ stresses.	Hydraulic fracturing or overcoring.	Preliminary information on the in situ stress at the reference repository location is in Chapter 4.
	Numerical model for regional and near-field stress profile for various configurations at multiple openings.	Model input should include expected repository conditions of temperature, in situ stress, rock-mass properties, and moisture condition.	Work to be performed.
	Construction method.	Not applicable.	Work to be performed.
R.1.5.A Determine the magnitude and distribution of thermal stresses in the rock mass for the proposed waste package storage configuration.	Size, shape, and thermal history of waste canister.	Not applicable.	Conceptual design.
	Depth and spacing of emplaced canisters.	Not applicable.	Conceptual design.
	Thermal properties: • Specific heat • Coefficient of thermal expansion • Thermal conductivity • Thermal diffusivity.	Identical to R.1.12.B.	Identical to R.1.12.B.
	Rock-mass deformation properties.	Identical to R.1.11.B.	Identical to R.1.11.B.
	Numerical model to determine temperature profiles and stress distributions in near-field using above input data.	Identical to R.1.13.B.	Identical to R.1.13.B.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 4 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.6.A (Related to R.1.7.A and R.1.48) Determine from case history evaluations the combinations of stress fields, rock properties, geologic structural features, and mine geometries that are typical of rock burst-prone areas, and assess the probability of rock bursts at or near the repository site.	Catalogue of in situ stress data, intact rock properties, rock-mass properties, areal extraction ratios, rate of extraction, dimension of openings, and geologic conditions for regions that have experienced rock bursts.	Not applicable.	Literature search in progress.
R.1.7.A (Related to R.1.6.A and R.1.48) Document occurrences of dynamic instability of test excavations at depth at the repository site.	Catalogue of observations related to dynamic instability (audible cracking, spalling, or bursting) including dates, times, and location.	Observations to be made at depth during construction and operation of exploratory tunnels.	Work to be performed.
R.1.8.A (Related to R.1.14.C and R.1.15.C) Determine the spatial variation of in situ stresses in the region of the repository.	Preexcavation stress measurements.	Measurements by hydraulic fracturing in selected boreholes.	Preliminary hydraulic fracturing work has been completed (see Chapter 4) in the candidate repository horizons.
	Confirmation measurements at depth.	Measurements by overcoring or other techniques at depth.	Work to be performed.
	Stress levels during construction and operation.	Multiple measurements throughout repository location to develop stress profile prior to construction and to monitor changes during construction.	Work to be performed.
R.1.9.A Determine the potential for subsidence caused by mine openings.	Approximate rock-mass strength and deformation properties for overlying strata (to surface).	Rock-mass properties at ambient conditions (estimated or measured) as described in R.1.11.B.	Some data available, see Chapter 3 (laboratory strength and deformation data for overlying Grande Ronde Basalt).
	Geologic characterization of overlying strata (to surface).	From geophysical work or exploratory drilling from surface.	Some data available, see Chapter 3.
	Estimate of probable tunnel failure modes, including size of failed region and amount of near-field deformation.	Analytical study of stability of tunnel system and literature search to identify possible mechanisms of upward movement of failed zones.	Work to be performed.
	Numerical model to assess overlying rock-mass response to development of failed region in tunnel near field.	Not applicable.	Work to be performed.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 5 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.10.A Define the acceptable range of test results for intact rock and rock-mass characteristics to support design activities.	Determine rock-mass parameters that significantly affect the design and feasibility of the repository. Eliminate those properties that, if varied over a reasonable range, would not change the design.	Not applicable.	Work to be performed.
	Analysis using numerical model that examines the interrelationship of rock-mass characteristics over their maximum practical range in regard to the repository design. The analysis will determine what combinations of rock-mass parameters, if any, would require significant design modifications by establishing various scenarios of rock-mass conditions.	Not applicable.	Work to be performed.
R.1.11.B (Identical to R.2.3.) Measure rock strength and deformation characteristics on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.	<u>Rock-Mass Strength Properties</u> • Shear strengths as function of pressure and temperature. • Failure envelope.	Static (creep) and quasi-static strain rates. Temperature 20^{o} to 300^{o}C. Confining or normal stresses 0 to 100 MPa. Load direction 0^{o} to 90^{o} to columnar joint direction. Candidate repository horizons or near-surface formation, if necessary.	Work to be performed.
	<u>Rock-Mass Deformation Properties</u> • Constitutive relationship, E, Y. • Creep deformation parameters.	Same as above.	Work to be performed.
	<u>Intact Lab Rock Samples - Strength Properties</u> • Unconfined compressive strength, C_o. • Cohesion, S_o. • Angle internal friction, ϕ. • Tensile strength, T_o.	Static (creep) and quasi-static strain rates. Temperature 20^{o} to 300^{o}C. Confining or normal stresses 0 to 100 MPa. Dry and saturated (undrained). Candidate repository horizons.	Initial data base presented in Chapter 4 of this document.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 6 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	<u>Intact Lab Rock Samples - Deformation Properties</u> • Constitutive relationship E, γ. • Creep deformation parameters.	Static (creep) and quasi-static strain rates. Temperature 20^{o} to $300^{o}C$. Confining or normal stresses 0 to 100 MPa. Dry and saturated (undrained). Candidate repository horizons.	Initial data base presented in Chapter 4 of this document.
	<u>Jointed Lab Rock Samples - Strength Properties</u> • Unconfined, triaxial compressive strength. • Peak, residual cohesion, S_p, S_r for joints. • Peak, residual-angle internal friction ϕ_p, ϕ_r for joints.	Static (creep) and quasi-static strain rates. Temperature 20^{o} to $300^{o}C$. Confining or normal stresses 0 to 100 MPa. Dry and saturated (undrained). Load direction 0^{o} to 90^{o} to joint direction. Candidate repository horizons.	Results of unconfined and triaxial compression tests on randomly jointed samples presented in Schmidt et al. (1980). Triaxial compression tests in creep mode on jointed samples now in progress.
	<u>Jointed Lab Rock Samples - Deformation Properties</u> • Constitutive relationship. • Normal, shear stiffness of joints K_n, K_s.	Static (creep) and quasi-static strain rates. Temperature 20^{o} to $300^{o}C$. Confining or normal stresses 0 to 100 MPa. Dry and saturated (undrained). Load direction 0^{o} to 90^{o} to joint direction. Candidate repository horizons.	Same as above.
	Physical properties of rock: • Density • Porosity • Hardness • Abrasiveness.	In laboratory at ambient conditions. Candidate repository horizons.	Density and porosity values reported in Chapter 4 of this document.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 7 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	Compressional and shear wave velocities.	In laboratory at: • Temperatures 20° to $300^\circ C$ • Pressures 0 to 100 MPa • Moisture, dry to saturated. Candidate repository horizons. At depth at same conditions as above.	Laboratory wave velocities reported in Chapter 4 of this document.
R.1.12.B (Identical to R.2.4.) Measure rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.	Specific heat, C.	Laboratory tests for each parameter at confining pressures from 0 to 100 MPa, temperatures 20° to $300^\circ C$, in dry and saturated conditions. Parallel and perpendicular to columnar discontinuities. In situ tests to determine and compare rock-mass thermal properties to laboratory-scale measurements.	Results of laboratory tests on Pomona, Umtanum, and middle Sentinel Bluffs flow samples for temperatures 20° to $300^\circ C$ are presented in Chapter 4. Near-Surface Test Facility Full-Scale Heater Tests #1 and #2 have produced rock-mass thermal properties for Pomona flow only (see Chapter 4). The jointed block test will provide confirming measurements in Pomona for temperatures of 20° to $200^\circ C$, pressures probably up to 20 MPa, and directions parallel and perpendicular to columns.
	Coefficient of thermal expansion, α.	Same as above.	Same as above.
	Thermal conductivity, K.	Same as above.	Same as above.
	Thermal diffusivity, d.	Same as above.	Same as above.
R.1.13.B Develop and validate mechanical, thermal, and thermomechanical models for performance of in situ tests and for design and performance of the repository.	Thermomechanical model to predict temperature, displacements, and stress changes.	Canister, room, and repository scale, nonlinear and linear, three-dimensional.	Modeling studies conducted to date indicate that available codes and models can be adapted to basalt. Model validation on a canister scale is in progress at the Near-Surface Test Facility.
	Laboratory and field testing for baseline data.	Data base and validation testing to be conducted at repository conditions of temperature (20° to $300^\circ C$), pressure (0 to 100 MPa), and moisture content (saturated or near saturated) in the Near-Surface Test Facility and in exploratory shaft facilities.	Some initial data presented in Chapter 4. Additional information will be produced as Near-Surface Test Facility and Exploratory Shaft-Phase I and II tests are completed.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 8 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	Field test data for model validation: • Temperature • Displacement • Stress.	Same as above.	Same as above.
R.1.14.C (Related to R.1.8.A and R.1.15.C) Develop stress measurement methods that will yield valid data in closely jointed basalt.	Performance characteristics of selected measurement methods.	Comparison tests in the Near-Surface Test Facility in rock mass of various qualities.	Limited information available from Near-Surface Test Facility site characterization testing.
		Field tests under known stress conditions.	Work to be performed.
		Laboratory tests for development and technique refinement.	Work to be performed.
		Tests at various orientations with respect to columnar structure.	Work to be performed.
		Confirmation tests.	Work to be performed.
	Modifications to improve measurement techniques and equipment.	Not applicable.	Work to be performed.
R.1.15.C (Related to R.1.8.A and R.1.14.C) Establish methods of validating measured in situ stress data.	Magnitude and direction of in situ stresses by hydraulic fracturing.	Series of tests in a representative area at depth for selected technique.	Preliminary hydraulic-fracturing work has been completed (see Chapter 4). Work to be performed for other techniques.
	Magnitude and direction of in situ stresses by overcoring techniques.	Same as above.	Work to be performed.
	Magnitude and direction of in situ stresses by other selected techniques.	Same as above.	Work to be performed.
	Statistical analysis to establish the validity of the results.	Same as above.	Work to be performed.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 9 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.16.D Evaluate and select methods of excavation and rock support that can economically and safely be constructed and at the same time maintain isolation capability of the engineered system.	Evaluation of methods of detecting rock-mass disturbances.	Not applicable.	Work to be performed.
	Field test performance of proposed detection methods if required.	Not yet specified.	Work to be performed.
	Comparison of depth and severity of disturbed rock zone resulting from various excavation methods.	Assess various types of drill and blast methods, tunnel boring method, and any other potential technique.	Work to be performed.
	Previous excavation experience in similar rock type.	Not applicable.	Work to be performed.
	Interaction of the candidate excavation method and the selected support methods.	Repository and shaft construction conditions.	For drilling of exploratory shaft, see Chapter 17.
	Boring machine cutter performance, production rate, alignment accuracy, and safety performance.	Repository and shaft construction conditions.	Same as above.
	Drill and blast method equipment performance, production rate, and safety performance.	Repository construction conditions.	For shaft station at candidate repository horizons planned in Exploratory Shaft-Phase I, see Chapter 17.
R.1.17.D Develop or adapt instrumentation and test methods to measure the nature and extent of rock-mass disturbance caused by candidate excavation methods and stress redistribution around tunnels and boreholes.	Review of techniques of detecting rock-mass disturbance.	Not applicable.	Work to be performed.
	Field test performance of selected techniques, if required.	To be determined.	Work to be performed.
	Criteria to evaluate severity of rock disturbance from given parameters.	Not applicable.	Work to be performed.
R.1.18.D Identify performance requirements for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste.	Repository failure scenarios.	Not applicable.	Initial work in progress.
	Hydraulic flow-rate model for each location to be sealed.	Repository seal/hydraulic flow computer model at repository conditions through 10^4 years.	Model development in progress. Preliminary hydrologic data available from borehole tests. (See Chapter 5.)
	Temperature profile data for each location to be sealed.	Repository temperature model for operating conditions.	Model development in progress.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 10 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	Disturbed rock zone permeability.	Measurement at repository ambient conditions before and after blasting or boring. Radial measurements to at least two tunnel diameters.	Work to be performed.
		Preliminary testing at Near-Surface Test Facility, advanced testing at depth, if required, in candidate repository horizons.	Work to be performed.
	Groundwater chemistry.	See Section 6.2 of this document.	See Section 6.2 of this document.
	Solubilities of hazardous radionuclides.	See Section 6.4 of this document.	See Section 6.4 of this document.
	Preliminary seal material performance data.	Repository operating conditions over 10^4 years.	Preliminary performance data reports in review.
R.1.19.D Select materials and develop testing techniques required to meet repository room and tunnel sealing criteria.	Repository room and tunnel sealing criteria.	See Work Element R.1.20.D.	Work in progress. See Work Element R.1.20.D.
	Seal material laboratory-scale research data: • Permeability • Sorption coefficient • Compatibility with rock • Physical/chemical properties.	Repository operating conditions.	Preliminary material research reports in review.
	Room and tunnel seal designs.	Not applicable.	Preconceptual designs currently in review.
R.1.20.D Determine the effect of temperature, rock-mass deformation, groundwater flow, and groundwater chemistry on materials used for seals.	Seal materials selected through studies.	Not applicable.	Preliminary materials selection studies being conducted.
	Repository seal locations.	Not applicable.	Preliminary studies on repository seal locations are being conducted.
	Repository temperatures.	Measured at seal locations as a function of time for 10^4 years.	Model development in progress. See Work Element R.1.13.B.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 11 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	Host rock permeability at seal locations after grouting.	Repository operating conditions.	See Work Element R.1.21.D.
	Groundwater pressure and flow at seal locations.	Repository hydrologic computer model.	Model development in progress. See Waste Package Work Element W.1.12.A.
	Groundwater chemistry.	See Sections 5.1.6 and 6.2 of this document.	See Sections 5.1.6 and 6.2 of this document.
R.1.21.D Develop grouts and grouting techniques that ensure acceptable sealing of the disturbed rock zone.	Disturbed rock zone characterization (see Work Element R.1.17.D).	From ground surface to candidate repository horizons for candidate excavation methods.	Work to be performed.
	Grout material research data: • Penetration of grout into rock as a function of pressure • Permeability of grouted zone	Repository pressure, temperature, and flow conditions.	Preliminary grouting lab test reports in review.
	• Geochemical compatibility.		Work to be performed.
	Acceptable permeability for grouted rock.	See Work Element R.1.60.	See Work Element R.1.60.
R.1.22.D Determine the effects of temperature, rock-mass deformation, and time on the permeability of the sealed rock zone.	Typical rock characterization for repository seal location.	Not applicable.	Preliminary studies on repository seal locations are being conducted.
	Disturbed rock zone permeability at seal locations.	Computer code coupling temperature, rock-mass deformation, time, and permeability.	Preliminary rock zone characterization is being conducted.
	Rock-mass deformation as a function of time and temperature for seal locations.	59^{o} to $200^{o}C$.	Work to be performed.
	Permeability as a function of repository operating conditions.	Repository operating conditions.	Host rock permeability as a function of time is under study.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 12 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	Extent of disturbed rock zone at seal locations after grouting.	Repository operating conditions.	Preliminary evaluation reported in Kelsall et al. (1982)
	Physical properties and chemical analysis of sealed rock specimens at elevated temperature.	59° to 200°C.	See Waste Package Work Element W.2.2.A.
R.1.23.D Select materials and develop testing techniques required to meet borehole sealing criteria.	Borehole sealing functional requirements.	Repository operating conditions.	See Work Elements R.1.66 and R.1.18.D.
	Borehole characterization at seal locations.	Rock chemistry, temperatures, and permeability.	Work in progress.
	Seal material characterization: • Bulk permeability • Chemical stability.	Laboratory simulation of repository operating conditions.	Materials selection studies being conducted.
	Seal/rock interface characteristics: • Interface permeability • Bond strength • Chemical stability.	Repository conditions.	Preliminary characteristics reported in Kelsall et al. (1982) and Clayton et al. (1981).
R.1.24.D Develop construction and test techniques required to meet repository tunnel and shaft sealing criteria.	Tunnel and shaft sealing functional design criteria.	Repository conditions.	Work to be performed.
	Tunnel/shaft sealing, analysis of published information regarding repository disturbed rock, and hydrologic conditions.	Not applicable.	Tunnel/shaft sealing literature research being conducted.
	Disturbed rock zone characterization at tunnel/shaft seal location.	Lab testing at repository operating conditions.	See Work Element R.1.18.D.
	Tunnel/shaft sealing material permeability.	Lab testing at repository operating conditions.	Laboratory research in permeability being conducted.
	Tunnel/shaft sealing designs.	Not applicable.	Schematic tunnel and shaft sealing designs are being conducted.
	Tunnel and shaft sealing laboratory-scale testing results.	Repository in situ pressures and temperatures.	Work to be performed.
	Seal performance model.	Repository operating conditions including groundwater flow conditions in and around repository.	Work to be performed.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 13 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.25.D Prepare final specifications for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste.	Test results of selected seal methods and materials	Repository operating conditions.	See Work Elements R.2.6 and R.2.8.
	Test results of selected repository backfill materials and methods.	Repository operating conditions.	See Work Element R.2.7.
	Performance assessment analysis results of repository backfill and sealing designs.	Repository operating conditions.	Preliminary assessment being performed.
R.1.26.D Develop methods and equipment for backfilling and sealing the repository, and demonstrate their effectiveness.	Repository sealing and backfill conceptual design.	Not applicable.	Work to be performed.
	Results of repository sealing and backfill lab and field studies.	Repository environmental conditions.	Work to be performed.
WORK ELEMENTS NOT RELATED TO ISSUES			
R.1.27 Determine which facilities or systems within the facility will be designated and classified as high-level waste.	List of facilities and functions.	Not applicable.	Conceptual design.
R.1.28 Assess the effects of adverse conditions on the design and performance of the repository.	Location and characteristics of gas deposits.	At candidate repository horizons, in Grande Ronde Basalt, and in immediately adjacent formations (above and below). In reference repository location and vicinity. By testing and/or direct measurement from surface, in boreholes from surface, in boreholes from repository during construction.	Boreholes have been drilled to various depths in and around the reference repository location. A description of the results of this activity can be found in Myers/Price et al. (1979) and Chapter 3 of this document. Information on exploration for gas deposits in the region is also presented in Chapter 3.
	Identification of rock-mass characteristics and geologic conditions (structural discontinuities, etc.) which, if encountered, will contribute to instability.	At candidate repository horizons, in Grande Ronde Basalt, and in immediately adjacent formations (above and below). In reference repository location and vicinity. By geophysical testing and/or direct measurement from surface, in boreholes from repository during construction.	Surface geophysical testing (seismic reflection and refraction, aeromagnetic, etc. surveys) has been conducted. Results are reported in Chapter 3 and Myers/Price et al. (1979).

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 14 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
		See also Work Element R.1.6.A and Chapter 13.	See also Work Element R.1.6.A and Chapter 13.
	Potential for flooding from surface waters.	At location of shafts and deep boreholes.	Flooding potential reviewed in Chapter 7. Protective features, if required, will be specified in Title II design.
	Seismicity of the region including and surrounding the reference repository location.	Identical to R.1.29 and R.1.30.	Identical to R.1.29 and R.1.30.
	Potential for groundwater inflow to shafts or tunnel system.	Inflow measurements from surface to reference repository horizons in boreholes, test shafts, and at-depth test facilities.	Inflows from each stratigraphic horizon have been calculated using available data.
	Effect of human intrusion.	Not applicable.	Assessment of mineral and other resource potential of the geologic setting are presented in Chapter 3 of this document.
R.1.29 (Related to R.1.30) Assess the effects of seismic events on underground openings during construction and operations.	Magnitude, recurrence rate, source location, and characteristics (length, mechanisms, etc.) of probable seismic events.	Monitoring of reference repository location region to establish baseline data.	BWIP permanent and portable surface monitoring stations in place from 1980. Downhole station operated for a portion of 1980. Details available in Chapter 3. Evaluation of historic data from region discussed in Myers/Price et al. (1979).
	Analysis of applicability of regional design-basis earthquake criteria to repository design.	Not applicable.	Work to be performed.
	Time history of ground motion parameters (displacement, velocity, acceleration frequency) with depth for design seismic event.	Not applicable.	Work to be performed.
	Numerical models of dynamic wave propogation in layered medium and dynamic loading of unsupported and supported rock and soil structures.	Not applicable.	Work to be performed.
	Case history information on structural damage or other effects of seismic events on subsurface structures.	Not applicable.	Preliminary study has indicated a number of literature sources for damage information, suggesting diminishing effect on structures with depth.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 15 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	Structural response of shaft liner/seal/rock interaction during dynamic loading.	Identical to Work Element R.1.30.	Identical to Work Element R.1.30.
	Method of dynamic analysis to assess structural response of openings and support systems to seismic event.	Not applicable.	Work to be performed.
	Seismic-monitoring data in repository structure.	Monitoring stations on rock and/or support system components at selected locations in repository until backfilling.	Work to be performed.
R.1.30 (Related to R.1.29) Assess the effects of seismic events on repository tunnel and shaft seals.	Magnitude, recurrence rate, source location, and characteristics (length, mechanism, etc.) of probable seismic events.	Identical to R.1.29.	Identical to R.1.29.
	Analysis of applicability of regional design-basis earthquake criteria to repository design.	Not applicable.	Work to be performed.
	Time history of ground motion parameters (displacement, velocity, acceleration, frequency) with depth for design seismic event.	Not applicable.	Work to be performed.
	Permeability of seal before and after design seismic event.	Laboratory or bench scale tests with vibratory and impulse loading. Field tests as appropriate.	Work to be performed.
	Instrumentation and techniques to monitor seal disturbance.	Not applicable.	Work to be performed.
R.1.31 Develop shielding requirements, operating, and access control procedures to limit the dose to repository personnel.	10 CFR 20 requirements.	None.	Existing regulations.
	Waste package dose rates.	None.	Functional design criteria (BWIP and KE/PB, 1982).
	Waste package storage configuration.	None.	Conceptual design.
	Method of waste package handling and transportation.	None.	Conceptual design.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 16 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.32	Surface facilities arrangement.	None.	Conceptual design.
Develop the procedures and requirements for controlling access to the repository site.	Hanford Site security requirements.	None.	Existing requirements.
R.1.33	Waste package storage configuration.	Not applicable.	Conceptual design.
Determine the techniques to be used for limiting, monitoring, and controlling the airborne radioactivity in the repository.	Waste package radionuclide inventory.	Not applicable.	Conceptual design.
	Ventilation system design.	Not applicable.	Conceptual design.
	Repository layout.	Not applicable.	Conceptual design.
	U.S. Nuclear Regulatory Commission requirements (10 CFR 20).	Not applicable.	Existing regulations.
	Available monitoring instrumentation.	Not applicable.	Conceptual design.
	Accident/failure analysis to determine possible releases.	Not applicable.	Work to be performed.
	Hanford Site practices.	Not applicable.	Existing regulations.
R.1.34	Repository temperature.	Not applicable.	See R.1.13.B.
Develop a design that will protect operations personnel against the effects of natural phenomena and environmental conditions.	Potential for rock instability.	Not applicable.	See R.1.6.A.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 17 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.35	Listing of safety-related systems.	Not applicable.	Conceptual design.
Determine the impact of the dynamic effects of equipment failure on safety-related systems and components.	Failure analysis.	Not applicable.	Work to be performed.
R.1.36	Identify disruptive natural or man-induced events.	Not applicable.	Work to be performed.
Define the structures or equipment necessary so that disruptive natural or man-induced events such as intrusion of gas, water, or explosion will not spread through the repository.	Analysis to determine probability of event and measures required to limit spread throughout the repository.	Not applicable.	Work to be performed.
	Effect of disruptive events on repository.	Not applicable.	Work to be performed.
R.1.37	Layout of repository.	None.	Conceptual design.
Determine the extent and severity of potential fires and explosions in the repository and their effect on the stability of the rock-support systems and other safety-related systems.	Rock support system design.	None.	Conceptual design.
	Safety-related equipment list.	None.	Conceptual design.
	Maximum credible fire and explosion analysis.	None.	Work to be performed.
	Ventilation system design.	None.	Conceptual design.
R.1.38	List of safety-related system equipment.	Not applicable.	Conceptual design.
Determine which combustible materials can be used in the design of components and equipment that have been designated as safety-related systems.	Proposed combustible material used in equipment.	Not applicable.	Work to be performed.
	Mine Safety and Health Administration regulations.	Not applicable.	Existing regulations.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 18 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.39 Develop fire and explosion alarm and protection systems for all equipment and facilities within the repository operations area that are required for safe operation of the repository.	Mine Safety and Health Administration regulations.	Not applicable.	Existing regulations.
	Layout of repository.	Not applicable.	Conceptual design.
	Ventilation and electrical system.	Not applicable.	Conceptual design.
R.1.40 Determine the reliability and protection required to ensure that safety-related systems operate adequately under adverse or emergency conditions.	List of safety-related equipment.	Not applicable.	Conceptual design.
	List of emergency and adverse conditions.	Not applicable.	Conceptual design.
	Results of reliability analysis.	Not applicable.	Work to be performed.
	Failure analysis.	Not applicable.	Work to be performed.
	Mine Safety and Health Administration regulations.	Not applicable.	Existing regulations.
R.1.41 Define what requirements are necessary to permit evacuation of personnel under emergency conditions.	Listing of emergency conditions.	Not applicable.	Conceptual design. The safety analysis report will describe the emergency conditions that may occur during repository construction and operation and the procedures necessary to evacuate or protect personnel under those conditions.
	Designated evacuation routes.	Not applicable.	Same as above.
	Listing of transportation requirements.	Not applicable.	Same as above.
	Hoist capacity and speed.	Not applicable.	Same as above.
	Mine Safety and Health Administration regulations.	Not applicable.	Existing regulations.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 19 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.42 Determine what facilities, equipment, and services are required to ensure a safe and timely response to any emergency conditions.	Type and frequency of potential emergency conditions (see Work Element R.1.43).	Not applicable.	Work to be performed.
	Mine Safety and Health Administration and U.S. Nuclear Regulatory Commission regulations and other codes that may be applicable.	Not applicable.	Existing and proposed regulations.
R.1.43 Determine which systems require redundant power supply, uninterrupted service, or standby service in the event of loss of primary power.	Mine Safety and Health Administration regulations for emergency operations.	Not applicable.	Existing regulations.
	Layout of repository electrical and ventilation systems.	Not applicable.	Conceptual design.
	Power requirements for safety-related systems.	Not applicable.	Conceptual design.
R.1.44 Determine which structures, systems, and components are important to safety; develop and implement appropriate inspection, testing, and maintenance programs.	Lists of structures, systems, and components used in repository.	Not applicable.	Conceptual design.
	List of equipment specifications.	Not applicable.	Work to be performed.
	Repository safety analysis and emergency requirements.	Not applicable.	Conceptual design.
	Mine Safety and Health Administration regulations.	Not applicable.	Existing regulations.
R.1.45 Assess the potential for criticality for the proposed waste packages and storage orientations under fully flooded storage conditions.	Waste package fissionable material.	Not applicable.	Conceptual design.
	Waste package storage locations.	Not applicable.	Conceptual design.
	Groundwater flow in repository.	Not applicable.	See Chapter 4 of this document.
	Quantities and distributions of fissionable materials.	Not applicable.	Anderson (1982).
	Backfill material solubility.	Not applicable.	Work to be performed.
	Criticality analysis of initial (contained) and isolated (released to near field) scenarios.	Not applicable.	Work to be performed.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 20 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.46 Determine what instrumentation and control systems are required to monitor and control safety-related systems.	Identification of all safety-related systems.	Not applicable.	Conceptual design.
	Mine Safety and Health Administration regulations.	Not applicable.	Existing regulations.
R.1.47 (Related to R.2.5) Develop, as required, instrumentation to measure stresses, deformation, temperature, and pore pressures reliably until backfill is emplaced.	Performance specifications for instrumentation used to determine stress, deformation, temperature, or pore pressure.	Literature search and manufacturers information.	Instrument development has been initiated in conjunction with the Near-Surface Test Facility test program.
	Performance testing for proposed instrumentation.	Repository conditions.	Work to be performed.
	Modifications that improve instrument performance, as required.	Not applicable.	Work to be performed.
R.1.48 (Related to R.1.6.A and R.1.7.A) Develop or adapt instrumentation and monitoring techniques to predict rock bursts.	Catalogue of in situ stress data, intact and rock-mass properties, areal extraction ratio, rate of extraction, size of openings, and geologic conditions for rock burst-prone areas.	Not applicable.	Literature search in progress.
	Literature search for successful use of instrumentation to predict or detect rock burst and spalling.	Not applicable.	Literature search in progress.
	Data analysis and interpretation techniques that can be appropriately used with monitoring instruments.	Not applicable.	Work to be performed.
	Characteristic response of monitoring parameters during rock burst or pre-burst conditions.	Examination of monitoring-system output to determine characteristic response based on frequency and/or amplitude that may indicate development of rock burst conditions testing in laboratory under repository conditions (20° to 300°C and 1 to 100 MPa).	Work to be performed.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 21 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	System performance, calibration, and check-out procedure.	Repository conditions.	Work to be performed.
	Stress conditions in or about rock burst-prone areas.	Monitoring of stress conditions ahead of excavation during construction of repository to detect sudden changes in stress levels, which may indicate rock burst condition.	No information available.
R.1.49 Determine the requirements necessary to assure that safety-related systems provide adequate protection to construction and operations personnel.	Potential safety hazards existing during construction and operation for all structures, systems, and equipment.	Not applicable.	Conceptual design.
	Appropriate Mine Safety and Health Administration regulations.	Not applicable.	Existing regulations.
R.1.50 Determine the requirements and procedures necessary for the safe receipt and surface storage of radioactive wastes.	Waste package dose rate.	Not applicable.	Conceptual design.
	U.S. Nuclear Regulatory Commission requirements.	Not applicable.	Proposed regulation 10 CFR 60.
	Waste handling surface facilities design.	Not applicable.	Conceptual design.
	Waste package design.	Not applicable.	Conceptual design.
	Shipping cask design.	Not applicable.	Conceptual design.
	Hanford Site requirements.	Not applicable.	Existing and proposed regulations.
R.1.51 Determine the ventilation requirements for the surface facilities that will contain radioactive materials.	List of buildings handling radioactive waste.	Not applicable.	Conceptual design.
	Characterization of waste form.	Not applicable.	Conceptual design.
	U.S. Nuclear Regulatory Commission ventilation and radionuclide release requirements.	Not applicable.	Existing regulation 10 CFR 20.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 22 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.52 (Related to R.1.33) Determine what equipment and controls are necessary to measure the amount and concentrations of radionuclides in any effluents from surface facilities with sufficient precision to determine that they conform to statutory release requirements.	Identical to R.1.33.	Not applicable.	Conceptual design.
R.1.53 Determine the facilities that are required for the treatment, processing, or packaging of radioactive waste generated at the repository operations area to permit safe disposal or transportation of these wastes.	Description of potential radioactive wastes generated by the repository. Description of waste processing equipment. Waste disposal locations.	Not applicable. Not applicable. Not applicable.	Conceptual design. Conceptual design. Conceptual design.
R.1.54 Determine the requirements for design of the surface waste disposal facilities to facilitate decommissioning.	List of proposed facilities that will contain radioactive material. Contaminated areas identified. Descriptions of current decontamination and decommissioning techniques.	Not applicable. Not applicable. Not applicable.	Conceptual design. Conceptual design. Work to be performed.
R.1.55 (Related to W.1.12.A) Determine that the interaction between the waste package, the underground facilities, and the geologic setting does not compromise the performance of the underground facilities.	Geochemical properties. Rock-mass properties. Radionuclide migration and transport characteristics.	Included in W.1.11.A and W.1.12.A. Included in R.1.11.B and R.1.12.B. Included in W.2.1.A.	Included in W.1.11.A and W.1.12.A. Included in R.1.11.B and R.1.12.B. Included in W.2.1.A.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 23 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.56 (Related to R.1.18.D, R.1.19.D, and R.1.66) Determine how to control groundwater influx and transit in the repository to maintain radionuclide release from engineered systems within the U.S. Nuclear Regulatory Commission appropriate release standards.	Included in Work Elements R.1.18.D, R.1.19.D, and R.1.66.	Included in Work Elements R.1.18.D, R.1.19.D, and R.1.66.	Included in Work Elements R.1.18.D, R.1.19.D, and R.1.66.
R.1.57 Provide an appropriate orientation, geometry, waste placement, and layout of the repository to ensure structural stability and containment of radionuclides.	Groundwater flow rates and directions.	In situ groundwater flow conditions.	See Chapter 3.
	In situ stress measurements at the candidate repository horizons. (Included in R.1.8.A)	In situ horizontal and vertical stress measurements and horizontal major and minor stress directions.	Preliminary results of hydrofracture tests indicate stress ratio of 2:1.
	Evaluation of repository configuration and tunnel support system.	Included in R.1.61.	Work to be performed.
	Waste package temperatures versus time over repository lifetime (numerical model).	Not applicable.	Work to be performed.
	Effects of temperature profile on support system and tunnel-configuration geometry.	Included in R.1.61.	Work to be performed.
R.1.58 Design the underground facility with sufficient flexibility to allow for adjustments during construction that will accommodate site-specific conditions identified by in situ testing or monitoring.	Identify potential adverse conditions.	Identical to R.1.28.	Identical to R.1.28.
	Parametric sensitivity analysis.	Identical to R.1.28.	Identical to R.1.28.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 24 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.59 Define the requirements necessary to allow for the emplacement or retrieval of waste packages during continuous excavation and construction of the repository.	Waste package storage configuration and design.	Not applicable.	Conceptual design.
	Waste package emplacement procedures and requirements.	Not applicable.	Conceptual design.
	Ventilation system requirements.	Not applicable.	Conceptual design.
	Repository construction procedures.	Not applicable.	Work to be performed.
R.1.60 (Included in R.1.36) Determine what safety requirements are necessary to isolate waste package storage rooms from other areas in the event that accidents occur.	Included in R.1.36.	Not applicable.	Included in R.1.36.
R.1.61 Develop rock support systems that are compatible with decommissioning requirements and that will function satisfactorily in the repository environment for the period of construction, operation, and retrieval (including effects of cooling prior to backfilling or retrieval).	Rate of convergence, support load, and extent of disturbed rock zone for proposed support systems.	Repository operating conditions.	Work to be performed.
	Tunnel stability before and after support installation.	Numerical modeling or empirical analysis.	Work to be performed.
	Decommissioning requirements.	Not applicable.	Work to be performed.
	Effect of repository environment on support components.	Repository operating conditions.	Work to be performed.
R.1.62 Define the requirements, equipment, and procedures necessary to retrieve the radioactive waste after emplacement in the repository if retrieval is ultimately required.	Waste package design, storage configuration, and dose rates.	Not applicable.	Conceptual design.
	Required retrieval rate.	Not applicable.	Conceptual design.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 25 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.63 (Related to R.1.56) Assess the requirements to monitor and provide effective control of groundwater intrusion, service water intrusion, or gas inflow into the repository during construction.	Water monitoring and control is included in R.1.56.	Water monitoring and control is included in R.1.56.	Water monitoring and control is included in R.1.56.
	Location and characteristics of gas deposits.	Included in Chapter 13.	Included in Chapter 13.
	Techniques for monitoring of gas level.	Ambient repository conditions.	Work to be performed.
	Method of reducing gas level to within acceptable Mine Safety and Health Administration regulations, if necessary.	Not applicable.	Work to be performed.
R.1.64 Define the subsurface ventilation requirements for the control of radioactive particulates and gases within and releases from the subsurface facility.	Design of repository and ventilation system.	Not applicable.	Conceptual design.
	U.S. Nuclear Regulatory Commission radionuclide release proposed criteria.	Not applicable.	Existing regulation 10 CFR 20.
	Radiation-monitoring equipment list.	Not applicable.	Work to be performed.
	Mine Safety and Health Administration regulations.	Not applicable.	Existing regulations.
R.1.65 Define ventilating system requirements during normal operations, including controls to ensure continued operation under emergency conditions.	Regulations.	Not applicable.	Existing regulations (MSHA, 1981; NRC, 1979; ACGIH, 1980).
	Underground temperature.	Not applicable.	Conceptual design.
	Predicted dust levels.	Not applicable.	Conceptual design.
	Predicted gas or fume levels.	Not applicable.	Work to be performed.
R.1.66 Determine functional requirements for selecting locations of repository seals and backfills as engineered barriers to effectively retard groundwater movement and radionuclide migration.	Repository design.	Not applicable.	Conceptual design.
	U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency requirements evaluated.	Not applicable.	Evaluation initiated.
	Seal and backfill material permeability and K_d laboratory measurements.	Repository operating condition K_d's for hazardous radionuclides identified in solubility studies.	See Waste Package Work Elements W.1.1.A, W.1.2.A, W.1.4.A, W.1.12.A, and W.2.4.A.
	Disturbed rock zone characterization: • Permeability • Joint properties • Fractures.	See Work Element R.1.72.	Preliminary evaluation reported in Kelsall et al. (1982).

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 26 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	Differential hydrologic pressure at seal locations.	Repository operating conditions after decommissioning.	Work to be performed.
	Repository sealing model.	Repository operating conditions over 10^4 years.	Model development in progress.
	Temperature profiles in repository.	Repository operating conditions.	Temperature model development in progress.
	Groundwater geochemistry.	See Waste Package Work Element W.1.12.A.	See Waste Package Work Element W.1.12.A.
	Backfill material expansion coefficient.	Repository temperature, pressure, and groundwater chemistry.	Preliminary work in progress.
R.1.67 Determine radionuclide sorption requirements for backfill materials to be used for repository rooms and tunnels.	Backfill material physical and chemical properties.	Backfill permeability and key radionuclide sorption coefficient at repository conditions for 10^4 years.	Preliminary data on sorption and precipitation of radionuclides in the presence of clays obtained (Salter et al., 1981).
	Radionuclide speciation in groundwater.	See Waste Package Work Element W.1.10.A for details.	See Waste Package Work Element W.1.10.A for details.
	Backfill functional requirements.	See Work Element R.1.66.	See Work Element R.1.66.
	Radionuclide transport rate through backfill material.	Flow-through experiments at repository conditions.	See Waste Package Work Element W.1.16.B.
	Sealing and backfill geochemical and hydrologic computer model.	Saturation to 10^4 years with repository groundwater and hazardous soluble radionuclides.	Model study in progress.
R.1.68 Define the appropriate requirements, equipment, and procedures necessary to handle, emplace, and retrieve the radioactive waste under operating conditions.	Waste package characteristics.	Not applicable.	Conceptual design.
	Transfer cask specifications.	Not applicable.	Conceptual design.
	U.S. Nuclear Regulatory Commission dose requirements for personnel.	Not applicable.	Existing regulation 10 CFR 20.
	Waste storage configuration.	Not applicable.	Conceptual design.
	Repository design.	Not applicable.	Conceptual design.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 27 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.1.69 (Related to R.1.50) Design hoist and hoist loading systems with sufficient capacity, redundancy, and monitoring systems to ensure that radioactive materials will be handled in a safe and reliable manner.	Waste package design and specifications.	Not applicable.	Anderson (1982).
	Transfer cask specifications.	Not applicable.	Conceptual design.
	Failure analysis.	Not applicable.	Work to be performed.
	Regulations applicable.	Not applicable.	Proposed regulations.
R.1.70 Determine the coupled effects of stress and elevated temperatures on the permeability of the rock mass.	Permeability of basalt rock mass in undisturbed condition at pre-excavation repository conditions of temperature and stress.	To be specified.	Preliminary data reported in Chapter 4.
	Variation in permeability of rock mass with temperature and pressure.	To be specified.	Work to be performed.
R.1.71 Estimate the extent of drying and resaturation of the host rock and backfill as functions of time and distance from the emplaced waste package, and determine the effects of such on the host rock.	Possible scenarios for groundwater intrusion into near field, including direction and velocity of flow and hydraulic head.	Numerical modeling.	Work to be performed.
	Effect of elevated temperatures on the pattern of groundwater intrusion.	Numerical modeling.	Work to be performed.
	Strength and deformation behavior of saturated rock.	To be specified.	Work to be performed.
	Effect of heated water on the characteristics of joints and infilling material with time. Relation of these effects to rock-mass behavior.	To be specified.	Work to be performed.
	Hydraulic head in near field prior to and during construction.	To be specified.	Data available from hydrology studies.
	Effect of heated water on the integrity of the structural support systems with time (See R.1.51).	To be specified.	Work to be performed.

TABLE 14-2. Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design. (Sheet 28 of 28)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	Models that predict groundwater inflow patterns and determine effect of pore pressure on deformation behavior of rock mass and backfill.	Repository operating conditions.	Work to be performed.
	Effect of saturation on characteristics of backfill material.	Laboratory and field testing at repository conditions (see W.1.13).	Work to be performed.
	Thermal properties of rock mass and backfill material.	Laboratory and field testing at repository conditions.	See R.1.12.B.
R.1.72 Prepare procedures that will ensure the development of a complete documented history of repository construction as specified in 60.134(c).	Not applicable.	Not applicable.	A set of procedures to maintain construction records will be written in accordance with 60.134(c) prior to construction of the exploratory shaft.
R.1.73 Prepare specifications for the control of explosives to include the provisions of 30 CFR 57.6.	Mine Safety and Health Administration regulations.	None.	Existing regulations.
	30 CFR 57.6.	None.	Existing regulations.
	State and local codes.	None.	Existing regulations.
	Specifications.	Not applicable.	Work to be performed.
R.1.74 Define and implement appropriate training, testing, certification, and qualification programs for operating and supervisory personnel.	Applicable training, testing, and certification requirements reviewed.	Not applicable.	Work to be performed.
	Training, testing, and certification programs defined.	Not applicable.	Work to be performed.
R.1.75 Define and implement methods and designs that will minimize resource utilization to the extent compatible with safety and performance requirements.	Repository design information.	Not applicable.	Conceptual design.
	Surface facilities design.	Not applicable.	Conceptual design.
	Available water, power, and materials resources assessed.	Not applicable.	Conceptual design.
	Environmental conditions assessed.	Not applicable.	Conceptual design.

The selection of the failure criterion, and thus the analysis method and models to properly represent the constitutive behavior of the rock mass, will be chiefly dependent on the results of the in situ testing at depth in the reference horizon selected for explortory shaft breakout from among the two candidate repository horizons. Test results that will influence the selection include: rock-mass strength and deformation properties, support system interaction and its effect on strength and deformation parameters, pore pressure, time-dependent effects, and the homogeneity of the rock mass. From this information a failure criterion for the rock mass/support system will be identified, either by adapting existing criteria or by developing an independent relationship that specifically describes the observed response of the rock mass.

Work Element R.1.2.A (Priority 1)

Evaluate the effect of underground construction sequence on the stability of openings.

Status

The status of numerical models required to determine the nature of stress distributions in the region of the tunnel system is discussed in Work Elements R.1.13.B and R.1.4.A. The status of the survey and literature study to determine conditions typically associated with rock bursting is addressed in Work Element R.1.6.A. The construction sequences investigated as a part of this work element will be those that are superior from a scheduling standpoint. These sequences will accommodate, in the most cost and time effective manner, activities associated with construction materials handling, ventilation, and waste emplacement.

Plans

A more careful consideration of the construction sequence is warranted for this site, in large part because of the apparent ratio of maximum horizontal-to-vertical in situ stress (2 to 1) and associated potential for rock bursting. The most commonly cited principle underlying the bursting phenomenon is buildup and explosive release of strain energy in the rock. Accordingly, potential and strain energies associated with advancing regions of the tunnel system during simulated excavation will be calculated using existing analysis techniques in conjunction with numerical models describing the mechanical behavior of the rock mass. An analysis of energy changes and energy balance for the anticipated repository excavation geometry, rate, and geologic conditions compared to those from documented stable and unstable excavations will be necessary to estimate which excavation sequences are unfavorable. The final objective will be to determine if the patterns of stress accumulation and redistribution, and the resulting deformations of the rock mass/support system can be accommodated without temporary overstressing that could lead to dynamic instability. The analysis will also determine if previously placed waste canisters are sufficiently far from the regions of significant stress-accumulation redistribution to be safe from any unanticipated unstable conditions.

Work Element R.1.3.A (Priority 1)

Determine the magnitude and the rate of deformation of tunnels and canister boreholes resulting from in situ, excavation-induced, and thermal-induced stresses, and how deformation is affected by backfill.

Status

Initial work on the selection and validation of thermomechanical models for determining time-dependent rock deformations is in progress (see Work Element R.1.13.B). While no tests to determine rock-mass deformation properties of the candidate repository horizons have been conducted, such tests in the Pomona flow at the Near-Surface Test Facility have been and are being conducted (see Chapter 4). These tests are expected to be useful in planning, instrumenting, and interpreting future in situ tests. Laboratory-scale tests have been conducted on some candidate repository horizon samples to determine short-term deformation characteristics, and creep tests are currently being initiated. Primary consideration has been given to a mixture of bentonite and crushed basalt for room backfilling purposes (see Chapter 10), but no attempt has been made to measure its engineering characteristics.

Plans

Tunnels and canister boreholes should be designed to minimize deformation so that the engineered barriers will reach an equilibrium state without further perturbation of the rock mass. Excessive deformations could affect disturbed rock zones, support system components, or canister retrieval efforts. The design activities will therefore include an analysis of the time history of deformations associated with tunnel and canister borehole walls, including the eventual effect of backfill emplacement. The analysis will begin by employing numerical models for thermomechanical behavior of the rock, time-dependent rock-mass-deformation characteristics, and empirical or numerical modeling methods of incorporating the support system deformation characteristics to determine the magnitude and rate of tunnel and borehole closure. This analysis will cover the period from excavation up to backfilling.

The tunnel and canister borehole backfills must satisfy criteria relating to both seepage and mechanical performance. A backfill design will be produced that meets seepage criteria and the corresponding engineering characteristics of the backfill will then be measured for analyzing the effect of the backfill on tunnel and borehole deformations. Tests will be conducted to measure the behavior of the backfill on saturation, including swelling pressures that may develop, and to define the time-dependent deformation characteristics for both as-constructed and saturated conditions.

The interaction between the backfill and the rock and support systems on both the canister backfill and tunnel scale will be determined using the applicable thermomechanical models. The resulting patterns of canister borehole deformation will then be analyzed to examine any potential impact on the ability to retrieve waste packages from the borehole.

Work Element R.1.4.A (Priority 1)

Determine the magnitude and distribution of excavation-induced stresses for single and multiple openings.

Status

Knowledge of the magnitude and distribution of excavation-induced stresses is necessary for use in determining the stability of the subsurface facilities and the deformation of tunnels and canister boreholes. Estimations of stress redistributions for multiple openings are also necessary to assess the potential for large-scale dynamic instability during construction as the volume of extracted rock increases.

The redistribution of stress caused by the proposed opening configuration of the repository design has not yet been fully analyzed to determine the impact of recently measured in situ stress conditions. The initial ratio of maximum horizontal-to-vertical stress used in the design was 1:1. Recent measurements at the candidate repository horizons indicate that the actual average ratio is 2:1 (see Section 4.6) and the conceptual design has now been modified to incorporate this information.

Plans

Work will continue on the development and validation of the numerical models used to evaluate the stress conditions. As access to the candidate repository horizons is achieved, the quality of the input information regarding both in situ stresses and deformation properties, will increase and allow improvements of the accuracy and reliability of the models. Alternate geometries and spacing of the openings will also be analyzed to evaluate the sensitivity of the stress profiles to change in the input parameters. The actual in situ testing of the stress distribution conducted at depth will provide confirmation of the models and design.

Work Element R.1.5.A (Priority 1)

Determine the magnitude and distribution of thermal stresses in the rock mass for the proposed waste package storage configuration.

Status

The analysis of the thermal stresses in the rock mass due to the selected waste package storage configuration will be performed by means of a numerical model that generates temperature profiles and stress distributions in the near field. Some of the necessary input data for this model are available (i.e., size, shape, and thermal history of the waste

canisters and the depth and spacing of the emplaced canisters). Preliminary specifications for these parameters are included in the conceptual design. Other data input, including the thermal properties of the rock mass (see Work Element R.1.12.B) and the rock-mass deformation properties (see Work Element R.1.11.B), will become available as a result of testing outlined in this chapter.

Plans

The numerical simulation to determine the temperature profile and stress distributions in the near field will be conducted as part of the performance assessment process prior to the Title II (detailed) design.

Work Element R.1.6.A (Related to R.1.7.A and R.1.48) (Priority 1)

Determine from case history evaluations the combinations of stress fields, rock properties, geologic structural features, and mine geometries that are typical of rock burst-prone areas, and assess the probability of rock bursts at or near the repository site.

Status

Work to be performed.

Plans

A literature search will be conducted and inquiries made of engineers practicing in burst-prone areas to document rock burst occurrences. Details of the conditions and events surrounding each burst will be tabulated, including, as a minimum, those factors that are currently known to be associated with the phenomenon (e.g., geologic structure, rock-mass properties, in situ stresses, extraction ratio, rate of extraction, dimensions of pillars). Factors will be weighted to indicate their significance to rock burst conditions, by noting the frequency with which they appear in the case histories. A comparison of these factors with conditions existing and anticipated at the repository location will be used to estimate the potential for rock bursting at the site.

Work Element R.1.7.A (Related to R.1.6.A and R.1.48) (Priority 2)

Document occurrences of dynamic instability of test excavations at depth at the repository site.

Status

Observations of the integrity of the walls of vertical exploratory boreholes, which are the only openings currently existing at the candidate repository horizons, indicate an absence of any signs of spalling or related dynamic phenomena.

Plans

A program of inspection of shafts and test facilities at and near the candidate repository horizons will be in place as these facilities are excavated. All personnel in the facilities will be instructed to document events indicative of instability, including formation of cracks, audible microcracking, spalling, slabbing, etc. Acoustic emission instrumentation may be installed to detect both surficial and deep-seated subaudible cracking that may precede rock bursting. Analysis of these observations will contribute to an assessment of the potential for rock bursts to occur as large-scale tunneling proceeds.

Work Element R.1.8.A (Related to R.1.14.C and R.1.15.C) (Priority 1)

Determine the spatial variation of in situ stresses in the region of the repository.

Status

Stresses can vary substantially from location to location, even over short distances, depending on the geologic factors in the area of concern. These factors include uniformity of the flow and joint structure, the relative location in the synclinal structure, and the presence of geologic discontinuities.

The spatial variation of stresses in the reference repository location will be evaluated through borehole measurements in advance of excavation and will be confirmed by in situ measurements after excavation. To date, the BWIP has conducted preliminary stress measurements in the candidate repository horizons for only one borehole (DC-12), the results of which are presented in Section 4.6.

Plans

The BWIP has planned independent verification of this key design factor by proposing to conduct additional hydraulic-fracturing tests at the candidate repository horizons. A series of tests will be conducted in borehole DC-12, where the previous tests were conducted as a check on the repeatability of stress measurements using different equipment and test operators.

Stresses will be measured by the BWIP in additional boreholes separated by at least 1.6 kilometers (1 mile) in the reference repository location by the hydraulic-fracturing method, in advance of excavation of the in situ test facilities. Tentatively, boreholes RRL-2, DC-4, DC-16A, and DC-17 have been identified as suitable for hydrofracture tests. Further tests will be conducted in the in situ test facilities in the candidate repository horizons when these facilities become available. Using methods to be developed under Work Element R.1.14.C, variations of the stresses within the in situ test area will be measured. Data obtained from these underground and preexcavation tests will provide sufficient information to verify the spatial variation of the in situ stress in the reference repository location.

Work Element R.1.9.A (Priority 3)

Determine the potential for subsidence caused by mine openings.

Status

A geologic characterization of strata overlying the candidate repository horizons has been conducted. Data obtained include stratigraphic and petrologic information and physical properties (density, wave velocities, etc.) obtained from surface and borehole geophysical testing. Results of these investigations can be found in Myers/Price et al. (1979) and Chapter 3 of this document. Some information on the strength and deformation characteristics of the overlying Grande Ronde Basalt has been obtained from laboratory tests on core samples. Work has not yet been initiated on hypothesizing the nature and extent of possible failures of the rock surrounding the repository tunnel systems and determining the corresponding effect, if any, such failures might have on overlying geologic formations.

Plans

Numerical models will be used to determine whether and how failures will propagate upward. A literature investigation will also be conducted to help identify possible mechanisms of subsidence, including such phenomena as "tunneling," which are not easily modeled. The results of these analyses will be used to estimate the probability of subsidence-type occurrences and determine any subsequent effect on the isolation capability of the repository.

Work Element R.1.10.A (Priority 2)

Define the acceptable range of test results for intact rock and rock-mass characteristics to support design activities.

Status

Work to be performed.

Plans

The acceptable range of rock-mass characteristics must be known by the designer so that the probability of encountering conditions for which there is no known or easily adopted design remedy can be factored into the evaluation of site suitability. The acceptable range of rock-mass characteristics must also be known for performance assessment purposes. If performance confirmation data indicate that rock-mass characteristics or conditions no longer conform to those used for original design, safety or isolation capability may be compromised. Alternate designs and remedial measures must be prepared to compensate for these changed circumstances, as required. Such alternate planning is necessary to achieve adequate flexibility of design.

A parametric and sensitivity analysis will be performed using applicable models to examine the relationship between characteristics and conditions of the natural and engineered systems and the ability of the repository to function as necessary to achieve safety and isolation objectives. The ability to function properly will generally be expressed in mathematical form, such as the factor of safety against static failure of the rock mass. The sensitivity analysis will then examine how this factor of safety varies with rock-mass cohesion, joint spacing, piezometric head, etc. The initial part of the analysis will identify those parameters that have the greatest impact on repository functions. An extended analysis will be used to examine potential unfavorable scenarios to determine what combination and what numerical range of these more important parameters may adversely affect the repository functions. The results of these analyses will be used as the basis for deciding which parameters to monitor during performance confirmation (Work Element R.2.1) and when these parameters no longer conform to design conditions and assumptions (Work Element R.2.2).

ISSUE R.1.B

Can satisfactory representative measurements or estimates of rock-mass strength be obtained?

Work Element R.1.11.B (Identical to R.2.3) (Priority 1)

Measure rock strength and deformation characteristics on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.

Status

As part of the Near-Surface Test Facility test program, preliminary estimates of rock-mass deformation properties and laboratory-scale deformation, strength, and time-dependent properties are being made. The strength and deformation properties of basalt on a rock-mass scale require further investigation. Emphasis will be placed on these tests.

Jointed Block Test No. 1, currently in progress at the Near-Surface Test Facility, will yield rock-mass deformation properties at temperatures of 20° to 300°C and confining pressures of 0 to about 20 megapascals for the exposed Pomona Member basalt. Although test results from the Pomona Member are not directly applicable to the candidate repository horizons, the generic similarities between flows will provide a basis from which qualitative estimates or interpretations of candidate repository horizon behavior can be made. No measurements of basalt rock-mass strength properties have been conducted to date.

Preliminary laboratory tests have been conducted on some candidate repository horizon core samples recovered from exploratory drilling. Deformation and strength properties of intact and jointed specimens at temperatures of 20° to 300°C and confining pressures of 0 to

70 megapascals have been determined. Due to the statistically limited number of samples available from the candidate repository horizons, the results are being used for conceptual repository design purposes only.

Laboratory creep tests of jointed Umtanum flow and Pomona Member core samples are currently in progress.

Plans

Laboratory tests will be conducted on candidate repository horizon samples obtained from the principal borehole (RRL-2) and from the exploratory shaft testing program. These tests will provide the required statistical data for confidence in the laboratory-scale strength and deformation properties for the anticipated repository conditions, including time-dependence, pore pressure, and jointing effects. These data, together with rock-mass geologic characterization information, will provide a means of estimating the strength and deformation characteristics of the rock mass. Confirmation of these estimates will be obtained from the appropriate rock-mass tests. Selection of the type of rock-mass tests and their detail will be based to some extent on results of tests at the Near-Surface Test Facility. Each rock-mass test location will be characterized through geologic mapping and laboratory physical and mechanical property tests. The relationship between the rock-mass test results and the corresponding characterization information can then be used to estimate rock-mass strength and deformation behavior more reliably. The results will establish the spatial variation of rock-mass behavior within the reference repository location.

Work Element R.1.12.B (Identical to R.2.4) (Priority 2)

Measure rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.

Status

Preliminary laboratory tests have been performed on samples recovered from the candidate repository horizons. Due to the statistically limited number of samples available, the results are being used for conceptual repository design purposes only.

Jointed Block Test No. 1, currently under way at the Near-Surface Test Facility, will yield values for thermal conductivity and coefficient of thermal expansion on a rock-mass scale, in the temperature range of 20° to $300^{\circ}C$ and at confining pressures of 0 to about 20 megapascals. The Near-Surface Test Facility tests will also yield information on the effects of structural discontinuities on the thermal properties of the rock mass. These tests are being conducted in the Pomona Member basalt, which limits their applicability to the candidate repository horizons. However, this field test information, when correlated with laboratory tests of Pomona Member samples, will provide a valuable basis for extrapolation of in situ properties of the candidate repository horizons from laboratory testing of core samples recovered from depth.

Plans

Tests conducted in the exploratory shaft will significantly increase the degree of confidence in the thermal property values. As more samples become available, additional laboratory testing will improve the statistical quality of the results. In situ testing will provide rock-mass scale values for thermal properties.

Work Element R.1.13.B (Priority 1)

Develop and validate mechanical, thermal, and thermomechanical models for performance of in situ tests and for design and performance of the repository.

Status

Sufficient numerical modeling studies have been conducted at the canister, room, repository, and regional scales in conjunction with proposed hard-rock nuclear waste repositories to conclude that available codes and models can be adapted and applied to the repository with little or no additional development. Canister-scale field tests for model validation will be completed during fiscal year 1983 in the Near-Surface Test Facility. These tests, along with additional data from the candidate repository horizons, will provide the basis for validation of canister-scale models. Final development of the data base of laboratory-scale physical, mechanical, and thermal properties required for model validation is in work.

Plans

Computer-based numerical models using finite element or finite difference methods are used to predict rock temperatures, deformations, and stresses due to construction activities and waste emplacement in the repository. These models are also used to assess the performance of the repository prior to closure, and to predict and evaluate results of in situ testing.

The complexity of the interactions between the natural and engineered systems requires that model development proceed on several scales. Canister-scale models will describe the behavior of the rock mass in and around the canister borehole. Room-scale models will describe the behavior of the rock mass in the near field, including the region of the tunnel periphery experiencing increased stress due to elevated temperatures and excavation. Repository-scale models will describe the interaction between tunnels and shafts, while the regional model will evaluate the effects on basalt flows adjacent to (above and below) the candidate repository horizons.

Each model selected for use will be validated as required, and model selection will be influenced by results of validation studies. Validation of the near-field and canister-scale models will be achieved through comparison of predicted and measured rock-mass behavior. Continued evaluation of results from Near-Surface Test Facility tests will provide preliminary validation and selection of models currently under consideration.

Selection of far-field models will be based on results of benchmark and sensitivity studies as well as performance records available from the engineering community. Near- and far-field models will be validated by comparison of predicted behavior and measured parameters (i.e., temperatures, deformation). Indirect confirmation of predicted performance will be provided by observations of related natural conditions and phenomena in the repository region.

ISSUE R.1.C

Are current methods of in situ stress measurement used at depth reliable enough to provide satisfactory data for design requirements?

Work Element R.1.14.C (Related to R.1.8.A and R.1.15.C) (Priority 1)

Develop stress measurement methods that will yield valid data in closely jointed basalt.

Status

Extensive field tests have been conducted in the Near-Surface Test Facility, before and after construction, as part of the site characterization effort. Measurement methods attempted included (1) overcoring with a U.S. Bureau of Mines' borehole deformation gauge, (2) jack fracturing, (3) hydraulic fracturing, and (4) use of the flat-jack method. None of the methods has been found entirely satisfactory for providing all the data needed to the level of accuracy required for repository design. However, these field investigations have yielded promising information on improvements in some of the methods to allow them to provide the required information.

The hydraulic fracturing method to measure stresses at the candidate repository horizons provided relatively consistent data. The accuracy and repeatability of the data will be verified by conducting additional tests in and around the repository location.

Plans

Plans are being formulated to improve the current measurement technology. The elements of the plan are likely to include some of the following:

- Trial application of selected standard measurement techniques in the Near-Surface Test Facility (including stress relief methods by the U.S. Bureau of Mines' gauge, Commonwealth Scientific and Industrial Research Organization hollow inclusion gauge, door stopper, Swedish Luleå cell, and cast inclusion)

- Application of these methods under controlled stress conditions in the Near-Surface Test Facility using a configuration similar to the ongoing block test

- Assessment of the feasibility of using less developed techniques such as the acoustic emission method and other geophysical methods.

The most promising methods will be identified and improved through laboratory tests and field trials in various rock-mass conditions.

Work Element R.1.15.C (Related to R.1.8.A and R.1.14.C) (Priority 2)

Establish methods of validating measured in situ stress data.

Status

Determination of a complete stress tensor at an underground location is an inherently difficult task. Variation of rock properties (inhomogeneity and anisotropy) and the effect of undiscovered geologic features near the measurement location result in pronounced scatter in data or yield incompatible data. Test operator and/or analyst's judgment plays an important role during the data reduction process. The judgment error can be minimized when more than one stress measurement method is used at one location (see Work Element R.1.14.C). Verifying the measured stress data by multiple methods could be useful to acquire more reliable and representative stress information. Techniques for selecting measurement methods and a statistical method of comparing data could also be useful.

Plans

As part of the plan described in Work Element R.1.14.C, the validation method will be established. The procedure will be refined during the in situ tests at the candidate repository horizons.

KEY ISSUE R.1.D

Can repository shafts, tunnels, and exploratory boreholes be constructed and sealed without causing preferential pathways for groundwater or increasing the potential for radionuclide migration from a nuclear waste repository such that compliance with appropriate U.S. Environmental Protection Agency regulations is not possible?

Work Element R.1.16.D (Priority 1)

Evaluate and select methods of excavation and rock support that can economically and safely be constructed and at the same time maintain isolation capability of the engineered system.

Status

An assessment of the feasibility and cost effectiveness of excavation technologies appropriate for use in constructing a repository in basalt is not currently available. Such an assessment will provide choices of cost-effective methods for constructing excavated openings in situ and identify potential technological options. The evaluations will also identify appropriate methods to construct unconventional room shapes (eliptical shape) if required for ground-specific conditions in basalt. Improvements of existing excavation technologies will be identified, if necessary and feasible, to accomplish cost-effective excavation of a repository in basalt, while still meeting the requirement for minimum rock wall damage.

Plans

A choice of several technologies is available for sinking, lining, and sealing large-diameter shafts in basalt. Such technological options include conventional drilling and blasting methods with grouting or freezing in advance of shaft sinking to control groundwater, blind boring, and a selective combination of conventional methods with blind boring in areas prone to heavy groundwater flow. The feasibility of boring large-diameter shafts in basalt is as yet unproven and will require the development of larger drill rigs and new shaft liner designs. However, blind boring has such overriding potential advantages (e.g., groundwater control, construction safety, isolation enhancement, cost/schedule improvements) over other methods that development, is highly desirable.

In Exploratory Shaft-Phase I a 1.83-meter- (6-foot-) finished diameter shaft will be sunk by blind boring. The nuclear waste repository in basalt conceptual design (currently in design review) is conservatively based on sinking five repository shafts ranging from 3.4 meters (11 feet) to 4.9 meters (16 feet) using the combined method (i.e., blind boring through the upper strata and conventionally sinking through the deeper basalt flows).

The final decision on the sinking method for repository shafts has not been reached and will be dependent on the shaft diameters finally selected for the repository, the depth of the selected repository horizon, site-specific geotechnical and hydrologic data, the results of the exploratory shaft sinking demonstration, and developments in the technology for blind boring that could occur over the next several years.

The feasibility of various tunnel excavation and rock support techniques will be assessed using information from experience in similar environments. If required, some excavation testing will be conducted prior to selection of the final design.

Work Element R.1.17.D (Priority 2)

Develop or adapt instrumentation and test methods to measure the nature and extent of rock-mass disturbance caused by candidate excavation methods and stress redistribution around tunnels and boreholes.

Status

Limited information has been obtained regarding the extent of the disturbed rock zone and the stress redistribution around tunnels in the Near-Surface Test Facility as part of the tests conducted therein. Potential methods of measuring rock-mass disturbance have been identified.

Plans

A literature search and discussions with personnel conducting similar research in this area will be performed. Field testing of the most promising methods will follow at the Near-Surface Test Facility. Methods of data analysis will be established for the most technically sound and feasible methods, through repetitive testing in the Near-Surface Test Facility and possibly at depth. Then tests will be conducted to study the effect of geometrical variations of tunnels in various rock-mass conditions.

Laboratory tests may be necessary to acquire baseline data to support some methods such as petite seismique, cross-hole seismic, and borehole permeability methods. These tests will be conducted in conditions similar to the in situ regime.

Work Element R.1.18.D (Priority 1)

Identify performance requirements for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste.

Status

Work is in progress to develop preliminary performance requirements for sealing by studying the repository site hydrology and assessing the solubility of hazardous radionuclides. To aid in performance assessment, a computer model will be used to determine flow conditions at each seal site for comparison with acceptance flow conditions identified in performance requirements.

Plans

This work element will develop general and specific performance requirements for repository room seals, tunnel and shaft seals, and for borehole sealing. The requirements will be based on preliminary seal material performance information currently being developed and requirements indicated in U.S. Nuclear Regulatory Commission proposed documents.

Performance requirements will be identified for each of the typical repository seal sites, so that when requirements for all sites are integrated, the results will meet or exceed repository seal system requirements indicated above.

Work Element R.1.19.D (Priority 1)

Select materials and develop testing techniques required to meet repository room and tunnel sealing criteria.

Status

Repository room and tunnel sealing criteria are being developed under Work Element R.1.18.D. Preliminary development of materials was conducted at The Pennsylvania State University Materials Research Laboratory. Major requirements are that materials should be mechanically adequate, well bonded to the host rock, stable and chemically durable, resistant to destructive expansion and contraction, resistant to radionuclide transport, tailored to be compatible with the surrounding rock and groundwater environment, and adequate to restrict severely the permeation of fluids, particularly in the interfacial zone between seal material and high-integrity host rock.

Plans

Ongoing materials research will result in repository room and tunnel seal materials recommendations based on the repository sealing criteria developed in Work Element R.1.18.D.

Large-scale repository room and tunnel seal testing will be assessed as part of an in situ testing program. Laboratory-scale testing will be used to screen materials so only final seal material candidates will be subjected to more detailed testing. Select seal materials will be field tested for performance verification. System performance will be extrapolated from the demonstrated performance of constituent components. The results of materials evaluation will be used to update predictive models and support final design.

Work Element R.1.20.D (Priority 1)

Determine the effect of temperature, rock-mass deformation, groundwater flow, and groundwater chemistry on materials used for seals.

Status

Materials research is in progress to screen, develop, and select materials to be used for seals. Materials recommended by the research team will be tested further for durability. Large-scale laboratory testing of borehole seal material was conducted at Terra Tek Laboratory, Salt Lake City. Studies are in progress to develop a repository temperature computer model that will predict rock temperatures for repository operating conditions at seal locations. The BWIP will investigate the

severity of the disturbed rock zone and its impact on host rock permeability. Studies are in progress to develop a model that will predict groundwater flow at seal locations and identify flow conditions the seal materials must withstand. A considerable amount of repository groundwater chemistry data has been developed and is presented in Chapters 5 and 6 of this document.

Plans

Laboratory testing of borehole seal materials is planned. These tests will be at or near in situ stress conditions. Testing will assess seal performance, serve to recommend seal materials, serve to observe the behavior of materials to be used for seals, and will lead to a measurement of the effect of repository operating temperatures on rock-mass deformation and permeability change. Seal material reactions related to groundwater chemistry will basically be measured in laboratory bench-scale testing similar to Waste Package Work Element W.1.4.A.

Work Element R.1.21.D (Priority 1)

Develop grouts and grouting techniques that ensure acceptable sealing of the disturbed rock zone.

Status

Grout and sealant materials research has been conducted by The Pennsylvania State University Materials Research Laboratory and the U.S. Army Corps of Engineers Waterways Experimental Station. Emphasis was on development of materials for use in a repository in basalt. Some of the seal materials investigated included Class H oil-well cement admixed with siliceous components such as fly ash, silica fume, fine quartz or slag, and calcined Ludox.

Plans

The viability and usefulness of grout-injection field tests in boreholes will be assessed.

Permeability testing of grouted disturbed rock zones at repository depth may be conducted to measure effectiveness of grout injections and provide data needed to analyze sealing.

Results of this effort will support design input and be used to update performance evaluation models. Test results will also provide technical support for grouting specifications.

Work Element R.1.22.D (Priority 1)

Determine the effects of temperature, rock-mass deformation, and time on the permeability of the sealed rock zone.

Status

Preliminary studies have been performed to identify the range of rock-mass deformation that could be expected as a function of in situ stress conditions, temperature, and time. The effect of deformation on permeability of sealed rock zones has yet to be determined. A document characterizing disturbed rock zones for conventional tunneling excavation is being prepared. Characterization of the grouted portion of disturbed rock zones will be developed in Work Element R.1.21.D.

Plans

Field-scale tests at potential repository depths may be needed to determine the relationships of rock-mass deformation with time, temperature, and permeability. These data will be used as input to performance assessment models that will be developed to describe permeability of the sealed rock zones over the lifetime of the repository. Host rock grouting and seal development information developed in Work Element R.1.21.D will also be input to these permeability assessment models. Field-scale sealing tests will likely continue throughout the repository operation period to validate the use of the models.

Work Element R.1.23.D (Priority 1)

Select materials and develop testing techniques required to meet borehole sealing criteria.

Status

Preliminary work is in progress to develop borehole sealing criteria. borehole sealing criteria for a repository in basalt are to be completed in preliminary form in fiscal year 1983 and will be included in a repository sealing criteria document.

Sealing material studies in conjunction with borehole sealing design are in progress by D'Appolonia Consulting Engineers. Terra Tek is developing nearly full-scale laboratory borehole testing techniques that will be capable of testing specimens of approximately 4.5-centimeter (16-inch) diameter by 91 centimeters (36-inches) long at repository in situ stresses.

A guarded straddle packer has been developed by Systems Science and Software to measure borehole host rock permeability. The system currently being tested is designed to measure in situ horizontal and vertical permeabilities.

Plans

Laboratory-scale research will continue to develop and select borehole sealing materials. In situ testing with the guarded straddle packer is being considered if satisfactory progress is made with preliminary system field testing.

Seal/rock interface bond and permeability characteristics will be assessed. Further work will aim at recommending seal materials and testing techniques required to meet pre-specified borehole sealing criteria.

Work Element R.1.24.D (Priority 1)

Develop construction and test techniques required to meet repository tunnel and shaft sealing criteria.

Status

Repository tunnel and shaft sealing criteria are presently under development in Work Elements R.1.18.D and R.1.66. Tunnel and shaft sealing design criteria are being documented. Work Element R.1.17.D will characterize the disturbed rock zone for typical tunnel and shaft seal locations.

Plans

Data from the laboratory-scale research will result in a list of recommended materials that meet design specifications produced by the National Waste Terminal Storage Program Office. Construction and test techniques will be developed. The results of testing will be compared with a seal performance assessment model. These comparisons will be analyzed and the results will verify that construction and test techniques meet specific criteria.

Work Element R.1.25.D (Priority 3)

Prepare final specifications for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste.

Status

Development of final specifications for sealing rooms, boreholes, tunnels, and shafts has not been initiated. The status achieved is indicated in Work Elements R.2.6 and R.2.8.

Plans

Final specifications for sealing rooms, boreholes, tunnels, and shafts will be prepared based on field test results of selected seal methods and materials tested under repository operating conditions.

The test results will be compared with performance assessment tests and the specifications revised if necessary. These specifications will become the basis for the final design of sealing techniques.

Work Element R.1.26.D (Priority 1)

Develop methods and equipment for backfilling and sealing the repository, and demonstrate their effectiveness.

Status

Development of site-specific sealing and backfilling technology may require testing of sealing methods and systems and verifying predicted behavior for site-specific conditions in basalt. These seals apply to boreholes from the surface, access shafts, tunnels, and emplacement rooms. In situ tests to measure seal performance are likely to require development of seal emplacement testing techniques and testing instrumentation. Backfilling and compaction technology may require modifications of pneumatic support technology currently used in mining operations. Design, construction, and testing of bulkheads for repository excavations in basalt may require techniques and systems that are unconventional in general mining practice. During fiscal year 1982, seal material development studies were initiated to support preparation of schematic seal designs.

Plans

Methods and equipment for backfill and repository sealing will be assessed using experience in other mining environments, literature studies, laboratory tests, and field tests. Performance assessment models and field tests will be used to demonstrate the effectiveness of such equipment and techniques.

THE FOLLOWING WORK ELEMENTS DO NOT RELATE TO ANY ISSUE, BUT ARE REQUIRED TO SATISFY THE CRITERIA LISTED IN SECTION 14.5.

Work Element R.1.27 (Priority 3)

Determine which facilities or systems within the facility will be designated and classified as high-level waste facilities.

Status

Surface buildings and facilities identified in the conceptual design are not specifically classified as high-level waste facilities; they are, however, classified as to quality assurance level, seismic and structural bases, and ventilation system requirements. The underground facility is classified as a high-level waste facility.

Plans

During the repository design and prior to submission of the license application, specific requirements will be developed for each surface building or facility. These requirements, based on the type of work to be accomplished in the building or facility, will determine the classification, safeguards, and security measures required to meet the U.S. Nuclear Regulatory Commission high-level waste facility proposed criteria.

Work Element R.1.28 (Priority 2)

Assess the effects of adverse conditions on the design and performance of the repository.

Status

Potential adverse conditions and the information needed to assess their effects on the design and performance of the repository are summarized in Table 14-2 for this work element. Data from surface exploration, boreholes, and geophysical surveys must be supplemented by in situ testing and underground exploration to fully assess the effect of adverse conditions.

Plans

Plans for assessing the effect of adverse conditions related to rock-mass characteristics (strength, deformation, etc.), geologic conditions (jointing, faulting, etc.), and seismicity are discussed in the appropriate work element narratives in this chapter (see Work Elements R.1.29, R.1.30, R.1.6.A, and R.1.10.B). The remaining potential adverse conditions are those related to ingress of water and natural gas into the repository during the operating period.

Plans for controlling the inflow of gas into repository facilities, including the identification of equipment and structures necessary for that task, are discussed in Work Elements R.1.36 and R.1.63 in this chapter. Plans for identifying the potential for gas-induced explosions or fires and for controlling the effects of any such events are discussed in Work Element R.1.37 in this chapter.

Intrusion of water into subsurface facilities could be caused either by flooding of the reference repository location by surface water or by inflow from water-bearing formations. Once the conditions surrounding potential surface flooding have been identified (see work elements in Chapter 13), a study of the potential for ingress to the shaft or tunnel system will be conducted. Hydrologic studies will provide a determination of flow paths and flow rates in the vicinity of shafts and underground workings will be conducted using appropriate numerical models or analytical techniques. In this manner, values of hydraulic heads will be determined for use in design of liners, seals, and other groundwater controls. Information on hydraulic heads and on groundwater inflow rates will be acquired from new boreholes and in the shaft and in situ test facilities (see Chapter 17). Observations from currently existing boreholes indicate that the inflow rate is extremely low at the candidate repository horizons. As new information is acquired it will be incorporated into estimates of hydraulic heads for use in the design of shaft and borehole seals. Plans for controlling groundwater inflow to both shafts and tunnels are addressed in Work Elements R.1.56, R.1.66, R.1.18.D and R.1.19.D in this chapter.

Work Element R.1.29 (Related to R.1.30) (Priority 3)

Assess the effects of seismic events on underground openings during construction and operations.

Status

Data related to this work element have been collected in a number of areas. Historical data on seismic activity in the Columbia Basin have been assembled, reviewed, and summarized in Myers/Price et al. (1979), Myers and Price (1981), and Chapter 3 of this document. Site-specific seismic monitoring data have been collected from an array of permanent and portable monitoring stations at the surface and from one downhole station in the region of the reference repository location. Results of this monitoring are discussed in Chapter 3. The need for additional downhole seismic monitoring stations to be located at the top of the basalt within the reference repository location is currently being evaluated. Case history information on the effects of seismic events on underground structures has been collected. The data reviewed describe a wide range of accelerations and velocities, but for the most part are limited to effects on shallower structures. Evidence shows that the subsurface facilities can withstand much more severe ground motion than surface facilities.

Plans

Once agreement has been reached on how to describe the seismicity of the site, the resulting seismic parameters will be used to determine the effect of seismicity on repository facilities. Established and verifiable methods to analyze the long-term effect of seismic events on deep excavations do not exist in the engineering community at this time. Techniques of analysis in use for shallow structures will be reviewed and state-of-the-art developments for deep structures will be followed to develop a repository seismic design methodology appropriate to basalt. Research into damage incurred by underground facilities as a result of seismic or similar dynamic events will continue. This information can be used with appropriate numerical models that describe ground motion and induced dynamic stresses to predict under what conditions damage to the repository can be anticipated. During construction, additional seismic monitoring stations may be established on the tunnel walls or on support system components to document the characteristics of any regional seismic events occurring during construction and operation. Such information will serve to confirm design data and will aid in assessing the extent of possible damage not visually evident. Seismic monitoring instruments will also complement other monitoring systems used to predict mining-induced seismicity (rock bursts).

Work Element R.1.30 (Related to R.1.29) (Priority 1)

Assess the effects of seismic events on repository tunnel and shaft seals.

Status

Parameters describing the seismicity of the site will be required as primary input to the resolution of this work element. Data needs to define the parameters and status of work are presented in Work Element R.1.29.

Plans

On a laboratory scale, samples containing prepared interfaces between the basalt and the proposed sealing material will be confined at appropriate stress levels and tested for permeability before and after repetitive axial loads have been applied. The rate and magnitude of dynamic loads will be selected based on results of modeling described in Work Element R.1.29. Bench-scale samples containing prepared basalt sealing material interfaces will be subjected to both continuous- and impulsive-type loading conditions using a shake table. Permeability will be measured using a large-scale permeameter or a scaled-down packer system. Field-scale test techniques will be used as necessary.

Field techniques developed to measure the presence and severity of rock-mass disturbance may be used to assess sealed rock disturbance resulting from seismic events. These techniques may help clarify any ambiguities in permeability test results and, where possible, will substitute for time-consuming permeability measurements.

Work Element R.1.31 (Priority 3)

Develop shielding requirements, operating, and access control procedures to limit the dose to repository personnel.

Status

Work to be performed.

Plans

Analysis of the dose rates from waste packages and the shielding characteristic of waste package handling equipment will be made. Waste package storage configurations will be analyzed and their effect on shielding requirements will be assessed. The appropriate U.S. Nuclear Regulatory Commission radiation standards will be reviewed, coupled with the preceding analysis, and will be used to calculate the shielding requirements. During the final design of the repository, any additional

shielding requirements needed will be identified and included. Procedures will be generated at that time, and a shielding and radiation analysis information report will be submitted to the U.S. Nuclear Regulatory Commission as part of the safety analysis report and in the repository license application. Since shielding requirements are an integral part of the design process, this assessment of shielding needs is an ongoing activity that parallels the design process.

Work Element R.1.32 (Priority 3)

Develop the procedures and requirements for controlling access to the repository site.

Status

The Hanford Site is the proposed location for a nuclear waste repository in basalt. The site is a limited access area for which security and access instructions are mandated by the existing U.S. Department of Energy procedures. The repository area has been designated as a unique access area for which the appropriate levels of control will be implemented.

Preliminary studies have been completed for the security system required for the repository. Those studies have resulted in the development of a security system described in the conceptual design.

Plans

Prior to final design, a review will be conducted of existing Hanford Site security requirements. The arrangement of surface facilities will be factored into this review, as will any special security requirements resulting from the operation of the underground facility. The final design on the repository will define the requirements and procedures necessary for controlling access to the repository.

Work Element R.1.33 (Priority 3)

Determine the techniques to be used for limiting, monitoring, and controlling the airborne radioactivity in the repository.

Status

Techniques for limiting, monitoring, and controlling airborne radioactivity in the repository have been identified in the conceptual design. The radiation standards described in 10 CFR 20 (NRC, 1979) are applicable to a nuclear waste repository in basalt.

Plans

A detailed review and analysis of the U.S. Nuclear Regulatory Commission requirements for monitoring and controlling airborne radioactivity in a repository will be made. Analysis of waste package content, repository configuration and layout, and accident scenarios and failure modes will be made to determine the identity of the isotopes that could be released in the event of an accident. This analysis will also determine the concentrations of airborne contaminants expected with the proposed ventilation system. The BWIP will then prepare specifications for monitoring instruments to detect these concentrations. Thus, techniques for limiting, monitoring, and controlling airborne radioactivity will be evaluated. As part of the design process, using the proposed repository layout, zones of increasing negative pressure separated by a system of isolation doors will be established. Any further requirements for the ventilation system may also be established at that time. The results of the evaluations will determine if additional controls for limiting, monitoring, and controlling airborne radioactivity in the repository will be necessary. The final repository design will include all equipment, instrumentation, and administrative provisions required for control of any and all airborne radionuclides.

Work Element R.1.34 (Priority 3)

Develop a design that will protect operations personnel against the effects of natural phenomena and environmental conditions.

Status

The repository conceptual design presents the ventilation and roof support systems to protect operations personnel during construction and operation.

Plans

As more data on repository ambient temperatures and potential for rock instability become available, the ventilation and roof support systems design will be upgraded and presented in the final design report.

Work Element R.1.35 (Priority 3)

Determine the impact of the dynamic effects of equipment failure on safety-related systems and components.

Status

A preliminary assessment of the impact of failure of safety-related equipment has been identified in the conceptual design. No analyses of dynamics effects have been conducted.

Plans

The repository design will be reviewed to identify the safety-related systems and their operating specifications. From this information the potential for dynamic failures will be analyzed to identify failure modes.

An evaluation of the impacts of failure on safety-related equipment, including dynamic and abnormal effects, will be completed and included in the final design of the repository and a safety analysis report.

Work Element R.1.36 (Priority 3)

Define the structures or equipment necessary so that disruptive natural or man-induced events such as intrusion of gas, water, or explosion will not spread through the repository.

Status

Structures and equipment that may be necessary to limit the spread of disruptive natural or man-induced events such as intrusion of gas, water, or explosion have not yet been defined.

Plans

Potential hazards will be evaluated, together with any natural or man-induced events that could occur during construction and operation of the repository. Analyses will be performed to determine the probability of these events and what structures or equipment would be required to limit their spread throughout the repository. The final repository design and safety analysis reports will identify these structures and equipment and their related hazards. Input will also be provided to the performance assessment model to ensure that the performance of the repository is not impaired.

Work Element R.1.37 (Priority 3)

Determine the extent and severity of potential fires and explosions in the repository and their effect on the stability of the rock support systems and other safety-related systems.

Status

No analysis has been performed to determine the effects of fires and explosions on the stability of the rock support systems and other safety-related systems.

Plans

During the final repository design stages, the BWIP will define the probability and consequences of potential fires and explosions. The analysis will take into account the layout of the repository, including the design of the rock support systems. A detailed scenario evaluating the sources and effects of potential fires and explosions will be made to determine the maximum credible incident. The effect of a fire or explosion on the ventilation system will also be explored and, where necessary, ventilation system design will be modified. Finally, a safety-related equipment list will be generated and incorporated into the final design. Thus, analysis of potential fires and explosions will be completed to determine the maximum temperature and/or other effects that could occur in the underground facilities. Where practicable, mathematical models may be used to determine the effects that a maximum credible fire or explosion will have on the underground facility, host rock, and tunnel support systems. Applicable guidelines from the Mine Safety and Health Administration will be examined to determine that the analysis for a nuclear waste repository located in basalt is equivalent to accepted mining practices.

Work Element R.1.38 (Priority 3)

Define which combustible materials can be used in the design of components and equipment that have been designated as safety-related systems.

Status

No data have been compiled on materials that could be used in the design of safety-related equipment or systems. Standard equipment and components are planned for use wherever practical. These will be evaluated to ensure that in the event of failure, safety of personnel or the facilities is not jeopardized.

Plans

A determination of which combustible materials can be used in the repository will be made. This will involve identifying those systems and equipment that may contain combustible materials and determining if their presence is compatible with current Mine Safety and Health Administration regulations. If the material is prohibited under these regulations, a substitute will be found or the system will be replaced.

Work Element R.1.39 (Priority 3)

Develop fire and explosion alarm and protection systems for all equipment and facilities within the repository operations area that are required for safe operation of the repository.

Status

Preliminary descriptions of fire and explosion alarm and protection systems for equipment and facilities within the repository operations area have been identified in the conceptual design.

Plans

The design of the fire and explosion alarm systems will be developed during the final design. The design of these systems will be integrated with the repository electrical and ventilation systems designs and will comply with Mine Safety and Health Administration regulations.

Work Element R.1.40 (Priority 3)

Determine the reliability and protection required to ensure that safety-related systems operate adequately under adverse or emergency conditions.

Status

Preliminary evaluations of safety-related system reliability have not been determined. The possible effects of adverse conditions on safety-related equipment have been identified in the conceptual design.

Plans

Reliability analysis will be completed on all safety-related equipment required in the repository. The results of credible accident scenarios that would result in emergency and/or adverse conditions will be used as a basis for these analyses. Information required to complete such analysis includes but is not limited to a list of safety-related equipment and failure analyses for various repository operation modes. Reliability analyses on safety-related systems will also be made, drawing on the considerable experience of the mining industry on equipment reliability required to ensure safety under adverse conditions within a mined facility. Applicable Mine Safety and Health Administration guidelines will be examined to determine that the analysis made by BWIP is equivalent to, or exceeds, accepted mining practices.

Work Element R.1.41 (Priority 3)

Define what requirements are necessary to permit evacuation of personnel under emergency conditions.

Status

Preliminary repository accident prevention measures have been identified in the conceptual design.

Plans

An accident analysis will be performed and requirements and procedures for the evacuation of personnel from the underground facility will be prepared and included in the final safety analysis report. Applicable Mine Safety and Health Administration guidelines will be examined to determine that the requirements and procedures are in accordance with accepted mining practices. Elements that will be taken into consideration in the accident analysis include, but are not limited to, hoist capacity and speed, evacuation routes, personnel transportation requirements, and applicable safety regulations. This analysis will also identify the emergency conditions (see Work Element R.1.42).

Work Element R.1.42 (Priority 3)

Determine what facilities, equipment, and services are required to ensure a safe and timely response to any emergency conditions.

Status

The present design philosophy, with respect to the definition of the facilities, equipment, and transportation required to effectively accommodate emergency conditions, is that the repository will, where possible, use existing site services to minimize unnecessary and costly replication. Future analysis will determine which, if any, key emergency support services must be independent of the Hanford Site facilities.

Plans

Information on failure modes in credible accident conditions will be analyzed to determine the potential for the type and frequency of various types of accidents that could lead to emergency conditions. Applicable Mine Safety and Health Administration and U.S. Nuclear Regulatory Commission regulations and applicable Hanford and local codes will also be consulted.

Work Element R.1.43 (Priority 3)

Determine which systems require redundant power supply, uninterrupted service, or standby service in the event of loss of primary power.

Status

Preliminary power requirements have been identified in the conceptual design.

Plans

All systems that require emergency, standby, or redundant power supplies to maintain the health and safety of construction and operating personnel will be identified in the Title II design. Uninterrupted power

will be supplied to those systems that cannot tolerate momentary power interruptions. As indicated in the conceptual design, standby power will be provided by two generators, each capable of furnishing 100 percent of the required emergency load. The power requirements of these systems will be calculated and the necessary capacity will be provided in the final design. All emergency systems will be compatible with the repository electrical and ventilation systems and will follow Mine Safety and Health Administration regulations.

Work Element R.1.44 (Priority 3)

Determine which structures, systems, and components are important to safety; develop and implement appropriate inspection, testing, and maintenance programs.

Status

Maintenance of components and equipment is a major ongoing design consideration. The maintenance approach used in the conceptual design for a nuclear waste repository in basalt is described in the conceptual design. Information contained therein includes lists of structures, systems, and components used in the repository and lists of equipment specifications. Repository safety analysis and emergency requirements are also listed.

Plans

During the final design phase of the repository, a detailed review of the appropriate inspection, testing, and maintenance procedures and programs will be conducted. Those systems that are important to safety will be identified and detailed procedures prepared to ensure that periodic inspections and maintenance are performed. During this analysis applicable Mine Safety and Health Administration guidelines will be examined to determine that the analysis is equivalent to accepted mining practices.

Work Element R.1.45 (Priority 3)

Assess the potential for criticality for the proposed waste packages and storage orientations under fully flooded storage conditions.

Status

Preliminary criticality analysis of the waste package containing spent fuel indicates that the tightly packed fuel rods within the canister leave little space for a moderator such as water. The proposed waste forms and configuration appear to preclude the possibility of nuclear criticality. These packages are emplaced in the repository storage rooms at intervals such that preliminary calculations indicate that criticality is not possible even under flooded conditions. No analysis has yet been performed for the waste package containing high-level waste or for transuranic waste to be stored in the repository.

Plans

Criticality analyses for waste packages containing high-level waste and for drums containing transuranic waste will be completed. Analyses will also be performed of all waste types, in all storage locations, emplaced in the repository under flooded conditions. The results of these analyses will be documented.

In addition, a migration scenario for radionuclide release after the 1,000-year containment period will be initiated. This study will analyze the criticality potential after degradation of the canister along a predicted groundwater flow path and include consideration of the sorption capability of the backfill in concentrating fissionable material.

Work Element R.1.46 (Priority 3)

Determine what instrumentation and control systems are required to monitor and control safety-related systems.

Status

A preliminary listing of safety-related instrumentation and control systems has been identified in the conceptual design.

