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BASALT WASTE ISOLATION PROJECT REVIEW BY PACIFIC NORTHWEST LABORATORY'S REVIEW TEAM

Letter Report

November 1983

Prepared for the
Richland Operations Office
U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

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PREFACE

Because this document reviews ongoing work done in connection with the Rockwell Hanford Operation's Basalt Waste Isolation Project, many of the references cited are non-publicly available memos, letters or meetings. Memos and letters are cited by author and date; in the case of meetings, we have indicated if vugraphs or notes are available in the reference list. To avoid a plethora of "RHO 1983a, b, c, d, etc.," references in the text, we have provided Rockwell's document number and the date of submission instead. Thus, the exploratory Shaft Test Plan would be cited in the text as (SD-BWI-TP-007, 1983). Both the complete reference and the in-text citation are provided in the chapter reference list.

The reader is assumed to be familiar with common abbreviations associated with the Basalt Waste Isolation Project. Specifically, these abbreviations include:

RHO for Rockwell Hanford Operations

BWIP for Basalt Waste Isolation Project

KE/PB for Kaiser Engineers and Parsons Brinckerhoff

SCR for Site Characterization Report

SCA for Site Characterization Analysis

SCP for Site Characterization Plan

RRL for Reference Repository Location

PNL for Pacific Northwest Laboratory

BMTP for Barrier Materials Test Plan.

SUMMARY

At the request of the Department of Energy, Richland Operations (DOE-RL), Pacific Northwest Laboratory (PNL) has reviewed the available data on the use of Hanford basalt as a nuclear waste repository. The DOE draft siting guidelines were used to identify selection criteria and to define conditions deemed to be "favorable," "potentially adverse," or "disqualifying." PNL found no conditions that would clearly disqualify Hanford as a repository, although we found, in some instances, that data were not sufficient to support conclusions, positive or negative. A number of so-called "favorable" characteristics were identified as well as some "potentially adverse" ones.

In the review of geology/geophysics data, we concluded that the most serious unresolved technical question is associated with the inability to define stratigraphic anomalies in Hanford basalts from the surface. These anomalies, which include locally thickened flow-top breccia, flow margins, canyon fills, cooling joint patterns, faults, and shear zones, will present some limitations on the design and construction of a repository. Uncontrolled entry into a high-pressure, water-bearing zone presents a potential flooding hazard during construction; difficulty in predicting the distance to such zones inhibits subsequent performance assessment analyses. Neither borehole testing, surface geophysics, nor sinking an experimental shaft will resolve these uncertainties. It is probable that they can only be resolved by underground multidirectional drillhole probing and specialized in situ geophysical testing in advance of, and subsequent to, actual repository mining operations.

The second major unresolved technical question is the uncertainty of the structural/tectonic model(s) of the site. Such a model(s) is needed to explain significant thinning of the basalts underlying Hanford as inferred from magnetotelluric surveys, the apparently anomalous east-west trend of the Yakima fold belt, the existence of faults (especially strike-slip type) not associated with folds, and the mechanical coupling, or lack thereof, between the basalts and the presumably crystalline basement.

While few problems appear to be associated with large earthquakes, data suggesting swarm earthquake activity in the proposed repository horizons may

require careful analysis. The concerns focus on fracture displacement and essentially unattenuated high frequency vibration that might affect canister retrievability. The possible dehydration, diagenesis, volume changes, and potential flushing of secondary minerals in the basalt joints needs to be studied under expected repository thermal and stress conditions.

Assessment of the Hanford basalts from a geohydrologic perspective leads to the conclusion that about as many "favorable" as "potentially adverse" DOE siting criteria are satisfied. At this point, no data disqualify the site on the basis of hydrology. The complexity of the multi-flow basalt system leads us to conclude that the Hanford site will require a major characterization effort to resolve hydrologic uncertainties to the point where performance assessment predictions can be made and defended. Understanding the nature of the magnitude of the vertical permeability of the basalt hydrologic system is the key to the characterization and, eventually, any licensing process. The hydrologic character of the geophysical anomalies in the RRL and Hanford Area must be understood before it is possible to accurately characterize the nature of the vertical innerconnections they support. Until all the information on potentiometric baseline, large scale pump tests, and other necessary regional and local site characterization data are available there can be no defensible estimate of groundwater travel time with appropriate uncertainty bounds. In spite of these complexities, it is our conclusion that, in all probability, the Hanford site will demonstrate a pre-emplacement groundwater travel time in excess of 1000 years when fully characterized.

Analysis of geochemical data leads us to conclude that on the basis of DOE siting guidelines, the Hanford basalt has several favorable attributes and no seriously unfavorable ones. Favorable attributes include pre-emplacement reducing conditions, neutral pH, average radionuclide complexing potential, and alteration mineralogy that increases adsorption potential and lowers permeability. The major unassessed technical question is the potential effect on radionuclide retention of high dissolved methane concentration under radiolytic conditions.

The ability to confirm chemical analyses, check analytical procedures and recover historical data has a major technical influence on the usefulness of geochemical data. In that light, PNL recommends that five general geochemical technical areas receive more attention: 1) procedure documentation; 2) data storage/management; 3) data adequacy; 4) data interpretation; and 5) reporting.

We found the waste package performance effort to be generally well conceived. We have some reservations, however, about the ability of the present program to achieve the necessary demonstration of performance within the available time period. Our first question has to do with the understanding of the chemistry of the groundwater under repository conditions. Until the combined effects of radiolysis and methane on the groundwater are understood, the usefulness of binary and ternary tests are limited. Likewise, we believe that the full range of the important variables has not been analyzed sufficiently. Hence the program will tend to give results which are limited to specific test conditions. A broader approach, probably using statistical design methodology, would better insure that the appropriate range of performance data are generated. We recommend an early simulation of the waste package/repository system be provided to validate property behavior based on selected subsets of the system variables. We further suggest the incorporation of geochemical tools (ion speciation, solubility, and perhaps, mass-transfer computer codes) when possible.

The characteristics of waste package packing as a function of emplacement methodology are currently under study. It is our opinion that more experiments are needed to define the thermal and mechanical specifications of the packing. Sealing of tunnels and shafts has not as yet received much attention. An extensive effort will be required to demonstrate that seals meet NRC standards.

An examination of the repository design documentation leads us to the conclusion that repository construction in Hanford basalt will be considerably more difficult and expensive than has been indicated to date. The high in situ stresses, combined with the basalt rock mass properties, indicate tunnel stability problems under combined thermal and excavation stresses. PNL believes heavier support may be required than indicated by the design and cost documents. These same rock properties will also complicate the sinking of large access shafts. While within the state-of-the-art, the successful demonstration of the sinking and lining of a 20-ft shaft to depth will, in our opinion, be a major task.

The ventilation system of the conceptual repository design does not address the potential of methane gas buildup during the construction and operation of the repository. PNL recommends that this receive thorough study. We found many inconsistencies between the design documents of Kaiser Engineers & Parsons Brinckerhoff (KE/PB) and the BWIP research data. We recommend that an intensive effort be made to integrate the two efforts before the SCP is issued.

BWIP work in performance assessment is in its formative stage but appears well directed. Progress