Plans

During the final design, all safety-related systems will be identified and evaluated with regard to the applicable Mine Safety and Health Administration regulations. Based on these regulations, the instrumentation or control devices necessary to monitor and control the safety systems will be incorporated into the final repository design and safety analysis reports.

Work Element R.1.47 (Related to R.2.5) (Priority 2)

Develop, as required, instrumentation to measure stresses, deformation, temperature, and pore pressures reliably until backfill is emplaced.

Status

Field tests conducted at the Near-Surface Test Facility have resulted in modifications of nearly all stress and deformation measuring instruments used on the project, including multipoint borehole extensometers, U.S. Bureau of Mines' borehole deformation gauges, and IRAD Manufacturing Company vibrating wire stressmeters. The modified extensometers have performed adequately for several months at temperatures up to 200°C. The other modified instruments either have shown instability at high temperature or require testing at in situ conditions to evaluate the adequacy of modifications. The Commonwealth Scientific and Industrial Research Organization borehole deformation gauge failed to perform adequately at high temperatures and probably will not be used to acquire repository data.

Plans

Specifications for commercially available rock and related instrumentation continue to be reviewed to examine the possibility of employing various instruments, especially for measurements of borehole stress and deformation. The review will include an instrument sensitivity analysis and an assessment of the potential for malfunction due to moist, high-temperature environments. Performance evaluation tests in the Near-Surface Test Facility and at depth will continue for both previously used and newly adopted instruments. Existing heater and block test setups will be used in this task. Laboratory tests and calibrations will be conducted, as needed, to verify that instrument accuracy can be maintained and to establish the survivability of instruments before field application. Estimates of modifications required to meet instrument performance objectives will be made for all instruments tested. Actual modifications will be made only to the most promising instruments as determined by these tests, in consultation with the instrument manufacturer and other instrumentation consultants.

Work Element R.1.48 (Related to R.1.6.A and R.1.7.A) (Priority 2)

Develop or adapt instrumentation and monitoring techniques to predict rock bursts.

Status

A multichannel acoustic emission monitoring system has been purchased and plans have been developed for locating the number and source location of acoustic emission events in the Near-Surface Test Facility related to microscopic and macroscopic cracking caused by thermal loading.

Plans

An investigation will be conducted to determine the state of the art in rock burst monitoring. Instrumentation applicable to such monitoring will be compared on the basis of sensitivity, range, reliability, and other instrument performance criteria, as well as on the basis of their projected ability to perform adequately in the operating repository environment. Mining experience with instrumentation for detection of rock burst or similar phenomena will be reviewed and the pre-burst data patterns identified and evaluated. The potential for successful application of such instrumentation in basalt will be assessed. One or more of the most promising techniques may then be selected for further field testing and evaluation depending on an analysis of the relative potential for the occurrence of bursting at the site (see Work Element R.1.6.A).

Work Element R.1.49 (Priority 3)

Determine the requirements necessary to assure that safety-related systems provide adequate protection to construction and operations personnel.

Status

Preliminary requirements to assure that adequate protection is provided to construction and operating personnel are identified in the conceptual design.

Plans

A complete evaluation of the safety requirements and potential hazards that exist during construction and operation of the repository will be conducted as part of the final design. Although 10 CFR 60.130(b) proposes that the repository operations area is not subject to Mine Safety and Health Administration regulations, they will be used for guidance wherever applicable.

Work Element R.1.50 (Priority 3)

Determine the requirements and procedures necessary for the safe receipt and surface storage of radioactive wastes.

Status

The receipt, handling, and emplacement of radioactive waste at the repository site are discussed in the conceptual design. The preliminary general requirements for buildings, facilities, and equipment to ensure the safe storage of the waste canisters are identified therein.

Plans

To determine the detailed requirements and procedures necessary for the safe receipt of radioactive wastes, the applicable waste handling requirements in U.S. Nuclear Regulatory Commission and U.S. Department of Energy documents will be studied. Information on waste package dose rate, configuration, and shipping will be collected to provide input to the design of the repository waste handling surface facilities. The detailed information on waste package and shipping cask design will also be utilized in this analysis.

Thus, the receipt, handling, and emplacement of radioactive waste will be conducted in accordance with existing regulations. Procedures will be prepared and equipment developed to assure the safety of operating personnel during waste handling. All of these elements will be factored into the final design of surface facilities.

Work Element R.1.51 (Priority 3)

Determine the ventilation requirements for the surface facilities that will contain radioactive materials.

Status

A preliminary study has been conducted of the repository surface-facility ventilation requirements and is included in the conceptual design.

Plans

The nature of the design process mandates an ongoing analysis of the effectiveness of surface-facility ventilation systems for those buildings that will contain radioactive materials. Information needed to complete this analysis consists of a list of buildings handling the radioactive waste material, the characteristics of various waste forms to be handled by the surface facilities, and an analysis of failure modes and credible-accident scenarios that could lead to the release of radioactive materials in the surface facilities. The U.S. Nuclear Regulatory Commission radiation standards and other ventilation standards for buildings in radiological use will be factored into the analysis. In addition, experience in this area at the Hanford Site will be reviewed. The final design will incorporate information on ventilation requirements for surface facilities and an analysis of impact of credible accident scenarios.

Work Element R.1.52 (Related to R.1.33) (Priority 3)

Determine what equipment and controls are necessary to measure the amount and concentrations of radionuclides in any effluents from surface facilities with sufficient precision to determine that they conform to statutory release requirements.

Status

No detailed evaluation has been made at this time of the equipment and controls necessary to measure the amounts and concentrations of radionuclides in any repository effluents. The requirements for instrumentation, control, and alarm systems in general are presented in the conpetual design.

Plans

A detailed evaluation of all equipment and controls that are necessary to measure the amounts and concentrations of radioactive materials that might be released from the underground system will be included in the safety analysis report and in final repository design documents.

Work Element R.1.53 (Priority 3)

Determine the facilities that are required for the treatment, processing, or packaging of radioactive waste generated at the repository operations area to permit safe disposal or transportation of these wastes.

Status

The conceptual design includes facilities and systems for the onsite handling and disposal of radioactive wastes generated by repository operations.

Plans

The design of facilities for the treatment, processing, or packaging of radioactive waste generated by the repository operations area will be included in the final repository design. Information necessary to complete the design includes a description of potential radioactive waste generated by the repository operations and a description of waste processing equipment designed to handle these materials. Placement of repository generated waste for final storage and waste disposal locations will be identified. Low-level waste generated by the repository could be handled in existing Hanford Site facilities if desired. That decision will be made during the final design process.

Work Element R.1.54 (Priority 3)

Determine the requirements for design of the surface waste disposal facilities to facilitate decommissioning.

Status

In the conceptual design, no effort was expended on the subject of design for decommissioning the surface facilities. No unusual problems would be expected for any of the buildings or facilities, except for the waste handling building. The hot cells, decontamination areas, and radioactive waste handling and treatment systems would require decontamination prior to decommissioning and will be designed to facilitate these operations.

Plans

The BWIP plans to include features to facilitate decommissioning in the final repository design. Radiological facilities and applicable decontamination and decommissioning techniques developed for use within the U.S. Department of Energy and radiological community will be reviewed. A compilation of design features including, but not limited to, the use of special paints, remote-handling techniques, and modular design for ease of decommissioning will be evaluated for inclusion in the final design.

Prior to finalization of design, a listing of the proposed facilities that will contain radioactive materials will be reviewed, contaminated areas identified, and any special decommissioning needs highlighted. The decommissioning of radiologically contaminated facilities will also be addressed in the safety analysis report.

Work Element R.1.55 (Related to W.1.12.A) (Priority 1)

Determine that the interaction between the waste package, the underground facilities, and the geologic setting does not compromise the performance of the underground facilities.

Status

The data and analyses generated within the waste package activity, described in Work Element W.1.12.A of Chapter 15, will provide the necessary guidance to the architect-engineer during preliminary design of the repository.

Plans

Experimental assessment of interactions within and external to the engineered system (the natural system) will provide detailed data on how the intrinsic geochemical and rock-mass properties affect the containment and controlled release of radionuclides from wastes emplaced in the repository. Analysis of the data, as described in Work Elements W.1.11.A, W.1.12.A, W.2.1.A, R.1.11.B, and R.1.12.B will provide the repository and waste package designer information to assure that the interactions resulting from construction and emplacement of wastes in a nuclear waste repository in basalt do not compromise the performance of the underground facilities.

Work Element R.1.56 (Related to R.1.18.D, R.1.19.D, and R.1.66) (Priority 1)

Determine how to control groundwater influx and transit in the repository to maintain radionuclide release from engineered systems within the U.S. Nuclear Regulatory Commission appropriate release standards.

Status

Included in Work Elements R.1.18.D, R.1.19.D, and R.1.66.

Plans

Included in Work Elements R.1.18.D, R.1.19.D, and R.1.66.

Work Element R.1.57 (Priority 1)

Provide an appropriate orientation, geometry, waste placement, and layout of the repository to ensure structural stability and containment of radionuclides.

Status

The most appropriate orientation and geometry of the underground facility within the candidate repository horizons has not yet been determined. A preliminary layout of the underground facility is in the conceptual design. The design consists of shafts located within a single shaft pillar, with storage rooms located on either side of the pillar. The orientation of the repository with respect to the direction of groundwater flow or major horizontal stresses has yet to be determined. The geometry and configuration of openings in the underground facility will probably be determined by the magnitude and direction of in situ stresses. A support system will be designed to provide maximum safety to construction and operating personnel.

The groundwater flow direction at the candidate repository horizons is presented in Chapters 5 and 13 and will be verified during exploratory shaft construction and testing. Preliminary calculations of temperature distribution versus time are presented in Anderson (1982, Appendix B).

Plans

In situ stress measurements at the candidate repository horizons have been scheduled for the exploratory shaft test program (see Work Element R.1.8.A). These measurements will include horizontal and vertical stress measurements, horizontal major and minor stress direction, and mechanical properties testing. These data, together with data generated from hydrologic tests planned in the exploratory shaft, will be input to models to determine the most appropriate orientation of the repository. In addition, the geometry and configuration of underground openings, support system requirements, and the layout of the repository will be optimized to enhance containment of the waste. The final repository design document will provide the rationale and justification for the overall repository layout.

Work Element R.1.58 (Priority 2)

Design the underground facility with sufficient flexibility to allow for adjustments during construction that will accommodate site-specific conditions identified by in situ testing or monitoring.

Status

The current conceptual design provides sufficient flexibility in the design to accommodate changes that may be warranted as a result of the exploratory shaft test program, pre-tunneling exploration, and the in situ

testing phase of site characterization. Results of these tests will be evaluated to determine if changes in the orientation, geometry, and layout of the repository are necessary.

Plans

Prior to final design, results from tests conducted in situ will be evaluated to determine if changes are warranted in repository design. Extensive use of design reviews and peer reviews will be made to determine the appropriateness of design relative to expected and disruptive conditions. During these reviews, failure analysis and its consequences will be taken into consideration in assessing design flexibility. The final design will provide sufficient flexibility to accommodate any specific condition that may arise during construction and operation of the repository. As proposed by 10 CFR 60.134(c), a system will be established for obtaining a data base to identify unexpected changes in conditions met during construction and operation. Contingency plans will be developed to accommodate mining through rock and zones with unacceptable permeability.

Work Element R.1.59 (Priority 3)

Define the requirements necessary to allow for the emplacement or retrieval of waste packages during continuous excavation and construction of the repository.

Status

The conceptual design specifies that subsurface storage space will be constructed at the same time that nuclear wastes are being received, handled, and stored.

Plans

The final repository design and safety analysis reports will define all conditions and safety-related areas that may be affected during parallel construction and waste emplacement in the underground facilities. Ventilation, transportation, and personnel access will be controlled by administrative means. Detailed procedures will be developed that include emergency evacuation requirements (Work Element R.1.41) and continuous monitoring of the storage rooms.

An analysis of waste package storage configuration and emplacement procedures, room ventilation design, and room installation requirements and construction procedures will be made to assure that they are consistent with requirements necessary to allow for the emplacement and/or retrieval of waste packages during the operating lifetime of the repository.

Work Element R.1.60 (Included in R.1.36) (Priority 3)

Determine what safety requirements are necessary to isolate waste package storage rooms from other areas in the event that accidents occur.

Status

In the event that an accident occurs in a storage room, which results in the release of particulate radioactive material, the storage room can be isolated by using the bulkhead doors provided at each end of each room. The normal function of these doors is to isolate the rooms from the ventilation system when they are fully loaded.

A more credible accident would be a sloughing of previously undetected surface contamination on a package. If this should happen, the contamination would be confined to a small area by means of a temporary plastic greenhouse, which would be removed after cleanup.

Plans

The design of waste package storage room isolation systems will be reviewed in the safety analysis report.

Work Element R.1.61 (Priority 3)

Develop rock support systems that are compatible with decommissioning requirements and that will function satisfactorily in the repository environment for the period of construction, operation, and retrieval (including effects of cooling prior to backfilling or retrieval).

Status

No applicable work has been done by the BWIP to date.

Plans

Currently available roof support techniques and materials will be reviewed and their effectiveness and survivability in the anticipated repository environment assessed. Field demonstrations of support systems or components will be conducted, if necessary. Engineering characteristics of the support systems and results from field tests will be used as input to numerical models describing the repository near field. Empirically derived analyses of support systems will also be examined. This will provide the data necessary to define the overall number of supports needed, the optimum spacing and geometry, and the long-term performance characteristics and stability of the tunnel for each support system. From this analysis, and analyses of cost and installation time, guidelines will be established for rock support systems.

Work Element R.1.62 (Priority 3)

Define the requirements, equipment, and procedures necessary to retrieve the radioactive waste after emplacement in the repository if retrieval is ultimately required.

Status

Waste storage configurations and waste package dose rates have been defined in the conceptual design. A preliminary retrieval rate for the conceptual repository has also been established.

Plans

During final design, applicable storage configurations, dose rates, and rates of retrieval will be used to design handling and retrieval equipment to meet applicable U.S. Nuclear Regulatory Commission criteria. This information will be input to the license application and the safety analysis report. Specific procedures for retrieval will be defined and incorporated into the appropriate documents.

Work Element R.1.63 (Related to R.1.56) (Priority 3)

Assess the requirements to monitor and provide effective control of groundwater intrusion, service-water intrusion, or gas inflow into the repository during construction.

Status

Information on the monitoring and control of groundwater intrusion is included in Work Element R.1.56.

The exploratory drilling program has provided limited information on the potential of gas pockets existing in or about the candidate repository horizons. A description of this work can be found in Myers/Price et al. (1979) and Chapter 3 of this report.

Plans

The current plans to monitor and control groundwater intrusion into the repository are described in Work Element R.1.56.

The potential for gas intrusion into the repository will be finalized during Title II design, based upon exploratory drilling and in situ testing. From this evaluation the final design of the instrumentation and ventilation systems will be completed in accordance with existing Mine Safety and Health Administration regulations. The plans for detecting gas pockets in advance of excavation are included in R.1.28 and R.1.37.

Work Element R.1.64 (Priority 3)

Define the subsurface ventilation requirements for the control of radioactive particulates and gases within and releases from the subsurface facility.

Status

A review of the waste container design and the design of the underground waste handling and emplacement systems indicates that a dangerous release of radioactive gases or particulates underground is not credible. However, in the highly unlikely event that such a release does occur, detectors in the containment exhaust ventilation system will alarm, and the exhaust air will be automatically diverted through high-efficiency particulate air filters before discharge from the stack.

Plans

Subsurface ventilation requirements for the control of radioactive particulates and gases within the facility and releases from the subsurface facilities will be defined. A review of regulatory requirements including U.S. Nuclear Regulatory Commission and Mine Safety and Health Administration regulations relative to airborne concentrations of and the acceptable release of radioactive particulates and gases from facilities will be made. The repository design process, particularly for the ventilation systems and for radiologic monitoring systems, will be based on an analysis of credible failure modes and accident scenarios. The interrelationships of this information will be analyzed and factored into the design process. Any possible release of radioactive particulates and/or gases from the subsurface facility will be identified and design steps to mitigate them will be incorporated into the final design of the repository. This information will be documented in the safety analysis report.

Work Element R.1.65 (Priority 3)

Define ventilating system requirements during normal operations, including controls to ensure continued operation under emergency conditions.

Status

Appropriate ventilation and cooling systems are necessary to provide the proper airflow and working environment for in situ testing and repository construction. Ventilation systems for a repository in basalt are unconventional because of the isolation of confinement and construction ventilation circuits and compensations required for repository temperature conditions. Ventilation systems for a repository may require space cooling arrangements, partial regulation of airflow in storage rooms, and optimum modes of directing ventilation circuits during repository construction and stepwise storage of the panels.

The requirements include provision for human respiration, removal of diesel and explosive fumes, and the reduction of the ambient air temperature from the expected 57° to a target 27°C (134° to 80°F) where workers may be present.

There is a special requirement to protect workers and the general public in the highly unlikely event that dangerous quantities of radioactive particulates are released into the airstream underground. Monitoring and control of airborne radioactivity is described in Work Element R.1.33.

Plans

A ventilation design will be finalized in Titles I and II design. These designs will be based on ventilation requirements of the Mine Safety and Health Administration, American Conference of Governmental Industrial Hygienists (ACGIH, 1980), U.S. Nuclear Regulatory Commission (NRC, 1979), and others. Information required prior to completion of design includes projected underground temperatures, predicted dust levels, and a prediction of gas and/or fuel levels expected in the repository. Failure modes and credible accident scenarios will also be factored into this analysis. Details on the adequacy of the ventilation design for occupied areas during normal operations until permanent closure will be presented in the safety analysis report.

Work Element R.1.66 (Priority 1)

> Determine functional requirements for selecting locations of repository seals and backfills as engineered barriers to effectively retard groundwater movement and radionuclide migration.

Status

The overall function of the engineered barrier system is to limit release of hazardous materials associated with nuclear waste to levels below established limits by means of an integrated system of physical and chemical barriers acting in concert with the geology. Repository seals and backfills are one element of the engineered system. The basic incentive for repository sealing is to assure that radionuclides do not have a direct pathway to the biosphere from the repository through any man-made penetrations.

An important aspect of this work element is to provide a multiple-component design concept (i.e., a seal system comprised of individual seal components). Each component is designed for a specific function and location within the system.

Work is in progress to identify functional requirements for repository seals and backfills to act as an engineered barrier to effectively retard groundwater movement and radionuclide migration.

Plans

Reviews of the repository design, repository hydraulic flow conditions, and seal material and performance model research will be conducted to establish seal element specific locations. This is an iterative process whereby location, size, and number of seal elements are varied and optimized to obtain the desired results. Chemical and engineering properties of host and barrier materials are major variables that will be established through ongoing research within the program.

Seal materials will be selected that retard groundwater flow to minimize radionuclide migration. Functional requirements for selecting locations of repository seals and backfills are presently under study in support of and will be used in developing sealing design criteria.

Work Element R.1.67 (Priority 1)

Determine radionuclide sorption requirements for backfill materials to be used for repository rooms and tunnels.

Status

Repository room and tunnel backfill functional requirements will be defined in Work Element R.1.66. Radionuclide sorption requirements are related to waste package development and are developed in Work Element W.1.7.B. Backfills can be tailored to remove specific radionuclides by sorption if required. Presently, backfill material is assumed to be a mixture of crushed basalt and an expansive clay (i.e., bentonite). Preliminary sorption and precipitation data for radionuclides in the presence of clay have been obtained from waste package studies by Salter et al. (1981). Ongoing model studies indicated in Work Element R.1.18.D will be used to define the portion of nuclide containment assigned to backfills.

Plans

Computer codes are being developed to calculate retardation of radionuclides. These codes will become part of an integrated seal and backfill assessment model.

Backfill material laboratory testing will include flow-through experiments based on repository radionuclides inventories, groundwater flow rates, and precipitation (solubilities) of hazardous radionuclides. These tests will develop backfill sorption characteristics and their effects on retardation of radionuclide migration.

Work Element R.1.68 (Priority 3)

Define the appropriate requirements, equipment, and procedures necessary to handle, emplace, and retrieve the radioactive waste under operating conditions.

Status

The present conceptual design describes the equipment necessary to handle and emplace radioactive wastes in a nuclear waste repository in basalt. This key element of the repository system will be upgraded through the design process until it is completely defined.

Plans

The final design of a repository will contain a detailed listing of the equipment and the procedures necessary to handle and emplace radioactive waste in basalt under normal operating conditions. Information included in this analysis will include waste package characteristics, transfer cask specifications, U.S. Nuclear Regulatory Commission radiation protection standards, and assessment of waste storage configurations, all of which will be input to repository design.

Work Element R.1.69 (Related to R.1.50) (Priority 3)

Design hoist and hoist loading systems with sufficient capacity, redundancy, and monitoring systems to ensure that radioactive materials will be handled in a safe and reliable manner.

Status

The definition and upgrading of hoist and hoist loading systems design is an ongoing part of the design process. Some information concerning hoist specifications is given in the conceptual design.

Plans

The design of hoist and hoist loading systems with sufficient capacity, redundancy, and monitoring systems to assure that radioactive materials will be handled in a safe and reliable manner will proceed through all design stages. Information input to the design process includes characteristics of the waste package, transfer cask specifications, and repository waste handling system layouts. Input to the analysis will come from an analysis of failure modes and/or credible accident scenarios. The U.S. Nuclear Regulatory Commission, Mine Safety and Health Administation, and Washington State regulations for hoisting equipment will be considered in the design process.

Work Element R.1.70 (Priority 1)

Determine the coupled effects of stress and elevated temperatures on the permeability of the rock mass.

Status

No information on the effects of stress and elevated temperatures on the permeability of a rock mass is presently available.

Plans

In situ permeability testing in boreholes, both from the surface and from excavations, should precede construction of any test facility at depth, to determine the permeability of the undisturbed rock mass. Permeability in the disturbed rock zone will be measured as specified in Work Elements R.1.18.D. The permeability of both the disturbed and undisturbed rock zones will likely be affected by thermal stresses introduced in the region of the waste package. The nature of these effects will be investigated in appropriate tests at depth for elevated temperatures and pressures. This testing will be conducted as a part of other full-scale hydrologic or rock mechanics tests. The detailed test plans have yet to be made.

Work Element R.1.71 (Priority 2)

Estimate the extent of drying and resaturation of the host rock and backfill as functions of time and distance from the emplaced waste package, and determine the effects of such on the host rock.

Status

A preliminary analysis of the drying and resaturation process is presented in Anderson (1982, Appendix B). This analysis was based on the repository conceptual design and waste package and backfill configurations.

The backfill and host rock drying and resaturation will be a cyclical process, beginning with the undisturbed and saturated host rock. Excavation will expose the host rock to the atmosphere through the repository ventilation system, which will produce some drying. As the waste emplacement is initiated, the heating of the basalt will dry the rock adjacent to the waste packages. After the panels, tunnels, and shafts are backfilled and sealed (expected to be 80 years after the final package is emplaced), the heat-generation rate will decrease and resaturation of the dried host rock will begin. In the period of approximately 90 to 1,000 years after the initiation of repository construction, the emplacement temperature will drop. The backfill will be slowly resaturated after sealing (Anderson, 1982).

Plans

The current analysis will be updated and improved during repository final design as more information on the at-depth condition becomes available. The effects of possible scenarios for groundwater intrusion into the near field, including direction and velocity of flow and hydraulic head, will be assessed. The effect of elevated temperatures on the pattern of groundwater intrusion will be analyzed. Strength and deformation

behavior of saturated rock will be factored into the determination of drying and saturation effects. The effect of heated water on the joints and infilling material with time and the relation of these effects to rock-mass behavior will be analyzed. Hydraulic head in the near field prior to and during construction will be measured. The effect of heated water on the integrity of the structural support systems with time will be determined.

Laboratory and in situ test programs will improve confidence in the values of strength, deformation, and thermal properties of the saturated rock at the candidate repository horizons. Additional tests will investigate the mechanical and thermal properties of the backfill under ambient repository conditions and the effect of heated water on the long-term structural integrity of the support systems.

All of this information will be used to improve the numerical models used for analysis and performance confirmation.

Work Element R.1.72 (Priority 3)

Prepare procedures that will ensure the development of a complete documented history of repository construction as specified in 60.134(c).

Status

Procedures have been developed as part of the BWIP quality assurance program for the site characterization efforts. Some of these procedures are applicable to the maintenance of construction records.

Plans

A design and construction quality assurance plan will be prepared that includes implementing quality assurance and quality control procedures. The procedures will assure that the project obtains adequate records as appropriate for the project manager and the license application. The plan and the procedures will be in accordance with federal, state, and local code requirements. The construction specifications will contain the requirement to develop adequate records.

The plan and the procedures will be approved prior to beginning construction of the exploratory shaft and will be revised periodically for adequacy and compliance.

Work Element R.1.73 (Priority 3)

Prepare specifications for the control of explosives to include the provisions of 30 CFR 57.6.

Status

No effort has been expended to date in preparing specifications for the handling of explosives.

Plans

In Title II design, specifications for handling explosives will be written and included with the application for the construction license.

Work Element R.1.74 (Priority 3)

> Define and implement appropriate training, testing, certification, and qualification programs for operating and supervisory personnel.

Status

No effort has been expended to date to define and implement training, testing, and certification programs.

Plans

During the final design, personnel in quality assurance will review applicable training, testing, and certification requirements in existing regulations. A training, testing, and certification program will be included in the application for an operating license. Where appropriate, such information will also be included in the safety analysis report.

Work Element R.1.75 (Priority 3)

> Define and implement methods and designs that will minimize resource utilization to the extent compatible with safety and performance requirements.

Status

The efficient and conservative use of resources was not explicitly considered in the conceptual design of the repository.

Plans

Trade studies of alternate design concepts will be made to ensure cost-effective resource utilization, prior to completion of final design.

14.3.2 Repository Performance Confirmation Issues and Work Elements

This section contains an analysis of the work needed to meet U.S. Nuclear Regulatory Commission proposed criteria. There are no issues associated with repository performance confirmation. The narratives (status and plans) are presented by work element.

The analysis of data needs and status of work supporting repository performance confirmation work elements are summarized in Table 14-3.

Work Element R.2.1 (Priority 3)

> Determine which characteristics of the natural and engineered systems need to be measured or monitored for performance confirmation, and establish any required baseline values for those characteristics prior to repository construction.

Status

Work is in progress on the selection and validation of numerical models required for the design sensitivity analysis. Some laboratory rock properties have been determined that will contribute to the performance confirmation program.

Plans

This work element is the first step in establishing a program of monitoring the performance of the natural and engineered systems during construction and operation. It establishes which parameters describing system performance are important and are convenient to monitor. Performance sensitivity to each parameter will be obtained from Work Element R.1.10.B, completed as a part of the design activities. The second step in the performance monitoring program is the actual collection and review of the selected parameters, a task outlined in Work Element R.2.2.

A parametric and sensitivity analysis (see Work Element R.2.5) will be conducted to define those characteristics and conditions of the natural and engineered systems that could impact how the repository functions in meeting safety and isolation requirements. These key parameters will be used in the final design; most will be monitored during construction and operation of the repository. Baseline values of the parameters will be obtained from the collected laboratory and in situ test results or initial data from in situ monitoring instrumentation.

The decision on which parameters to monitor and where and when to monitor them will be made with due consideration to the physical and logistical practicality of measuring and processing reliable data.

TABLE 14-3. Work Element Analysis: Data Needs and Status Supporting Performance Confirmation. (Sheet 1 of 3)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.2.1 Determine which characteristics of the natural and engineered systems need to be measured or monitored for performance confirmation, and establish any required baseline values for those characteristics prior to repository construction.	Parametric sensitivity analysis to determine significant characteristics. Specifications for baseline data.	Not applicable. Repository ambient conditions prior to construction or waste emplacement.	Work to be performed. Work to be performed.
R.2.2 Develop a plan for comparing confirmation data and conditions during construction and operation with design data and conditions to determine if significant differences exist that will require modification to the design or construction method.	Parameters to be monitored. Monitoring instrumentation and data processing requirements. Procedures for data evaluation and distribution.	Not applicable. Not applicable. Not applicable.	Work to be performed. Work to be performed. Work to be performed.
R.2.3 (Identical to R.1.11.B) Measure rock strength and deformation characteristics on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.	Identical to R.1.11.B.	Identical to R.1.11.B.	Identical to R.1.11.B.
R.2.4 (Identical to R.1.12.B) Measure rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.	Identical to R.1.12.B.	Identical to R.1.12.B.	Identical to R.1.12.B.
R.2.5 (Related to R.1.47) Deploy instrumentation, as required, to reliably measure stresses, deformation, temperature, and pore pressures until backfill is emplaced.	Identical to R.1.47. Measurement locations, number of instruments, and data sampling rate required. Stress, deformation, temperature, and pore pressure levels throughout repository.	Identical to R.1.47. Not applicable. Ambient repository conditions during construction and operation.	Identical to R.1.47. Work to be performed. Work to be performed.

TABLE 14-3. Work Element Analysis: Data Needs and Status Supporting Performance Confirmation. (Sheet 2 of 3)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
R.2.6 Conduct field tests, as required, of borehole plugging to demonstrate that materials and emplacement methods meet requirements.	Borehole plugging requirements.	See Work Elements R.1.18.D and R.1.23.D.	See Work Elements R.1.18.D and R.1.23.D.
	Results of borehole plugging materials development studies.	Repository operating conditions.	Materials studies in progress.
	Results of borehole plug emplacement equipment development.	Repository operating conditions.	See Work Element R.1.26.D.
	Lab test results of borehole plugging.	In situ pressures and temperature.	Work in progress.
R.2.7 Conduct field tests, as required, of repository room, tunnel, and shaft backfill placement to demonstrate that materials and emplacement methods meet requirements.	Requirements for repository backfill: • Room • Tunnel • Shaft.	Repository operating conditions.	See Work Elements R.1.18.D and R.1.66.
	Results of repository backfill materials development: • Room • Tunnel • Shaft.	Repository operating conditions.	Preliminary materials studies in progress.
	Repository backfill design.	Repository operating conditions.	Preliminary work in progress.
	Results of repository backfill equipment development, as required.	Repository operating conditions.	Work to be performed.
R.2.8 Conduct field tests, as required, of repository tunnel and shaft seals to demonstrate that materials emplacement methods meet functional requirements.	Repository tunnel and shaft seal functional requirements.	Repository operating conditions.	See Work Element R.1.66.
	Results of tunnel and shaft seal materials laboratory tests.	Repository operating conditions.	Research work in progress screening proposed materials.

TABLE 14-3. Work Element Analysis: Data Needs and Status Supporting Performance Confirmation. (Sheet 3 of 3)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	Tunnel and shaft seal designs.	Not applicable.	Preconceptual design in review.
	Proposed emplacement methods: • Tunnel • Shaft.	Not applicable.	Work in progress.
R.2.9 Develop, as required, instrumentation, techniques, and procedures for monitoring the integrity of the waste package in situ.	Isotopes that could be released during operating period.	Not applicable.	Work to be performed.
	Survey of available monitoring equipment.	Not applicable.	Work to be performed.
	Requirements of test section.	Not applicable.	Work to be performed.
R.2.10 Develop a laboratory testing and monitoring program, as required, to evaluate the internal and external conditions of representative waste packages subjected to a simulated repository environment.	Evaluation of need for laboratory facility.	Laboratory such as Near-Surface Test Facility capable of reproducing repository environment and accommodating radioactive waste packages.	Work to be performed.
	Representative waste packages.	None.	Work to be performed. See Chapter 15, W.3.4.
	Repository environment conditions as a function of time.	Not applicable.	Conceptual design.

Work Element R.2.2 (Priority 3)

Develop a plan for comparing confirmation data and conditions during construction and operation with design data and conditions to determine if significant differences exist that will require modification to the design or construction method.

Status

Work to be performed.

Plans

The primary function of this program is to outline procedures for handling and evaluating data from the performance confirmation monitoring process. The input data will be in the form of numerical values for measured parameters describing the repository characteristics. A comparison of data and conditions obtained during construction and early operations will be made with design data and conditions to determine whether modifications to the design are required. This assessment will be a continuing process during repository construction and operation.

Work Element R.2.3 (Identical to R.1.11.B) (Priority 1)

Measure rock strength and deformation characteristics on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.

Status

Identical to R.1.11.B.

Plans

Identical to R.1.11.B.

Work Element R.2.4 (Identical to R.1.12.B) (Priority 2)

Measure rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.

Status

Identical to R.1.12.B.

Plans

Identical to R.1.12.B.

Work Element R.2.5 (Related to R.1.47) (Priority 2)

Deploy instrumentation, as required, to reliably measure stresses, deformation, temperature, and pore pressures until backfill is emplaced.

Status

Identical to R.1.47.

Plans

Plans for development of instrumentation are reported in Work Element R.1.47.

The location and number of instruments and the data sampling rates required to monitor the natural and engineered systems during construction and operation of the repository will be determined on the basis of behavior predicted in the design analysis, results of in situ tests, and accepted engineering practice. Information needed for these decisions will be developed in Work Elements R.1.4.A and R.1.5.A for stresses and temperature, R.1.71 for pore pressures, and R.2.5 for the acceptable range of test results. In addition, physical and logistic constraints associated with data collection from in situ facilities will be assessed.

Work Element R.2.6 (Priority 2)

Conduct field tests, as required, of borehole plugging to demonstrate that materials and emplacement methods meet requirements.

Status

Work is in progress to develop borehole sealing requirements. Information will be obtained from Work Elements R.1.18.D and R.1.23.D. Laboratory research on sealing materials is in progress.

Plans

Borehole sealing field test plans will be developed based on the results of material development studies, emplacement equipment development studies, and laboratory-scale materials testing. Field testing will be performed as deemed appropriate to test seal designs and emplacement methods developed in laboratory-scale research. Instrumentation to measure seal effectiveness will be developed as part of Work Element R.1.26.D.

Work Element R.2.7 (Priority 2)

Conduct field tests, as required, of repository room, tunnel, and shaft backfill placement to demonstrate that materials and emplacement methods meet requirements.

Status

Requirements for repository room, tunnel, and shaft backfill are being developed. Materials studies for backfills are being conducted. The Pennsylvania State University Materials Research Laboratory and the U.S. Army Corps of Engineers Waterways Experimental Station have screened possible backfill mixtures based on preliminary design requirements provided by the Office of Nuclear Waste Isolation repository seal design engineer, D'Appolonia Consulting Engineers.

Plans

A backfill field test will be performed as required, once defined from laboratory and planning studies. Development of backfill emplacement methods will depend on specific backfill design details and materials selections.

Work Element R.2.8 (Priority 2)

Conduct field tests, as required, of repository tunnel and shaft seals to demonstrate that materials emplacement methods meet functional requirements.

Status

Functional requirements for repository tunnel and shaft seals are being developed in Work Element R.1.66. Materials research is in progress. Development of emplacement methods will be based on preliminary design details.

Plans

Field tests of repository tunnel and shaft seal designs will be developed based on tunnel and shaft seal material laboratory-scale research results. Emplacement methods will be developed in Work Element R.1.24.D in accordance with the functional requirements developed in Work Element R.1.66.

Work Element R.2.9 (Priority 3)

Develop, as required, instrumentation, techniques, and procedures for monitoring the integrity of the waste package in situ.

Status

Work to be performed.

Plans

The instrumentation and procedures required to monitor the integrity of the waste package in any test panel of the repository, as well as in waste disposal panels, will be developed in final design. Information

required for this analysis is the prediction of isotopes that could be released during the operating period, a survey of available monitoring equipment, and the definition of requirements for both the test panel and the monitoring waste disposal panels.

Work Element R.2.10 (Priority 3)

> Develop a laboratory testing and monitoring program, as required, to evaluate the internal and external conditions of representative waste packages subjected to a simulated repository environment.

Status

Work is yet to be performed. No applicable information is currently available in the BWIP.

Plans

Construction of a full waste package assemblage is planned (see Section 15.4, paragraph 18). Acceptance-test procedures for the waste package will be developed (see Chapter 15, W.3.4).

14.4 SUMMARY OF BASALT WASTE ISOLATION PROJECT REPOSITORY DESIGN AND CONSTRUCTION AND PERFORMANCE CONFIRMATION ACTIVITIES

The status and plans for each of the work elements associated with repository design and construction and performance confirmation criteria and/or issues were presented in Section 14.3. In this section, a brief description of all the technical work being undertaken by the BWIP on these tasks is provided in summary narrative form. These narratives are accompanied by a logic diagram (Fig. 14-2) that describes, in general form, the main activities to accomplish the work, as well as the points in time at which the issues presented in Section 14.3 will be resolved. Chapter 17 will present schedules and milestones for the work described in this chapter. Each box on the logic diagram is keyed to the following narrative material. Each section of the narrative also contains a list of the work elements that support the tasks designated.

As noted in Section 14.1, the design activity is the key work element that will determine the requirements for the data gathering activities for the repository design and construction and performance confirmation tasks. A wide range of testing has been scoped to define the rock-mass characteristics, response to construction activities, thermal loading, geologic conditions, and interaction with the support systems. These data will be input to the performance assessment models and repository design activities.

A tunnel, shaft, and borehole sealing test program is described that defines the materials, equipment, and techniques necessary to meet the U.S. Nuclear Regulatory Commission proposed criteria for repository closure and long-term isolation of radioactive waste.

As additional results from ongoing and planned studies are analyzed, testing plans will be further refined.

<u>Summary Activity Narratives</u>

1. <u>Input to BWIP Plan</u>

   The inputs to the BWIP plan summarize the work to be performed. These inputs reflect the experience gained from tests at the Near-Surface Test Facility, conceptual design, and engineering studies previously completed. This work will ultimately produce detailed repository specifications to ensure that the repository meets the requirements for nuclear waste disposal.

   <u>Applicable Work Elements</u>

   Input to the initial BWIP plan has been completed. The BWIP updates technical plans on an as-needed basis. The definition (technical planning) of the work required to meet criteria presented in Chapter 14 forms the basis of the work elements in this chapter.

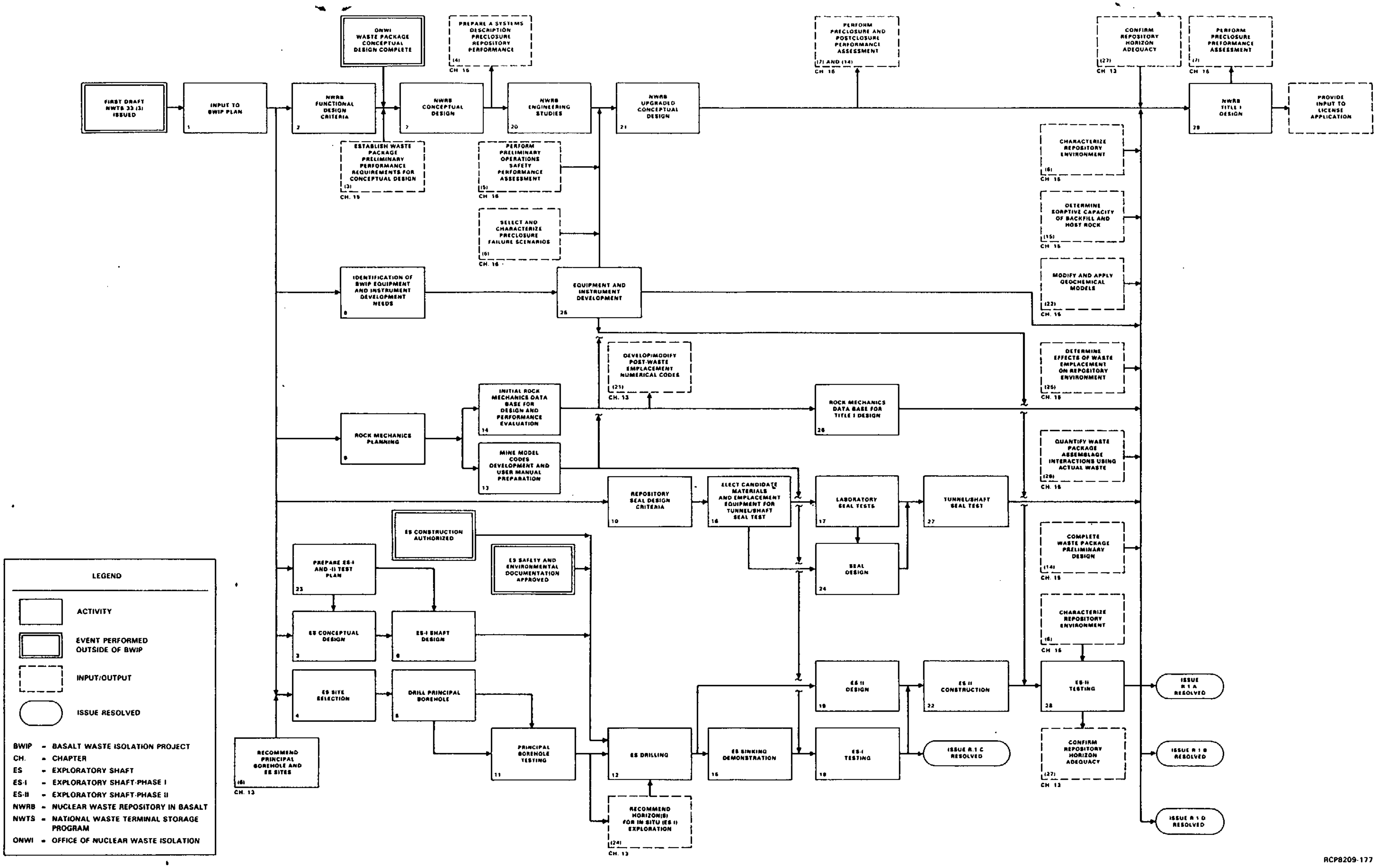

FIGURE 14-2. Logic Diagram for Geoengineering and Repository Design.

2. Nuclear Waste Repository in Basalt Functional Design Criteria

Based on preconceptual design guidelines, engineering studies were performed that resulted in a selected repository concept. The preconceptual design guidelines, supporting studies, and selected concept formed the basis for performing repository preconceptual design. Based on this work, functional design criteria were prepared. The functional design criteria define repository functions and design requirements. The approved functional design criteria provide the technical basis for the conceptual design of a nuclear waste repository in basalt.

Applicable Work Elements

Work completed (BWIP and KE/PB, 1982).

3. Exploratory Shaft Conceptual Design

Exploratory shaft conceptual design work will proceed concurrent with drilling of the principal borehole at the exploratory shaft site. The conceptual design for the exploratory shaft will be based on approved functional design criteria and will be consistent with the test plan for Exploratory Shaft-Phase I.

Applicable Work Elements

R.1.1.A, R.1.8.A, R.1.11.B, R.1.12.B, R.1.13.B, R.1.16.D, R.1.35, R.1.37, R.1.38, and R.1.39.

4. Exploratory Shaft Site Selection

A specific site for the principal borehole was recommended (see Site Activity 6 in Section 13.4) to the U.S. Department of Energy in September 1981 and approved in May 1982. Assuming that no unacceptable conditions are found during drilling of the principal borehole, the exploratory shaft will be constructed within a few hundred meters of the principal borehole.

Applicable Work Elements

R.1.11.B and R.1.12.B.

5. Drill Principal Borehole

The objective of this activity is to drill the principal borehole. This hole is a cored borehole that will be drilled to provide information for exploratory shaft design and to ascertain the overall suitability of the proposed location for an exploratory shaft at the reference repository location.

Applicable Work Elements

R.1.11.B and R.1.12.B.

6. Exploratory Shaft-Phase I Shaft Design

Detailed design will be initiated following conceptual design approval by the U.S. Department of Energy-Richland Operations Office. Results from the drilling and testing of the principal borehole will be incorporated into detailed design. The detailed design will provide the basis for beginning exploratory shaft construction work when authorized by U.S. Department of Energy-Richland Operations Office.

Applicable Work Elements

R.1.1.A, R.1.8.A, R.1.11.B, R.1.12.B, R.1.13.B, R.1.16.D, R.1.35, R.1.37, R.1.38, and R.1.39.

7. Nuclear Waste Repository in Basalt Conceptual Design

Conceptual design of the nuclear waste repository in basalt is based on the approved functional design criteria and the approved waste package preconceptual design. The nuclear waste repository in basalt conceptual design report will be accompanied by a conceptual system design description, a project cost estimate, and a project schedule. Engineering studies were performed that led to a concept selection on which the conceptual system design description was based. The completed conceptual design report will serve as a basis for follow-up engineering studies and preparation of an upgraded conceptual design report.

Applicable Work Elements

Work in design review.

8. Identification of Basalt Waste Isolation Project Equipment and Instrument Development Needs

The BWIP equipment and instrument development needs will be identified to define project equipment and instrument development requirements. This will ensure that hardware and technology are available to support field and in situ testing activities and the safe, cost-effective construction, operation, and decommissioning of a nuclear waste repository in basalt. The equipment and instrument development to be conducted will be limited to that required to meet site-specific requirements. The planning will identify the hardware required for repository construction, operation, and decommissioning.

Applicable Work Elements

R.1.14.C, R.1.46, R.1.47, R.1.48, R.2.5, and R.2.9.

9. Rock Mechanics Planning

The BWIP will identify the rock mechanics data requirements and geotechnical issues requiring resolution to support repository design, construction, and performance evaluation. The BWIP rock mechanics

planning will define the laboratory, field, and in situ testing required to complete the data base, as well as delineate the modeling and analytical tools needed to support analysis. Data requirements include intact and jointed properties, rock-mass characteristics, and rock response to thermal loading at canister, room, and repository scales.

Applicable Work Elements

R.1.6.A, R.1.10.B, R.1.11.B, R.1.12.B, R.1.13.B, R.1.30, R.1.70, and R.1.71.

10. Repository Seal Design Criteria

The objective of the repository seal design criteria development activity is to develop site-specific repository seal design criteria, evaluate proposed basalt seal designs, and conduct field and in situ testing, as required, to validate seal designs.

Applicable Work Elements

For work elements, see Activities 16, 17, 24, 27, and 31 in this section.

11. Principal Borehole Testing

Principal borehole testing in support of Exploratory Shaft-Phase I design and construction will be conducted under this activity. Borehole testing in the principal borehole will be conducted to assess the overall suitability of the site by verifying that the depth to the candidate repository horizons, thickness, and hydraulic conductivity fit existing criteria. These tests will provide the design information required for shaft design and selection of porthole locations, and will ascertain the overall suitability of the proposed location for an exploratory shaft at the candidate repository horizons.

Applicable Work Elements

S.1.1.A, S.1.5.1, S.1.7.A, S.1.8.A, S.1.9.A, S.1.10.A, S.1.26.C, S.1.30.C, S.1.35.C, R.1.9.A, R.1.28, W.2.1.A.

12. Exploratory Shaft Drilling

The start of exploratory shaft drilling begins after receipt of the necessary authorizations to begin construction and approvals of safety and environmental documentation. These authorizations and approvals will be provided by U.S. Department of Energy.

Surface facilities construction includes the surface facilities required for shaft construction, testing, and operations. Included will be a headframe and hoist system and other facilities and utilities required to operate the facility.

Applicable Work Elements

R.1.11.B, R.1.16.D, and R.1.21.D.

13. Mine Model Codes Development and User Manual Preparation

The objective of this activity is to develop, benchmark, and document rock mechanics numerical models needed to support the repository data base activity and the upgraded repository conceptual design. A limited number of models will be documented for thermomechanical analysis of basalt on a canister, room, and repository scale. Models will be used in support of the rock mechanics test programs, repository design and construction, licensing, and performance evaluation. Model and documentation updating will continue on a level-of-effort basis through the remainder of the program.

Applicable Work Elements

R.1.10.B, R.1.11.B, R.1.12.B, R.1.13.B, and R.2.1.

14. Initial Rock Mechanics Data Base for Design and Performance Evaluation

The objective of this activity is to conduct and analyze the results of the laboratory, field, and in situ tests needed to provide the initial rock mechanics data base for the upgraded repository conceptual design, analysis, and performance evaluation. The data base will include the results of laboratory tests on intact and jointed samples at ambient and elevated temperatures and pressures, field characterization of basalt, field tests of rock-mass response at elevated temperatures, and conceptual design analysis. The data base will be used for design parameter inputs, design criteria specifications, stability analysis, and performance assessment.

Applicable Work Elements

R.1.11.B, R.1.12.B, R.1.13.B, R.2.1, R.2.2, R.2.5, and R.2.10.

15. Exploratory Shaft Sinking Demonstration

Sinking of the exploratory shaft will demonstrate that a 1.83-meter (6-foot) diameter shaft can be blind bored at the reference repository location and successfully grout sealed from the groundwater system. Based on the demonstration, an assessment will be made of the applicability of blind boring repository size shafts.

The final decision on the sinking method for repository shafts has not been reached and will be dependent on the shaft diameters finally selected for the repository, the depth of the selected repository horizon, site-specific geotechnical and hydrologic data, the results of the exploratory shaft sinking demonstration, and developments in the technology for blind boring that could occur over the next several years.

Applicable Work Elements

R.1.11.B, R.1.16.D, and R.1.21.D.

16. Select Candidate Materials and Emplacement Equipment for Tunnel/Shaft Seal Test

The purpose of this activity is to select candidate materials and emplacement equipment or tunnel/shaft seal tests based on seal designs and seal material development activities. The objectives of this activity are:

(1) Develop seal materials that are chemically stable and that inhibit fluid flow and radionuclide migration

(2) Provide structural integrity and meet design life criteria

(3) Determine if existing technology and equipment are adequate

(4) Initiate trade studies supported by laboratory and component field tests, as required, to determine the materials and equipment for use in the field. The information collected within this activity will then be supplied as input to the upgraded conceptual design activities.

Applicable Work Elements

R.1.19.D through R.1.23.D, R.1.26.D, R.2.6, R.2.7, and R.2.8.

17. Laboratory Seal Tests

The objective of this activity is to complete a series of borehole seal materials tests in basalt and select candidate materials suitable for repository storage room, tunnel, and shaft seals. The activity includes (1) developing and selecting borehole seal materials, (2) ensuring the durability and stability of borehole seals, and (3) conducting laboratory permeability and other mechanical tests of borehole seals in a test block of basalt under simulated conditions typical of the Hanford Site.

Applicable Work Elements

R.1.18.D, R.1.19.D, R.1.20.D, R.1.21.D, and R.1.23.D.

18. Exploratory Shaft-Phase I Testing

A major objective of Exploratory Shaft-Phase I is to provide access to the candidate repository horizons for additional detailed in situ testing. The technical objectives for Phase I are:

(1) Shaft Construction: Demonstrate that an exploratory shaft can be sunk at the reference repository location, and assess the construction method.

(2) Shaft Seal: Verify that an exploratory shaft can successfully seal off the groundwater system, and evaluate the effects of shaft construction on the surrounding rock at the reference repository location.

(3) Hydrologic Properties: Measure the hydraulic properties (e.g., hydraulic conductivity) of the candidate repository horizons to provide input to a preliminary estimate of its isolation capability in the vicinity of the exploratory shaft.

(4) Geomechanics: Conduct geomechanics tests (e.g., in situ stress) and provide a preliminary rock-mass characterization of the candidate repository horizons.

Exploratory Shaft-Phase I Porthole Tests.

Exploratory Shaft-Phase I porthole tests will be conducted to assess the extent and character of changes in permeability of the construction-affected zone around the exploratory shaft.

Shaft Casing Seal Verification.

Porthole testing will be conducted at the candidate repository horizons to determine the effectiveness of the grout that seals the space between the shaft casing and the surrounding host rock to isolate the various aquifers from each other and from the candidate repository horizons.

Preliminary Hydrologic Assessment.

Tests will be conducted in horizontal laterals drilled out from the exploratory shaft to assess vertical hydraulic conductivity in the host rock. Data from these tests will be used in support of the repository performance assessment.

Preliminary Geomechanics Characterization.

As the underground access becomes available, stress measurements and rock-mass characterization will be conducted. These data will be used as input to modify, if necessary, the design of underground openings.

Applicable Work Elements

Objective (1): R.1.16.D and R.1.17.D
Objective (2): R.1.21.D and R.1.28
Objective (3): S.1.24.C, S.1.25.C, S.1.26.C, S.1.28.C, and S.1.30.C
Objective (4): R.1.12.B, R.1.14.C, and R.2.1.

19. Exploratory Shaft-Phase II Design

Detailed design of the Exploratory Shaft-Phase II and subsequent testing at depth will be initiated following conceptual design approval by U.S. Department of Energy-Richland Operations Office. Results from the shaft construction and initial in situ tests will be incorporated into the detailed design of these facilities. The detailed design will provide the basis for construction when authorized by U.S. Department of Energy-Richland Operations Office.

Applicable Work Elements

R.1.1.A, R.1.6.A, R.1.7.A, R.1.8.A, R.1.11.B, R.1.12.B, R.1.13.B, R.1.16.D, R.1.35 through R.1.44, R.1.49, and R.1.63.

20. Nuclear Waste Repository in Basalt Engineering Studies

Based on the completed repository conceptual design report, engineering studies will be conducted that could affect an upgraded conceptual design. The engineering studies will be based on the expanded technical knowledge and revised program guidance evolving subsequent to the period of original conceptual design preparation. Subjects of potential engineering studies include cost trade-offs, optimization of key repository design concepts, impact of site-specific parameters on repository design, integration of repository facilities with the exploratory shaft, and alternate construction methods for shafts and tunnels. The results of the completed engineering studies will serve as a basis for revising the functional design criteria and upgrading the conceptual design report.

Applicable Work Elements

R.1.11.B, R.1.12.B, R.1.13.B, and R.1.46.

21. Nuclear Waste Repository in Basalt Upgraded Conceptual Design

The conceptual design will be upgraded to reflect current technical information, National Waste Terminal Storage Program strategies, and regulatory requirements. The upgraded conceptual design will be based on the waste package conceptual design, results of completed engineering studies, BWIP equipment and instrument development plans, an initial rock mechanics data base, rock mechanics thermomechanical models, repository seal studies, and upgraded site data.

As part of the upgraded conceptual design of the nuclear waste repository in basalt, an upgraded conceptual design report will be prepared. The nuclear waste repository in basalt upgraded conceptual design report will be accompanied by a project cost estimate, and a project schedule. When approved and issued, the upgraded conceptual design report will be used as a basis for preparing Title I design criteria and a Schedule 44 capital budget request for repository design and long-lead procurement.

Applicable Work Elements

R.1.6.A, R.1.8.A, R.1.11.B, R.1.12.B, R.1.13.B, R.1.16.D, R.1.18.D, R.1.19.D, and R.1.66.

22. Exploratory Shaft-Phase II Construction

Construction of the Exploratory Shaft-Phase II will be initiated after completion of the detailed design. As currently conceived, this facility would consist of approximately 300 meters of tunnels extending horizontally from the Phase I shaft station. Authorization to proceed with construction will be provided by U.S. Department of Energy-Richland Operations Office. Additional in situ testing will be conducted, as required, at the selected repository site to support repository design verification.

Applicable Work Element

R.1.7.A.

23. Prepare Exploratory Shaft-Phase I and II Test Plan

The Exploratory Shaft Test Plan defines the technical objectives of the test program to be performed in the facility. The objective of Phase I of the Exploratory Shaft Test Program is the in situ characterization of the selected candidate repository horizon and immediate surroundings to resolve key site-suitability issues that could not be resolved from the surface or through small boreholes. The objective of Phase II of the Exploratory Shaft Test Program is to obtain in situ information to allow a final assessment of the site's suitability and provide design input as required for construction authorization. The test plan will be issued in November 1982 for National Waste Terminal Storage Program review.

Applicable Work Elements

For work elements, see Activities 11, 18, and 28 in this section.

24. Seal Design

This activity will proceed concurrently with the materials screening, emplacement equipment selection, and with laboratory testing activities. The objective is to develop seal designs compatible with the repository conceptual design. These designs will specify seal locations, component dimensions, materials properties, and construction methods. They will refer to site stratigraphy and hydrology and will take into account laboratory testing of candidate materials. The activity will include development of seal system analytical models.

The seal designs will incorporate site and penetration data obtained from the selected repository horizon.

Applicable Work Elements

R.1.9.A, R.1.10.B through R.1.13.B, R.1.16.D through R.1.26.D, R.1.30, R.1.47, R.1.66, R.1.67, R.1.70, R.1.71, R.2.6, R.2.7, and R.2.8.

25. Equipment and Instrument Development

This activity includes the design, fabrication, and testing of equipment and instruments for which technology is currently not available to meet site-specific requirements. The end items of this development work are equipment and instrument specifications for hardware to support field and in situ testing activities and repository construction, operation, and decommissioning. Hardware specifications are input to repository Title I design.

Applicable Work Elements

R.1.14.C, R.1.16.D, R.1.46, R.1.47, R.1.48, R.2.5, and R.2.9.

26. Rock Mechanics Data Base for Title I Design

The objective of this activity is to complete the data base development required to support repository Title I design, analysis, and performance evaluation. It will include conducting laboratory, field, and in situ tests and analyzing the results. The data base will provide information on intact and jointed samples at ambient and elevated temperatures and pressures, field characterization of basalt, field tests of rock-mass response at elevated temperatures, and upgraded conceptual design analysis. The data base will be used for design parameter inputs, design criteria verification, stability analysis, and performance evaluation.

Applicable Work Elements

R.1.8.A, R.1.11.B, R.1.12.B, R.1.70, and R.2.1.

27. Tunnel/Shaft Seal Test

The purpose of this testing activity is to plan and conduct tests to validate (confirm) seal design. The scope of this activity includes tests, as required, for room backfill, tunnel seals, shaft seals, and borehole seals. Materials information developed by the BWIP will be utilized within this activity.

Applicable Work Elements

R.1.19.D, R.1.21.D through R.1.24.D, R.1.26.D, R.2.6, R.2.7, and R.2.8.

28. Exploratory Shaft-Phase II Testing

Tests will be conducted under this activity for the purpose of resolving geotechnical and hydrologic issues and to further support the information base obtained from Exploratory Shaft-Phase I testing and to support a decision on repository siting. The technical objectives for Phase II are:

(1) Provide geotechnical information to enable characterization of a larger volume of the candidate repository horizons.

(2) Conduct detailed measurements of hydrologic properties (e.g., hydraulic conductivity) of the reference repository location and long-term hydrologic tests to further support the site suitability assessment conducted after Exploratory Shaft-Phase I.

(3) Determine the extent of applicability of data from the Near-Surface Test Facility to the candidate repository horizons.

Applicable Work Elements

Objective (1): S.1.1.A, S.1.2.A, S.1.3.A, S.1.4.A, S.1.6.A, R.1.2.A, R.1.4.A, R.1.8.A, R.1.11.B, R.1.12.B, R.1.13.B, R.1.14.C, R.1.15.C, R.1.16.D, R.1.17.D, R.1.48, R.1.57, R.1.70, and R.2.1.
Objective (2): S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, S.1.30.C, S.1.35.C, S.1.36.C, R.1.57, R.1.70, R.2.1, and W.2.13.D.
Objective (3): R.1.12.B, R.1.13.B, R.1.14.C, and R.1.70.

29. Nuclear Waste Repository in Basalt Title I Design

Following receipt of a directive authorization from the U.S. Department of Energy, Title I design will commence. Title I design will be supported by the completed waste package design, preliminary repository performance evaluation, completed equipment and instrument development, rock mechanics data base, and repository seal development activity.

Completion of Title I design consists of the issuance of the Title I design report, which summarizes Title I design. The Title I design report will serve as a basis for preparation of Title II design. Information developed during Title I design will be included in ongoing performance assessment activities and license application documentation (preliminary safety analysis report and environmental report) preparation.

Applicable Work Elements

R.1.11.B, R.1.12.B, R.1.14.C, R.1.33, R.1.35, R.1.37, R.1.38, R.1.40, R.1.42 through R.1.45, R.1.49, R.1.55, R.1.56, R.1.58 through R.1.65, R.1.67, R.1.69, and R.1.71.

14.5 REPOSITORY CRITERIA/ISSUES/WORK ELEMENTS

The criteria, issues, and work elements discussed in the narratives in Section 14.3 are presented here (Table 14-4). Introductory comments concerning their development and organization are contained in the preface to Chapters 13, 14, and 15.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 1 of 40)

Technical criteria	Issues	Work element
	R.1 - Design	
<u>Containment of Wastes</u> <u>(60.111(2))</u> The engineered system shall be designed so that even if full or partial saturation of the underground facility were to occur, and assuming anticipated processes and events, the waste packages will contain all radionuclides for at least the first 1,000 years after permanent closure. This requirement does not apply to transuranic waste unless transuranic waste is emplaced close enough to high-level waste that the transuranic release rate can be significantly affected by the heat generated by the high-level waste. For clarification see: NWTS 33(1), 3.4.2 NWTS 33(4), 3.1 NWTS 33(4), 3.2.1 NWTS 33(4), 4.3.2.1	R.1.A Can stability and isolation capability of the repository be maintained in the presence of coupled in situ, excavation-induced, and thermal-induced stresses?	R.1.1.A Determine the methodology for design and analysis of subsurface openings and their support systems. R.1.2.A Evaluate the effect of underground construction sequence on the stability of openings. R.1.3.A Determine the magnitude and the rate of deformation of tunnels and canister boreholes resulting from in situ, excavation-induced, and thermal-induced stresses, and how deformation is affected by backfill.
<u>High-Level Waste Releases</u> <u>(60.111(b)(2)(ii)(A))</u> For high-level waste, the engineered system shall be designed so that, after the first 1,000 years following permanent closure, the annual release rate of any radionuclide from the engineering system into the geologic setting, assuming anticipated processes and events, is at most one part in 100,000 of the maximum amount of that radionuclide calculated to be		R.1.4.A Determine the magnitude and distribution of excavation-induced stresses for single and multiple openings. R.1.5.A Determine the magnitude and distribution of thermal stresses in the rock mass for the proposed waste package storage configuration.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 2 of 40)

Technical criteria	Issues	Work element
present in the underground facility (assuming no release from the underground facility) at any time after 1,000 years following permanent closure. This requirement does not apply to radionuclides whose contribution is less than 0.1 percent of the total annual curie release as prescribed by this paragraph. For clarification see: 10 CFR 60.111(b)(2)(iii)(A)		R.1.6.A (Related to R.1.7.A and R.1.48) Determine from case history evaluations the combinations of stress fields, rock properties, geologic structural features, and mine geometries that are typical of rock burst-prone areas, and assess the probability of rock bursts at or near the repository site.
<u>TRU Releases</u> <u>(60.111(b)(2)</u>(iii)(A)) For transuranic waste, the engineered system shall be designed so that following permanent closure the annual release rate of any radionuclide from the underground facility into the geologic setting, assuming anticipated processes and events, is at most one part in 100,000 of the maximum amount calculated to be present in the underground facility (assuming no release from the underground facility) at any time following permanent closure. This requirement does not apply to radionuclides whose contribution is less than 0.1 percent of the annual curie release as prescribed by this paragraph. For clarification see: 10 CFR 60.111(b)(2)(ii)(B)		R.1.7.A (Related to R.1.6.A and R.1.48) Document occurrences of dynamic instability of test excavations at depth at the repository site. R.1.8.A (Related to R.1.14.C and R.1.15.C) Determine the spatial variation of in situ stresses in the region of the repository. R.1.9.A Determine the potential for subsidence caused by mine openings.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 3 of 40)

Technical criteria	Issues	Work element
<u>Potentially Adverse Conditions</u> <u>(60.123)</u> 60.123(b)(16) Rock or ground conditions that would require complex engineering measures in the design and construction of the underground facility or in the sealing of boreholes and shafts. 60.123(b)(17) Geomechanical properties that do not permit design of stable underground openings during construction, waste emplacement, or retrieval operations. For clarification see: NWTS 33(2), 3.4.1 10 CFR 60.124(c)(b) 10 CFR 60.132(a)(2) 10 CFR 60.132(e) 10 CFR 60.132(f) 10 CFR 60.132(k)	R.1.B Can satisfactory representative measurements or estimates of rock-mass strength be obtained?	R.1.10.A Define the acceptable range of test results for intact rock and rock-mass characteristics to support design activities. R.1.11.B (Identical to R.2.3) Measure rock strength and deformation characteristics on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture. R.1.12.B (Identical to R.2.4) Measure rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.
<u>Additional Design Requirements for the Underground Facility</u> <u>(60.132(e))</u> (e) Design of subsurface openings. (1) Subsurface openings shall be designed to maintain stability throughout the construction and operation periods. If structural support is required for stability, it shall be designed to be compatible with long-term deformation, hydrologic, geochemical, and thermomechanical		R.1.13.B Develop and validate mechanical, thermal, and thermomechanical models for performance of in situ tests and for design and performance of the repository.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 4 of 40)

Technical criteria	Issues	Work element
characteristics of rock and to allow subsequent placement of backfill.		
(2) Structures required for temporary support of zones of weak or highly fractured rock shall be designed so as not to impair the placement of permanent structure or the capability to seal excavated areas used for the containment of wastes.		
(3) Subsurface openings shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock over the long term. The size, shape, orientation, and spacing of openings and the design of engineered support systems shall take the following conditions into consideration:		
(i) natural stress conditions;	R.1.C	R.1.14.C (Related to R.1.8.A and R.1.15.C)
(ii) deformation characteristics of conditions and thermal loading;	Are current methods of in situ stress measurement used at depth reliable enough to provide satisfactory data for design requirements?	Develop stress measurement methods that will yield valid data in closely jointed basalt.
(iii) The kinds of weaknesses or structural discontinuities found at various locations in the geologic repository;		R.1.15.C (Related to R.1.8.A and R.1.14.C)
(iv) Equipment requirements; and		Establish methods of validating measured in situ stress data.
(v) The ability to construct the underground facility as designed so that stability of the rock is enhanced.		

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 5 of 40)

Technical criteria	Issues	Work element
For clarification see: 10 CFR 60.132(e)(1) 10 CFR 60.132(e)(2)		
60.132(f) (f) Rock excavation. The design of the underground facility shall incorporate excavation methods that will limit damage to and fracturing of rock. For clarification see: 10 CFR 60.132(f) NWTS 33(3), 4.4.2 NWTS 33(3), 4.2 10 CFR 60.123 (b)(16)(17) <u>Construction Specifications for Surface and Subsurface Facilities (60.134(d)</u> (d) Rock excavation. The methods used for excavation shall be selected to reduce to the extent practicable the potential to create a preferential pathway for groundwater or radioactive waste migration or increase migration through existing pathways. For clarification see: 10 CFR 60.134(d) 10 CFR 60.133(a)	R.1.D Can repository shafts, tunnels and exploratory boreholes be constructed and sealed without causing preferential pathways for groundwater or increasing the potential for radionuclide migration from a nuclear waste repository such that compliance wth appropriate U.S. Environmental Protection Agency regulations is not possible?	R.1.16.D Evaluate and select methods of excavation and rock support that can economically and safely be constructed and at the same time maintain isolation capability of the engineered system. R.1.17.D Develop or adapt instrumentation and test methods to measure the nature and extent of rock-mass disturbance caused by candidate excavation methods and stress redistribution around tunnels and boreholes.
<u>Design of Shafts and Seals for Shafts and Boreholes</u> (60.133) (a) Shaft design. Shafts shall be designed so as not to create a preferential pathway for migration of groundwater and so as not to increase the potential for migration through existing pathways.		

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 6 of 40)

Technical criteria	Issues	Work element
For clarification see: NWTS 33(3), 4.6.2.4 10 CFR 60.134(d)		
(b) Shaft and borehole seals. Shaft and borehole seals shall be designed so that: (1) Shafts and boreholes will be sealed as soon as possible after they have served their operational purpose. (2) At the time of permanent closure sealed shafts and boreholes will inhibit transport of radionuclides to at least the same degree as the undisturbed units of rock through which the shafts or boreholes pass. In the case of soluble rocks, the borehole and shaft seals shall also be designed to prevent groundwater circulation that would result in dissolution. (3) Contact between shaft and borehole seals and the adjacent rock does not become a perferential pathway for water. (4) Shaft and borehole seals can accomodate potential variations of stress, temperature, and moisture.		R.1.18.D Identify performance requirements for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste. R.1.19.D Select materials and develop testing techniques required to meet repository room and tunnel sealing criteria. R.1.20.D Determine the effect of temperature, rock-mass deformation, groundwater flow, and groundwater chemistry on materials used for seals. R.1.21.D Develop grouts and grouting techniques that ensure acceptable sealing of the disturbed rock zone.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 7 of 40)

Technical criteria	Issues	Work element
(5) The materials used to construct the seals are appropriate in view of the geochemisty of the rock and groundwater system, anticipated deformations of the rock, and other in situ conditions. For clarification see: NWTS 33(3), 4.6.2.4 10 CFR 60.133(a) 10 CFR 60.133(b) NWTS 33(3), 4.6.2 NWTS 33(3), 4.6.2.1 10 CFR 60.142(a)		R.1.22.D Determine the effects of temperature, rock-mass deformation, and time on the permeability of the sealed rock zone. R.1.23.D Select materials and develop testing techniques required to meet borehole sealing criteria. R.1.24.D Develop construction and test techniques required to meet repository tunnel and shaft sealing criteria. R.1.25.D Prepare final specifications for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste. R.1.26.D Develop methods and equipment for backfilling and sealing the repository, and demonstrate their effectiveness.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 8 of 40)

Technical criteria	Issues	Work element
Concepts (60.102) (a) The high-level waste facility. The U.S. Nuclear Regulatory Commission exercises licensing and related regulatory authority over those facilities described in Section 203 (3) and (4) of the Energy Reorganization Act of 1974. Any of these facilities is designated as a high-level waste facility. For clarification see: NWTS 33(1), 3.1.2 NWTS 33(1), 5.0 NWTS 33(1), 5.6	None.	R.1.27 Determine which facilities or systems within the facility will be designated and classified as high-level waste facilities.
Potentially Adverse Conditions (60.123) The following are potentially adverse conditions. The presence of any such conditions may compromise site suitability and will require careful analysis and such measures as are necessary to compensate for them adequately pursuant to 60.124. (a) (4) Earthquakes which have occurred historically that if they were to be repeated could affect the geologic repository significantly. (b) (15) Processes that would reduce sorption, result in degradation of the rock strength, or adversely affect the performance of the engineered system.	None.	R.1.28 Assess the effects of adverse conditions on the design and performance of the repository. R.1.29 (Related to R.1.30) Assess the effects of seismic events on underground openings during construction and operations. R.1.30 (Related to R.1.29) Assess the effects of seismic events on repository tunnel and shaft seals.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 9 of 40)

Technical criteria	Issues	Work element
For clarification see: NWTS 33(1), 3.3.2 NWTS 33(2), 3.4.2 NWTS 33(2), 3.5.5 NWTS 33(3), 3.4 NWTS 33(3), 4.2.1 10 CFR 60.123(a) 10 CFR 60.124 10 CFR 60.130(b)(2)		
<u>General Design Requirements for the Geologic Repository Operations Area.</u> (60.130) (a) Sections 60.130 through 60.134 specify minimum requirements for the design of and construction specifications for the geologic repository operations area. All design and construction criteria must be consistent with the results of site characterization activities. (b) Systems, structures, and components of the geologic repository operations area shall satisfy the following: (1) Radiological protection. The structures, systems, and components located within restricted areas shall be designed to maintain radiation doses, levels, and concentrations of radioactive material in air in those restricted areas within the limits specified in Part 20 of this chapter.	None.	See following page.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 10 of 40)

Technical criteria	Issues	Work element
These structures, systems, and components shall be designed to include:		
(i) Means to limit concentrations of radioactive material in air;		
(ii) Means to limit the time required to perform work in the vicinity of radioactive materials, including, as appropriate, designing equipment for ease of repair and replacement and providing adequate space for ease of operation;		
(iii) Suitable shielding;		R.1.31
(iv) Means to monitor and control the dispersal of radioactive contamination;		Develop shielding requirements, operating, and access control procedures to limit the dose to repository personnel.
(v) Means to control access to high radiation areas of airborne radioactivity areas; and		
(vi) A radiation alarm system to warn of increases in radiation levels, concentrations of radioactive material in air, and of increased radioactivity released in effluents. The alarm system shall be designed with redundancy and in situ testing capability.		R.1.32 Develop the procedures and requirements for controlling access to the repository site. R.1.33 Determine the techniques to be used for limiting, monitoring, and controlling the airborne radioactivity in the repository.
For clarification see: NWTS 33(1), 4.2 NWTS 33(3), 4.2.1 NWTS 33(3), 4.2.4 NWTS 33(3), 4.5.10.1 10 CFR 60.111(a) 10 CFR 60.130(b)(2)(i) 10 CFR 60.132(b)(1)		

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 11 of 40)

Technical criteria	Issues	Work element
60.130(b)(2) (2) Protection against natural phenomena and environmental conditions. (i) The structures, systems, and components important to safety shall be designed to be compatible with anticipated site characteristics and to accommodate the effects of environmental conditions, so as to prevent interference with normal operation, maintenance and testing during the entire period of construction and operations. (ii) The structures, systems, and components important to safety shall be designed so that natural phenomena and environmental conditions anticipated at the site will not result in any relevant time period in failure to achieve the performance objectives. For clarification see: 10 CFR 60.130(b)(2)(i) 10 CFR 60.130(b)(2)(ii) 10 CFR 60.132(k)	None.	R.1.34 Develop a design that will protect operations personnel against the effects of natural phenomena and environmental conditions.
60.130(b)(3) (3) Protection against dynamic effects of equipment failure and similar events. The structures, systems, and components important to safety shall be designed to withstand dynamic effects that could result from	None.	R.1.35 Determine the impact of the dynamic effects of equipment failure on safety-related systems and components.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 12 of 40)

Technical criteria	Issues	Work element
equipment failure, such as missile impacts, and similar events and conditions that could lead to loss of their safety functions. For clarification see: 10 CFR 60.130(b)(3)		
60.132(a)(4) (4) The underground facility shall be designed so that the effects of disruptive events such as intrusions of gas, water, or explosions will not spread through the facility.	None.	R.1.36 Define the structures or equipment necessary so that disruptive natural or man-induced events such as intrusion of gas, water, or explosion will not spread through the repository.
60.130(b)(4) (4) Protection against fires and explosions. (i) The structures, systems, and components important to safety shall be designed to perform their safety functions during and after fires or explosions in the geologic repository operations area. (ii) To the extent practicable, the geologic repository operations area shall be designed to incorporate the use of noncombustible and heat-resistant materials. For clarification see: NWTS 33(3), 3.1 10 CFR 60.132(a)(3)	None.	R.1.37 Determine the extent and severity of potential fires and explosions in the repository and their effect on the stability of the rock support systems and other safety-related systems. R.1.38 Define which combustible materials can be used in the design of components and equipment that have been designated as safety-related systems.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 13 of 40)

Technical criteria	Issues	Work element
(iii) The geologic repository operations area shall be designed to include explosion and fire detection alarm systems and appropriate suppression systems with sufficient capacity and capability to reduce the adverse effects of fires and explosions on structures, systems, and components important to safety. (iv) The geologic repository operations area shall be designed to include means to protect systems, structures, and components important to safety against the adverse effects of either the operation or failure of the fire suppression systems. For clarification see: NWTS 33(3), 4.2.1 NWTS 33(3), 4.3.2 10 CFR 60.130(b)(4)(i) 10 CFR 60.130(b)(4)(ii) 10 CFR 60.130(b)(4)(iii) 10 CFR 60.130(b)(4)(iv)		R.1.39 Develop fire and explosion alarm and protection systems for all equipment and facilities within the repository operations area that are required for safe operation of the repository. R.1.40 Determine the reliability and protection required to ensure that safety-related systems operate adequately under adverse or emergency conditions.
60.130(b)(5) (5) Emergency capability. (i) The structures, systems, and components important to safety shall be designed to maintain control of radioactive waste, and permit prompt termination of and evacuation of personnel during an emergency. (ii) The geologic repository operations area shall be designed to include onsite facilities and services that ensure a safe and	None.	R.1.41 Define what requirements are necessary to permit evacuation of personnel under emergency conditions. R.1.42 Determine what facilities, equipment, and services are required to ensure a safe and timely response to any emergency conditions.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 14 of 40)

Technical criteria	Issues	Work element
timely response to emergency conditions and that facilitate the use of available offsite services (such as fire, police, medical, and ambulance service) that may aid in recovery from emergencies. For clarification see: NWTS 33(3), 4.2.1 NWTS 33(3), 4.3.8 10 CFR 60.130(b)(5)(i) 10 CFR 60.130(b)(5)(ii)		
60.130(b)(6) (6) Utility services. (i) Each utility service system shall be designed so that essential safety functions can be performed under both normal and emergency conditions. (ii) The utility services important to safety shall include redundant systems to the extent necessary to maintain, with adequate capacity, the ability to perform their safety functions. (iii) The emergency utility services shall be designed to permit testing of their functional operability and capacity. This will include the full operational sequence of each system when transferring between normal and emergency supply sources, as well as the operation of associated safety systems.	None.	R.1.43 Determine which systems require redundant power supply, uninterrupted service, or standby service in the event of loss of primary power.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 15 of 40)

Technical criteria	Issues	Work element
(iv) Provisions shall be made so that, if there is a loss of the primary electric power source or circuit, reliable and continued emergency power is provided to instruments, utility service systems, and operating systems, including alarm systems. This emergency power shall be sufficient to allow safe conditions to be maintained. All systems important to safety shall be designed to permit them to be maintained at all times in a functional mode. For clarification see: NWTS 33(3), 4.2.1 NWTS 33(3), 4.3.6 10 CFR 60.130(b)(6)(i) 10 CFR 60.130(b)(6)(ii) 10 CFR 60.130(b)(6)(iii) 10 CFR 60.130(b)(6)(iv)		
60.130(b)(7) (7) Inspection, testing, and maintenance. The structures, systems, and components important to safety shall be designed to permit periodic inspection, testing, and maintenance, as necessary, to ensure their continued functioning and readiness. For clarification see: 10 CFR 60.130(b)(7) NWTS 33(3), 4.3.1	None.	R.1.44 Determine which structures, systems, and components are important to safety; develop and implement appropriate inspection, testing, and maintenance programs.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 16 of 40)

Technical criteria	Issues	Work element
60.130(b)(8) (8) Criticality control. All systems for processing, transporting, handling, storage, retrieval, emplacement, and isolation of radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or subsequential changes have occurred in the conditions essential to nuclear criticality safety under normal and accident conditions. The calculated effective multiplication factor (k_m) must be sufficiently below unity to show at least a 5 percent margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation. For clarification see: 10 CFR 60.130(b)(8)	None.	R.1.45 Assess the potential for criticality for the proposed waste packages and storage orientations under fully flooded storage conditions.
60.130(b)(9) (9) Instrumentation and control systems. Instrumentation and control systems shall be designed to monitor and control the behavior of engineered systems important	None.	R.1.46 Determine what instrumentation and control systems are required to monitor and control safety-related systems.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 17 of 40)

Technical criteria	Issues	Work element
to safety over anticipated ranges for normal operation and for accident conditions. The systems shall be designed with sufficient redundancy to ensure that adequate margins of safety are maintained. For clarification see: NWTS 33(3), 4.2.1 10 CFR 60.130(b)(9)		R.1.47 (Related to R.2.5) Develop, as required, instrumentation to measure stresses, deformation, temperature, and pore pressures reliably until backfill is emplaced. R.1.48 (Related to R.1.6.A and R.1.7.A) Develop or adapt instrumentation and monitoring techniques to predict rock bursts.
60.130(b)(10) (10) Compliance with mining regulations. To the extent that the U.S. Department of Energy is not subject to the Federal Mine Safety and Health Act of 1977, as to the construction and operation of the geologic repository operations area, the design of the geologic repository operations area shall nevertheless include such provisions for worker protection as may be necessary to provide reasonable assurance that all structures, systems, and components important to safety can perform their intended functions. Any deviation from relevant design requirements in 30 CFR, Chapter 1, Subchapters D, E, and N will give rise to a rebuttable presumption that this requirement has not been met.	None.	R.1.49 Determine the requirements necessary to assure that safety-related systems provide adequate protection to construction and operations personnel.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 18 of 40)

Technical criteria	Issues	Work element
For clarification see: NWTS 33(3), 4.2.2 NWTS 33(3), 4.3.1 NWTS 33(1), 4.1.2 40 CFR 91		
Additional Design Requirements for Surface Facilities in the Geologic Repository Operations Area. (60.131) (a) Facilities for receipt and retrieval of waste. Surface facilities in the geologic repository operations area shall be designed to allow safe handling and storage of wastes at the site, whether these wastes are on the surface before emplacement or as a result of retrieval from the underground facility. The surface facilities shall be designed so as to permit inspection repair and decontamination of such wastes and their containers. Surface storage capacity is not required for all emplaced waste. For clarification see: NWTS 33(1), 3.3.1 NWTS 33(3), 4.5.4 NWTS 33(3), 4.5.3 NWTS 33(1), 2.5 NWTS 33(3), 3.5 NWTS 33(3), 4.5.1 NWTS 33(3), 4.5.7 10 CFR 60.131(a) NWTS 33(3), 4.5.10.1 NWTS 33(3), 4.5.10.3 NWTS 33(3), 4.5.2 10 CFR 60.71(b)	None.	R.1.50 Determine the requirements and procedures necessary for the safe receipt and surface storage of radioactive wastes.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 19 of 40)

Technical criteria	Issues	Work element
60.131(b) (b) Surface facility ventilation. Surface facility ventilation systems supporting waste transfer, inspection, decontamination, processing, or packaging shall be designed to provide protection against radiation exposures and offsite releases as provided in 60.111.	None.	R.1.51 Determine the ventilation requirements for the surface facilities that will contain radioactive materials.
60.131(c) (c) Radiation control and monitoring: (1) Effluent control. The surface facilities shall be designed to control the release of radioactive materials in effluents during normal and emergency operations. The facilities shall be designed to provide protection against radiation exposures and offsite releases as provided in 60.111. (2) Effluent monitoring. The effluent monitoring systems shall be designed to measure the amount and concentration of radionuclides in any effluent with sufficient precision to determine whether releases conform to the design requirement for effluent control. The monitoring systems shall be designed to include alarms that can be periodically tested.	None.	R.1.52 (Related to R.1.33) Determine what equipment and controls are necessary to measure the amount and concentrations of radionuclides in any effluents from surface facilities with sufficient precision to determine that they conform to statutory release requirements.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 20 of 40)

Technical criteria	Issues	Work element
For clarification see: NWTS 33(3), 4.5 10 CFR 60.131(c)(1) 10 CFR 60.131(c)(2) 10 CFR 60.131(b)		
60.131(d) (d) Waste treatment. Radioactive waste treatment facilities shall be designed to process any radioactive wastes generated at the geologic repository operations area into a form suitable to permit safe disposal at the geologic repository operations area or to permit safe transportation and conversion to a form suitable for disposal at an alternative site in accordance with any regulations that are applicable. (e) Consideration of decommissioning. The surface facility shall be designed to facilitate decommissioning. For clarification see: 10 CFR 60.131(d)	None.	R.1.53 Determine the facilities that are required for the treatment, processing, or packaging of radioactive waste generated at the repository operations area to permit safe disposal or transportation of these wastes. R.1.54 Determine the requirements for design of the surface waste disposal facilities to facilitate decommissioning.
<u>Additional Design Requirements for the Underground Facility</u>. (60.132) (a) General criteria for the underground facility. (1) The underground facility shall be designed so as to perform its safety	None.	R.1.55 (Related to W.1.12.A) Determine that the interaction between the waste package, the underground facilities, and the geologic setting does not compromise the performance of the underground facilities.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 21 of 40)

Technical criteria	Issues	Work element
functions assuming interactions among the geologic setting, the underground facility, and the waste package.		
(2) The underground facility shall be designed to provide for structural stability, control of radionuclide releases, as necessary to comply with the performance objectives of 60.111.		R.1.56 (Related to R.1.18.D, R.1.19.D, and R.1.66). Determine how to control groundwater influx and transit in the repository to maintain radionuclide release from engineered systems within the U.S. Nuclear Regulatory Commission appropriate release standards.
(3) The orientation geometry, layout, and depth of the underground facility, and the design of any engineered barriers that are part of the underground facility shall enhance containment and isolation of radionuclides to the extent practicable at the site. For clarification see: 10 CFR 60.132(a)(3) 10 CFR 60.132(a)(4) 10 CFR 60.123(b)(16)(17)		R.1.57 Provide an appropriate orientation, geometry, waste placement, and layout of the repository to ensure structural stability and containment of radionuclides.
60.132(b) (b) Flexibility of design. The underground facility shall be designed with sufficient flexibility to allow adjustments, where necessary, to accommodate site-specific conditions identified through in situ monitoring, testing, or excavation.	None.	R.1.58 Design the underground facility with sufficient flexibility to allow for adjustments during construction that will accommodate site-specific conditions identified by in situ testing or monitoring.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 22 of 40)

Technical criteria	Issues	Work element
For clarification see: 10 CFR 60.132(b) 10 CFR 60.132(b)(2)		
60.132(c) (c) Separation of excavation and waste emplacement (modular concept). If concurrent excavation and emplacement of wastes are planned, then: (1) The design shall provide for such separation of activities into discrete areas (modules) as may be necessary to assure that excavation does not impair waste emplacement or retrieval operations. For clarification see: 10 CFR 60.132(c)(1)	None.	R.1.59 Define the requirements necessary to allow for the emplacement or retrieval of waste packages during continuous excavation and construction of the repository. R.1.60 (Included in R.1.36) Determine what safety requirements are necessary to isolate waste package storage rooms from other areas in the event that accidents occur.
60.132(d) (d) Design for retrieval of waste. The underground facility shall be designed to: (1) Permit retrieval of waste in accordance with the performance objectives (60.111); (2) Ensure sufficient structural stability of openings and control of groundwater to permit the safe conduct of waste retrieval operations; and	None.	R.1.61 Develop rock support systems that are compatible with decommissioning requirements and that will function satisfactorily in the repository environment for the period of construction, operation, and retrieval (including effects of cooling prior to backfilling or retrieval).

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 23 of 40)

Technical criteria	Issues	Work element
(3) Allow removal of any waste packages that may be damaged or require inspection without compromising the ability of the geologic repository to meet the performance objectives. (60.111) For clarification see: 10 CFR 60.132(d)(3)		
<u>Performance Objectives</u> (60.111(a)(2)) (2) Retrievability of waste. The geologic repository operations area shall be designed so that the entire inventory of waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are complete. A reasonable schedule for retrieval is one that requires no longer than about the same overall period of time than was devoted to the construction of the geologic repository operations area and the emplacement of wastes. For clarification see: NWTS 33(3), 4.5.9 10 CFR 60.111(a)(2)	None.	R.1.62 Define the requirements, equipment, and procedures necessary to retrieve the radioactive waste after emplacement in the repository if retrieval is ultimately required.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 24 of 40)

Technical criteria	Issues	Work element
Additional Design Requirements for the Underground Facility 60.132(g) (g) Control of water and gas. (1) Water and gas control systems shall be designed to be of sufficient capability and capacity to reduce the potentially adverse effects of groundwater intrusion, service water intrusion, or gas inflow into the underground facility. (2) Water and gas control systems shall be designed to control the quantity of water or gas flowing into or from the underground facility, monitor the composition of gases, and permit sampling of liquids. (3) Systems shall be designed to provide control of water and gas in both waste emplacement areas and excavation area. 60.132(g) (4) Water control systems shall be designed to include storage capability and modular layouts that ensure that unexpected inrush or flooding can be controlled and contained.	None.	R.1.63 (Related to R.1.56) Assess the requirements to monitor and provide effective control of groundwater intrusion, service water intrusion, or gas inflow into the repository during construction.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 25 of 40)

Technical criteria	Issues	Work element
(5) If the intersection of aquifers or water-bearing geologic structures is anticipated during construction, the design of the underground facility shall include plans for cutoff or control of water in advance of the excavation. (6) If linings are required, the contact between the lining and the rock surrounding subsurface excavations shall be designed so as to avoid the creation of any preferential pathway for groundwater or radionuclide migration. For clarification see: 10 CFR 60.132(g)(1) 10 CFR 60.132(g)(2) 10 CFR 60.132(g)(3) 10 CFR 60.132(g)(4) 10 CFR 60.132(g)(5) 10 CFR 60.132(g)(6) 10 CFR 60.134(f)		
60.132(h) (h) Subsurface ventilation. The ventilation system shall be designed to: (1) Control the transport of radioactive particulates and gases within and releases from the subsurface facility in accordance with the performance objectives;	None.	R.1.64 Define subsurface ventilation requirements for the control of radioactive particulates and gases within and releases from the subsurface facility.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 26 of 40)

Technical criteria	Issues	Work element
(2) Permit continuous occupancy of all excavated areas during normal operations through the time of permanent closure; (3) Accommodate changes in operating conditions such as variations in temperature and humidity in the underground facility; (4) Include redundant equipment and fail-safe control systems as may be needed to assure continued functions under normal and emergency conditions; and (5) Separate the ventilation of excavation and waste emplacement areas. For clarification see: 10 CFR 60.132(h) NWTS 33(3), 4.3.4 NWTS 33(3), 4.3.3		R.1.65 Define ventilating system requirements during normal operations, including controls to ensure continued operation under emergency conditions.
60.132(i) (i) Engineered barriers. (1) Barriers shall be located where shafts could allow access for groundwater to enter or leave the underground facility. (2) Barriers shall create a waste package environment which favorably controls chemical reactions affecting the performance of the waste package.	None.	R.1.66 Determine functional requirements for selecting locations of repository seals and backfills as engineered barriers to effectively retard groundwater movement and radionuclide migration.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 27 of 40)

Technical criteria	Issues	Work element
(3) Backfill placed in the underground facility shall perform its functions assuming anticipated changes in the geologic setting.		
(ii) Backfill placed in the underground facility shall serve the following functions: (A) It shall provide a barrier to groundwater movement into and from the underground facility. (B) It shall reduce creep deformation of the host rock that may adversely affect (1) waste package performance or (2) the local hydrological system. (C) It shall reduce and control groundwater movement within the underground facility. (D) It shall retard radionuclide migration.		R.1.67 Determine radionuclide sorption requirements for backfill materials to be used for repository rooms and tunnels.
(iii) Backfill placed in the underground facility shall be selected to allow for adequate placement and compaction in underground openings.		
For clarification see: 40 CFR 191 10 CFR 60.132(i)(1) 10 CFR 60.132(i)(2) 10 CFR 60.132(i)(3) 10 CFR 60.132(i)(3)(i) NWTS 33(3), 4.6.1 10 CFR 60.132(i)(3)(ii)		

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 28 of 40)

Technical criteria	Issues	Work element
60.132(j) (j) Waste handling and emplacement. (1) The systems used for handling, transporting, and emplacing radioactive wastes shall be designed to have positive, fail-safe designs to protect workers and to prevent damage to waste packages. (2) The handling systems for emplacement and retrieval operations shall be designed to minimize the potential for operator error. For clarification see: NWTS 33(3), 4.5.5 NWTS 33(1), 2.4 NWTS 33(3), 4.2.8 NWTS 33(1), 3.4.1 10 CFR 60.132(j)(2) Construction Specifications for Surface and Subsurface Facilities (60.134(g)) (g) Waste handling and emplacement. The construction specifications shall provide for demonstration of the effectiveness of handling equipment and systems for emplacement and retrieval operations under operating conditions.	None.	R.1.68 Define the appropriate requirements, equipment, and procedures necessary to handle, emplace, and retrieve the radioactive waste under operating conditions.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 29 of 40)

Technical criteria	Issues	Work element
Design of Shafts and Seals for Shafts and Boreholes (60.133(c)) (c) Shaft conveyances used in radioactive waste handling. (1) Shaft conveyances used to transport radioactive materials shall be designed to satisfy the requirements as set forth in 60.130 for systems, structures, and components important to safety. (2) Hoists important to safety shall be designed to preclude cage free-fall. (3) Hoists important to safety shall be designed with a reliable cage location system. (4) Hoist loading and unloading systems shall be designed with a reliable system of interlocks that will fail safely upon malfunction. (5) Hoists important to safety shall be designed to include two independent indicators to indicate when waste packages are in place, grappled, and ready for transfer. For clarification see: 10 CFR 60.133(c) NWTS 33(3), 4.2.7	None.	R.1.69 (Related to R.1.50) Design hoist and hoist loading systems with sufficient capacity, redundancy, and monitoring systems to ensure that radioactive materials will be handled in a safe and reliable manner.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 30 of 40)

Technical criteria	Issues	Work element
Additional Design Requirements for the Underground Facility (60.132(k))	None.	
(k) Design for thermal loads.		R.1.70
(1) The underground facility shall be designed so that the predicted thermal and thermomechanical response of the rock will not degrade significantly the performance of the repository or the ability of the natural or engineered barriers to retard radionuclide migration.		Determine the coupled effects of stress and elevated temperatures on the permeability of the rock mass.
(2) The design of waste loading and waste spacings shall take into consideration:		
(i) Effects of the design of the underground facility on the thermal and thermomechanical response of the host rock and the groundwater system;		
(ii) Features of the host rock and geologic setting that affect the thermomechanical response of the underground facility and barriers including, but not limited to, behavior and deformational characteristics of the host rock, the presence of insulating layers, aquifers, faults, orientation of bedding planes, and the presence of discontinuities in the host rock; and		R.1.71 Estimate the extent of drying and resaturation of the host rock and backfill as functions of time and distance from the emplaced waste package, and determine the effects of such on the host rock.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 31 of 40)

Technical criteria	Issues	Work element
(iii) The extent to which fracturing of the host rock is influenced by cycles of temperature increase and decrease. For clarification see: NWTS 33(3), 4.4.3 NWTS 33(3), 2.3 10 CFR 60.130(b)(2)		
<u>Construction Specifications for Surface and Subsurface Facilities</u> (60.134) (a) General requirement. Specifications for construction shall conform to the objectives and technical requirements of Sections 60.130 through 60.133. (b) Construction management program. The construction specifications shall facilitate the conduct of a construction management program that will ensure that construction activities do not adversely affect the suitability of the site to isolate the waste or jeopardize the isolation capabilities of the underground facility, boreholes, shaft, and seals, and that the underground facility is constructed as designed. (c) Construction records. The construction specifications shall include requirements for the development of a complete documented history of repository	None.	R.1.72 Prepare procedures that will ensure the development of a complete documented history of repository construction as specified in 60.134(c).

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 32 of 40)

Technical criteria	Issues	Work element
construction. This documented history shall include at least the following: (1) Surveys of underground excavations and shafts located via readily identifiable surface features or monuments; (2) Materials encountered; (3) Geologic maps and geologic cross sections; (4) Locations and amount of seepage; (5) Details of equipment, methods, progress, and sequence of work; (6) Construction problems; (7) Anomalous conditions encountered; (8) Instrumental locations, readings, and analysis; (9) Location and description of structural support systems (10) Location and description of dewatering systems; and (11) Details, methods of emplacement, and location of seals used.		

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 33 of 40)

Technical criteria	Issues	Work element
For clarification see: 10 CFR 60.134(b) 10 CFR 60.131(g) NWTS 33(1), 2.4 NWTS 33(3), 4.3.5		
60.134(e) (e) Control of explosives. If explosives are used, the provisions of 30 CFR 57.6 (Explosives) issued by the Mine Safety and Health Administration, Department of Labor, shall be met, as minimum safety requirements for storage, use, and transport at the geologic repository operations area. For clarification see: NWTS 33(3), 4.2.6 10 CFR 60.134(e)	None.	R.1.73 Prepare specifications for the control of explosives to include the provisions of 30 CFR 57.6.
<u>Training and Certification Program</u> (60.161) The U.S. Department of Energy shall establish a program for training, proficiency testing, certification, and requalification of operating and supervisory personnel. For clarification see: NWTS 33(3), 4.3.7	None.	R.1.74 Define and implement appropriate training, testing, certification, and qualification programs for operating and supervisory personnel.
<u>Effective Resource Utilization</u> The safe disposal and isolation of radioactive wastes shall be achieved in a manner that provides effective utilization of resources. For clarification see: NWTS 33(1), 2.6	None.	R.1.75 Define and implement methods and designs that will minimize resource utilization to the extent compatible with safety and performance requirements.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 34 of 40)

Technical criteria	Issues	Work element
Consideration of Alternatives Alternatives considered in the design of repository components should be evaluated for their beneficial impact on repository performance and for effective use of available economic and natural resources. For clarification see: NWTS 33(1), 2.6	None.	The National Waste Terminal Storage Program is considering basalt, tuff, and salt at several sites as alternatives (see Chapter 19 of this document).
R.2 - Performance Confirmation		
Performance Confirmation Requirements General Requirements for Performance Confirmation (60.137) The geologic repository operations area shall be designed so as to permit implementation of a performance confirmation program that meets the requirements of Subpart F of this part. For clarification see: 10 CFR 60.137 NWTS 33(1), 2.3	None.	R.2.1 Determine which characteristics of the natural and engineered systems need to be measured or monitored for performance confirmation, and establish any required baseline values for those characteristics prior to repository construction.
Subpart F-Performance Confirmation General Requirements (60.140) (a) The performance confirmation program shall ascertain whether: (1) Actual subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the limits assumed in the licensing review; and	None.	R.2.2 Develop a plan for comparing confirmation data and conditions during construction and operation with design data and conditions to determine if significant differerences exist that will require modification to the design or construction method.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 35 of 40)

Technical criteria	Issues	Work element
(2) Natural and engineered systems and components required for repository operations, or which are designed or assumed to operate as barriers after permanent closure are functioning as intended and anticipated.		
(b) The program shall have been started during site characterization and it will continue until permanent closure.		
(c) The program will include in situ monitoring, laboratory and field testing, and in situ experiments, as may be appropriate to accomplish the objective as stated above.		
(d) The confirmation program shall be implemented so that:		R.2.3 (Identical to R.1.11.B)
(1) It does not adversely affect the natural and engineered elements of the geologic repository.		Measure rock strength and deformation characteristics on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.
(2) It provides baseline information and analysis of that information on those parameters and natural processes pertaining to the geologic setting that may be changed by site characterization, construction, and operational activities.		R.2.4 (Identical to R.1.12.B) Measure rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 36 of 40)

Technical criteria	Issues	Work element
(3) It monitors and analyzes changes from the baseline condition of parameters that could affect the performance of a geologic repository. (4) It provides an established plan for feedback and analysis of data, and implementation of appropriate action. For clarification see: NWTS 33(1), 2.3 10 CFR 60.140 NWTS 33(1), 2.7		
<u>Confirmation of Geotechnical and Design Parameters</u> (60.141) (a) During repository construction and operation, a continuing program of surveillance, measurement, testing, and geologic mapping shall be conducted to ensure that geotechnical and design parameters are confirmed and to ensure that appropriate action is taken to inform the U.S. Nuclear Regulatory Commission of changes needed in design to accomodate actual field conditions encountered. (b) Subsurface conditions shall be monitored and evaluated against design assumptions. For clarification see: 10 CFR 60.141(a) 10 CFR 60.141(b)		

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 37 of 40)

Technical criteria	Issues	Work element
60.141(c) (a) During repository construction and operation, a continuing program of surveillance, measurement, testing, and geologic mapping shall be conducted to ensure that geotechnical and design parameters are confirmed and to ensure that appropriate action is taken to inform the U.S. Nuclear Regulatory Commission of changes needed in design to accommodate actual field conditions encountered. (b) Subsurface conditions shall be monitored and evaluated against design assumptions. For clarification see: 10 CFR 60.141(a) 10 CFR 60.141(b)		
60.141(c) (c) As a minimum, measurements shall be made of rock deformations and displacement, changes in rock stress and strain, rate and location of water inflow into subsurface areas, change in groundwater conditions, rock-pore water pressures including those along fractures and joints, and the thermal and thermo-mechanical response of the rock mass as a result of development and operations of the geologic repository. For clarification see: 10 CFR 60.141(c)	None.	R.2.5 (Related to R.1.47) Deploy instrumentation, as required, to reliably measure stresses, deformation, temperature, and pore pressures until backfill is emplaced.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 38 of 40)

Technical criteria	Issues	Work element
60.141(e) (e) In situ monitoring of the thermomechanical response of the underground facility shall be conducted until permanent closure to ensure that the performance of the natural and engineering features are within design limits. For clarification see: 10 CFR 60.141(e) NWTS 33(3), 4.5.8 NWTS 33(3), 4.2.1 NWTS 33(3), 4.4.1 NWTS 33(3), 8.2.1 NWTS 33(3), 4.6.3		
60.141(d) (d) These measurements and observations shall be compared with the original design bases and assumptions. If significant differences exist between the measurements and observations and the original design bases and assumptions, the need for modifications to the design or in construction methods shall be determined and these differences and the recommended changes reported to the U.S. Nuclear Regulatory Commission. For clarification see: 10 CFR 60.141(d)		

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 39 of 40)

Technical criteria	Issues	Work element
Design Testing (60.142) (a) During the early or developmental stages of construction, a program for in situ testing of such features as borehole and shaft seals, backfill, and the thermal interaction effects of the waste packages, backfill, rock, and groundwater shall be conducted. (b) The testing shall be initiated as early as is practicable. For clarification see: 10 CFR 60.142(a)(b) 10 CFR 60.133(b)	None.	R.2.6 Conduct field tests, as required, of borehole plugging to demonstrate that materials and emplacement methods meet requirements.
60.142(c) (c) A backfill test section shall be constructed to test the effectiveness of backfill placement and compaction procedures against design requirements before permanent backfill placement is begun. For clarification see: 10 CFR 60.142(c)	None.	R.2.7 Conduct field tests, as required, of repository room, tunnel, and shaft backfill placement to demonstrate that materials and emplacement methods meet requirements.
60.142(d) (d) Test sections shall be established to test the effectiveness of borehole and shaft seals before full-scale operation proceeds to seal boreholes and shafts.	None.	R.2.8 Conduct field tests, as required, of repository tunnel and shaft seals to demonstrate that materials emplacement methods meet functional requirements.

TABLE 14-4. Criteria, Issues, and Work Elements for Geoengineering and Repository Design. (Sheet 40 of 40)

Technical criteria	Issues	Work element
For clarification see: 10 CFR 60.142(c) 10 CFR 60.142(d)		
<u>Monitoring and Testing Waste Packages (60.143)</u> (a) A program shall be established at the repository for monitoring the condition of the waste packages. Packages chosen for the program shall be representative of those to be emplaced in the repository. (b) Consistent with safe operation of the repository, the environment of the waste packages selected for the waste package monitoring program shall be representative of the emplaced wastes. (c) The waste package monitoring program shall include laboratory experiments which focus on the internal condition of the waste packages. To the extent practical, the environment experienced by the emplaced waste packages within the repository during the waste package monitoring program shall be duplicated in the laboratory experiments. (d) The waste package monitoring program shall continue as long as practical up to the time of permanent closure. For clarification see: NWTS 33(3), 4.5.9 NWTS 33(1), 2.3	None.	R.2.9 Develop, as required, instrumentation, techniques, and procedures for monitoring the integrity of the waste package in situ. R.2.10 Develop a laboratory testing and monitoring program, as required, to evaluate the internal and external condition of representative waste packages subjected to a simulated repository environment.

14.6 SUMMARY

The approach used to define work is a key part of the BWIP technical planning process. The details of the work needed to meet the criteria were presented initially as generalized work elements. These specific work elements are further analyzed to identify in detail the data required and the analysis needed to complete the work element. The detailed description of the work needed to satisfy any specific applicable technical criteria was provided in tabular and narrative form in Section 14.3. These descriptions allow the reader to gain an understanding of the present status and future plans for each item of work proposed. A tabulation of all the criteria, work elements, and issues for repository design and construction and performance confirmation was presented in Section 14.5.

Section 14.2 contained a summary of criteria considered resolved in the BWIP. Where debate or controversy about the available information or technology existed, issues were defined to highlight this fact. The resolution of these issues, as BWIP work progresses, will be highlighted in the BWIP semiannual progress reports.

A logic diagram of the work described in this chapter was presented in Section 14.4. The logic diagram is accompanied by a brief narrative describing each element of the diagram and serves to present the overall and generalized scope of the work described in this chapter in summary form. By consolidating the detailed elements of work into a more concise form, the flow and direction of repository design and construction and performance confirmation activities can be more readily depicted. The logic diagram also identifies points at which the issues presented in this chapter will be resolved. Each narrative accompanying the logic diagram contains a listing of applicable work elements. Although individual test and confirmation activities are for the most part not called out in the logic diagram (Fig. 14-2), the reader can ascertain the depth and scope of the testing and performance confirmation activities by reading the individual status and plan descriptions in Section 14.3.

Finally, Chapter 17 of this document contains schedules for the resolution of the issues presented in Section 14.3, as well as a listing of technical milestones associated with the work described in this chapter. Chapter 17 ties all of the plans for the entire BWIP into one integrated description with schedules and milestones, to provide a capsule summary of the direction and scope of work being planned by the BWIP to complete site characterization activities.

14.7 REFERENCES

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15. WASTE PACKAGE AND SITE GEOCHEMISTRY ISSUES AND PLANS

15.1 INTRODUCTION

This chapter summarizes the results of the investigations presently being conducted and those being planned to resolve issues or data needs identified in Chapter 6 (Site Geochemistry) and Chapter 11 (Waste Package). The subsections chosen for this chapter are (1) waste package design, (2) site geochemistry and testing, and (3) performance confirmation (Fig. 15-1).

The U.S. Nuclear Regulatory Commission (NRC) has designated certain of its proposed criteria as performance objectives in 10 CFR 60 (NRC, 1981). These proposed criteria have been incorporated in the criteria/issues/work elements under waste package design, since they provide the driving mechanism for the design process. These performance criteria also affect the requirement for geochemistry work and, therefore, must be factored into the testing and performance confirmation process used; but their initial and primary impact is on the design process. Another reason for this "organization" is that the release and containment criteria form the bases for the work in waste package and site geochemistry. Dealing with them separately would have led to a set of redundant issues and work elements. The issues from Chapters 6 and 11 that are discussed in Section 15.3 are tabulated in Table 15-1.

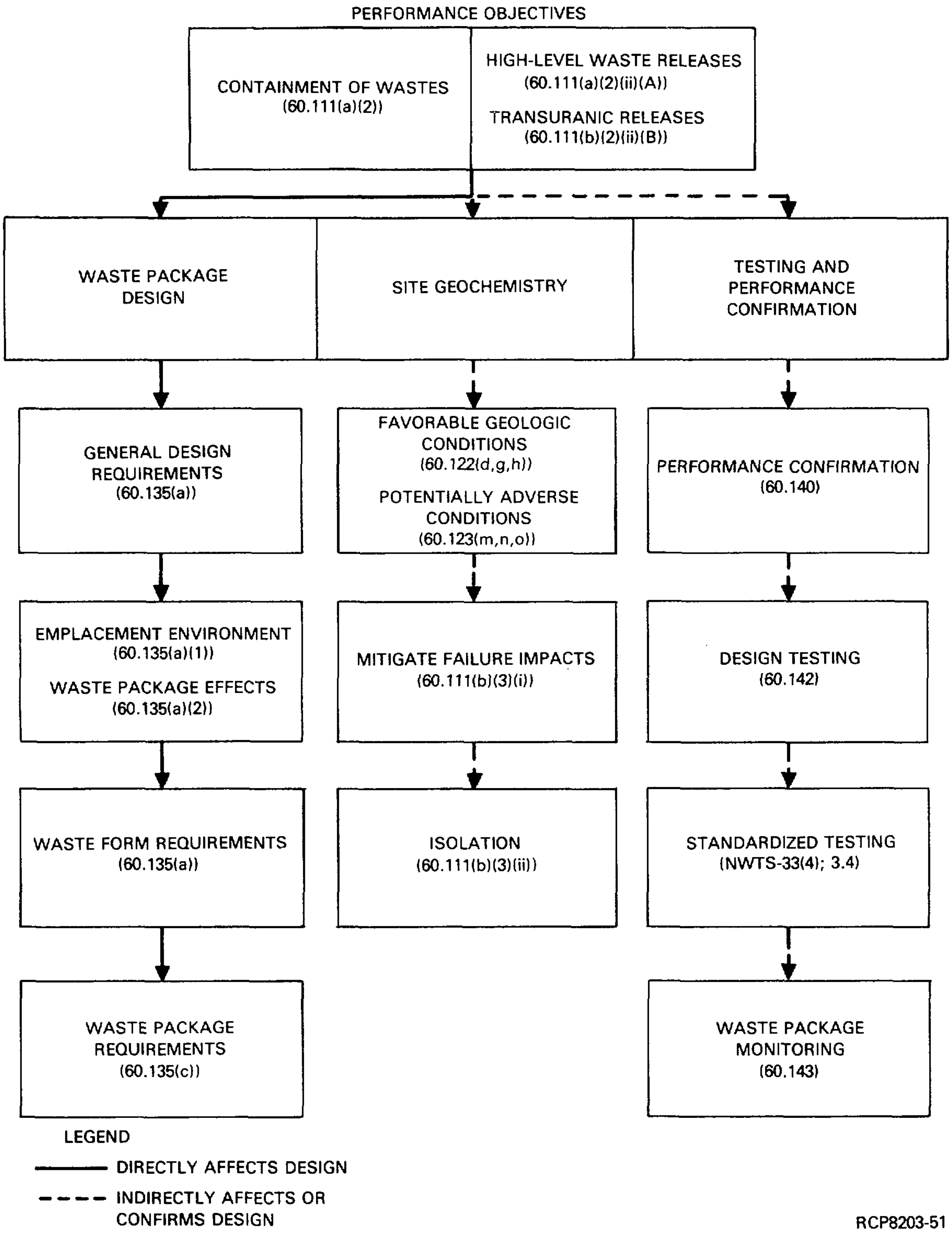

FIGURE 15-1. Key Proposed Criteria Governing Waste Package, Site Geochemistry, and Testing and Performance Confirmation Issues and Work Elements (numbers/words in parentheses relate to 10 CFR 60 (NRC, 1981) and NWTS-33(4) (NWTS, 1981d)).

TABLE 15-1. Issues for Waste Package, Site Geochemistry, and Testing and Performance Confirmation.

Issue	Issue number	Chapter
<u>W.1 - Design</u>		
Does the very near-field interaction between the waste package and its components, the underground facility, and the geologic setting compromise waste package or engineered system performance? (i.e., What is the maximum expected release rate from the engineered system, and does the geologic setting prevent the waste package containment objective from being achieved?)	W.1.A	11
Is a unique borehole backfill required?	W.1.B	11
<u>W.2 - Site Geochemistry</u>		
Are the geochemical and hydrologic properties of the geologic setting (in conjunction with the waste forms) sufficient to meet or exceed U.S. Nuclear Regulatory Commission proposed waste isolation requirements?	W.2.A	6
What is the relative importance of waste form leach rates versus solubility of key radionuclides in the near-field environment for controlling release?	W.2.B	6
Can valid Eh measurements for the candidate repository horizons in the reference repository location be made either by potentiometric measurement or indirectly by measurement of dissolved redox couples?	W.2.C	6
To what degree does the geologic setting retard migration of key radionuclides from the engineered system in meeting U.S. Environmental Protection Agency draft release criteria?	W.2.D	6
<u>W.3 - Testing and Performance Confirmation</u>		
How can very near-field waste/barrier/rock materials interaction data, as measured experimentally, be extrapolated over time to reasonably assure that overall waste package and repository performance meets regulatory criteria?	W.3.A	6,11

15.2 SUMMARY OF CRITERIA FULLY SATISFIED

15.2.1 Issues

The investigations on geochemistry as part of the Hanford Site characterization activities supporting design of waste packages for a nuclear waste repository in basalt were started later than were the other site characterization studies reported in this site characterization report. The waste package studies are in the data gathering and analysis stage in support of gaining an understanding of site geochemistry and the expected interaction of the site with the waste package. The Basalt Waste Isolation Project (BWIP) staff has raised a number of issues in Chapters 6 and 11 that have not been resolved. Although much is known about the geochemistry and waste package interactions of the site, information on issue resolutions, as proposed by the U.S. Nuclear Regulatory Commission will, of necessity, be part of the BWIP semiannual progress reports.

15.2.2 Criteria

The completed investigations into site geochemistry, waste package design, and waste package testing and performance confirmation have led the BWIP toward meeting a number of U.S. Nuclear Regulatory Commission proposed criteria. These proposed criteria are all related to waste package acceptance specifications, are associated with Work Elements W.1.21, W.1.22, W.1.23, W.1.25, and W.1.26, and are discussed in Section 15.3. This will be verified at the time of licensing to demonstrate compliance.

15.3 UNRESOLVED ISSUES AND PLANS FOR THEIR RESOLUTION

This section contains a narrative and tabular analysis of the work needed to meet proposed regulatory criteria. The work element analysis tables summarize the information contained in the narratives. This section is organized into three subsections: (1) Waste Package Design, (2) Site Geochemistry, and (3) Testing and Performance Confirmation. Each subsection is further subdivided by individual issues. The narratives (status and plans) for each issue are presented by work element. A discussion of work elements that are not associated with issues is also included.

15.3.1 Waste Package Design Issues and Work Elements

The analysis of data needs and status of work supporting waste package design issues and work elements are contained in Table 15-2

ISSUE W.1.A

Does the very near-field interaction between the waste package and its components, the underground facility, and the geologic setting compromise waste package or engineered system performance? (i.e., What is the maximum expected release rate from the engineered system, and does the geologic setting prevent the waste package containment objective from being achieved?)

Work Element W.1.1.A (Identical to W.1.18.B) (Priority 2)

Determine the maximum operating temperature limits for waste form, backfill, canister, and host rock.

Status

The operating temperature limits for candidate waste package materials have been estimated from available data. Since conditions under which available data were obtained are not completely representative of the conditions expected in the repository environment, the estimated limits were derived from extrapolations of existing data.

Operating temperature limits for the waste forms are related to the physical integrity of the waste form prior to contact by groundwater and to chemical reactions of the waste form in contact with groundwater after loss of containment by the canister. Prior to contact with groundwater, a temperature limit of 500°C for a borosilicate glass incorporating processed wastes was established to avoid devitrification of the glass.

TABLE 15-2. Work Element Analysis: Data Needs and Status Supporting Waste Package Design Issues and Work Elements. (Sheet 1 of 10)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
W.1.1.A (Identical to W.1.18.B) Determine the maximum operating temperature limits for waste form, backfill, canister, and host rock.	Waste form dissolution in a basalt waste package environment. Backfill dehydration behavior and alteration rates at atmospheric pressure and elevated temperature in the presence and absence of water. Canister materials corrosion rates in the repository environment as a function of temperature. Thermal limitation of host rock for the reference repository configuration.	Determination of limiting thermal conditions for waste package component materials and host rock for waste package design.	Limits tentatively specified for conceptual design based on theoretical application of available data (Anderson, 1982, Section 2.4). Materials testing and thermal stress analyses of host rock and repository configuration initiated.
W.1.2.A (Related to W.1.7.A, includes discussion of W.1.11.A) Determine conditions that affect design of waste packages, including thermal loading, mechanical loading, and chemical environment, during handling, shipment, emplacement, retrieval, and after repository decommissioning.	Temperatures of waste package components. Mechanical loading of waste package components. Groundwater migration rates into waste package. Chemical composition: Eh and pH of groundwater in contact with the waste package components.	Calculational models that are representative of repository and waste package designs.	Estimates have been used in waste package conceptual design and form the basis for waste package design requirements (Anderson, 1982).
W.1.3.A (Identical to W.2.7.A, includes discussion of W.1.8.A) Determine the effect of the waste package radiation environment on near-field geochemistry, waste package, and barrier material performance.	<u>Testing in a Radiation Field</u> • Corrosion rate of canister materials • Physicochemical stability limits of backfill materials • Radiolysis products of Grande Ronde groundwater • Dissolution mechanism and dissolution rate of waste forms.	Testing for the effect of radiation on stability and degradation rates of barrier materials will be achieved by two methods: (1) Imposition of a radiation field on standard canister and backfill testing apparatus (2) Inclusion of barrier materials including cladding, with radioactive waste forms <u>inside</u> hydrothermal autoclaves of a hot-cell facility.	 Preliminary investigations are in progress. Preliminary investigations are in progress.

TABLE 15-2. Work Element Analysis: Data Needs and Status Supporting Waste Package Design Issues and Work Elements. (Sheet 2 of 10)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
		The latter method will ultimately be preferable, as it can better duplicate expected repository conditions, including the correct spectrum of radioactive decay energies.	
W.1.4.A (Identical to W.2.5.A and W.2.9.B, see W.1.12.A) Determine the projected solubilities, kinetic behavior, and distribution of aqueous species for key radionuclides which might be released from the waste package.	<u>Key Radionuclide Solubilities</u> • Steady-state solution compositions and phase assemblages	Determine key radionuclide solubilities and identify steady-state solid phases present or formed in representative basalt groundwaters under the range of environmental conditions expected for the repository: (T = 60° to 300°C, oxidizing-reducing conditions, pH 6 to 10). Also see W.1.12.A and W.3.7.	Estimates of actinide solubilities under expected repository conditions have been made, based on available thermodynamic data (Wood, 1980; Rai et al., 1981; Sections 6.3, 6.4.1, and 11.3.2). No applicable measured radionuclide solubilities are available.
	• Dissolution/precipitation reaction kinetics for waste form and waste package materials	Evaluate the kinetics of the radionuclide dissolution-precipitation reactions under conditions expected for the repository. Also see W.1.12.A and W.3.7.	Preliminary investigations are in progress.
	• Identification of radionuclide speciation in groundwater.	See W.1.10.A for details.	See W.1.10.A for details.
W.1.5.A (Identical to W.2.2.A) Determine the extent of Eh-pH and groundwater compositional control by the host basalt after repository closure.	<u>Groundwater/Solution Chemistry</u> • pH, Eh • Chemical composition.	(1) In situ data from drill holes (2) Experimental data from autoclave tests	(1)(a) Groundwater chemistry data (including pH) available (Gephart et al., 1979, Chapter III). (b) Preliminary Eh estimates available (Jacobs and Apted, 1981).
		(3) Time-dependent compositional data from hydrothermal basalt-groundwater experiments at elevated temperature and pressure.	(2) Preliminary data only (Wood et al., 1982).

TABLE 15-2. Work Element Analysis: Data Needs and Status Supporting Waste Package Design Issues and Work Elements. (Sheet 3 of 10)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	Mineralogy		
	• Mineral assemblages • Mineral chemistry • Basalt glass-phase chemistry.	(1) In situ data from drill holes. (2) Time-dependent compositional data from hydrothermal basalt-groundwater experiments at elevated temperature and pressure.	Mineralogical data from drill holes available (Myers and Price, 1981). No adequate data on glass-phase chemistry available.
W.1.6.A (Includes discussion of W.1.11.A, see also W.2.2.A) Determine the susceptibility of candidate canister materials to degradation (i.e., corrosion, hydriding, fatigue, etc.) in the repository near-field environment.	Screening Tests (Semi-Quantitative) Uniform corrosion rates (millimeters per year).	Select materials and complete corrosion screening tests at $250^{\circ}C$, 300 bars in simulated Grande Ronde groundwater at repository Eh and pH conditions.	Literature search completed (Smith et al., 1980, Section 2.7; Westerman, 1980). Corrosion screening tests of candidate materials initiated (Section 11.2.5).
	Advanced Tests (Quantitative) • Uniform corrosion rates (millimeters per year)	Narrow the number of candidate materials to two or three and conduct quantitative tests at temperatures ranging from 100° to $300^{\circ}C$, 300 bars in simulated Grande Ronde groundwater over the range of Eh and pH expected in the repository (including radiation effects).	Preliminary investigations are in progress.
	• Nonuniform corrosion susceptibility: Pitting corrosion Crevice corrosion Intergranular corrosion Stress corrosion	Same as above.	Preliminary investigations are in progress.
	• Environmental (hydrogen) embrittlement: Crack initiation and propagation rate	Same as above.	Preliminary investigations are in progress.
	• Materials interactions (assemblage tests):		

TABLE 15-2. Work Element Analysis: Data Needs and Status Supporting Waste Package Design Issues and Work Elements. (Sheet 4 of 10)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	Uniform corrosion.	Test the selected canister material in the presence of simulated and actual waste forms and backfill (which includes crushed basalt) at temperatures ranging from 100° to 300°C, 300 bars in simulated Grande Ronde groundwater over the range of Eh and pH expected in the repository.	Preliminary investigations are in progress.
	Nonuniform corrosion (see list above).	Same as above.	Preliminary investigations are in progress.
W.1.7.A (Related to W.1.2.A) Determine design properties, including thermal, physical, mechanical, and chemical, for waste package component materials and host rock.	Waste form reaction with groundwater in the presence of backfill and host rock.	Determine expected radionuclide release rate from waste form.	Estimated properties used for waste package conceptual design (Anderson, 1982) are included in design requirements.
	• Backfill properties: Thermal conductivity Hydraulic conductivity Effective diffusivity Swelling pressure Reaction with groundwater in the presence of waste form and host rock Reaction with radionuclides released from the waste form.	Select and specify backfill material with optimum combination of properties.	
	• Canister: Corrosion rate in groundwater.	Provide corrosion allowance for use in waste package design.	
W.1.8.A (Included in W.1.3.A) Determine the effect of radiation on the performance of the waste form, backfill, and near-field host rock.	Information needs included in W.1.3.A.	Measurement conditions included in W.1.3.A.	Status included in W.1.3.A.
W.1.9.A (Included in W.1.12.A) Determine the release rate (performance) of candidate waste forms in the repository near-field environment.	Information needs included in W.1.12.A.	Measurement conditions included in W.1.12.A.	Status included in W.1.12.A.

TABLE 15-2. Work Element Analysis: Data Needs and Status Supporting Waste Package Design Issues and Work Elements. (Sheet 5 of 10)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
W.1.10.A (Identical to W.2.6.A) Determine the formation and stability of radionuclide complexes and/or colloids over expected repository near-field and far-field conditions.	Key radionuclide speciation in groundwater.	Determine effect of complexing ligands present in representative basalt groundwater or radionuclide solubility and sorption behavior over the temperature range (60° to 300°C), the Eh range (oxidizing-reducing), and the pH range (6 to 10) expected for the repository. Identify key radionuclide species in representative basalt groundwaters over the expected range of environmental conditions.	Preliminary data indicate that OH^-, HCO_3^{-2} and CO_3^{-2} are the dominant complexing ligands in the basalt system (Sections 6.4.1 and 6.4.2) (Barney and Wood, 1980; Salter et al., 1981a; 1981b). Experiments to determine the effect of complexation on radionuclide behavior in the basalt system are in progress. Preliminary investigations are in progress to define radionuclide species in representative basalt groundwaters; estimates are being made from available thermodynamic data and by inference from available applicable sorption data.
	Key radionuclide colloid formation and stability in groundwater.	Determine, in representative basalt groundwaters, the effect of colloid formation on the solubility and transport of radionuclides in the basalt geohydrologic system over the range of temperature, pH, Eh, and radiation conditions expected for the repository.	Preliminary investigations are in progress.
W.1.11.A (Included in W.1.2.A and W.1.6.A) Determine the chemical properties and inflow rate of groundwater and their effect on canister corrosion during the 1,000-year containment period.	Information needs included in W.1.2.A and W.1.6.A.	Measurement conditions included in W.1.2.A and W.1.6.A.	Status included in W.1.2.A and W.1.6.A.
W.1.12.A (Identical to W.2.3.A and W.1.19.B, includes discussion of W.1.9.A) Determine the extent to which the interaction between the canister materials, waste form, backfill, and host rock in a saturated environment results in retardation of radionuclides.	<u>Testing with Simulated Waste Forms</u> (a) Canister corrosion rates. (b) Physicochemical stability of backfills. (c) Dissolution mechanisms and rates of waste forms and cladding.	Hydrothermal-interaction studies of barrier materials are to be carried out with controlled experimental parameters over the relevant range of repository conditions (see W.2.4.A and W.2.11). Near-field repository conditions will be buffered by hydrothermal reactions of the barrier materials themselves with groundwater. The	Hydrothermal testing of simple binary and complex mixtures of waste-package components with and without the presence of host rock has been initiated to determine whether interaction of components detrimentally affects the release of radionuclides in a repository environment.

TABLE 15-2. Work Element Analysis: Data Needs and Status Supporting Waste Package Design Issues and Work Elements. (Sheet 6 of 10)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	(d) Steady-state solution chemistry. (e) Radionuclide concentrations in groundwater. (f) Interactive or synergistic effects of multiple barriers. (g) Mineralogical and chemical characterizations of alteration phases for basalt, backfill, and waste forms. (h) Rates of chemical reactions. (i) Radionuclide sorption coefficients. For a discussion of the use of nonradioactive analogues, see W.3.7.	temperature dependence on the type and rates of reactions are the most crucial experimental parameters. Temperatures should range between 100° and 300°C, with a total pressure of 300 bars (corresponding to full lithostatic pressure). Periodic sampling of groundwater solutions at the pressure and temperature of the test is crucial in determining the rate of approach to steady-state solution composition and, hence, long-term radionuclide release rates (see W.2.8.A, W.2.12.D, and W.3.7).	References are in the same order as the information needs: (a) Anderson (1981); Westerman (1980). (b) Preliminary investigations are in progress. (c) Holloway et al. (1981); Apted (1981). (d) Holloway et al. (1981); Apted (1981). (e) Holloway et al. (1981); Rai and Strickert (1980). (f) Preliminary investigations are in progress. (g) Holloway et al. (1981); Apted (1981). (h) Preliminary investigations are in progress. (i) Salter et al. (1981a; 1981b); Barney (1981a, 1981b).
	<u>Testing with Tracer-Doped and/or Fully Loaded Forms</u> (Similar to W.1.3.A) (a) Canister corrosion rates (b) Physicochemical stability of backfills (c) Dissolution mechanisms and rates of waste forms (d) Steady-state solution chemistry (e) Radionuclide concentration in groundwater	Same as for testing with simulated waste forms, with the inclusion of radiation effects arising from presence of actual radioactive waste.	Preliminary investigations are in progress; feasibility study for hot-cell testing in progress.

TABLE 15-2. Work Element Analysis: Data Needs and Status Supporting Waste Package Design Issues and Work Elements. (Sheet 7 of 10)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	(f) Mineralogical and chemical characterization of alteration phases for basalt, backfill, and waste forms (g) Rates of chemical reactions (h) Interactive or synergistic effects of multiple barriers (i) Effect of radiation on hydrothermal reactions.		
W.1.13.B Assess the impact of waste storage in a borehole with no backfill on waste containment and isolation.	See narrative for W.1.13.B. Information needs are contained in W.1.8.A, W.1.14.B, W.1.15.B, and W.1.16.B.	Measurement conditions are contained in W.1.8.A, W.1.14.B, W.1.15.B, and W.1.16.B.	Preliminary investigations are in progress.
W.1.14.B Determine the need for special tailoring agents in backfill to moderate the corrosivity (Eh and pH) of the groundwater contacting the canister.	Experimental groundwater solution compositions and radionuclide release rates from hydrothermal tests in the basalt/water and bentonite/water system. Solubilities of key radionuclides in and near the waste package.	Use of simulated Grande Ronde groundwater and reference basalt as starting materials. Hydrothermal tests conducted from 150° to 300°C at 300 bars. In situ experimental measurement of Eh and pH.	Hydrothermal tests in the basalt/groundwater system completed at 200° and 300°C (Wood et al., 1982). Preliminary investigations are in progress.
W.1.15.B (See also W.1.16.B) Define the characteristics of the backfill materials required to retard the flow of groundwater to the canister. Identify potential backfill materials with these characteristics.	Permeability and swelling pressure of backfill mixture (mixtures of basalt and other materials, primarily bentonite).	Measure these properties as a function of temperature, density, backfill composition, moisture content, and grain size.	Preliminary investigations are in progress.
W.1.16.B Define the characteristics of the backfill material required to reduce the rate of radionuclide release from the waste package. Identify backfill materials with these characteristics.	Permeability and swelling pressure (see W.1.15.B). Thermal stability of potential backfill materials (primarily basalt and bentonite) by means of periodic measurement of solution samples and analytical scanning transmission electron	 Complete hydrothermal rocking-autoclave experiments in the temperature range 150° to 300°C, 300 bars. Use reference crushed basalt and simulated groundwater.	 Wood et al. (1982).

TABLE 15-2. Work Element Analysis: Data Needs and Status Supporting Waste Package Design Issues and Work Elements. (Sheet 8 of 10)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	microscopy, X-ray diffraction, and scanning electron microscope analysis of solids.	Complete long-term (6-month) cold seal experiments under the same conditions as above.	Preliminary investigations are in progress (Koster van Groos, 1981).
		Complete dehydration experiments at 200° and 500°C.	Preliminary data on sorption and precipitation of radionuclides in presence of clays obtained. Salter et al. (1981a; 1981b).
	Sorption (distribution coefficients) and precipitation (solubilities) of hazardous radionuclides through measurement at expected solution concentrations of radionuclides.	Complete experiments at 65° to 150°C under oxic and anoxic conditions. Use simulated groundwater.	
	Radionuclide transport rates through backfill material.	Complete flow-through experiments at 65° to 150°C using simulated groundwater.	Preliminary investigations are in progress.
W.1.17.B (Identical to W.1.8.A, included in W.1.3.A) Determine the effect of radiation damage on the performance of the waste form, backfill, and host rock.	Information needs identical to W.1.8.A and included in W.1.3.A.	Measurement conditions identical to W.1.8.A and included in W.1.3.A.	Status identical to W.1.8.A and included in W.1.3.A.
W.1.18.B (Identical to W.1.1.A) Determine the maximum operating temperature limits for waste form, backfill, canister, and host rock.	Information needs identical to W.1.1.A.	Measurement conditions identical to W.1.1.A.	Status identical to W.1.1.A.
W.1.19.B (Identical to W.1.12.A and W.2.3.A) Determine the extent to which the interaction between the canister material, waste form, backfill, and host rock in a saturated environment results in retardation of radionuclides.	Information needs identical to W.1.12.A and W.2.3.A.	Measurement conditions identical to W.1.12.A and W.2.3.A.	Status identical to W.1.12.A and W.2.3.A.

TABLE 15-2. Work Element Analysis: Data Needs and Status Supporting Waste Package Design Issues and Work Elements. (Sheet 9 of 10)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
W.1.20.B (Included in W.2.13.D) Determine if a waste package backfill is required to provide acceptable containment in the event of premature canister failure.	*Information needs included in W.2.13.D.*	*Measurement conditions included in W.2.13.D.*	*Status included in W.2.13.D.*
WORK ELEMENTS NOT RELATED TO ISSUES			
W.1.21 Develop waste package acceptance specifications for waste solidification that meet U.S. Nuclear Regulatory Commission proposed requirements.	Reference waste form physical and chemical characteristics and performance of the waste form under repository conditions. Final waste package design documents will contain a specification for waste performance characteristics that will include acceptance criteria.	Not applicable.	Present high-level waste and transuranic reference waste forms are in solid form (Anderson, 1982, Section 2.1.2.1).
W.1.22 Develop waste package acceptance specifications for consolidation that meet U.S. Nuclear Regulatory Commission proposed requirements.	An assessment of the need for consolidation of transuranic oxide will be performed for the updated conceptual design of a nuclear waste repository in basalt. Consolidation techniques for transuranic oxides will be developed if required.	Not applicable.	Present reference waste forms for high-level waste in a nuclear waste repository in basalt include reprocessed waste (glass) and spent fuel, if declared waste. The consolidation requirements for solidified, contaminated, inorganic oxides (from incineration), the reference transuranic waste form, have not yet been determined.
W.1.23 Develop waste package acceptance specifications for combustibles that meet U.S. Nuclear Regulatory Commission proposed requirements.	None presently needed. Final waste package design documents will contain a specification for combustibles if required.	Not applicable.	Present reference high-level waste and transuranic waste forms are noncombustible (Anderson, 1982, Section 2.1.2.1).
W.1.24 Determine the impact of the reprocessing technique (including waste fractionization) on waste package design.	None at present. If further analysis indicates that migration of key radionuclides cannot be controlled by either the engineered or natural system, then a trade-off study on alternatives for control of that isotope will be needed.	Not applicable.	Present studies of waste form (and content) compatibility with a nuclear waste repository in basalt indicate that all isotopes expected to be contained in either spent fuel, transuranic, or reprocessed commercial or defense waste solidified as a glass will be contained

TABLE 15-2. Work Element Analysis: Data Needs and Status Supporting Waste Package Design Issues and Work Elements. (Sheet 10 of 10)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
			by the engineered and natural systems to within current proposed regulatory limits (Section 11.3.2.4).
W.1.25 Develop waste package acceptance specifications for explosive, pyrophoric, and chemically reactive materials that meet U.S. Nuclear Regulatory Commission proposed requirements.	None presently needed. Final waste package design documents will contain a specification that excludes explosive, pyrophoric, and chemically reactive waste materials from the repository.	Not applicable.	Present reference high-level waste and transuranic waste forms are nonexplosive, nonpyrophoric, and chemically inert over expected and abnormal repository conditions (Anderson, 1982, Section 2.1.2.1).
W.1.26 Develop waste package acceptance specifications for free liquids that meet U.S. Nuclear Regulatory Commission proposed requirements.	None presently needed. Final waste package design documents will contain a specification that excludes liquid wastes.	Not applicable.	Present reference high-level waste and transuranic waste forms are solids. There are no plans to accept liquid waste (Anderson, 1982, Section 2.1.2.1).
W.1.27 Determine the waste package handling, shipping (including drop tests), emplacement, and retrievability requirements.	None presently needed. Final repository design documents will contain specifications for these items.	Not applicable.	The BWIP repository conceptual-design documents provide information on waste package receipt, handling, and retrieval. Shipment of waste packages to the repository will comply with existing U.S Department of Transportation regulations. Present BWIP requirements for the contained waste assembly stipulate a 7.3-meter (24-foot) drop test, and fail-safe handling requirements (Anderson, 1982, Section 2.5.2).
W.1.28 Develop waste package acceptance specifications for identification that meet U.S. Nuclear Regulatory Commission proposed requirements.	Waste identification specifications will be defined in final waste package design documents.	Not applicable.	Preliminary investigations are in progress.

A temperature limit of 380°C was established for spent fuel to avoid fuel-rod cladding rupture (Anderson, 1982, Section 2.4). Intact cladding in contact with repository groundwater during the postcontainment period would also be expected to maintain its long-term integrity. These premises will be verified. After loss of containment by the canister and contact with groundwater, the relationship between chemical reactions of the groundwater (dissolution rates, solubility of radionuclides) must be accounted for in waste package design, so the waste package system meets the release rate requirements for the engineered system (waste package and repository). Data required for accurate definition of waste form material properties and limits are not available at the present for a repository in basalt. A materials development test program has been planned and work has been initiated to obtain the required data.

The operating temperature limit of the waste package is constrained by the physical and chemical properties of the backfill. A temperature limit of 300°C for a backfill containing sodium bentonite was selected on the basis of data indicating that higher temperatures could result in loss of structural water (hydroxyl groups) at atmospheric pressure (Anderson, 1982, Section 2.4). The loss of structural water would cause the bentonite to irreversibly alter to a mica with a resultant increase in permeability. Useful performance of the bentonite-containing waste package backfill is dependent on a low permeability of the material. In present waste package concepts, the maximum backfill temperature appears to be a potential limiting thermal specification. Materials tests have been planned and initiated that will provide data that are directly applicable to backfill materials in a repository in basalt.

An operating temperature limit for canister/overpack materials is related to structural properties of the materials selected and the ability to define the corrosion behavior of the materials. The temperature limit for structural properties was established and permits evaluation by elastic analysis using short-term tensile properties. The basis for establishing the temperature limit at 430°C (800°F) is contained in ASME (1980). The temperature limit for accurate definition of corrosion behavior of the materials is currently defined by the maximum temperature used in corrosion tests. It is planned that the maximum test temperature used in development tests will exceed expected corrosion temperatures during repository service.

The temperature limits for the host rock of a repository in basalt do not appear to be limiting factors in waste package designs using a bentonite-containing backfill. A design limit of 500°C for "dry" rock was initially specified to avoid decrepitation of the intact basalt blocks in the formation. Subsequent calculations performed in support of repository design indicate that rock stresses produced by transient thermal gradients, instead of a maximum rock temperature, may limit thermal loading. Additional limiting criteria will be established in the course of repository design efforts. Hydrothermal tests that have been planned or just initiated are expected to reveal the occurrence of chemical reactions between the waste form/backfill and the host rock that could reduce waste package performance at high temperatures.

Plans

A materials development and test program will be completed that resolves the waste package materials performance limits, including maximum temperature, for use in waste package design and performance assessment. Results from waste/rock/barrier interaction hydrothermal tests will provide data on chemical interactions between waste package components and groundwater in the repository environment and their effects on performance limits of the materials. Results from hydrothermal tests of backfill/buffer materials will provide data that will define the materials performance throughout the range of expected environmental conditions and will identify any limiting environmental conditions that prevent the backfill/buffer from performing its assigned function. Results from corrosion testing of canister/overpack materials will provide data that form the basis for materials selection and that establish the appropriate corrosion allowance for waste package design.

Work Element W.1.2.A (Related to W.1.7.A, includes discussion of W.1.11.A) (Priority 1)

Determine conditions that affect design of waste packages, including thermal loading, mechanical loading, and chemical environment, during handling, shipment, emplacement, retrieval, and after repository decommissioning.

Status

The conditions currently affecting design of the waste packages were estimated using simple analyses of selected models for repository and waste package concepts. Temperature effects have been discussed in W.1.1.A. The key factor in defining waste package design is the time required for groundwater migration into the repository and waste packages. Much of the data used for the analyses were derived from theoretical extrapolation of hydrologic and materials data. These conditions are being used for waste package conceptual design. In the course of preliminary waste package and repository design, more detailed models and more rigorous analyses will be used to define the conditions affecting waste package design. Directly applicable data will be obtained from planned development testing, which will be used in conjunction with the models to define the limiting conditions affecting waste package design. The conditions affecting design of waste packages will be updated and input into the preliminary and final waste package design.

Plans

Thermal hydraulic models of the waste package, repository, and host rock will be used to estimate the time for migration of groundwater around and into the waste package. The results will depend on the specific repository and waste package designs selected, so the evaluations will be updated for the conceptual, preliminary, and final design phases.

Work Element W.1.3.A (Identical to W.2.7.A, includes discussion of W.1.8.A) (Priority 2)

Determine the effect of the waste package radiation environment on near-field geochemistry, waste package, and barrier material performance.

Status

At the low neutron flux levels associated with nuclear waste, measurable neutron-induced radiation effects on barrier materials are not expected to occur during the period of isolation in the repository. Hence, the major concern in evaluating candidate barrier materials, including the host rock, is the effect of the gamma radiation. Incidental radiation can affect the stability of barrier materials by affecting changes in (1) bulk physical structure, (2) any protective layer, and/or (3) chemistry of the intruding groundwater. During the containment period, alpha and beta radiation will not penetrate the canister (to the surrounding media). The possibility of effects of alpha radiation on groundwater after containment is assumed lost will be evaluated. Researchers have concluded that gamma radiation principally affects the groundwater and does so by producing chemical changes (radiolysis) through excitation and ionization processes (Stobbs and Swallow, 1962; Byalobzheskii, 1970; Wu, 1978). The primary radiolysis process in aqueous solutions is the decomposition of water to form short-lived radicals (e_{aq}, H^+, OH^-, HO_2^-) and the longer-lived molecular products, H_2 and H_2O_2. If, in some manner, the radiolytic hydrogen is continuously removed from the system, the oxidation potential (Eh) of the solution could increase and remain high. This increase in Eh would be generally deleterious to the stability of canister materials and could also lead to an increase in solution concentrations (and, hence, release rates) of multivalent radionuclides.

Conversely, it can be hypothesized that, in a sealed and decommissioned repository constructed in basalt, where highly reducing conditions (e.g., low Eh) are expected to be imposed by the host rock (Jacobs and Apted, 1981), a high-hydrogen fugacity will tend to suppress the deleterious effects of radiolysis reaction on Eh. Thus, the corrosiveness and solution properties of any intruding groundwater may be unaffected or minimally affected by radiation.

Radiation effects on candidate backfill materials are not well understood at this time, but should not affect the important functional characteristics (e.g., a chemical physical barrier to water and radionuclide transport) (Friedlander et al., 1964). This, however, should be verified through testing in a high-intensity gamma field. The aspect of related testing of radioactive waste forms is addressed separately in Work Element W.3.4.A.

Plans

Tests to determine the effects of intense gamma radiation on waste package materials are planned. For the candidate canister/overpack materials, a corrosion test previously conducted on candidate materials at elevated temperatures and under reducing conditions will be repeated by locating the autoclave in a high-intensity gamma field during the test. At present, only one test of this type has been planned; it will be used to verify the hypothesis of radiolytic suppression of deleterious radiation effects. Should the corrosion rates increase in the test, however, further testing in a radiation field will be required to identify the mechanism(s) causing the accelerated corrosion. A similar test will be conducted to determine the effect of radiation on buffer materials, including crushed basalt.

Measuring the effects of radiation on barrier materials will also be included in hydrothermal testing on radioactive waste forms, including waste package materials and the repository host rock. These testing activities must be conducted in a laboratory and must use actual waste forms. Hot-cell testing is expected to begin by the end of fiscal year 1983. Solution chemistry measurements during the tests and postexperimental examination of reaction products will be used to determine if radiation could be responsible for any observed changes in the performance of waste package component materials.

Work Element W.1.4.A (Identical to W.2.5.A and W.2.9.B; see W.1.12.A) (Priority 1)

Determine the projected solubilities, kinetic behavior, and distribution of aqueous species for key radionuclides which might be released from the waste package.

Status

Solubility data are more useful than leach rate data in predictive modeling of radionuclide release from a waste package in basalt. Leach rate data define the rate at which material goes into solution. Leach rate data are often erroneously assumed to be fixed for a given solid phase (e.g., waste form). Leach rates are not fixed for each solid phase, because they are dependent on temperature, pressure, pH, Eh, solution chemistry, and available surface area, as well as contact time and water-flow rate. The effect of these parameters on leach rates is different for each radionuclide and/or waste form, although in general there is an increase in leach rates with increasing temperature. As a result, there is considerable difficulty in extrapolating leach rate data over the long times and range of environmental conditions required for a safety assessment of a repository. The dissolution behavior of a solid, as a function of time, is shown in Figure 15-2. Leach rates are represented by tangents to the solution concentration versus time curve. Until steady-state is reached, leach rates will vary considerably with time. For example, if the leach rate for a radionuclide is derived from data obtained over a limited period of time and is then extrapolated to a much longer time period, the calculated solution concentration for that radionuclide can

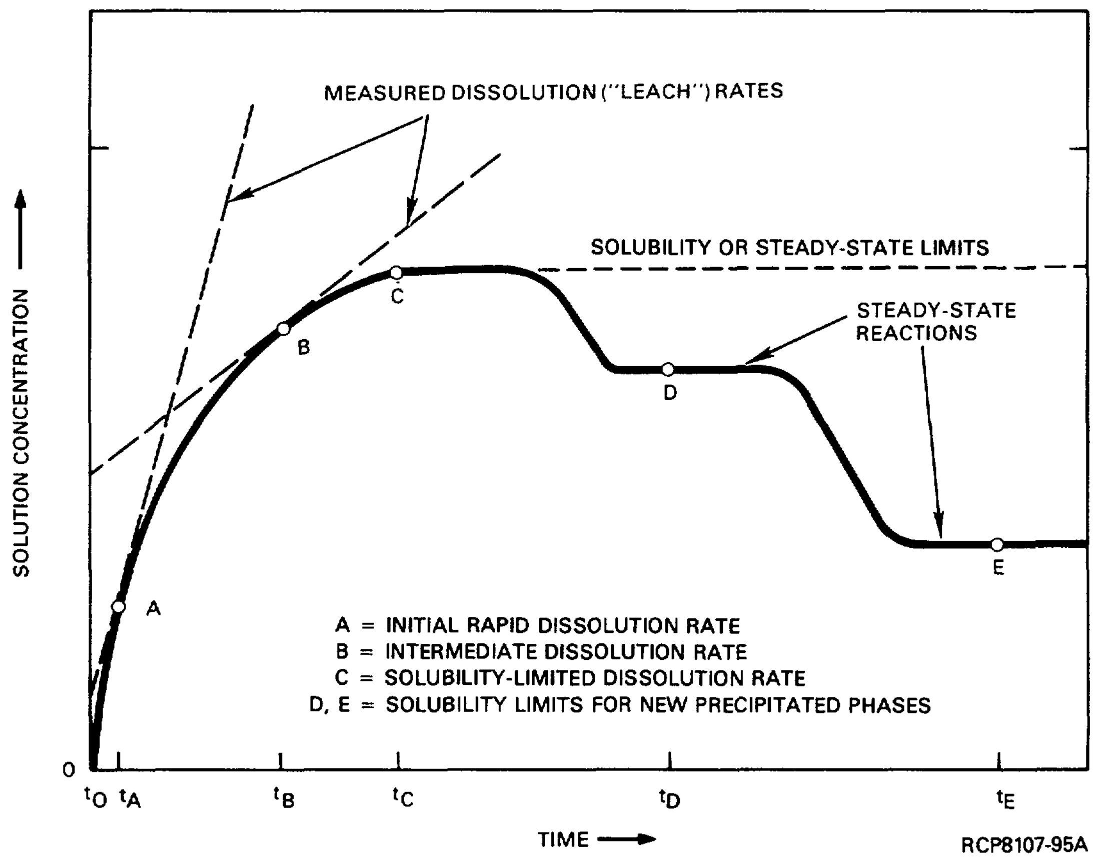

FIGURE 15-2. Solid Dissolution Behavior as a Function of Time.

be erroneously high. However, as solubility limits for dissolving/precipitating phases are approached, the solution concentration of that radionuclide will reach a steady-state condition, representing a balance between the rates of dissolution and precipitation of phases containing that radionuclide (see Work Element W.3.5).

Solubilities of solid phases, unlike leach rates, are independent of time and water flow rate. For a given chemical component (radionuclide), its solubility is fixed by the most soluble mineral phase containing that component in the geochemical system. The solubility controlled solution concentration of this radionuclide is, therefore, time invariant as long as a new radionuclide-bearing phase does not precipitate. Thermodynamic principles dictate that under constant conditions minerals change with time to those with lower free energy (i.e., greater stability, hence, lower solubility) in that system. Radionuclide solubilities, therefore, can provide the maximum possible solution concentrations for the radionuclides for a specific set of environmental conditions. For these reasons, solubility data for many radionuclide-bearing phases, although still dependent on environmental conditions, can be more useful in determining long-term radionuclide release rates than can leach rate data. However, for those radionuclides that may be solubility controlled

at concentration levels above those permissible by current regulatory criteria (e.g., cesium, selenium, technetium, iodine, etc.), waste form dissolution rate data (leach rate data) may be useful for evaluating radionuclide release from the repository. These waste form dissolution rates are being determined by long-term static experiments and/or low-flow rate (comparable to that observed in basalt) dynamic experiments under the conditions expected for the basalt environment. Thus, for those radionuclide-bearing phases with very low solubilities in the basalt environment, maximum release rates should be established by solubility data; for those radionuclides with higher solubility-controlled solution concentrations in the basalt environment, release rates may be controlled by the dissolution rate of the waste form (leach rate).

The solubility of a radionuclide-bearing phase is dependent on the environmental conditions (Eh, pH, temperature, etc.) of the geohydrologic system. Generally, a strongly reducing environment, such as is present in the basalt environment, results in lower solubilities (by as much as 6 to 8 orders of magnitude) for radionuclide-bearing phases than does an oxidizing environment. Slightly alkaline (high pH) groundwater, such as Grande Ronde groundwater, also generally leads to lower solubilities for radionuclide-bearing phases. Increasing temperature can result in an increase in solubilities, although the degree of sensitivity to temperature is different for different radionuclides. For instance, predicted uranium solubilities show little significant temperature dependence in the basalt environment (Wood, 1980).

Limited solubility data are available for phases containing uranium, plutonium, neptunium, and americium, and these data have been extrapolated to the basalt environmental conditions (see Sections 11.3.2 and 6.4; Wood, 1980; Rai et al., 1981). The available solubility estimates indicate that the release of these radionuclides should be solubility controlled under ambient repository conditions, although this has yet to be confirmed experimentally. Other important radionuclides that may have solubility-limited release rates are ^{229}Th, ^{230}Th, ^{231}Pa, ^{79}Se, ^{93}Zr, ^{107}Pd, ^{126}Sn, ^{151}Sm, and $^{243-246}Cm$. However, insufficient data are available at this time to estimate the solubilities of solid phases containing these radionuclides under the expected repository conditions. As the requisite solubility and dissolution rate data become available, the estimates extrapolated from the available data used in evaluating radionuclide release from a repository in basalt will be updated.

Only limited amounts of pertinent waste form/radionuclide dissolution data and radionuclide solubility data are available. Leach rate data for simulated spent fuel and borosilicate glass in distilled water are available for various temperatures (see Sections 11.3.2 and 6.3). No leach rate data are available for the various waste forms under conditions (pH, Eh, groundwater composition) applicable to a repository in basalt, although Holloway et al. (1981) have studied the effect of basalt on solubility/steady-state solution concentrations for hydrothermal alteration of a tailored ceramic waste form.

The status of studies on the interaction of groundwater with the radioactive waste, waste canister, and backfill material is found in Work Element W.1.12.A.

Plans

Laboratory experiments are currently being conducted to determine the solubilities of the key radionuclides (the actinides and transuranics, in particular) under conditions applicable to a repository in basalt. Data from these experiments will be used to verify and/or update present radionuclide solubility estimates. Savannah River Laboratories, Pacific Northwest Laboratory, and the Materials Characterization Center plan to conduct long-term static and low flow rate dynamic leach tests of simulated spent fuel and borosilicate glass under various environmental conditions for the National Waste Terminal Storage Program. Some of these data may be used by the BWIP. The behavior of these waste forms, under conditions pertinent to the Columbia River basalt environment, is currently being investigated by the BWIP. Specifically, experiments on the interactions between the waste form, basalt, and groundwater have been initiated over the temperature, pressure, and Eh-pH conditions expected for the repository. Data from these investigations will be used to evaluate the release of radionuclides from a repository in basalt.

While solubility constraints are the best simplified approach to characterization of radionuclide transport, the limitations of the approach will be considered in detail. In particular, there exist nonrelated natural examples of supersaturation with respect to certain chemical constituents. Apparent supersaturation levels may reach several orders of magnitude for indefinite, but generally transitory, time periods. The possible factors affecting these systems (kinetics, nucleation, growth inhibition, etc.) will affect the correctness of the application of radionuclide solubility. They must also be considered and dismissed (where possible) on a factor-by-factor basis. Otherwise, they will be incorporated into an uncertainty factor to be associated with the solubility calculations, which is an approach that is usually, but not always, found to be successful in predicting measured chemical concentrations in natural waters.

The information obtained in these studies will serve to define preliminary design criteria used as a basis for designing a site-specific waste package for basalt.

Work Element W.1.5.A (Identical to W.2.2.A) (Priority 1)

Determine the extent of Eh-pH and groundwater compositional control by the host basalt after repository closure.

Status

The current understanding of groundwater chemistry, pH, and Eh control in the basalt groundwater system is summarized in Section 11.4. The BWIP is confident that the chemical conditions discussed are close to the actual conditions expected in a repository constructed in basalt. Current understanding of the nature of the Eh-pH controlling mechanism is not known, but

control probably results from glass/H_2O/secondary mineral interactions. It is desirable to determine the exact mechanism to be able to predict groundwater chemistry, pH, and Eh as a function of time and temperature and to validate data obtained empirically. Jacobs and Apted (1981) have suggested one possible mechanism for groundwater chemistry, pH, and Eh control in the basalt groundwater system. The proposed mechanism, involving the dissolution of basalt glass and the precipitation of secondary minerals, would control Eh to values between the quartz-fayalite-magnetite and hematite-magnetite buffers (see Section 11.4.1.4) at both ambient and elevated temperatures. Indirect Eh measurements (oxygen depletion) from preliminary 200°C basalt groundwater hydrothermal experiments support the proposed mechanism and suggest control to be very rapid (within several hundred hours). Additionally, steady-state solution compositions from these experiments are very similar to the composition of in situ groundwaters. These preliminary results suggest that the mechanism(s) controlling solution chemistry, pH, and Eh are similar at both ambient and elevated temperatures. Further refinement and confirmation of these concepts will result from carefully designed basalt-H_2O hydrothermal experiments and detailed in situ analyses of the basalt groundwater system.

Plans

The BWIP plans to experimentally determine more precisely the Eh conditions present in the basalt groundwater system and to develop a realistic model of the overall mechanism controlling water chemistry. Kinetics or changes from oxidizing to reducing conditions will be studied, including the ability of basalt to mitigate solution Eh changes caused by changes in solution composition. This modeling will be accomplished by utilizing mineralogic, water-chemistry, dissolved-gas, and thermodynamic data to develop a model that realistically describes Eh and pH behavior as a function of temperature. To validate the Eh-pH model, in addition to generating groundwater chemistry data at elevated temperatures, data from hydrothermal experiments for the basalt groundwater system will be compared and contrasted with data obtained from drill holes. In this way, the actual controlling mechanism, which probably involves interactions among the basalt glass phase, groundwater, and secondary minerals, may be defined. These interactions may be used to predict the rate of Eh-pH control for a sealed repository. Additionally, solution chemistry data (e.g., SO_4^{-2}/HS^- ratios), as a function of temperature and time, may yield information useful for estimating the rate of Eh reduction in a sealed repository.

Work Element W.1.6.A (Includes discussion of W.1.11.A; see also W.2.2.A) (Priority 1)

Determine the susceptibility of candidate canister materials to degradation (i.e., corrosion, hydriding, fatigue, etc.) in the repository near-field environment.

Status

A canister/materials testing program has been initiated by the BWIP that has as its objective the selection of materials for the design of waste packages to meet the U.S. Nuclear Regulatory Commission proposed 1,000-year total radionuclide containment criterion. Using the environmental conditions expected in a repository constructed in basalt as a basis, a list of potential canister materials was prepared from a literature survey (Smith et al., 1980) of applicable laboratory corrosion tests. Corrosion screening tests were initiated to narrow the list of materials and select two or three candidates for advanced testing. Several nickel, iron, copper, and titanium base alloys have been exposed to deoxygenated, simulated Grande Ronde groundwater at 250°C and pH 9.92. Anoxic conditions, typical of those expected in a decommissioned repository constructed in basalt, were maintained by slowly purging the pressure vessels with an argon 0.19-percent hydrogen mixture. The results of these tests and other tests conducted elsewhere (Westerman, 1980) in simulated groundwater of similar composition, but under less-effective oxygen control, yielded corrosion rates that were extremely low (see Section 11.2.5). These preliminary data indicate that relatively inexpensive materials, not normally considered to be corrosion resistant in oxygenated aqueous solution (e.g., carbon steel and cast iron), might be used for canisters to be emplaced in basalt. The results of this testing phase provided support for the preparation of waste package conceptual design specifications for basalt (Anderson, 1982, Section 2.1.2.2).

Plans

The corrosion screening tests will be continued in a more quantitative manner to ensure that a sufficient data base is developed for selection of two or three candidate materials for advanced testing. Corrosion tests will be conducted under conditions relevant to those existing during the operating phase and after repository decommissioning. Concurrent with this testing, mechanical testing to measure crack initiation and propagation rates will be performed to further assess the susceptibility of each metal or alloy to environmentally induced embrittlement. Available data will support the preparation of waste package preliminary design specifications for basalt.

Methods of precise Eh and pH control will be developed for use in advanced corrosion testing. The testing will be conducted to quantitatively assess the interaction of candidate canister materials with the expected repository environment. For these advanced corrosion tests, specimens of suitable geometry will be used to quantitatively measure uniform corrosion rates and susceptibility and pitting corrosion, crevice corrosion, intergranular corrosion, stress corrosion cracking, and bacterial corrosion.

Both short- and long-term corrosion tests will be employed. The short-term tests will (1) quantify the effects of temperature on corrosion, (2) establish corrosion rates in a stagnant environment that is saturated with corrosion products, (3) assess the effects of radiation on

corrosion, and (4) determine the kinetics and stability of film formation on canister materials and its ability to prevent preferential attack (pitting and crevice corrosion). The first of these tests is pertinent, because the repository temperature changes with time. The second set of tests simulates the conditions under which the canister is expected to corrode (i.e., in a stagnant environment where the water-to-metal ratio is small). The third set of these tests is necessary to determine if radiation significantly enhances corrosion and if corrosion mechanisms are altered by a radiation field. The fourth set of tests is necessary since the ability of the metal to form a stable and protective surface film is of paramount importance in predicting long-term behavior of canister materials in the basalt environment. The long-term corrosion testing will be conducted to help determine whether or not extrapolations from short-term results are reliable.

Mechanical testing will be scoped to assess the susceptibility of the canister materials to hydrogen embrittlement and stress corrosion cracking. (Hydrogen embrittlement is thought to be a stress corrosion cracking mechanism.) Stress corrosion cracking is a form of degradation in which tensile stresses (residual and applied) may act with the corrosive environment to initiate and cause cracks through a structure. Static, fatigue, and slow strain rate tests will be employed to assess the material susceptibility to environmentally induced mechanical degradation.

Waste/barrier/rock interaction corrosion studies will also be conducted under hydrothermal conditions expected at the candidate repository horizons. Most of the quantitative materials interaction data pertinent to canister materials performance will be developed in tests, employing simulated waste forms and assemblages of waste package components (e.g., backfill, canister).

Such tests will be both static and flow-through-type experiments. A lesser number of tests will be repeated in hot cells, employing actual waste forms to better simulate actual repository conditions and to measure the interaction of the canister/overpack materials with other components of the waste package. The data from the interaction tests will be available in time for the preparation of the waste package final design specifications for basalt.

Work Element W.1.7.A (Related to W.1.2.A) (Priority 1)

Determine design properties, including thermal, physical, mechanical, and chemical, for waste package component materials and host rock.

Status

Design properties for waste package component materials are derived currently from analysis of available data for the candidate waste package and host rock materials. These estimated properties are being used for waste package conceptual design. Development testing is planned to provide directly applicable data for use in waste package design.

Plans

The plans for resolution of design properties for waste package component materials are included in the plans described in Paragraph W.1.2.A.

Work Element W.1.8.A (Included in W.1.3.A) (Priority 2)

Determine the effect of radiation on the performance of the waste form, backfill, and near-field host rock.

Status

Included in W.1.3.A.

Plans

Included in W.1.3.A.

Work Element W.1.9.A (Included in W.1.12.A) (Priority 1)

Determine the release rate (performance) of candidate waste forms in the repository near-field environment.

Status

Included in W.1.12.A.

Plans

Included in W.1.12.A.

Work Element W.1.10.A (Identical to W.2.6.A) (Priority 1)

Determine the formation and stability of radionuclide complexes and/or colloids over expected repository near-field and far-field conditions.

Status

Grande Ronde groundwater is of low ionic strength and mildly alkaline with a pH of 9.4 buffered by the dissociation of silicic acid (Gephart et al., 1979, Chapter III; Smith et al., 1980, Section 2.4). The high pH of the groundwater is conducive to the formation of metal (radionuclide) hydroxides and hydroxyoxides. In turn, many of these metal hydroxides are potentially capable of forming polymers or colloids at these pH values. Therefore, the basalt groundwater chemistry may enhance the formation of radionuclide colloids or polymers, which in turn can affect radionuclide transport behavior. However, there are no data available at present on the formation and stability of radionuclide colloids or polymers in the basalt geohydrologic system. The basalt groundwater also contains a significant number of complexing ligands (CO_3^{2-}, HCO_3^-, SO_4^{2-}, F^-) in low

concentrations that can compete with the hydroxides for the radionuclides (Gephart et al., 1979, Chapter III). There are no data available at present that define radionuclide speciation over the range of expected environmental conditions in the basalt groundwaters. Estimates of dominant speciation, based on available thermodynamic data and inferences from available sorption data, are being made for the basalt system. The sorption data indicate that, at the high pH of the groundwater, only the CO_3^{-2} and HCO_3^- appear to significantly affect radionuclide sorption and solubility behavior (Barney, 1981a; Salter 1981a; 1981b). The carbonate/bicarbonate ligands appear to form stable anionic or neutral species with many of the actinides and transuranics and, therefore, reduce their sorption onto the basalt and increase their solubilities in the groundwater. The stability of these complexes decreases with increasing temperature (see Section 6.4 for details). There are no data available at this time concerning the effect of the radiation field on radionuclide complexation and colloid formation under conditions applicable to the basalt geohydrologic system. The radiation field, however, is not expected to significantly affect radionuclide behavior, except in the very near field. There also are insufficient data available presently to accurately assess the effect of complexation and colloid formation on radionuclide transport, although the available data do suggest that complexation will not be a significant detrimental factor.

Plans

Ongoing research to evaluate the effect of complexing organic and inorganic ligands on radionuclide sorption and solubility behavior, as a function of speciation, for the key radionuclides will be continued. Experiments are being planned to identify the dominant radionuclide species in basalt groundwaters and to evaluate conditions that could lead to possible radionuclide colloid formation and then to evaluate subsequent "particulate transport" on overall radionuclide transport in the basalt geohydrologic system. These experiments will be flow-through (dynamic) sorption experiments (see Work Element W.2.4.A). The possible effects of the radiation field on radionuclide geochemical behavior also will be investigated and research conducted as necessary to evaluate this parameter. Results from these experiments will permit the evaluation of the effects of radionuclide complexation and colloid formation on transport in the basalt geohydrologic system.

Work Element W.1.11.A (Included in W.1.2.A and W.1.6.A) (Priority 1)

Determine the chemical properties and inflow rate of groundwater and their effect on canister corrosion during the 1,000-year containment period.

Status

Included in W.1.2.A and W.1.6.A.

Plans

Included in W.1.2.A and W.1.6.A.

Work Element W.1.12.A (Identical to W.2.3.A and W.1.19.B, includes discussion of W.1.9.A). (Priority 1)

Determine the extent to which the interaction between the canister materials, waste form, backfill, and host rock in a saturated environment results in retardation of radionuclides.

Status

The evaluation of the suitability of the Hanford Site must be based on the draft regulations and proposed regulatory criteria (EPA, 1981; NRC, 1981), which determine the required long-term performance of a nuclear waste repository in basalt (see Work Element W.2.12.D). The geologic barriers of the repository site, plus the man-made engineered barriers of the waste package, comprise the total barrier to release of materials to the biosphere. Where the natural barriers of the repository itself cannot meet or exceed the regulatory criteria, the performance of engineered barriers must supplement the performance of the geologic barriers to ensure proper regulatory compliance. The long-term performance of the barrier materials of a waste package is being evaluated by means of a program of site-specific hydrothermal testing of waste package components, both individually and as an integrated assembly.

The long-term stability and performance of candidate barrier materials is chiefly, though not exclusively, determined by their chemical interaction with the groundwaters that will eventually saturate the repository. The dominant process for hydrothermal interactions in the waste/barrier/basalt system is gradual dissolution of coexisting primary solid phases (see Work Element W.3.7). Dissolution will be accompanied by precipitation and growth of an assemblage of secondary alteration phases that are more stable under the given repository conditions (Helgeson, 1968). For the conceptual waste package design, the primary phases include silicates/oxides in basalt, backfill, buffer, and waste form components, and the metals or alloys for overpack and canister components.

The various dissolution/growth mechanisms for each solid are qualitatively similar, yet can be meaningfully divided into several separate categories. A useful division is along the functional requirements assigned to each waste package component. Canister/overpack materials must be designed to be relatively inert to groundwater (i.e., low dissolution (corrosion) rates). Buffer, backfill, and basalt components, in turn, will be somewhat more reactive toward groundwater, with the expectation that these reactions may buffer the geochemical parameters of the groundwater at beneficial levels. The waste form, in turn, must demonstrate a high resistance to release of contained radionuclides under projected hydrothermal conditions.

Corrosion of proposed metal and/or alloy materials is the main degradation process for canister/overpack components. A variety of corrosion reactions can occur between dissolved constituents of the groundwater and the canister surface (see Section 11.3.2.3). In some cases, desirable passivation of metallic components can be caused by formation of a stable oxide layer on the surface of the metal. This layer may act to prevent or limit further corrosion of the metal.

The dissolution of basalt (and, by extension, backfill and buffer components) and attendant growth of secondary alteration phases will control (buffer) the geochemical parameters within the repository. This is because basalt, especially the glassy portion, is volumetrically the dominant reactive solid phase (see Section 11.4.1.4). Also, the alteration phases formed, such as clays and zeolites, are phases that will significantly absorb radionuclides and retard their migration to the accessible environment.

Waste forms show a complex set of hydrothermal interactions with groundwater (see Section 11.3.2.1). At low temperatures (less than 100°C) for glass waste forms, there is appreciable ion exchange (leaching) of the glass surface and attendant development of a leach layer. At higher temperatures for glass and for crystalline waste forms at all temperatures, matrix dissolution is the dominant process. Actually, both processes occur at all conditions, but the relative rates of the two can vary strongly as a function of temperature, solution composition, and degree of structural ordering of the solid waste form.

Dissolution by whatever process is only a part of the controlling mechanism for possible release of radionuclides. Subsequent precipitation of more stable secondary alteration phases may greatly limit the eventual total release by imposition of solubility limits (see Work Element W.1.4.A). The current BWIP hydrothermal testing program for waste/barrier/basalt interactions has emphasized laboratory tests (see Work Element W.3.7) performed on simulated* waste forms and on simple combinations of simulated waste forms plus basalt plus barrier materials. The resulting data on solution compositions and solid alteration products have been used to evaluate waste form degradation under basalt-specific repository conditions (Apted, 1981; Holloway et al., 1981). This led to early identification of radionuclides that are not strongly sorbed or precipitated from solution (Salter et al., 1981a; 1981b; Barney, 1981a) and that, therefore, may require special attention to ensure their isolation within the waste package (Barney and Wood, 1980; Wood and Rai, 1981). It has also supplied isothermal, time-invariant compositional data on sampled solutions. These data can be coupled with realistic hydrologic flow data on very near-field modeling for calculation of meaningful radionuclide release rates.

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*Simulated waste forms contain only those elements commonly considered to occur "in stable form" in nature. This list includes uranium and thorium.

Previous utilization of simulated waste forms for initial barrier-materials testing was justified for several reasons. Measurement and evaluation of the effects of temperature, pressure, Eh, pH, proportion of reacting phases, and many other relevant testing parameters contribute to a large number of necessary tests to be performed. Because of the cost and operational difficulties for conducting tests in intense radiation fields, it proved to be cost effective to utilize waste forms containing nonradioactive chemical analogs, rather than radioactive elements, for initial tests. There are, however, two major problems that may arise with the exclusive use of simulated waste forms. The first problem is that the actinide elements and technetium found in nuclear-waste do not have stable isotopes that can be used in simulated waste forms. Secondly, the effect of radiation on chemical conditions (e.g., the radiolysis of groundwater and possible effect on Eh condition) is absent in testing with simulated waste.

Plans

Barrier materials testing with simulated waste in no way obviates the need for testing with tracer doped and fully loaded nuclear waste. The following fully radioactive waste form/rock/barrier interaction tests in a hot-cell facility are needed:

- Test the reliability of experiments using simulated waste forms by comparison with the results of experiments with actual waste forms (see Work Element W.3.7).
- Study the key radionuclides in actual waste that cannot be represented by stable isotopes and, thus, are not contained in simulated waste.
- Determine the effects of a radiation field on barrier performance (see Work Element W.1.3.A).
- Test potential seal, grout, and tunnel lining materials used either in tunnel support systems or in borehole or shaft construction and seals for compatibility with the geochemical system to assure that the waste isolation potential of the engineered system is not jeopardized.
- Evaluate the potential for formation of colloids and/or other species capable of particulate transport.
- More closely simulate conditions (e.g., radiolysis) in the repository.
- Test the effect of waste form aggregation (crushed versus bulk) on the degradation and release of waste forms.

In addition, advanced hydrothermal hot-cell testing of engineering-scale waste packages will be scoped to measure identified critical interactions between the several components of the waste package that incorporates a

radioactive waste form. Available test data will be reconciled with model predictions. Output of the validated performance model will be used to predict the long-term performance of waste packages emplaced in a repository located in basalt.

Plannint of hot-cell testing of barrier materials is under way. Results from such hydrothermal tests, utilizing actual radioactive waste forms in conjunction with other barrier materials, represent the final data necessary for performance evaluation of both the waste package and the geologic barriers in a repository located in basalt.

ISSUE W.1.B

Is a unique borehole backfill required?

Work Element W.1.13.B (Priority 1)

Assess the impact of waste storage in a borehole with no backfill on waste containment and isolation.

Status

The primary design function of the borehole backfill is to aid the waste form in limiting the release of radionuclides from the engineered barrier system (waste package and repository) to less than those required by proposed 10 CFR 60 criteria (NRC, 1981). If it can be shown that the backfill is not needed to perform this function, then there will be no impact of waste storage in a borehole with no backfill. However, repository design considerations may require a backfill in the waste emplacement boreholes to prevent subsidence after permanent closure (see Work Element R.1.9.A).

Plans

Several areas of investigation must be completed before this work element can be resolved. Primary input to the resolution of this factor will be the combination of waste package degradation modeling and near-field geochemical radionuclide transport modeling that will determine the effectiveness and need for various parts of the system to adequately control radionuclide release. Inputs to this modeling effort include the effects of a low-permeability backfill on canister corrosion and waste form leaching and the capability of the backfill to limit release of potentially troublesome radionuclides from solution through chemical reaction (see Work Elements W.1.8.A, W.1.14.B, W.1.15.B, and W.1.16.B). Cost effectiveness consideration will also be factored into these analyses as needed. The information developed in this work element will provide critical input into preliminary waste package design.

Work Element W.1.14.B (Priority 2)

Determine the need for special tailoring agents in backfill to moderate the corrosivity (Eh and pH) of the groundwater contacting the canister.

Status

Theoretical calculations and experimental data suggest that dissolved oxygen introduced into the groundwater during the repository construction and waste emplacement (operating) phases is the primary chemical agent that may promote rapid corrosion of canister materials. If it can be demonstrated that oxygen activity will be reduced to extremely low levels through groundwater interaction with basalt or major backfill materials before significant groundwater canister corrosion can occur, then special backfill tailoring agents will not be needed (see Work Element W.2.2.A). If a backfill material with a significant amount of crushed basalt is chosen, then it is unlikely that special tailoring agents will be required to create a moderate pH and a highly reducing environment in the backfill. Indirect proof of this hypothesis has been demonstrated in hydrothermal basalt/synthetic groundwater experiments at 200° and 300°C (Wood et al., 1982). In these experiments, the detection of sulfide in experimental solution samples suggests that a reduction of sulfate to sulfide occurred in a relatively short time (less than 3 months). This reaction indicates that a highly reducing environment (Eh approximately equal to -0.5) was rapidly established in the system.

Plans

Experimental techniques are being developed to measure Eh (e.g., oxygen activity) and pH under hydrothermal conditions. These experiments will permit a direct measurement of oxygen consumption rates, thereby determining how quickly the repository environment returns to highly anoxic conditions after closure. Hydrothermal experiments will be completed at 150°C in the basalt groundwater system and compared to the results from the 200° and 300°C experiments used to study alteration products. Inferences concerning the Eh of all hydrothermal experiments will be made for those experiments in which the Eh is not measured directly from groundwater characteristics (e.g., temperature, pH, composition). Should specific tailoring agents be required, they will be developed as needed.

Work Element W.1.15.B (See also W.1.16.B) (Priority 2)

Define the characteristics of the backfill materials required to retard the flow of groundwater to the canister. Identify potential backfill materials with these characteristics.

Status

Minimization of groundwater transport through the backfill is most easily accomplished by engineering a low-permeability medium that limits mass transport to diffusion. Previous studies (Pusch, 1979; Smith et al., 1980, Section 2.8) show that compacted sodium bentonite clay provides a nearly impermeable medium that has the capacity to swell and seal fractures during a saturation process. A calculation of "average" velocities due to diffusional versus convective transport suggests that a maximum backfill hydraulic conductivity of 10^{-11} meters per second is sufficient to limit groundwater transport to diffusion (Wood et al., 1982). Experimental work with bentonite/sand mixtures shows that a combination of 25 percent bentonite/75 percent sand has an acceptable hydraulic conductivity (Wheelwright et al., 1981). A similar mixture of basalt and bentonite should also have an acceptable hydraulic conductivity, because the bentonite component controls the permeability of the medium.

Plans

Experiments to measure hydraulic conductivities/swelling pressures and mechanical strengths of various basalt/bentonite mixtures are planned. These parameters will be measured as a function of temperature and density. These data will be used to verify the acceptability of the reference waste package backfill mixture of 25 percent bentonite/75 percent basalt by volume (Anderson, 1982, Section 2.1.23). The acceptability, on the basis of permeability, of other potential backfill mixtures will also be investigated (e.g., crushed basalt and sand).

Work Element W.1.16.B (Priority 1)

Define the characteristics of the backfill material required to reduce the rate of radionuclide release from the waste package. Identify backfill materials with these characteristics.

Status

A backfill component effectively reduces the rate of radionuclide release from the waste package by: (1) minimizing groundwater contact with the waste form, thereby reducing the waste form leach rate and (2) maintaining a reducing waste package environment that promotes extremely low solubilities of radionuclides (e.g., actinides), thereby assuring that their release rates fall below acceptable limits. The capability of a backfill component to effectively retard radionuclide transport is dependent on: (1) the specific hazardous radionuclides of interest, (2) the sorptive and reactive capacity of the backfill materials, (3) the thermal stability of the backfill materials, and (4) the permeability of the backfill materials (see Work Element W.1.15.B).

Specific radionuclides have been identified and candidate backfill materials have been chosen that could react with these radionuclides. Limiting the retardation studies of backfill materials to key radionuclides

(i.e., those whose solubilities exceed release criteria) significantly reduces the amount of experimentation required. Sorption/reaction experiments are currently being conducted over the range of geochemical conditions expected to occur during the life of the repository. Experiments are being conducted in the 65° to 150°C temperature range under oxic and anoxic conditions (Salter et al., 1981a; 1981b); a simulated repository groundwater is being used in these experiments. Hydrothermal experiments are also being conducted under site-specific conditions in the range of 150° to 300°C to determine the thermal stability limits of backfill materials (Wood et al., 1982). In addition, the effects of dehydration on the structural stability of hydrated candidate backfill materials (e.g., smectite clays, zeolites) are being investigated.

Plans

On the basis of the data being generated currently, suitable backfill-material mixtures will be chosen and flow-through experiments completed under repository conditions to measure radionuclide transport through a saturated backfill. These data will then provide an accurate means of determining whether radionuclide transport rates can be controlled satisfactorily by the backfill materials. Modeling of radionuclide transport through the backfill will also be completed, taking into account such elements as temperature, backfill composition, groundwater composition, waste form leaching rates, and the expected "quiescent" conditions around the waste package. Comparison of model results and experimental results will be used to validate the accuracy of the model.

Work Element W.1.17.B (Identical to W.1.8.A, included in W.1.3.A) (Priority 2)

Determine the effect of radiation damage on the performance of the waste form, backfill, and host rock.

Status

Identical to W.1.8.A and included in W.1.3.A.

Plans

Identical to W.1.8.A and included in W.1.3.A.

Work Element W.1.18.B (Identical to W.1.1.A) (Priority 2)

Determine the maximum operating temperature limits for waste form, backfill, canister, and host rock.

Status

Identical to W.1.1.A.

Plans

Identical to W.1.1.A.

Work Element W.1.19.B (Identical to W.1.12.A and W.2.3.A) (Priority 1)

Determine the extent to which the interaction between the canister material, waste form, backfill, and host rock in a saturated environment results in retardation of radionuclides.

Status

Identical to W.1.12.A and W.2.3.A.

Plans

Identical to W.1.12.A and W.2.3.A.

Work Element W.1.20.B (Included in W.2.13.D) (Priority 1)

Determine if a waste package backfill is required to provide acceptable containment in the event of premature canister failure.

Status

Included in W.2.13.D.

Plans

Included in W.2.13.D.

THE FOLLOWING WORK ELEMENTS DO NOT RELATE TO ANY ISSUE, BUT ARE REQUIRED TO SATISFY THE CRITERIA LISTED IN SECTION 15.4.

Work Element W.1.21 (Priority 3)

Develop waste package acceptance specifications for waste solidification that meet U.S. Nuclear Regulatory Commission proposed requirements.

Status

Present reference forms for high-level and transuranic wastes are solids (Anderson, 1982, Section 2.1.2.1).

Plans

Information on physical and chemical characteristics of reference waste forms and the performance of the waste forms under repository conditions will be obtained under Work Elements W.1.1.A through W.1.12.A. Final waste package design documents will contain a specification for waste solidification and will include acceptance criteria.

Work Element W.1.22 (Priority 3)

Develop waste package acceptance specifications for consolidation that meet U.S. Nuclear Regulatory Commission proposed requirements.

Status

Present reference forms for high-level waste in a nuclear waste repository in basalt include reprocessed waste and spent fuel if declared waste.

The consolidation requirements for solidified, contaminated, inorganic oxides (from incineration), the reference transuranic waste form, have not yet been determined (Section 11.1; Anderson, 1982, Section 2.1.2.1).

Plans

Functional analysis on need for consolidation of transuranic oxides will be performed for the updated conceptual design of a nuclear waste repository in basalt. Consolidation techniques for transuranic oxides will be developed if required.

Work Element W.1.23 (Priority 3)

Develop waste package acceptance specifications for combustibles that meet U.S. Nuclear Regulatory Commission proposed requirements.

Status

Present reference high-level and transuranic waste forms are noncombustible (Anderson, 1982, Section 2.1.2.1).

Plans

None needed presently. Final waste package design documents will contain a specification for combustibles if required.

Work Element W.1.24 (Priority 2)

Determine the impact of the reprocessing technique (including waste fractionization) on waste package design.

Status

Present studies of waste form (and content) compatibility with a nuclear waste repository in basalt indicate that all significant isotopes expected to be contained in either reprocessed waste or spent fuel (if declared waste) will be contained by the engineered and natural systems to the appropriate U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency limits (Section 11.3.2.4).

Plans

None at present. If further analysis by the National Waste Terminal Storage Program indicates that migration of key radionuclides cannot be controlled by either the engineered or natural system, then a trade-off study on alternatives for control of that isotope will be needed.

Work Element W.1.25 (Priority 3)

Develop waste package acceptance specifications for explosive, pyrophoric, and chemically reactive materials that meet U.S. Nuclear Regulatory Commission proposed requirements.

Status

Present reference high-level and transuranic waste forms, canisters, and backfill materials are nonexplosive, nonpyrophoric, and chemically inert over expected and abnormal repository conditions (Anderson, 1982, Section 2.1.2.1).

Plans

None needed presently. Final waste package design documents will contain a specification excluding explosive, pyrophoric, and chemically reactive waste materials from the repository.

Work Element W.1.26 (Priority 3)

Develop waste package acceptance specifications for free liquids that meet U.S. Nuclear Regulatory Commission proposed requirements.

Status

Present reference high-level and transuranic waste forms are solids. There are no plans to accept liquid waste (Anderson, 1982, Section 2.1.2.1).

Plans

None needed presently. Final waste package design documents will contain a specification excluding liquid wastes.

Work Element W.1.27 (Priority 3)

Determine the waste package handling, shipping (including drop tests), emplacement, and retrievability requirements.

Status

The BWIP repository conceptual design (Chapter 10) provides information on waste package receipt, handling, and retrieval.

Shipment of the waste package to the repository will comply with existing U.S. Department of Transportation regulations.

Present BWIP requirements for the contained waste assembly stipulate a 24-foot drop test and fail-safe handling requirements (Anderson, 1982, Section 2.5.2).

Plans

None needed presently. Final repository design documents will contain specifications for these items.

Work Element W.1.28 (Priority 3)

Develop waste package acceptance specifications for identification that meet U.S. Nuclear Regulatory Commission proposed requirements.

Status

Information not yet available.

Plans

Waste identification specifications will be defined in final waste package design documents.

15.3.2 Site Geochemistry Issues and Work Elements

The analysis of data needs and status of work supporting site geochemistry issues and work elements are contained in Table 15-3.

ISSUE W.2.A

Are the geochemical and hydrologic properties of the geologic setting (in conjunction with the waste forms) sufficient to meet or exceed U.S. Nuclear Regulatory Commission proposed waste isolation requirements?

Work Element W.2.1.A (Related to W.2.4.A) (Priority 2)

Determine the effect on radionuclide mobility of changes in the primary and secondary mineralogical conditions in the near field and far field of the repository, along the expected pathway to the biosphere.

TABLE 15-3. Work Element Analysis: Data Needs and Status for Site Geochemistry Issues and Work Elements. (Sheet 1 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
W.2.1.A (Related to W.2.4.A) Determine the effect on radionuclide mobility of changes in the primary and secondary mineralogical conditions in the near field and far field of the repository, along the expected pathway to the biosphere.	Variation of mineralogy and petrology in Grande Ronde Basalts for both primary and secondary minerals. Statistical analysis of mineral composition to determine relevance of materials used in sorption experiments to regional mineral variations (see W.2.4.A for discussion of solubility and sorption effects of radionuclide mobility).	Data from vertical boreholes in the reference repository location, along the predicted flow paths to the biosphere, and from samples found in the exploratory shaft. Not applicable.	Mineralogy and petrology of Columbia River basalts and interbeds are known. Additional data on variation of mineralogy with depth are needed. Chapters 3 and 6; Noonan et al. (1980). Preliminary investigations are in progress.
W.2.2.A (Identical to W.1.5.A) Determine the extent of Eh-pH and groundwater compositional control by the host basalt after repository closure.	Information needs identical to W.1.5.A.	Measurement conditions identical to W.1.5.A.	Status identical to W.1.5.A.
W.2.3.A (Identical to W.1.12.A and W.1.19.B) Determine the effects of waste/barrier/rock/water interactions on the performance of the underground facility or geologic setting.	Information needs identical to W.1.12.A and W.1.19.B.	Measurement conditions identical to W.1.12.A and W.1.19.B.	Status identical to W.1.12.A and W.1.19.B.
W.2.4.A Demonstrate that geochemical conditions in the near and far field are such that transport of radionuclides is retarded for sufficient time to satisfy waste isolation requirements.	Key radionuclide solubilities and solubility products • Extent of radionuclide complexation • Colloid formation.	See W.1.4.A for details. See W.1.10.A for details. Radionuclide solubility and sorption data should be determined over the range of expected physicochemical conditions.	See W.1.4.A for details. See W.1.10.A for details. The ambient and expected range of physicochemical conditions for the repository has been established.

TABLE 15-3. Work Element Analysis: Data Needs and Status for Site Geochemistry Issues and Work Elements. (Sheet 2 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
		• Temperature, pressure • pH, Eh • Groundwater composition • Basalt mineralogy/petrology. For a discussion of the work elements concerning specific repository physicochemical conditions, see W.1.1.A (temperature), W.2.10.C (Eh), W.1.5.A (groundwater pH, Eh), W.2.1.A (mineralogy).	Smith et al. (1980, Section 2.5); Gephart et al. (1979, Chapter III); Sections 4.1.1, 4.1.4, 6.1, 6.2, and 11.4.1.2 of this document.
	Key radionuclide sorption data • Distribution coefficient values (screening tests)	Determine static, equilibrium, radionuclide distribution-coefficient values for basalt flow interiors, basalt flow tops, secondary minerals, and interbed materials at appropriate temperatures (25°C to 300°C) in representative simulated groundwaters under both oxic and anoxic conditions.	Distribution-coefficient values are available for approximately 70 percent of the key radionuclides for the representative geologic materials under appropriate physicochemical conditions (Smith et al., 1980, Section 2.10; Barney, 1981b; Salter et al., 1981a; 1981b; Ames and McGarrah, 1980; Ames, 1980; Barney, 1981a; Serne, 1978; Relyea, 1980).
	• Equilibrium sorption-desorption isotherms	Narrow the list of key radionuclides. Determine steady-state sorption-desorption isotherm equations for key radionuclides for basalt flow top, secondary minerals, and interbed materials at appropriate temperatures (25°, 60°, 150°C, 300°C) in representative simulated groundwaters and under oxic and anoxic conditions.	Key radionuclides selected (Barney and Wood, 1980; Wood, 1980). Sorption isotherm equations have been determined under applicable environmental conditions, for approximately 20 percent of the key radionuclides for Umtanum basalt. Desorption isotherm (Salter et al., 1981a; 1981b; Section 6.4.2) experiments initiated. Additional studies are planned using middle Sentinel Bluffs flow samples.

TABLE 15-3. Work Element Analysis: Data Needs and Status for Site Geochemistry Issues and Work Elements. (Sheet 3 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	• Dynamic sorption-desorption equations.	Determine the kinetics of sorption-desorption reactions. Develop equations to describe the kinetic reactions, when necessary. Determine the dynamic (flow-through) sorption behavior of key radionuclides on crushed and intact basalt or interbed materials under appropriate repository conditions. Investigate effects of radionuclide complexation and colloid formation on sorption behavior (see W.1.10.A, particulate transport).	Sorption-desorption kinetics experiments initiated for basalt and secondary minerals. Preliminary investigations are in progress.
		Incorporate appropriate equilibrium on kinetic desorption equations into available near-field geochemical models and far-field groundwater transport models.	Available sorption models are being investigated for use with transport models. Only simple distribution-coefficient values have been utilized in radionuclide transport models to date (Wood, 1980; Arnett et al., 1981; Sections 6.3.3.2 and 11.3.2.4; Chapter 12)
		Determine what field tests are necessary to verify laboratory data and radionuclide transport models (see W.3.6 for details).	See W.3.6 for details.
W.2.5.A (Identical to W.1.4.A and W.2.9.B) Determine the projected solubilities and distribution of aqueous species for key radionuclides which might be released from the waste package.	Information needs identical to W.1.4.A and W.2.9.B.	Measurement conditions identical to W.1.4.A and W.2.9.B.	Status identical to W.1.4.A and W.2.9.B.
W.2.6.A (Identical to W.1.10.A) Determine the formation and stability of radionuclide complexes and/or colloids over expected repository near- and far-field conditions.	Information needs identical to W.1.10.A.	Measurement conditions identical to W.1.10.A.	Status identical to W.1.10.A.

TABLE 15-3. Work Element Analysis: Data Needs and Status for Site Geochemistry Issues and Work Elements. (Sheet 4 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
W.2.7.A (Identical to W.1.3.A) Determine the effect of the waste package radiation environment on near-field geochemistry, waste package, and barrier material performance.	Information needs identical to W.1.3.A.	Measurement conditions identical to W.1.3.A.	Status identical to W.1.3.A.
W.2.8.A Determine acceptable release rates of key radionuclides from the engineered system as a function of containment time, groundwater travel time to the accessible environment, and water flow through the repository.	Radionuclide inventories.	Not applicable.	Data available (see Section 11.1).
	Radionuclide solubilities. Radionuclide sorption characteristics.	In situ site conditions (relevant groundwater composition and physicochemical conditions) and consideration of elevated temperatures.	Very limited data available for radionuclide solubilities under in situ conditions (see Section 6.4.1). No data available at elevated temperatures.
	Groundwater flow rates.	In situ groundwater flow conditions.	Preliminary hydrologic data available for calculation of groundwater flow (Gephart et al., 1979, Chapter III). Refinement of data necessary for rigorous analysis.
	Geochemistry of groundwater flow path.	Not applicable.	Section 5.1.5 discusses regional hydrochemistry.
W.2.9.B (Identical to W.1.4.A and W.2.5.A) Determine the projected solubilities and distribution of aqueous species for key radionuclides which might be released from the waste package.	Information needs identical to W.1.4.A and W.2.5.A.	Measurement conditions identical to W.1.4.A and W.2.5.A.	Status identical to W.1.4.A and W.2.5.A.
W.2.10.C Determine the method and technique that can be utilized to provide valid in situ Eh measurements for the reference repository location.	<u>Ambient Eh</u> • In situ Eh of Grande Ronde groundwaters • An accepted method of measurement.	Efforts to determine in situ Eh values of the reference repository location will focus on three separate, but complimentary, technologies for Eh determination: (1) Measurement of dissolved redox couples	Preliminary measurements of Grande Ronde groundwaters made and Eh estimates from redox couples calculated. Redox couples for basalt minerals were analyzed (Jacobs and Apted, 1981).

TABLE 15-3. Work Element Analysis: Data Needs and Status for Site Geochemistry Issues and Work Elements. (Sheet 5 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
		(2) Potentiometric methods using reversible electrodes (3) Measurement using redox-indicator dyes	Use of potentiometric methods are being evaluated (Danielson, 1980; Niedrach, 1980).
WORK ELEMENTS NOT RELATED TO ISSUES			
W.2.11 (Discussed in W.2.13.D) Determine how the geochemical and physical properties of the geologic setting mitigate the impact of premature failure of the waste package.	Information needs discussed in W.2.13.D.	Measurement conditions discussed in W.2.13.D.	Status discussed in W.2.13.D.
W.2.12.D (Related to W.2.11) Determine on a radionuclide-specific basis whether U.S. Nuclear Regulatory Commission proposed repository release rates or U.S. Environmental Protection Agency draft release limits are the limiting repository requirements.	Radionuclide inventories. Radionuclide solubilities. Radionuclide sorption data. Geohydrologic site characteristics.	(see W.2.8.A) (see W.2.8.A) (see W.2.13.D) (see W.2.13.D)	(see W.2.8.A) (see W.2.8.A) (see W.2.13.D) (see W.2.13.D)
W.2.13.D (Includes discussion of W.1.20.B and W.2.11) Determine to what degree the characteristics of the geologic setting complement the engineered system.	Geohydrologic Site Characteristics • Pressure, temperature • pH, Eh conditions • Groundwater chemistry • Basalt chemistry • Basalt physical characteristics (porosity, density, etc.)	(1) In situ drill hole and outcrop data to describe the undisturbed site. Characteristics important to overall performance.	(1) Preliminary data concerning geohydrologic characteristics are available in this report. Other selected references include Gephart et al., 1979, Chapter III; Myers and Price, 1981; Schmidt et al., 1980; Foundation Sciences, Inc., 1980; 1981; Jacobs and Apted, 1981. Refinement of much of the physical data is necessary for a rigorous treatment of W.2.13.D.

TABLE 15-3. Work Element Analysis: Data Needs and Status for Site Geochemistry Issues and Work Elements. (Sheet 6 of 6)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	• Hydrologic properties (heads, permeability, etc.).	(2) Data at given range of temperatures to address near-field site performance.	(2) Small amount of preliminary data only for groundwater and basalt chemistry at elevated temperature is available (Wood et al., 1982). Data on hydrologic and basalt physical properties of elevated temperature are not available.
	<u>Geohydrologic Controlled Radionuclide Behavior</u> • Radionuclide sorption (see W.1.4.A) • Radionuclide solubility (see W.1.4.A)	(1) In situ physicochemical conditions to determine far-field site performance.	(1) Preliminary performance assessments made and definition of further needs for sorption and solubility complete (see Section 6.4). No data available on complexing and colloid formation.
	• Radionuclide complexing (see W.1.10.A) • Radionuclide colloid formation (see W.1.10.A).	(2) Data at elevated temperature to address near-field site performance.	(2) Preliminary data on radionuclide sorption available (see Section 6.4.2). No data available on solubility complexing or colloid formation at elevated temperature.

Status

Information on mineral variability in the near field (induced by heat) and in the far field (as a result of regional geologic heterogeneity) is required to predict geochemical behavior of radionuclides during transit toward the biosphere. The mineralogy of the candidate horizons and nearby flows is particularly important, since the host rock plays a dominant role in determining the geochemical environment of the repository. Near-field thermal effects on radionuclide mobility through the host rock are discussed in Work Elements W.1.4.A and W.1.12.A.

The general mineralogy and petrology of the Columbia River basalts and interbeds are known, and the variation in mineralogy with depth is known to a limited degree. Additional information is needed, however, to state with confidence the mineralogical variation along any given pathway to the biosphere.

Specifically, the mineralogy of primary phases of the Umtanum and nearby flows is known principally from an electron microprobe study by Noonan et al. (1980). This study, coupled with the observation that the bulk compositon of the Umtanum flow varies within restricted limits (see Chapter 3), suggests that the mineralogic variability of the Umtanum flow is limited. However, more extensive sampling and analysis are required to completely document this conclusion. Very limited data are available on the compositional variation of primary phases in flows near the Umtanum and, thus, additional information on these flows is required. Data on the mineralogy of the middle Sentinel Bluffs flow are becoming available, and a data base comparable to that for the Umtanum flow will be developed.

Plans

Additional analyses will be made of the petrography and mineralogy of samples, including entablature, colonnade, and interbed materials collected from selected depths in core wells near or at the reference repository location. Sampling will emphasize the Grande Ronde Basalt, but will also include samples of overlying flows and interbeds. Grande Ronde Basalts will be emphasized, because the bulk of the radionuclide travel time will be in this formation. Both primary and secondary minerals will be analyzed. This analysis will include a determination of ferrous/ferric ratios for whole-rock basalt samples and possibly for select redox controlling phases. This will serve to support the estimates of redox buffering capacity for these materials. Analytical techniques will include point counting, image analysis, electron microprobe analysis, scanning electron microscope analysis, analytical scanning transmission electron microscopy, and X-ray diffraction.

Mineralogic and petrographic data from the studies of samples from vertical boreholes will be used to estimate mineralogic and petrographic variation along any given, predicted path of radionuclide migration.

Where statistical analysis demonstrates mineralogic variations that depart significantly from those materials utilized in laboratory sorption studies, these new materials will be tested to determine their effects on radionuclide mobility.

<u>Work Element W.2.2.A</u> (Identical to W.1.5.A) (Priority 1)

Determine the extent of Eh-pH and groundwater compositional control by the host basalt after repository closure.

<u>Status</u>

Identical to W.1.5.A.

<u>Plans</u>

Identical to W.1.5.A.

<u>Work Element W.2.3.A</u> (Identical to W.1.12.A and W.1.19.B) (Priority 1)

Determine the effects of waste/barrier/rock/water interactions on the performance of the underground facility or geologic setting.

<u>Status</u>

Identical to W.1.12.A and W.1.19.B.

<u>Plans</u>

Identical to W.1.12.A and W.1.19.B.

<u>Work Element W.2.4.A</u> (Priority 1)

Demonstrate that geochemical conditions in the near and far field are such that transport of radionuclides is retarded for sufficient time to satisfy waste isolation requirements.

<u>Status</u>

The current accepted values for the prevailing near-field physicochemical conditions in a repository in basalt are discussed and summarized in Section 11.4. The ambient far-field physicochemical conditions for basalt are summarized in Sections 6.1 and 6.2. A more detailed discussion of the status of knowledge and future plans for evaluating specific repository physicochemical conditions may be found in Work Elements W.1.1.A, W.1.5.A, W.2.1.A, and W.2.10.C. The basalt geochemical environment can affect radionuclide transport by controlling radionuclide solubility and sorption behavior--the two dominant retardation mechanisms in the basalt geohydrologic system--and by mitigating waste package degradation. The present assessment of expected near-field and far-field repository conditions is that they are rather benign, with respect to deleterious

effects on waste package performance (containment), and actually may be advantageous, in terms of their effect on potential radionuclide transport. A summary of radionuclide solubility behavior in the basalt geohydrologic system is presented in Section 6.4.1. A discussion of the status and plans for evaluating solubility behavior is presented in Work Element W.1.4.A. A detailed summary of the sorption behavior of key radionuclides in the basalt geohydrologic system is presented in Section 6.4.2. A discussion of the status and plans for evaluating radionuclide sorption behavior is presented below.

Radionuclide distribution coefficient values have been determined for the sorption of the majority of the key radionuclides on representative geologic materials under conditions applicable to geohydrology for the basalt system (Salter et al., 1981a; 1981b; Barney, 1981a; 1981b; Ames, 1980; Ames and McGarrah, 1980; 1981a; 1981b). These distribution coefficient values are used currently in radionuclide transport models to evaluate the radionuclide retardation capabilities of the basalt geohydrologic system (Wood, 1980; Arnett et al., 1981). However, this method has two basic limitations: (1) it assumes equilibrium (i.e., a reversible system) and (2) it assumes that sorption is linearly dependent on radionuclide concentration. In addition, the measured distribution coefficient values do not distinguish between precipitation and sorption reactions. The assumptions implicit in the use of simple distribution coefficient based models are not valid for all radionuclides; sorption isotherms are often nonlinear, and some sorption reactions can be controlled kinetically and/or can be irreversible. To improve the evaluation of radionuclide retardation for use in transport modeling, radionuclide sorption-desorption isotherms are currently being determined for the basalt geohydrologic system (Salter et al., 1981a; 1981b). These isotherm "equations" describe sorption as a function of radionuclide concentration and will replace the distribution coefficient values in the retardation equation. Sample radionuclide distribution coefficient values, however, can be used to qualitatively evaluate the retardation capabilities of the geohydrologic system and to establish reasonable experimental parameters for more advanced sorption experiments (kinetic and flow-through sorption). Kinetics and reversibility of the radionuclide sorption reactions in the basalt geohydrologic system are also being determined. Kinetic sorption equations, where applicable, can be used in place of equilibrium sorption isotherms to determine radionuclide retardation. Present investigations of both equilibrium and kinetic sorption behavior, over the range of repository conditions, and the development of mathematical functions (sorption isotherms, etc.) to describe this behavior will permit the accurate assessment of radionuclide retardation.

Plans

The ongoing sorption experiments to determine radionuclide sorption isotherms, kinetic behavior, and reversibility of the sorption reactions for all key radionuclides will be continued. The effect of complex forming ligands on sorption behavior will be evaluated. The variables

being evaluated are described by Barney (1981b). Evaluation of nonreversible sorption in interbed materials (Barney, 1982) is being conducted. Evaluation of these data will determine whether an equilibrium isotherm or a kinetic equation should be used to describe the sorption behavior of each key radionuclide. The equations developed from these data will be used to evaluate radionuclide retardation factors for use in transport modeling. In addition, dynamic (flow-through) sorption experiments will be conducted to refine and/or update these sorption equations and to evaluate particulate/colloid transport of radionuclides in the basalt geohydrologic system (see Work Element W.1.10.A). The flow-through experiments will also provide data on the effect of radionuclide complexation/speciation on radionuclide transport. Radionuclide migration tests in the field will be conducted, if required, to verify the experimentally defined sorption equations.

Work Element W.2.5.A (Identical to W.1.4.A and W.2.9.B) (Priority 1)

Determine the projected solubilities and distribution of aqueous species for key radionuclides which might be released from the waste package.

Status

Identical to W.1.4.A and W.2.9.B.

Plans

Identical to W.1.4.A and W.2.9.B.

Work Element W.2.6.A (Identical to W.1.10.A) (Priority 1)

Determine the formation and stability of radionuclide complexes and/or colloids over expected repository near- and far-field conditions.

Status

Identical to W.1.10.A.

Plans

Identical to W.1.10.A.

Work Element W.2.7.A (Identical to W.1.3.A) (Priority 2)

Determine the effect of the waste package radiation environment on near-field geochemistry, waste package, and barrier material performance.

Status

Identical to W.1.3.A.

Plans

Identical to W.1.3.A.

Work Element W.2.8.A (Priority 1)

Determine acceptable release rates of key radionuclides from the engineered system as a function of containment time, groundwater travel time to the accessible environment, and water flow through the repository.

Status

Key parameters affecting the release of radionuclides from a repository include:

- Containment time
- Water flow through a repository
- Groundwater travel times to the accessible environment
- Radionuclide sorption
- Radionuclide solubility.

Estimates of acceptable release rates from the engineered system, based on U.S. Environmental Protection Agency draft regulations and a range of values for the above parameters, allow the sensitivity of acceptable release rates to various event scenarios to be evaluated. Performance requirements are sensitive to scenarios through the resulting water travel times, flow rates, and containment times of a given scenario. By estimating performance requirements as a function of these parameters, performance requirements can be derived that allow the integration and optimization of the site and engineered system characteristics.

Plans

The BWIP plans to proceed in determining acceptable release rates as a function of containment time, groundwater travel time, and water flow through the repository for spent fuel, commercial high-level waste, defense high-level waste, and possibly transuranic wastes. The resulting release rates will be compared to available waste form performance data, as well as release rates limited by radionuclide solubilities. In this way, the required performance of other components within the engineered barrier system may be determined.

ISSUE W.2.B

What is the relative importance of waste form leach rates versus solubility of key radionuclides in the near-field environment for controlling release?

Work Element W.2.9.B (Identical to W.1.4.A and W.2.5.A) (Priority 1)

Determine the projected solubilities and distribution of aqueous species for key radionuclides which might be released from the waste package.

Status

Identical to W.1.4.A and W.2.5.A.

Plans

Identical to W.1.4.A and W.2.5.A.

ISSUE W.2.C

Can valid Eh measurements for the candidate repository horizons in the reference repository location be made either by potentiometric measurement or indirectly by measurement of dissolved redox couples?

Work Element W.2.10.C (Priority 1)

Determine the method and technique that can be utilized to provide valid in situ Eh measurements for the reference repository location.

Status

The current understanding of the prevailing Eh values in a nuclear waste repository in basalt under present and expected repository conditions is addressed in Section 11.4. Current evidence indicates that the Eh values of Hanford groundwaters are more reducing than the hematite-magnetite oxygen buffer. These indirect studies are confirmed by higher temperature experimental hydrothermal studies on the Umtanum basalt, which indicate that Eh is buffered at reducing conditions by groundwater reaction with basaltic glass (Jacobs and Apted, 1981). This Eh is low enough to retard (but not necessarily prevent) corrosion degradation of proposed metals or alloy canister materials. These same reducing conditions lead to generally lower solubilities for multivalent radionuclides and increase the extent of radionuclide sorption on basaltic phases.

There are, however, problems associated with obtaining representative in situ Eh measurements and these are well documented (e.g., Morris and Stumm, 1967; Stumm and Morgan, 1981). Of particular interest are discussions by Benson (1978) concerning the special problems at the Hanford

Site associated with both potentiometric and indirect measurements of Eh by the measurement of dissolved redox couples. These discussions indicate that representative Eh determinations for the repository horizons might not be obtainable from direct potentiometric measurements made on solutions sampled at the surface. Surface measurements are currently being made at borehole sites outside the reference repository location. To provide qualitative information about redox conditions at the proposed repository horizons, in situ measurements will be required at or near the reference repository location.

Plans

Future efforts to determine Eh within the candidate repository horizons of the reference repository location will focus on:

- In situ potentiometric Eh measurements (Danielson, 1980)
- Measurement of dissolved redox couples (Seward, 1974; Boulegue and Michard, 1979)
- Use of redox indicator dyes (ASTM, 1975).

In situ potentiometric Eh measurements may be obtained through the use of solid-state Eh probe equipment being developed currently for the BWIP. These measurements may be made in future boreholes penetrating the repository horizon within the reference repository location. Alternatively, the technique of using redox indicator dyes for determining the amount of dissolved oxygen and water could perhaps be applied to basalt groundwaters at depth. This method, which uses an indigo-carmine dye solution, is based on the fact that dissolved oxygen reacts rapidly under alkaline conditions with the dye to produce color changes. These color changes can be related colorimetrically to the amount of oxygen present and, therefore, the Eh.

In addition, analyses of reference redox couples (e.g., sulfur speciation, arsenic +3/arsenic +5, carbon dioxide/methane) will be performed to calculate Eh conditions for groundwater zones adjacent to the repository horizons in boreholes within the reference repository location.

In the future, surface measurements of Eh will be compared with downhole potentiometric measurements and Eh values will be calculated from acceptable redox couples. Results will be reviewed and the most credible data will be used as the reference repository Eh. However, the ability to measure in situ Eh conditions at repository depths is dependent on development of new equipment. Current technology permits measurements of Eh only at land surface and in shallow depth (i.e., 100 meters).

THE FOLLOWING WORK ELEMENT DOES NOT RELATE TO ANY ISSUE, BUT IS REQUIRED TO SATISFY THE CRITERIA LISTED IN SECTION 15.4.

Work Element W.2.11 (Discussed in W.2.13.D) (Priority 1)

Determine how the geochemical and physical properties of the geologic setting mitigate the impact of premature failure of the waste package.

Status

Discussed in W.2.13.D.

Plans

Discussed in W.2.13.D.

ISSUE W.2.D

To what degree does the geologic setting retard migration of key radionuclides from the engineered system in meeting U.S. Environmental Protection Agency draft release criteria?

Work Element W.2.12.D (Related to W.2.11) (Priority 1)

Determine on a radionuclide-specific basis whether U.S. Nuclear Regulatory Commission proposed repository release rates or U.S. Environmental Protection Agency draft release limits are the limiting repository requirements.

Status

The performance evaluation modeling for spent fuel (see Section 11.3.2.4) has defined the release rates from a waste package for specific radionuclides that are necessary to meet U.S. Environmental Protection Agency draft criteria. Relative to the one part in 10^5 U.S. Nuclear Regulatory proposed Commission requirement, some radionuclides may have release rates lower than 10^{-5} parts per year, while other radionuclides may have release rates faster than this and still meet the U.S. Environmental Protection Agency draft requirements (see Chapter 11, Table 11-24). Many of these required release rates for various nuclides could be met by solubility constraints alone.

Plans

The BWIP plans to determine the appropriate release rates for specific nuclides to meet U.S. Environmental Protection Agency draft criteria for high-level and transuranic wastes, and to relate these release rates to the U.S. Nuclear Regulatory Commission 10^{-5} parts per year proposed requirement. For these analyses, in addition to the analysis for spent fuel, solubilities and retardation factors for all key radionuclides will be compiled and used to assess waste form release rates. In this way, the required release rates may be defined and used to evaluate the necessary

performance of the various components of the waste package/repository system. This information will provide the basis for preparation of design criteria and specifications.

Work Element W.2.13.D (Includes discussion of W.1.20.B and W.2.11) (Priority 1)

Determine to what degree the characteristics of the geologic setting complement the engineered system.

Status

Preliminary analyses by Burkholder (1982) and Wood (1980) have shown that, for a repository in basalt, the performance of the geologic site dominates the performance of the overall system in limiting radionuclide releases. It is important to augment such general analyses with the best available site-specific data (see Work Element W.2.4.A). By conservatively modeling nuclide releases through the site without considering engineered barrier performance, the net performance of the site can be assessed. In this way, the complementary performance of the site relative to the engineered barrier system can be determined, as well as the ability of the site to mitigate premature waste package failures.

Plans

The BWIP plans to determine the performance of the site in limiting nuclide releases with the use of radionuclide transport modeling. The approach will involve the assumption of zero waste package performance to address the ability of the site to contain radionuclides. In addition, conservative assumptions concerning site transport characteristics (sorption, water velocity, release scenarios, etc.) will be combined with information about radionuclide release rates and solubility limits. This performance modeling will address spent fuel, commercial high-level, defense high-level, and transuranic wastes in current conceptual repository designs and will take into consideration the most current regulatory criteria. It will also determine whether a waste package backfill will be required to provide acceptable containment in the event of premature canister failure.

15.3.3 Testing and Performance Confirmation Issues and Work Elements

The analysis of data needs and status of work supporting testing and performance confirmation issues and work elements are contained in Table 15-4. A more detailed analysis of performance issues and work elements is found in Chapter 16 of this document.

TABLE 15-4. Work Element Analysis: Data Needs and Status for Testing and Performance Confirmation Work Elements. (Sheet 1 of 3)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
W.3.1.A Define appropriate statistical techniques so that laboratory and field materials interaction data can be extrapolated over time to provide a reasonable assurance of the long-term performance of the engineered system.	Statistical techniques for test design. Statistical techniques for data interpretation.	Not applicable. Not applicable.	Preliminary investigations are in progress. Preliminary investigations are in progress.
W.3.2.A Determine the thermodynamic and kinetic arguments that can be used to extrapolate short-term (less than 2 years per experiment) materials test (hydrothermal) data.	Static Tests • Steady-state solution compositions • Rates of hydrothermal reactions.	(1) Confirm isothermal steady-state solution compositions by varying grain size, water/solid rock, and different initial concentrations of radionuclides (or analogue elements). (2) Monitor changes in solution composition with time. Calculate rate-controlling mechanisms for hydrothermal reactions as a function of temperature.	Literature survey of the thermodynamic and kinetic constraints to data extrapolation completed. Analysis discussed in work narratives. (1) and (2) Holloway et al., 1981; Apted, 1981. (2) Mottl and Holland, 1978; Lasaga, 1981.
	Dynamic Tests • Solution composition flow-through • Rates of hydrothermal reactions.	(1) Validate the flow rate conditions over which isothermal-solution compositions from dynamic flow-through tests match steady-state solution compositions from static tests. (2) Determine what thicknesses of barrier materials (both natural and man-made) are required before flow-through solution compositions match steady-state solution compositions from static tests.	Radionuclide release rates, based on thermodynamic solubility, have been applied to the basalt system. (1) Effect of nonthermodynamic constraints applied to basalt system (Dibble and Tiller, 1981a; 1981b; Potter and Dibble, 1981). (2) Preliminary investigations are in progress.

TABLE 15-4. Work Element Analysis: Data Needs and Status for Testing and Performance Confirmation Work Elements. (Sheet 2 of 3)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
		(3) Monitor changes in solution composition with time and path length. Determine rate-controlling mechanisms for hydrothermal reactions as a function of temperature and flow rate for key radionuclides.	(3) Preliminary investigations are in progress.
W.3.3.A Develop and/or use numerical modeling techniques to predict the environmental conditions, package degradation, and radionuclide behavior of emplaced wastes in or near the engineered system.	Codes for very near-field analysis.	Not applicable.	Codes available: BETA, DAMSWEL, ANSYS, HEATING5, MAGNUM 2D, MAXISM, and CHAINT (Section 12.3). Codes being developed: BARIER, WAPPA, and PROTOCOL (Section 12.3).
	Laboratory and field environmental, package degradation, and radionuclide migration data.	See W.1.2.A, W.1.4.A, W.1.9.A, W.2.2.A, W.2.5.A, and W.2.6.A.	See W.1.2.A, W.1.4.A, W.1.9.A, W.2.2.A, W.2.5.A, and W.2.6.A.
W.3.4.A Determine what natural analogues of waste package components can be used to verify the compatibility of the waste package with the repository environment.	• Identify relevant natural materials. • Establish a basis for comparing or contrasting their performance with waste package component materials.	Basis for performance comparison: • Estimate age • Establish environmental history • Compare environmental history with projected variations in repository conditions.	Review durability of metals found in archaeological objects, metal meteorites, and natural metals (Johnson and Francis, 1980). Study initiated and near completion to assess durability of native copper found in basalt flows in upper Michigan.
W.3.5 Develop an acceptance test procedure for waste packages.	Acceptance test procedures for waste packages will be defined in repository operating instructions and in final waste package design documents.	None.	Preliminary investigations are in progress.
W.3.6 Determine and conduct field, engineering, and in situ testing as may be appropriate to meet design needs and U.S. Nuclear Regulatory Commission proposed performance requirements.	May include: • Demonstration of waste package assembly, emplacement, and retrievability capability	To be determined.	No data available.

TABLE 15-4. Work Element Analysis: Data Needs and Status for Testing and Performance Confirmation Work Elements. (Sheet 3 of 3)

Work element	Information needs (data and analysis)	Mandatory measurement conditions	Status achieved (references)
	• Waste package material behavior and thermal response: Canister corrosion Backfill resaturation rate Backfill swelling pressure	To be determined.	No data available.
	• Radionuclide migration.	Tracer-well injection test in two closely spaced boreholes into the candidate repository horizons.	No data available.
W.3.7 Determine suitability of using nonradioactive chemical analogues for actual waste forms in the hydrothermal testing program.	Hot-Cell Testing Steady-state solution chemistry from radioactive waste form/groundwater reactions: • Stable concentrations of matrix elements of the waste form • Concentrations of radionuclides released from the waste form • pH • Eh.	As described in W.1.12.A, conduct hydrothermal degradation tests on tracer-doped and fully loaded radioactive waste forms under expected repository conditions at 150° and 300°C in a hot-cell facility. Compare these results with earlier results on similar systems utilizing nonradioactive (cold) synthetic waste forms. Document the effect, if any, of radiation on steady-state solution chemistry.	Planning for hot-cell testing of barrier materials is under way.
		Evaluate whether stable isotopes are suitable analogues of radioactive isotopes of the same element. Also evaluate if analogous stable elements can be used in place of radioactive elements.	No data available.
W.3.8 Determine requirements for monitoring. Define parameters, methodology, interpretive criteria, and actions.	In situ waste package performance confirmation during repository operating periods. Data needs are not presently known and will be determined.	Monitor performance of selected waste packages emplaced in the first panel of the repository and compare with results of an associated laboratory testing program.	Preliminary investigations are in progress.

ISSUE W.3.A

How can very near-field waste/barrier/rock materials interaction data, as measured experimentally, be extrapolated over time to reasonably assure that overall waste package and repository performance meets regulatory criteria?

Work Element W.3.1.A (Priority 1)

Define appropriate statistical techniques so that laboratory and field materials interaction data can be extrapolated over time to provide a reasonable assurance of the long-term performance of the engineered system.

Status

The U.S. Nuclear Regulatory Commission in 10 CFR 60 proposes that there be "reasonable assurance" that proposed criteria for pre-1,000-year containment and post-1,000-year controlled release of radionuclides will be met by nuclear waste packages in geologic repositories (NRC, 1981). Barrier material testing programs devised to meet this requirement of "reasonable assurance" will be limited, however, to test durations that are extremely short, relative to the regulatory time period over which barrier materials are expected to remain functional. It has been proposed that performance evaluation tests on barrier materials could be achieved by elevating laboratory physicochemical parameters to values that accelerate the expected degradation mechanisms (NWTS, 1981f). The results from such short-term, accelerated testing could then be used to establish reasonable assurance for barrier material performance over much longer time periods.

Accelerated tests, however, need to be devised to take full advantage of statistically designed experiments. Statistical approaches to the design and interpretation of barrier material test data have recently received attention by the National Waste Terminal Storage Program (NWTS, 1981e). The chief advantage from a statistical approach is that the number of test conditions can be minimized without degrading the quality of the experimental data and subsequent predictions of expected lifetime for barrier materials under normal conditions. Such an approach, if predicted on scientific theory, can utilize both intertest and intratest comparison of data for support and verification of waste package performance assessment. Such a statistical approach to accelerated testing is being implemented by the BWIP.

Plans

Development of a statistical approach to accelerated barrier material tests (NWTS, 1981e) is fundamentally based on expert scientific opinion. Before any testing is performed, it is necessary that a scientific, quantifiable model for barrier degradation be constructed from expert judgment. The model is the connective link between the experimental testing

and the performance assessment programs for any repository site. This model must include the various types of degradation mechanisms for barrier materials. The relative importance of these mechanisms as a function of environmental parameters of the repository (e.g., temperature, pressure, radiation field, groundwater composition) should also be incorporated.

From the degradation model and identification of environmental parameters of "stresses" that affect degradation, a complete factorial design (Hoel and Levine, 1964) comprised of all possible combinations of high and low values for "stresses" can be formed. Expected values for degradation rates can be assigned for each of these factorial combinations, based on either expert scientific opinion or previous experimentation. In the simplest case, these ratings may only be relative rankings of the severity of the associated test parameters. A factorial "tree" can then be developed that graphically plots the assigned ratings of degradation as a function of the several test parameters under investigation.

There are several important uses for this statistically developed factorial tree:

- The parameters that provide the greatest increase in degradation rate can be easily identified. This is useful for organizing an accelerated testing program.

- The factorial tree permits elimination of combinations of test parameters that can be expected to provide only minimal acceleration in testing. This capability is crucial for test programs with finite human and equipment resources and limited time for testing.

- The factorial tree is a graphic representation of the degradation model. New test data can be used to revise the severity rating of combinations of test paramaters on degradation rate. Thus, earlier degradation models can be continually updated and improved as new data are obtained.

In summary, the development of statistical factorial analysis, based on expected degradation models of barrier materials, can assist in establishing and refining experimental design for accelerated testing. However, as has been shown in previous work elements, project emphasis will be placed on the identification and proof of degradation mechanisms and the development of a "scientifically quantifiable" model of waste package degradation and release. Further study on statistical approaches to experimental design and testing will be made to ensure that barrier material testing is rapid, yet cost effective. Factorial design provides for repeated verification of initial models with each subsequent test result and permits revision of initial models to accommodate newer, conflicting data. In this manner, the scientific models for barrier material degradation can be used to extrapolate short-term laboratory tests to 1,000-year proposed regulatory performance objectives with reasonable assurance.

Work Element W.3.2.A. (Priority 1)

Determine the thermodynamic and kinetic arguments that can be used to extrapolate short-term (less than 2 years per experiment) materials test (hydrothermal) data.

Status

The meaningful extrapolation of short-term hydrothermal test results to the much longer time periods to assure isolation of nuclear waste is closely allied to the common dilemma experienced by geoscientists attempting to extrapolate similar laboratory data (test of less than 2 years duration) to natural geochemical/mineralogical processes that occur over time scales of hundreds to millions of years. Geochemists and experimental petrologists have accordingly developed several theories, based on chemical, thermodynamic, and kinetic-reaction principles, to address this extrapolation problem. These theories have been validated by the observation of repeated agreements between theoretical predictions and observed natural examples in a variety of geochemical systems. These interpretive theories, already in common use by the geochemical community, serve as the basis for extrapolation of hydrothermal test results on waste/barrier/basalt interactions to time scales suitable to appropriate U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency isolation criteria.

Solubility constraints on the release of radionuclides are the prime thermodynamic justification for the extrapolation of short-duration test results to longer time scales. The hydrothermal interactions of waste/barrier/basalt represent overall irreversible dissolution/precipitation reactions (Helgeson, 1968), which may be summarized simply by the expression:

$$\begin{array}{l}\text{Solution (initial) + Primary (unstable) Phases} \rightleftharpoons \\ \text{Solution (final) + Secondary (stable) Phases}\end{array} \qquad (15\text{-}1)$$

The Ostwald step rule, a useful, albeit empirical, observation from natural and experimental studies of hydrothermally altered rocks (Fyfe and Verhoogen, 1958), states that the transition from an unstable to a stable phase generally occurs through the formation of a series of intermediate metastable phases, and that the thermodynamic instability of these intermediate phases will decrease as the reaction progresses. The thermodynamic parameter measuring the relative stability of a phase in a hydrothermal system is its free energy; that is, the total driving force for reaction between solids and solution. This free energy is also a direct measure of solubility of a solid phase (Garrels and Christ, 1965), so that the relative hydrothermal stability of phases can be directly determined from relative solubilities; i.e., the most soluble phase will be the least stable. At any point during a step-wise alteration reaction process, the composition of the solution will be governed by the relative solubilities of coexisting phases.

In the limiting case, in which only the most stable solid phases are present, solubility data can be measured directly (Wood and Rai, 1981; Rai et al., 1981) from solution composition or evaluated from thermodynamic data, when available (Pourbaix, 1966; Garrels and Christ, 1965). It is important to stress that such solubility data are independent of time and reaction pathway because of the equilibrium nature of the system. Because all chemical systems evolve toward equilibrium (i.e., an assemblage of stable phases), the use of solubility limits to predict the long-term release rates of radionuclides from a waste package-repository system is a justifiable initial model.

The application of thermodynamic solubility constraints can be extended to a more general model for hydrothermal reactions between solution and metastable solids. In this case, there is assumed to be one (or more) metastable solid phases coexisting in solution with compositionally related phases that are thermodynamically more stable. It should be noted that these more stable phases are not necessarily the most stable of all compositionally related phases. As the less stable/more soluble phase begins to dissolve toward its own well-defined solubility limit, the solution concentration will first reach the solubility limit of the more stable/less soluble coexisting phase. At this juncture, the more stable phase will begin to grow as its solubility limit is exceeded. Thus, the dissolution rate of the less stable phase and the concurrent growth rate of the more stable phase are opposing processes, seeking to establish their own solubility control of solution composition (Lasaga, 1981; Holloway et al., 1981; Apted, 1981; Mottl and Holland, 1978).

For example, if the irreversible dissolution of an unstable phase, such as glass, is rapid relative to the growth of a more stable alteration phase, the solution composition will reflect mainly the solubility of the glass (for equal areas of glass and alteration phase). If the relative reaction rates were reversed, such that the alteration phase grows much faster than the primary phase dissolves, then the bulk solution composition will be primarily determined by the solubility of the alteration phase (Berner, 1980; Dibble and Tiller, 1981a; 1981b). Intermediate, steady-state reactions (note that these are not equilibrium reactions) exist between these extremes, representing a balancing of the rates at which chemical components are being dissolved from unstable primary phases and the rates at which the same components are removed from solution into more stable secondary phases. Steady-state conditions will eventually change with time, as the more stable phases nucleate and grow or unstable phases become totally consumed. This, in turn, will cause the solution to attain new steady-state compositions. The concentration of dissolved components represented by these evolving steady-state reactions must decrease with reaction progress (i.e., longer periods of time), because each new phase must be more stable, hence less soluble, than the previous phases. It can be expected, therefore, that if hydrothermal tests are conducted for durations sufficient to attain a steady-state reaction, these data will provide conservative radionuclide release rates relative to equilibrium solubility expected to control the actual long-term release rates.

These rates of dissolution and growth are functions of several variables (Dibble and Tiller, 1981a; 1981b), including temperature, reaction-activation energy, reactive surface area (or reactive surficial mass), solution concentrations, and available free energy of the system, which is the difference in free energy (or solubility) between the unstable reacting phase(s) and the stable product phase(s). This kinetic model, based on the energetics and mechanisms controlling dissolution and growth processes, serves also as the justification for a variety of experimental techniques that can be adopted to actually accelerate the test. By speeding up the rates of dissolution and growth, the results of short-duration laboratory tests can be made to approach a state of reaction identical to that achieved in nature over much longer periods.

The Interface Working Group on Accelerated Testing, an NWTS Program advisory committee, for example, has suggested that, by increasing the temperature of laboratory tests, the reaction rates of hydrothermal interaction tests on waste package components can be dramatically increased. This same technique is in common usage in chemical engineering technology (e.g., Boudart, 1968) and in geochemical/petrologic research (e.g., Mottl and Holland, 1978). The assumption that the same dissolution/growth mechanisms are operative at both high and low hydrothermal temperature is, however, often not justified. This is particularly true for the hydrothermal study of glass reactions, which apparently is dominated initially at low temperature (25°C) by ion exchange (surface leaching) (White et al., 1980) and controlled at high temperature (200°C) by matrix dissolution (Karkhanis et al., 1980).

Standard experimental studies of alteration products and resultant water chemistry of basalt/water reaction utilize powdered samples of basalt (e.g., Liou et al., 1974; Mottl and Holland, 1978; Moody and Meyer, 1979). The accepted rationale for this procedure is that, by effectively increasing the reactive surface area or surficial mass of the basalt, the time required for reaction and formation of new solid phases is greatly expedited. For powdered samples, the high surface areas to mass ratio of the sample ensures that the entire mass added will be the effective reactive surficial mass. Uncertainty in estimating reactive surficial mass of monoliths, and uncontrollable changes in this parameter because of cracking, create problems of interpreting or extracting meaningful kinetic data from dissolution or solubility tests.

Finally, it has been shown recently (Dibble and Tiller, 1981a; 1981b; Potter and Dibble, 1981) that nonthermodynamic parameters, such as porosity and permeability (i.e., flow rate), may affect the alteration mineral assemblage produced in hydrothermal systems. High flow rates of solution through a rock system results in thorough mixing of interface and bulk solutions, permitting a relatively greater portion of the available free energy of the system to be utilized in surface detachment/attachment processes. This both prevents large degrees of oversaturation near mineral surfaces and increases the rates of dissolution and growth, resulting in more rapid formation of the most stable phases (Dibble and Tiller, 1981a; 1981b). The great advantage of this technique is that use of a variable flow rate to accelerate kinetic reaction rates should not involve any change in the operative reaction mechanism.

Plans

The current use of non-flow-through (static) tests in the rocker-type autoclaves for the bulk of the experimental program is justified on grounds of lower cost, simplicity of operation, greater experimental control, and the fact that the relatively slow rates of solution flow in natural rock (10^{-3} to 10^{-5} meters per year in the Grande Ronde Basalt) are probably well approximated by the confined flow in a rocker-type autoclave. Flow-through hydrothermal autoclaves are, however, being developed and constructed by the BWIP. The freedom to vary both flow rate and temperature (up to 300°C), with minimal loss of scientific relevance between experiments, will permit a thorough examination of long-term alteration processes under hydrothermal conditions, eliminating the need for long-term experiments. Use of high flow rates will promote rapid attainment of more stable phases. It will then be possible to confirm, from static tests using conventional rocker-type autoclaves, the range of flow rates over which the steady-state results are applicable to the long-term performance assessment of waste packages emplaced in basalt.

Work Element W.3.2.A (Priority 1)

The flow rate of groundwater in the very near field surrounding the waste emplacement hole will likely be very low given the estimates/measurements of hydraulic conductivities in the central portions of the basalt flows (Chapter 5). If the groundwater transit time across the waste package is on the order of 1,000 years, BWIP will need to determine whether the steady-state flow system will approach nearly equilibrium conditions in terms of dissolved species. Furthermore, it will be necessary to verify that the range of high flow rates that will provide results can be extrapolated to a repository time frame and repository flow conditions. In these high flow rate tests, the solution in contact with the dissolving phase might always be undersaturated with respect to that phase, thereby enhancing dissolution reactions because of the higher driving force. In the repository, on the other hand, the solution might be saturated with the "dissolving" phase, thereby retarding the dissolution process. The approach to equilibrium or near equilibrium concentrations (activities) of reactant and product species in slowly flowing solutions will be factored into any attempt to predict long-term dissolution/precipitation behavior.

Emphasis of BWIP studies will be broadened to include analysis of corrosion data, as well as previously described material interaction results, as part of data extrapolation studies. Both the experimental data from materials testing and the interpretation thereof will be subject to extensive peer review. These reviews will assess the materials data extrapolation techniques used by the BWIP. The consensus gained thereby will provide assurance that short-term materials test data have been appropriately input to performance activities.

Work Element W.3.3.A (Priority 1)

Develop and/or use numerical modeling techniques to predict the environmental conditions, package degradation, and radionuclide behavior of emplaced wastes in or near the engineered system.

Status

Very near-field waste package modeling is divided into three subactivities. These are the modeling of environmental conditions, waste package degradation, and the behavior of radionuclides under very near-field geochemical conditions. A summary description of existing models is contained in Section 12.3 of this document. Factors that require modeling relative to the waste package environment are the thermal, mechanical, fluid, radiologic, and geochemical conditions during the repository lifetime. Codes that are available for very near-field analysis include BETA, DAMSWEL, ANSYS, HEATING5, MAGNUM 2D, and CHAINT. Additional codes under development are PROTOCOL, BARIER, and WAPPA.

HEATING5, a finite-difference heat conduction code, has been used (Altenhofen, 1981) to estimate temperatures for vertically emplaced waste packages in basalt (Section 11.3.2.2). A two-dimensional finite-element code, MAGNUM 2D, is being used to simulate the fluid environment expected around a waste package. Codes are presently undergoing development and/or preliminary evaluation to determine the extent and duration of dehydration adjacent to an emplaced waste package. Shielding codes to simulate the waste package radiation environment and to provide the exposure levels and cumulative dose to each waste package component are also being studied. Preliminary estimates of the chemical state of radionuclide in the near-field and the very near-field environment (pH and Eh) have also been made (Sections 6.2.3 and 11.4) using a variety of chemical equilibrium codes, but with limited success. Direct measurement and/or extrapolation of these parameters from redox couples of associate minerals (for Eh) is still the most satisfactory means of obtaining pH and Eh information. Present waste package degradation modeling has been limited to testing the applicability of BARIER and WAPPA to the basalt system.

Modeling of radionuclide transport has been primarily used to evaluate waste package performance requirements (Wood, 1980), using a closed-form analytic solution to the one-dimensional radionuclide transport equation developed by Haderman (1980), as described in Sections 11.2.3.4, 12.3.1.2.3, and 12.4.2.

Codes presently being evaluated for assessment of very near-field geochemical behavior include MAGNUM 2D and CHAINT (Sections 12.3 and 12.4.2 of this document). The Materials Characterization Center is developing a model called PROTOCOL that may also be useful in this area (Mendel, 1981). As other codes become available to the National Waste Terminal Storage Program, they will be evaluated on an as-needed basis.

Plans

A part of the waste package-related modeling activity is to identify and model environmental conditions and package degradation mechanisms that may detrimentally alter the ability of the chosen barrier materials (man-made and natural) to perform their design functions. Predictive modeling of key processes within the waste package system (i.e., corrosion, alteration of hydraulic properties, geochemical properties of backfill materials, waste form leaching) will be completed to extrapolate short-term laboratory data (less than 2 years) over a repository lifetime (greater than 1,000 years). As more accurate data obtained under repository-specific conditions become available, the predictive quality of the modeling effort will be upgraded. The degradation model will provide input to waste package design requirements and performance assessment. Codes presently under development include BARIER and WAPPA (Section 12.3 of this document). As these and other codes become available to the National Waste Terminal Storage Program, they will be evaluated on an as-needed basis. There is also the need to generate or modify existing codes that are capable of modeling the very near-field radionuclide behavior for a repository in basalt. The integration of information from both modeling and testing efforts (i.e., laboratory sorption and solubility data) is critical to predicting performance. These quantitative geochemical models will supply the source term data, which will input to (1) the far-field radionuclide transport codes being developed in the BWIP hydrologic characterization activity and (2) the waste package/repository design process. Information especially relevant to the waste package/repository design process includes near-field waste form (radionuclide) release rates and the incorporation of near-field radionuclide behavior into performance assessment models for conceptual/preliminary designs of waste packages.

Work Element W.3.4.A (Priority 3)

Determine what natural analogs of waste package components can be used to verify the compatibility of the waste package with the repository environment.

Status

Of the several metallic materials currently being considered for fabrication of canisters, copper and iron can be found in their native state in geologic and archaeological formations. Natural analogs of the iron-nickel alloys, some of which are also candidates for canisters, exist as metal meteorites that are iron based and contain 5 to 60 percent nickel. While the environments they have existed in over the centuries may not be well known, much can be learned about metal stability (longevity) from an assessment of these metallic and mineral natural analogs of waste package components.

A review has been completed (Johnson and Francis, 1980) of the durability of metals found in archaeological objects, metal meteorites, and native metals. The study examines the range of metal durability of

these materials and assesses factors which appear to have contributed to extended durability. The authors note that several metals, including copper and iron, exist as archaeological artifacts. They have been found in cases, tombs, graves, and shipwrecks. Many are in surprisingly good condition, even those that have lain under the sea for a thousand years. The results of this review provide a measure of confidence that metallic materials can be selected that will have a reasonable assurance of meeting canister/overpack longevity requirements.

A study has been concluded by the BWIP which examined the native copper found in basalt flows of the Keweenaw Peninsula in upper Michigan (Crisman and Jacobs, 1982). The native copper, which precipitated from high-temperature (200° to 300°C) hydrothermal solutions between 500 and 800 million years ago, has remained relatively unaltered in the Portage Lake basalt groundwater system. These copper-bearing basalts have existed at least since the end of the last glacial age in that region (10,000 years ago). Preliminary petrographic examination of samples of the copper-bearing basalt from the near-surface flow shows the copper to be stable, with no corrosion or gradation between it and the other mineral phases present. The proportions of the ionic species in the groundwater found in the near-surface zone of the basalt are similar to that found in the Saddle Mountains groundwater at Hanford. This similarity provides a basis for comparison.

Plans

The study of the copper-bearing Keweenaw basalt will continue. The objective will be to attempt to establish the environmental history of these near-surface deposits to provide a basis for comparing or contrasting them with a copper canister emplaced in the basalt at Hanford. The natural iron deposits that occur on Disko Island, Greenland are of interest to the BWIP, since carbon steel is the leading candidate material for waste canisters to be emplaced in basalt at Hanford. The iron on Disko Island is associated with basalt and ranges in size from small particles to masses weighing up to 20 tons. Plans are being made to characterize these iron deposits, using methods similar to those employed in the Keweenaw copper/basalt study.

The Oklo natural fission reactor is of interest because of its relevance to the study of radionuclide behavior in backfills. This phenomenon refers to the occurrence of a self-sustaining fission chain reaction in a series of rich uranium-ore pockets located in an extensive Precambrian pitchblende deposit in Gabon, West Africa. Several billion years ago, the uranium formed critical masses whose duration extended over several thousand years. Studies are presently being conducted to reconstruct the radionuclide history of the Oklo site (Cowan, 1976; Norris, 1979; 1980a; 1980b; Curtis, 1980; 1981a; 1981b). These studies will be monitored for their relevance to the BWIP waste package program. Other natural analogs to the BWIP waste package will be reviewed for their potential for verifying long-range performance of materials in the basalt environment.

Work Element W.3.5 (Priority 3)

Develop an acceptance test procedure for waste packages.

Status

Preliminary investigations are in progress.

Plans

Acceptance test procedures for waste packages will be defined in repository operating instructions and in final waste package design documents.

Work Element W.3.6 (Priority 1)

Determine and conduct field, engineering, and in situ testing as may be appropriate to meet design needs and U.S. Nuclear Regulatory Commission proposed performance requirements.

Status

The identification of appropriate field, engineering, and in situ testing needed to complement laboratory testing for waste package design and performance assessment is being made by the BWIP.

Plans

A review of the needs and identification of appropriate field, engineering, and in situ testing is planned. This effort will lead to the preparation of a plan and the conduct of performance confirmation testing, if required, to meet the requirements of the National Waste Terminal Storage Program and regulatory agencies of the Federal Government.

Field, engineering, and in situ testing of waste packages to verify waste/barrier/rock interactions (canister corrosion, backfill resaturation, etc.) identified in laboratory-scale testing will be considered. However, it is felt that such interaction rates would be extremely slow under in situ conditions and probably could not be accurately measured for the relatively short term associated with this testing. This type of testing is planned for hot cells, where means of accelerating the interaction rates can be used and accurately controlled. In situ monitoring of materials interactions should be left for the first panel of the repository, where monitoring can be conducted over the longer operating period (see Work Element W.3.8). Migration tests to assess the behavior of radionuclides in the basalt at Hanford will be evaluated to assess their appropriateness. Radionuclide migration tests being conducted elsewhere (Hoffman, 1979; Lundstrom et al., 1978) will be monitored to determine their effectiveness. A well injection test at Hanford is being considered to measure radionuclide travel times.

To support the continued design of the horizontal borehole waste package (see Section 11.2.3), a backfill development test will be conducted to demonstrate that the backfill can be pneumatically emplaced with the possible use of vibration to achieve the required density. This testing could be followed if found appropriate with a field test to demonstrate that the waste package can be remotely emplaced and retrieved from a backfilled horizontal borehole if design studies support the continued development of this emplacement concept.

Such tests will serve to support the development of design criteria and support the preparation of a preliminary and final design for a waste package in basalt.

Work Element W.3.7 (Priority 2)

Determine suitability of using nonradioactive chemical analogs for actual waste forms in the hydrothermal testing program.

Status

The current hydrothermal testing program (see Work Element W.1.12.A) for waste/barrier/basalt interactions is focused on achieving an adequate understanding of the relevant chemical reactions in this system. Such information is basic to the long-term modeling efforts for performance evaluation of a waste package in a repository located in basalt. Emphasis has been placed on simple waste package component testing (e.g., waste-water, waste-basalt-water) that can be used in interpreting subsequent test results from more chemically complex tests that involve multiple waste package components.

The radioactive nature of the nuclear waste component imposes an intense gamma-radiation field, which could be an important parameter affecting chemical reactions in the waste/barrier/basalt system. Measurement of the effects of temperature, pressure, Eh, pH, proportion of reacting phases, and many other relevant geochemical parameters will contribute to the number of tests to be performed. Because of the cost and operational difficulties of conducting tests in intense radiation fields, it has proven to be cost effective to utilize waste forms containing nonradioactive chemical analogs, rather than radioactive elements, for initial tests.

A large number of fission products occurring in spent fuel assemblies do have nonradioactive isotopes that can be incorporated into simulated waste forms. These elements include strontium, cesium, carbon, iodine, selenium, zirconium, palladium, tin, and several others. From a chemical standpoint, the chemical bonding interactions are identical for all isotopes of the same element. It can be expected, therefore, that use of simulated, nonradioactive waste forms in testing will provide meaningful performance evaluation information on proposed waste forms for these elements.

There are, however, two major problems that may arise with the exclusive use of simulated waste forms. First, the actinide elements and technetium do not have stable isotopes that can be used in simulated waste forms. Analog elements may be used, based on expected periodic chemical properties and observed similarity of compounds. For example, molybdenum is often used as an analog for technetium and stable trivalent lanthanide elements for radioactive trivalent actinide elements. The limitation to this approach is that, under some test conditions, the chemical similarity "assumed" will no longer be valid. Second, the effect of radiation on chemical condition (e.g., the radiolysis of groundwater and possible effect on Eh conditions) is absent in testing of simulated waste. Preliminary evidence indicates that radiolysis should not lead to large differences in leach rates between simulated and radioactive waste forms (Friedman et al., 1980; McVay et al., 1981). More work at a greater number of test conditions and on multiple component assemblages is needed to validate this conclusion.

Plans

Hydrothermal testing of tracer-doped and fully loaded radioactive waste forms, both alone and in the presence of other waste package components, is being proposed in a report on the feasibility of using Rockwell Hanford Operations hot cells. Hot-cell testing is scheduled to begin in fiscal year 1984. At that juncture, a large body of test results from simulated waste form testing, by both BWIP and other National Waste Terminal Storage Program laboratories, will be available to help define and limit the number of tests needed to be performed in a hot-cell facility.

Test results will be assessed to determine whether differences in behavior between analogs and actual waste materials are significant. Attention will be focused on the effects of radiation on chemical reactions on or between waste package components. Areas of concern include canister degradation and the degradation and dissolution of proposed waste forms.

There is another advantage to testing with tracer-doped and fully loaded waste forms. Many radionuclides are solubility limited at minute concentrations in aqueous solutions (Wood and Rai, 1981). Because radionuclides generally have specific radioactive decay energies, radiation counting techniques can be used to provide analytical data on solution chemistry that far exceed standard chemical analytical techniques.

Work Element W.3.8 (Priority 3)

Determine requirements for monitoring. Define parameters, methodology, interpretive criteria, and actions.

Status

Preliminary investigations are in progress.

Plans

Techniques for measuring waste package performance will be developed and a monitoring program will be planned and conducted in the first waste disposal panel of the repository at Hanford.

15.4 SUMMARY OF BASALT WASTE ISOLATION PROJECT WASTE PACKAGE DESIGN, SITE GEOCHEMISTRY, AND RELATED TESTING AND PERFORMANCE ACTIVITIES

The status and plans for each of the work elements associated with waste package design, site geochemistry, and testing and performance-confirmation criteria and/or issues were presented in Section 15.3. In this section, a brief description of all the technical work being undertaken by the BWIP on these tasks is provided in summary narrative form. These narratives are accompanied by a logic diagram (Fig. 15-3) that describes, in general form, the main activities to accomplish the work, as well as the points at which the issues presented in Section 15.3 will be resolved. Schedules and milestones for the work described in this chapter will be presented in Chapter 17, along with those for the other issue and plans chapters (Chapters 13, 14, and 16). Each box on the logic diagram is keyed to the narrative material. Each section of the narrative also contains a list of the work elements that support the tasks designated.

As noted in Section 15.1, the design activity is the key work element that will determine the requirements for the data-gathering activities for the waste package design, site geochemistry, and testing and performance confirmation tasks. A wide range of material testing activities has been scoped to define the near-field repository environment, far-field repository environment, waste form stability, and waste/barrier/rock interactions and to provide waste package design verification. The materials data will provide the basis for the preparation of site-specific waste package design specifications to support the National Waste Terminal Storage Program waste package design effort and the BWIP repository design efforts.

Summary Activity Narratives

1. Prepare Input to Basalt Waste Isolation Project Plan

   The inputs to the BWIP plan summarize the work that will be performed by the waste package and site activities. This work will ultimately produce detailed waste package system specifications to ensure that the National Waste Terminal Storage Program waste package designs meet nuclear waste repository in basalt requirements.

   Applicable Work Element

   Initial work completed. The BWIP updates technical plans on an annual basis. The definition (technical planning) of the work required to meet criteria covered in Chapter 15 forms the basis of the work elements in this chapter.

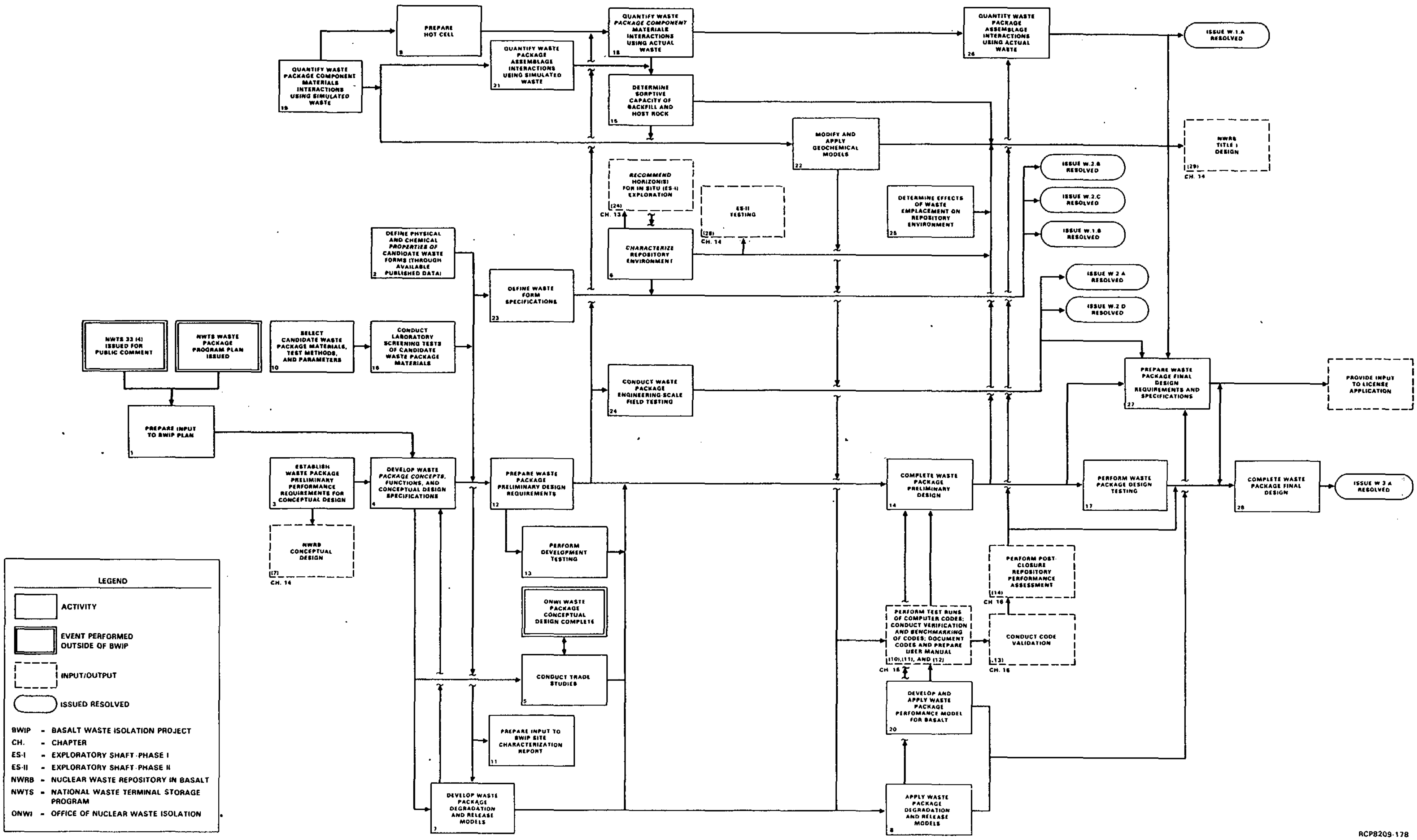

FIGURE 15-3. Logic Diagram for Waste Package and Site Geochemistry.

2. Define Physical and Chemical Properties of Candidate Waste Forms (through available published data)

The work on the waste package activity will be initiated by defining the physical and chemical properties of candidate waste forms. This is necessary because they will determine the design complexity of the waste packages required to prevent release of unacceptable amounts of radionuclides to the accessible environment. This design approach is the result of variations in the stability of the candidate waste forms currently being evaluated by the National Waste Terminal Storage Program.

Applicable Work Element

Work completed (Smith et al., 1980, Section 6).

3. Establish Waste Package Preliminary Performance Requirements for Conceptual Design

Preliminary performance requirements will be established for waste packages to be emplaced in a repository constructed in basalt. The preliminary performance requirements will be based on an assessment of the maximum permissible release rates of radionuclides from the near field of the repository. The release rate assessment will, in turn, be based on a one-dimensional transport model, which assumes equilibrium sorption/desorption behavior of all radionuclides. The transport model will calculate the maximum rate of release for each radionuclide that would ensure that concentrations in groundwater discharging to the accessible environment remain below acceptable levels as defined by federal regulations.

Applicable Work Element

Work completed, see Anderson (1982).

4. Develop Waste Package Concepts, Functions, and Conceptual Design Specifications

The preliminary waste package performance requirements will provide the basis for the development of waste package concepts and functions for spent fuel, transuranic wastes, and high-level wastes. These will permit required canister/overpack and backfill/buffer materials characteristics to be defined, from which data requirements for materials hydrothermal testing can be identified. Development of waste package concepts and functions will also support the preparation of waste package conceptual design specifications for the National Waste Terminal Storage Program waste package design effort.

Applicable Work Element

Work completed, see Anderson (1982).

5. Conduct Trade Studies

Trade studies will be identified and conducted as a result of allocation of performance requirements based on proposed regulatory criteria and expected site performance. Such analysis could result in the definition of performance requirements for the individual components (waste form, canister, and backfill) of the waste package subsystem leading to systems optimization of waste package design. If analysis of the present conceptual design reveals a requirement for an enhanced waste package design, trade studies aimed at optimizing cost/performance benefits for design alternatives will be conducted.

Applicable Work Element

W.1.2.A, W.1.7.A., W.1.13.B, W.1.20.B, W.1.24, W.2.8.A, and W.2.13.D.

6. Characterize Repository Environment

Geochemical characterization activities include the definition of host rock properties, such as the composition and petrology of primary and secondary minerals, as well as groundwater compositions in the repository near and far fields. This information will be coupled with laboratory and field hydrothermal tests and radionuclide-migration results to provide input to the assessment of radionuclide retardation.

Applicable Work Elements

W.1.1.A, W.1.2.A, W.1.4.A, W.1.7.A, W.1.10.A, W.1.18.B, W.2.1.A, W.2.4.A, W.2.5.A, W.2.6.A, W.2.9.B, W.2.10.C, W.2.11, W.2.13.D, and W.3.2.A.

7. Develop Waste Package Degradation and Release Models

Currently available waste package performance assessment models will be updated to meet BWIP specifications for basalt site-specific conditions and designs. The model, in conjunction with the geochemical model, will be used to evaluate the performance of waste package designs. The model will incorporate waste form dissolution mechanisms, dehydration/hydration of the waste package backfill and adjacent host rock, metallic corrosion, mechanical loading of the canister, possible backfill degradation mechanisms, and radionuclide releases from the waste package. These models will become part of the suite of models used for performance assessment described in Chapter 16.

Applicable Work Elements

W.1.2.A, W.1.5.A, W.1.9.A, W.1.11.A, W.1.12.A, W.1.13.B, W.1.16.B, W.1.19.B, W.2.2.A, W.2.3.A, W.2.4.A, W.2.8.A., W.2.12.D, W.2.13.D, W.3.3.A, and W.3.2.A.

8. Apply Waste Package Degradation and Release Models

The waste package performance assessment (degradation and release) model developed above will be used, in conjunction with laboratory test data, to evaluate waste package design concepts. These analyses will allow decisions to be made concerning the performance and cost effectiveness of various components of the waste package. The information generated by the waste package degradation and release model will be input into the performance assessment activities described in Chapter 16.

Applicable Work Elements

W.1.2.A, W.1.5.A, W.1.11.A, W.1.12.A, W.1.13.B, W.1.16.B, W.2.2.A, W.2.3.A, W.2.4.A, W.2.8.A, W.2.12.D, W.2.13.D, W.3.2.A, and W.3.3.A.

9. Prepare Hot Cell

Hot-cell facilities will be identified and prepared for waste package materials testing in the presence of actual waste forms. These tests are needed, although limited in number, to (1) more closely simulate conditions in the repository; (2) test the reliability of experiments using simulated waste forms, by comparing them with the results of experiments with actual waste forms; (3) study the key radionuclides in actual waste (technetium, plutonium, americium, neptunium) that cannot be represented by stable isotopes and, thus, are not contained in simulated waste; and (4) determine the effects of a radiation field on materials performance.

Applicable Work Elements

W.1.3.A, W.1.4.A, W.1.6.A, W.1.8.A, W.1.12.A, W.1.17.B, W.1.19.B, and W.3.7.

10. Select Candidate Waste Package Materials, Test Methods, and Parameters

Candidate waste package materials will be selected for testing, based on the materials characteristics required for compatibility with the waste package/basalt environment, while maintaining maximum compatibility with the remainder of the National Waste Terminal Storage Program transportation, waste handling, and repository system. Test methods and parameters will be selected for materials-evaluation activities.

Development of techniques for controlling Eh and pH in the range of values expected at elevated temperatures in the repository will allow the precise determination of waste package materials performance by laboratory (cold) and hot-cell testing.

Applicable Work Elements

Work completed, see Sections 11.2.2.1 and 11.3.2.3.

11. Prepare Input to Basalt Waste Isolation Project Site Characterization Report

    The waste package and site geochemistry chapters of this document will be prepared to reflect the current status of waste package technology development as it affects the reference repository site at Hanford.

    Applicable Work Element

    Work completed, see Chapters 6 and 11.

12. Prepare Waste Package Preliminary Design Requirements

    Preliminary design requirements for waste packages to be emplaced in a repository in basalt will be prepared, based on the current understanding of the waste form performance, repository environment, and waste package materials interactions. These requirements will support the BWIP design effort for waste packages to be emplaced in a repository at Hanford.

    Applicable Work Elements

    W.1.1.A, W.1.2.A, W.1.7.A, W.1.12.A, W.2.3.A, W.1.14.B, W.1.13.B, and W.1.19.B.

13. Perform Development Testing

    The reference conceptual design for the nuclear waste repository in basalt envisions the emplacement of canistered high-level nuclear waste in long (61-meter (200-foot)) horizontal emplacement holes extending between repository operating tunnels. The continued development of waste packages for this disposal configuration requires, first, that successful emplacement of the backfill around waste canisters lying end-to-end in the waste package borehole be demonstrated. This is the only development test presently planned to support waste package design. Should the backfilling tests of the long emplacement hole indicate that the required backfill density cannot be achieved, development testing (including fabrication testing of alternate waste package designs) will be required.

    Applicable Work Element

    W.3.6.

14. Complete Waste Package Preliminary Design

Preliminary designs for waste packages to be isolated in a nuclear waste repository in basalt will be completed based on preliminary design specifications.

Applicable Work Element

A preliminary design report will be prepared.

15. Determine Sorptive Capacity of Backfill and Host Rock

Sorption experiments will be conducted to determine the sorption-desorption and kinetic behavior of key radionuclides in the host rock (geohydrologic system). Evaluation of these data, plus data being developed on the solubility of key radionuclides (see Section 12), will define the performance requirements for the waste package backfill. Static and dynamic (flow-through) experiments will be used to determine the sorption behavior of key radionuclides in the repository geohydrologic system and candidate backfill materials to support waste package design. Equations developed from these data will also be used to evaluate radionuclide retardation factors for use in transport modeling.

Applicable Work Elements

W.1.3.A, W.1.4.A, W.1.8.A, W.1.9.A, W.1.10.A, W.1.12.A, W.1.16.B, W.1.17.B, W.1.19.B, W.2.1.A, W.2.3.A, W.2.4.A, W.2.5.A, W.2.6.A, W.2.7.A, W.2.8.A, W.2.9.B, W.2.11, W.2.12.D, W.2.13.D, W.3.2.A, and W.3.7.

16. Conduct Laboratory Screening Tests of Candidate Waste Package Materials

Early laboratory testing will determine the hydrothermal reactions between basalt, simulated waste, and groundwater, and, with the results of laboratory screening tests of candidate canister/overpack and backfill/buffer materials, will be used to develop site-specific waste package preliminary design specifications for the generic National Waste Terminal Storage Program waste package design effort. The basalt/groundwater hydrothermal reaction experiments will be used to determine the effectiveness of Eh control by the repository host rock.

Applicable Work Elements

W.1.5.A, W.1.9.A, and W.2.2.A.

17. Perform Waste Package Design Testing

The U.S. Nuclear Regulatory Commission proposed rule for disposal of high-level radioactive wastes in geologic repositories requires a

demonstration of effectiveness of waste handling equipment and systems for emplacement and retrieval operations. Also the National Waste Terminal Storage Program emphasizes field testing of retrievability. Coupled with these requirements is the need to demonstrate that the reference waste packages, developed from preliminary designs, can be successfully emplaced and retrieved remotely from the long horizontal boreholes. This design (field) testing will follow the backfilling development testing (see Activity 13) and will be scoped to provide information to support waste package final design.

Applicable Work Element

W.3.6.

18. Quantify Waste Package Component Materials Interactions Using Actual Waste

Upon completion of hot-cell preparation, hydrothermal testing will be initiated on waste package component materials to quantify their interaction in the presence of actual waste forms. The purpose of these tests will be to quantitatively determine: (1) variations in groundwater pH, Eh, and composition as a function of temperature and the solid phases present; (2) location of key radionuclides that may have precipitated from solution; and (3) degree of dissolution of the initial solid phases. With the ability to control Eh and pH within the autoclaves, the full range of anticipated repository conditions can be simulated.

Applicable Work Elements

W.1.1.A, W.1.2.A, W.1.3.A, W.1.4.A, W.1.6.A, W.1.7.A, W.1.8.A, W.1.9.A, W.1.10.A, W.1.11.A, W.1.12.A, W.1.13.B, W.1.14.B, W.1.16.B, W.1.17.B, W.1.18.B, W.1.19.B, W.1.20.B, W.1.24, W.2.3.A, W.2.5.A, W.2.6.A, W.2.7.A, W.2.8.A, W.2.9.B, W.3.2.A, W.3.4.A, and W.3.7.

19. Quantify Waste Package Component Materials Interactions Using Simulated Waste

The bulk of materials interaction studies will be conducted using simulated waste forms. In this way, the majority of the materials evaluation data will be developed at a significant cost savings. This advanced hydrothermal testing will be conducted to quantify the performance of candidate waste package materials under conditions expected in a repository in basalt. Static and flow-through tests will measure the interactions between the waste package components over a range of conditions (temperature, pH, and Eh) expected in the repository. These tests will also help define the role of Eh in changing the solubility of key radionuclides.

Applicable Work Elements

W.1.1.A, W.1.2.A, W.1.3.A, W.1.4.A, W.1.6.A, W.1.7.A, W.1.8.A, W.1.9.A, W.1.10.A, W.1.11.A, W.1.12.A, W.1.13.B, W.1.14.B, W.1.15.B, W.1.16.B, W.1.17.B, W.1.18.B, W.1.19.B, W.1.20.B, W.1.24, W.2.1.A, W.2.3.A, W.2.5.A, W.2.6.A, W.2.7.A, W.2.8.A, W.2.9.B, W.3.2.A., W.3.4.A, and W.3.7.

20. Develop and Apply a Waste Package Performance Model for Basalt

Performance assessment modeling and data from materials testing and natural analogs of backfills, canister, and waste forms is used along with accelerated field tests to verify waste package designs prior to repository operations. The waste package performance assessment model will consist of three major submodels: (1) a geochemical model that describes the behavior of radionuclides within the waste package and near field, (2) a degradation model that describes the physical and chemical processes affecting the waste package during containment and after breaching, and (3) a statistical model which will estimate waste package failure in the repository. The performance assessment model will be used to model radionuclide release from the very near-field region of a repository located in basalt and as input into the performance assessment activities described in Chapter 16.

Applicable Work Elements

W.1.2.A, W.1.4.A, W.1.9.A, W.2.8.A, W.2.11, W.2.13.D, W.3.3.A, W.3.4.A, W.3.6, and W.3.7

21. Quantify Waste Package Assemblage Interactions Using Simulated Waste

For this stage of hydrothermal testing, partial waste package assemblages will be exposed to expected repository conditions in the presence of simulated waste forms. During this stage, it is the responsibility of the hydrothermal testing program to ascertain the ability of the BWIP performance models to correctly predict the effectiveness of the waste package in retarding radionuclide transport. Therefore, experimental results that do not corroborate the model will lead to upgrading the model, which could, in turn, lead to minor changes in the barrier thicknesses. Both static and flow-through experiments will be used to test the waste package designs.

Applicable Work Elements

W.1.2.A, W.1.4.A, W.1.6.A, W.1.7.A, W.1.10.A, W.1.11.A, W.1.12.A, W.1.15.B, W.1.16.B, W.1.19.B, W.1.20.B, W.2.1.A, W.2.3.A, W.2.5.A, W.2.6.A, and W.2.9.B.

22. Modify and Apply Geochemical Models

A quantitative assessment of the near-field geochemical behavior of radionuclides will be made using one or more available geochemical models. Geochemical models, in conjunction with the waste package performance assessment model, will provide a source term for input into repository and far-field performance assessments. The geochemical model will be modified and validated with data from solubility, precipitation kinetics, sorption, and waste/barrier/rock interaction experiments, as well as from applicable natural analog studies. These models will become part of the suite of models used for performance assessment in Chapter 16.

Applicable Work Elements

W.1.9.A, W.1.13.B, W.1.16.B, W.1.20.B, W.1.24, W.2.8.A, W.2.11.D, W.2.12.D, W.2.13.D, W.3.2.A, and W.3.4.A.

23. Define Waste Form Specifications

The specific composition for reference commercial and defense high-level waste glass form has not been specified. Since a nuclear waste repository in basalt must safely isolate the waste forms received, such specifications are a key input to the design process. Waste form characteristics are a key part of the basis for assessing the designs of the waste package in terms of the allocated performance requirements for the engineered system. Detailed product specifications for the waste forms, which will form the basis of BWIP waste package preliminary design, will be documented after being mutually agreed upon by National Waste Terminal Storage Program participants.

Applicable Work Elements

W.1.1.A, W.1.4.A, W.1.9.A, W.1.12.A, W.2.3.A, W.2.5.A, W.1.18.B, W.1.19.B, and W.2.9.B.

24. Conduct Waste Package Engineering-Scale Field Testing

Concurrent with the hot-cell testing, field testing of engineering-scale waste packages will be carried out to support the preparation of the waste package final design specifications and aid in verifying the designs for waste packages to be emplaced in basalt.

Applicable Work Elements

W.3.5 and W.3.6.

25. Determine Effects of Waste Emplacement on Repository Environment

The process of verifying the effectiveness of a waste package requires an understanding of the effects of the emplacement of waste

on the repository environment. This information also provides input to the waste package design process, since not only does the emplaced waste act on the repository environment, but conversely, the waste package must be designed to obviate potential negative effects of repository geochemistry and thermomechanical effects. This task collects geochemical data from thermal modeling efforts (Activities 4, 8, and 21), radiation effects studies (Activities 15, 18, and 24), and waste/barrier/rock interaction studies (Activities 7, 14, 15, 17, and 18) (Fig. 15-3), as well as information from rock mechanics (see Chapters 4 and 14) and documents them into an integrated assessment of the effects of waste emplacement on the repository environment.

Applicable Work Elements

W.1.2.A, W.1.3.A, W.1.4.A, W.1.5.A, W.1.6.A, W.1.7.A, W.1.8.A, W.1.9.A, W.1.11.A, W.1.12.A, W.1.13.B, W.1.14.B, W.1.15.B, W.1.16.B, W.1.17.B, W.1.18.B, W.1.19.B, W.1.20.B, W.1.24, W.2.1.A, W.2.2.A, W.2.3.A, W.2.4.A, W.2.5.A, W.2.6.A, W.2.7.A, W.2.8.A, W.2.9.B, W.2.11, W.2.12.D, W.2.13.D, W.3.2.A, W.3.3.A, W.3.4.A, and W.3.7.

26. Quantify Waste Package Assemblage Interactions Using Actual Waste

Engineering-scale waste package assemblages, using actual waste, will be exposed to conditions simulating those expected in the repository. This will identify waste/barrier/rock/groundwater interactions that are likely to occur over time. The data will provide support for preparation of the repository waste package final design specifications and repository environmental report/license application, and will include: (1) finalization of proportions, dimensions, and compositions of the various waste package components, with a quantifiable assessment of the factor of safety needed for the final waste package design; (2) evaluation of the waste package system's ability to meet containment criteria (containment of all radionuclides), especially for the case of early failure of the canister/overpack components; (3) evaluation of waste package performance in meeting the postcontainment controlled release criteria; (4) confirmation of performance of complete waste package by means of scaled flow-through testing, simulating anticipated repository conditions; and (5) documentation of waste package performance to aid in licensing of a nuclear waste repository in basalt.

Applicable Work Elements

W.1.2.A, W.1.4.A, W.1.6.A, W.1.7.A, W.1.10.A, W.1.11.A, W.1.12.A, W.1.16.B, W.1.19.B, W.1.20.B, W.2.3.A, W.2.5.A, W.2.6.A, and W.2.9.B.

27. Prepare Waste Package Final Design Requirements and Specifications

The results of preliminary waste package performance evaluations, using the verified BWIP performance model, together with data accumulated from hot-cell, engineering, and field testing, will provide

support for the preparation of the repository waste package final design requirements and specifications. These specifications will ensure that the designs being developed by the BWIP waste package design subcontractor meet the needs of a repository in basalt. By this time, a sufficient waste package data base will have been developed to support repository Title I design effort and the preparation of the environmental report/license application for the construction of a repository at Hanford.

Applicable Work Elements

W.1.1.A, W.1.7.A, W.1.12.A, W.1.13.B, W.1.14.B, W.1.15.B, W.1.16.B, W.1.18.B, W.1.19.B, W.1.20.B, W.1.21, W.1.22, W.1.23, W.1.25, W.1.26, W.1.27, W.1.28, W.2.3.A, W.2.13.D, and W.3.5.

28. Complete Waste Package Final Design

Waste package final design will be developed and will be based on design specifications prepared from the results of materials hydrothermal testing and waste package design testing.

Applicable Work Element

A waste package final design report will be prepared.

15.5 WASTE PACKAGE AND SITE GEOCHEMISTRY CRITERIA/ISSUES/WORK ELEMENTS

The criteria, issues, and work elements utilized in the narratives in Section 15.3 are presented here (Table 15-5). Introductory comments concerning their development and organization are contained in Section 15.1.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 1 of 15)

Technical criteria	Issues	Work element
	W.1 - Design	
General Requirements of Design (60.135(a)) The design of the waste package shall include the following elements: Containment of Wastes (60.111(b)(2)) The engineered system shall be designed so that even if full or partial saturation of the underground facility were to occur, and assuming anticipated processes and events, the waste packages will contain all radionuclides for at least the first 1,000 years after permanent closure. This requirement does not apply to transuranic waste unless transuranic waste is emplaced close enough to high-level waste that the transuranic release rate can be significantly affected by the heat generated by the high-level waste. For clarification see: NWTS 33(1), 3.4.2 NWTS 33(4), 3.1 NWTS 33(4), 3.2.1 NWTS 33(4), 4.3.2.1	W.1.A Does the very near-field interaction between the waste package and its components, the underground facility, and the geologic setting compromise waste package or engineered system performance? (i.e., What is the maximum expected release rate from the engineered system, and does the geologic setting prevent the waste package containment objective from being achieved?)	W.1.1.A (Identical to W.1.18.B) Determine the maximum operating temperature limits for waste form, backfill, canister, and host rock. W.1.2.A (Related to W.1.7.A, includes discussion of W.1.11.A) Determine conditions that affect design of waste packages, including thermal loading, mechanical loading, and chemical environment, during handling, shipment, emplacement, retrieval, and after repository decommissioning. W.1.3.A (Identical to W.2.7.A, includes discussion of W.1.8.A) Determine the effect of the waste package radiation environment on near-field geochemistry, waste package, and barrier material performance. W.1.4.A (Identical to W.2.5.A, W.2.9.B, see W.1.12.A) Determine the projected solubilities, kinetic behavior, and distribution of aqueous species for key radionuclides which might be released from the waste package.
High-Level Waste Releases (60.111(b)(2)(ii)(A)) For high-level waste, the engineered system shall be designed so that, after the first 1,000 years following permanent closure, the annual release rate of any radionuclide from the		

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 2 of 15)

Technical criteria	Issues	Work element
engineering system into the geologic setting, assuming anticipated processes and events, is at most one part in 100,000 of the maximum amount of that radionuclide calculated to be present in the underground facility (assuming no release from the underground facility) at any time after 1,000 years following permanent closure. This requirement does not apply to radionuclides whose contribution is less than 0.1 percent of the total annual curie release as prescribed by this paragraph. For clarification see: 10 CFR 60.111(b)(2)(iii)(A)		W.1.5.A (Identical to W.2.2.A) Determine the extent of Eh-pH and groundwater compositional control by the host basalt after repository closure. W.1.6.A (Includes discussion of W.1.11.A, see also W.2.2.A) Determine the susceptibility of candidate canister materials to degradation (i.e., corrosion, hydriding, fatigue, etc.) in the repository near-field environment.
Transuranic Releases (60.111(b)(2)(ii)(B)) For transuranic waste, the engineered system shall be designed so that following permanent closure the annual release rate of any radionuclide from the underground facility into the geologic setting, assuming anticipated processes and events, is at most one part in 100,000 of the maximum amount calculated to be present in the underground facility (assuming no release from the underground facility) at any time following permanent closure. This requirement does not apply to radionuclides whose contribution is less than 0.1 percent of the annual curie release as prescribed by this paragraph. For clarification see: 10 CFR 60.111(b)(2)(ii)(B))		W.1.7.A (Related to W.1.2.A) Determine design properties, including thermal, physical, mechanical, and chemical, for waste package component materials and host rock. W.1.8.A (Included in W.1.3.A) Determine the effect of radiation on the performance of the waste form, backfill, and near-field host rock. W.1.9.A (Included in W.1.12.A) Determine the release rate (performance) of candidate waste forms in the repository near-field environment.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 3 of 15)

Technical criteria	Issues	Work element
Emplacement Environment (60.135(a)(1)) The waste package shall be designed so that the in situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the function of the waste packages. The design shall include but not be limited to consideration of the following factors: solubility, oxidation/reduction reactions, corrosion, hydriding, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads, and synergistic interactions. For clarification see: 10 CFR 60.135(a)(1)		W.1.10.A (Identical to W.2.6.A) Determine the formation and stability of radionuclide complexes and/or colloids over expected repository near-field and far-field conditions.
Waste Package Effect on the Underground Facility Natural Barriers (60.135(a)(2)) The waste package shall be designed so that the in situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the performance of the underground facility or the geologic setting. The design shall include but not be limited to consideration of the following factors: solubility, oxidation/reduction		W.1.11.A (Included in W.1.2.A and W.1.6.A) Determine the chemical properties and inflow rate of groundwater and their effect on canister corrosion during the 1,000-year containment period.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 4 of 15)

Technical criteria	Issues	Work element
reactions, corrosion, hydriding, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads, and synergistic interactions. For clarification see: 10 CFR 60.135(a)(2)		W.1.12.A (Identical to W.2.3.A and W.1.19.B, includes discussion of W.1.9.A) Determine the extent to which the interaction between the canister materials, waste form, backfill, and host rock in a saturated environment results in retardation of radionuclides.
	W.1.B Is a unique borehole backfill required?	W.1.13.B Assess the impact of waste storage in a borehole with no backfill on waste containment and isolation. IF A UNIQUE BOREHOLE BACKFILL IS REQUIRED, THE FOLLOWING FACTORS ARE NEEDED. SOME OF THESE FACTORS MAY NEED COMPLETION TO DECIDE ISSUE W.1.B. W.1.14.B Determine the need for special tailoring agents in backfill to moderate the corrosivity (Eh and pH) of the groundwater contacting the canister. W.1.15.B (See also W.1.16.B) Define the characteristics of the backfill materials required to retard the flow of groundwater to the canister. Identify potential backfill materials with these characteristics.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 5 of 15)

Technical criteria	Issues	Work element
		W.1.16.B Define the characteristics of the backfill material required to reduce the rate of radionuclide release from the waste package. Identify backfill materials with these characteristics.
		W.1.17.B (Identical to W.1.8.A, included in W.1.3.A) Determine the effect of radiation damage on the performance of the waste form, backfill, and host rock.
		W.1.18.B (Identical to W.1.1.A) Determine the maximum operating temperature limits for waste form, backfill, canister, and host rock.
		W.1.19.B (Identical to W.1.12.A and W.2.3.A) Determine the extent to which the interaction between the canister material, waste form, backfill, and host rock in a saturated environment results in retardation of radionuclides.
		W.1.20.B (Included in W.2.13.D) Determine if a waste package backfill is required to provide acceptable containment in the event of premature canister failure.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 6 of 15)

Technical criteria	Issues	Work element
Waste Form Requirement (60.135(b)) Radioactive waste that is employed in the underground facility shall meet the following requirements: (1) Solidification All such radioactive wastes shall be in solid form and placed in sealed containers.	None.	W.1.21 Develop waste package acceptance specifications for waste solidification that meet U.S. Nuclear Regulatory Commission proposed requirements.
(2) Consolidation Particulate waste forms shall have been consolidated (for example, by incorporation into an encapsulating matrix) to limit the availability and generation of particulates.	None.	W.1.22 Develop waste package acceptance specifications for consolidation that meet U.S. Nuclear Regulatory Commission proposed requirements.
(3) Combustibles All combustible radioactive wastes must have been reduced to a noncombustible form unless it can be demonstrated that a fire involving a single package will neither compromise the integrity of other packages, nor adversely affect any safety-related structures, systems, or components.	None.	W.1.23 Develop waste package acceptance specifications for combustibles that meet U.S. Nuclear Regulatory Commission proposed requirements.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 7 of 15)

Technical criteria	Issues	Work element
Waste Package Requirements (60.135(c)) The waste package design shall meet the following requirements: (1) Explosive, Pyrophoric, and Chemically Reactive Materials The waste package shall not contain explosive or pyrophoric materials or chemically reactive materials that could interfere with operations in the underground facility or compromise the ability of the geologic repository to satisfy the performance objectives.	None.	W.1.24 Determine the impact of the reprocessing technique (including waste fractionization) on waste package design. W.1.25 Develop waste package acceptance specifications for explosive, pyrophoric, and chemically reactive materials that meet U.S. Nuclear Regulatory Commission proposed requirements.
(2) Free Liquids The waste package shall not contain free liquids in an amount that could impair the structural integrity of waste package components (because of chemical interactions or formation of pressurized vapor) or result in spillage and spread of contamination in the event of package perforation.	None.	W.1.26 Develop waste package acceptance specifications for free liquids that meet U.S. Nuclear Regulatory Commission proposed requirements.
(3) Handling Waste packages shall be designed to maintain waste containment during transportation, emplacement, and retrieval.	None.	W.1.27 Determine the waste package handling, shipping (including drop tests), emplacement, and retrievability requirements.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 8 of 15)

Technical criteria	Issues	Work element
(4) Unique Identification A label or other means of identification shall be provided for each package. The identification shall not impair the integrity of the package and shall be applied in such a way that the information shall be legible at least to the end of the retrievable storage period. Each package identification shall be consistent with the package's permanent written records. For clarification see: NWTS 33(1), 2.7 NWTS 33(1), 3.2.3 NWTS 33(1), 3.4.1 NWTS 33(1), 3.4.2 NWTS 33(2), 3.2.2 NWTS 33(2), 3.4 NWTS 33(4), 3.2 NWTS 33(4), 3.2.1 NWTS 33(4), 3.2.3 NWTS 33(4), 3.3 10 CFR 60.132(d)(3)	None.	W.1.28 Develop waste package acceptance specifications for identification that meet U.S Nuclear Regulatory Commission proposed requirements.
W.2 - Site Geochemistry		
Favorable Conditions in the Geologic Setting (60.122) The geologic setting shall exhibit an appropriate combination of these favorable conditions so that, together with the engineered system, the favorable conditions present are sufficient to provide reasonable assurance that performance objectives will be met.	W.2.A Are the geochemical and hydrologic properties of the geologic setting (in conjunction with the waste forms) sufficient to meet or exceed U.S. Nuclear Regulatory Commission proposed waste isolation requirements?	W.2.1.A (Related to W.2.4.A) Determine the effect on radionuclide mobility of changes in the primary and secondary mineralogical conditions in the near field and far field of the repository, along the expected pathway to the biosphere.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 9 of 15)

Technical criteria	Issues	Work element
For clarification see: 10 CFR 60.122		W.2.2.A (Identical to W.1.5.A) Determine the extent of Eh-pH and groundwater compositional control by the host basalt after repository closure.
(d) The nature and rates of geochemical processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste.		W.2.3.A (Identical to W.1.12.A and W.1.19.B) Determine the effects of waste/barrier/rock/water interactions on the performance of the underground facility or geologic setting.
(g) Geochemical conditions that (1) promote precipitation or sorption of radionucides; (2) inhibit the formation of particulates, colloids, and inorganic and organic complexes that increase the mobility of radionuclides; and (3) inhibit the transport of radionuclides by particulates, colloids, and complexes.		W.2.4.A Demonstrate that geochemical conditions in the near and far field are such that transport of radionuclides is retarded for sufficient time to satisfy waste isolation requirements.
(h) Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having increased capacity to inhibit radionuclide migration.		W.2.5.A (Identical to W.1.4.A and W.2.9.B) Determine the projected solubilities and distribution of aqueous species for key radionuclides wich might be released from the waste package.
<u>Potentially Adverse Conditions in the Disturbed Zone</u> <u>(60.123)</u> The presence of any of the following potentially adverse conditions may compromise site suitability and will require careful analysis and such measures as are necessary to compensate for them adequately (pursuant to 10 CFR 60.124).		W.2.6.A (Identical to W.1.10.A) Determine the formation and stability of radionuclide complexes and/or colloids over expected repository near- and far-field conditions.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 10 of 15)

Technical criteria	Issues	Work element
For clarification see: 10 CFR 60.123(b) (m) Conditions in the host rock that are not reducing conditions. (n) Groundwater conditions in the host rock, including but not limited to high ionic strength or ranges of Eh-pH, that could effect the solubility and chemical reactivity of the engineered systems. (o) Processes that would reduce sorption, result in degradation of the rock strength, or adversely affect the performance of the engineered system.		W.2.7.A (Identical to W.1.3.A) Determine the effect of the waste package radiation environment on near-field geochemistry, waste package, and barrier-material performance. W.2.8.A Determine acceptable release rates of key radionuclides from the engineered system as a function of containment time, groundwater travel time to the accessible environment, and water flow through the repository.
For clarification see: NWTS 33(2), 3.2 NWTS 33(2), 3.2(1) NWTS 33(2), 3.2(2) NWTS 33(2), 3.3(1) NWTS 33(2), 3.4(1) NWTS 33(2), p. 7.3.3 NWTS 33(3), 4.4.3	W.2.B What is the relative importance of waste form leach rates versus solubility of key radionuclides in the near-field environment for controlling release?	W.2.9.B (Identical to W.1.4.A and W.2.5.A) Determine the projected solubilities and distribution of aqueous species for key radionuclides which might be released from the waste package.
	W.2.C Can valid Eh measurements for the candidate repository horizons in the reference repository location be made either by potentiometric measurement or indirectly by measurement of dissolved redox couples?	W.2.10.C Determine the method and technique that can be utilized to provide valid in situ Eh measurements for the reference repository location.
<u>Mitigate Impacts of Failure of Engineered System</u> <u>(60.111(b)(3)(i))</u> During the containment period, the geologic setting shall mitigate the impact of premature failure of the engineered system. For clarification see: 10 CFR 60.111(b)(3)(ii)	None.	W.2.11 (Discussed in W.2.13.D) Determine how the geochemical and physical properties of the geologic setting mitigate the impact of premature failure of the waste package.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 11 of 15)

Technical criteria	Issues	Work element
Isolation (60.111(b)(3)(ii)) Following the containment period, the geologic setting, in conjunction with the engineered system as long as that system is expected to function, and alone thereafter, shall be capable of isolating radioactive waste so that transport of radionuclides to the accessible environment shall be in amounts and concentrations that conform to such generally applicable environmental standards as may have been established by the U.S. Environmental Protection Agency. For clarification see: NWTS 33(1), 2.1 NWTS 33(4), 2.1 NWTS 33(4), 3.1	W.2.D To what degree does the geologic setting retard migration of key radionuclides from the engineered system in meeting U.S. Environmental Protection Agency draft release criteria?	W.2.12.D (Related to W.2.11) Determine on a radionuclide-specific basis whether U.S. Nuclear Regulatory Commission proposed repository release rates or U.S. Environmental Protection Agency draft release limits are the limiting repository requirements. W.2.13.D (Includes discussion of W.1.20.B and W.2.11) Determine to what degree the characteristics of the geologic setting complement the engineered system.
W.3 - Testing and Performance Confirmation		
Standardized Testing (33(4), 3.4) Standardized, reproducible testing that is based upon sound statistical principles shall be developed to support predictions of waste package and waste form performance under conditions postulated for the operational and long-term containment and isolation phases. (a) Conditions The tests shall simulate expected or design basis conditions and conditions resulting from interactions with other disposal system components within practical limits.	W.3.A How can very near-field waste/barrier/rock materials interaction data, as measured experimentally, be extrapolated over time to reasonably assure that overall waste package and repository performance meets regulatory criteria?	W.3.1.A Define appropriate statistical techniques so that laboratory and field materials interaction data can be extrapolated over time to provide a reasonable assurance of the long-term performance of the engineered system. W.3.2.A Determine the thermodynamic and kinetic arguments that can be used to extrapolate short-term (less than 2 years per experiment) materials test (hydrothermal) data.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 12 of 15)

Technical criteria	Issues	Work element
(b) Extrapolations Where extrapolation of test data is required, test results shall be applied conservatively to the verification of the waste package and waste form performance models used in judging waste package acceptability. (c) Nondestructive Testing Nondestructive testing shall be provided for a statistically significant number of waste canisters prior to emplacement. For clarification see: NWTS 33(4), 3.4		W.3.3.A Develop and/or use numerical modeling techniques to predict the environmental conditions, package degradation, and radionuclide behavior of emplaced wastes in or near the engineered system. W.3.4.A Determine what natural analogues of waste package components can be used to verify the compatibility of the waste package with the repository environment.
	None.	W.3.5 Develop an acceptance test procedure for waste packages.
Performance Confirmation (60.140) General Requirements: (60.140) (a) The performance confirmation program shall ascertain whether: (1) Actual subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the limits assumed in the licensing review.	None.	W.3.6 Determine and conduct field, engineering, and in situ testing as may be appropriate to meet design needs and U.S. Nuclear Regulatory Commission proposed performance requirements. W.3.7 Determine suitability of using nonradioactive chemical analogues for actual waste forms in the hydrothermal testing program.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 13 of 15)

Technical criteria	Issues	Work element
(2) Natural and engineered systems and components required for repository operations, or which are designed or assumed to operate as barriers after permanent closure are functioning as intended or anticipated.		
(b) The program shall have been started during site characterization and it will continue until permanent closure.		
(c) The program will include in situ monitoring, laboratory and field testing, and in situ experiments, as may be appropriate to accomplish the objective as stated above.		
(d) The confirmation program shall be implemented so that:		
(1) It does not adversely affect the natural and engineered elements of the geologic repository.		
(2) It provides baseline information and analysis of that information on those parameters and natural processes pertaining to the geologic setting that may be changed by site characterization, construction, and operational activities.		
(3) It monitors and analyzes changes from the baseline condition of parameters that could affect the performance of a geologic repository.		

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 14 of 15)

Technical criteria	Issues	Work element
(4) It provides an established plan for feedback and analysis of data, and implementation of appropriate action. For clarification see: NWTS 33(4), 3.1 NWTS 33(4), 3.4		
<u>Design Testing</u> (60.142) (a) During the early or developmental stages of construction, a program for in situ testing of such features as borehole and shaft seals, backfill, and the thermal interaction effects of the waste packages, backfill, rock, and groundwater shall be conducted. (b) The testing shall be initiated as early as is practicable. (c) A backfill test section shall be constructed to test the effectiveness of backfill placement and compaction procedures against design requirements before permanent backfill placement is begun.	None.	
<u>Waste Package Monitoring Program</u> (60.143) (a) A program shall be established at the repository for monitoring the condition of the waste packages. Packages chosen for the program shall be representative of those to be emplaced in the repository.	None.	W.3.8 Determine requirements for monitoring. Define parameters, methodology, interpretive criteria, and actions.

TABLE 15-5. Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry. (Sheet 15 of 15)

Technical criteria	Issues	Work element
(b) Consistent with safe operation of the repository, the environment of the waste packages selected for the waste package monitoring program shall be representative of the emplaced wastes. (c) The waste package monitoring program shall include laboratory experiments which focus on the internal condition of the waste packages. To the extent practical, the environment experienced by the emplaced waste packages within the repository during the waste package monitoring program shall be duplicated in the laboratory experiments. (d) The waste package monitoring program shall continue as long as practical up to the time of permanent closure. For clarification see: NWTS 33(1), 2.3 NWTS 33(4), 3.4		

15.6 SUMMARY

A methodology for defining the work required to satisfy applicable regulatory and programmatic technical criteria in the areas of waste package design, site geochemistry, and related testing and performance confirmation is presented in Section 15.1. The approach used to define work is a key part of the BWIP technical planning process. The details of the work needed to meet the criteria were presented initially as generalized work elements (statements of work). These specific work elements were further analyzed to identify in detail the data required and the analysis needed to complete each work element. The detailed description of the work needed to satisfy any specific applicable technical criteria is provided in tabular and narrative form in Section 15.3. These descriptions allow the reader to gain an understanding of the present status and future plans for each item of work proposed. A tabulation of all the criteria, work elements, and issues for waste package design, site geochemistry, and testing and performance confirmation is presented in Section 15.5.

Section 15.2 contains a summary of criteria considered resolved in the BWIP. Where debate or controversy about the available information or technology existed, issues were defined to highlight this fact. The resolution of these issues, as project work progresses, will be highlighted in the BWIP semiannual progress reports.

A logic diagram of the work described in this chapter is presented in Section 15.4. The logic diagram is accompanied by a brief narrative describing each element of the diagram and serves to present in summary form the overall and generalized scope of work described in this chapter. By consolidating the detailed elements of work into a more concise form, the flow and direction of waste package design, site geochemistry, and testing and performance confirmation activities can be more readily depicted. The logic diagram also identifies points at which the issues presented in this chapter will be resolved. Each narrative accompanying the logic diagram contains a listing of applicable work elements. Although individual test and confirmation activities are for the most part not called out in the logic diagram (Fig. 15-3), the reader can ascertain the depth and scope of the testing and performance confirmation activities by reading the individual status and plans descriptions in Section 15.2.

Finally, Chapter 17 of this document contains schedules for the resolution of the issues presented in Section 15.2 and a listing of technical milestones associated with the work described in this chapter and the other issue chapters (Chapters 13, 14, and 16). Chapter 17 thus ties all of the plans for the entire project into one integrated description with schedules and milestones to provide a capsule summary of the direction and scope of work being planned by the BWIP to complete site characterization.

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16. PERFORMANCE ASSESSMENT ISSUES AND PLANS

16.1 INTRODUCTION

This chapter integrates the status and plans of the preclosure work elements and postclosure-related work elements and issues described in Chapters 13 through 15 that are performance oriented.

The objectives of performance assessment of a geologic repository for nuclear waste are:

(1) Integrate all site characterization, materials testing, analytical results, and design requirements

(2) Demonstrate compliance with regulatory criteria

(3) Identify additional data needs

(4) Determine requirements for repository and waste package design

(5) Provide assurance of operations personnel and public safety during repository operation

(6) Provide assurance of long-term waste isolation.

The last objective is the major objective of performance assessment. The first five objectives must be achieved in order to achieve the major objective.

> Postclosure performance assessment, as defined in Chapter 12, is the prediction of component and system behavior, relative to containment and isolation of radioactive wastes. These predictions will be used to evaluate their conformance with regulatory standards.

The process of performance assessment involves defining failure or disruptive scenarios and the assessment of the consequences of that failure for the isolation system, over a range of anticipated and postulated conditions. The ultimate aim of postclosure performance assessment is the integration of the information obtained from site, repository, and waste package studies, design activities, and field and in situ testing, by use of conceptual and numerical models, to assure the public that the construction, operation, and decommissioning of a repository will not cause an unacceptable impact on present or future generations.

Preclosure performance assessment activities are focused on assessing the safety of the operating repository, including transportation and retrievability options, under both normal and accidental operating conditions.

The process of assessing the safety of the engineered system involves the identification of various work operations and the events that might cause accidents, developing detailed operation and event scenarios, evaluating hazards associated with each operation for given accident scenarios, and examining preventive or mitigative measures for the cases evaluated. The primary purpose of the preclosure safety performance analysis is to provide assurance that the repository can be operated in a manner that will assure the safety of operating personnel and the general public.

The focus of the Basalt Waste Isolation Project (BWIP) site work and scientific/engineering investigations thus far has been on the postclosure aspects of radionuclide release and transport; therefore, the discussions in this chapter emphasize postclosure performance assessment. The subject of preclosure performance assessment and the BWIP's approach to resolving it is in an early stage of development and is only addressed in a summary fashion.

The results of BWIP preclosure performance assessment activities will serve to guide the preparation of an updated conceptual design for a nuclear waste repository in basalt and provide valuable input into postclosure performance assessment activities since design considerations are an important element of the postclosure assessment. The relationship of performance assessment to other BWIP activities is illustrated in Figure 16-1.

16.1.1 Criteria Organization and Selection of Issues

The criteria (Section 16.5) and, therefore, the issues and work elements described in Section 16.3 are organized into four subsections. These subsections were chosen to clarify the logic of relating criteria to ongoing work. The subsections chosen for this chapter are preemplacement site performance, postclosure performance of the engineered system, postclosure performance of the waste isolation system, and preclosure repository performance. The U.S. Nuclear Regulatory Commission has designated certain of its criteria as performance objectives in 10 CFR 60 (NRC, 1981a). For a nuclear waste repository in basalt, these criteria relate to preemplacement groundwater travel time and the stability of the geologic setting, waste containment, and waste release. These criteria, in conjunction with the U.S. Environmental Protection Agency draft regulations (EPA, 1981), form the primary basis for postclosure repository performance assessment. Requirements for preclosure repository performance assessment are included only in the description of the content of the License Application (NRC, 1981b), as is a further definition of requirements for the postclosure assessment. The criteria that are applicable to performance assessment are identified in Figure 16-2.

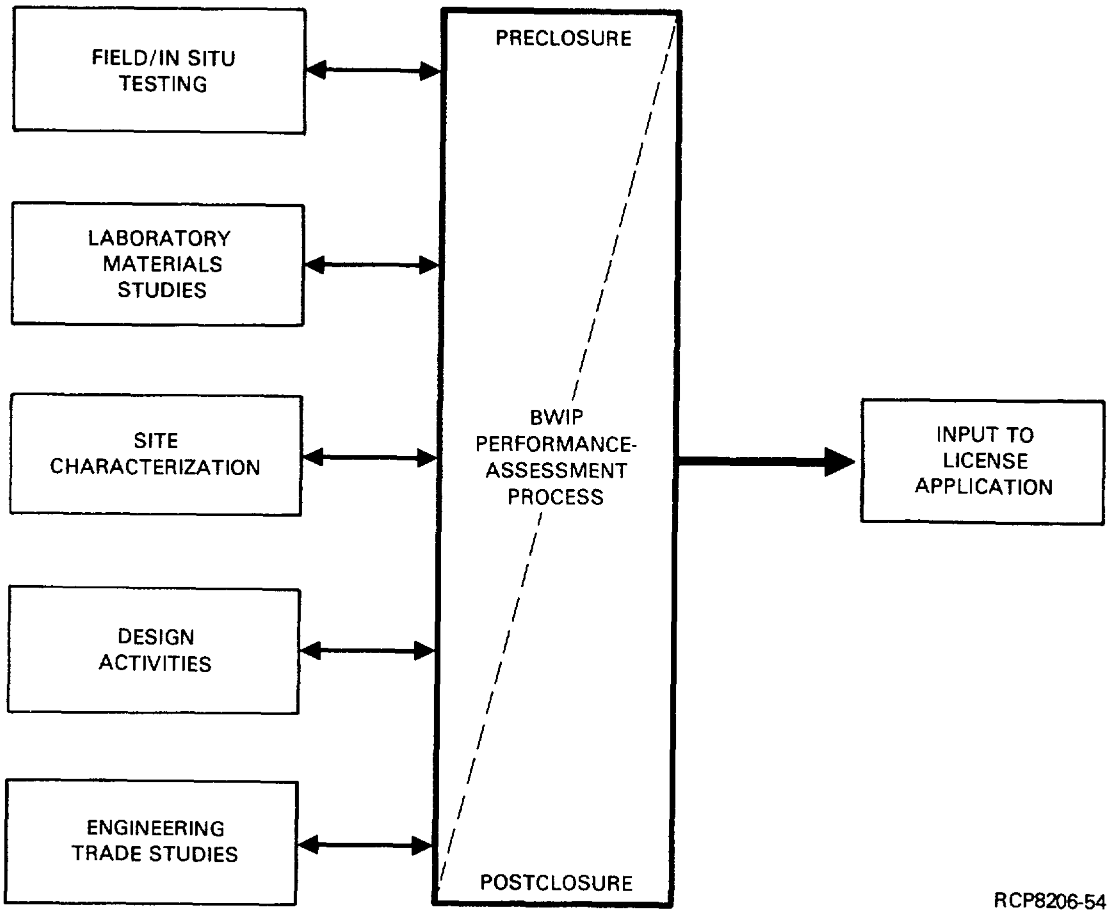

FIGURE 16-1. Relationship of Performance Assessment to Other Basalt Waste Isolation Project Activities.

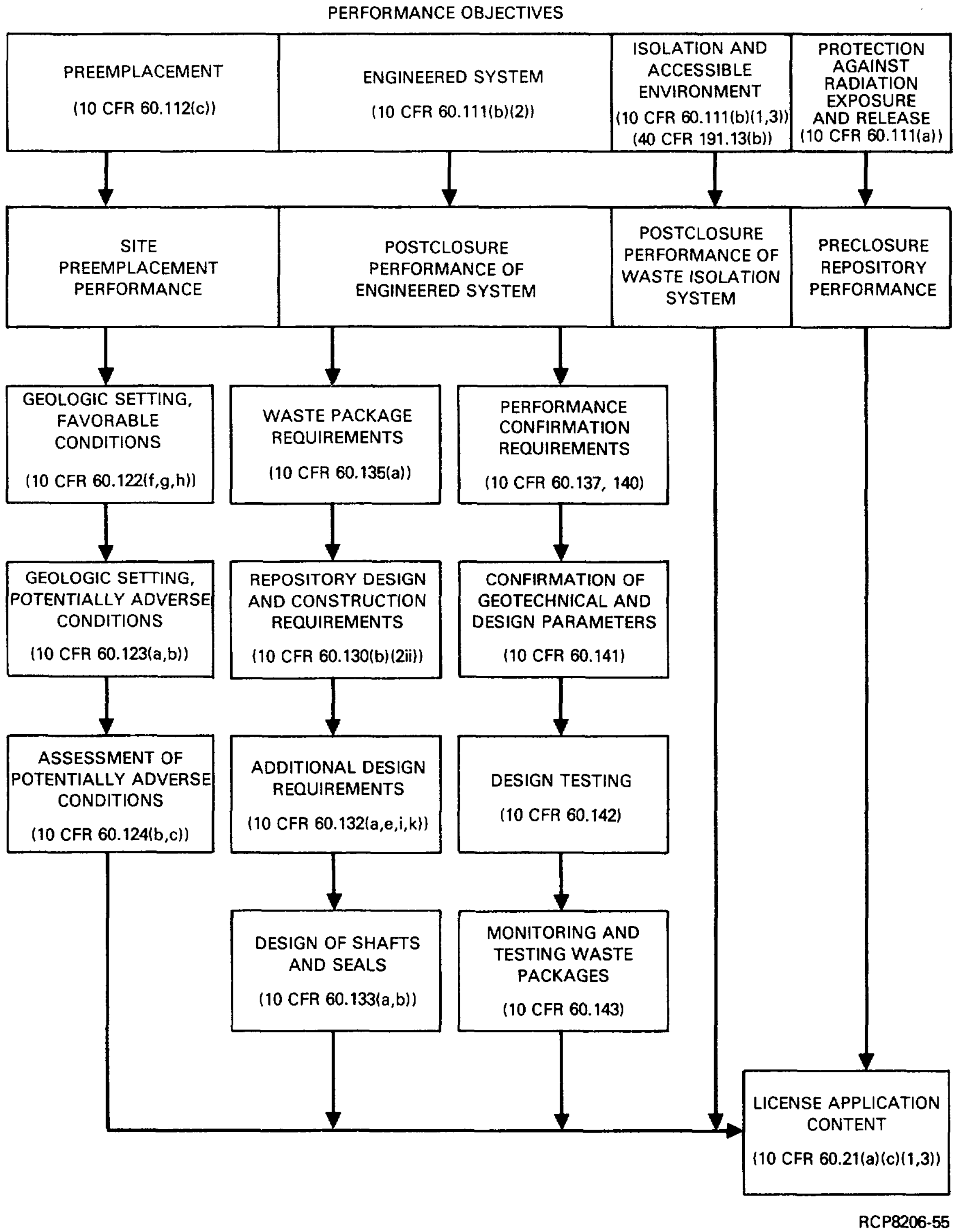

FIGURE 16-2. Criteria Governing Performance-Assessment Issues and Work Elements (numbers/letters in parentheses relate to 10 CFR 60 and 40 CFR 191 (EPA, 1981; NRC, 1981a)).

The identification of work needed and issues requiring resolution, which are listed in the criteria/issue/work element tables (Section 16.5), are comparable to those found in Chapters 13, 14, and 15. No unique issues are identified in this chapter. Three issues that relate to post-closure performance assessment are listed in Table 16-1. No issues are related to preclosure performance assessment. While the postclosure performance assessment issues are relatively clearly stated, straightforward, and definitive, their resolution is strongly tied to many work elements in Chapters 13, 14, and 15 that may constitute performance assessment subissues. Many of these work elements are related by the fact that proof of compliance with technical and administrative criteria depends on the reliability of the data and of the numerical models to predict isolation system and subsystem performance.

16.1.2 Work Element Analysis: Data Needs and Status

To describe the work in sufficient detail to identify required resources, the BWIP has defined the specific items of information required to complete a given work element. Most of the work elements required to meet the performance-related criteria listed in Figure 16-2 are described in detail in Chapters 13, 14, and 15 of this document, where they are associated with one of the performance assessment issues or a related performance subissue. Such work elements are referenced in this chapter, but the descriptions are not repeated. Where a unique element of work is identified that has no basis in the preceding chapters, it is clearly identified, and narrative describing the status of the work and plans for its completion are provided in Section 16.3.

16.1.3 Issues/Work Elements Numbering System

Each of the performance assessment subsections is designated by a unique identification number (P.1 = Preemplacement Site Performance, P.2 = Postclosure Performance of the Engineered System, P.3 = Postclosure Performance of the Waste Isolation System, and P.4 = Preclosure Repository Performance). Each new work element associated with these sections that is required to satisfy a given criterion or criteria grouping is numbered consecutively throughout a given section. All new work elements associated with preemplacement site performance are numbered P.1.1---P.1.n, where n is the last new work element in the section.

TABLE 16-1. Issues for Performance Assessment.

Issue	Issue number	Chapter
P.1 <u>Preemplacement Site Performance</u> Are the pre-waste-emplacement ground-water travel times near the repository sufficient to assure compliance with U.S. Nuclear Regulatory Commission proposed technical criteria?	S.1.C-SC	5, 12, 13
P.2 <u>Postclosure Performance of the Engineered System</u> Does the very near-field interaction between the waste package and its components, the underground facility, and the geologic setting compromise waste package or engineered system performance? (i.e., What is the maximum expected release rate from the engineered system, and does the geologic setting prevent the waste package containment objective from being achieved?) (Related to Issues W.2.A, W.3.A, R.1.A, R.1.B, and R.1.D)	W.1.A-WA	11, 12, 15
P.3 <u>Postclosure Performance of the Waste Isolation System</u> What is the total amount (activity) of radionuclides potentially releasable to the accessible environment in a 10,000-year period, and is this amount in compliance with appropriate U.S. Environmental Protection Agency regulations? (Related to Issue W.2.D)	S.1.D-SD	12, 13
P.4 <u>Preclosure Repository Performance</u> No issues have been identified.		

The integration of performance-oriented issues and work elements from Chapters 13, 14, and 15 with work elements that are unique to Chapter 16 requires a modification of the numbering system used in Chapters 13, 14, and 15. The issues related to preemplacement, engineering, and waste isolation performance from Chapters 13 and 15 have been identified by their original designators, with the addition of the letters SC, WA, and SD. These additional letters are appended to each work element to identify the associated issue; i.e., Work Element P.3.1-SD is associated with Issue S.1.D-SD; Work Element S.1.30.C-SD is now associated with Issue S.1.D-SD. Note that the repeated work elements may not be associated with the same issue in Chapter 16 as they were in earlier chapters.

Many of the work elements described in Section 16.5, which serve to resolve the issues identified in this chapter, are a subset of the work elements originally identified with Issues S.1.C, W.2.D, and S.1.D. Those work elements that only provide input data to the performance assessment process were not reused in this chapter. Examination of Chapters 13 through 15 did, however, identify additional work elements that support the resolution of a given performance-oriented issue, and these were added to the additional work element lists in Section 16.5 to complete the integration process. For example, Issue S.1.C (from Chapter 13) is found associated with U.S. Nuclear Regulatory Commission proposed criteria on both groundwater flow characteristics and geochemistry. Work elements on groundwater flow characteristics are discussed in Chapter 13, but the geochemistry work is discussed in Chapter 15. Therefore, applicable preemplacement geochemistry performance-oriented work elements have been added to Section P.1, Preemplacement Site Performance.

16.1.4 Organization of Chapter 16

Section 16.1 introduces performance assessment concepts and relates them to the scope of the preceding Chapters 13, 14, and 15. It introduces the performance-oriented issues selected from Chapters 13, 14, and 15 and identifies the criteria governing performance assessment. The format of the tables of criteria, issues, and work elements is described.

Section 16.2 deals with criteria considered fully addressed by the BWIP.

Section 16.3 lists the performance-related work elements by organizational subsection (Preemplacement Site Performance, Postclosure Performance of the Engineered System, Postclosure Performance of the Waste Isolation System, and Preclosure Repository Performance). For work elements that are unique to this chapter, a narrative containing status and plans is provided. For work elements that have been discussed in prior planning chapters, only the statement of the work element is repeated to provide for continuity to the reader.

Section 16.4 contains a summary of the overall logic behind BWIP performance assessment activities in narrative and graphic form.

Section 16.5 contains the criteria/issue/work element tasks that were used as the basis for identifying work needed.

Section 16.6 contains a brief summary description of the information contained in this chapter.

Section 16.7 contains the references to the literature cited in this chapter.

The information provided in this chapter is an integration of the performance-oriented work elements taken from the preceding chapters and serves to identify how the BWIP will approach verifying the performance of a nuclear waste repository in basalt. The information resulting from the completion of the work elements cited will serve, when completed, to demonstrate whether or not the issues on postclosure performance assessment can be resolved. This will allow a detailed assessment of the suitability of the basalts beneath the Hanford Site as a site for a repository at the time of licensing.

16.2 SUMMARY OF FULLY ADDRESSED CRITERIA

16.2.1 Issues

Although the staff has discussed the issues on performance assessment in the data chapters of this document, performance assessment by its very nature cannot be completed nor issues resolved until all the data have been gathered and interpreted and performance projections have been made and validated. There are no fully resolved issues on performance assessment.

16.2.2 Criteria

None of the criteria listed in the criteria/issue/work element tables in Section 16.5 have been fully satisfied.

16.3 UNRESOLVED ISSUES AND PLANS FOR THEIR RESOLUTION

This section contains a narrative analysis of work needed to meet U.S. Nuclear Regulatory Commission proposed criteria on performance assessment. The section is organized into four subsections: Preemplacement Site Performance, Postclosure Performance of the Engineered System, Postclosure Performance of the Waste Isolation System, and Preclosure Repository Performance. Narratives (status and plans) are provided for the new work elements specific to performance assessment. Only a statement of the work element is provided for those elements of work that have appeared previously in Chapters 13, 14, or 15.

16.3.1 Preemplacement Site Performance

ISSUE S.1.C-SC

Are the pre-waste-emplacement groundwater travel times near the repository sufficient to assure compliance with U.S. Nuclear Regulatory Commission proposed technical criteria?

Work Element P.1.1-SC (Identical to P.2.1-WA and P.3.1-SD) (Priority 1)

Prepare a systems description for postclosure repository performance defining all subsystem models (including those used for preemplacement assessment), as well as the criteria on which they are based.

Status

This work has not yet been initiated.

Plans

A broad technical information base will be needed to carry out the various functions of the postclosure repository performance assessment. This information base will provide a complete description of the repository system (i.e., engineered facility and geologic setting). Typical categories of data for the systems description are room and pillar design, canister placement and loading strategy, waste inventory and thermal output, thermal and hydraulic properties of the engineered barriers and backfill materials, thermal and hydrologic properties of the emplacement horizon and surrounding rock mass, solubility and sorption properties of the waste form, etc. This technical information will be catalogued and documented in (1) the BWIP data packages, (2) research integration reports, and (3) a computerized data base. In addition to the technical-information base, a set of performance criteria will be compiled for the various subsystems of the repository system. The criteria will be derived from the criteria developed and proposed by the National Waste Terminal Storage Program (NWTS, 1981a; 1981b; 1981c; 1981d), U.S. Nuclear Regulatory Commission proposed technical criteria (NRC, 1981a), and the

U.S. Environmental Protection Agency draft regulations (EPA, 1981). The postclosure systems description will also contain a summary description of all codes, including data requirements, by subsystem, which will be utilized by the BWIP for postclosure analysis. Performance subsystems include those dealing with groundwater travel times, radionuclide release, release rates at various boundaries, waste package degradation, and dose to man. An assessment of accuracy requirements for data will also be included in the systems description.

Work Element S.1.30.C-SC (Related to S.1.7.A, S.1.9.A, S.1.11.B, S.1.17.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, S.1.29.C, and S.1.31.C) (Priority 1)

Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models.

Work Element S.1.31.C-SC (Related to S.1.30.C, S.1.33.C, S.1.34.C, S.1.38.D, and S.1.39.D) (Priority 1)

Develop and/or modify numerical codes that adequately simulate groundwater flow and travel times under pre-waste-emplacement conditions.

Work Element S.1.33.C-SC (Related to S.1.30.C, S.1.31.C, S.1.34.C, S.1.37.D, S.1.39.D, and S.1.41.D) (Priority 1)

Using selected models, predict groundwater travel time from the repository location to the accessible environment under pre-waste-emplacement conditions.

Work Element S.1.34.C-SC (Related to S.1.24.C, S.1.25.C, S.1.26.C, S.1.30.C, S.1.31.C, and S.1.33.C) (Priority 1)

Determine the bounds of uncertainty in model predictions of pre-waste-emplacement groundwater travel time.

Work Element W.2.13.D-SC (Includes discussion of W.1.20.B and W.2.11.C) (Priority 1)

Determine to what degree the characteristics of the geologic setting complement the engineered system.

Work Element P.1.2-SC (Identical to P.2.2-WA and P.3.2-SD) (Priority 1)

Conduct verification, validation, and benchmarking of all codes used for performance assessment.

Status

This work has not been initiated.

Plans

To qualify the broad set of performance assessment codes, a systematic testing and evaluation effort will be conducted to verify, benchmark, and validate the major codes. Verification of individual codes will be achieved by testing 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. Code benchmarking will consist of code-to-code comparisons in which simulations obtained with the BWIP codes are compared to those obtained with other available codes. The benchmark test cases will be based on data representative of the actual repository setting. The computer codes will be judged to be fully benchmarked when reasonable consensus between the independent code predictions is achieved. Validation of the performance assessment codes will be performed on two levels: (1) validation using data from laboratory experiments and (2) validation with field data from the candidate siting area. The first level of validation will be performed and completed with the verification and benchmarking, whereas the second level will be an ongoing effort conducted over the period of site characterization. During the validation process, analyses will be made to define what level of comparison of model predictions with field data are required for validation. Such analyses for the data-needs tables in Chapters 13 through 15 will be made in conjunction with sensitivity analyses of model inputs. The validation of an individual code will be considered complete when a sufficient degree of correlation is achieved between model prediction and the measured data.

Work Element P.1.3-SC (Identical to P.2.3-WA and P.3.3-SD) (Priority 2)

Document codes and prepare user manuals in accordance with regulatory guides and national quality assurance standards (ANSI/ASME, 1979).

Status

This work has just been formally initiated.

Plans

Documentation of the major performance assessment codes will consist of the following: (1) technical report, (2) user manual, and (3) internal documentation in the code source listing. The technical report will contain information on the model theory, numerical techniques, and results from the code verification and benchmarking. The user manual will contain instructions for use of the code, sample input and output for selected test cases, and a copy of the code source listing. The document will be prepared in accordance with the BWIP procedures written to meet NUREG 0856 (NRC, 1981c) and other applicable guidelines.

16.3.2 Postclosure Performance of the Engineered System (Priority 2)

ISSUE W.1.A-WA (Related to W.2.A, W.3.A, R.1.A, R.1.B, and R.1.D)

Does the very near-field interaction between the waste package and its components, the underground facility, and the geologic setting compromise waste package or engineered system performance? (i.e., What is the maximum expected release rate from the engineered system, and does the geologic setting prevent the waste package containment objective from being achieved?)

Work Element P.2.1-WA (Identical to P.1.1-SC and P.3.1-SD) (Priority 1)

Prepare a systems description for postclosure repository performance, defining all subsystem models (including those used for preemplacement assessment) as well as the criteria on which they are based.

Status

Identical to P.1.1-SC.

Plans

Identical to P.1.1-SC.

Work Element W.1.12.A-WA (Identical to W.2.3.A and W.1.19.B, includes discussion of W.1.9.A) (Priority 1)

Determine the extent to which the interaction between the canister materials, waste form, backfill, and host rock in a saturated environment results in retardation of radionuclides.

Work Element W.3.1.A-WA (Priority 1)

Define appropriate statistical techniques so that laboratory and field materials interaction data can be extrapolated over time to provide a reasonable assurance of the long-term performance of the engineered system.

Work Element W.3.2.A-WA (Priority 1)

Determine the thermodynamic and kinetic arguments that can be used to extrapolate short-term (less than 2 years per experiment) materials test (hydrothermal) data.

Work Element W.3.3.A-WA (Priority 1)

Develop and/or use numerical modeling techniques to predict the environmental conditions, package degradation, and radionuclide behavior of emplaced wastes in or near the engineered system.

Work Element W.3.4.A-WA (Priority 3)

Determine what natural analogues of waste package components can be used to verify the compatibility of the waste package with the repository environment.

Work Element R.1.2.A-WA (Priority 1)

Evaluate the effect of underground construction sequence on the stability of openings.

Work Element R.1.3.A-WA (Priority 2)

Determine the magnitude and the rate of deformation of tunnels and canister boreholes resulting from in situ, excavation-induced, and thermal stresses, and how deformation is affected by backfill.

Work Element R.1.5.A-WA (Priority 2)

Determine the magnitude and distribution of thermal stresses in the rock mass for the proposed waste package storage configuration.

Work Element R.1.9.A-WA (Priority 3)

Determine the potential for subsidence caused by mine openings.

Work Element R.1.10.B-WA (Priority 2)

Define the acceptable range of test results for intact rock and rock-mass characteristics to support design activities.

Work Element R.1.13.B-WA (Priority 1)

Develop and validate mechanical, thermal, and thermomechanical models for performance of in situ tests and for design and performance of the repository.

Work Element R.1.18.D-WA (Priority 1)

Identify performance requirements for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste.

Work Element R.1.22.D-WA (Priority 1)

Determine the effects of temperature, rock-mass deformation, and time on the permeability of the sealed rock zone.

Work Element R.1.29-WA (Related to R.1.30) (Priority 3)

Assess the effects of seismic events on underground openings during construction and operations.

Work Element R.1.66-WA (Priority 1)

Determine functional requirements for selecting locations of repository seals and backfills as engineered barriers to effectively retard groundwater movement and radionuclide migration.

Work Element R.1.67-WA (Priority 1)

Determine radionuclide sorption requirements for backfill materials to be used for repository rooms and tunnels.

Work Element P.2.2-WA (Identical to P.1.2-SC and P.3.2-SD) (Priority 1)

Conduct verification, validation, and benchmarking of all codes used for performance assessment.

Status

Identical to P.1.2-SC.

Plans

Identical to P.1.2-SC.

Work Element P.2.3-WA (Identical to P.1.3-SC and P.3.3-SD) (Priority 2)

Document codes and prepare user manuals in accordance with regulatory guides and national quality assurance standards (ANSI/ASME, 1979).

Status

Identical to P.1.3-SC.

Plans

Identical to P.1.3-SC.

16.3.3 Postclosure Performance of the Waste Isolation System

ISSUE S.1.D-SD (Related to Issue W.2.D)

What is the total amount (activity) of radionuclides potentially releasable to the accessible environment in a 10,000-year period, and is this amount in compliance with appropriate U.S. Environmental Protection Agency regulations? (Related to Issue W.2.D)

Work Element P.3.1-SD (Identical to P.1.1-SC and P.2.1-WA) (Priority 1)

Prepare a systems description for postclosure repository performance defining all subsystem models (including those used for preemplacement assessment), as well as the criteria on which they are based.

Status

Identical to P.1.1-SC.

Plans

Identical to P.1.1-SC.

Work Element S.1.41.D-SD (Related to S.1.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.23.B, S.1.24.C through S.1.26.C, and S.1.30.C) (Priority 1)

Identify credible disruptive events and potentially unfavorable process scenarios and estimate the associated properties and conditions of the host basalt near the repository site; develop bounding estimates for probabilities of occurrence for each event, as needed.

Work Element S.1.30.C-SD (Related to S.1.7.A, S.1.9.A, S.1.11.B, S.1.17.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, S.1.29.C, and S.1.31.C) (Priority 1)

Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models.

Work Element S.1.37.D-SD (Related to S.1.30.C, S.1.31.C, S.1.33.C, S.1.34.C, and S.1.39.D) (Priority 1)

Develop and/or modify numerical codes that can reliably predict the changes in the processes determining the rate and extent of radionuclide transport under post-waste-emplacement conditions.

Work Element S.1.39.D-SD (Related to S.1.24.C through S.1.30.C, S.1.37.D, S.1.38.D, S.1.40.D, R.1.13.D, W.1.20.D, W.2.4.A, W.2.8.A, W.2.11.D, and W.2.13.D) (Priority 1)

Using selected models, predict radionuclide mass fluxes to the accessible environment.

Work Element S.1.40.D-SD (Related to S.1.39.D) (Priority 2)

Determine the bounds of uncertainty in the model predictions of radionuclide fluxes to the accessible environment.

Work Element P.3.2-SD (Identical to P.1.2-SC and P.2.2-WA) (Priority 1)

Conduct verification, validation, and benchmarking of all codes used for performance assessment.

Status

Identical to P.1.2-SC.

Plans

Identical to P.1.2-SC.

Work Element P.3.3-SD (Identical to P.1.3-SC and P.2.3-WA) (Priority 2)

Document codes and prepare user manuals in accordance with regulatory guides and national quality assurance standards (ANSI/ASME, 1979).

Status

Identical to P.1.3-SC.

Plans

Identical to P.1.3-SC.

Work Element P.3.4-SD (Priority 1)

Perform a postclosure performance assessment for the waste isolation system for inclusion in the License Application.

Status

This work has not yet been started.

Plans

Upon completion of verification, validation, benchmarking, and documentation of all codes and models, the BWIP will perform a waste isolation performance assessment for inclusion in the License Application.

16.3.4 Preclosure Repository Performance

ISSUES

No issues have been identified.

Work Element P.4.1 (Priority 1)

Prepare an operating performance systems description identifying all engineered system structures, subsystems, and components important to safety.

Status

A draft of a systems specification document, based on early conceptual-design efforts and aimed at identifying engineering requirements and specifications for all engineered system structures, subsystems, and components has been prepared in outline form to allow the analysis of the engineered system. An annotated outline for a more complete engineered-system description to use as the basis for preclosure safety analysis is presently in preparation.

Plans

The BWIP will prepare, as part of the BWIP performance assessment plan, a detailed description of the structures, components, subsystems, and unit operations of the engineered system (repository and waste package). In addition to the description of the engineered system, the systems description will contain an analysis of criteria/measures for assessing the safety of the operating repository analogous to 10 CFR 50 Appendix A (NRC, 1980) (i.e., single point-failure mode) and will define the requirements for data on repository operating subsystems, components, and structures.

Work Element P.4.2 (Done in parallel with Work Element P.4.3) (Priority 1)

Prepare a preliminary preclosure repository safety assessment for normal operations and accidental conditions, based on the repository and waste package conceptual designs.

Status

The conceptual design for a repository and a waste package in basalt (KE/PB, 1982; AESD, 1982), in conjunction with the operating performance systems description (Work Element P.4.2) and the selection of failure scenarios (Work Element P.4.3), will provide the basis for a preliminary repository safety assessment.

Plans

A preliminary performance assessment, based on engineered system conceptual designs, will be performed to assess both industrial and radiation safety. Steps included in this analysis are:

(1) Identification and classification of all operations involving a potential hazard into separate "unit operations"

(2) Evaluation of each unit operation and the consequences of its hazard, including dose assessment, where necessary

(3) Development of preventive and/or mitigative measures for each of the unit operations under normal conditions.

The assessment of the safety for accidental conditions involves:

(1) Identification of credible natural and man-induced events that might initiate accidental conditions

(2) Development of detailed scenarios for each event (Work Element P.4.3)

(3) Evaluation of the consequences of each selected event scenario

(4) Examination in detail of preventive and/or mitigative measures appropriate to reduce the consequences or occurrence probability of each event.

The results of the preliminary preclosure performance assessment will provide guidance to the repository and waste package upgraded conceptual design.

Work Element P.4.3 (Done in parallel with Work Element P.4.2) (Priority 1)

Select and characterize preclosure failure scenarios.

Status

This work has not yet been initiated.

Plans

Using the completed repository and waste package conceptual designs and the operating performance systems description as a basis, the BWIP will select and rationalize preclosure failure scenarios. The analysis of failure scenarios will consist of developing scenarios for each likely and/or unlikely event and then evaluating the consequences of each selected event. Three categories of abnormal events appear to merit analysis. These are internal occurrences (explosion, fire, criticality, leaking waste canisters, waste shaft accidents...); externally induced occurrences (earthquake, tornado, flood, aircraft crash...); and transportation accidents. These scenarios will be listed and classified by type and probability category (likely or unlikely events) and used as a basis for the preliminary preclosure repository performance assessment described in Work Element P.4.2. Many of these items are discussed individually in Chapter 14.

Work Element R.1.35 (Priority 3)

Determine the impact of the dynamic effects of equipment failure on safety-related systems and components.

Work Element R.1.49 (Priority 3)

Determine the requirements necessary to assure that safety-related systems provide adequate protection to construction and operations personnel.

Work Element P.4.4 (Priority 1)

Prepare a preclosure safety performance assessment for normal operations and for accidental failure scenarios, including preventive and mitigative measures, for inclusion in the License Application.

Status

No work has been initiated.

Plans

This activity will be initiated upon completion of the upgraded conceptual repository and waste package design. The results and accompanying analysis will be included as part of the project's safety analysis report, which is a part of the License Application (NRC, 1981b).

16.4 SUMMARY OF BASALT WASTE ISOLATION PROJECT PERFORMANCE ASSESSMENT ACTIVITIES

The status and plans for each of the work elements associated with the assessment of preemplacement site performance, postclosure performance of the engineered system, postclosure performance of the waste isolation system, and preclosure repository performance criteria and/or issues were presented in Section 16.3. In this section, a brief description of all the technical work being undertaken by the BWIP on these tasks is provided in summary narrative form. These narratives are accompanied by a logic diagram (Fig. 16-3) that describes, in general form, the main activities to accomplish the work, as well as the points at which the issues presented in Section 16.1 will be resolved. Schedules and milestones for the work described in this chapter will be presented in Chapter 17, along with those for Chapters 13, 14, and 15. Each box on the logic diagram is keyed to the narrative material. Each section of the narrative also contains a list of the work elements that support the tasks designated.

As noted in Section 16.1, the performance assessment activity provides a means of integrating and evaluating the activities reported in the other chapters of this document. For the sake of clarity, the logic diagram showing the technical tasks in performance assessment is only divided into preclosure and postclosure activities. All the elements of postclosure performance assessment apply to the assessments of site preemplacement, the engineered system, and the waste isolation system. When completed, the performance assessment activities will provide a clear demonstration of whether a nuclear waste repository in basalt will cause an acceptable or unacceptable impact on present or future generations.

<u>Summary Activity Narratives</u>

1. <u>Plan Postclosure Preliminary Performance Assessment</u>

   As part of the project's technical planning activities, an initial approach to postclosure performance assessment was developed.

   <u>Applicable Work Elements</u>

   Work completed. Planning has resulted in the material presented in Chapter 12.

2. <u>Perform Preliminary Postclosure Performance Assessment and Define Code Input Requirements</u>

   The following preliminary performance assessments have been made and reported in Chapter 12:

   - Preliminary assessment of groundwater transit times (Section 12.4.1)

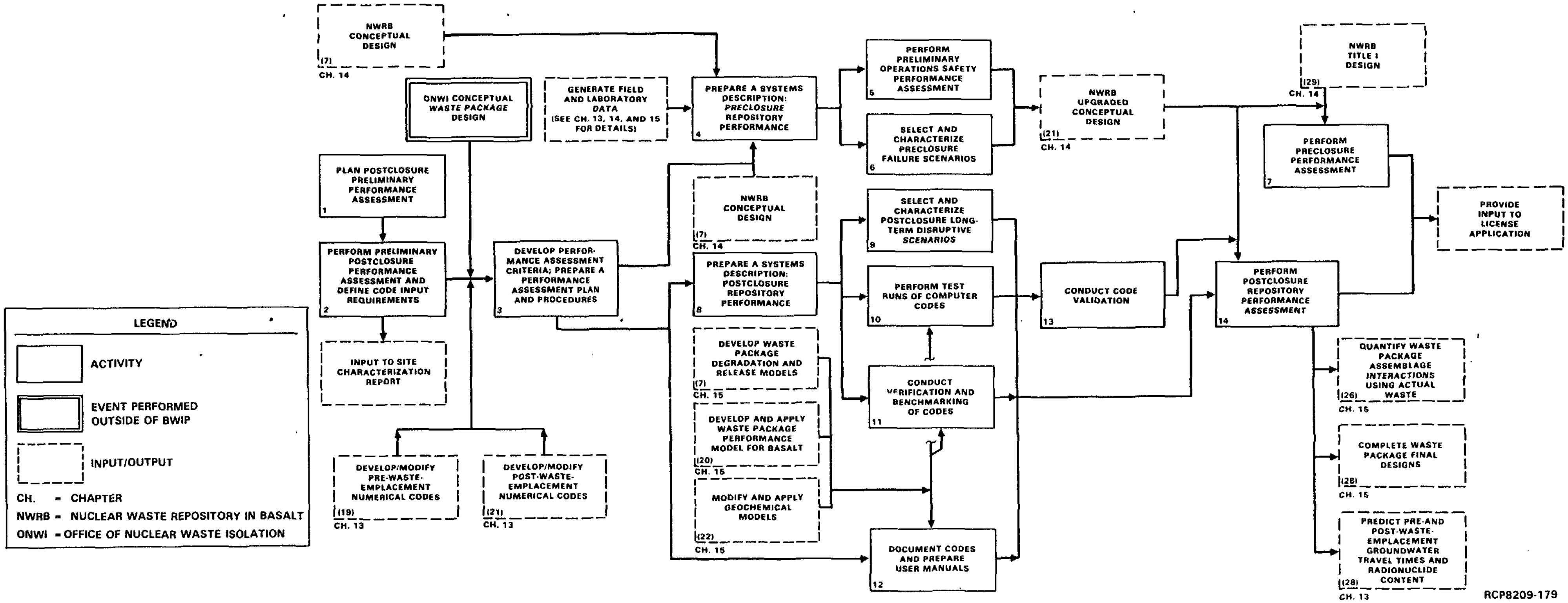

FIGURE 16-3. Logic Diagram for Performance Assessment.

- Very near-field studies of release from the engineered system to the accessible environment related to U.S. Nuclear Regulatory Commission proposed criteria (NRC, 1981a) (Section 12.4.2)

- Near-field studies to assess release to the accessible environment relative to draft U.S. Environmental Protection Agency regulations (EPA, 1981) (Section 12.4.3).

Applicable Work Elements

Work has been completed and was presented in Chapter 12. Applicable references were reported in Sections 12.4.1 through 12.4.3.

3. Develop Performance Assessment Criteria; Prepare a Performance Assessment Plan and Procedures

A performance assessment plan is being prepared that describes the approach to performance assessment used by the BWIP. This plan will treat both preclosure and postclosure performance assessment. The plan will contain criteria for performance assessments, describe the scope of performance assessment activities, identify the results that the BWIP expects from performance assessment, define the BWIP approach to control of modeling activities, including documentation and change control requirements, define the procedures needed to control performance assessment activities in a traceable manner, evaluate methods for determining the BWIP approach to uncertainty analysis, and in general serve to guide the BWIP performance assessment activities. After completion of the performance assessment plan, the procedures identified in the plan will be written and incorporated into the BWIP procedure manual.

Applicable Work Elements

This work has been initiated.

4. Prepare a Systems Description: Preclosure Repository Performance

The BWIP staff will prepare, as part of the BWIP performance assessment plan, a detailed description of the structures, components, subsystems, and unit operations of the engineered system (repository and waste package). In addition to the description of the engineered system, the systems description will contain an analysis of criteria and techniques for assessing the safety of the operating repository analogous to 10 CFR 50 Appendix A (NRC, 1980) (i.e., single failure criteria) and will define the requirements for data on repository operating subsystems, components, and structures.

Applicable Work Element

P.4.1.

5. Perform Preliminary Operations Safety Performance Assessment

A preliminary performance assessment, based on engineered system conceptual designs, will be performed to assess both industrial and radiation safety. Steps included in this analysis are:

(1) Identification and classification of all operations involving a potential hazard into separate "unit operations"

(2) Evaluation of each unit operation and the consequences of its hazard, including dose assessment, where necessary

(3) Development of preventive and/or mitigative measures for each of the unit operations under normal conditions.

The assessment of the safety for accidental conditions involves:

(1) Identification of credible events that might initiate accidental conditions

(2) Development of detailed scenarios for each event (Work Element P.4.3)

(3) Evaluation of the consequences of each selected event scenario

(4) Evaluation of the applicability of ALARA (as low as reasonably achievable) concept to a given design failure scenario and its consequence

(5) Examination in detail of preventive and/or mitigative measures appropriate to reduce the consequences or occurrence probability of each event.

The results of the preliminary preclosure repository performance assessment will provide guidance to the repository and waste package upgraded conceptual design.

Applicable Work Elements

P.4.2 and P.4.3.

6. Select and Characterize Preclosure Failure Scenarios

Using the completed repository and waste package conceptual designs and the operating performance systems description as a basis, the BWIP will select and rationalize preclosure failure scenarios. The analysis of failure scenarios will consist of developing scenarios for each likely and/or unlikely event and then evaluating the consequences of each selected event.

Applicable Work Elements

P.4.3, R.1.29, R.1.35, and R.1.49.

7. Perform a Preclosure Performance Assessment

This activity will be initiated on completion of the upgraded conceptual repository and waste package design. This assessment will be finalized based on repostiory Title II design effort. The results and accompanying analysis will be included as part of the project safety analysis report, which is a part of the License Application.

Applicable Work Element

P.4.4.

8. Prepare a Systems Description: Postclosure Repository Performance

A broad technical information base will be needed to carry out the various functions of the postclosure repository performance assessment. This information base will provide a complete description of the repository system (i.e., engineered facility and geologic medium). Typical categories of data for the systems description are room and pillar design, canister placement and loading strategy, waste inventory and thermal output, thermal and hydraulic properties of the engineered barriers and backfill materials, thermal and hydrologic properties of the emplacement horizon and surrounding rock mass, solubility and sorption properties of the waste form, etc. This technical information will be catalogued and documented in: (1) the BWIP data packages, (2) research integration reports, and (3) a computerized data base. In addition to the technical information base, a set of performance criteria will be compiled for the various subsystems of the repository system. The criteria will be derived from the criteria and regulations proposed and developed by the National Waste Terminal Storage Program (NWTS, 1981a; 1981b; 1981c; 1981d), the U.S. Nuclear Regulatory Commission (NRC, 1981a), and the U.S. Environmental Protection Agency (EPA, 1981). The postclosure systems description will also contain a summary description of all codes, including data requirements, that will be utilized by the BWIP for postclosure analysis by subsystem. Performance subsystems include those dealing with groundwater travel times, radionuclide release, release rates at various boundaries, waste package degradation, and dose to man. An assessment of accuracy requirements for data will also be included in the systems description.

Applicable Work Elements

P.1.1-SC, P.2.1-WA, and P.3.1-SD.

9. Select and Characterize Postclosure Long-Term Disruptive Scenarios

Selection and characterization of postclosure disruptive scenarios defines the credible events and processes and resultant radionuclide pathways that must be considered as the basis for repository site selection and engineered system design. The basic objective of this

activity is to establish scenarios having reasonable probability of occurrence and sufficient consequences to represent a meaningful design basis. The approach to scenario selection includes selection of criteria for inclusion or exclusion of specific scenarios, establishment of mechanisms for selecting the design basis scenario suite (e.g., expert consensus, analysis, site exploration), and definition and implementation of the methods by which pathway characteristics for each applicable scenario will be selected. Scenario description documents, culminating in a final report documenting scenarios for use in analyses supporting the repository construction License Application, will be prepared periodically during conduct of this work element.

Applicable Work Element

S.1.41.D through S.1.61.D, S.2.1, S.2.3, and S.2.5.

10. Perform Test Runs of Computer Codes

Computer test applications or runs with the major performance-assessment models will be performed for the purpose of (1) developing a detailed understanding of flow and transport processes in the basalt and (2) to assure that the computer codes are capable of describing the unique characteristics of the basalt. Some computer test runs will consist of parametric and sensitivity studies to provide information on the key hydrologic and other parameters. Other computational test runs will be designed to determine the capabilities and limitations of the computer codes to handle the expected range of repository conditions and hydrogeologic properties. This effort will be used as the basis for determining if additional model development is needed. Technical reports and articles will be prepared that will document the major results and findings of this effort.

Applicable Work Elements

S.1.30.C-SC, S.1.31.C-SC, S.1.33.C-SC, S.1.34.C-SC, S.1.37.D-SD, S.1.39.D-SD, S.1.40.D-SD, W.1.12.A-WA, W.2.13.D-SC, W.3.3.A-WA, R.1.2.A-WA, R.1.3.A-WA, R.1.5.A-WA, R.1.9.A-WA, R.1.10.B-WA, R.1.13.B-WA, R.1.18.D-WA, R.1.22.D-WA, R.1.29-WA, R.1.66-WA, and R.1.67-WA.

11. Conduct Verification and Benchmarking of Codes

To qualify the broad set of performance assessment codes, a systematic testing and evaluation effort will be conducted to verify, validate, and benchmark the major codes. Verification of individual codes will be achieved by testing 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. Code benchmarking will consist of code-to-code comparisons in which simulations obtained with the BWIP codes are compared to those obtained with other available codes. The benchmark test cases will be based on data representative of the actual repository setting. The computer codes will be judged to be fully benchmarked when reasonable consensus between the independent code predictions is achieved.

Applicable Work Elements

P.1.2-SC, P.2.2-WA, P.3.2-SD, W.3.1.A-WA, W.3.2.A-WA, W.3.4.A-WA, S.1.31.C-SC, S.1.37.D-SD, and S.1.40.D-SD.

12. Document Codes and Prepare User Manuals

Documentation of the major performance assessment codes will consist of the following: (1) technical report, (2) user manual, and (3) internal documentation in the code source listing. The technical report will contain information on the model theory, numerical techniques, and results from the code verification and benchmarking. The user manual will contain instructions for use of the code, sample input and output for selected test cases, and a copy of the code source listing. The document will be prepared in accordance with the BWIP procedures written to meet draft NUREG 0856 (NRC, 1981c), NQA-1 (ANSI/ASME, 1979), and other applicable guidelines.

Applicable Work Elements

P.1.3-SC, P.2.3-WA, and P.3.3-SD.

13. Conduct Code Validation

Validation of the performance assessment codes will be performed on two levels; (1) validation using data from laboratory experiments and (2) validation with field data from the candidate siting area. The first level of validation will be performed and completed with the verification and benchmarking, whereas the second level will be an ongoing effort conducted over the period of site characterization. The validation of an individual code will be considered complete when a sufficient degree of correlation is achieved between model prediction and the measured data.

Applicable Work Elements

P.1.2-SC, P.2.2-WA, P.3.2-SD, W.3.1.A-WA, W.3.1.A-WA, W.3.2.A-WA, W.3.4.A-WA, S.1.31.C-SC, S.1.37.D-SD, and S.1.40.D-SD.

14. Perform Postclosure Repository Performance Assessment

This activity will be initiated on completion of verification, validation, benchmarking, and documentation of all codes. Information from the updated conceptual waste package and repository designs will be used to describe the engineered system. The verified data obtained from laboratory, field, and in situ testing will be incorporated into the performance assessment of the waste isolation system in support of the License Application. Details of these activities are described below.

- Conduct Post-Waste-Emplacement Numerical Modeling

  Modeling work will be conducted to calculate the transport of key radionuclides and, in turn, to calculate the total activity of these radionuclides leaving the near-field boundary over a 10,000-year period. Work will be carried out in three areas: (1) canister- and room-scale modeling, utilizing rock stress/strain, heat transport, fracture-flow, and radionuclide transport data; (2) repository-scale modeling, utilizing heat transport, groundwater flow, and radionuclide transport data; and (3) far-field-scale modeling, utilizing groundwater flow and radionuclide transport data. The analysis performed will consider release under current geohydrologic conditions and postulated disruptive event conditions. Modeling work and acquisition of data will be performed in an iterative fashion as data are generated from hydrologic, geologic, rock mechanics, and waste package work.

- Conduct Uncertainty Analysis

  The radionuclide transport analysis carried out to estimate fluxes will also entail some bounding of the predictive uncertainty. This work will consist to two separate modeling efforts involving: (1) predictions of radionuclide transport using deterministic models and conservative data values and (2) application of probabilistic transport models that estimate the partial model validation using distribution of mass-flux values. These probabilistic calculations will be used as an independent check of the deterministic predictions, as well as a basis for quantifying likelihood of compliance with performance criteria.

- Perform Consequence Analysis

  An evaluation of plausible scenarios will be continued using consequence analysis. Additional modeling work will be undertaken to determine if the consequences of a particular event are sufficiently small to cause the issue of probability of occurrence to be of limited or no interest; i.e., even if the probability of occurrence of an event is 1, the radionuclides would be contained in the deep basalt away from the accessible environment. If it is determined that an event or process has a potentially insignificant consequence, the overall risk will be calculated from the consequence and the probability of occurrence formulated.

  Applicable Work Elements

  P.3.4-SD, S.1.1.A-SA through S.1.10.A-SA, S.1.11.B-SB through S.1.36.C-SC, and S.1.37.D-SD through S.1.61.D-SD.

16.5 PERFORMANCE ASSESSMENT CRITERIA/ISSUES/WORK ELEMENTS

The criteria, issues, and work elements utilized in the narratives in Section 16.3 are presented here (Table 16-2). Introductory comments concerning their development and organization are contained in Section 16.1.

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment. (Sheet 1 of 12)

Technical criteria	Issues	Work element
	P.1 - Preemplacement Site Performance	
Required Characteristics of the Geologic Setting (60.112(c)) The geologic repository shall be located so that pre-waste-emplacement groundwater travel times through the far-field to the accessible environment are at least 1,000 years. Favorable Conditions (60.122(f)(g)(h)) (f) A host rock that provides the following groundwater characteristics (1) Low groundwater content (2) Inhibition of groundwater circulation in the host rock (3) Inhibition of groundwater flow between hydrogeologic units or along shafts, drifts, and boreholes (4) Groundwater travel times, under pre-waste-emplacement conditions, between the underground facility and the accessible environment that substantially exceed 1,000 years. (g) Geochemical conditions that (1) Promote precipitation or sorption of radionuclides	S.1.C-SC Are the pre-waste-emplacement groundwater travel times near the repository sufficient to assure compliance with U.S. Nuclear Regulatory Commission proposed technical criteria?	P.1.1-SC (Identical to P.2.1-WA and P.3.1-SD) Prepare a systems description for postclosure repository performance defining all subsystem models (including those used for preemplacement assessment), as well as the criteria on which they are based. S.1.30.C-SC (Related to S.1.7.A, S.1.9.A, S.1.11.B, S.1.17.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, S.1.29.C, and S.1.31.C) Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models. S.1.31.C-SC (Related to S.1.30.C, S.1.33.C, S.1.34.C, S.1.38.D, and S.1.39.D) Develop and/or modify numerical codes that adequately simulate groundwater flow and travel times under pre-waste-emplacement conditions.

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment. (Sheet 2 of 12)

Technical criteria	Issues	Work element
(2) Inhibit the formation of particulates, colloids, and inorganic and organic complexes that increase the mobility of radionuclides		S.1.33.C-SC (Related to S.1.30.C, S.1.31.C, S.1.34.C, S.1.37.D, S.1.39.D, and S.1.41.D)
(3) Inhibit the transport of radionuclides by particulates, colloids, and complexes.		Using selected models, predict groundwater travel time from the repository location to the accessible environment under pre-waste-emplacement conditions.
(h) Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having increased capacity to inhibit radionuclide migration.		S.1.34.C-SC (Related to S.1.24.C, S.1.25.C, S.1.26.C, S.1.30.C, S.1.31.C, and S.1.33.C)
For clarification see: 10 CFR 60.112 (b,c) 10 CFR 60.123 (a,b) 10 CFR 60.124 (b,c)		Determine the bounds of uncertainty in model predictions of pre-waste-emplacement groundwater travel time.
		W.2.13.D-SC (Includes discussion of W.1.20.B and W.2.11.C)
		Determine to what degree the characteristics of the geologic setting complement the engineered system.
		P.1.2-SC (Identical to P.2.2-WA and P.3.2-SD)
		Conduct verification, validation, and benchmarking of all codes used for performance assessment.
		P.1.3-SC (Identical to P.2.3-WA and P.3.3-SD)
		Document codes and prepare user manuals in accordance with regulatory guides and national quality assurance standards (ANSI/ASME, 1979).

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment.
(Sheet 3 of 12)

Technical criteria	Issues	Work element
P.2 - Postclosure Performance of the Engineered System		
Performance Objectives (60.111(b)(2)(3)) (2) Performance of the engineered system. (i) Containment of wastes. The engineered system shall be designed so that even if full or partial saturation of the underground facility were to occur, and assuming anticipated processes and events, the waste packages will contain all radionuclides for at least the first 1,000 years after permanent closure. This requirement does not apply to transuranic waste unless transuranic waste is emplaced close enough to high-level waste that the transuranic release rate can be significantly affected by the heat generated by the high-level waste. (ii) Control of releases.	W.1.A-WA (Related to W.2.A, W.3.A, R.1.A, R.1.B, and R.1.D) Does the very near-field interaction between the waste package and its components, the underground facility, and the geologic setting compromise waste package or engineered system performance? (i.e., What is the maximum expected release rate from the engineered system, and does the geologic setting prevent the waste package containment objective from being achieved?)	P.2.1-WA (Identical to P.1.1-SC and P.3.1-SD) Prepare a systems description for postclosure repository performance, defining all subsystem models (including those used for preemplacement assessment) as well as the criteria on which they are based. W.1.12.A-WA (Identical to W.2.3.A and W.1.19.B, includes discussion of W.1.9.A) Determine the extent to which the interaction between the canister materials, waste form, backfill, and host rock in a saturated environment results in retardation of radionuclides. W.3.1.A-WA Define appropriate statistical techniques so that laboratory and field materials interaction data can be extrapolated over time to provide a reasonable assurance of the long-term performance of the engineered system.

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment. (Sheet 4 of 12)

Technical criteria	Issues	Work element
(A) For high-level waste, the engineered system shall be designed so that, after the first 1,000 years following permanent closure, the annual release rate of any radionuclide from the engineered system into the geologic setting, assuming anticipated processes and events, is at most one part in 100,000 of the maximum amount of that radionuclide calculated to be present in the underground facility (assuming no release from the underground facility) at any time after 1,000 years following permanent closure. This requirement does not apply to radionuclides whose contribution is less than 0.1% of the total annual curie release as prescribed by this paragraph.		W.3.2.A-WA Determine the thermodynamic and kinetic arguments that can be used to extrapolate short-term (less than 2 years per experiment) materials test (hydrothermal) data. W.3.3.A-WA Develop and/or use numerical modeling techniques to predict the environmental conditions, package degradation, and radionuclide behavior of emplaced wastes in or near the engineered system. W.3.4.A-WA Determine what natural analogues of waste package components can be used to verify the compatibility of the waste package with the repository environment.
(B) For transuranic waste, the engineered system shall be designed so that following permanent closure the annual release rate of any radionuclide from the underground facility into the geologic setting, assuming anticipated processes and events, is at most one part in 100,000 of the maximum amount calculated to be present in the underground facility (assuming no release from the underground facility) at any time following permanent closure. This requirement does not apply to radionuclides whose contribution is less than 0.1% of the annual curie release as prescribed by this paragraph.		R.1.2.A-WA Evaluate the effect of underground construction sequence on the stability of openings. R.1.3.A-WA Determine the magnitude and the rate of deformation of tunnels and canister boreholes resulting from in situ, excavation-induced, and thermal stresses, and how deformation is affected by backfill.

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment. (Sheet 5 of 12)

Technical criteria	Issues	Work element
(3) Performance of the geologic setting. (i) Containment period. During the containment period, the geologic setting shall mitigate the impacts of premature failure of the engineered system. The ability of the geologic setting to isolate wastes during the isolation period, in accordance with paragraph (b)(3)(ii) of this section, shall be deemed to satisfy this requirement. For clarification see: 10 CFR 60.130(b)(ii) 10 CFR 60.132(a,e,f,k) 10 CFR 60.133(a,b) 10 CFR 60.135(a) 10 CFR 60.137 10 CFR 60.140 10 CFR 60.141 10 CFR 60.142 10 CFR 60.143		R.1.5.A-WA Determine the magnitude and distribution of thermal stresses in the rock mass for the proposed waste package storage configuration. R.1.9.A-WA Determine the potential for subsidence caused by mine openings. R.1.10.B-WA Define the acceptable range of test results for intact rock and rock-mass characteristics to support design activities. R.1.13.B-WA Develop and validate mechanical, thermal, and thermomechanical models for performance of in situ tests and for design and performance of the repository. R.1.18.D-WA Identify performance requirements for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste. R.1.22.D-WA Determine the effects of temperature, rock-mass deformation, and time on the permeability of the sealed rock zone.

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment. (Sheet 6 of 12)

Technical criteria	Issues	Work element
		R.1.29-WA (Related to R.1.30) Assess the effects of seismic events on underground openings during construction and operations. R.1.66-WA Determine functional requirements for selecting locations of repository seals and backfills as engineered barriers to effectively retard groundwater movement and radionuclide migration. R.1.67-WA Determine radionuclide sorption requirements for backfill materials to be used for repository rooms and tunnels. P.2.2-WA (Identical to P.1.2-SC and P.3.2-SD) Conduct verification, validation, and benchmarking of all codes used for performance assessment. P.2.3-WA (Identical to P.1.3-SC and P.3.3-SD) Document codes and prepare user manuals in accordance with regulatory guides and national quality assurance standards (ANSI/ASME, 1979).

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment.
(Sheet 7 of 12)

Technical criteria	Issues	Work element
P.3 - Postclosure Performance of the Waste Isolation System		
Performance Objectives (60.111(b)(1)) (b) Performance of the geologic repository after permanent closure (1) Overall system performance. The geologic setting shall be selected and the subsurface facility designed so as to assure that releases of radioactive materials from the geologic repository following permanent closure conform to such generally applicable environmental radiation protection standards as may have been established by the U.S. Environmental Protection Agency. Isolation (60.111(b)(3)(ii)) (ii) Isolation period. Following the containment period, the geologic setting, in conjunction with the engineered system as long as that system is expected to function, and alone thereafter, shall be	Issue S.1.D-SD (Related to Issue W.2.D) What is the total amount (activity) of radionuclides potentially releasable to the accessible environment in a 10,000-year period, and is this amount in compliance with appropriate U.S. Environmental Protection Agency regulations? (Related to Issue W.2.D)	P.3.1-SD (Identical to P.1.1-SC and P.2.1-WA) Prepare a systems description for postclosure repository performance defining all subsystem models (including those used for preemplacement assessment), as well as the criteria on which they are based. S.1.41.D-SD (Related to S.1.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.23.B, S.1.24.C through S.1.26.C, and S.1.30.C) Identify credible disruptive events and potentially unfavorable process scenarios and estimate the associated properties and conditions of the host basalt near the repository site; develop bounding estimates for probabilities of occurrence for each event, as needed.

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment.
(Sheet 8 of 12)

Technical criteria	Issues	Work element
capable of isolating radioactive waste so that transport of radionuclides to the accessible environment shall be in amounts and concentrations that conform to such generally applicable environmental standards as may have been established by the U.S. Environmental Protection Agency. For the purpose of this paragraph, the evaluation of the site shall be based upon the assumption that those processes operating on the site are those which have been operating on it during the Quaternary Period, with perturbations caused by the presence of emplaced radioactive wastes superimposed thereon.		S.1.30.C-SD (Related to S.1.7.A, S.1.9.A, S.1.11.B, S.1.17.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, S.1.29.C, and S.1.31.C) Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models. S.1.37.D-SD (Related to S.1.30.C, S.1.31.C, S.1.33.C, S.1.34.C, and S.1.39.D) Develop and/or modify numerical codes that can reliably predict the changes in the processes determining the rate and extent of radionuclide transport under post-waste-emplacement conditions.
<u>Contents of the Application (60.21(c)(1)(ii)(B,C))</u> (B) Analyses to determine the degree to which each of the favorable and adverse conditions, if present, has been characterized, and the extent to which it contributes to or detracts from isolation.		S.1.39.D-SD (Related to S.1.24.C through S.1.30.C, S.1.37.D, S.1.38.D, S.1.40.D, R.1.13.D, W.1.20.D, W.2.4.A, W.2.8.A, W.2.11.D, and W.2.13.D) Using selected models, predict radionuclide mass fluxes to the accessible environment.

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment.
(Sheet 9 of 12)

Technical criteria	Issues	Work element
(C) An evaluation of the expected performance of the proposed geologic repository noting the rates and quantities of expected releases of radionuclides to the accessible environment as a function of time. In executing this evaluation, the U.S. Department of Energy shall assume that those processes operating on the site are those which have been operating on it during the Quaternary Period and superpose the perturbations caused by the presence of emplaced radioactive waste on the natural processes.		S.1.40.D-SD (Related to S.1.39.D) Determine the bounds of uncertainty in the model predictions of radionuclide fluxes to the accessible environment. P.3.2-SD (Identical to P.1.2-SC and P.2.2-WA) Conduct verification, validation, and benchmarking of all codes used for performance assessment. P.3.3-SD (Identical to P.1.3-SC and P.2.3-WA) Document codes and prepare user manuals in accordance with regulatory guides and national quality assurance standards (ANSI/ASME, 1979). P.3.4-SD Perform a postclosure performance assessment for the waste isolation system for inclusion in the License Application.

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment.
(Sheet 10 of 12)

Technical criteria	Issues	Work element
	P.4 - Preclosure Repository Performance	
Content of Application (60.21(c)(1)(ii)(D)) (D) An analysis of the expected performance of the major design structures, systems, and components, both surface and subsurface, that bear significantly on the suitability of the geologic repository for disposal of radioactive waste assuming the anticipated processes and events and natural phenomena from which the design bases are derived. For the purposes of this analysis, it shall be assumed that operations at the geologic repository operations area will be carried out at the maximum capacity and rate of receipt of radioactive waste stated in the application. (60.21(c)(3)) (3) A description and analysis of the design and performance requirements for structures, systems, and components of the geologic repository which are important to safety. This analysis shall consider:	None identified.	P.4.1 Prepare an operating performance systems description identifying all engineered system structures, subsystems, and components important to safety. P.4.2 (Done in parallel with Work Element P.4.2) Prepare a preliminary preclosure repository safety assessment for normal operations and accidental conditions, based on the repository and waste package conceptual designs. P.4.3 (Done in parallel with Work Element P.4.2) Select and characterize preclosure failure scenarios. R.1.35 Determine the impact of the dynamic effects of equipment failure on safety-related systems and components.

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment.
(Sheet 11 of 12)

Technical criteria	Issues	Work element
(i) The margins of safety under normal and conditions that may result from anticipated operational occurrences, including those of natural origin; (ii) The adequacy of structures, systems, and components provided for the prevention of accidents and mitigation of the consequences of accidents, including those caused by natural phenomena; and (iii) The effectiveness of engineered and natural barriers, including barriers that may not be themselves a part of the geologic repository operations area, against the release of radioactive material to the environment. The analysis shall also include a comparative evaluation of alternatives to the major design features that are important to radionuclide containment and isolation, with particular attention to the alternatives that would provide longer radionuclide containment and isolation.		R.1.49 Determine the requirements necessary to assure that safety-related systems provide adequate protection to construction and operations personnel. P.4.4 Prepare a preclosure safety performance assessment for normal operations and for accidental failure scenarios, including preventive and mitigative measures, for inclusion in the License Application.

TABLE 16-2. Criteria, Issues, and Work Elements for Performance Assessment. (Sheet 12 of 12)

Technical criteria	Issues	Work element
<u>Performance Objectives (60.111a)</u> (a) Performance of the geologic repository operations area through permanent closure. (1) Protection against radiation exposures and releases of radioactive material. The geologic repository operations area shall be designed so that until permanent closure has been completed radiation exposures and radiation levels, and releases of radioactive materials to unrestricted areas, will at all times be maintained within the limits specified in Part 20 of this chapter and any generally applicable environmental standards established by the U.S. Environmental Protection Agency.		

16.6 SUMMARY

The methodology developed in Chapters 13, 14, and 15 for defining the work required to satisfy applicable regulatory and programmatic technical and administrative criteria has been applied to preclosure and postclosure performance assessment. The description of the work needed to meet criteria defined in the work elements was described in narrative form in Section 16.3. These descriptions allow the reader to gain a general understanding of the present status and future plans for each item of work proposed. A logic diagram for the work described in this chapter was presented in Section 16.4, accompanied by a brief narrative describing each element of the diagram; these serve to present in summary form the overall and generalized scope of work described in this chapter. By consolidating the detailed work elements into more concise form, the flow and direction of the performance assessment activities can be more readily depicted. The logic diagram also identifies the points at which the issues presented in this chapter will be resolved. A tabulation of all the criteria, work elements, and issues for the assessment of preemplacement site performance, postclosure performance of the engineered system, postclosure performance of the waste isolation system, and preclosure repository performance was presented in Section 16.5.

Finally, Chapter 17 of this document will contain schedules for the resolution of the issues presented in Section 16.1 and a listing of technical milestones associated with the work described in this chapter, as well as from the other issue chapters (Chapters 13, 14, and 15). Chapter 17 thus ties all of the plans for the entire project into one integrated description, with schedules and milestones, to provide a capsule summary of the direction and scope of work being planned by the BWIP to complete site characterization.

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17. SITE CHARACTERIZATION PROGRAM

17.1 INTRODUCTION

This chapter summarizes the Basalt Waste Isolation Project (BWIP) Site Characterization Program to complete the work elements described in the preceding issues and plans chapters (13 through 16). The exploratory shaft construction and in situ testing are detailed in this chapter.

Key issues, issues, and work elements were identified by analysis of the regulatory and technical criteria defined in the proposed 10 CFR 60 (NRC, 1981), NWTS-33(1) through (4) (NWTS, 1981a; 1981b; 1981c; 1981d), draft 40 CFR 191 (EPA, 1981), and other criteria documents. Key issues and other issues are questions that require answers to satisfy the proposed regulatory and technical criteria. Work elements identify the work required to satisfy the criteria, key issues, and other issues. The status and plans for completion of the work elements were described in the issues and plans chapters. Issues and key issues currently identified in Chapters 13 through 16 are shown in Table 17-1. The table is divided into key issues, which either confirm or eliminate the basalts underlying the Hanford Site as a potential repository site, and issues, which are technical questions about which there is some controversy.

Neither key issues nor issues necessarily have single products, such as reports, associated with their resolution. The resolution of these questions will occur as the result of obtaining sufficient information from the group of associated work elements. The results of the work elements will be published in various reports. The BWIP semiannual progress reports will also serve to update the resolution of key issues and issues.

The logic diagrams shown in Chapters 13 through 16 indicate the main activities to accomplish the work of the BWIP and the time where the issues will be resolved. The specific relationships between work elements and the activity blocks in the logic diagrams are listed in the narratives accompanying each logic diagram. Each sequence shown is one of several that could be selected and is somewhat flexible in response to schedule and budgetary requirements. The logic diagrams may also be changed as increased knowledge is acquired.

The schedules shown in this chapter have been constructed based on the logic diagrams in Chapters 13 through 16. These schedules will be updated semiannually in response to the increased knowledge of the site, changes in priorities, changes in regulatory guidance, and changes in budget. The program schedules shown in this chapter show the status of the program as it is known at the present time. The Site Characterization Program progress toward determining the acceptability of the site will be reflected in the BWIP semiannual progress reports.

TABLE 17-1. Basalt Waste Isolation Project Issues Identified in Chapters 13, 14, 15, and 16. (Sheet 1 of 2)

Issues	Issue number	Chapter
Key Issues		
What is the total amount (activity) of radionuclides potentially releasable to the accessible environment in a 10,000-year period, and is this amount in compliance with appropriate U.S. Environmental Protection Agency regulations?	S.1.D	5, 6, 12, 13, 16
Can stability and isolation capability of the repository be maintained in the presence of coupled in situ, excavation-induced, and thermal-induced stresses?	R.1.A	4, 10, 14
Can repository shafts, tunnels, and exploratory boreholes be constructed and sealed without causing preferential pathways for groundwater or increasing the potential for radionuclide migration from a nuclear waste repository such that compliance with appropriate U.S. Environmental Protection Agency regulations is not possible?	R.1.D	10, 14
Issues		
What are the geologic, mineralogic, and petrographic characteristics of the candidate repository horizons and surrounding strata within the reference repository location?	S.1.A	3, 13
What are the nature and rates of past, present, and projected structural and tectonic processes within the geologic setting and reference repository location?	S.1.B	3, 13
Are the pre-waste-emplacement groundwater travel times near the repository sufficient to assure compliance with U.S. Nuclear Regulatory Commission proposed technical criteria?	S.1.C	5, 12, 13, 16
Does the very near-field interaction between the waste package and its components, the underground facility, and the geologic setting compromise waste package or engineered system performance? (i.e., What is the maximum expected release rate from the engineered system, and does the geologic setting prevent the waste package containment objective from being achieved?)	W.1.A	11, 12, 15, 16

TABLE 17-1. Basalt Waste Isolation Project Issues Identified in Chapters 13, 14, 15, and 16. (Sheet 2 of 2)

Issues	Issue number	Chapter
Is a unique borehole backfill required?	W.1.B	11, 15
Are the geochemical and hydrologic properties of the geologic setting (in conjunction with the waste forms) sufficient to meet or exceed U.S. Nuclear Regulatory Commission proposed waste isolation requirements?	W.2.A	6, 15
What is the relative importance of waste form leach rates versus solubility of key radionuclides in the near-field environment for controlling release?	W.2.B	6, 15
Can valid Eh measurements for the candidate repository horizons in the reference repository location be made either by potentiometric measurement or indirectly by measurement of dissolved redox couples?	W.2.C	6, 15
To what degree does the geologic setting retard migration of key radionuclides from the engineered system in meeting U.S. Environmental Protection Agency draft release criteria?	W.2.D	6, 15
How can very near-field waste/barrier/rock materials interaction data, as measured experimentally, be extrapolated over time to reasonably assure that overall waste package and repository performance meets regulatory criteria?	W.3.A	6, 11, 15
Can satisfactory representative measurements or estimates of rock-mass strength be obtained?	R.1.B	4, 14
Are current methods of in situ stress measurement used at depth reliable enough to provide satisfactory data for design requirements?	R.1.C	4, 14

17.2 IN SITU TEST FACILITIES

17.2.1 Overview

Two candidate repository horizons are presently under consideration at the reference repository location. The in situ test facilities in support of site characterization for the BWIP will consist of an exploratory shaft and underground tunneling within the candidate repository horizon selected for breakout. The exploratory shaft is currently planned to be sunk through the Umtanum flow. The decision on the flow selected for breakout is currently planned for May 1983. In situ testing will be supplemented by field testing to be performed in the Near-Surface Test Facility, as described in Chapter 14. To execute a disciplined stepwise program for the development of in situ facilities, the Exploratory Shaft Program has been broken into two phases (DOE, 1982).

- The Phase I activities associated with the exploratory shaft have the following objectives:
  - To provide access to the candidate repository horizons for the eventual conduct of site characterization investigations and testing in the horizon selected for breakout.
  - To allow determination of the site's geotechnical suitability for use as a potential location for a test and evaluation facility.

Both objectives must be satisfied before subsequent phases are initiated.

- The Phase II activities associated with the exploratory shaft have the following objective:
  - To allow determination of the site's suitability for use as a repository, by closing those site-related issues that are identified in the site characterization report as being resolvable by the exploratory shaft and limited underground exploration.

Technical objectives were established for the conduct of Phase I and Phase II test programs for the assessment of site suitability. Work elements that must be satisfied to fulfill the technical objectives have been defined. Specific tests have been identified to obtain the needed data. Test plans are being prepared that provide the basis for detailed designs of both the test facilities and the tests themselves. The schedule for preparing exploratory shaft test plans, construction, and testing, and analysis is shown in Figure 17-1. Tests will be conducted based on the detailed designs and procedures prepared as part of the test design phase. Test results will be assessed and documented to provide input to the License Application for a nuclear waste repository in basalt.

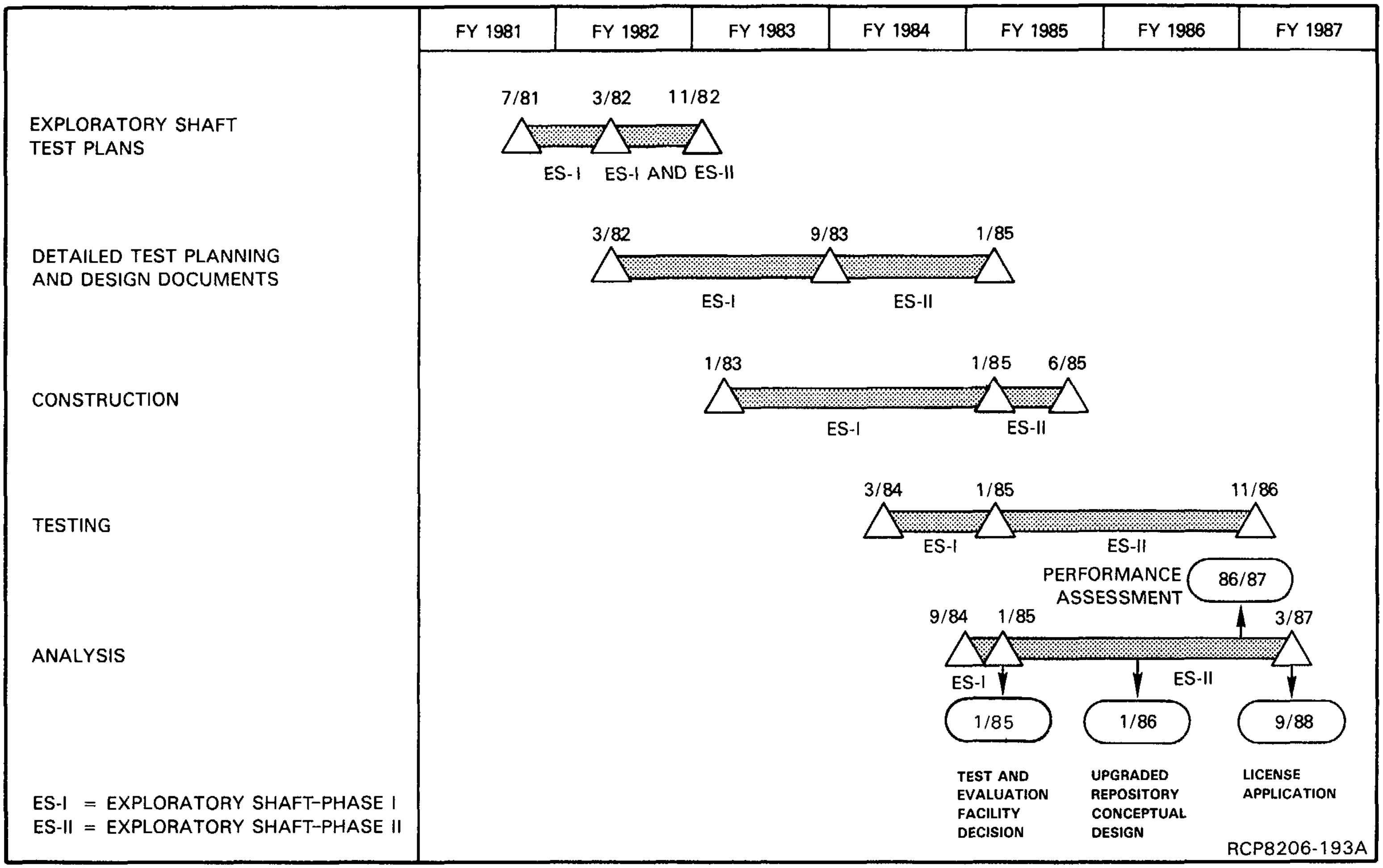

FIGURE 17-1. Exploratory Shaft Schedule for Test Plans, Construction, and Testing.

Exploratory Shaft-Phase I and II facility design requirements are being established to meet the test objectives. Additional considerations of mine safety codes and accepted design practices were also used to establish the specific Exploratory Shaft-Phase I and II design features.

Since the objective of constructing the in situ test facilities is to obtain in situ test data, proven design features will be utilized wherever possible to minimize the facility construction schedule and maximize the test time available. In the process of constructing the facility, information will be obtained to assess mining techniques. Upon completion of the Exploratory Shaft-Phase I and II test programs, sufficient in situ testing will have been performed to establish the suitability of the site for construction of a nuclear waste repository in basalt.

Additional in situ testing may follow Phase II if the Hanford Site is selected for a repository location. A detailed discussion of at-depth testing is not within the scope of this Site Characterization Report, since this testing is not part of the site suitability assessment.

17.2.2 Exploratory Shaft-Phase I Activities

The following technical objectives have been defined by the BWIP within the scope of the National Waste Terminal Storage Program strategy (DOE, 1982) for the Exploratory Shaft-Phase I activities:

- Test Program Objective 1: Provide the design information required for shaft design and selection of porthole locations and ascertain the overall suitability of the proposed location for an exploratory shaft at the reference repository location.

- Test Program Objective 2: Demonstrate that an exploratory shaft can be sunk at the reference repository location and assess the construction method.

- Test Program Objective 3: Verify that an exploratory shaft can successfully seal off the groundwater system and evaluate the effects of shaft construction on the surrounding rock at the reference repository location.

- Test Program Objective 4: Measure the hydraulic properties (e.g., hydraulic conductivity) of the candidate repository horizon selected for breakout to provide input to a preliminary estimate of its isolation capability in the vicinity of the exploratory shaft.

- Test Program Objective 5: Conduct geomechanics tests (e.g., in situ stress measurements) and provide a preliminary rock-mass characterization of the candidate repository horizon selected for breakout.

The Exploratory Shaft Test Program is organized in sequential steps. The site-specific data from the principal borehole (RRL-2) will be used to assure that the overall subsurface conditions are suitable for exploratory shaft siting at the reference repository location. Data obtained from the principal borehole will define the site-specific stratigraphy, including depth, thickness, and properties of aquifers and competent flows separating the candidate repository horizons from the overlying and underlying groundwater system. These data are required for construction of the exploratory shaft to establish drilling techniques and mud density, grout schedule, major principal stress orientation, and locations for testing through portholes from inside the shaft. The location of the exploratory shaft, principal borehole (RRL-2), and additional site characterization boreholes (RRL-6 and RRL-14), which will be utilized to obtain additional site-specific information, are shown in Figure 17-2.

If the overall suitability of the proposed location for the exploratory shaft is confirmed by the principal borehole, (Test Program Objective 1 (Phase I)), construction of an exploratory shaft at the reference repository location to provide access to candidate repository horizons will be initiated using blindhole boring. Since an acceptable repository site is unworthy of further consideration if the basalts and underlying groundwater system at Hanford cannot be penetrated with safety and confidence, it is prudent that the constructibility of a shaft be demonstrated. The exploratory shaft will serve to demonstrate that a shaft can be sunk at the reference repository location and successfully grout sealed from the Hanford groundwater system. A conceptual arrangement of the exploratory shaft during the Phase I program is shown in Figure 17-3.

Selection of the candidate horizon for breakout will be based on the borehole data obtained from the site characterization boreholes (RRL-6 and RRL-14) as well as the principal borehole (RRL-2). These will be compiled in a report on geologic, hydrologic, rock mechanics, geochemical, and economic aspects of the candidate repository horizons. This information will be analyzed by means of a formal decision analysis technique. The various characteristics of the candidate repository horizons will be judged either favorable or unfavorable, the characteristics will be weighted according to their relative importance, and the horizons will be ranked to select the best horizon for breakout. This study is scheduled for completion by May 1983.

Flooding is one of the risks associated with underground construction. A good seal is needed to safely isolate the various aquifers from each other and from the selected candidate repository horizon (Test Program Objective 3 (Phase I)). Grout is conventionally used to fully seal the space between the shaft casing and the host rock. Verification of the adequacy of the shaft seal is mandatory for the safety of downhole personnel and subsequent tunneling operations.

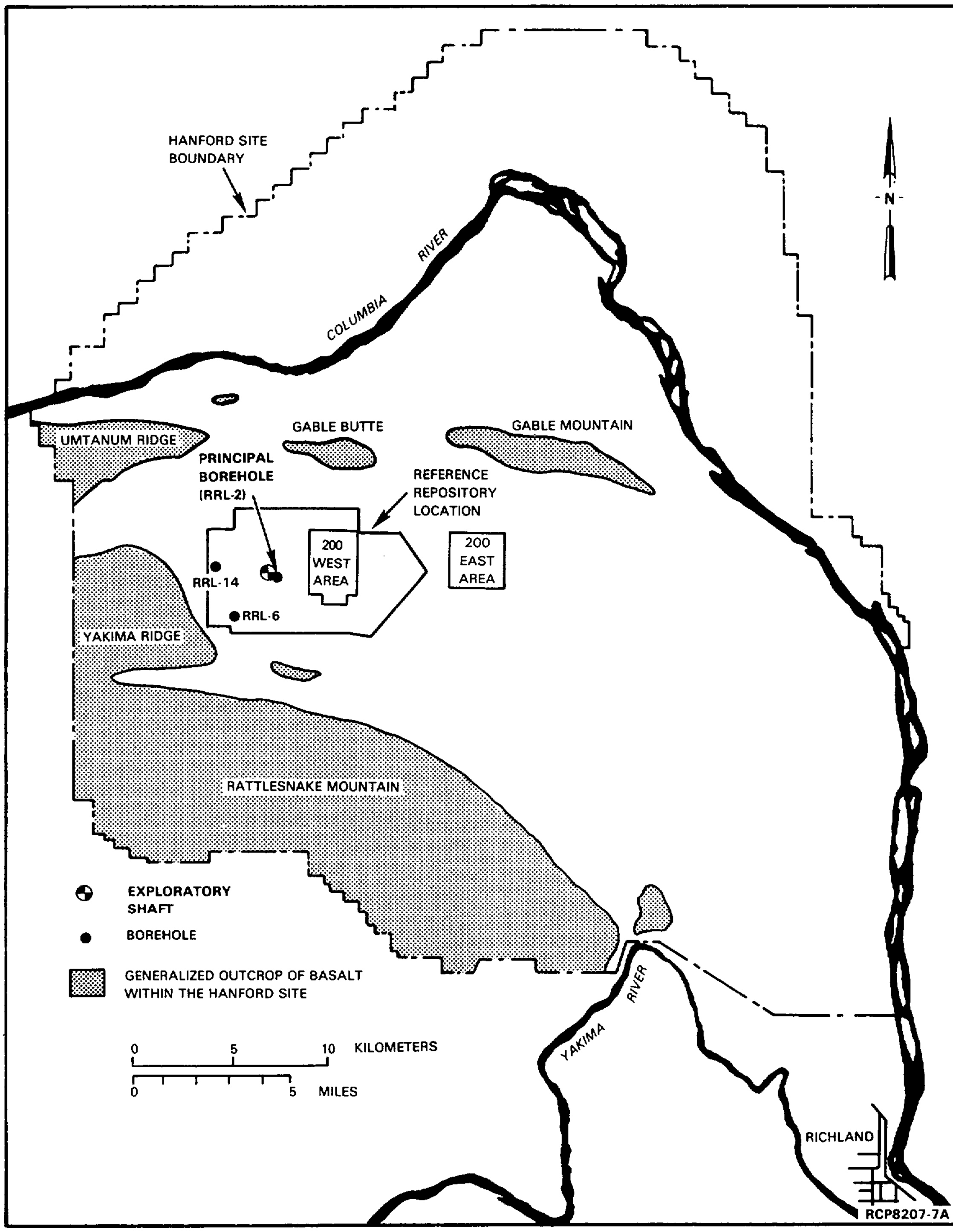

FIGURE 17-2. Location of Exploratory Shaft, Principal Borehole (RRL-2), and Two Support Boreholes (RRL-6 and RRL-14).

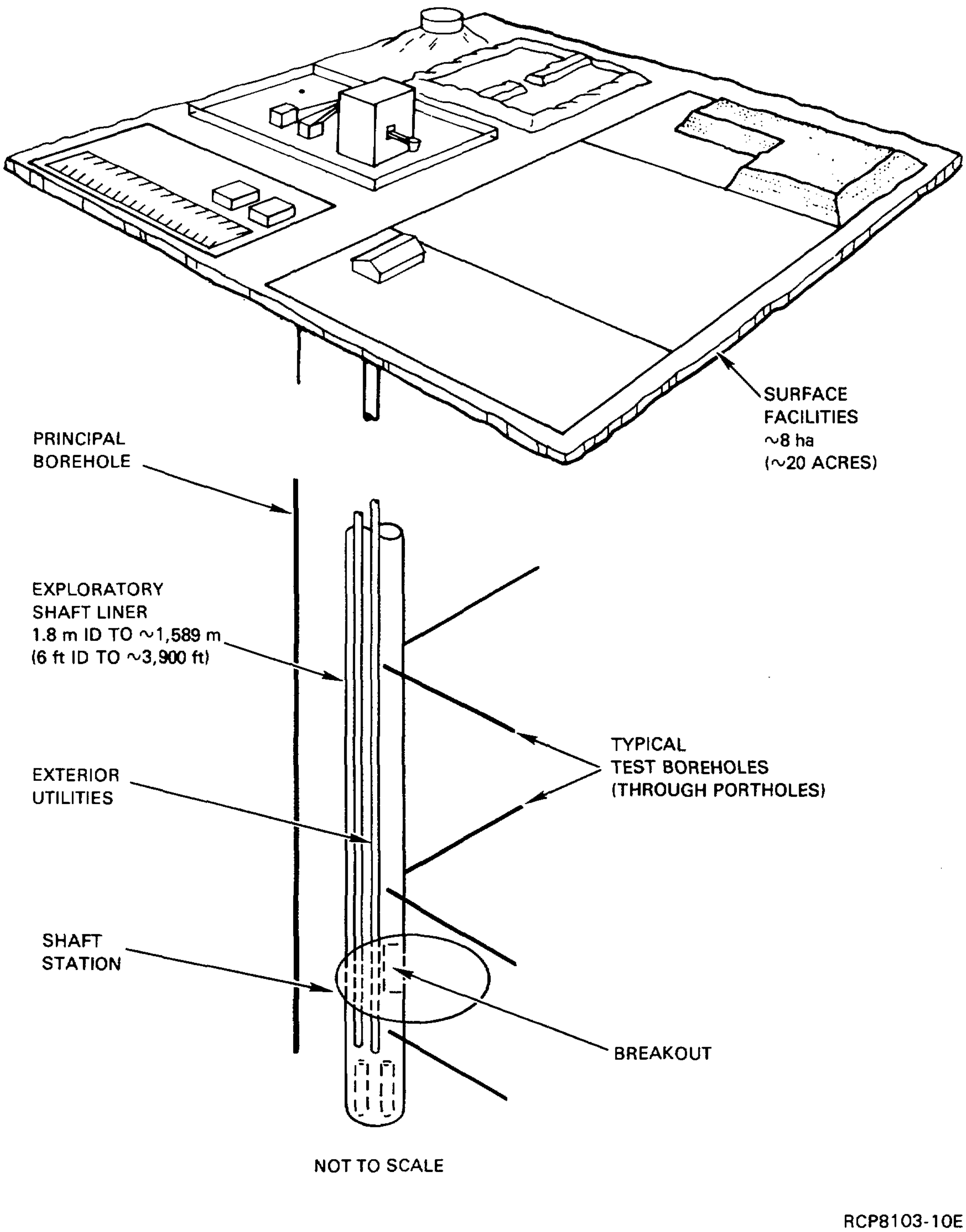

FIGURE 17-3. Exploratory Shaft-Phase I Conceptual Arrangement.

Changes in the host rock adjacent to an excavation will occur due to construction activities. Increases in the permeability of the construction-affected zone could provide a path around or through the seal between the shaft liner and the rock and could reduce the seal's effectiveness. The extent, character, and changes in permeability of the construction-affected zone around the exploratory shaft must be understood to permit development of an effective seal between the shaft liner and the rock (Test Program Objective 3 (Phase I)).

Several parameters (e.g., hydraulic conductivity, thermal field as a function of time and space, potential head distribution, repository size, radionuclide content and associated half-lives, etc.) are considered when assessing the capability of a host rock to isolate nuclear waste materials (Test Program Objective 4 (Phase I)). Vertically drilled surface boreholes limit testing mainly to horizontal and shallow dipping fractures. In contrast, the exploratory shaft will provide access to measure the hydraulic properties of steeply inclined-to-vertical jointed systems. The vertical hydraulic conductivity is a critical parameter for the modeling of isolation of nuclear waste materials. Vertical transport is the controlling flow mode for isolation. Horizontal boreholes will be drilled from the exploratory shaft and hydrologic tests conducted to obtain head levels and vertical hydraulic conductivity in the Grande Ronde Basalt. These data will then be input to numerical models used in modeling the very near and near fields to predict radionuclide concentrations as a function of time and space. These predictions will be used to determine the waste isolation capability of the candidate repository horizon selected for breakout at the reference repository location.

The in situ state of stress and rock-mass characteristics are the most significant parameter governing the stability of the underground opening (Test Program Objective 5 (Phase I)). Thus, the characterization of the initial state of stress and the rock-mass properties is mandatory for the design of permanent underground structures. As the underground access becomes available, stress measurements and rock-mass characterization work will be conducted. In addition, the rock-mass movement around the shaft station during and after the construction will be monitored. The test data obtained will play an important role in the design of various in situ tests to be conducted during Exploratory Shaft-Phase II.

17.2.3 Exploratory Shaft-Phase I Testing

The following description of Exploratory Shaft-Phase I testing is organized to parallel the five technical objectives mentioned earlier (Section 17.2.2). These tests support selected work elements described in Chapters 13 through 16. The relationship of the exploratory shaft tests to the rest of the program can be determined by referring to the work elements in Section 17.2.4 and then to the appropriate logic diagram in earlier chapters. The schedule for the exploratory shaft activities is included as part of the repository schedule under test facilities (Section 17.3).

17.2.3.1 Principal Borehole Tests to Supply Shaft Design Data and Assess Site Suitability (Test Program Objective 1 (Phase I)). The principal borehole (RRL-2) was drilled in the vicinity of the exploratory shaft into the next competent flow beneath the Umtanum flow. Examination of the core and downhole tests provided the key site-specific data required for shaft design and the selection of porthole locations in the shaft. The borehole also served to ensure that the overall stratigraphy and hydrologic regime were consistent with conditions predicted as a result of prior drilling activities. Two additional site characterization boreholes (RRL-6 and RRL-14) have been used to verify the results obtained from the principal borehole (RRL-2). Since qualitative hydrologic baseline information for the reference repository location is lacking, a series of hydrologic tests is planned for selected horizons. The data obtained will be input to the hydrologic modeling effort to improve the prediction of nuclide migration as a function of time and space for the near-field region. The key results expected to be obtained from the principal borehole are given in Table 17-2. The stratigraphy in the principal borehole is shown in Figure 17-4.

After completion of the hydrologic testing in the principal borehole, the candidate repository horizons will be tested for state of in situ stress, using the hydrofracturing method, which will be the first determination of the in situ stress at the reference repository location.

Following the completion of hydrofracturing tests, specific horizons will be isolated and monitored to help understand the effects of shaft drilling on the groundwater regime in the vicinity of the exploratory shaft. At the conclusion of the tests in the Exploratory Shaft-Phase I, the principal borehole will be available for long-term hydrologic monitoring until required later in the Exploratory Shaft-Phase II test program.

17.2.3.2 Shaft Sinking Demonstration (Test Program Objective 2 (Phase I)). The sinking of the exploratory shaft will serve to demonstrate the ability to construct a shaft in the basalts underlying the Hanford Site, utilizing the blind boring technique. The shaft sinking demonstration will be complete when the liner is dewatered and the liner integrity confirmed. Evaluation of blind bore shaft sinking will include comparison of drilling data with data from conventionally mined shafts. This evaluation will determine which technique is preferable. Key parameters to be measured are given in Table 17-3.

17.2.3.3 Shaft Seal Verification (Test Program Objective 3 (Phase I)). To evaluate grout-emplacement techniques, portholes will be utilized to permit core samples of the grout and grout rock interface to be obtained in selected areas around the shaft station. Final verification of the shaft seal will be the successful breakout and inspection of the exposed grout and host rock in the shaft station. The construction-affected zone around the exploratory shaft will be characterized by extending test holes through the affected zone and into the undisturbed host rock. Visual, nondestructive and destructive examination of core samples will provide information on the extent of the bond, character, and permeability of the grout and construction-affected zone. The key results expected from the shaft seal verification are given in Table 17-4.

TABLE 17-2. Principal Borehole Tests. (Sheet 1 of 2)

Test Program Objective 1 (Phase I): Provide the design information required for shaft design and selection of porthole locations and ascertain the overall suitability of the proposed location for an exploratory shaft at the reference repository location.

Key tests	Key parameters measured	Units	Predicted value	Rationale for consideration of key parameters
GEOLOGIC	Depth to top of candidate repository horizon:			Cost of construction and operation is a function of depth.
	• Middle Sentinel Bluffs	m (ft)	905 (2,970) (2,993 actual)	
	• Umtanum		1,100 (3,610) (3,607 actual)	
	Thickness of candidate repository horizon interior:			Constructibility: The repository will be constructed in the competent basalt of the flow interior.
	• Middle Sentinel Bluffs	m (ft)	78 (255) (245 actual)	
	• Umtanum		45 (148) (84 actual)	
	In situ temperature of candidate horizon:			In situ temperature affects the quantity of waste placed and cost of air conditioning.
	• Middle Sentinel Bluffs	°C (°F)	49 to 54 (120 to 130) (124 actual)	
	• Umtanum		54 to 60 (130 to 140) (138 actual)	

TABLE 17-2. Principal Borehole Tests. (Sheet 2 of 2)

Test Program Objective 1 (Phase I): Provide the design information required for shaft design and selection of porthole locations and ascertain the overall suitability of the proposed location for an exploratory shaft at the reference repository location.

Key tests	Key parameters measured	Units	Predicted value	Rationale for consideration of key parameters
HYDROLOGIC	Horizontal hydraulic conductivity (K_h) of reference flow interior, heads in water-bearing strata, storativity, and effective porosity will be used to calculate groundwater transport times.	mg/L	C_i < 40 CFR 191*	These parameters provide the needed input to assess whether the groundwater pathway provides the needed isolation to retard radionuclide transport to the biosphere.
ROCK MECHANICS	Maximum horizontal-stress magnitude	MPa (ksi)		Stability of underground opening is influenced directly by the in situ state of stress.
	• Middle Sentinel Bluffs		45 to 55 (6.5 to 8.0)	
	• Umtanum		55 to 69 (8.0 to 10.0)	

C_i = Radionuclide concentration.

*At boundary specified in draft 40 CFR 191 (EPA, 1981).

FORMATION	MEMBER OR SEQUENCE	DEPTH (THICKNESS) IN FEET* PREDICTED	ACTUAL	
Saddle Mountains Basalt	SEDIMENTS		0 - 603 (603)	
	ELEPHANT MOUNTAIN MEMBER	593 - 678 (85)	603 - 686 (83)	
	RATTLESNAKE RIDGE INTERBED	678 - 778 (100)	686 - 783 (97)	
	POMONA MEMBER	778 - 913 (135)	783 - 941 (158)	
	SELAH INTERBED	913 - 963 (50)	941 - 986 (45)	
	ESQUATZEL MEMBER	963 - 1,088 (125)	986 - 1,004 (118)	
	COLD CREEK INTERBED	1,088 - 1,158 (70)	1,104 - 1,167 (63)	
	UMATILLA MEMBER	1,158 - 1,383 (225)	1,167 - 1,399 (232)	
	MABTON INTERBED	1,383 - 1,523 (140)	1,399 - 1,523 (124)	
Wanapum Basalt	PRIEST RAPIDS MEMBER	1,523 - 1,685 (162)	1,523 - 1,689 (166)	
		1,685 - 1,755 (70)	1,689 - 1,749 (40)	
	ROZA MEMBER	1,755 - 1,925 (170)	1,749 - 1,922 (173)	
	FRENCHMAN SPRINGS MEMBER	1,925 - 2,665 (740)	1,925 - 2,683 (758)	
	VANTAGE INTERBED	2,665 - 2,680 (15)	2,683 - 2,687 (4)	
Grande Ronde Basalt	SENTINEL BLUFFS	2,680 - 2,970 (290)	2,687 - 2,993 (306)	
	MIDDLE SENTINEL BLUFFS	2,970 - 3,235 (265)	2,993 - 3,255 (262)	CANDIDATE HORIZON
	SENTINEL BLUFFS	3,235 - 3,465 (230)	3,255 - 3,475 (220)	
	McCOY CANYON	3,465 - 3,610 (145)	3,475 - 3,607 (132)	
	UMTANUM	3,610 - 3,825 (215)	3,607 - 3,839 (232)	CANDIDATE HORIZON
	VERY HIGH MgO	3,825 - 3,875 (50)	3,839 - 3,892 (53)	
	SCHWANA	3,875 - TD	3,892 - 3,973 TD (81)	

*TO CONVERT FROM FEET TO METERS, MULTIPLY BY 0.3048

RCP8204-148B

FIGURE 17-4. Preliminary Stratigraphy in the Principal Borehole (RRL-2).

TABLE 17-3. Shaft Sinking Demonstration--Key Results.

Test Program Objective 2 (Phase I). Demonstrate that an exploratory shaft can be sunk at the reference repository location and assess the construction method.

Key tests	Key parameters measured	Units	Predicted value	Rationale for consideration of key parameters
CONSTRUCT-IBILITY ASSESSMENT	Hole verticality	minutes per 30 m (100 ft)	3	Technology verification: reasonably vertical shaft is required to avoid problems with porthole drilling and shaft hoisting.
	Hole alignment	m (ft)	±0.3 (1) over total depth	Technology verification: A reasonably straight shaft is required to install the stiff steel casing and attached grout and service lines.
	Equipment availability	$\frac{\text{Actual operating time}}{\text{Scheduled operating time}} \times 100\%$	97	Technology verification: This parameter affects construction schedule and cost.
	Bit on bottom time	$\frac{\text{Bit on bottom time}}{\text{Scheduled operating time}} \times 100\%$	80	Same as above.
	Cutter life	m (ft)/cutter	90 (300)	Same as above.
	Production rate	m (ft)/d	5 (15)	Same as above.
	Disabling injuries	$\frac{\text{Disabling injuries} \times 200{,}000}{\text{Man-hours worked}}$	TBD	Safety verification: Safety is a major consideration in determining the acceptability of a shaft sinking method.
	Drilling start to casing checkout	months	12	Schedule verification: Schedule is a major consideration in determining the acceptability of a shaft sinking method.
	Contract cost	dollars/m (ft)	TBD	Cost verification: Cost is a major consideration in determining the acceptability of a shaft sinking method.

TBD = To be determined.

TABLE 17-4. Shaft-Seal Verification--Key Results.

Test Program Objective 3 (Phase I): Verify that an exploratory shaft can successfully seal off the groundwater system and evaluate the effects of shaft construction on the surrounding rock at the reference repository location.

Key tests	Key parameters measured	Units	Predicted value	Rationale for consideration of key parameters
GEOLOGIC	Depth of disturbed rock	m (ft)	1 (3)	Isolation: Construction-affected zone must be identified.
HYDROLOGIC	Water inflow	L/s (gal/min)	TBD*	Constructibility: This parameter verifies proper grout placement.
	Pressure differential	MPa (lb/in2)	TBD*	Same as above.
ROCK MECHANICS	Grout strength	MPa (ksi)	21 (3)	Same as above.
CONSTRUCTIBILITY ASSESSMENT--No separate tests				

TBD = To be determined.
*Dependent on safety and design requirements.

17.2.3.4 Preliminary Hydrologic Isolation Assessment (Test Program Objective 4 (Phase I)). Drilling of horizontal test holes and inclined test holes through portholes in the shaft will be performed above, below, and in the horizon selected for breakout. The locations of the test boreholes is diagrammatically shown in Figure 17-5. The lengths of these boreholes are dependent on the geometry of the flow being tested and has not been determined. Lengths are not expected to exceed 75 meters (250 feet). The basic hydrologic tests will consist of hydraulic head, hydraulic conductivity, and sampling for water chemistry. The key data measurements are given in Table 17-5.

17.2.3.5 Preliminary Geomechanics Characterization (Test Program Objective 5 (Phase I)). Geomechanics characterization work will include in situ stress measurements in the shaft station and rock-mass movement around the shaft station during and after construction. An overcoring technique is being developed in tests being conducted at the Near-Surface Test Facility and will be utilized for the in situ stress measurements. The tests will provide information on the magnitude and orientation of the principal rock stresses. Key data for the pre-station breakout and shaft station geomechanics characterization are included in Table 17-6.

17.2.4 Relationship of Exploratory Shaft-Phase I Test Program Objectives to the Site Characterization Report Work Elements

The work elements identified to support the Exploratory Shaft-Phase I test program objectives are in the listing that follows. Selected tests that may be required to collect data to support the work elements are identified in Table 17-7. These work elements do not represent the complete list required for site characterization. This table reflects the relationship of tests that support work elements necessary to meet Exploratory Shaft-Phase I test program objectives (in a matrix format). For example, the uniaxial compression test (laboratory mechanical properties) is one of the tests performed to support work element R.1.4.A relating to Exploratory Shaft-Phase I Test Program Objective 5.

TEST PROGRAM OBJECTIVE 1 (PHASE I)

Provide the design information required for shaft design and selection of porthole locations and ascertain the overall suitability of the proposed location for an exploratory shaft at the reference repository location.

Work Elements

S.1.1.A Determine the thickness and continuity of the candidate repository horizons within the reference repository location.

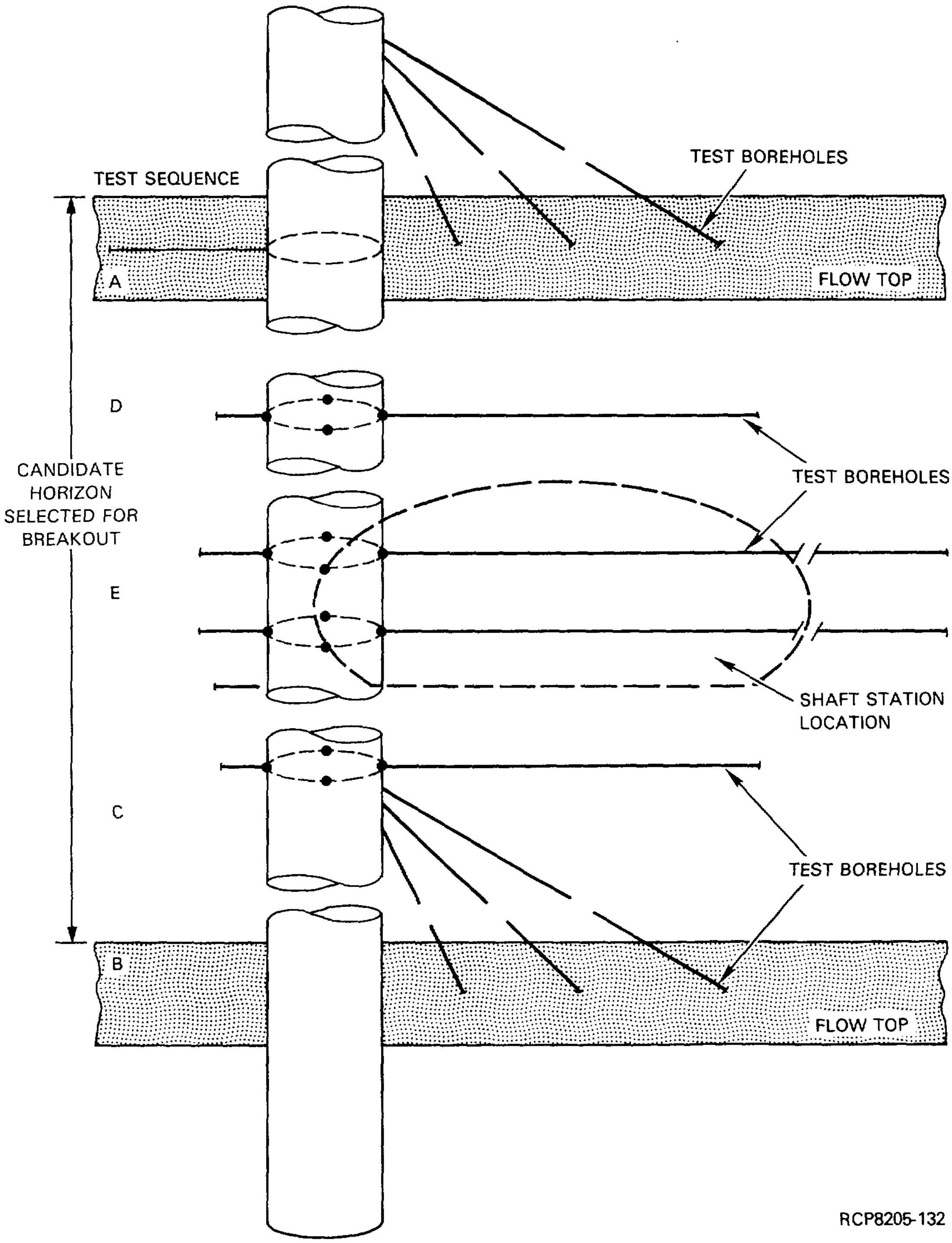

FIGURE 17-5. Conceptual Test Borehole Locations for Exploratory Shaft-Phase I.

TABLE 17-5. Pre-Station Hydrologic Isolation Assessment Data--Key Results.

Test Program Objective 4 (Phase I): Measure the hydraulic properties (e.g., hydraulic conductivity) of the candidate repository horizon selected for breakout to provide input to a preliminary estimate of its isolation capability in the vicinity of the exploratory shaft.

Key tests	Key parameters measured	Units	Predicted value	Rationale for consideration of key parameters
HYDROLOGIC (Umtanum flow) assumption $\frac{K_v}{K_h} = 10$	Vertical hydraulic conductivity (interior)	m (ft)/s	$<10^{-8}$ ($<10^{-7}$)	Vertical hydraulic conductivity is an important parameter determining the waste isolation capability of the horizon ultimately selected for breakout, the performance of the rock will be assessed using three-dimensional transport models that predict potential nuclide migration as a function of space and time.
	Horizontal hydraulic conductivity (interior)	Same as above	$<10^{-9}$ ($<10^{-8}$)	Same as above.
	Hydraulic head	m (ft) above mean sea level	114 to 130 (375 to 425)	Input parameter required to determine hydraulic gradient.
	Hydraulic gradient	Velocity ratio	0.01 to 0.1	Input parameter required to predict path lines and travel time using groundwater flow models.
	Effective porosity	Percent	10^{-2} to 10^{-4}	Input parameter required to predict path lines and travel time using groundwater flow models.
	Dispersivity	m (ft)	<1 (3)	Same as above.
	Storativity (interior)	Dimensionless	Approaching the compressibility of water $\sim 10^{-5}$	Determination of storativity provides means of back checking porosity values determined from tracer tests.
	Water chemistry (nonisotopic, isotopic, trace element, dissolved gases)	NA	Sodium-chloride Total dissolved solids (>800 mg/L) Age >32,000 yr	Hydrochemical parameters provide information on composition, origin, age of groundwater, and relative aquifer intercommunication.

NA = Not applicable.

TABLE 17-6. Pre-Station Breakout and Shaft Station Geomechanics Characterization Data.

Test Program Objective 5 (Phase I): Conduct geomechanics tests (e.g., in situ stress measurements) and provide a preliminary rock-mass characterization of the candidate repository horizon selected for breakout.

Key tests	Key parameters measured	Units	Predicted value	Rationale for consideration of key parameters
ROCK MECHANICS	Magnitude of the maximum horizontal stress (σ_{Hmax}):			The stress concentration factor around the opening is a function of vertical and horizontal stresses.
	• Umtanum	MPa (ksi)	55 to 69 (8.0 to 10.0)	
	• Middle Sentinel Bluffs		45 to 55 (6.5 to 8.0)	
	Ratio of maximum horizontal and vertical stress (σ_{Hmax}/σ_{V})	Dimensionless	2.0 to 2.5	Same as above.
	Ratio of maximum and minimum horizontal stress ($\sigma_{Hmax}/\sigma_{Hmin}$)	Same as above	1.5 to 2.0	The tunnel layout in the repository horizon should be oriented with respect to the maximum horizontal stress to minimize the stress concentration. The stress concentration around the vertical shaft is a function of $\sigma_{Hmax}/\sigma_{Hmin}$.
	Compressive strength	MPa (ksi)	211 (31)	Constructibility: ground support is a function of rock strength.

TABLE 17-7. Test Program Objectives, Tests, and Site Characterization Report Work Element Matrix for Exploratory Shaft-Phase I.

SITE CHARACTERIZATION REPORT WORK ELEMENT NUMBER

1,2,3,4,5 = TEST PROGRAM OBJECTIVE NUMBER

TEST	S.1.1.A	S.1.5.A	S.1.7.A	S.1.8.A	S.1.9.A	S.1.10.C	S.1.24.C		S.1.25.C	S.1.26.C		S.1.27.C	S.1.28.C	S.1.30.C		S.1.35.C	R.1.4.A	R.1.9.A	R.1.12.B	R.1.14.C	R.1.16.D	R.1.17.D		R.1.21.D	R.2.1		W.2.8.A	W.2.10.C
GEOLOGIC CHARACTERIZATION																												
LITHOLOGY LOGGING	1	1	1	1	1		1	4			4	4		1	4				5	5	2	2		3			1	1
FRACTURE LOGGING		1		1	1		1	4				4	4	1	4			1		5	2	2	3	3			1	
DISPERSIVE X-RAY		1		1	1																							
PALEOMAGNETISM	1			1																								
GEOCHEMISTRY	1	1	1	1	1		1	4		1	4	4	4		4										4	5	1	1
DOWNHOLE GEOPHYSICS																												
APPARENT RESISTIVITY	1			1			1	4			4	4	4								2							1
SELF-POTENTIAL	1			1			1	4			4	4	4		4						2							1
GAMMA RAY EMISSION	1			1								4	4		4													
NEUTRON ABSORPTION (MOISTURE CONTENT)	1			1			1	4			4	4	4	1	4	1			5		2			3				
GAMMA RAY ABSORPTION (BULK DENSITY)	1			1			1	4				4	4		4	1		1						3				
SEISMIC VELOCTIY	1			1																5	2	2	3		4	5		
THERMAL LOGGING	1										4	4							5					3				1
CALIPER LOGGING (BOREHOLE)	1			1			1	4				4									2							
LABORATORY PHYSICAL PROPERTIES																												
DENSITY (BULK AND GRAIN)		1	1	1	1		1	4					4			1	5		5		2	2	3				1	
POROSITY (APPARENT AND TOTAL)		1	1	1	1		1	4		1			4				5	1	5		2		3				1	
THERMAL CONDUCTIVITY																			5									
PERMEABILITY							1	4					4			1			5				3				1	
LABORATORY MECHANICAL PROPERTIES																												
UNIAXIAL COMPRESSION		1		1	1												5*	1	5	5	2	2	3	3	4	5		
TRIAXIAL COMPRESSION		1		1	1												5	1	5	5	2		3	3	4	5		
TENSILE STRENGTH (BRAZILIAN)																				5								
THERMAL EXPANSION				1	1														5									
SPECIFIC HEAT																			5									
HYDROLOGIC																												
WATER POTENTIAL (HYDRAULIC HEAD)						1	1	4	4			4	4	1											4	5		
HYDROCHEMISTRY		1				1	1	4		1	4	4	4		4				5						4	5	1	1
PUMP/SLUG/PULSE						1	1	4		1				1	4	1								3				
CONSTANT HEAD INJECTION						1	1	4	4				4	1	4	1												
WATER INFLOW												4	4								2				4	5		
HYDROLOGIC MONITORING							1	4						1	4									3			1	
TRACER												4	4															
PRESSURE DURATION									4			4	4												4	5		
DRILLING SURVEILLANCE																												
DRILLING RATE																					2	2						
CALIPER LOG (SHAFT)																		1						3				
CUTTING LOG																						2						
IN SITU TESTING																												
HYDRAULIC FRACTURING		1			1												5	1		5	2		3					
OVERCORING																	5			5			3					
EXTENSOMETER MONITORING																	5						3		4	5		
ROCKBOLT LOAD CELL MONITORING																	5						3					
JACKING TESTS																	5											
BOREHOLE DEFORMATION																					2							
UNDERGROUND MAPPING		1																										

*EXAMPLE USED IN TEXT, SECTION 17.2.4.

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S.1.5.A Determine the orientation, distribution, aperture infilling (secondary mineralization), and origin of fractures, discontinuities, and heterogeneities within the candidate repository horizons.

S.1.7.A Determine the stratigraphic characteristics of the flows above and below the candidate repository horizons.

S.1.8.A Determine the structural, textural, mineralogic, and petrographic characteristics of the rocks above and below the candidate repository horizons.

S.1.9.A Determine the orientation, distribution, aperture infilling (secondary mineralization), and origin of fractures, discontinuities, and heterogeneities within rocks above and below the candidate repository horizons.

S.1.10.A Determine the presence and characteristics of other possible anomalies that could serve as zones of greater permeability.

S.1.26.C Determine the hydrochemistry of the basalt groundwater system.

S.1.30.C Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models.

S.1.35.C Determine the groundwater content of the host rock.

R.1.9.A Determine the potential for subsidence caused by mine openings.

W.2.1.A Determine the effect on radionuclide mobility of changes in the primary and secondary mineralogical conditions in the near field and far field of the repository, along the expected pathway to the biosphere.

W.2.10.C Determine the method and technique that can be utilized to provide valid in situ Eh measurements for the reference repository location.

W.2.8.A Determine acceptable release rates of key radionuclides from the engineered system as a function of containment time, groundwater travel time to the accessible environment, and water flow through the repository.

TEST PROGRAM OBJECTIVE 2 (PHASE I)

Demonstrate that an exploratory shaft can be sunk at the reference repository location and assess the construction method.

Work Elements

R.1.16.D Evaluate and select methods of excavation and rock support that can economically and safely be constructed and at the same time maintain isolation capability of the engineered system.

W.2.10.C Determine the method and technique that can be utilized to provide valid in situ Eh measurements for the reference repository location.

R.1.17.D Develop or adapt instrumentation and test methods to measure the nature and extent of rock-mass disturbance caused by candidate excavation methods and stress redistribution around tunnels and boreholes.

TEST PROGRAM OBJECTIVE 3 (PHASE I)

Verify that an exploratory shaft can successfully seal off the groundwater system and evaluate the effects of shaft construction on the surrounding rock at the reference repository location.

Work Elements

R.1.17.D Develop or adapt instrumentation and test methods to measure the nature and extent of rock-mass disturbance caused by candidate excavation methods and stress redistribution around tunnels and boreholes.

R.1.21.D Develop grouts and grouting techniques that ensure acceptable sealing of the disturbed rock zone.

R.1.28 Assess the effects of adverse conditions on the design and performance of the repository.

TEST PROGRAM OBJECTIVE 4 (PHASE I)

Measure the hydraulic properties (e.g., hydraulic conductivity) of the candidate repository horizon selected for breakout to provide input to a preliminary estimate of its isolation capability in the vicinity of the exploratory shaft.

Work Elements

S.1.24.C Determine the hydraulic properties of the groundwater flow system.

S.1.25.C Determine the hydraulic heads of the groundwater flow system.

S.1.26.C Determine the hydrochemistry of the basalt groundwater system.

S.1.27.C Determine the geometry of and interaction between the confined flow systems.

S.1.28.C Determine the extent of vertical groundwater movement between the confined, unconfined, and surface water systems.

S.1.30.C Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models.

TEST PROGRAM OBJECTIVE 5 (PHASE I)

Conduct geomechanics tests (e.g., in situ stress measurements) and provide a preliminary rock-mass characterization of the candidate repository horizon selected for breakout.

Work Elements

R.1.4.A Determine the magnitude and distribution of excavation-induced stresses for single and multiple openings.

R.1.12.B Measure rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.

R.1.14.C Develop stress measurement methods that will yield valid data in closely jointed basalt.

R.2.1 Determine which characteristics of the natural and engineered systems need to be measured or monitored for performance confirmation, and establish any required baseline values for those characteristics prior to repository construction.

17.2.5 Exploratory Shaft-Phase I Construction

The exploratory shaft is currently planned to be blind hole bored to a depth of approximately 1,177 meters (3,860 feet) (exact depth to be determined by observation of core). A shaft station will be constructed within the selected candidate repository horizon. The finished inside diameter of the steel-lined shaft will be 1.8 meters (6 feet). The shaft will initially be drilled with a 365-centimeter (144-inch) bit from the surface to the top of basalt at approximately 195 meters (640 feet). A 285-centimeter (112-inch) inside-diameter liner will be installed and the remainder of the exploratory shaft will be bored with a 280-centimeter (110-inch) diameter bit to the total depth. The steel lining will be

placed by floating it into the mud-filled hole and subsequently grouting it in place using cement and chemical sealing grouts. A schematic of the exploratory shaft is shown in Figure 17-6. The shaft station for the exploratory shaft will consist of an opening from the steel liner of approximately 120° to 180° and approximately 12 meters (40 feet) of tunnel to provide space for geomechanics tests and future staging for follow-on Exploratory Shaft-Phase II construction. Services will be installed in the shaft to accommodate testing during Phases I and II.

Facilities at the ground surface to support the Exploratory Shaft Program will consist of:

- Headframe and shaft conveyance systems
- Ventilation systems
- Electrical, water, sanitary, and communications systems
- Temporary buildings for administration
- Roadways, fences, and other site improvements.

17.2.6 Exploratory Shaft-Phase II Activities

The following technical objectives have been defined for the Exploratory Shaft-Phase II activities:

- Test Program Objective 1: Provide geotechnical information to enable characterization of a volume of the candidate repository horizon selected for breakout to allow a decision on the suitability of this site for a repository.
- Test Program Objective 2: Measure the hydraulic properties (e.g., hydraulic conductivity) of the reference repository site to establish the isolation capability of the candidate repository horizon selected for breakout to meet U.S. Nuclear Regulatory Commission proposed requirements.
- Test Program Objective 3: Confirm the applicability of thermomechanical data from the Near-Surface Test Facility to the candidate repository horizon selected for breakout.

The geotechnical characterization of the candidate repository horizons includes the composition, mechanical properties, and geologic structure of a representative volume of the reference repository site. To achieve this objective, penetration and testing of a representative volume of the reference repository site must be achieved. The candidate repository horizon selected for breakout at the reference repository site must be thick enough and internally consistent and predictable to support construction (and operation) of a repository and to support its isolation from the biosphere.

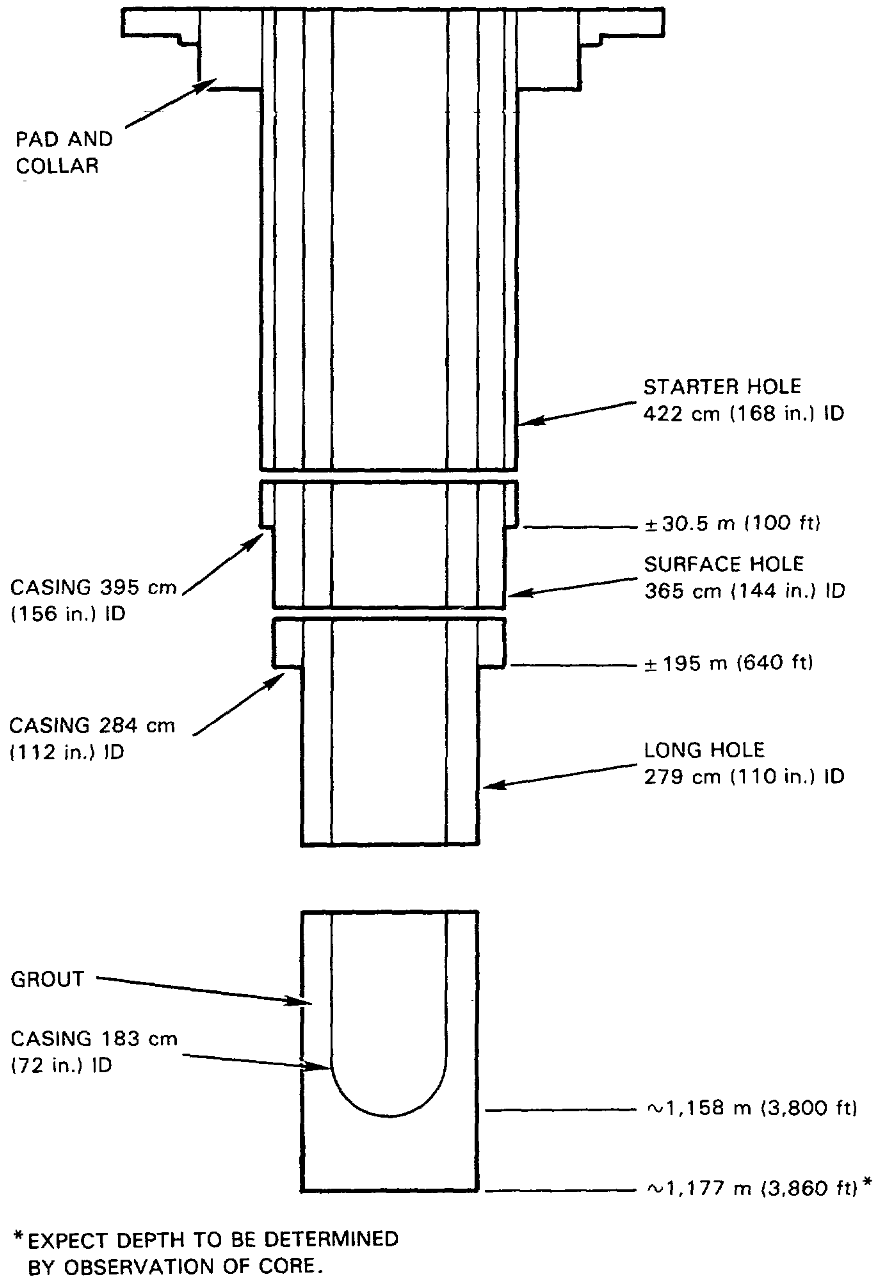

FIGURE 17-6. Exploratory Shaft.

The test data obtained in the Exploratory Shaft-Phase I will play an important role in the detailed design of the various in situ tests to be conducted in Phase II. It is not possible to determine the exact tests and the detailed test designs until access to the candidate repository horizons is available through the exploratory shaft. A series of observations during construction of the Exploratory Shaft-Phase II, in situ stress measurements, laboratory tests of rocks removed from the exploratory shaft construction area, and horizontal exploratory coring will be utilized to allow a final geotechnical assessment of the site's suitability and to provide repository design information prior to submittal of the License Application.

To allow a final assessment of the site suitability from a hydrologic standpoint, the vertical groundwater paths must be identified by testing. The vertical hydraulic conductivity of the candidate repository horizons and the flows above and below these horizons must be carefully determined for the hydrologic modeling effort because vertical transport is likely to be the controlling factor for radionuclide migration. The exploratory shaft will enable the drilling of horizontal boreholes from the shaft into the zones to be tested. These horizontal holes will permit testing in a direction that could not be adequately conducted through surface boreholes. These data will be used in modeling the near-field processes to predict radionuclide migration as a function of time and space, based on actual field data. These predictions will be used to evaluate the waste isolation capability of the repository location.

Significant geomechanical field testing has been performed at the Near-Surface Test Facility in the Pomona basalt. The Pomona basalt was chosen for the site of the Near-Surface Test Facility because of its similarity to the candidate horizons. To effectively make use of the information already available to the BWIP, Exploratory Shaft-Phase II will be utilized to relate the information obtained near the surface to the candidate horizon selected for breakout. This will greatly increase the data base and allow significant resource savings by not repeating tests previously performed.

The conceptual configuration of Exploratory Shaft-Phase II is presented in Figure 17-7.

17.2.7 Exploratory Shaft-Phase II Tests

The major tests proposed to resolve the project objectives are:

- Geomechanical tests
- Hydrologic isolation assessment
- Applicability of Near-Surface Test Facility data.

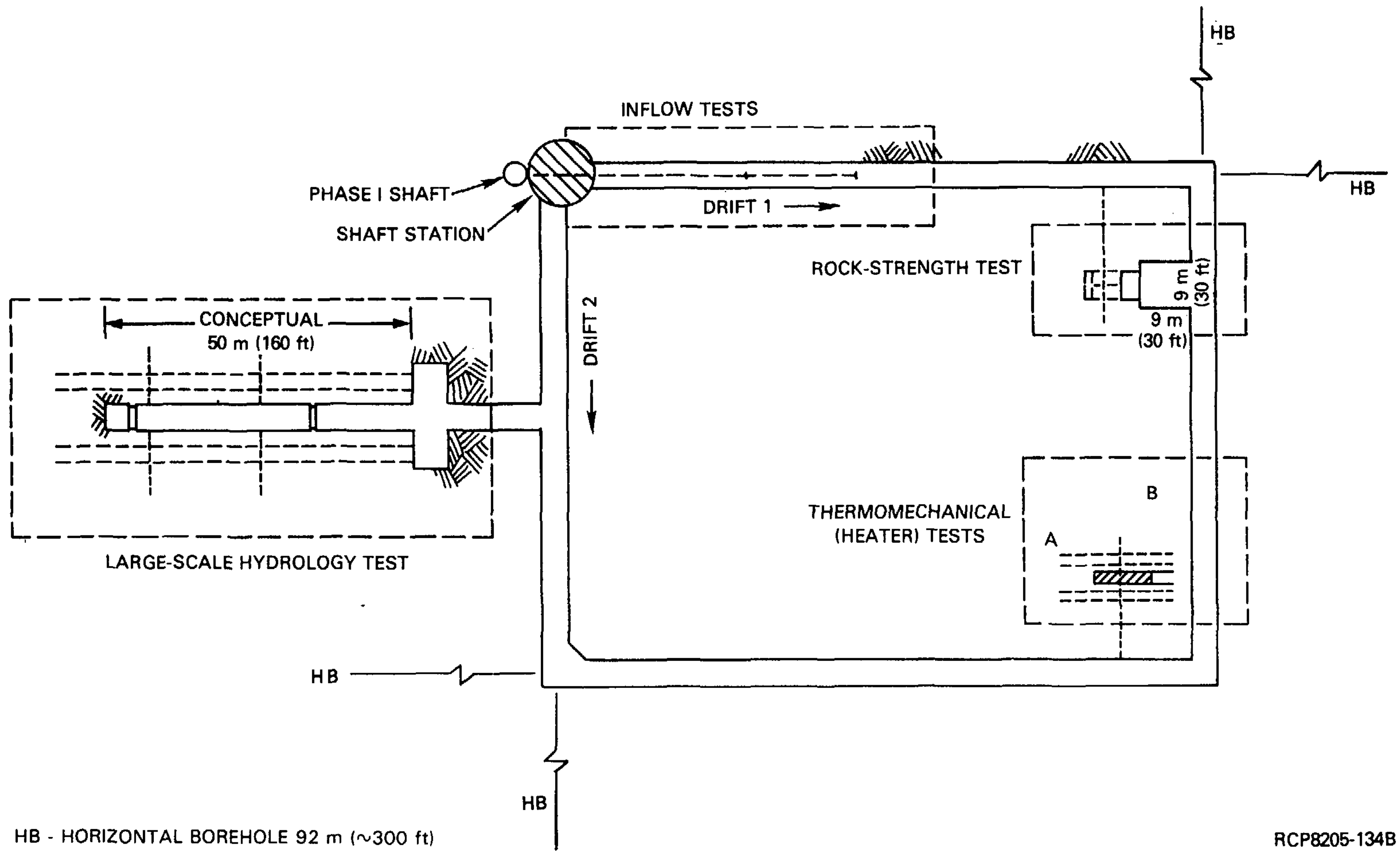

FIGURE 17-7. Exploratory Shaft-Phase II Conceptual Configuration.

17.2.7.1 <u>Geomechanical Tests (Test Program Objective 1 (Phase II))</u>. Up to 305 meters (1,000 feet) of tunnels will be constructed in the selected candidate repository horizon from the Exploratory Shaft-Phase I shaft station. These tests will provide opportunities for characterization, measurements of in situ stress, rock strength, and excavation closure rates and magnitudes. In addition, horizontal boreholes from the drifts will provide representative cores from the selected candidate repository horizon.

Preexcavation boreholes will precede excavation of drifts, crosscuts, and chambers. Evaluation of the rock will be performed to establish the character of the host rock with respect to mine safety. Excavation progress will be documented on a daily basis by photographing and cataloging features of newly mined surfaces. Extensometers will be installed at the earliest possible date to measure excavation closure rates and to ensure the adequacy of tunnel support techniques. Following completion of the underground excavations, exploratory boreholes will be cored from the maximum extent of the excavations approximately 92 meters (300 feet) to obtain cores of the selected candidate repository horizon. The cores will be evaluated to establish confidence in the acceptability of the lateral homogeneity of the host rock. Additional rock mechanics tests will be performed to compare the state of in situ stress in the exploratory shaft area with the measurements from hydrofracturing and overcoring stress measurements taken in the Exploratory Shaft-Phase I.

Tests may be conducted, if required, to establish the rock-mass strength. No specific test has been identified for this purpose but ongoing testing of equipment, procedures, and techniques at the Near-Surface Test Facility could be used to develop the testing techniques. The testing possibilities range from observational techniques comparing conditions underground to properties obtained from core samples, to the performance of a sophisticated test configured so that the failure planes will include both natural joints and intact rock. The key parameters expected to be obtained from the geotechnical characterization are presented in Table 17-8.

17.2.7.2 <u>Hydrologic Isolation Assessment (Test Program Objective 2 (Phase II))</u>. Testing initiated during the breakout of the exploratory shaft will be continued. Inflow tests will be performed utilizing the horizontal holes drilled above and below the shaft station in the selected candidate repository horizon. These holes will be used to monitor the changes in head as the excavation of the Exploratory Shaft-Phase II tunnels progresses. Consideration will be given to the use of tracers to determine effective porosity and dispersion. Additional porthole tests will be conducted in the exploratory shaft to ascertain vertical hydraulic conductivity of flows above the selected candidate repository flow. These tests will be performed to aid in assessment of the isolation potential of the flows above the selected candidate repository flow.

TABLE 17-8. Tests to Support Geotechnical Characterization.

Parameter	Type of test
Host rock structure, material characteristics	Mining surveillance, core logging, and underground mapping
Physical, mechanical, thermal properties	Core testing
In situ stresses, including spatial variations, as required, to confirm candidate repository horizon characteristic stresses	Overcoring and hydrofracturing
Tunnel convergence monitoring	Extensometer • Closure rates • Closure magnitude
Rock-mass strength	To be determined

Based on the conditions measured in the inflow test around the shaft station and following Exploratory Shaft-Phase II excavation, the need for a large-scale water flow test will be determined. If water inflows are extremely small, a drift that can be isolated and ventilated will be used to measure water inflow on a large area. If water inflows are somewhat larger than expected, it is possible that only measurements of water volume flowing into the sump will be needed or required to determine total water inflow over a large area. The exact features of this test cannot be determined until observations of actual underground conditions are conducted. Key parameters to be measured as part of the hydrologic isolation assessment are presented in Table 17-9.

7.2.7.3 Applicability of Near-Surface Test Facility Data (Test Program Objective 3 (Phase II)). A small-scale heater test is planned to be conducted at depth to relate the information obtained at the Near-Surface Test Facility to the selected candidate repository horizon. The test configuration will be as simple as possible, consistent with data requirements, and will reflect lessons learned at the Near-Surface Test Facility. The principal purpose of the small-scale heater tests will be to assess the thermal conductivity of the selected candidate repository horizon and to verify the extent of decrepitation which occurs as a result of the heater test. Key parameters to be obtained from the Near-Surface Test Facility data verification are included in Table 17-10.

TABLE 17-9. Tests to Support Determination of Hydrologic Properties.

Parameter	Type of test
Hydraulic head	Candidate horizon* boreholes (horizontal) • Static pressure • Water temperature • Water density
Induced hydraulic gradient	Candidate horizon* boreholes (horizontal) • Differential pressure between points
Hydraulic conductivity	Candidate horizon* boreholes (horizontal) • Flow rate • Water pressure • Hydraulic gradient
Conductivity tensor	Large-scale hydrologic testing • Flow rate • Water pressure • Hydraulic gradient
Dispersion and effective porosity	Large-scale hydrologic testing • Tracer concentrations
Water chemistry (nonisotopic, isotopic, trace elements, dissolved gases)	Candidate horizon* • Water-sample laboratory analyses

*Selected for breakout.

TABLE 17-10. Near-Surface Test Facility Applicability Studies.

Parameter	Type of test
In situ stress before heating	Overcoring in heater area boreholes
Rock mass thermal properties • Conductivity • Expansion coefficient • Induced stress • Induced-fracture initiation, propagation, decrepitation	Heater test

17.2.8 Relationship of Exploratory Shaft-Phase II Test Program Objectives to the Site Characterization Report Work Elements

The work elements identified to support the Exploratory Shaft-Phase II test program objectives are in the listing that follows. Selected tests that may be required to collect data to support the work elements are identified in Table 17-11. These work elements do not represent the complete list required for site characterization.

This table reflects the relationship of tests which support work elements necessary to meet Exploratory Shaft-Phase II test program objectives (in a matrix format).

TEST PROGRAM OBJECTIVE 1 (PHASE II)

Provide geotechnical information to enable characterization of a volume of the candidate repository horizon selected for breakout to allow a decision on the suitability of this site for a repository.

Work Elements

S.1.1.A Determine the thickness and continuity of the candidate repository horizons within the reference repository location.

S.1.2.A Determine the dip, strike, fold wavelength, and amplitude of the candidate repository horizons within the reference repository location.

S.1.3.A Determine what deformational features are likely to intersect the candidate repository horizons within the reference repository location.

S.1.4.A Determine the primary internal structure of the candidate repository horizons within the reference repository location.

S.1.6.A Determine the mineralogic and petrographic characteristics of the candidate repository horizons including the composition, texture, and abundance of both primary and secondary phases; apply data as appropriate to predict fracture distribution in Work Element S.1.5.A.

R.1.2.A Evaluate the effect of the underground construction sequence on the stability of the openings.

R.1.4.A Determine the magnitude and distribution of excavation-induced stresses for single and multiple openings.

R.1.8.A Determine the spatial variation of in situ stresses in the region of the repository.

TABLE 7-11. Test Program Objectives, Tests, and Site Characterization Report Work Element Matrix for Exploratory Shaft-Phase II.

1,2,3 = TEST PROGRAM OBJECTIVE NUMBER

SITE CHARACTERIZATION REPORT WORK ELEMENT NUMBER

TEST	S.1.1.A	S.1.2.A	S.1.3.A	S.1.4.A	S.1.6.A	S.1.24.C	S.1.25.C	S.1.26.C	S.1.27.C	S.1.28.C	S.1.30.C	S.1.35.C	S.1.36.C	R.1.2.A	R.1.4.A	R.1.5.A	R.1.8.A	R.1.11.B	R.1.12.B		R.1.13.B		R.1.14.C		R.1.15.C	R.1.16.C	R.1.17.C	R.1.48	R.1.57		R.1.70			R.2.1		W.2.13.D
GEOLOGIC CHARACTERIZATION																																				
LITHOLOGY LOGGING	1	1	1	1	1				2		2				1		1	1		3		3					1	1		2			3	1		2
FRACTURE LOGGING			1	1	1	2			2	2	2						1	1		3		3					1			2			3	1		2
DISPERSIVE X-RAY					1																															
PALEOMAGNETISM	1	1		1	1																															
GEOCHEMISTRY	1					2		2																									3			2
DOWNHOLE GEOPHYSICS																																				
APPARENT RESISTIVITY	1	1																																1		
SELF-POTENTIAL	1	1																																1		
GAMMA RAY EMISSION	1	1																																		
NEUTRON ABSORPTION (MOISTURE CONTENT)	1	1										2						1	1	3																
GAMMA RAY ABSORPTION (BULK DENSITY)	1	1																																1		
SEISMIC VELOCITY	1	1	1		1				2					1				1	3								1	1								
THERMAL LOGGING			1							2	2							1	1	3		3			1							2	3	1		2
LABORATORY PHYSICAL PROPERTIES																																				
DENSITY (BULK AND GRAIN)			1	1		2						2		1				1	1	3								1			1	2				
POROSITY (APPARENT AND TOTAL)			1	1		2			2			2		1				1										1			1	2				
THERMAL CONDUCTIVITY																					1															
PERMEABILITY									2			2		1				1														2				
LABORATORY MECHANICAL PROPERTIES																																				
UNIAXIAL COMPRESSION			1		1										1			1			1			3	1									1		
TRIAXIAL COMPRESSION			1		1									1	1			1			1		1	3	1									1		
TENSILE STRENGTH (BRAZILIAN)														1																						
THERMAL EXPANSION																		1																		
SPECIFIC HEAT																		1																		
HYDROLOGIC																																				
WATER POTENTIAL (HYDRAULIC HEAD)			1			2	2		2	2	2		2																	2				1	2	2
HYDROCHEMISTRY					1	2		2		2	2	2	2																				3		2	2
PUMP/SLUG/PULSE			1			2			2	2			2																							
CONSTANT HEAD INJECTION						2				2	2		2																	2	1	2	3		2	2
WATER INFLOW						2			2			2	2																							2
HYDROLOGIC MONITORING						2					2		2																			2			2	
TRACER						2							2																							
PRESSURE DURATION							2						2																							2
IN SITU TESTING																																				
HYDRAULIC FRACTURING					1										1		1	1					1	3					1	2	1	2	3		2	
OVERCORING														1	1	3	1	1			1		1	3		1	1	1	1		1	2	3		2	
EXTENSOMETER MONITORING														1		3							1		1	1	1	1								
ROCKBOLT LOAD CELL MONITORING														1	1			1								1	1	1	1							
PORE PRESSURE CELL MONITORING														1				1								1		1								
JACKING TESTS															1		1				1	3	1			1	1						3			
MICROSEISMIC (ACOUSTIC EMISSION)																												1								
PHOTOGRAPHY				1																																
UNDERGROUND MAPPING				1	1				2					1	1		1					3	1			1	1		1							
HEATER TESTS																3		1				3											3			

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R.1.11.B Measure rock strength and deformation characteristics on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.

R.1.12.B Measure rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.

R.1.13.B Develop and validate mechanical, thermal, and thermomechanical models for performance of in situ tests and for design and performance of the repository.

R.1.14.C Develop stress measurement methods that will yield valid data in closely jointed basalt.

R.1.15.C Establish methods of validating measured in situ stress data.

R.1.16.D Evaluate and select methods of excavation and rock support that can economically and safely be constructed and at the same time maintain isolation capability of the engineered system.

R.1.17.D Develop or adapt instrumentation and test methods to measure the nature and extent of rock-mass disturbance caused by candidate excavation methods and stress redistribution around tunnels and boreholes.

R.1.48 Develop or adapt instrumentation and monitoring techniques to predict rock bursts.

R.1.57 Provide an appropriate orientation, geometry, waste placement, and layout of the repository to ensure structural stability and containment of radionuclides.

R.1.70 Determine the coupled effects of stress and elevated temperatures on the permeability of the rock mass.

R.2.1 Determine which characteristics of the natural and engineered systems need to be measured or monitored for performance confirmation, and establish any required baseline values for those characteristics prior to construction.

TEST PROGRAM OBJECTIVE 2 (PHASE II)

Measure the hydrologic properties (e.g., hydraulic conductivity) of the reference repository site to establish the isolation capability of the candidate repository horizon selected for shaft breakout to meet U.S. Nuclear Regulatory Commission proposed requirements.

Work Elements

S.1.24.C Determine the hydraulic properties of the groundwater flow system.

S.1.25.C Determine the hydraulic heads of the groundwater flow systems.

S.1.26.C Determine the hydrochemistry of the basalt groundwater system.

S.1.27.C Determine the geometry of and interaction between the confined flow systems.

S.1.28.C Determine the extent of vertical groundwater movement between the confined, unconfined, and surface water systems.

S.1.30.C Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models.

S.1.35.C Determine the groundwater content of the host rock.

S.1.36.C Determine the nature of groundwater circulation in the host rock.

R.1.57 Provide an appropriate orientation, geometry, waste placement, and layout of the repository to ensure structural stability and containment of radionuclides.

R.1.70 Determine the coupled effects of stress and elevated temperatures on the permeability of the rock mass.

R.2.1 Determine which characteristics of the natural and engineered systems need to be measured or monitored for performance confirmation, and establish any required baseline values for those characteristics prior to repository construction.

W.2.13.D Determine to what degree the characteristics of the geologic setting complement the engineered system.

TEST PROGRAM OBJECTIVE 3 (PHASE II)

Confirm the applicability of thermomechanical data from the Near-Surface Test Facility to the candidate repository horizon selected for shaft breakout.

Work Elements

R.1.12.B Measure the rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.

R.1.13.B Develop and validate mechanical, thermal, and thermomechanical models for performance of in situ tests and for design and performance of the repository.

R.1.14.C Develop stress measurement methods that will yield valid data in closely jointed basalt.

R.1.70 Determine the coupled effects of stress and elevated temperatures on the permeability of the rock mass.

R.1.5.A Determine the magnitude and distribution of thermal stresses in the rock mass for the proposed waste package storage configuration.

17.2.9 Exploratory Shaft-Phase II Construction

Construction of the Exploratory Shaft-Phase II will follow the completion of in situ stress determinations in the Exploratory Shaft-Phase I at the shaft station. Exploratory Shaft-Phase II will be constructed utilizing the drill-and-controlled-blast technique and may include working of as many as two headings at one time. Construction will consist of drifts constructed from the shaft station. The total lateral extent of these drifts will not exceed 305 meters (1,000 feet), because of ventilation constraints. The conceptual design of the Exploratory Shaft-Phase II has not been initiated. A conceptual configuration showing the underground excavations and test areas for Phase II activities was presented in Figure 17-7.

17.2.10 Decommissioning Considerations

The objective of decommissioning of the exploratory shaft is to minimize any permanent impact from its presence. Essentially, this means ensuring that vertical groundwater interconnection through the shaft area is minimized. Two options are being considered for the exploratory shaft. The first option is to include the exploratory shaft as part of the repository; thus, its decommissioning would not occur until the repository is decommissioned. The second option is to isolate the repository from the shaft, thereby permitting decommissioning prior to repository operation.

Assuming that the exploratory shaft requires decommissioning prior to the start of repository operation, the underground excavations would be isolated from the shaft by sealing the connecting drift. Present concepts are that an area would be bulkheaded off and pressure grouted to reduce or eliminate bypass groundwater flow. At the candidate repository horizon, all construction materials (steel liner, conduits, etc.) would be removed and the tunnels would be backfilled and pressure grouted to establish an imbedded plug to completely isolate the candidate repository horizon from the vertical flow path. This technique would be repeated at other stratigraphic levels in the shaft where competent rock provides the necessary stability and sealing potential. The interior of the shaft would be backfilled between the imbedded plugs.

17.3 PLANNING SUMMARY

The schedules in this section show when the activities will be accomplished to complete the work elements and to resolve the outstanding issues identified in Chapters 13 through 16 (Table 17-1). The time frame on which each issue is scheduled to be resolved is shown for each chapter of plans and issues (Fig. 17-8 through 17-11). The schedule for construction of the exploratory shaft is shown in Figure 17-9.

The numbers in parentheses (associated with each activity on the schedule) correspond with the same number and activity reflected on the logic networks. A narrative for each of these activities can be found in Chapters 13 through 16.

The dates for resolution of specific issues are related both to the time necessary to complete the work elements and to the major milestones for which issue resolution is required. However, the resolution of an issue does not necessarily mean that a particular report will be issued. The two principal milestones related to the resolution of issues are (1) issuing the final BWIP semiannual progress report and (2) submitting the License Application to obtain a Construction Authorization. The final BWIP semiannual progress report is scheduled for completion during the second quarter of fiscal year 1987. Submission of the License Application is scheduled for the fourth quarter of fiscal year 1988 (Fig. 17-12). The issues whose resolution is scheduled to be documented in the final BWIP semiannual progress report and the License Application are listed in Table 17-12. The BWIP semiannual progress reports will report progress toward resolution of issues. The key issues (S.1.D, R.1.A, and R.1.D) will be resolved before the final BWIP semiannual progress report.

TABLE 17-12. Issues Scheduled to be Resolved in Time to Report in the Final BWIP Semiannual Progress Report and the License Application.

Issues for final BWIP semiannual progress report	Issues for License Application
S.1.A	W.1.A
S.1.B	W.2.A
S.1.C	W.2.D
S.1.D	W.3.A
R.1.A	
R.1.B	
R.1.C	
R.1.D	
W.1.B	
W.2.B	
W.2.C	

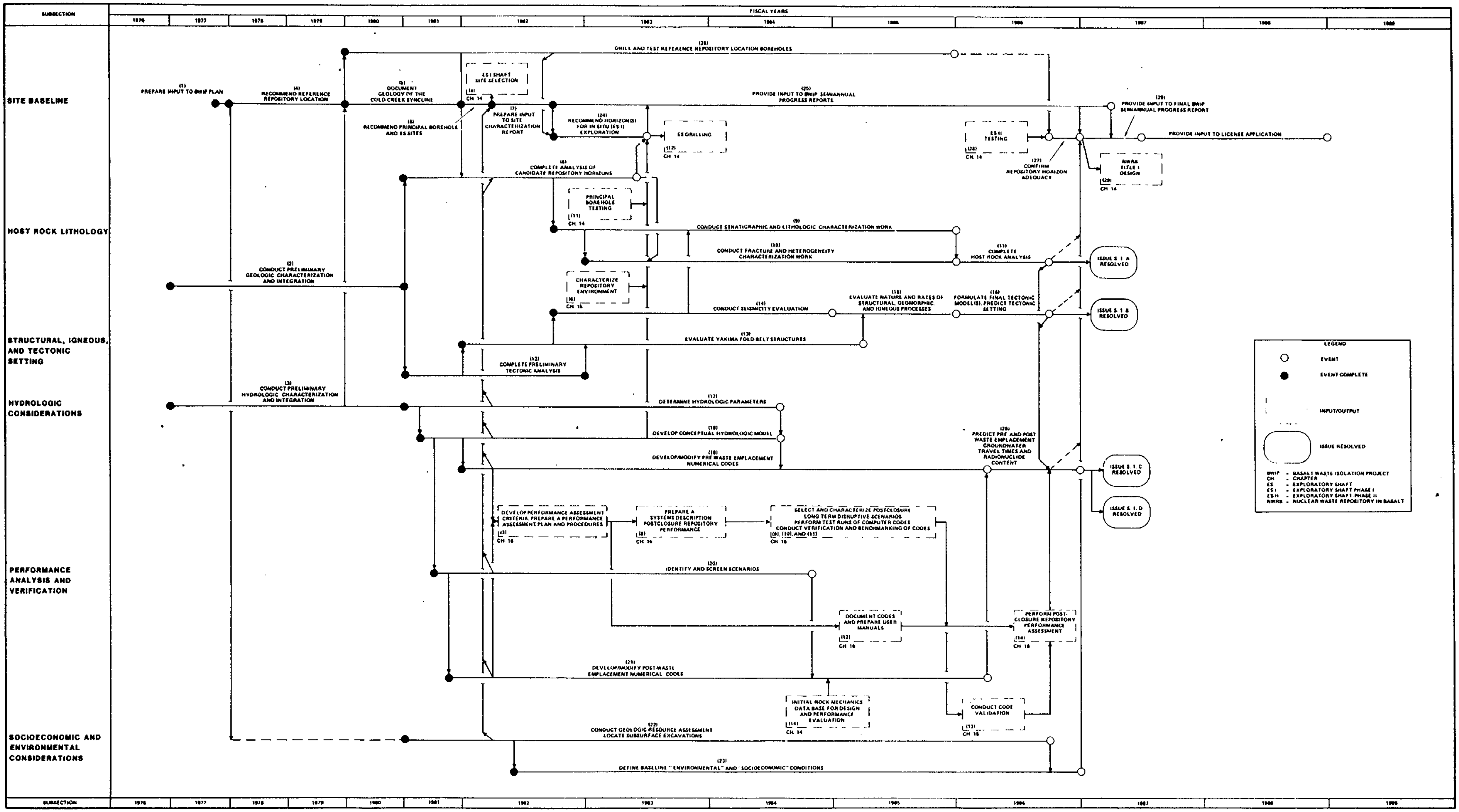

FIGURE 17-8. Schedule for Resolution of Site Issues.

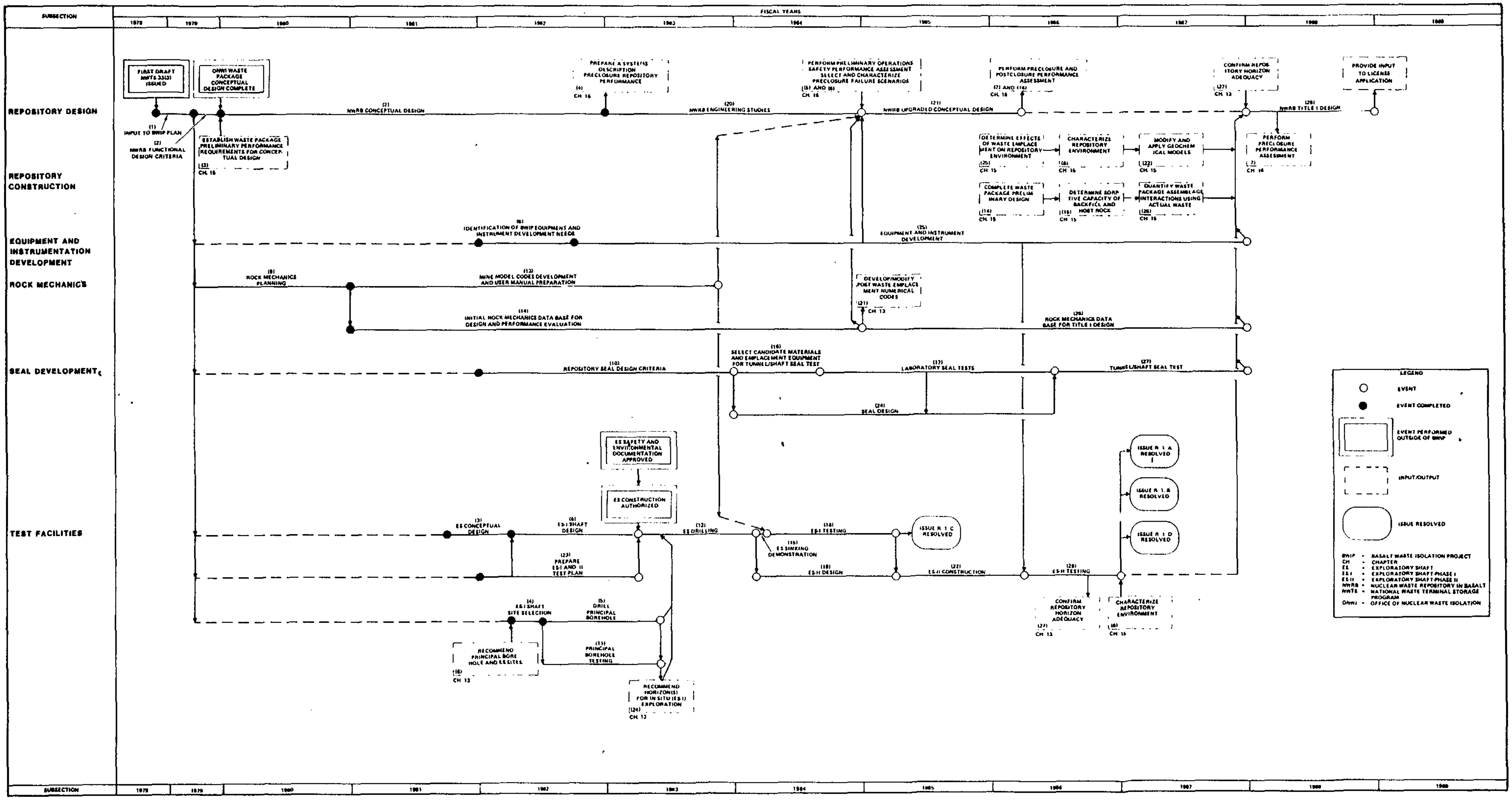

FIGURE 17-9. Schedule for Resolution of Geoengineering and Repository Design Issues.

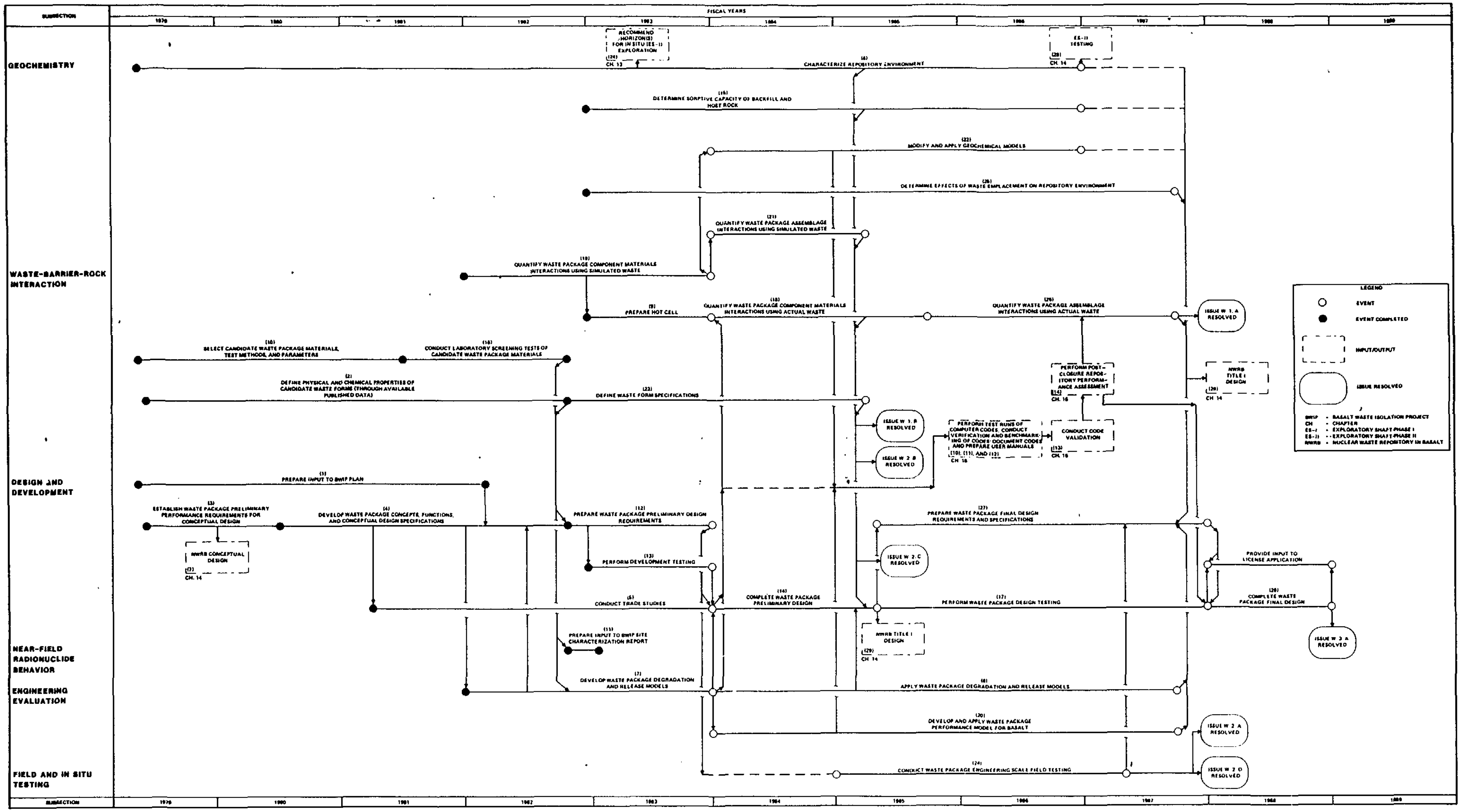

FIGURE 7-10. Schedule for Resolution of Waste Package and Site Geochemistry Issues.

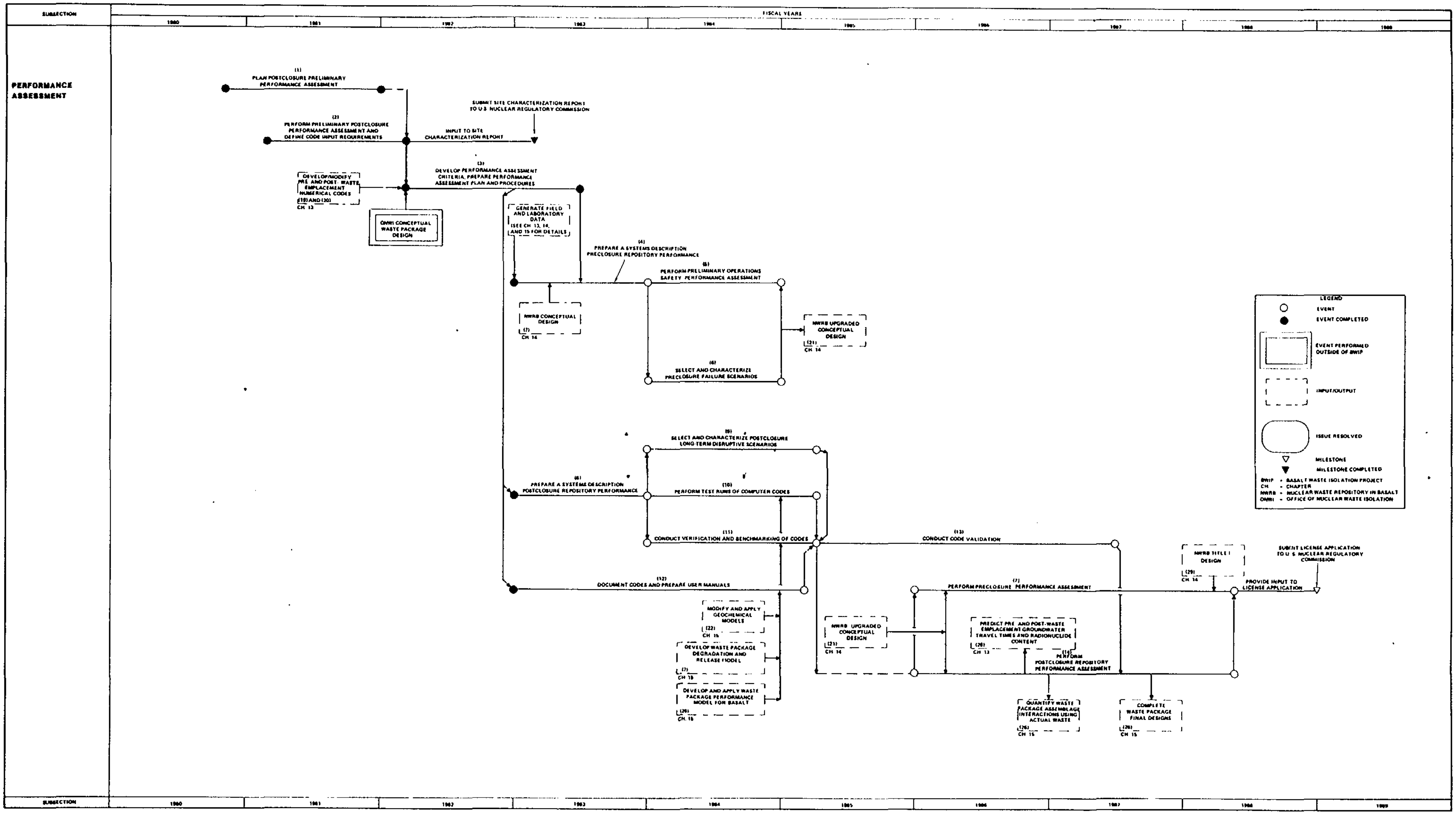

FIGURE 7-11. Schedule for Resolution of Performance Assessment Issues.

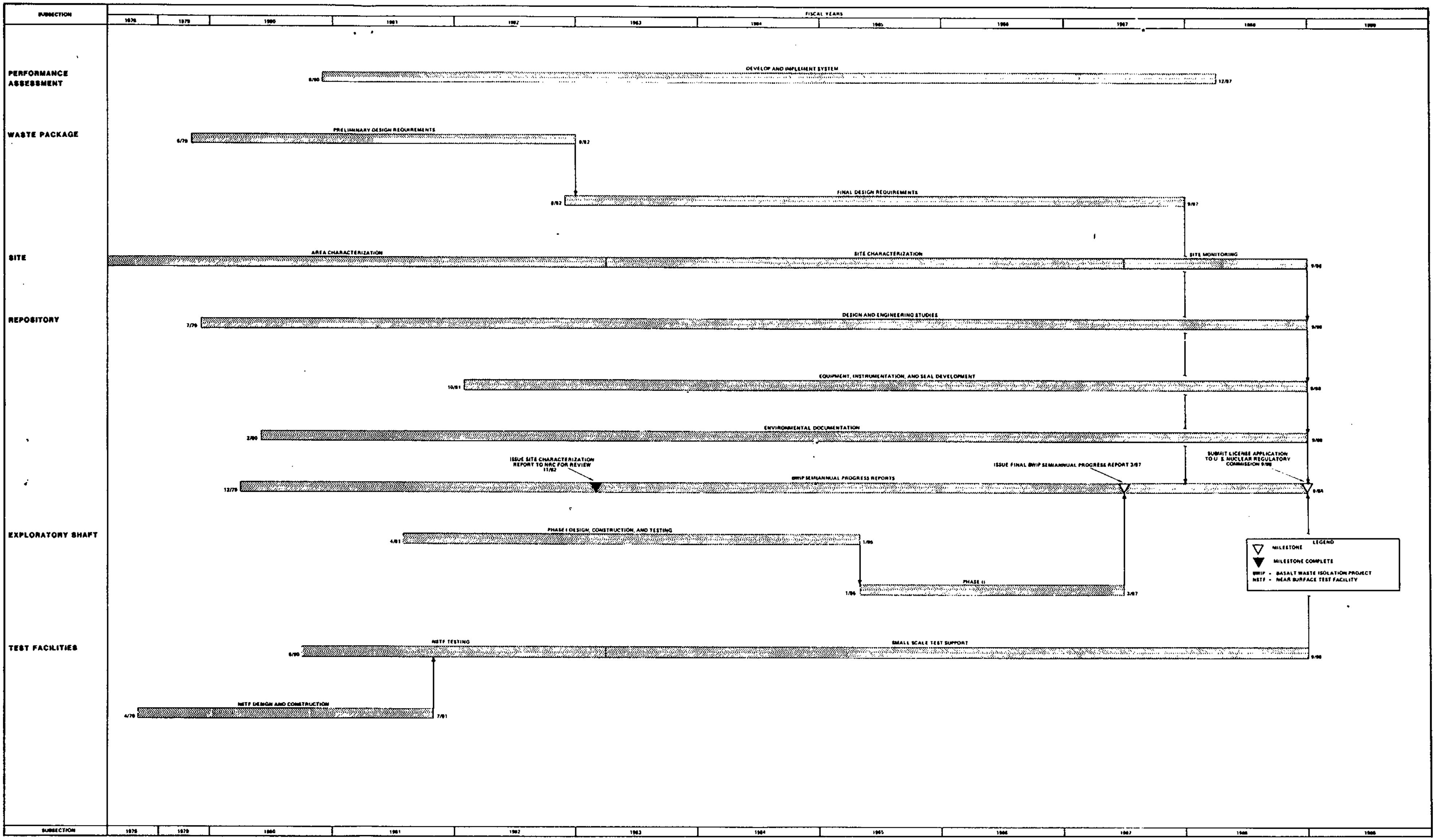

FIGURE 17-12. Summary Schedule for the License Application.

17.4 U.S. NUCLEAR REGULATORY COMMISSION ISSUES

In May 1982, the U.S. Nuclear Regulatory Commission identified siting and design suitability issues specifically for the BWIP (NRC, 1982). The issues identified by the U.S. Nuclear Regulatory Commission were not selected with the same definitions as used by the BWIP in Chapters 13 through 16 of this Site Characterization Report. However, the issues are an appropriate breakdown of concerns. Information regarding the U.S. Nuclear Regulatory Commission issues is distributed throughout this Site Characterization Report. Table 17-13 has been prepared to guide the reader to the sections where this information (or plans for acquiring such information) is located. Specifically, Table 17-13 contains references to the data (Chapters 2 through 12) where the specific U.S. Nuclear Regulatory Commission issues are discussed and to Chapters 13 through 16 where either the specific issue (plans) is discussed or the major data supporting analysis of the U.S. Nuclear Regulatory Commission is to be collected.

The U.S. Nuclear Regulatory Commission defined an issue as "a broad question that is critical to suitability of the site or to the adequacy of the design" (NRC, 1982). The U.S. Nuclear Regulatory Commission desires these questions answered during site characterization so that they may consider them during processing of the Construction Authorization Application. These issues are based on the proposed provisions of Subpart E of 10 CFR 60 (NRC, 1981) as are the BWIP issues and work elements; therefore, the organization of this Site Characterization Report is compatible with these U.S. Nuclear Regulatory Commission issues.

TABLE 17-13. U.S. Nuclear Regulatory Commission Issue Questions.
(Sheet 1 of 9)

Conditions Before Waste Emplacement	Location of information	Plans provided in Chapters 13 through 17 Number of related planning work elements
A. <u>RADIONUCLIDE TRANSPORT</u>		
A-1 What is the accessible environment for application of the U.S. Environmental Protection Agency standard on radionuclide releases?	12.1.3	S.1.33.C, Glossary
A-2 What is the basis for identification of the hydrostratigraphic units that are used for modeling and testing?	3.5, 5.1.3, 12.4, 13.3, 16.3.1	S.1.A.1 through S.1.A.10
a. How is the choice of units supported by data from lithology/stratigraphy, hydraulic parameters, and hydraulic heads?	3.5, 12.4	S.1.1.A, S.1.7.A, S.1.8.A, S.1.24.C through S.1.26.C, S.1.30.C
b. How is water chemistry used to identify hydrostratigraphic units?	5.1.5, 5.1.6, 5.2.3, 6.2	S.1.26.C, S.1.42.D
c. What is the relationship between the hydrostratigraphic units and the unit tests for hydrologic parameters?	3.5, 5.1.3.3, 5.1.4, 5.1.5, 5.1.6, 12.4, 13.3.7	S.1.24.C, S.1.25.C, S.1.26.C
d. What is the relationship between the hydrostratigraphic units and the units used in groundwater modeling?	12.4.1, 12.4.3	S.1.30.C, S.1.33.C, S.1.34.C

TABLE 17-13. U.S. Nuclear Regulatory Commission Issue Questions.
(Sheet 2 of 9)

Conditions Before Waste Emplacement (continued)	Location of information	Plans provided in Chapters 13 through 17 — Number of related planning work elements
A-3 What are the groundwater recharge and discharge locations, mechanisms, and amounts for the Pasco Basin groundwater flow systems?		
a. What is the water balance for the Pasco Basin?	5.1.9, 7.3, 7.4.1	S.1.30.C
b. What are the groundwater recharge locations, mechanisms, and amounts for the Pasco Basin?	5.1.2.3, 5.1.4.2, 7.3	S.1.30.C
c. What are the groundwater discharge locations, mechanisms, and amounts for the Pasco Basin?	5.1.2.3, 5.1.4.2, 7.3	S.1.30.C
d. What are the hydrologic parameters of each unit tested?	5.1.3	S.1.24.C, S.1.25.C, S.1.26.C
e. What boundary conditions are used to model the flow systems?	12.4	S.1.33.C
f. What is the basis for selection of the boundary conditions?	12.4	S.1.30.C, S.1.33.C
g. What is the ratio of vertical-to-horizontal permeability?	12.4	S.1.24.C

TABLE 17-13. U.S. Nuclear Regulatory Commission Issue Questions.
(Sheet 3 of 9)

Conditions Before Waste Emplacement (continued)	Location of information	Plans provided in Chapters 13 through 17 — Number of related planning work elements
h. What information on groundwater movement is provided by the water temperature distributions?	5.1.5.2, 5.1.5.3, 5.1.5.4	S.1.25.C, S.1.30.C
i. What information on groundwater chemistry is provided by a study of water chemistry?	5.1.5, 5.1.6, 6.2	S.1.26.C, W.2.2.A, W.2.4.A
j. What information on groundwater movement is provided by the by the water age determinations?	5.1.6, 5.2.3	S.1.26.C
A-4 What are the effects of groundwater chemistry on radionuclide migration?		W.1.12.A, W.2.3.A, W.2.4.A
a. What is the chemistry of the groundwater?	5.1.5, 5.1.6, 5.2.3, 6.2	S.1.26.C
b. What are the important radionuclide species to be expected in the groundwater?	5.1.6, 5.2.3, 6.3, 6.4	S.1.39.D, W.1.4.A, W.2.4.A, W.2.5.A
c. What are the solubilities of expected radionuclides species?	6.4.1	S.1.26.C, W.2.5.A
d. What is the capacity of the groundwater system to buffer Eh and pH?	5.1.5	S.1.26.C, W.2.2.A

TABLE 17-13. U.S. Nuclear Regulatory Commission Issue Questions.
(Sheet 4 of 9)

Conditions Before Waste Emplacement (continued)	Location of information	Plans provided in Chapters 13 through 17 — Number of related planning work elements
e. What is the contribution of particulates and colloids in the groundwater to radionuclide retardation?	6.4.1	S.1.26.C, W.2.6.A
A-5 What are the effects of the host rocks and mineral phases on radionuclide migration?	6.2, 6.4	
a. What are the principal mineral phases that are in contact with the groundwater?	6.1, 6.3	S.1.5.A, S.1.6.A S.1.8.A, S.1.9.A
b. What is the contribution of the mineral phases to radionuclide migration?	6.3, 6.4	P.1.1-SC, S.1.5.A S.1.6.A, S.1.7.A, S.1.9.A, S.1.30.C, S.1.38.D, S.1.42.D, W.1.3.A, W.1.4.A, W.1.10.A, W.1.12.A W.2.1.A, W.2.2.A, W.2.3.A, W.2.4.A, W.2.5.A, W.2.13.D,
A-6 What are the groundwater flow paths and travel times under present conditions?	5.1.4.2, 12.4.1, 12.4.3,	All work elements associated with Issue S.1.C.
a. How and to what extent do structural, stratigraphic, and lithologic heterogeneities affect groundwater flow?	3.5, 3.7, 5.1.5, 5.1.6, 5.1.7, 5.1.10	S.1.1.A through S.1.10.A, S.1.12.B, S.1.27.C, through S.1.29.C

TABLE 17-13. U.S. Nuclear Regulatory Commission Issue Questions.
(Sheet 5 of 9)

Conditions After Waste Emplacement		Location of information	Plans provided in Chapters 13 through 17 — Number of related planning work elements
A-7	What are the expected effects of groundwater flow paths, groundwater travel times, and possible radionuclide releases of future, repository-induced changes?	12.4.1, 12.4.2, 12.4.3, Chapter 16	S.1.37.D, S.1.41.D, R.1.56, R.1.67, R.1.70, R.1.71
A-8	What are the expected effects on groundwater flow paths, groundwater travel times, and possible radionuclide releases of future, natural changes?	12.2, 12.3, 12.4	S.1.D, S.1.32.C, S.1.37.D through S.1.61.D
A-9	What are the expected effects on groundwater flow paths, groundwater travel times, and possible radionuclide releases of future, human-induced changes, excepting repository-induced changes?	12.3, 12.4, 13.3, 15.3	S.1.41.D, S.1.44.D through S.1.48.D, S.1.50.D, S.2.3. All work elements associated with Issues W.1.A and W.2.A.
	B. STABILITY		
B-1	What is the nature of changes that would affect groundwater flow due to repository construction and waste emplacement?		
	a. What is the effect due to repository construction?	Chapter 10	R.1.3.A, R.1.22.D, R.1.63
	b. What is the effect due to waste emplacement?	12.4.3	R.1.3.A, R.1.70, R.1.71.A, S.1.37.D, S.1.38.D, S.1.39.D, S.1.40.D, S.1.51.D

TABLE 17-13. U.S. Nuclear Regulatory Commission Issue Questions.
(Sheet 6 of 9)

Conditions After Waste Emplacement (continued)	Location of information	Plans provided in Chapters 13 through 17 — Number of related planning work elements
B-2 What is the nature of changes that would affect radionuclide retardation due to repository construction and waste emplacement?	6.4, Chapter 10, 11.4	R.1.55, R.1.56, R.1.67, R.1.70
a. What are likely phase changes in the minerals that are in contact with the groundwater?	6.1, 6.3.2, 6.3.3	W.1.3.A, W.1.4.A, W.1.5.A, W.1.12.A, W.2.13.D, W.3.2.A, R.1.55, R.1.22.D
b. What are the kinetics of likely phase change?		W.1.4.A, W.1.5.A, W.1.12.A, W.3.2.A
c. What are the cumulative effects of (a) and (b) on radionuclide retardation?	6.4	W.1.4.A, W.2.1.A, W.2.4.A
B-3 What are the probabilities and nature of natural changes that would affect repository performance?	3.7.2, 3.8.2, 7.2, 8.3.2	S.1.32.C, S.1.41.D, S.1.42.D, S.1.43.D
B-4 What are the probabilities and nature of human-induced changes, excluding repository construction, that would affect repository performance?	5.1.9, 7.1.5, 7.3, 7.4.1	S.1.41.D, S.1.44.D through S.1.48.D, S.1.50.D, S.2.3
a. What are the probabilities and nature of groundwater withdrawals that would affect repository performance?	5.1.9, 7.3	S.1.24.C, S.1.26.C, S.1.28.C, S.1.33.C, S.1.41.D, S.1.43.D through S.1.50.D
b. What are the probabilities and nature of groundwater recharge that would affect repository performance?	5.1.9.3	S.1.24.C, S.1.26.C, S.1.28.C, S.1.33.C, S.1.41.D, S.1.43.D through S.1.50.D

TABLE 17-13. U.S. Nuclear Regulatory Commission Issue Questions.
(Sheet 7 of 9)

Conditions After Waste Emplacement (continued)	Location of information	Plans provided in Chapters 13 through 17 Number of related planning work elements
B-5 What is the seismic hazard and risk to surface and subsurface facilities?	3.7, 3.8, Chapter 10	R.1.28, R.1.29, R.1.30, R.1.34, R.1.50, S.1.11.B through S.1.22.B, S.1.39.D, S.1.41.D, S.1.45.D, S.1.44.D, S.1.52.D, S.1.54.D, S.1.55.D, S.1.56.D, S.1.57.D
B-6 How does the value of mineral resources at the repository location compare with the values in other areas of similar size within the geologic setting?	3.9	S.2.3
C. <u>REPOSITORY DESIGN</u>		
C-1 Are the repository design criteria and the functional description shown to be complete and accurate with respect to the performance objectives?	14.2	R.1.66. All work elements associated with Issues R.1.A and R.1.D.
a. How do the design criteria accommodate the retrievability option?	10.1, 10.5	R.1.59, R.1.61, R.1.62, W.1.2.A, W.1.7.A
b. How do the design criteria assure that rock stress will not significantly impact the long-term performance of the waste package?	4.5, 10.4	R.1.13.B, R.1.55, R.1.57, R.1.70, R.1.71, W.1.2.A

TABLE 17-13. U.S. Nuclear Regulatory Commission Issue Questions.
(Sheet 8 of 9)

Conditions After Waste Emplacement (continued)	Location of information	Plans provided in Chapters 13 through 17 Number of related planning work elements
C-2 Is the design shown to be consistent with the design criteria and the functional description and appropriate to satisfaction of the performance objective?	Purpose of Chapter 10, 16.3.4	All work elements associated with Issues W.1.A, R.1.A, R.1.D.
C-3 How is the conceptual design shown, by analysis, to accommodate mechanical and thermal effects due to construction and waste emplacement?	10.4	All work elements associated with Issue R.1.A.
C-4 How is the conceptual design shown, by analysis, to accommodate high horizontal stress in the repository host rock?	10.4	All work elements associated with Issue R.1.A.
a. What is the effect of in situ stress field on repository orientations, shape and dimension of openings, and mode of waste emplacement?	10.3, 10.4	R.1.57, S.1.15.B, S.1.20.B. All work elements associated with Issue R.1.C.
C-5 How is repository performance expected to be affected by construction of the exploratory shaft?	17.2	All work elements associated with Issue R.1.D.

NOTE: Issues C-3, C-4, and C-5 can be viewed as subissues of C-1 and C-2, but are treated separately here for emphasis.

D. <u>ENGINEERED BARRIERS</u>		
D-1 How are the engineered barriers components predicted to perform through the period of waste isolation?	Chapter 12, 16.3.2, 16.3.3	

TABLE 17-13. U.S. Nuclear Regulatory Commission Issue Questions.
(Sheet 9 of 9)

Conditions After Waste Emplacement (continued)	Location of information	Plans provided in Chapters 13 through 17 — Number of related planning work elements
a. What are the predicted repository conditions relevant to performance of each engineered barrier component?	10.5, 10.6, 11.4	W.1.1.A, W.1.2.A, R.1.7.A, R.1.20, R.1.16.D through R.1.26.D
b. What are the likely failure modes relevant to performance of each engineered barrier component?	11.2.2, 11.2.2.2, 11.4, 16.3.1, 16.3.2, 16.3.3, 16.3.4	R.1.28, R.1.30, W.1.3.A, W.1.6.A, W.1.8.A, W.1.9.A
c. What is the effect on radionuclide transport of changes in chemistry of the engineered barriers as a result of waste emplacement?	11.4.3	R.1.20.D, R.1.22.D, R.1.66, R.1.67. All work elements associated with the Issues W.1.A and W.2.A.

NOTE: This issue will be analyzed separately with respect to waste form, waste package, backfill, and seals.

E. INSTITUTIONAL CONCERNS		
E-1 What was the decision-making process for selection of the candidate area and site, including technical, institutional, and environmental factors?	2.1, 2.2, 2.3, 2.4	Chapter 2 this document fully addresses this issue.
E-2 What other sites are under construction for characterization?	Chapter 19	

17.5 REFERENCES

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NWTS, 1981c, NWTS Program Criteria for Mined Geologic Disposal of Nuclear Waste, Repository Performance and Development Criteria, DOE/NWTS-33(3), National Waste Terminal Storage Program, U.S. Department of Energy, Washington, D.C.

NWTS, 1981d, NWTS Program Criteria for Mined Geologic Disposal of Nuclear Waste, Waste Package Performance Criteria, DOE/NWTS-33(4), National Waste Terminal Storage Program, U.S. Department of Energy, Washington, D.C.

18. QUALITY ASSURANCE

Described in this chapter is the quality assurance program that has been applied to date and will be applied during site characterization for the Basalt Waste Isolation Project (BWIP). The quality assurance program is applied to all project areas, including, but not limited to, characterization, waste-package design, repository design, and performance assessment. Application of the quality assurance program unique to the aforementioned areas is provided under the appropriate subsection. The BWIP quality assurance program is based on the criteria of 10 CFR 50, Appendix B (NRC, 1980), supplemented by the National Consensus Standard ANSI/ASME NQA-1 (ANSI/ASME, 1979), additional addenda in ANSI/ASME (1981a; 1981b), and by the U.S. Department of Energy (DOE)-Headquarters program guidance.

Applicable requirements from NQA-1 (ANSI/ASME, 1979; 1981a; 1981b) as described in this chapter have been implemented by the participating principal contractors (operating contractor and architect-engineer) and their suppliers during the site screening process. These requirements will continue to be implemented by the principal contractors and their suppliers during the site characterization program and will include the exploratory shaft construction manager and his suppliers. Certification requirements of NQA-1 have been applied to nondestructive examination personnel during site screening. Certification requirements will additionally be imposed on the principal contractors and their suppliers' inspection and acceptance testing personnel associated with the exploratory shaft liner fabrication and installation during site characterization. The quality assurance records management system for the BWIP was upgraded during the site screening program to ensure full compliance with NQA-1 requirements before initiating the site characterization program. Enhancements have been affected in the areas of records administration (indexing and classification); receipt control; facility modifications for storage, preservation, and safekeeping, and retrieval capabilities through a comprehensive document registration system.

18.1 ORGANIZATION

The organizational structure, functional responsibilities, levels of authority, and lines of communication for activities affecting quality of the BWIP have been established and documented. The organizational structure for the DOE-Richland Operations Office (DOE-RL) for the BWIP is depicted in Figure 18-1. The DOE-RL Manager has assigned the responsibility for management, direction, and coordination for the safety, safeguards and security, and quality assurance programs to the Assistant Manager for Safety, Safeguards and Quality Assurance. The Assistant Manager for Safety, Safeguards and Quality Assurance has delegated the responsibility for development and coordination of the DOE-RL quality assurance program to the Safety and Quality Assurance Division Director. The Safety and Quality Assurance Division Director, in concert with the BWIP Project Manager, assures that each principal contractor (operating contractor, architect-engineer, and construction manager) establishes an adequate quality assurance program for his activities affecting the BWIP.

The BWIP Project Manager, who reports to the Assistant Manager for Project and Facilities Management at DOE-RL and receives programmatic guidance from the Division of Waste Repository Deployment Director at DOE-Headquarters, verifies that the principal contractors have identified appropriate quality assurance requirements for their activities and are effectively implementing their quality assurance programs. These responsibilities and authorities are documented in DOE-RL Order 5700.1 (DOE-RL, 1980).

The DOE-RL has delegated responsibility, through DOE-RL Order 5700.1 (DOE-RL, 1980), to develop and implement quality assurance programs for assigned projects and programs to its prime contractors. However, the DOE-RL retains responsibility for their content. The DOE-RL has delegated the responsibility to develop the overall quality assurance program for the BWIP, as well as to monitor the performance of the principal contractors involved in the project, to Rockwell Hanford Operations (Rockwell).

The organizational structure, functional responsibilities, levels of authority, and lines of communication for activities affecting quality on Rockwell projects and programs at the Hanford Site have been documented. The organizational structure for Rockwell is depicted in Figure 18-2. Establishment and verification of proper implementation of the generic quality assurance program for Rockwell is the responsibility of the Director, Quality Assurance Function. The Director, Quality Assurance Function has authority to stop work and withhold nonconforming items or activities from use. Implementation of the quality assurance program for the BWIP is the responsibility of the BWIP Director. The Director, Quality Assurance Function and the BWIP Director and Associate Director are appointed by and are responsible to the Rockwell Vice President and General Manager.

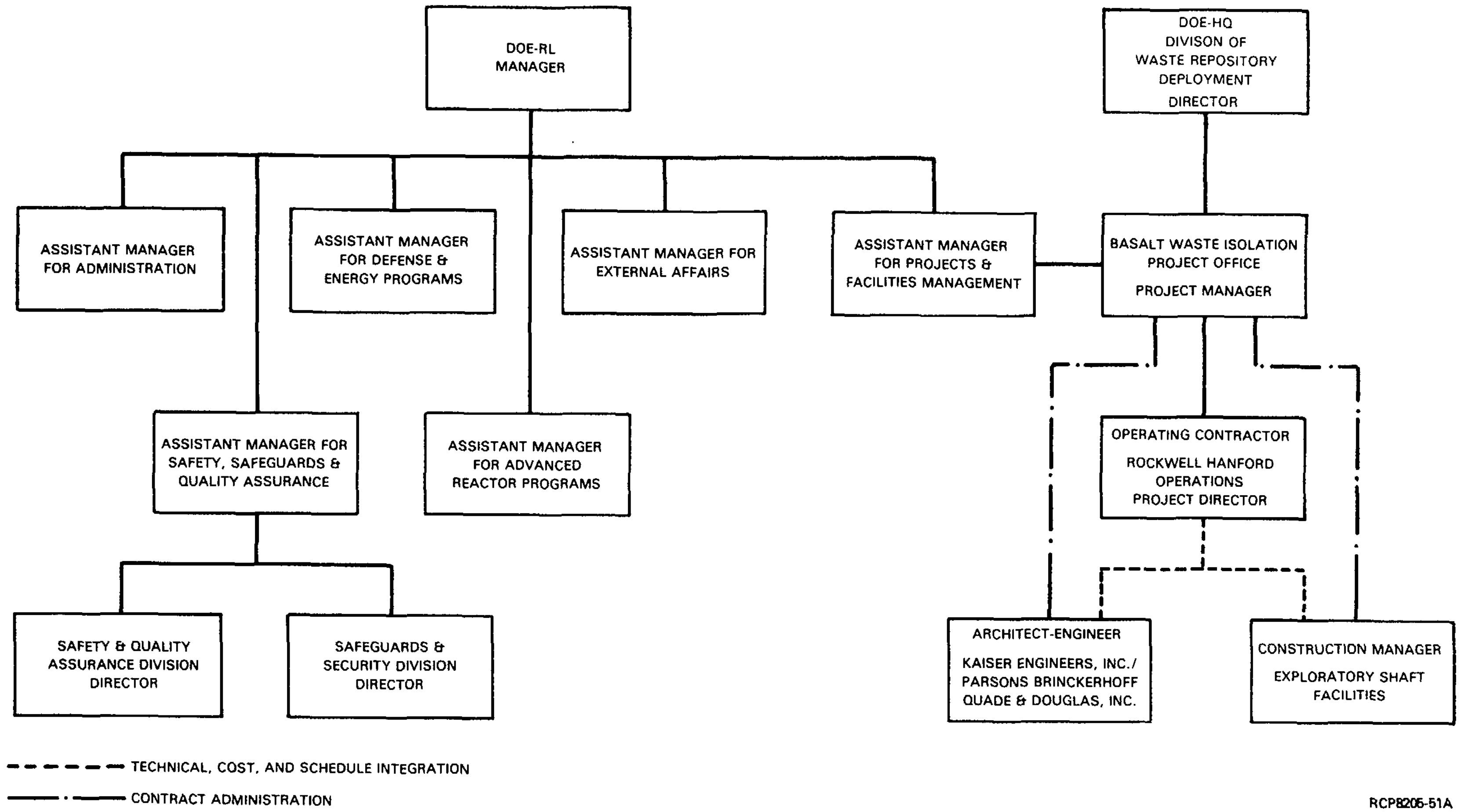

FIGURE 18-1. Basalt Waste Isolation Project Management Organization.

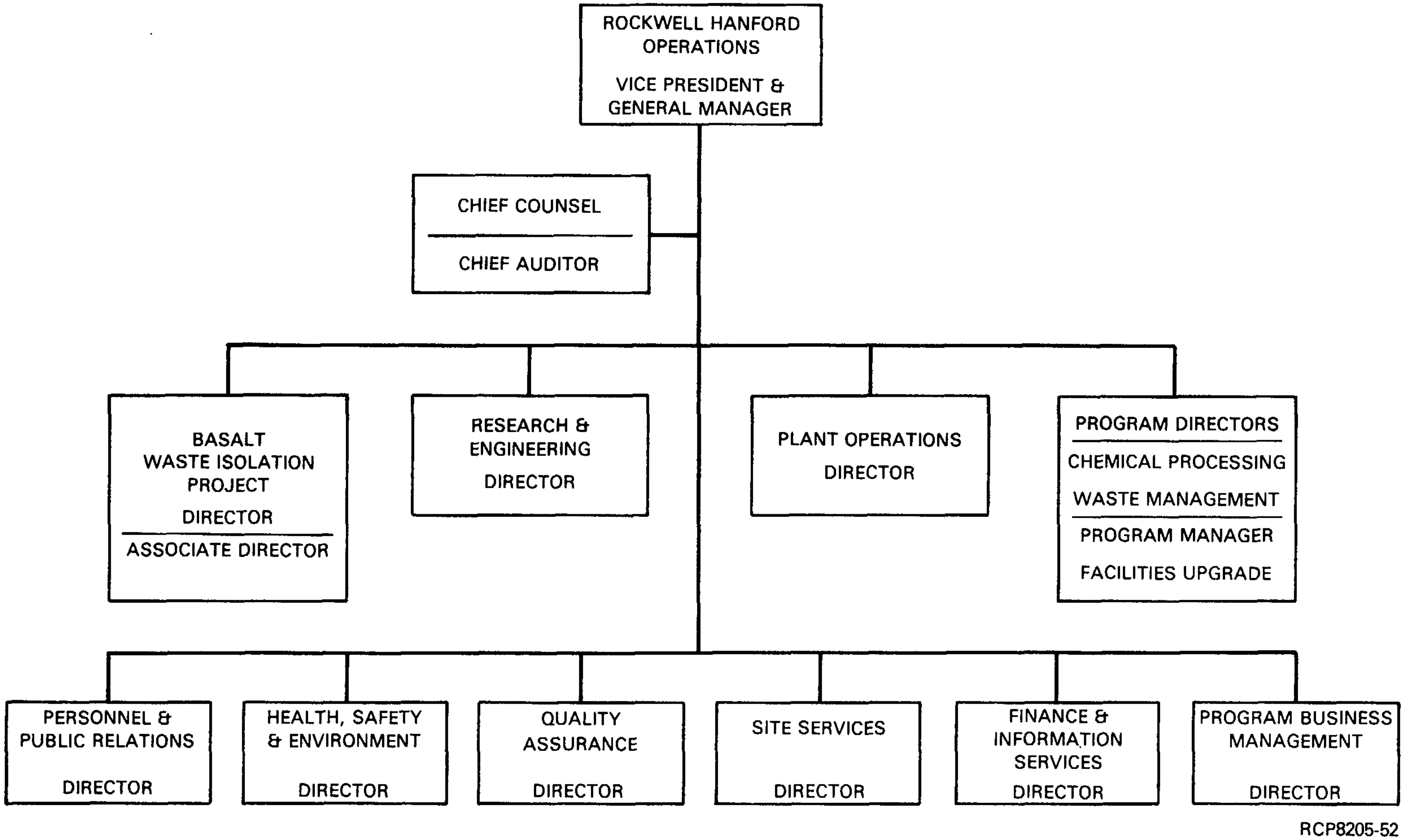

FIGURE 18-2. Rockwell Hanford Operations Organization.

The Rockwell organizational structure for the BWIP is depicted in Figure 18-3. The Rockwell Quality Assurance Function supports the BWIP through "matrix" management. The BWIP Quality Assurance Manager is appointed by the Director, Quality Assurance Function with concurrence of the BWIP Director. The BWIP Quality Assurance Manager reports directly to the Director, Quality Assurance Function and is delegated responsibility for identifying the requirements from the overall Rockwell quality assurance program that are applicable to the BWIP and for verifying their effective implementation.

The responsibilities and authorities of the above positions, as well as all positions depicted on Figure 18-3, are documented in existing Rockwell policies and individual position descriptions. Functional charters for the BWIP and Quality Assurance Function and program charters for each program within the BWIP are also documented in Rockwell policies.

Organizational structures of other onsite or offsite prime DOE-RL contractors supporting the BWIP are documented in their quality assurance manuals and are reviewed for adequacy by Rockwell. Rockwell assures appropriate organizational structure of its subcontractors during the procurement review. These measures assure that organizational freedom exists for those individuals who verify quality throughout the entire project.

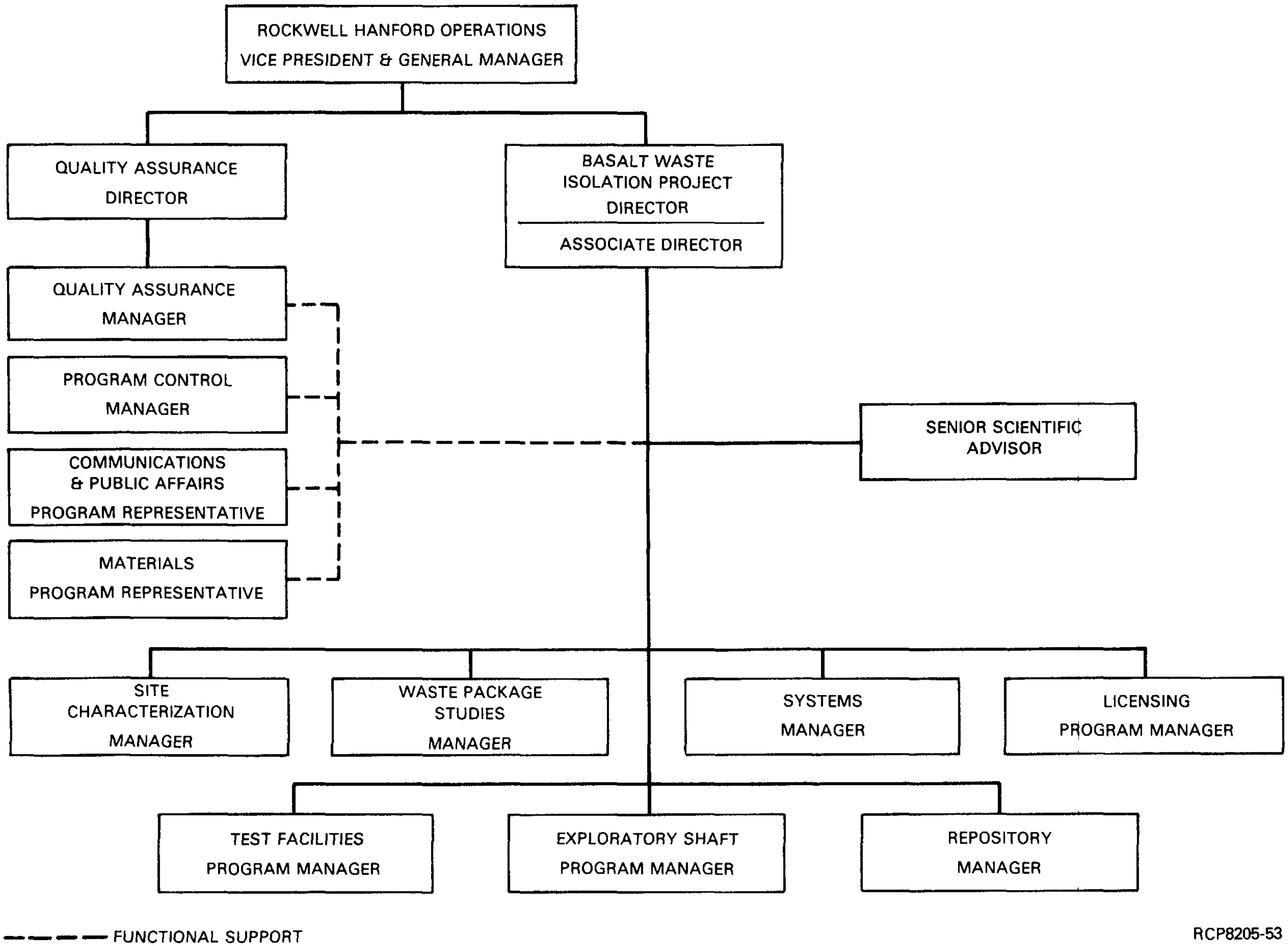

FIGURE 18-3. Rockwell Hanford Operations/Basalt Waste Isolation Project Organizations.

18.2 QUALITY ASSURANCE PROGRAM

The Secretary of the DOE, in DOE Order 5700.6A (DOE-HQ, 1981a), has allowed the program secretarial officers and field-office managers the discretion to define the quality assurance requirements to be implemented on their programs and projects. This order endorses the use of national consensus standard NQA-1 (ANSI/ASME, 1979; 1981a; 1981b) as the preferred quality assurance standard to be used on nuclear programs. Accordingly, the Director, Division of Waste Repository Deployment has established in a supplemental memorandum (Cooley, 1981) that National Waste Terminal Storage Program quality assurance programs will be in conformance with all basic and supplementary requirements of NQA-1 (ANSI/ASME, 1979; 1981a; 1981b) with the exclusions, modifications, and additions delineated in an attachment to the memorandum. Likewise, the Manager, DOE-RL has endorsed the use of NQA-1 (ANSI/ASME, 1979; 1981a; 1981b) on all programs and projects that are under his purview. The quality assurance program for the BWIP has therefore been established to satisfy the basic and supplementary requirements of NQA-1 (ANSI/ASME, 1979; 1981a; 1981b), which complement the quality assurance program requirements of 10 CFR 60, Subpart G (NRC, 1981) for site screening and site characterization activities.

The generic quality assurance program used by Rockwell for DOE-RL-sponsored programs and projects is documented in an existing Rockwell manual of policies and in implementing functional procedures manuals. Management policies for Rockwell are issued under the authority of the Rockwell Vice President and General Manager's office. Functional directors are responsible for development of their implementing functional-procedures manuals. Rockwell's Quality Assurance Function reviews and documents concurrence with these functional procedures that affect quality.

Rockwell policy requires the maintenance of an effective quality assurance program to assure the requisite level of quality in all areas of contract performance. Quality will not be compromised in relation to costs or schedules. The quality assurance program provides for the planning and accomplishment of activities affecting quality under suitably controlled conditions, including use of appropriate equipment, suitable environmental conditions for accomplishing the activities, and assurance that prerequisites for any given activity have been satisfied. The program provides for any special controls, processes, test equipment, tools, and skills to attain the required quality and for necessary verification of quality through inspection, test, surveillance, and audit. Quality assurance requirements applicable to the BWIP and an index and description of applicable procedures from the generic Rockwell quality assurance program are provided in a quality assurance program plan for the BWIP. The other principal contractors are required to document quality assurance program plans for their activities.

The BWIP quality assurance program is applied to the development, control, and use of computer code programs. Rockwell has established methods by which software is written, organized, structured, and documented so that computer programs can be validated, maintained, modified, and understood by scientific programmers. Implementing procedures have been documented in a BWIP procedures manual.

Software is divided into two categories: developmental and production. Developmental software is experimental in nature, is not released outside of Rockwell, and is under the user's control. Production software is that run on a recurring or scheduled basis to support the BWIP, is subject to release outside of Rockwell, and is under the control of the BWIP Technical Computer Systems Unit under the BWIP Test Facilities Program. The BWIP Technical Computer Systems Unit is responsible for change control, archiving, and traceability of production software. The Manager, BWIP Technical Computer Systems Unit is responsible for establishing programming standards for code documentation and structure. These measures assure that each code and version of a code are as correct as possible and that traceability of various codes and versions is maintained.

Rockwell assigns quality assurance levels to designate the quality assurance effort applicable to the design and construction of engineered structures, systems, or components. The levels are based on importance to nuclear safety and degree of quality effort required. Quality assurance levels are established during conceptual design for construction projects. Quality assurance requirements for activities not directly associated with physical components, such as service contracts or research and development activities, are developed on a case-by-case basis in accordance with established procedures.

Management of those organizations implementing the quality assurance program for the BWIP regularly assesses the adequacy of that part of the program for which they are responsible. Quarterly reviews are held with the DOE. Project and functional reviews are routinely scheduled with the Rockwell Vice President and General Manager and affected directors through executive control meetings. Program team meetings are regularly scheduled to assess the status of each program within the BWIP (i.e., Systems, Waste Package, Site, Repository, Regulatory and Institutional, Near-Surface Test Facility/Support Laboratories, Exploratory Shaft, and Program Management).

Rockwell policy requires managers to train new employees regarding job requirements and to establish formal and on-the-job training to assure personnel are qualified to perform their duties in a safe, efficient, and effective manner. A documented BWIP training program has been established to assure that proficiency is achieved and maintained by BWIP personnel in areas of project organization, systems, management, and technical operations. Training of BWIP quality assurance personnel in procedural familiarization and conduct of critical tasks is the responsibility of Rockwell's Quality Assurance Function. Internal training requirements for Rockwell quality assurance personnel have been established through a documented training program.

Other principal contractors are required to train and qualify their personnel in accordance with the requirements of NQA-1 (ANSI/ASME, 1979; 1981a; 1981b). Subcontractors are required to supply personnel qualifications for quality-related activities when the scope of work warrants. These qualifications are then reviewed by technical or quality assurance personnel, as applicable, as part of the supplier-quality-system evaluation.

18.3 DESIGN CONTROL

To identify and control the BWIP criteria and requirements, a "baseline" control concept has been established by Rockwell. A National Waste Terminal Storage Program baseline, DOE-RL baseline, and Rockwell baseline have been established that identify controlling documents at the various program levels. The baseline documents and a change control policy are documented in a BWIP configuration management plan and are supported by implementing procedures in a BWIP functional manual. Summaries of current data traceable to documented sources that are used for all design as well as internal studies, modeling work, and subcontractor studies are controlled for the BWIP by a Rockwell data package manual. This assures all work is accomplished using the same traceable data.

The design process followed on DOE-RL construction projects is prescribed in DOE-RL Order 5700.2 (DOE-RL, 1982). This order establishes the required sequence of design activities, requirements, and procedures to be followed in the planning, management, scheduling, execution, reporting, and closeout of all DOE-RL projects. Policies and objectives, responsibilities and authorities, and procedures and requirements for the development and maintenance of general design criteria and for their application in the planning and design or acquisition of DOE's facilities are contained in DOE Order 6430 (DOE-HQ, 1981b). This order has been distributed for use during a coordination period. A project management plan is also prepared by Rockwell for each construction project, which defines project objectives and goals, schedules, major milestones, required resources, and organizational responsibilities. Rockwell has established procedures in its functional procedures manuals that document interface control among participating organizations. These procedures establish responsibilities and define requirements for review, approval, release, distribution, and revision of documents involving design interfaces.

It is Rockwell policy that independent, third-party reviews be conducted for evaluation and approval of all new engineering documentation as well as changes to existing documentation. Implementing procedures have been developed in Rockwell's functional manuals that require all review comments to be dispositioned and the results of all reviews to be documented. Following resolution of comments, the approved design documents are issued through an engineering release system in accordance with established procedures. Subsequent to the release of design documents, engineering changes are made in accordance with established procedures under Rockwell's engineering change management system. All approved engineering changes to released engineering documents are governed by controlled measures commensurate with those applied to the original document.

Where design adequacy is to be verified by qualification tests, the tests are identified in an engineering-released test plan prepared by Rockwell. Test plans are used to control qualification testing in the major BWIP test-program areas, such as the Near-Surface Test Facility, Exploratory Shaft, Hydrologic Drilling and Testing, and Waste Package studies. These test plans are then implemented through the use of controlled test procedures. These procedures include the following, as

applicable: (1) specified requirements and acceptance limits, (2) test prerequisites (e.g., equipment accuracy and calibration requirements and environmental conditions), (3) step-by-step instructions for performing the tests, (4) mandatory inspection-hold points, (5) provisions for evaluating results, and (6) requirements for documenting results.

To provide evaluation and assessment of interpretations, judgments, and decisions pertaining to activities that are not well suited to more conventional verification methods, a formal peer-review process has been established for the BWIP. Both external and internal peer reviews are conducted in accordance with documented procedures. External peer reviews are those imposed on the BWIP from outside of Rockwell as requested by the DOE. Internal peer reviews are instituted within the BWIP at the request of the BWIP Director when an investigation is required.

Results of design and peer reviews, as well as the final released design documents and changes thereto, are incorporated into the BWIP records retention system in accordance with established procedures.

18.4 PROCUREMENT-DOCUMENT CONTROL

Applicable regulatory requirements, technical requirements, and quality assurance program requirements, necessary to assure quality, are imposed on the DOE-RL onsite contractors through DOE-field office and -Headquarters orders. In the case of the offsite architect-engineer and construction manager, applicable DOE orders and quality assurance requirements are specified in the contract statement of work. All DOE-RL principal contractors are committed to develop and implement quality assurance programs that satisfy the requirements of NQA-1 (ANSI/ASME, 1979; 1981a; 1981b). Principal contractors are required to include appropriate provisions from this standard to their subtier suppliers in the procurement documents. Procurement-document-control practices of all the principal contractors are subject to review by Rockwell quality assurance.

Rockwell has established procedures in its functional procedures manuals for the review of Rockwell procurement documents by qualified, independent quality assurance personnel. All BWIP purchase requisitions, invitations for bid, purchase orders, service agreements, and consultant-services contracts require approval by Rockwell's Quality Assurance Function.

Procurement planning is accomplished each fiscal year between the Rockwell Material Function and the BWIP program managers. A procurement plan is published annually. Purchase requisitions are prepared by the BWIP program managers and Program Business Management Function representatives. The purchase requisition requires approval by Quality Assurance Function to assure adequate quality provisions. The Material Function then prepares invitations for bid, which are also approved by the Quality Assurance Function to assure no changes have occurred to the quality requirements of the purchase requisition. The BWIP program managers, Material Function buyers, and Quality Assurance Function representatives then participate in the bid evaluations and supplier selection. Where a quality assurance program is required, a quality survey is performed by the Quality Assurance Function. Suppliers are required to have an acceptable quality program prior to initiation of activities affected by the program. Once a supplier has been selected, the Material Function prepares a purchase order or other appropriate contract document. This purchase order or contract requires approval by the Quality Assurance Function to assure that quality provisions are consistent with the invitation for bids and that the supplier has been approved.

18.5 INSTRUCTIONS, PROCEDURES, AND DRAWINGS

Activities affecting quality are prescribed by and performed in accordance with documented instructions, procedures, or drawings of a type appropriate to the circumstances. Drawing requirements are specified for the Hanford Site through the Hanford Plant Standards and Hanford Specifications Systems. A BWIP functional procedures manual has been developed for the project by Rockwell. Procedures from this manual as well as from other Rockwell functional procedures manuals, which implement the BWIP quality assurance program, are identified in a BWIP quality assurance program index. Other principal contractors and Rockwell subcontractors are required in the procurement documents to either adopt these procedures for performance of their work or develop their own procedures. All procedures and design drawings for the BWIP are reviewed for adequacy by the Rockwell Quality Assurance Function. These measures assure that instructions, procedures, and drawings include quantitative or qualitative acceptance criteria for determining that important activities have been satisfactorily accomplished.

18.6 DOCUMENT CONTROL

Each principal contractor is required to establish measures that control the preparation, issue, and change of documents that affect quality to assure that correct documents are being employed. Rockwell has established both a technical- and an administrative-document-control system for the BWIP. Technical-document control is the responsibility of the technical coordination and control group of the BWIP Systems Department. Administrative-document control is the responsibility of the Rockwell Finance and Information Services Function. Policy and implementing procedures have been established in Rockwell functional manuals for the preparation, issuance, and change control of technical and administrative documents.

Technical documents intended for internal and limited external distribution are administered by the Engineering Data Management Unit within the Technical Coordination and Control Group. Typical examples of technical documents include:

- Design documents (e.g., standards and specifications, drawings, design criteria, analyses, design changes) including documents related to computer codes
- Test plans and reports
- Facility operating procedures
- Project-management plans
- Nonconformance reports
- As-built documents
- Operating documents.

Administrative documents are those that describe any business or scientific activity, plan, or procedure of Rockwell, but do not directly control the design, construction, testing, or operation of a facility, process, or equipment. Document Control within the Finance and Information Services Function is responsible for providing issuance, distribution, and accountability control of all Rockwell administrative documents, as well as all documents that are given public distribution. Typical examples of administrative documents include:

- Policy and policy-implementing procedure manuals
- Program, financial, quality assurance, and readiness-review (startup) plans
- Topical reports

- Safety/security investigations
- Laboratory and research notebooks.

Both technical and administrative documents require internal review by designated organizations to assure technical or administrative adequacy and inclusion of appropriate quality requirements. Rockwell's Quality Assurance Function review and approval are required on all documents involving quality-related aspects of the BWIP. Procedures require the same level of review and approval on changes to issued documents, except those involving only minor editorial changes.

Where documents, such as facility operating procedures, are required to be available at the work locations, Rockwell has established an operating-document-control system. This system involves use of a "third party" organization responsible for assuring that controlled documents are available at the work locations through such measures as color coding documents, physically placing and removing documents at the work location, assigning individual document numbers, and auditing. Where such a degree of control is not required, documents are controlled through the use of controlled distribution, route cards, and revision receipt forms.

18.7 CONTROL OF PURCHASED ITEMS AND SERVICES

The procurement of items and services for the BWIP is controlled to assure conformance with specified requirements. The DOE-RL monitors the activities of its principal contractors in the areas of systems, waste package studies, site, test facilities, exploratory shaft, repository design, project control, and quality assurance. Each contractor is responsible for controlling those items and services that it procures on behalf of the DOE-RL. Rockwell oversees both its own and other principal-contractor controls over suppliers through surveillance and audit to assure that project quality requirements are satisfied.

Organizational responsibilities and interfaces among Rockwell's BWIP, Material, and Quality Assurance organizations for the control of purchased material, equipment, and services are defined in the functional procedures manuals. Verification of suppliers' quality-related activities is accomplished by Rockwell's Quality Assurance Function through source inspection and surveillance activities that are planned and accomplished in accordance with documented quality assurance procedures. Source inspection and surveillance plans identify which characteristics are to be verified, the verification methods, and the supplier documentation required.

Selection of Rockwell suppliers is documented and filed. Both the coordinating agency for supplier evaluation and the Hanford index of qualified supplier systems are used. Where no information exists on a proposed supplier, a supplier-quality-system evaluation is performed by the Quality Assurance Function in accordance with documented procedures and checklists.

Rockwell policy requires inventories of spare parts to be maintained for the continued and reliable operation of facilities and equipment. Organizational responsibilities have been documented for the selection, procurement, and inventory maintenance of those spare parts that ensure continuity and safety of operations. Procurement of spare parts is subject to the same quality assurance program controls, codes and standards, and technical requirements as the original procurement or as modified to preclude repetition of any identified defects.

The Rockwell Quality Assurance Function performs receiving inspection to assure that (1) material is properly identified and corresponds to information on the purchase order and receiving report (2) material and acceptance records satisfy the inspection plan prior to installation or use, and (3) specified quality assurance records are received and available onsite prior to installation or use. Items accepted and released are identified as to their inspection status with status tags and receiving reports prior to installation, further work, or forwarding to a controlled storage area.

Quality assurance documentation required by the purchase order must be furnished by the supplier prior to acceptance of the item. Procurement requirements that have not been met and any deficiencies in the hardware identified by the supplier are documented and dispositioned by a supplier deviation-request form. The review and acceptance of the supplier's documentation are documented in Rockwell Quality Assurance Function procedures manuals. A standard quality assurance inspection plan has been developed to provide verification requirements for commercial, "off-the-shelf" items procured by Rockwell.

18.8 IDENTIFICATION AND CONTROL OF ITEMS

Measures have been established to assure that adequate identification is maintained on items, or on records traceable to the items, to prevent inadvertent use of incorrect material or loss of sample identity. Identification of material to be installed in engineered structures, such as the Near-Surface Test Facility and the Exploratory Shaft, is delineated in the applicable construction and procurement specifications. Detailed procedures have been developed by Rockwell to assure adequate identity of samples collected in the field, such as rock core, hand specimens, and water samples, to assure traceability back to the point of sampling and to assign responsibilities for identification of samples and verification of proper identification.

Rockwell uses purchase order or certified quality designated numbers to mark material for identification purposes. Material impractical to mark is tagged or packaged with the appropriate identification number. Associated quality assurance documentation (e.g., mechanical/chemical test reports, purchase orders, inspection records, receiving reports) is also marked with the designated purchase order or certified quality designated numbers to provide traceability. The Rockwell Quality Assurance Function verifies that material traceability is maintained throughout fabrication, assembly, storage, and installation. Implementing procedures have been established that document responsibilities for identifying and verifying proper identification of items.

18.9 CONTROL OF PROCESSES

Processes affecting quality of items or services are controlled through use of instructions, procedures, drawings, checklists, travelers, or other appropriate means. These measures assure that process parameters are controlled and that specified environmental conditions are maintained.

Special processes that control or verify quality are performed by qualified personnel using qualified procedures in accordance with specified requirements. The NQA-1, Supplement S-1, "Terms and Definitions," (ANSI/ASME, 1979; 1981a; 1981b) defines a special process as: "a process, the results of which are highly dependent on the control of the process or the skill of the operators, or both, and in which the specified quality cannot be readily determined by inspection or test of the product." Special processes are primarily limited to construction and fabrication activities during site screening and characterization phases of the BWIP, such as the Near-Surface Test Facility and Exploratory Shaft Programs. Special processes include welding, heat treating, nondestructive testing, and shotcreting. It is the responsibility of the organization performing the special process to adhere to the approved procedures for special processes. The appropriate qualification records are maintained by these organizations and are transmitted to the BWIP Records Retention Center for their specified retention times.

Rockwell has established a special-process-control system that is documented in a manual containing nondestructive examination and special process procedures. This manual establishes personnel-qualification requirements, personnel-certification requirements, and qualified procedures used when Rockwell is performing special processes. The Rockwell Quality Assurance Function approves all Rockwell-qualified procedures and certifies personnel dealing with nondestructive examination in accordance with American Society for Nondestructive Testing Recommended Practice SNT-TC-IA (ASNT, 1975). Rockwell-subcontractor and other principal-contractor special-process personnel and procedure qualifications are reviewed for adequacy by the Rockwell Quality Assurance Function.

18.10 INSPECTION

An inspection program has been established for activities affecting quality during the site selection and characterization stages. Inspection planning is required by all principal contractors and their subcontractors and is established based on the significance of the activity in accomplishing program objectives. All forms of inspection for the BWIP quality assurance program are required to be performed by qualified individuals who do not perform, directly supervise, or report directly to those who supervise the activity being inspected.

The type of inspection varies with the activities being performed. Construction and shop fabrications generally involve in-process inspection by the organization performing the activity, with final acceptance inspection (Title III) accomplished by the responsible design organization. Source and receiving inspection is performed by the procuring organization. In-service inspection of operating test facilities is performed by Rockwell. Second-level inspection is performed through surveillance by Rockwell's Quality Assurance Function. Surveillance is also performed on such activities as drilling, core logging, and water sampling and testing to assure accomplishment of these activities in accordance with documented procedures. Where mandatory inspection-hold points are required, they are incorporated into the appropriate documents.

Source, receiving, in-process, final, and surveillance-inspection activities are performed in accordance with documented plans, procedures, instructions, checklists, or travelers that include the following:

- Characteristics and activities to be inspected
- Description of method of inspection
- Identification of individuals or groups responsible for performing inspection activity
- Acceptance and rejection criteria or appropriate reference
- Required procedures, drawings, and specifications with appropriate revision status
- Recording inspector or data recorder and results of the inspection
- Specified necessary measuring and test equipment, including accuracy requirements.

Inspection results are documented, evaluated, and their acceptability determined by designated responsible individuals or groups.

Rockwell has established and documented an inspection program in a manual of quality assurance procedures. The procedures identify organizational responsibilities for Rockwell inspection. A qualification program is established for Rockwell inspectors and is kept current. All inspection activities are planned by established inspection-plan forms and travelers. Surveillances are scheduled on a quarterly basis. When direct inspection of process items is impossible or impractical, monitoring of process methods, equipment, and personnel is used to verify quality. Rockwell's Quality Assurance Function assures that other principal contractors and Rockwell subcontractors establish and implement inspection programs that satisfy NQA-1 (ANSI/ASME, 1979; 1981a; 1981b) requirements for inspection.

18.11 TEST CONTROL

Rockwell prepares test plans for major test programs such as the Near-Surface Test Facility, Exploratory Shaft, and Hydrologic Drilling and Testing. Controlled test procedures are applied to tests that verify conformance of items to specified requirements; that demonstrate satisfactory performance of items in service; or that produce data, recommendations, or other bases for a decision on a potential site for a nuclear waste repository. Characteristics to be tested and methods to be employed are specified for all tests.

All testing is conducted in accordance with test procedures. These procedures include the following, as applicable:

- Specified requirements and acceptance limits
- Test prerequisites (e.g., equipment accuracy and calibration requirements and environmental conditions)
- Step-by-step instructions for performing the tests
- Mandatory inspection-hold points
- Provisions for evaluating results
- Requirements for documenting results.

Functional testing of facilities or equipment on DOE-RL-authorized projects is normally required by the architect-engineer in the design specifications. The architect-engineer prepares a detailed acceptance-test procedure in accordance with criteria established in the Hanford plant standards system. Each acceptance-test procedure clearly establishes the responsibilities for conducting, recording, witnessing, and approving the test. Rockwell uses operability test procedures to control functional testing of new facilities or equipment changes in operating facilities.

18.12 CONTROL OF MEASURING AND TEST EQUIPMENT

Tools, gauges, instruments, and other measuring and testing devices used for acceptance inspection or collection of data require control, calibration, and adjustment at established frequencies by the using organization. Each contractor is required to establish a calibration program that addresses:

- The method and interval of calibration for each item requiring calibration
- The provisions for traceability of reference or transfer standards to nationally recognized standards or, if no nationally recognized standard exists, documentation of the basis for calibration
- The methods used to evaluate previous results when measuring and test equipment is found to be out of calibration
- The methods used to indicate the status of measuring and test equipment
- The provision for calibration of records.

Special calibration or control measures are not required for devices such as rulers, tape measures, levels, or other such devices if normal commercial practices provide adequate accuracy.

A Rockwell quality assurance calibration system has been documented. This plan defines responsibilities and provides for regularly scheduled calibration of specific equipment as well as inventory, historical records, and traceability to known standards for all Rockwell calibration activities. Calibration systems of other principal contractors, their subcontractors, and Rockwell subcontractors supporting the BWIP are subject to review and audit by Rockwell's Quality Assurance Function.

18.13 HANDLING, STORING, AND SHIPPING

Contractors involved in the handling, storing, cleaning, packaging, shipping, and preservation of items for the BWIP are required to control these activities in accordance with established work and inspection instructions, drawings, specifications, shipment instructions, or other pertinent specified documents or procedures. Any special provisions for engineered hardware are specified in the design documents by the responsible design organization and are verified by the procuring, fabrication, or construction contractors. Special procedures have been established by Rockwell for the handling, storing, preservation, packaging, shipping, and labeling of geotechnical samples used during the site screening and characterization stages. These measures have also been applied to the laboratory samples used for waste package and repository design studies.

Procedures have been documented in the Rockwell Material and Quality Assurance Functions' procedures manuals for the handling, storing, and shipping of Rockwell-procured or -fabricated items. Rockwell's Quality Assurance Function verifies that handling, storing, and shipping requirements are specified and properly implemented on both procured and fabricated items. Rockwell warehouses, control stations, and manufacturing storage areas are inspected by Rockwell's Quality Assurance Function on a quarterly basis to assure compliance with specified requirements.

18.14 INSPECTION, TEST, AND OPERATING STATUS

Contractors involved in inspection and testing activities during construction and fabrication and others involved in facilities operations are required to indicate the status of individual items either on or immediately adjacent to the items. These measures are applied where it is necessary to assure that only items that have received the required inspections and tests are installed, used, and operated, and that only the proper items, such as valves and switches, are used during operations. Status is maintained through indicators, such as physical location and tags, markings, shop travelers, stamps, inspection records, or other suitable means, throughout the receiving, storage, fabrication, and installation activities. Contractors are required to document these measures in appropriate procedures and instructions and also prescribe the authority for application and removal of status indicators.

Rockwell's Quality Assurance Function has documented procedures that describe the control for application and removal of inspection stamps and status indicators for Rockwell-procured or -fabricated items. Rockwell's Quality Assurance Function has sole responsibility for application and removal of inspection stamps and status indicators. When a nonconformance item is detected during inspection or test, Rockwell's Quality Assurance Function assures the condition is documented on a nonconformance report and that a "hold" tag or label is applied to the item to prevent inadvertent installation or use prior to approved corrective action.

18.15 CONTROL OF NONCONFORMING ITEMS

Items that do not conform to specified requirements are controlled to prevent inadvertent installation or use. As defined in NQA-1, Supplement S-1 (ANSI/ASME, 1979; 1981a; 1981b) and modified by Cooley (1981), an item is "an all-inclusive term used in place of any of the following: appurtenance, assembly, component, equipment, material, module, part, structure, subassembly, subsystem, unit, data, sample, geologic environment, or prototypic hardware." Nonconforming material items are identified by marking, tagging, or other methods directly on the individual items or their containers or packages or by segregation in a designated holding area until proper disposition. Nonconforming data or activities are identified as such through the applicable documentation (nonconformance reports, data sheets, test reports, etc.). A standard nonconformance-report form has been developed for use at the Hanford Site that provides for item identification, hold-tag number, inspection criteria, nonconformance description, disposition and justification, approvals, and closeout.

Principal contractors are required to establish procedures that delineate how nonconforming characteristics are to be reviewed and how recommended dispositions are to be proposed and approved in their area of contract performance. Principal contractors must also define responsibility and authority for the evaluation and disposition. These responsibilities are identified by Rockwell in a project management plan for DOE-RL-approved construction projects. Final disposition with technical justification is documented and included with the nonconformance description into the BWIP records retention system. Accepted deviations or repairs are reflected in the as-built records where such records are required. All repaired or reworked items require reexamination to the original acceptance criteria unless the approved disposition establishes alternate criteria.

Rockwell's Quality Assurance Function has documented procedures that provide for the identification, segregation, review, disposition, and notification to affected organizations of Rockwell-identified nonconformances. These procedures provide identification of authorized individuals for independent review of nonconformances, including disposition, through documented-material-review boards. Rockwell's Quality Assurance Function approval is required on all Rockwell nonconformance-report dispositions and closeouts. Rockwell's Quality Assurance Function follows nonconformance reports on a monthly basis, using charts or graphs, and reports these quality trends to the Vice President and General Manager and his direct staff in the monthly executive control meetings.

18.16 CORRECTIVE ACTION

Principal contractors are required to identify and correct conditions adverse to quality that may occur in their areas of contract performance. Followup action is required to verify implementation of corrective action. Corrective action is required on any deficiency identified through inspection, surveillance, or audit.

Significant conditions that differ, by virtue of their magnitude or repetition, from those normally encountered during the course of routine verification activities require documentation as to identification, cause, and corrective action and are reported to appropriate levels of management. A Corrective Action Request System has been established by Rockwell to control significant conditions and may be applied both internally and externally to other project participants when warranted. Procedures are documented by Rockwell's Quality Assurance Function, which assigns responsibility for initiating corrective action requests, evaluating adequacy of responses and followup action, and for closeout to Rockwell's Quality Assurance Function.

18.17 QUALITY ASSURANCE RECORDS

A quality assurance records system for the BWIP has been established by Rockwell. The records system is defined, implemented, and enforced in accordance with a records management plan and implementing procedures established by Rockwell. An indexing system has been established with retention times and disposition in accordance with DOE Order 1324.2 (DOE-HQ, 1980) and NQA-1 (ANSI/ASME, 1979; 1981a; 1981b). The applicable design specifications, procurement documents, procedures, and other documents are required to specify the records to be generated, supplied, or maintained by the principal contractors until they are turned over to the DOE-RL or other authorized disposal. Organizations generating records are responsible for their storage, preservation, and safekeeping until transmitted to the BWIP records retention center for final retention. The requirements of NQA-1 (ANSI/ASME, 1979; 1981a; 1981b) are applied for control of quality assurance records for the BWIP.

To prepare for potential licensing requirements for the exploratory shaft, should it eventually be considered for a repository shaft, a construction-acceptance and -inspection record system has been established by Rockwell. The construction-acceptance and -inspection record system provides for integrated work planning and tracks the identity and status of documentation used during the construction process. This documentation is indexed and directly related to the design baseline. The construction-acceptance and -inspection record system satisfies the requirements for baseline identification and startup activities by providing accumulation, indexing, storage, and retrieval methods for the design, construction, and as-built documentation generated by all principal contractors and their subcontractors.

18.18 AUDITS

Planned and scheduled quality assurance audits are conducted by the DOE, Rockwell, other principal contractors, and subcontractors where required. The auditing organizations are required to select and assign auditors who are independent of any direct responsibility for performance of the activities they will audit. An audit team, which may consist of one or more auditors, is selected prior to the beginning of each audit. An audit-team leader, qualified to the requirements of NQA-1 (ANSI/ASME, 1979; 1981a; 1981b), is appointed to organize and direct the audit. Audits are performed in accordance with written procedures or checklists at intervals consistent with the schedule for accomplishing the activities and importance of the activities to the overall BWIP mission.

Audit results are required to be documented by the auditing personnel and reported to the management having responsibility for the area audited. Management of the audited area must respond to adverse findings and provide planned corrective action. The adequacy of the planned corrective action is evaluated by the auditing organization. Followup action is required to verify implementation of the corrective action. Audit plans, audit reports, written replies, and records of completion of corrective action are a part of the BWIP quality assurance records system.

Rockwell plans and schedules both internal and external audits in a manner to provide coverage and coordination with ongoing BWIP quality assurance program activities. An audit schedule is established annually. Audits are conducted in accordance with established procedures and checklists. Areas to be audited include, but are not limited to, geologic and hydrologic characterization activities, procurement control, indoctrination and training programs, interface control among principal contractors, nonconformance and corrective-action control systems, calibration systems, activities associated with computer codes, and waste package and repository design control. The audit process includes an objective evaluation of quality-related practices, procedures, activities, and items and a review of documents and records to assure that the quality assurance program is effective and properly implemented. Audit results are analyzed by Rockwell's Quality Assurance Function and the results are reported to the BWIP Director and his affected department managers.

18.19 REFERENCES

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19. IDENTIFICATION OF ALTERNATE SITES

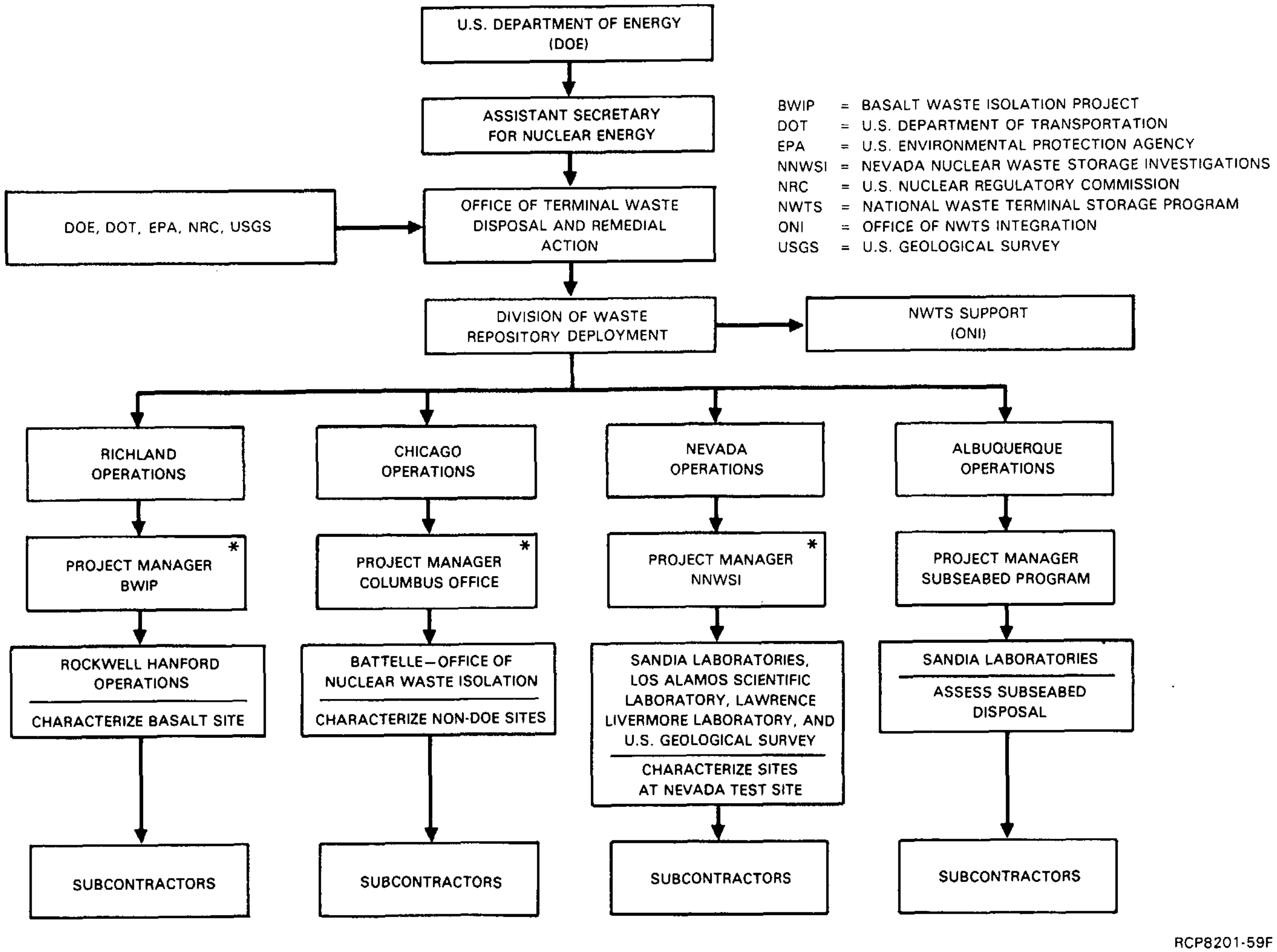
19.1 INTRODUCTION

The National Waste Terminal Storage (NWTS) Program is being conducted by the U.S. Department of Energy (DOE) to identify and characterize suitable sites for the geologic isolation of high-level radioactive waste. The NWTS Program also aims at developing the technology needed to construct, operate, and decommission geologic nuclear waste repositories. The NWTS Program is under the direction of the Director, Office of Terminal Waste Disposal and Remedial Action, and is coordinated by the Division of Waste Repository Deployment at DOE-Headquarters. Support to the Division of Waste Repository Deployment is provided by the Office of NWTS Integration. Three geologic field projects are presently part of the NWTS Program: the Basalt Waste Isolation Project (BWIP), the Office of Nuclear Waste Isolation (ONWI), and the Nevada Nuclear Waste Storage Investigations (NNWSI) Program. The NWTS Program organization is shown in Figure 19-1.

The NWTS geologic field projects are presently centered on investigating the basalts beneath the Hanford Site (BWIP), various geologies within the Nevada Test Site (NNWSI) with emphasis on volcanic tuff, and various salt regions throughout the United States (ONWI). In addition, ONWI is studying crystalline rocks as potential long-term options for geologic disposal. The regions presently under consideration for the geologic disposal of nuclear waste are summarized in Figure 19-2.

Basalt, volcanic tuff, and salt are the primary media under consideration as the first three site alternatives; the schedules for each of these geologies are shown in Figure 19-3. Currently planned schedules for site characterization reports involving the primary media are as follows: basalt--November 1982, tuff--June 1983, and salt--July 1983. This chapter briefly summarizes the ongoing work at alternatives other than basalt, which are also being considered.

The alternatives presently being studied by ONWI have been selected based on national screening studies. The basalts and volcanic tuffs were selected on the basis that these media were located in sites owned by the United States Government and presently dedicated to nuclear programs. Siting criteria being applied to selecting a repository site within the Hanford Site are comparable, however, to those resulting from the national screening process as discussed in Chapter 2.



*GEOLOGIC PROJECTS DISCUSSED IN THIS CHAPTER.

FIGURE 19-1. National Waste Terminal Storage Program Organization.

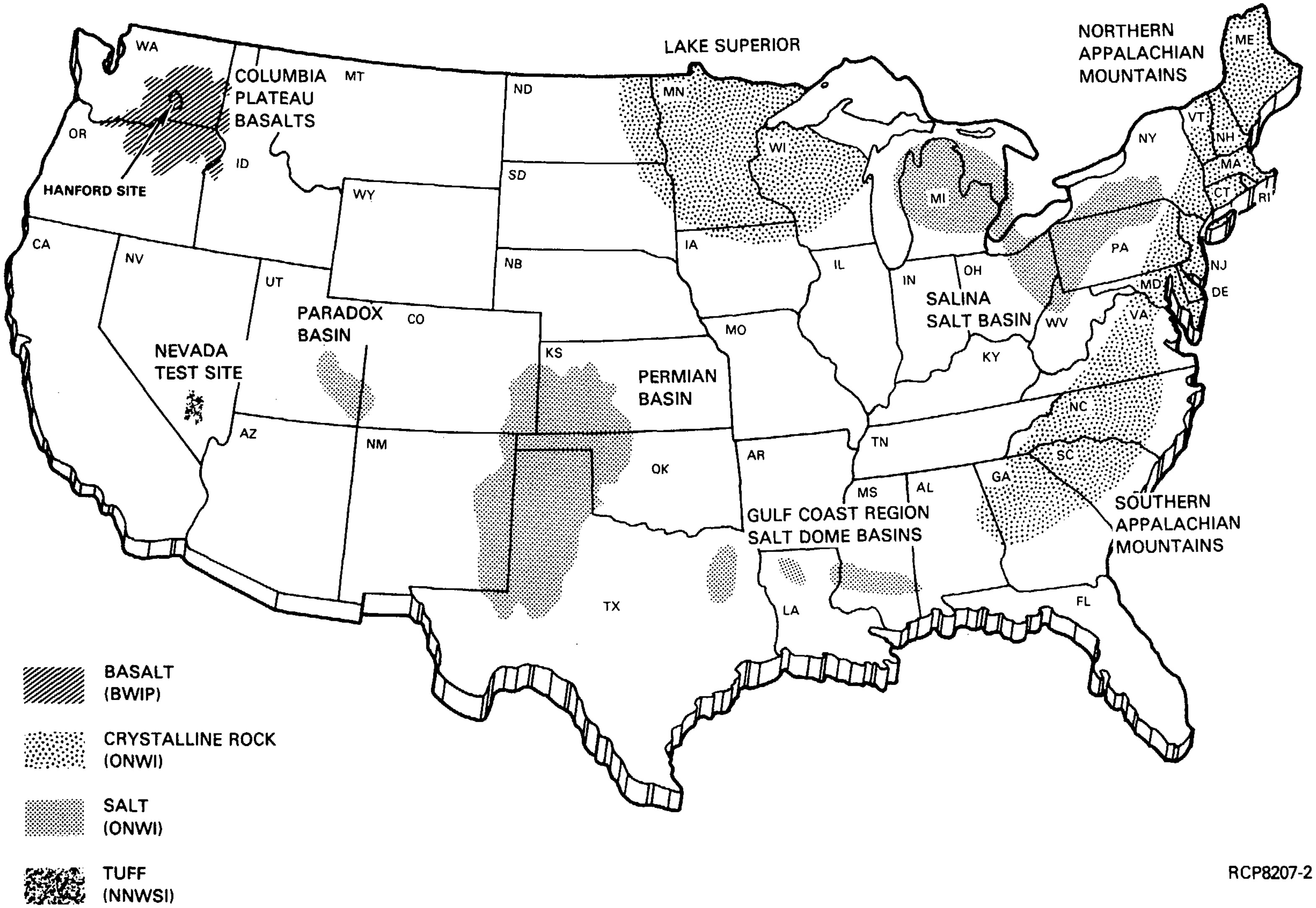


FIGURE 19-2. Regions That are Being Considered for Geologic Disposal of Radioactive Waste.

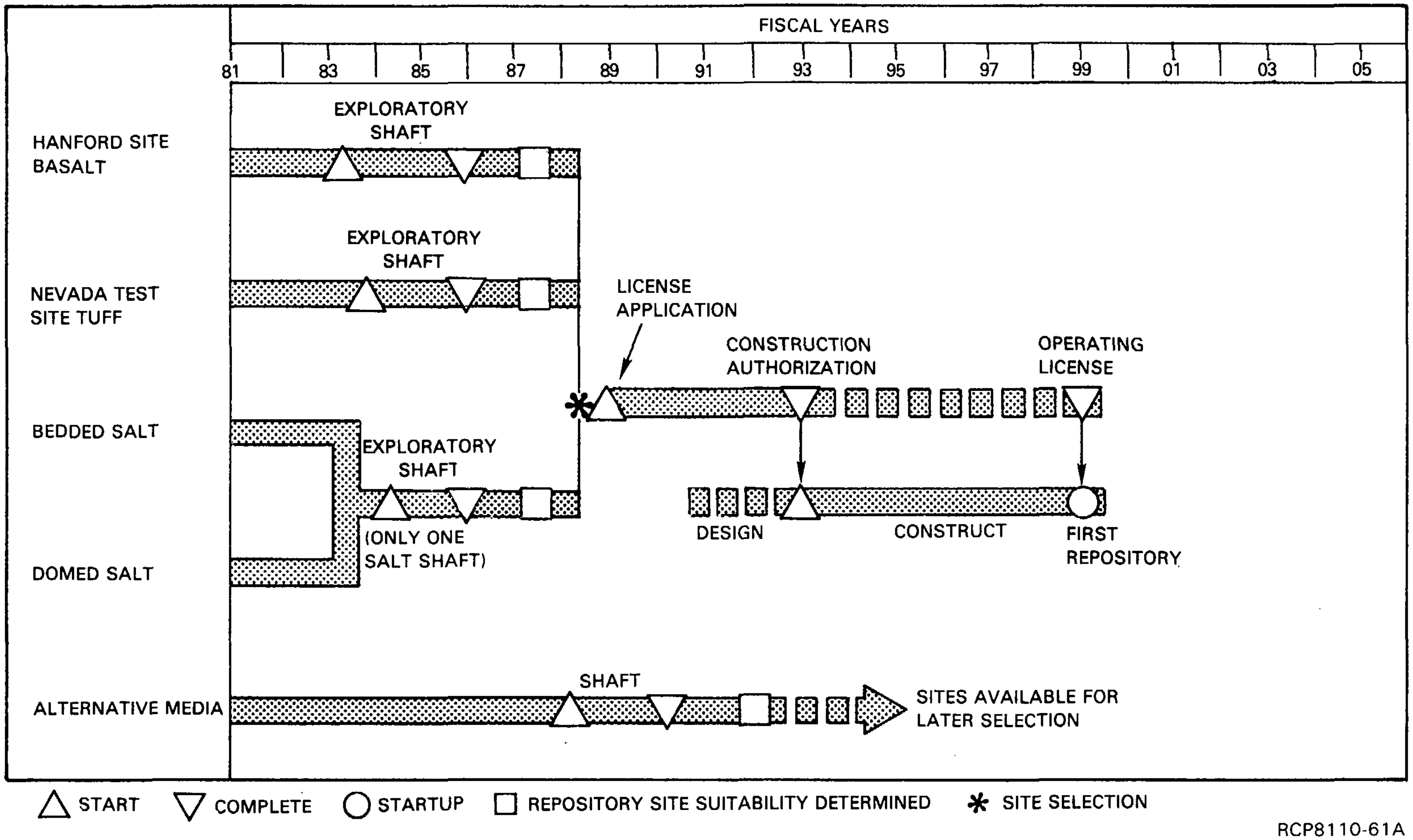


FIGURE 19-3. National Waste Terminal Storage Program Schedule for Accomplishing Site-Specific Characterization Leading to First Repository.

19.2 GENERIC NATIONAL WASTE TERMINAL STORAGE SITING PROCESS

The NWTS Program siting investigations are following a formal three-step siting process that begins with a national screening and culminates in detailed site characterization of candidate sites for a nuclear waste repository. This siting process is described in the DOE Public Draft, National Plan for Siting High-Level Radioactive Waste Repositories and Environmental Assessment (DOE, 1982). The first phase of the siting process is site screening, which covers the activities planned to find sites favorable for waste isolation. A number of approaches have been used to initiate screening studies, with each approach eventually using common steps to arrive at and to evaluate specific sites.

The DOE has used three approaches to identify starting points for screening studies rather than relying on a single approach, consistent with its objective to be conservative in its approach.

(1) A host-rock approach was initiated by identifying regions containing potentially suitable host-rock types. Early in the NWTS Program, rock salt was so identified, and regions in the conterminous United States containing salt domes and bedded-salt formations were delineated as starting points for site screening. Recently, the DOE has screened the United States for regions containing "crystalline" (intrusive igneous and high-grade metamorphic) rocks such as granite.

(2) In addition, the DOE has initiated siting studies at federally owned land tracts in Nevada and Washington (known as the Nevada Test Site and the Hanford Site), which have been committed to nuclear activities and which may contain suitable host rocks at appropriate depths for a repository.

(3) Another approach, province screening, is based on scrutiny of successively smaller subdivisions of broad provinces where geohydrologic conditions include multiple natural barriers to radionuclide migration. This approach is being implemented by the U.S. Geological Survey on an experimental basis in one of eleven geohydrologic provinces of the United States. A province working group, composed of earth scientists from the states in that province and the U.S. Geological Survey, is initiating the prototypical studies.

The candidate sites from which the first site for a repository will be selected were identified using the host rock and land-use approaches. The province screening and other approaches may identify alternate sites for later repositories.

Once candidate sites are identified, detailed site studies are initiated. This phase involves the effort to assess whether a site can pass regulatory scrutiny and meet other societal concerns. The characteristics of the site must be thoroughly assessed, first from surface activities including boreholes, then at depth from the base of an exploratory shaft. Data obtained from such detailed studies will be used to evaluate the suitability of the site for waste isolation.

The next phase of the siting process is site selection. As currently envisioned, site selection is the process by which one or more suitable sites are selected for licensing. National, state, and local participation in public meetings and hearings will review the process by which a site is recommended and the suitability of the recommended site. Additional review will begin when the DOE applies to the U.S. Nuclear Regulatory Commission (NRC) for a license to receive and process nuclear material at a DOE-selected repository site.

19.3 SALT (BEDDED/DOMED) AS AN ALTERNATIVE

Salt sites, both bedded and domed, are currently being evaluated by ONWI. Studies evaluating disposal in salt were initiated following recommendation by the National Academy of Sciences (National Research Council, 1957). Evaluation and investigations of the possibility of bedded or domed salt as a disposal medium for nuclear wastes have progressed in several regions of the United States (see Fig. 19-2).

Subsequent screening of the bedded- and domed-salt locations throughout the United States has led to the selection of four regions for further characterization: the Gulf Coast Region Salt Dome Basins, Paradox Basin, Permian Basin, and Salina Salt Basin, discussed in the following paragraphs.

19.3.1 Gulf Coast Region Salt Dome Basins

The Gulf Coast salt domes comprise one of the regions identified by the DOE, through its national screening process, as having potential for siting a nuclear waste repository.

Efforts have progressed toward locating a suitable site in a salt dome in the Gulf Coast region. Of the more than 500 salt domes that exist in the region (consisting of Texas, Louisiana, and Mississippi), eight were identified during regional studies as having the greatest potential for ultimately siting a repository. Studies were concentrated on these eight domes (Fig. 19-4). One was subsequently eliminated (Palestine) from further studies, three were deferred (Lampton, Rayburns, and Keechi), and four were recommended for further study (Richton, Vacherie, Cypress Creek, and Oakwood). Further study of these domes was deferred for a variety of reasons; e.g., concerns over depth and size, dissolutioning uncertainties, resource potential, and land-use conflicts, depending on the dome involved. Two of those recommended (Richton in Mississippi and Vacherie in Louisiana) were assessed as being the more favorable for detailed characterization. Oakwood Dome has also been deferred from further study at this time.

19.3.2 Bedded Salt of the Paradox Basin

The Paradox Basin is one of the salt regions identified during exploration and screening by the DOE as having potential for the eventual siting of a nuclear waste repository. Four areas, Salt Valley, Gibson Dome, Elk Ridge, and Lisbon Valley (Fig. 19-5) were recommended for further study in 1979.

Results from investigations conducted to date indicate that bedded salt layers of sufficient thickness are present at suitable depths in the Paradox Basin. A recommendation on a specific location (Gibson Dome) for detailed site characterization and investigation was made in 1982. The Paradox Basin Region is currently in the location phase of the site characterization process.

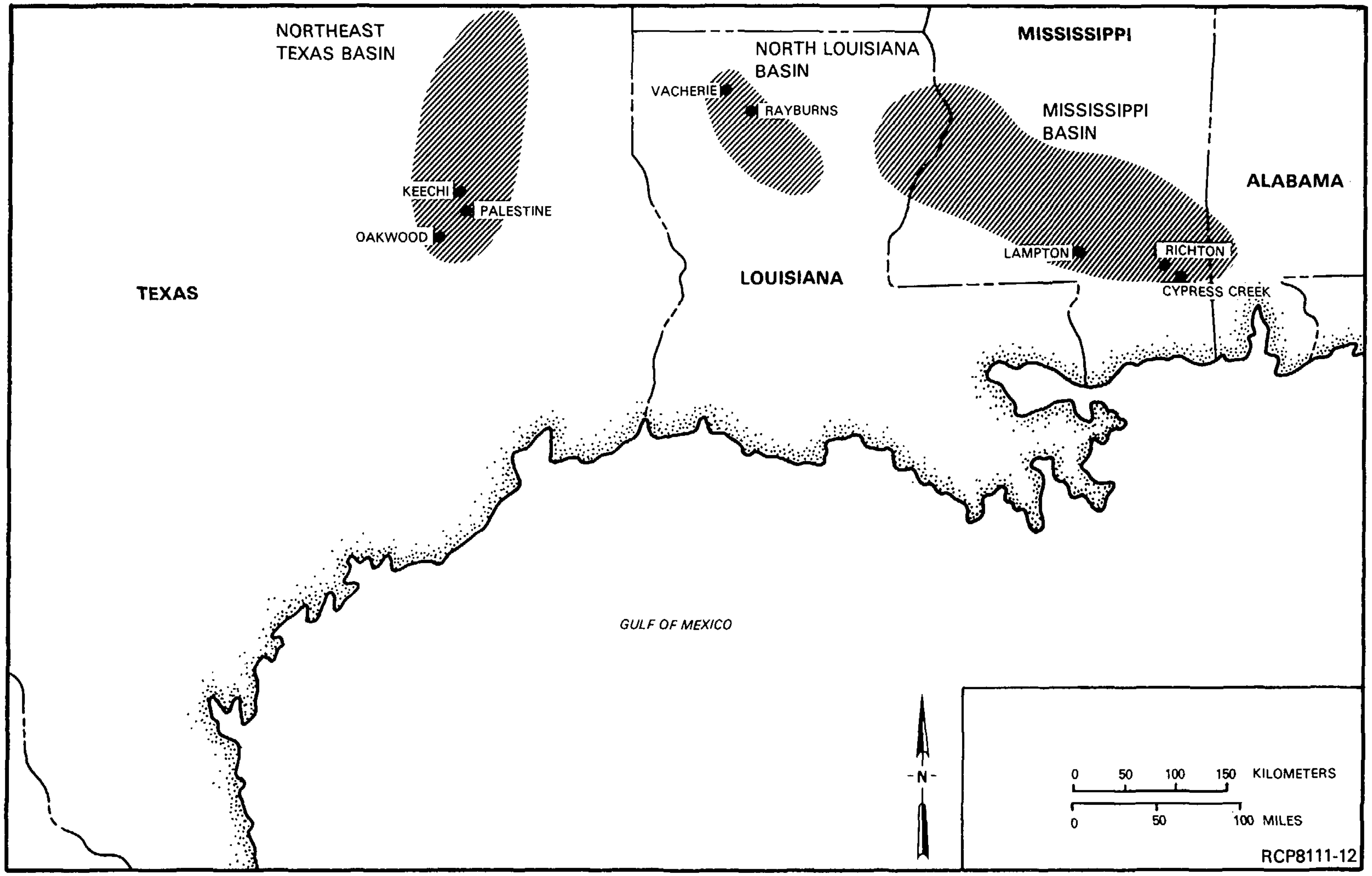


FIGURE 19-4. Eight Gulf Coast Region Salt Domes Recommended for Further Study by the U.S. Geological Survey (Anderson et al., 1973; Ledbetter et al., 1975).

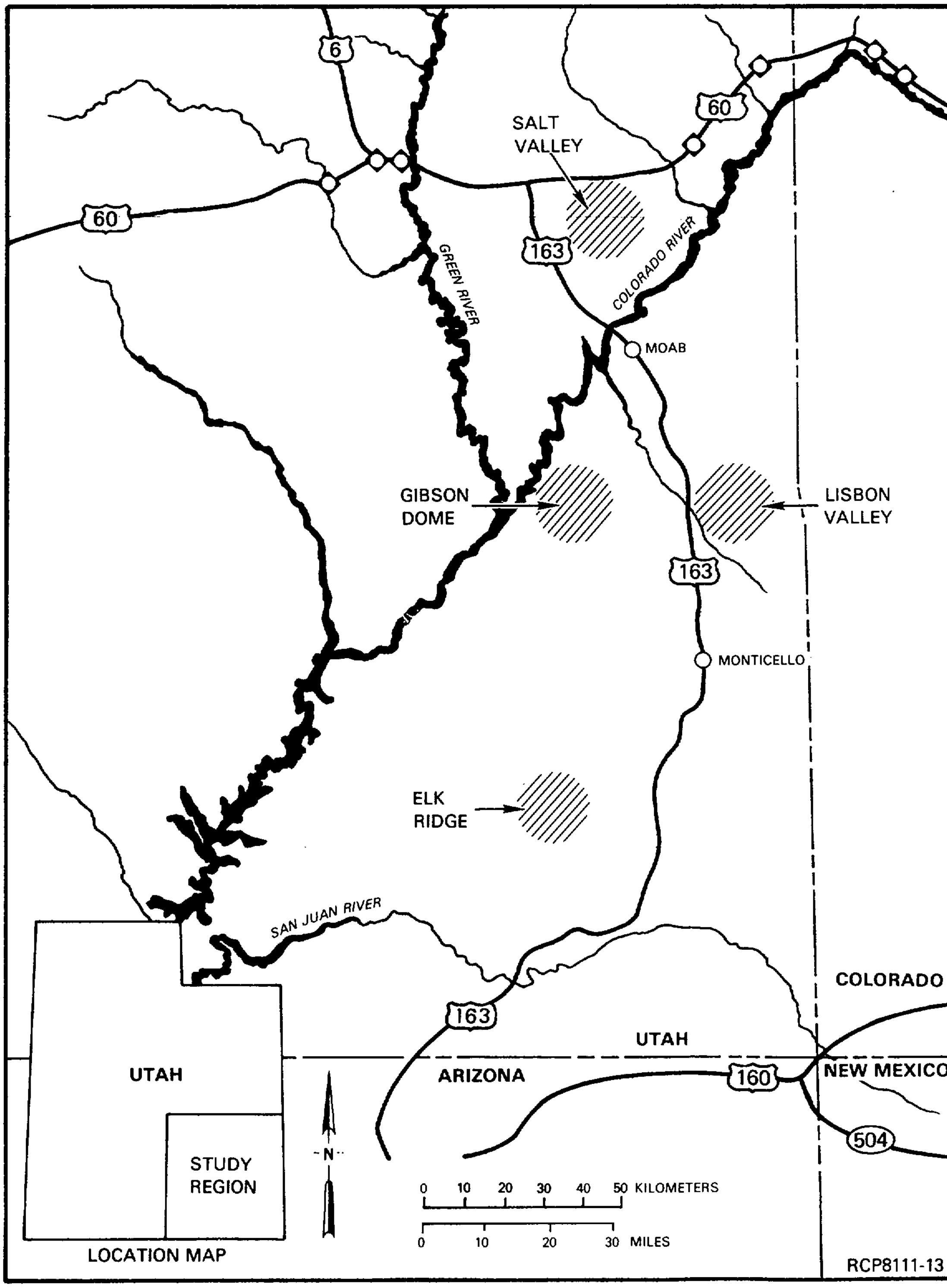


FIGURE 19-5. Areas of the Paradox Basin Identified for Further Evaluation (Hite and Lohman, 1973).

19.3.3 Bedded Salt of the Permian Basin

The Permian Basin is another of the bedded-salt regions identified by the DOE as having potential for the siting of a nuclear waste repository. The Palo Duro and Dalhart subbasins of the Permian Basin were identified as potential areas for siting a repository; within the Palo Duro Basin, two locations were recommended for further study (Fig. 19-6). Regional and area characterization has been completed, and preliminary elements of the location phase of the site characterization process are currently under way.

19.3.4 Bedded Salt of the Salina Basin

The Salina Salt Basin is another of the bedded-salt regions identified by the DOE as having potential for the siting of a nuclear waste repository. A regional study of the Salina Salt Basin (Fig. 19-7) has been made from the existing geologic literature and data available from public and private sources. Regional studies have been completed for the Ohio and New York portions of the Salina Salt Basin. The initial evaluations identified study areas that appear to be geologically favorable for more detailed field investigations. The Michigan portion of the basin has not been sufficiently studied to allow the identification of detailed study areas.

No field investigations have been conducted by the DOE in the Salina Salt Basin, although some fieldwork in support of repository siting has been done by the U.S. Geological Survey in New York and in Pennsylvania (DOE, 1980). At present, no part of the basin can be judged acceptable or unacceptable for repository siting. The work in this basin has been indefinitely deferred.

19.3.5 Summary of Planned Characterization Activities for Salt

The ONWI, as part of the NWTS Program, is proceeding with the characterization of potential repository locations containing salt on a schedule consistent with identifying a single exploratory shaft site by mid-1983. A site characterization report for the prime salt site is currently planned to be issued to the NRC in July 1983.

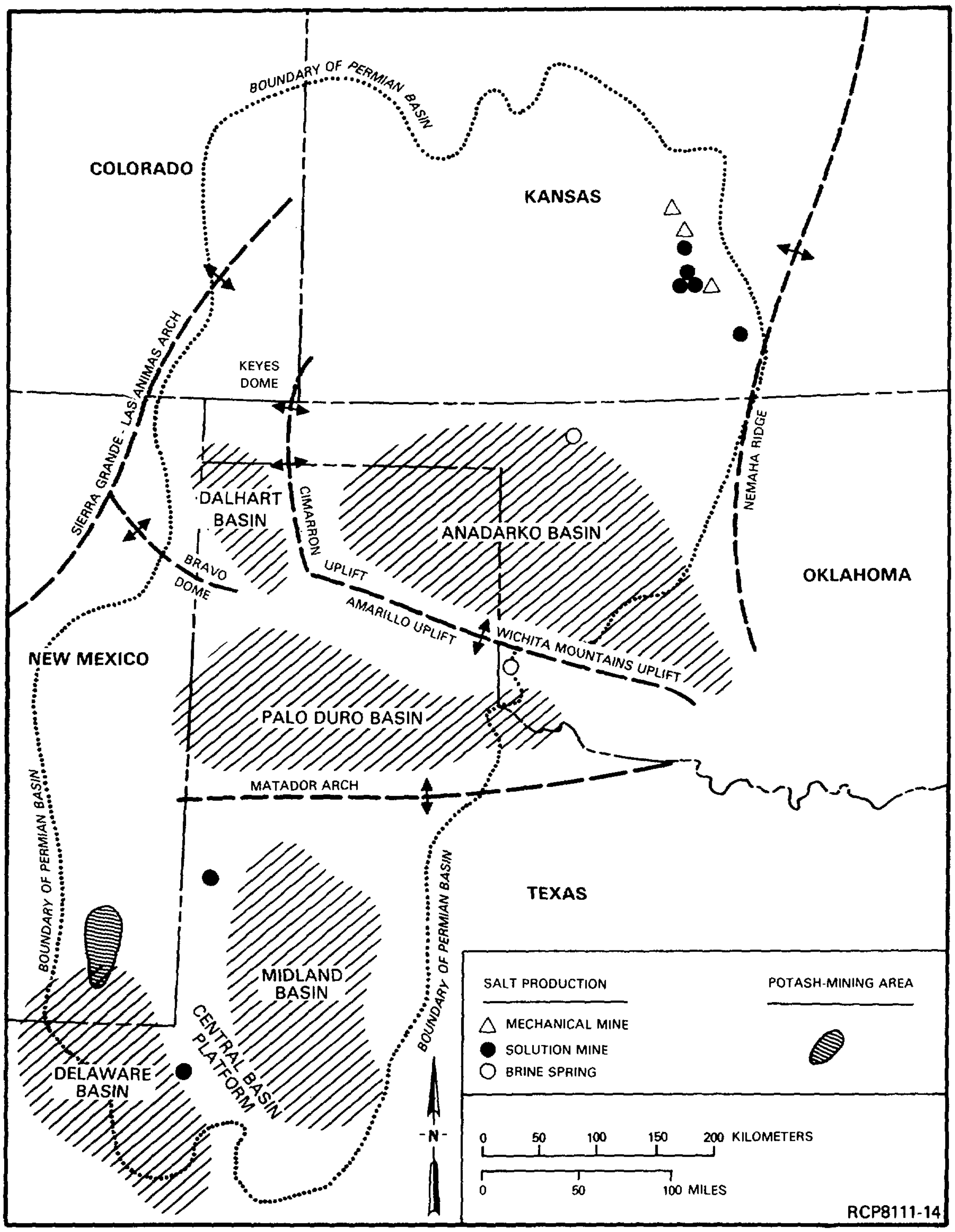


FIGURE 19-6. Map of the Permian Basin (Johnson and Gonzales, 1978).

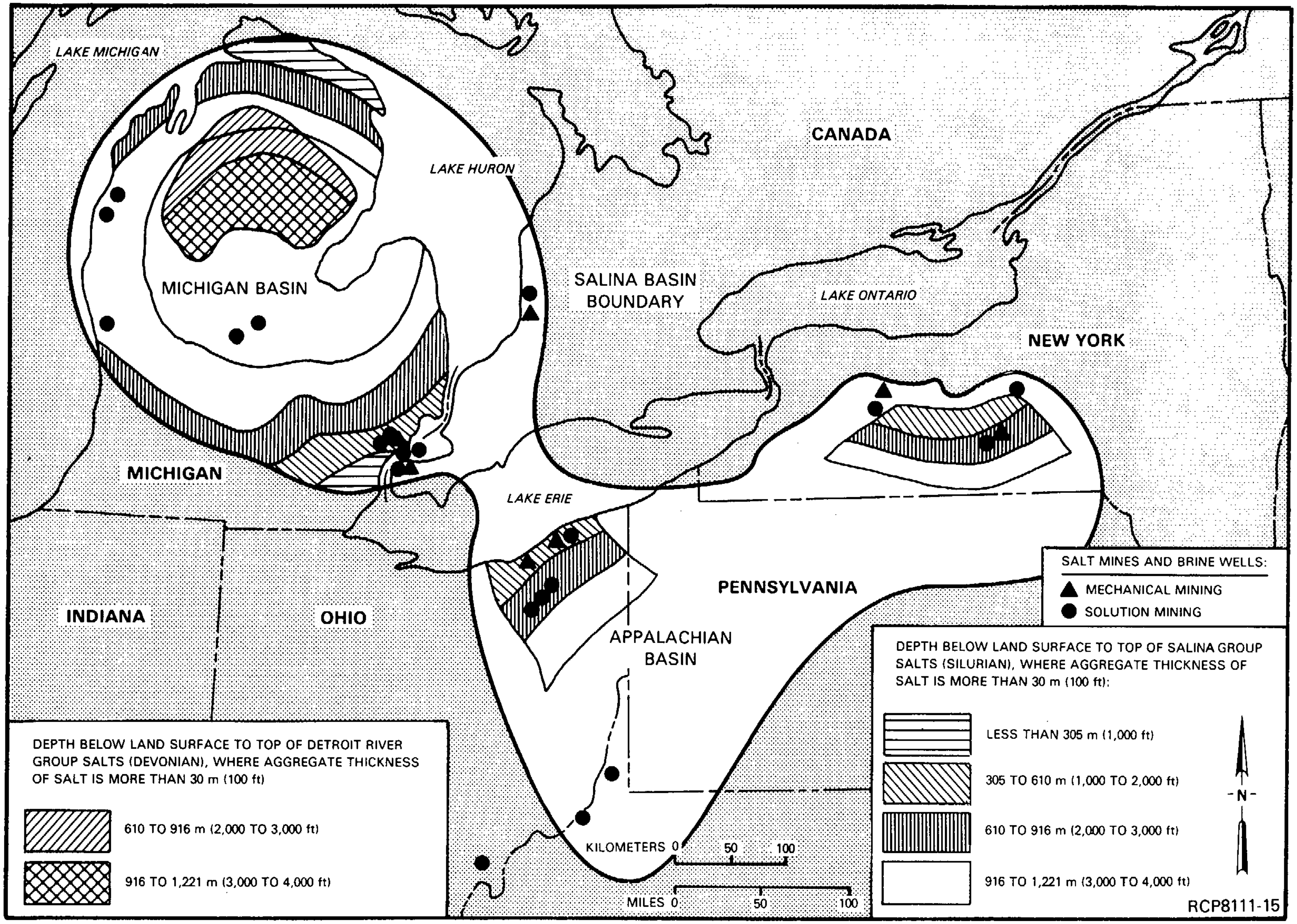


FIGURE 19-7. Map of Michigan and Northern Appalachian Basins (Salina Basin) (Johnson and Gonzales, 1978).

19.4 TUFF AS AN ALTERNATIVE

Investigations of volcanic tuff at the Nevada Test Site are currently being conducted by the NNWSI Project as an additional potential medium for the disposal of nuclear wastes. These investigations are being managed by the DOE-Nevada Operations Office.

19.4.1 Nevada Test Site Investigations

The NNWSI Project was formally organized in 1977 to investigate and determine whether specific underground rock masses at the Nevada Test Site (alluvium, granite, argillite, or tuff) are suitable for permanently disposing of highly radioactive wastes, and to study and determine whether the Nevada Test Site would qualify as a suitable repository site. Work also focused on determining whether a nuclear waste repository would be compatible with present and future nuclear weapons testing activities at the Nevada Test Site.

Investigations of the central block of Syncline Ridge (Fig. 19-8) were suspended because of its geologic complexity and, shortly thereafter, the entire Syncline Ridge area was also deferred from further consideration because of its proximity to weapons-testing areas. Subsequent exploratory drilling and surface work were concentrated on selected areas of the southwest quadrant of the Nevada Test Site. These areas included Wahmonie, Calico Hills/Topopah Wash, and Yucca Mountain (Fig. 19-8).

19.4.2 Exploration of Tuff

Upon reviewing the geologic, geophysical, and hydrologic data for the Wahmonie, Yucca Mountain, and Calico Hills/Topopah Wash areas, the U.S. Geological Survey recommended that exploration for a potential repository location be focused on the tuffaceous media of Yucca Mountain. Exploration and characterization efforts were intensified there and no new studies were initiated for the other areas of the Nevada Test Site. Preliminary design work has begun in preparation for an exploratory shaft at Yucca Mountain to further characterize potential repository horizons.

19.4.3 Summary of Planned Characterization Activities for Tuff

Presently, the NNWSI Project is proceeding with characterization of potential repository locations on a schedule consistent with identifying the specific exploratory shaft site in fiscal year 1983. Also, the NNWSI Program is continuing the geologic and hydrologic investigation of Yucca Mountain and the surrounding area. A site characterization report for the Nevada Test Site is currently planned to be submitted to the NRC in June 1983.

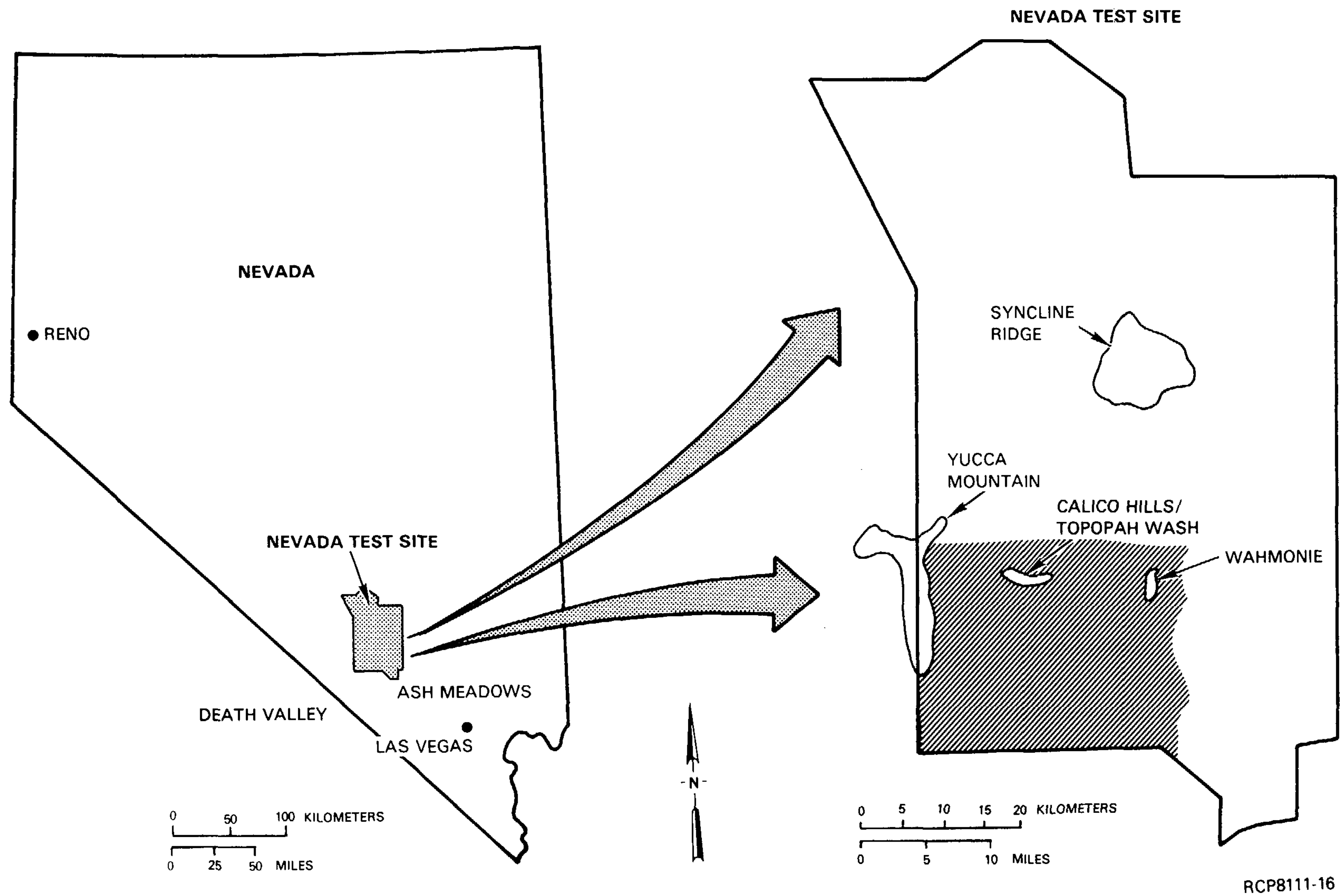


FIGURE 19-8. Location of the Nevada Test Site and Current Exploration Areas (DOE, 1980).

19.5 GRANITE, OTHER CRYSTALLINE ROCKS, AND OTHER MEDIA AS ALTERNATIVES

Activities based on the alternatives of granite, other crystalline rocks, and other media have not progressed to the stage of detailed site study and are only potential future mined geologic repository site alternatives.

19.5.1 Granite and Other Crystalline Rocks

Regional studies of crystalline rocks have begun in 17 states in regions of the Appalachians and Lake Superior. Currently, the DOE is participating in a joint granite-testing program with Sweden called Stripa (Witherspoon and Degerman, 1978; Witherspoon et al., 1981). Also, a test facility in granite has been installed within a tunnel at the Nevada Test Site (Ramspott et al., 1979). Contractors to the U.S. Geological Survey and DOE have completed preliminary surveys of existing data on granitic and other crystalline hard rocks. The DOE is also participating in crystalline media studies being conducted by the Atomic Energy Commission Limited in Canada. These activities, domestic and foreign, have kept granite and other crystalline rocks as candidates for future repositories.

Further data and studies are needed on preliminary recommendations to study Canadian Shield and Appalachian granitic rocks. The DOE has requested participation of representatives from the host states in these siting studies. Regional literature-phase studies have begun in Minnesota and Michigan, and plans for proposed characterization are being negotiated in Wisconsin (DOE, 1982) (see Fig. 19-2).

19.5.2 Other Media

A national screening survey for alternatives in other media has not gone beyond the planning stage. No siting activity in argillaceous rocks is presently planned (DOE, 1982).

19.5.3 Summary of Planned Activities for Granite, Other Crystalline Rocks, and Other Media

At present, ONWI is finalizing regional studies in crystalline rocks and is developing plans for future investigations.

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APPENDIX - GLOSSARY FOR THE SITE CHARACTERIZATION REPORT

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.

accessible environment -- includes the atmosphere, land surfaces, surface waters, oceans, and parts of the lithosphere containing groundwater that are more than 10 kilometers (6.7 miles) in any direction from the edge of the original location of the radioactive wastes in a disposal system.

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.

actinide -- a chemical element in the series beginning with atomic number 89 and continuing through 103.

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.

aggradation -- the building up of the Earth's surface by deposition.

airborne -- supported by air. Airborne contamination applies to radioactive material suspended in the air.

air change -- the rate of change of ventilation air, usually in terms of air changes per hour.

air monitor -- air sampler with associated electronic circuitry for the continuous detection of radioactivity, to warn personnel of changes in airborne radioactivity.

air sample -- a sample of air for determining the amount of radioactive material present.

ALARA -- see as low as reasonably achievable.

alluvial plain -- 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).

alluvium -- 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.

alpha decay -- 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.

alpha particle -- a positively charged particle emitted in the radioactive decay of certain nuclides. Made up of two protons and two neutrons bound together, it is identical to the nucleus of a helium atom. It is the least penetrating of the three common types of radiation, alpha, beta, and gamma.

anoxic -- a general term meaning in the absence of oxygen, usually implying reducing conditions.

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.

aquiclude -- 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. (Supplants the terms aquiclude, aquitard, and aquifuge.)

aquifer -- a body of rock that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells or springs. Water horizon; groundwater reservoir.

aquitard -- see aquiclude.

artesian -- refers to water confined underground under pressure so that the water will rise in a well. Thus an artesian water body is one that is confined under hydraulic pressure since its hydraulic head rises above the top of the aquifer unit.

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.

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.

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 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 groundwaters 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.

block faulting -- a type of vertical faulting in which the crust is divided into structural or fault blocks of different elevations and orientations.

BWIP -- see Basalt Waste Isolation Project.

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.

canister -- (as related to radioactive materials) the primary metal or ceramic container for remote-handled solid transuranic waste, high-level waste, or spent fuel. The canister affords physical containment for the waste, but is not primarily designed to provide shielding.

canister array -- (as related to a repository) the geometric configuration of emplaced nuclear waste canisters; usually associated with terminal storage.

canistered waste -- (as related to waste package) canister and contents, including waste form and any liner, stabilizer, or internal shielding material.

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.

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.)

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.

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.).

coda-length magnitude -- the coda is the latter part of a seismogram following the early, identifiable body waves. Coda length is a measure of signal duration measured from the first-arriving wave to the time when the signal amplitude no longer exceeds some prescribed value (commonly twice the amplitude of background seismic noise).

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.

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 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).)

concreting -- in tunneling, a method of support in which tunnel surfaces are coated with concrete and sometimes containing reinforcing bar patterns. (See also shotcrete.)

confined aquifer -- a subsurface water-bearing region having defined, relatively impermeable upper and lower boundaries and containing confined groundwater 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.

conglomerate -- (as related to geology) a cemented clastic rock containing rounded or dissimilar fragments of gravel or pebble size.

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 -- see canister.

containerized waste -- container and contents including waste form and any liner or stabilizing material.

containment -- (as related to radioactivity) the retention or confinement of radioactivity within prescribed boundaries by use of physical barriers. In this document, usually retention of radionuclides within a system to the exclusion of its release outside that system in unacceptable quantities or concentrations.

-- (as defined in 10 CFR 60 (NRC, 1981a)) the confinement of radioactive waste within a designated boundary.

contamination (general) -- undesired radioactive material present on outside surfaces. This contamination can be either transferable or fixed. Radiation penetrating the walls of a waste package from within is not contamination.

controlled access area -- any specific area into which entry by personnel is regulated by physical barrier or administrative procedure.

controlled area (as used by NRC) -- a surface location extending horizontally no more than 10 kilometers (6.7 miles) in any direction from the edge of the disturbed rock zone and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure (NRC, 1981a). The outer edge of the controlled area marks the inner edge of the accessible environment.

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.

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.

corrective action -- measures taken to rectify conditions adverse to quality and, where necessary, to preclude repetition.

criterion -- a standard rule or test by which something can be judged.

criticality -- state of being critical; a self-sustaining neutron chain reaction.

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.

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.

daughter product -- a nuclide that results from radioactive decay. Thus radium-226 decays to radon-220, which in turn decays to polonium-216. The radon is the daughter of the radium, and polonium is the daughter of the radon.

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 (repository) -- activities associated with final backfilling and sealing of shafts and entries to underground excavations and the end of surface facility use (including demolition, dismantling, etc.) (See permanent closure.)

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.)

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.

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.

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.

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.

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.)

discharge point (or area) -- in groundwater hydraulics, the point (or area) where water comes out of an aquifer onto the surface.

discing -- see core discing.

dissolution -- the taking up of a substance by a liquid (i.e., water) with the formation of a homogeneous solution (liquid phase).

distribution coefficient -- 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).

disturbed rock zone -- that portion of the geologic setting whose physical or chemical character has changed as a result of subsurface facility construction or from heat generated by the emplaced radioactive wastes such that the resultant changes of character may have a significant effect on the performance of the geologic repository (NRC, 1981b). The BWIP adds a further bounding condition on the disturbed rock zone near the emplaced waste which eliminates its site variability. The BWIP defines the disturbed rock zone as the maximum extent of the 100°C isotherm created by emplacement of wastes. The extent of the disturbed rock zone outside of the area of the thermal pulse is defined as a maximum (theoretical) limit of ten times the radius of the tunnel or shaft diameters. This zone falls outside the area normally considered above, and is defined to allow a conservative estimate of the envelope of rock in which geochemical alteration of waste form/rock can occur.

DOE -- U.S. Department of Energy.

dome (general) -- a dome-shaped landform or rock mass; a large igneous intrusion whose surface is convex upward with sides sloping away at low but gradually increasing angles; an uplift or an anticlinal structure, either circular or elliptical in outline, in which the rock dips gently away in all directions.

dome (salt) -- 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.

dose commitment -- 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.

dose rate -- radiation dose received per unit of time.

drift -- (as related to mining) horizontal, or nearly horizontal, mined passageway.

-- (as related to geology) a general term for all rock material transported either by a glacier or by proglacial meltwater.

drum -- a metal or composition (fiberglass) cylindrical container used for the transportation, storage, and disposal of waste materials.

earthquake swarm -- a series of minor earthquakes, none of which may be identified as the main shock, occurring in a limited area and time.

eddy bar -- an accumulation of sand and gravel in an eddying current marginal to a main catastrophic flood channel.

Eh -- 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.

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

emplacement medium -- the material in which a repository is built and into which the waste will be placed. (See also host rock.)

emplacement site -- (as related to waste management) the prepared position where the assembled waste package resides.

engineered barrier -- an addition to the geological environment which has been designed, fabricated, and emplaced to minimize or preclude radionuclide transport.

engineered system -- (1) the underground facility, waste package, shaft and tunnel seals, tunnel backfill, and disturbed rock zone caused by excavation or from the high heat pulse generated by the emplaced radioactive waste. (2) The waste package plus the underground facilities, including the envelope of rock to the maximum extent of the $100^{\circ}C$ isotherm.

engineering scale -- 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.

entablature -- the upper to the middle portion of a basalt flow that has thinner and less regular columns than the lower portion or colonnade.

Environmental Assessment -- a documented determination as to whether a proposed project is expected to have a significant environmental impact and therefore requires the preparation of an Environmental Impact Statement. It is specified by law to be a concise public document, for which a federal agency is responsible, that serves to (a) briefly provide sufficient evidence and analysis for determining whether to prepare an Environmental Impact Statement or a finding of no significant impact; (b) aid an agency's compliance with the National Environmental Policy Act (NEPA, 1970) when an Environmental Impact Statement is necessary; (c) facilitate preparation of a statement when necessary; (d) the document shall include brief

discussions of the need for the proposal of alternatives, as required by Section 102(2)(E) of NEPA (1970), of the environmental impacts of the proposed action and alternatives, and a listing of agencies and persons consulted.

Environmental Impact Statement -- a detailed written statement as required by Section 102(2)(C) of NEPA (1970).

Environmental Report -- 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.

eolian -- 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.

EPA -- U.S. Environmental Protection Agency.

ephemeral stream -- a stream that flows in direct response to precipitation and is dry at some or most of the time during the year.

epicenter -- the point on the Earth's surface directly above the focus or place of origin of an earthquake.

erosion -- the general natural process by which materials at the surface of the Earth are loosened, worn down, and transported from their original locations.

exclusion area -- 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.

facies -- part of a rock body as differentiated from other parts by origin, appearance, and composition.

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 zone of fractures in the crust of the Earth along which differential slippage of the adjacent Earth materials has occurred parallel to the fracture plane. Some faults are only a few centimeters (inches) long and have displacements measured in fractions of 1 centimeter (0.39 inch); others are kilometers (miles) long with displacements in hundreds of meters (feet).

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 system -- a system of parallel or nearly parallel faults that are related to a particular deformational episode.

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.

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.

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, 1981b)) 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 contact -- a planar or irregular surface where two different types or ages of rock meet (i.e., between two basalt flows).

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.

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.

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.

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.

geologic disposal -- placement of radioactive waste in carefully selected deep stable geologic formations.

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).

geomorphic process -- the mode in which physical and chemical agents modify the Earth's surface.

geomorphology -- the interpretive study of the genesis and evolution of land forms.

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.

geotransport -- in this document, movement of radionuclides through subsurface soils and rocks, especially movement with the groundwater. 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.)

glaciofluvial -- of, pertaining to, produced by, or resulting from combined glacial meltwaters.

TABLE 1. Geologic Column and Scale of Time.

Periods of time/ systems of rocks	Epochs of time/ series of rocks	Age (years x 10^6 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

gouge -- the clay or clayey material in a fault zone. Also crushed rock along a fault slip.

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.

groundwater -- subsurface water existing in the saturated zone, including underground streams.

groundwater 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.

groundwater residence time -- the time that groundwater remains in an aquifer or aquifer system.

groundwater travel time -- the time required for groundwater to flow along a path length.

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.

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.

high-level radioactive wastes -- (as used by the EPA (1981)) (1) wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, in a facility for reprocessing spent nuclear fuels. (2) The concentrated wastes from subsequent extraction cycles or equivalent. (3) Solids derived from such wastes. (4) Spent nuclear fuel if disposed of without reprocessing.

-- (as defined in 10 CFR 60 (NRC, 1981b)) (1) irradiated reactor fuel, (2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) solids into which such liquid wastes have been converted.

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 -- (1) the medium within which radioactive waste is emplaced for disposal. (2) Sometimes used as the particular horizon in which the waste is emplaced in a repository. (3) Major constituent geologic formation in a mine. In the Columbia River basalt, host rock and formation are not the same. The host rock will most likely be a flow unit, such as the Umtanum or middle Sentinel Bluffs flow within the Grande Ronde Basalt of the Columbia River Basalt Group. (See also emplacement medium.)

-- (as defined in 10 CFR 60 (NRC, 1981b)) the geologic medium in which the waste is emplaced.

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 gradient -- in an aquifer, the change of total head per unit of distance at a given point and 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 groundwater 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.

hydrogeologic unit -- any soil or rock unit or subsurface zone that has a distinct influence on the storage or movement of groundwater by virtue of its porosity or permeability.

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 groundwater and the movement of dissolved substances.

hydrologic transport -- transport of solutes through a geologic formation due to movement of groundwater.

hydrology -- hydrology is the science of hydraulics as it pertains to groundwater, 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).

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, 1981b) 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.)

intercalated -- occurring between two rock layers or within a series of layers.

interflow -- occurring between flows, as in interflow zone.

intergranular -- 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.

interim storage -- 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.

intersertal -- 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.

interstitial compounds -- interstitial deposits formed subsequently to the rock formations whose pores they have filled by impregnation.

intracanyon -- occurring within a canyon.

ion exchange -- (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.

isolation (for nuclear waste) -- segregating wastes from the accessible environment (biosphere) to the extent required to meet applicable radiological performance standards.

-- (as defined in 10 CFR 60 (NRC, 1981b)) 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.

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.

lacustrine -- pertaining to, produced by, or formed in a lake or lakes.

lahar -- a type of mudflow composed chiefly of volcaniclastic materials on the flank of a volcano.

license application -- a document 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.

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.

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.

long-lived isotope -- a radioactive nuclide which decays at such a slow rate that a quantity of it will exist for an extended period.

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.

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.

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 -- (as used by the EPA (1981)) any individual who is not engaged in operations involving the management, storage, and disposal of materials covered by these standards and guides. A worker so engaged is a member of the public except when on duty at a site.

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.

microseismic region -- the area in which an earthquake is recorded by instruments only.

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).

modal analysis -- the analysis of the actual mineral composition of a rock, usually expressed in weight or volume percentages.

model -- in applied mathematics, the analytical or mathematical representation or quantification of a real system and the ways that phenomena occur within that system. Individual or subsystem models can be combined to given system models. Deterministic and probabilistic models are two types of mathematical models.

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).)

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 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.

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 -- U.S. Nuclear Regulatory Commission.

NWTS Program -- National Waste Terminal Storage Program.

ONI -- Office of NWTS Integration.

ONWI -- Office of Nuclear Waste Isolation.

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.)

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.

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.

paludal -- pertaining to a marsh or swamp.

panel -- separate series of storage rooms designed for the storage of 1 year's (nominal) waste receipts.

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.

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 -- performance assessment considers failure of a system and consequences (to man or the environment) as a result of the failure. If the probability of failure is considered, the process becomes a risk analysis.

-- (as used by the EPA (1981)) an analysis which identifies those events and processes which might affect the disposal system, examines their effects upon its barriers, and estimates the probabilities and consequences of the events. The analysis need not evaluate risks from all identified events. However, it should provide a reasonable expectation that the risks from events not evaluated are small in comparison to the risks which are estimated in the analysis. The analysis should address the uncertainties in the estimates. To provide reasonable confidence in its results, the analysis shall be subjected to peer review by technically competent individuals independent of the organization preparing the assessment.

performance confirmation -- (NRC, 1981b) 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 -- (NRC, 1981b) final backfilling of the underground facility and the sealing of shafts and boreholes. (See decommissioning (repository).)

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. (See also hydraulic gradient.)

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 nongeologic) 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.

piezometric -- in hydrology, an imaginary 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, $CaAl_2Si_2O_8$.

Pleistocene -- the first epoch before the Holocene (or present time) of the Quaternary Period. (See also geologic time scale.)

Pliocene -- 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.)

plug (geology) -- (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.

plug (scientific technology) -- (1) a piece of material to fill a hole. (2) A small segment of material removed from a larger object.

plug (shaft or borehole) -- a watertight seal in a shaft formed by removing the lining and inserting a concrete and/or metal dam, or by placing a plug of clay over ordinary debris used to fill the shaft up to the location of the plug.

population dose (population exposure) -- the summation of individual radiation doses received by all those exposed to the sources or event being considered.

pore -- 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.

porosity -- 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.

$$\text{porosity} = n = \frac{V_v}{V_T}\text{, where } V_v = \text{volume of voids and } V_T = \text{total volume.}$$

porosity log -- a determination of pore volume per unit volume of formation made from a sonic log, density log, neutron log, or resistivity log.

potential, hydraulic -- see hydraulic potential (or hydraulic head).

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.)

Precambrian -- the first of the eras of geologic time. (See also geologic time scale.)

preclosure period (as related to a repository) -- the period of time from the inception of construction activities, including waste emplacement and monitoring through the end of permanent closure activities.

protected or endangered species -- those plants and animals officially listed in FWS (1973) and NEPA (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.

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.

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.

quality control -- those quality assurance actions which provide a means to control and measure the characteristics of an item, process, or facility to established requirements.

Quaternary faults -- faults that have formed or experienced movement during the Quaternary Period.

Quaternary igneous activity -- intrusion or extrusion of molten rock material into or onto the Earth's crust during the Quaternary Period.

Quaternary Period -- the youngest of the periods of the Cenozoic Era, extending from 1.8 million years ago to the present. (See also geologic time scale.)

rad -- 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.

radiation (ionizing) -- particles and electromagnetic energy emitted by nuclear transformations that are capable of producing ions when interacting with matter; gamma rays and alpha and beta particles are primary examples.

radiation zone -- an area that contains radioactive materials or radiation field in quantities significant enough to require control of personnel entry to the area.

radioactive decay -- property of undergoing spontaneous nuclear transformation (disintegration) in which nuclear particles or electromagnetic energy (alpha particles, beta particles or gamma photons) are emitted.

radioactive material -- in general, any material which spontaneously emits atomic particles or rays from the nuclei of its atoms.

radioactive waste -- (as defined in 10 CFR 60 (NRC, 1981b)) high-level waste and any radioactive materials other than high-level waste that are received for emplacement in a geologic repository.

radioactive waste, high-level -- see high-level radioactive wastes.

radiolysis -- decomposition (splitting) of chemical molecules (often water) due to interactions with radiation.

radiometric dating -- the calculation of age in years of a material, based on the decay of naturally occurring radioactive isotopes.

radionuclide -- an unstable, radioactive isotope which decays toward a stable state at a characteristic rate by the emission of ionizing radiation(s).

radionuclide retardation factor -- a characteristic (usually chemical) of the hydrological or geochemical regime that slows the migration or transport of a radionuclide by sorption or other processes. The radionuclide retardation factor gives the ratio of the groundwater velocity to the solute velocity.

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 NEPA (1970) and CEQ (1978). (See also as low as reasonably achievable (ALARA).)

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 groundwater 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.

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.

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 (federal) -- a federally owned and operated facility for storage or disposal of specific types of waste from DOE sites and/or commercial nuclear operations.

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.

residual uncertainty -- those inherent uncertainties in data, modeling, and assumed future conditions that cannot be eliminated.

retrievability -- capability to remove waste from its place of isolation, using planned engineering procedures, with approximately the same level of effort and radiation exposure as required to place the waste. The definition implies that on retrieval there will be no loss of radioactive material or loss of waste package container integrity.

retrievable storage -- storage of radioactive materials in such a manner as to preserve the ability to retrieve the stored material without loss of container integrity.

retrieval -- the act of intentionally removing radioactive waste from the underground location at which the waste had previously been emplaced for disposal.

reverse fault -- a fault in which the hanging wall appears to have moved upward relative to the foot wall.

Richter scale -- 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.)

right-lateral offset -- an offset or fault, the displacement of which is right-lateral separation. (See also dextral shear.)

risk -- the product of probability and consequence of an event.

rubble -- loose, unconsolidated rock consisting mostly of large, angular rocks intermixed with a small amount of soil or earthy material.

rupture -- as relates to radioactive packaging, a breach of the barrier provided by the radioactive material container.

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 -- a subsurface zone in which water fills the interstices and is under pressure greater than atmospheric pressure.

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 -- 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.)

sedimentary -- 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.

seismic -- pertaining to, characteristic of, or produced by earthquakes or Earth vibrations.

seismic refraction method -- 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.

shaft -- 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.

shear -- (1) a strain that causes contiguous parts of a body to slide relative to each other in a direction parallel to their plane of contact. (2) Surfaces and zones of failure by shear, or surfaces along which differential movement has taken place.

shielding -- 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.

shipping cask -- a specially designed container used for shipping radioactive materials.

shipping container -- an enclosure for the transport of packages which do not emit hazardous levels of radiation.

shotcrete -- 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. (See also concreting.)

site qualification -- all scientific and engineering investigations designed to ascertain that a specific site has characteristics that will permit a repository facility to be licensed at that site.

site subsystem -- the zone between the accessible environment and the disturbed rock zone. (Comparable to NRC's "controlled area" and the geologic setting.)

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.

sonic log -- a geophysical log made by an instrument, lowered and raised in a borehole or well, that continuously records, as a function of depth, the velocity of sound waves as they travel over short distances in the adjacent rocks. The log reflects lithologic changes.

sorption -- the binding, on a microscopic scale, of one substance to another, such as by adsorption or ion exchange. In this document, the word is especially used in the sorption of solutes, such as dissolved radionuclides, onto aquifer solids or waste package materials. This occurs by means of close-range chemical or physical forces.

sorptive capacity -- the measure of a material's ability to sorb specific constituents from a liquid as it passes through the material.

source term -- 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.

specification -- 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.

specific heat -- 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).

spent fuel -- nuclear reactor fuel that, through nuclear reactions (irradiation), has been sufficiently depleted of fissile material to require its removal from the reactor.

spent fuel waste -- the final form of spent fuel as waste which could include the fuel in some mechanically processed or disassembled form.

spiracle -- 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.

spoils -- 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.

stability -- (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.

-- (as defined in 10 CFR 60 (NRC, 1981b)) 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.

storage coefficient -- the volume of water an aquifer releases from, or takes into storage, per unit surface area of the aquifer, and per unit change in head. 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.

stratigraphic setting -- the characteristics of the rock layers or other units in the geologic environment.

stratigraphy -- the branch of geology that deals with the definition and interpretation of the rock strata, the conditions of their formation, their character, arrangement, sequence, age, distribution, and, especially, their correlation by the use of fossils and other means of identification.

strike -- 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.

strike-slip fault -- a fault in which the net slip is horizontal or parallel to the fault's strike. (See also dip-slip fault.)

subsidence -- sinking of a part of the Earth's crust relative to adjacent parts.

subsurface facility -- 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.

-- (as defined in 10 CFR 60 (NRC, 1981b)) the underground portions of the geologic repository operations area including openings, backfill materials, shafts, and boreholes as well as shaft and borehole seals.

suprabasalt -- that group of deposits that lie above, and are stratigraphically younger than, basalt.

surface facilities -- engineered repository facilities on the Earth's surface.

surface faulting -- differential ground displacement at or near the surface caused directly by fault movement.

surficial -- of or pertaining to a surface, especially the Earth's surface.

surveillance -- the act of observing or monitoring the effects of systems operations and/or verifying whether an item or activity conforms to specified requirements.

syncline -- downfolded strata that form a trough. Beds dip toward the center of a syncline.

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 -- pertaining to the forces involved in, the processes causing, or the rock structures and external forms resulting from, the deformation of the Earth's crust.

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 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 -- branch of geology dealing with the broad structures of the upper part of the Earth's crust, their origins, mutual relationships, and evolution.

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.

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.

till -- an unsorted and unstratified mixture of glacial debris having a wide range of clast sizes.

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.

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); 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.

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 groundwater that has a water table or upper surface at atmospheric pressure.

unsaturated medium -- that portion of a soil or rock column where void spaces are filled with a mixture of both air and water. This is opposite of a saturated medium where all void spaces are water filled.

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.

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.

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 -- (as defined in 10 CFR 60 (NRC, 1981b)) the radioactive waste materials and any encapsulating or stabilizing materials, exclusive of containers.

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.

waste matrix -- the material that surrounds and contains the waste and to some extent protects it from being released into the surrounding rock and groundwater. Only material within the canister (or drum or box) that contains the waste is considered part of the waste matrix.

waste package -- the sealed canister and overpack (if present), which includes the waste form, as well as the enclosing envelope that separates the waste from the unexcavated rock and the repository backfill. The enclosing envelope may include the canister, buffer or shielding, overpack, and discrete backfill in the emplacement hole, and any other structures, enclosures, or materials reaching to the surace of the rock (borehole emplacement) or tunnel wall (for tunnel emplacement).

water budget -- the quantification of the amount of water entering, moving through, and leaving a flow system; sometimes called water balance.

water table -- upper water surface of an unconfined aquifer at which the 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.)

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.

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APPENDIX - ACRONYMS AND ABBREVIATIONS

acre-ft	acre-foot
acre-ft/yr	acre-foot per year
a.m.	ante meridiem
AN-ASQ/3A	serial number of a magnetometer
ANSI	American National Standards Institute
API	American Petroleum Institute
approx.	approximately
Apr.	April
ARH-DC	Atlantic Richfield Hanford Company-deep cavern (borehole designation)
ASME	American Society of Mechanical Engineers
ASNT	American Society of Nondestructive Testing
ASTM	American Society for Testing and Materials
Aug.	August
Battelle Memorial Inst.	Battelle Memorial Institute
B.C.	before Christ
BC PUD	Benton County Public Utility District
BCR-1	(U.S. Geological Survey's Standard) Basalt Columbia River-1
bkgd	background
bldg.	building
BPA	Bonneville Power Administration
BPA JD	Bonneville Power Administration transmission line
BWIP	Basalt Waste Isolation Project
BWR	boiling water reactor
^oC	degree Celsius; degrees centigrade
$^oC/km$	degree Celsius per kilometer
cal	calorie
cal/g^oC	calorie per gram degree Celsius
C.D.	community development
CETA	Cooperative Education and Training Act

CFR	Code of Federal Regulations
cfs	cubic foot per second
Ci	curie
cm	centimeter
cm^3	cubic centimeter
cm/cm^oK	centimeter per centimeter degree kelvin
COE	U.S. Army, Corps of Engineers
C_o	strength
CSIRO	Commonwealth Scientific and Industrial Research Organization
d	distance; day; thermal diffusivity
$\overline{d}$	diversity
DB	borehole designation (Diamond Borehole)
DC	borehole designation (Deep Cavern)
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDH	borehole designation (Double Drilled Hole)
DDT	dichlorodiphenyltrichloroethane
Dec.	December
deg	degree
DH	borehole designation (Drill Hole)
DI	disabling injury
DOE	U.S. Department of Energy
DOE-HQ	U.S. Department of Energy-Headquarters
DOE-RL	U.S. Department of Energy-Richland Operations Office
d/yr	days per year
E	elasticity; east
e.g.	exempli gratia (for example)
Eh	measurement of oxygen potential useful to indicate oxidizing and reducing conditions
EL	elevation
EPA	U.S. Environmental Protection Agency

ER	existing record
ERDA	U.S. Energy Research and Development Administration
ERTS	Earth Resource Technology Satellite (LANDSAT)
ES	exploratory shaft
et al.	et alii (and others)
etc.	et cetera (and so forth)
^oF	degree Fahrenheit
Feb.	February
FFTF	Fast Flux Test Facility
Fig.	figure
ft	foot
ft^2	square foot
ft^3	cubic foot
FS#1	Full-Scale Heater Test #1
FS#2	Full-Scale Heater Test #2
FY	fiscal year
g	gravity; gram
gal/min	gallons per minute
g/cm^3	gram per cubic centimeter
Gen. Tel.	General Telephone Company of the Northwest, Inc.
GPa	gigapascal
gpm	gallons per minute
GR 1 GR 2	Grande Ronde flow designation particular to a given outcrop or core hole--not correlative
GWe	gigawatt electric
ha	hectare
HDO	monodeuterated water
HLW	high-level waste
HM	hematite-magnetite
hr	hour
hr/yr	hours per year

I-82	Interstate 82
IAP/KT	ion activity product/dissociation constant at temperature
ID or I.D.	inside diameter
i.e.	id est (that is)
in.	inch
in^2	square inch
in^3	cubic inch
in./hr	inch per hour
IRAD	IRAD Manufacturing Company
J	joule
Jan.	January
JD	see BPA JD
J/kg^{o}C	joule per kilogram degree Celsius
J/kg^{o}K	joule per kilogram degree kelvin
Jul.	July
Jun.	June
K	thermal conductivity
^{o}K	degree kelvin
K_1, K_i, etc.	site ranking weight constants
kcal	kilocalorie
K_d	coefficient distribution
KF AGAR	test for streptococci count
kg	kilogram
kg/tU	kilogram per metric ton of uranium
k_h	hydraulic conductivity
kJ	kilojoule
kJ/kg^{o}C	kilojoule per kilogram degree Celsius
kJ/kg^{o}K	kilojoule per kilogram degree kelvin
k_m	calculated effective multiplication factor
km	kilometer
km^2	square kilometer

km^3	cubic kilometer
K_n	normal joint stiffness
kPa	kilopascal
K_s	sheer joint stiffness
ksi	kips per square inch
kV	kilovolt
kW	kilowatt
L	liter
lb	pound
lb/in^2	pounds per square inch
l.t., LT, or L.T.	local time
L/tU	liter per metric ton of uranium
M	magnitude of earthquake
m	meter
m^2	square mile
m^3	cubic meter
Mar.	March
meq	milliequivalent
meq/L	milliequivalent per liter
MET	meteorological tower
meteorology field oper.	Meteorological Field Operations Building
mg	milligram
Mgal/d	thousands of gallons per day
$mg/dm^2 \cdot yr$	milligram per decimeter square per year
mg/L	milligram per liter
mg/m^3	milligram per cubic meter
mi	mile
mi/hr	mile per hour
min	minute
M_L	local magnitude
mL	milliliter
mL/g	milliliter per gram
MM	modified Mercalli

mm	millimeter
m/m	meter per meter
mm/hr	millimeter per hour
mo	month
mol/L	mole per liter
MPa	megapascal
mR	milliroentgen
m/s	meter per second
m^2/s	square meter per second
m^3/s	cubic meter per second
mt.	mount/mountain
MTHM	metric ton of heavy metal
MW	megawatt
mW	milliwatt
MWd/thm	megawatt days per metric ton heavy metal
mW/m^2	milliwatt per square meter
N	north; Grande Ronde magnetostratigraphic unit; normal polarity
N_1	Grande Ronde magnetostratigraphic unit; normal polarity unit 1
N_2	Grande Ronde magnetostratigraphic unit; normal polarity unit 2
N_3	Grande Ronde magnetostratigraphic unit; normal polarity unit 3
N_0	Imnaha magnetostratigrahic unit; normal polarity
NA	not applicable; not available
n/cm^2·sec	neutron flux
ND	not determined; none detected
NE	northeast
NF	not forecasted
N. Fk. Clearwater River	North Fork Clearwater River
ng	nanogram
ng/mL	nanogram per milliliter
NNWSI	Nevada Nuclear Waste Site Investigation(s)
No. or no.	number
NOP	no precipitation

Nov.	November
NQA-1	National Quality Assurance
NR	not reported
NRC	U.S. Nuclear Regulatory Commission
NSTF	Near-Surface Test Facility
NTU	nephelometric turbidity units
Nucl Engr	Nuclear Engineer Corporation (previously NECLO, currently run by U.S. Ecology, Inc.)
NW	northwest
NWTS	National Waste Terminal Storage (Program)
Oct.	October
OD or O.D.	outside diameter
ONI	Office of NWTS Integration
ONWI	Office of Nuclear Waste Isolation
oz	ounce
p.	page
Pa	pascal
p/b	part per billion
PCB	polychlorinated biphenyl
pCi	picocurie
pCi/mL	picocuries per milliliter
pH	hydrogen ion concentration
Phillips Pac. Chemical	Phillips Pacific Chemical
PMF	probable maximum flood
PMP	probable maximum precipitation
p/m	part per million
PNL	Pacific Northwest Laboratory
pp.	pages
PSAR	Preliminary Safety Analysis Report
psi	pound per square inch
PST	Pacific Standard Time
PUREX	plutonium-uranium extraction
PWR	pressurized water reactor
p/yr	part per year

Q	quantity of flow rate
QFM	quartz-fayalite-magnetite
R	Grande Ronde magnetostratigraphic unit; reversed polarity
R_1	Grande Ronde magnetostratigraphic unit; reversed polarity unit 1
R_2	Grande Ronde magnetostratigraphic unit; reversed polarity unit 2
R_3	Grande Ronde magnetostratigraphic unit; reversed polarity unit 3
R_0	Imnaha magnetostratigraphic unit; reversed polarity
R. 20 E.	Range 20 East of the Willamette Meridian
radioecology lab	radioecology laboratory
Rainier Nat. Bank	Rainier National Bank
REF	reference
Rockwell	Rockwell Hanford Operations
RRL-1	Reference Repository Location Well Number 1
RSH-1	Rattlesnake Hills Well Number 1
S	south
s	second
SE	southeast
sec	second
sec.	section
Sep.	September
S_o	normal cohesion
S_p	peak joint cohesion
S_r	residual joint cohesion
St.	Saint
STRIPA	location of Swedish granite mine used for international disposal demonstrations (150 km west of Stockholm, Sweden)
sub	substation
SW	southwest

T	temperature
t	metric ton
T. 15 N.	Township 15 North
TBD	to be determined
TD	total depth
tel exch	telephone exchange
thm	metric ton of heavy metal
THOREX	thorium fuel cycle
T_o	tensile strength
TRU	transuranic
TYP	typical
UM-UF	coliform fecal count test
Univ. of Washington	University of Washington
U.S.	United States
USBM	U.S. Bureau of Mines
USGS	U.S. Geological Survey
Var	variety
vol%	volume percent
vs	versus
W	west; watt
WATEQ-F	computer code Fortran version of NATEQ
WI	Wooded Island
wk	week
W/kg	watt per kilogram
W/L	watt per liter
W/m^2	watt per square meter
W/m^oK	watt per meter degree kelvin
WNP	Washington Public Power Supply System, Inc. Nuclear Plant
WPPSS	Washington Public Power Supply System, Inc.
wt%	weight percent
WW-6	Walla Walla Gas and Oil Company Well #6

yd^3	cubic yard
yr	year
z	depth of earthquake

NUMBERS

200 E	200 East Area
200 W	200 West Area
3-D	three-dimensional

SYMBOLS

α	alpha
&	and
$\angle$	angle
ϕ	angle of internal friction; cohesion
$\sim$	approximately
β	beta
℄	centerline
ΔT	change in temperature
τ_0	cohesion
σ	compressive stress normal to plane of failure
$^\circ$	degrees. For location, as in 120° 15'. For temperature, as in $^\circ$C
$	dollar
$>$	greater than
$\geq$	greater than or equal to
α_t	gross alpha
β_t	gross beta
σ_H	horizontal stress
σ_{Hmax}	horizontal stress maximum
σ_{Hmin}	horizontal stress minimum

$<$	less than
$\leq$	less than or equal to
μCi	microcuries
μg	microgram
$\mu g/m^3$	micrograms per cubic meter
$\mu g/L$	micrograms per liter
$\mu g/mL$	micrograms per milliliter
μm	micrometer
$\mu mhos$	micromhos
μ	micron
μs	microsecond
$\mu s/ft$	microseconds per foot
$'$	minute
x	multiplied by
$\simeq$	nearly equal to
#	number
ϕ_p	peak friction angle
%	percent
$^o/oo$	per mil (per thousand)
$\pm$	plus or minus
ν	Poisson's ratio
ϕ_r	residual friction angle
$\sqrt{\ }$	square root of
σ	standard deviation
Σ	summation
σ_v	vertical stress

13.4 SUMMARY OF BASALT WASTE ISOLATION PROJECT SITE ACTIVITIES

The status and plans for each of the work elements associated with geologic and hydrologic considerations and environmental and socioeconomic considerations were presented in Section 13.3. In this section, a brief description of all the technical work being undertaken by the BWIP on these tasks is provided in summary narrative form. These narratives are accompanied by a logic diagram (Fig. 13-4) that describes, in general form, the main activities to accomplish the work and those points at which the issues presented in Section 13.3 will be resolved. Schedules and milestones for the work described in this chapter are presented in Chapter 17. Each box on the logic diagram is keyed to the narrative material. Each section of the narrative also contains a list of the work elements that support the tasks designated.

As noted in Section 13.1, much of the site work is oriented toward an evaluation of the geologic and hydrologic stability of the reference repository location. As such, most of the activities identified in the logic chart (Fig. 13-4) involve characterization and modeling work that can be used to assess the postclosure performance of a repository in basalt.

Summary Activity Narratives

1. Prepare Input to Basalt Waste Isolation Project Plan

   The site input to the BWIP plan describes geologic, hydrologic, environmental, socioeconomic, and performance assessment activities necessary to identify, characterize, and evaluate a site for a licensed repository within basalt at the Hanford Site. It also includes activities that relate to the exploratory shaft. Site activities shown in the logic diagram (Fig. 13-4) include those that directly or indirectly support all phases of the BWIP leading up to, and including, the license application for repository construction.

   Applicable Work Elements

   Initial work completed. The BWIP updates technical plans on a continuing basis. The definition (technical planning) of the work required to meet proposed criteria and draft regulations, covered in Chapter 13, forms the basis for this planning.

2. Conduct Preliminary Geologic Characterization and Integration

   Initial geologic characterization work of the BWIP consisted of the collection and interpretation of basic geologic data for the Washington State portion of the Columbia Plateau. On the basis of this data, a preliminary interpretation of the stratigraphic, structural, and tectonic setting of the Pasco Basin was formulated.

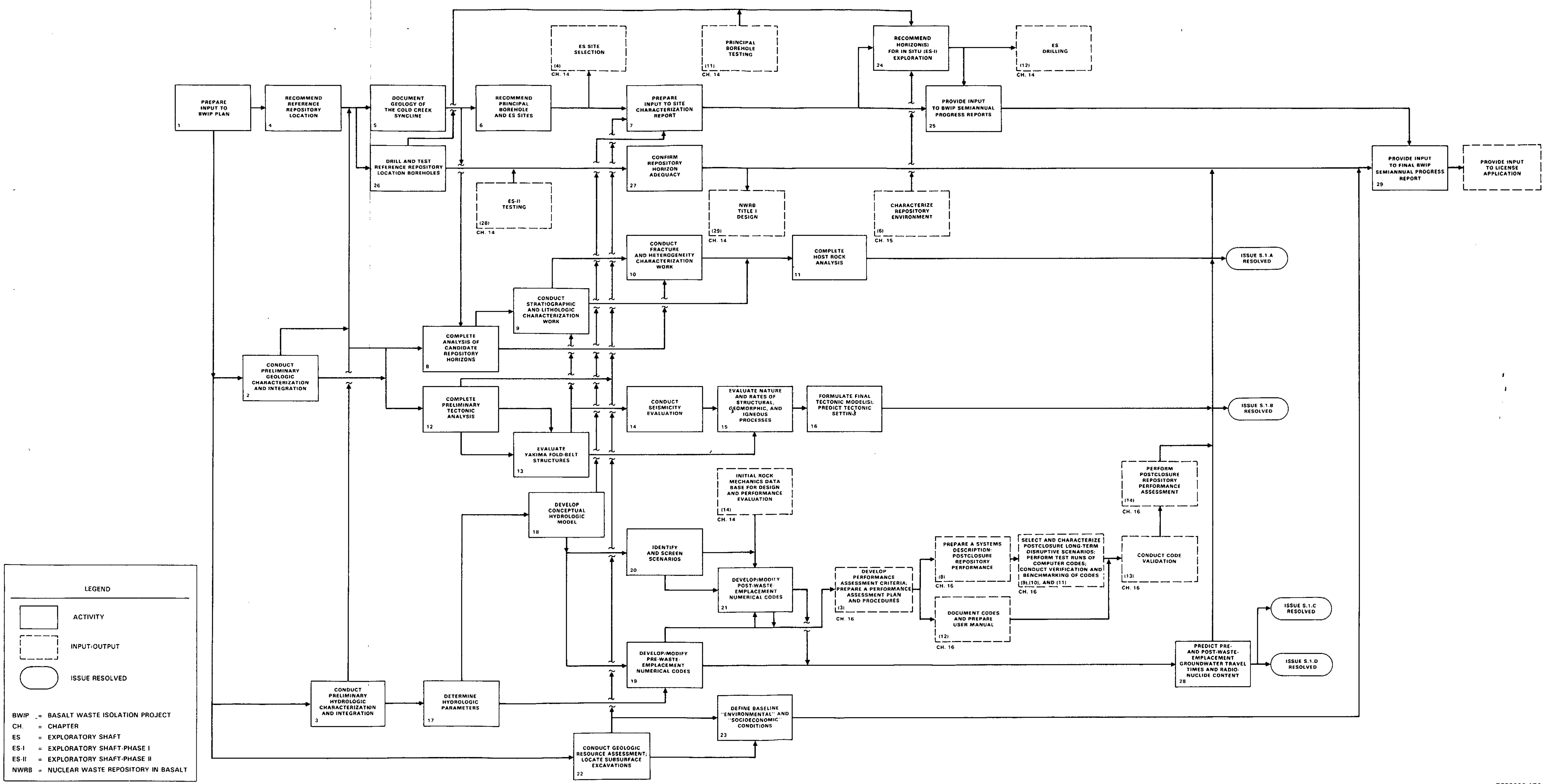

FIGURE 13-4. Logic Diagram for Site.

14.4 SUMMARY OF BASALT WASTE ISOLATION PROJECT REPOSITORY DESIGN AND CONSTRUCTION AND PERFORMANCE CONFIRMATION ACTIVITIES

The status and plans for each of the work elements associated with repository design and construction and performance confirmation criteria and/or issues were presented in Section 14.3. In this section, a brief description of all the technical work being undertaken by the BWIP on these tasks is provided in summary narrative form. These narratives are accompanied by a logic diagram (Fig. 14-2) that describes, in general form, the main activities to accomplish the work, as well as the points in time at which the issues presented in Section 14.3 will be resolved. Chapter 17 will present schedules and milestones for the work described in this chapter. Each box on the logic diagram is keyed to the following narrative material. Each section of the narrative also contains a list of the work elements that support the tasks designated.

As noted in Section 14.1, the design activity is the key work element that will determine the requirements for the data gathering activities for the repository design and construction and performance confirmation tasks. A wide range of testing has been scoped to define the rock-mass characteristics, response to construction activities, thermal loading, geologic conditions, and interaction with the support systems. These data will be input to the performance assessment models and repository design activities.

A tunnel, shaft, and borehole sealing test program is described that defines the materials, equipment, and techniques necessary to meet the U.S. Nuclear Regulatory Commission proposed criteria for repository closure and long-term isolation of radioactive waste.

As additional results from ongoing and planned studies are analyzed, testing plans will be further refined.

Summary Activity Narratives

1. Input to BWIP Plan

   The inputs to the BWIP plan summarize the work to be performed. These inputs reflect the experience gained from tests at the Near-Surface Test Facility, conceptual design, and engineering studies previously completed. This work will ultimately produce detailed repository specifications to ensure that the repository meets the requirements for nuclear waste disposal.

   Applicable Work Elements

   Input to the initial BWIP plan has been completed. The BWIP updates technical plans on an as-needed basis. The definition (technical planning) of the work required to meet criteria presented in Chapter 14 forms the basis of the work elements in this chapter.

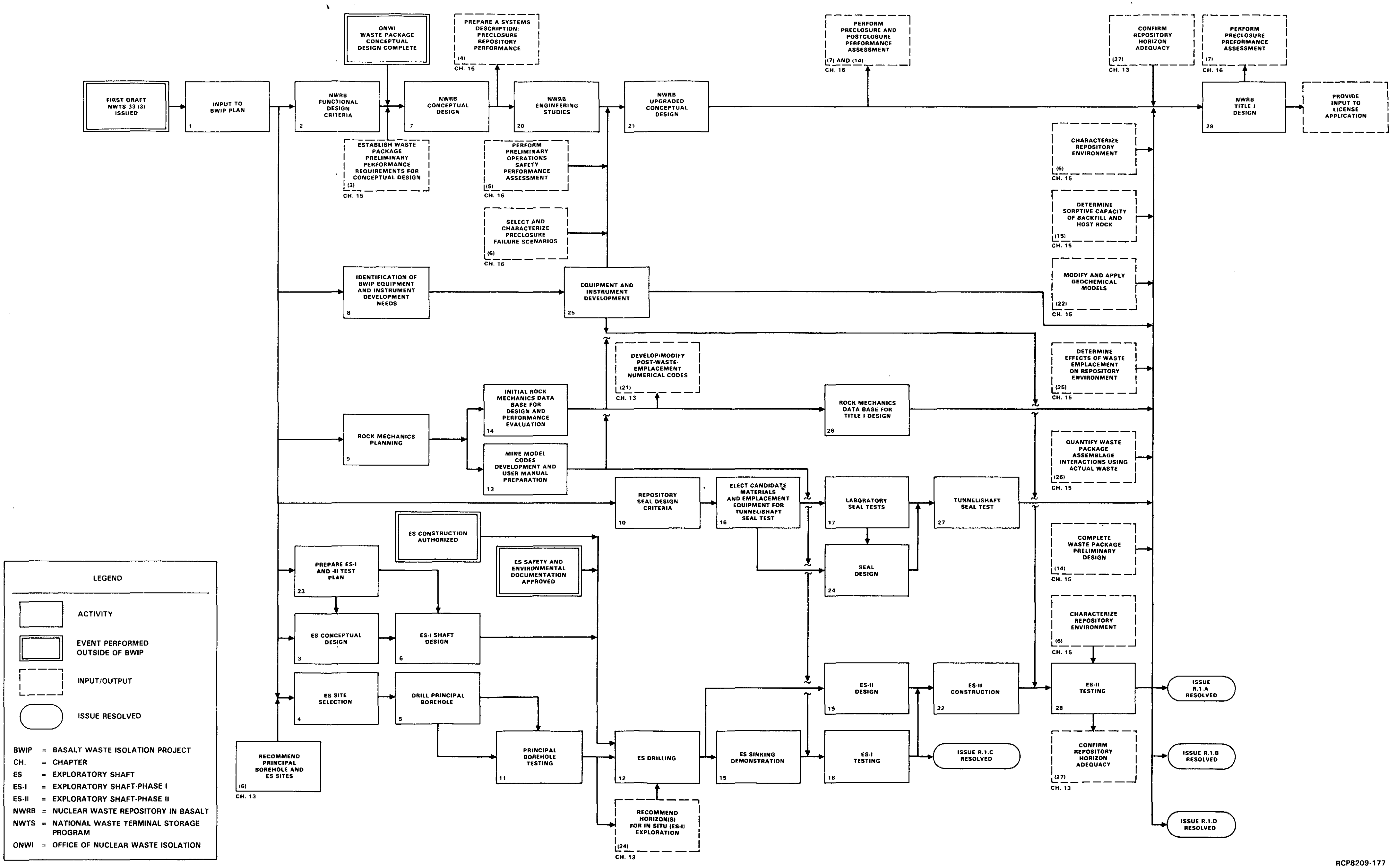

FIGURE 14-2. Logic Diagram for Geoengineering and Repository Design.

15.4 SUMMARY OF BASALT WASTE ISOLATION PROJECT WASTE PACKAGE DESIGN, SITE GEOCHEMISTRY, AND RELATED TESTING AND PERFORMANCE ACTIVITIES

The status and plans for each of the work elements associated with waste package design, site geochemistry, and testing and performance-confirmation criteria and/or issues were presented in Section 15.3. In this section, a brief description of all the technical work being undertaken by the BWIP on these tasks is provided in summary narrative form. These narratives are accompanied by a logic diagram (Fig. 15-3) that describes, in general form, the main activities to accomplish the work, as well as the points at which the issues presented in Section 15.3 will be resolved. Schedules and milestones for the work described in this chapter will be presented in Chapter 17, along with those for the other issue and plans chapters (Chapters 13, 14, and 16). Each box on the logic diagram is keyed to the narrative material. Each section of the narrative also contains a list of the work elements that support the tasks designated.

As noted in Section 15.1, the design activity is the key work element that will determine the requirements for the data-gathering activities for the waste package design, site geochemistry, and testing and performance confirmation tasks. A wide range of material testing activities has been scoped to define the near-field repository environment, far-field repository environment, waste form stability, and waste/barrier/rock interactions and to provide waste package design verification. The materials data will provide the basis for the preparation of site-specific waste package design specifications to support the National Waste Terminal Storage Program waste package design effort and the BWIP repository design efforts.

Summary Activity Narratives

1. Prepare Input to Basalt Waste Isolation Project Plan

    The inputs to the BWIP plan summarize the work that will be performed by the waste package and site activities. This work will ultimately produce detailed waste package system specifications to ensure that the National Waste Terminal Storage Program waste package designs meet nuclear waste repository in basalt requirements.

    Applicable Work Element

    Initial work completed. The BWIP updates technical plans on an annual basis. The definition (technical planning) of the work required to meet criteria covered in Chapter 15 forms the basis of the work elements in this chapter.

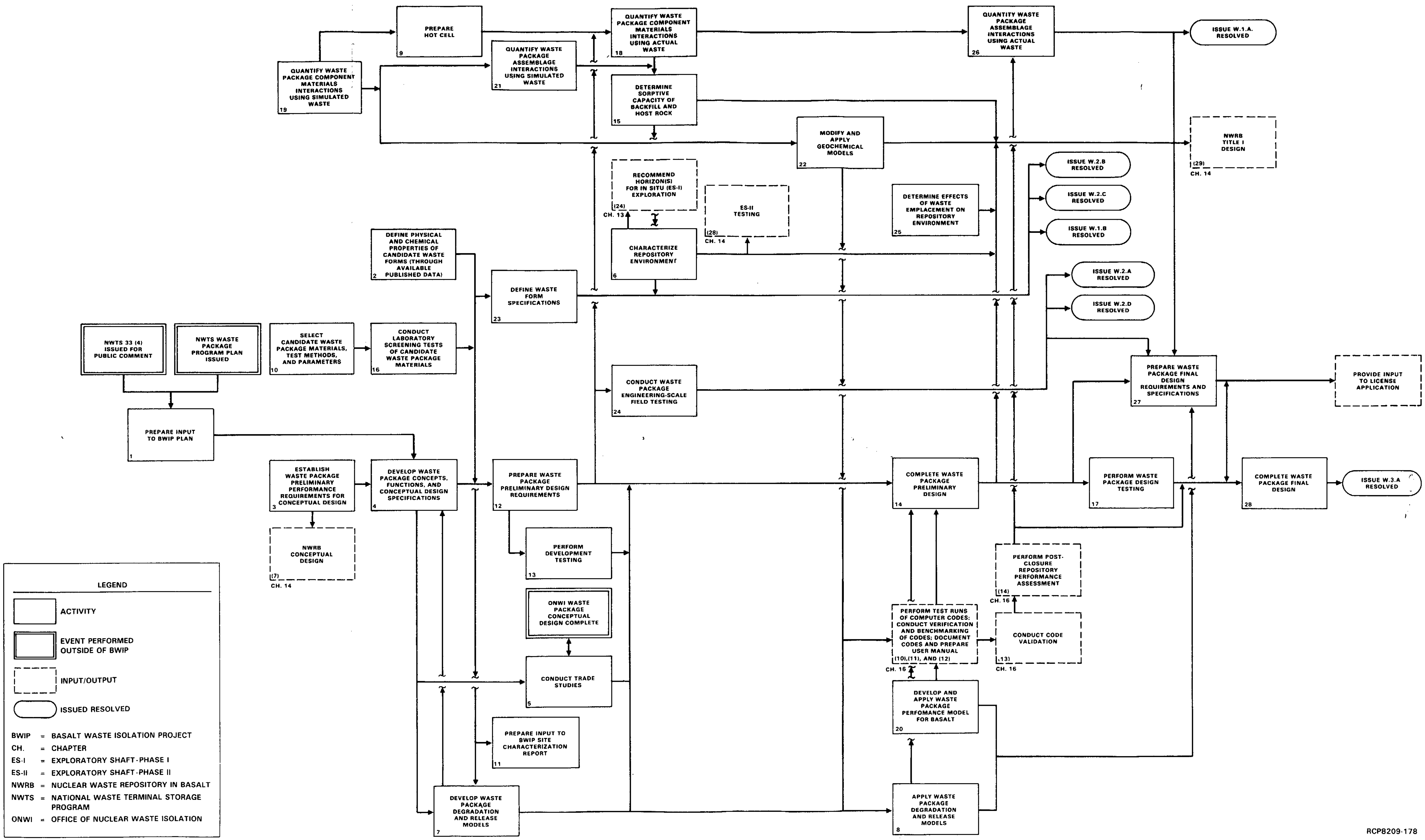

FIGURE 15-3. Logic Diagram for Waste Package and Site Geochemistry.

16.4 SUMMARY OF BASALT WASTE ISOLATION PROJECT PERFORMANCE ASSESSMENT ACTIVITIES

The status and plans for each of the work elements associated with the assessment of preemplacement site performance, postclosure performance of the engineered system, postclosure performance of the waste isolation system, and preclosure repository performance criteria and/or issues were presented in Section 16.3. In this section, a brief description of all the technical work being undertaken by the BWIP on these tasks is provided in summary narrative form. These narratives are accompanied by a logic diagram (Fig. 16-3) that describes, in general form, the main activities to accomplish the work, as well as the points at which the issues presented in Section 16.1 will be resolved. Schedules and milestones for the work described in this chapter will be presented in Chapter 17, along with those for Chapters 13, 14, and 15. Each box on the logic diagram is keyed to the narrative material. Each section of the narrative also contains a list of the work elements that support the tasks designated.

As noted in Section 16.1, the performance assessment activity provides a means of integrating and evaluating the activities reported in the other chapters of this document. For the sake of clarity, the logic diagram showing the technical tasks in performance assessment is only divided into preclosure and postclosure activities. All the elements of postclosure performance assessment apply to the assessments of site preemplacement, the engineered system, and the waste isolation system. When completed, the performance assessment activities will provide a clear demonstration of whether a nuclear waste repository in basalt will cause an acceptable or unacceptable impact on present or future generations.

Summary Activity Narratives

1. Plan Postclosure Preliminary Performance Assessment

   As part of the project's technical planning activities, an initial approach to postclosure performance assessment was developed.

   Applicable Work Elements

   Work completed. Planning has resulted in the material presented in Chapter 12.

2. Perform Preliminary Postclosure Performance Assessment and Define Code Input Requirements

   The following preliminary performance assessments have been made and reported in Chapter 12:

   - Preliminary assessment of groundwater transit times (Section 12.4.1)

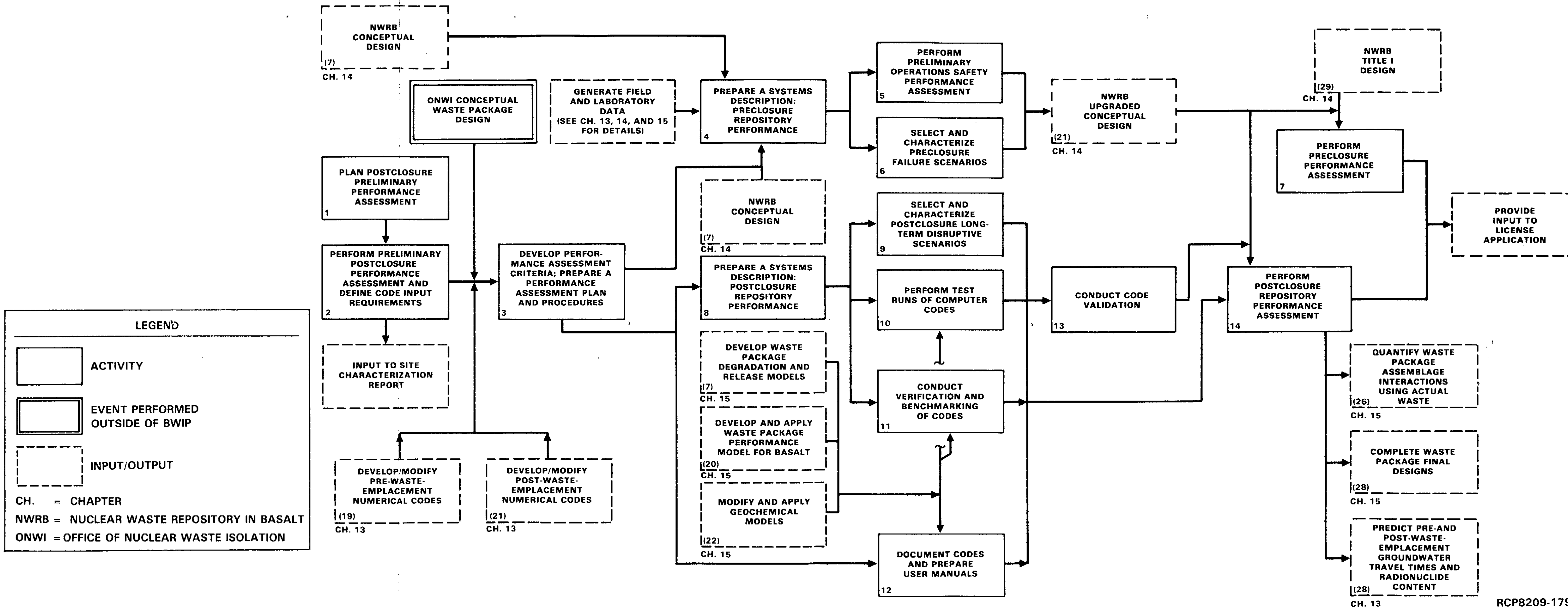

FIGURE 16-3. Logic Diagram for Performance Assessment.

17.3 PLANNING SUMMARY

The schedules in this section show when the activities will be accomplished to complete the work elements and to resolve the outstanding issues identified in Chapters 13 through 16 (Table 17-1). The time frame on which each issue is scheduled to be resolved is shown for each chapter of plans and issues (Fig. 17-8 through 17-11). The schedule for construction of the exploratory shaft is shown in Figure 17-9.

The numbers in parentheses (associated with each activity on the schedule) correspond with the same number and activity reflected on the logic networks. A narrative for each of these activities can be found in Chapters 13 through 16.

The dates for resolution of specific issues are related both to the time necessary to complete the work elements and to the major milestones for which issue resolution is required. However, the resolution of an issue does not necessarily mean that a particular report will be issued. The two principal milestones related to the resolution of issues are (1) issuing the final BWIP semiannual progress report and (2) submitting the License Application to obtain a Construction Authorization. The final BWIP semiannual progress report is scheduled for completion during the second quarter of fiscal year 1987. Submission of the License Application is scheduled for the fourth quarter of fiscal year 1988 (Fig. 17-12). The issues whose resolution is scheduled to be documented in the final BWIP semiannual progress report and the License Application are listed in Table 17-12. The BWIP semiannual progress reports will report progress toward resolution of issues. The key issues (S.1.D, R.1.A, and R.1.D) will be resolved before the final BWIP semiannual progress report.

TABLE 17-12. Issues Scheduled to be Resolved in Time to Report in the Final BWIP Semiannual Progress Report and the License Application.

Issues for final BWIP semiannual progress report	Issues for License Application
S.1.A	W.1.A
S.1.B	W.2.A
S.1.C	W.2.D
S.1.D	W.3.A
R.1.A	
R.1.B	
R.1.C	
R.1.D	
W.1.B	
W.2.B	
W.2.C	

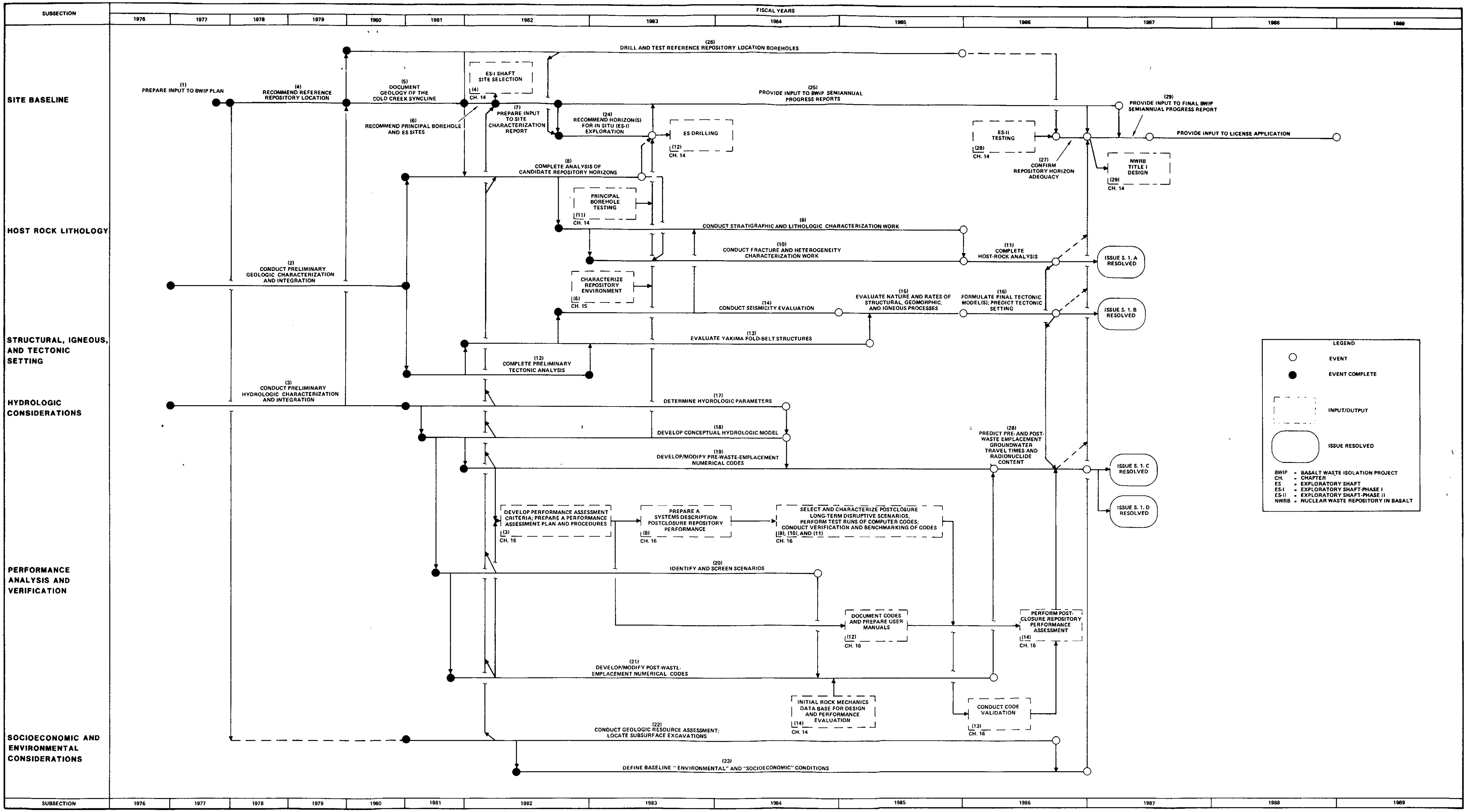

FIGURE 17-8. Schedule for Resolution of Site Issues.

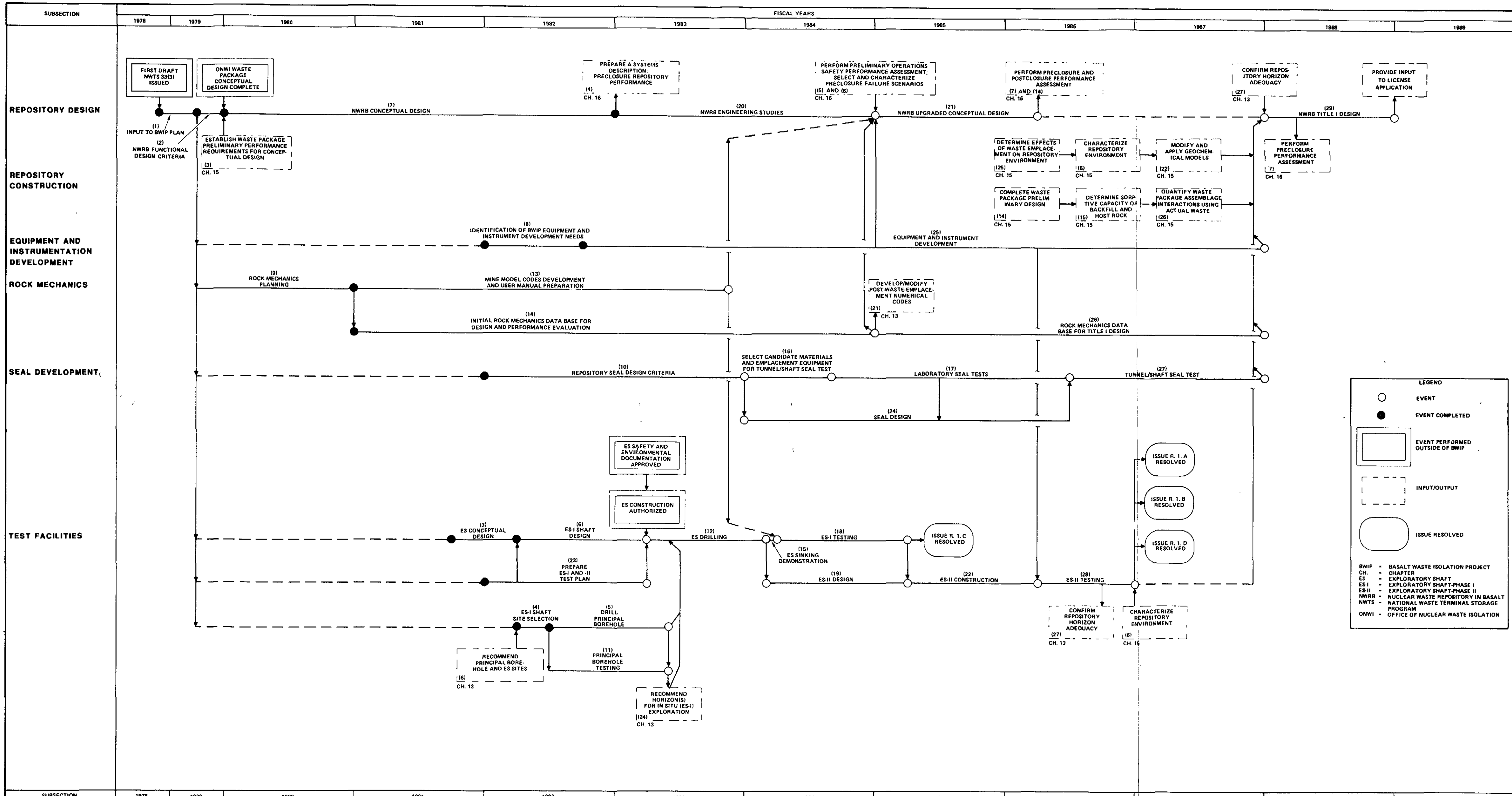

FIGURE 17-9. Schedule for Resolution of Geoengineering and Repository Design Issues.

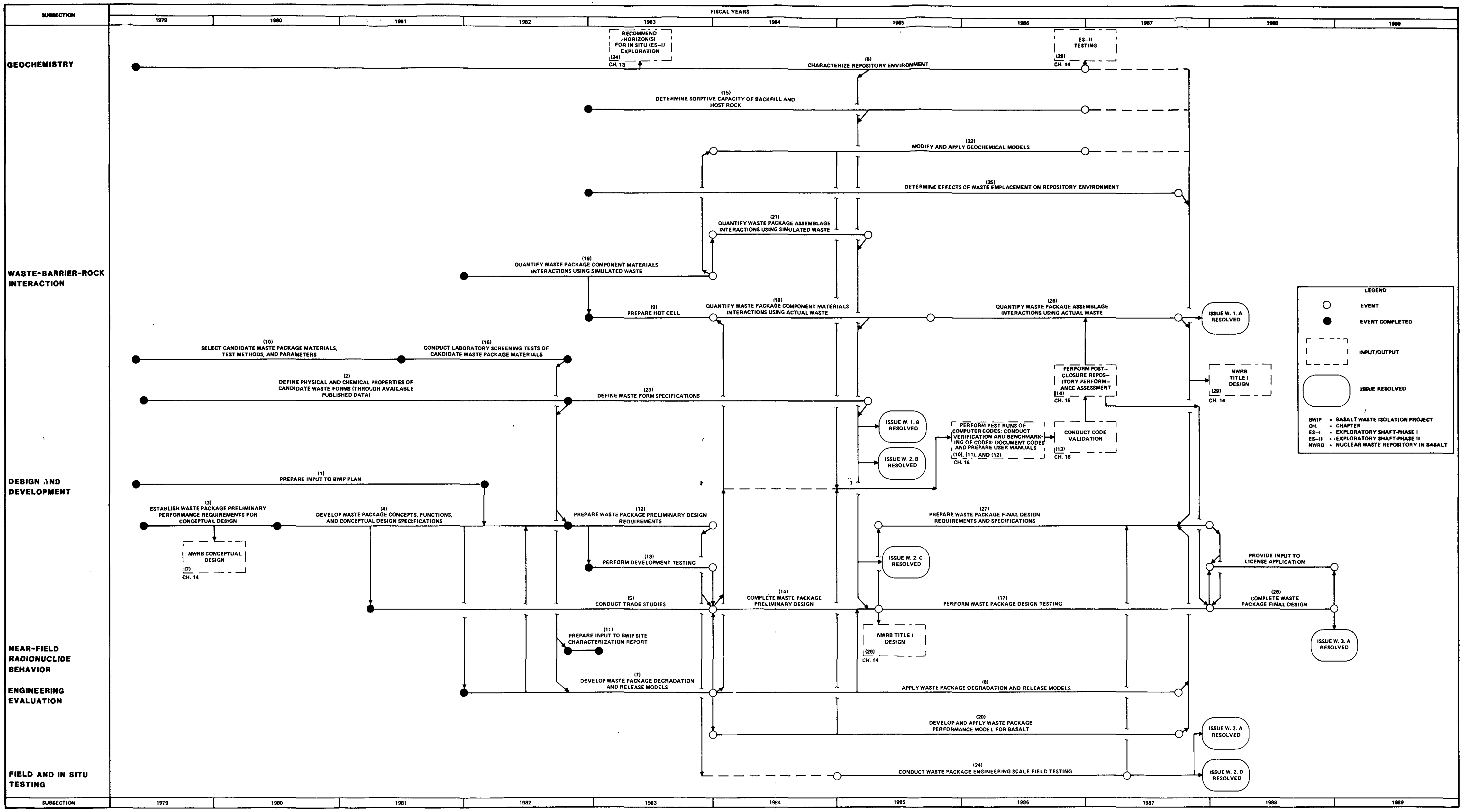

FIGURE 7-10. Schedule for Resolution of Waste Package and Site Geochemistry Issues.

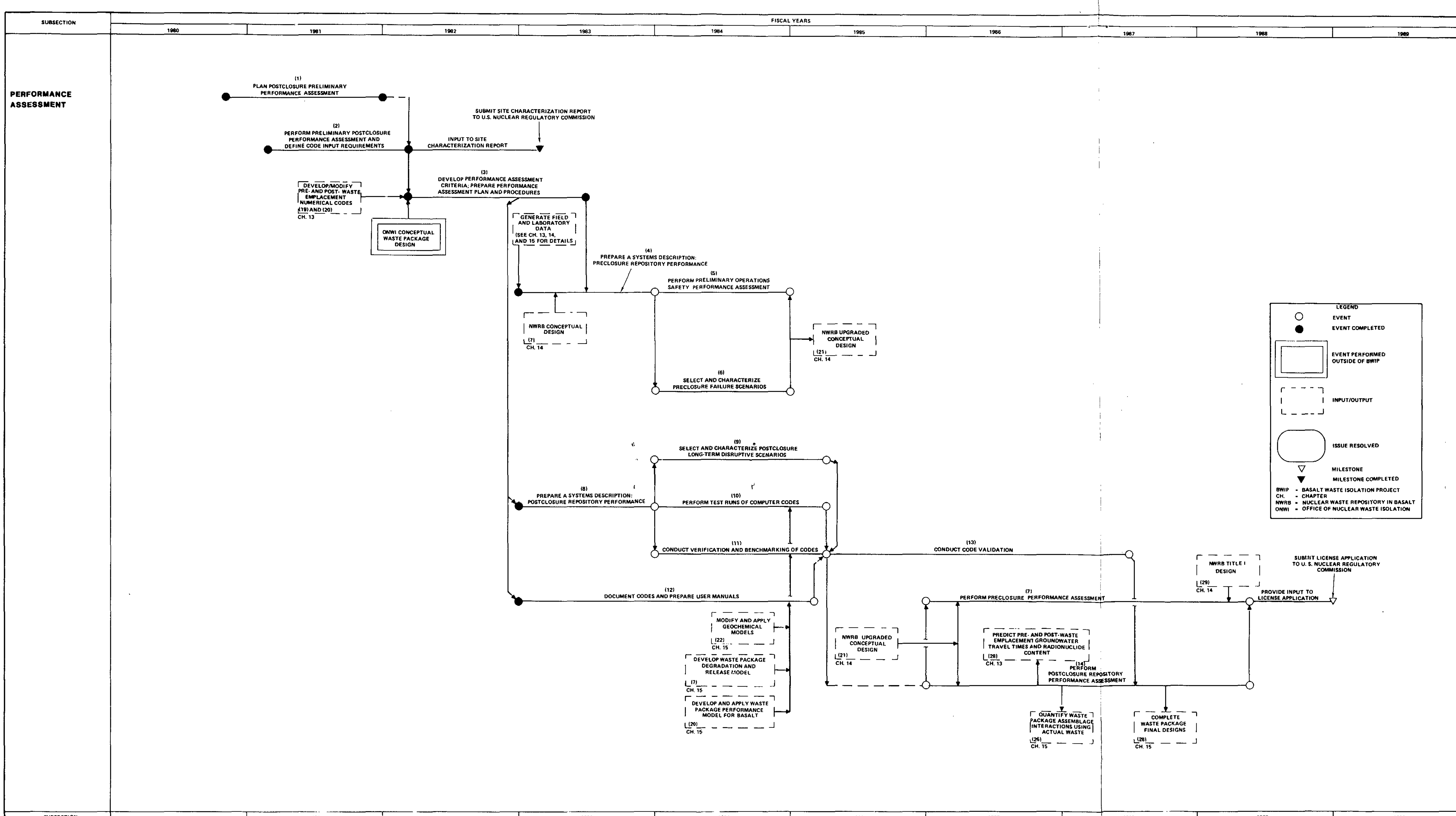

FIGURE 7-11. Schedule for Resolution of Performance Assessment Issues.

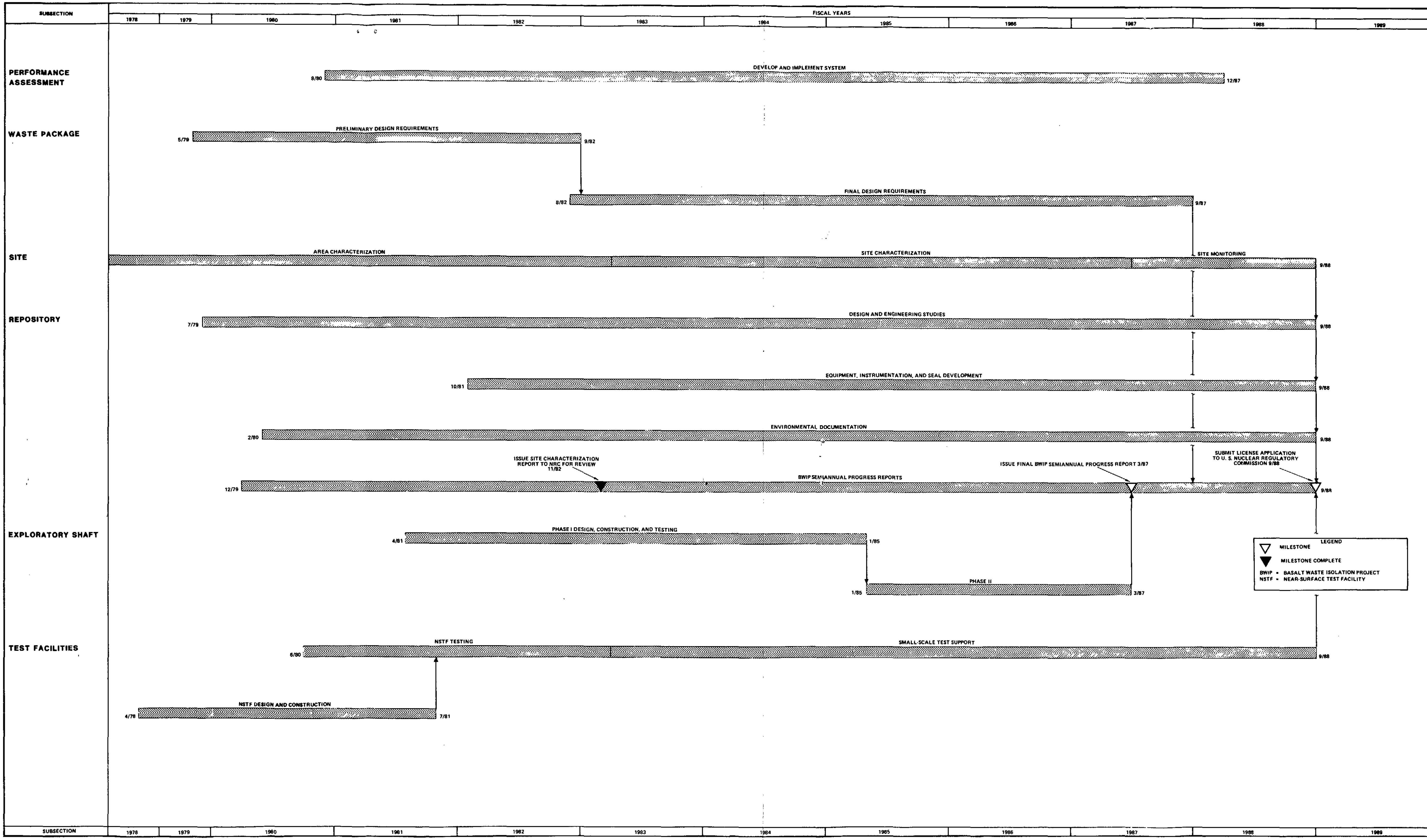

FIGURE 17-12. Summary Schedule for the License Application.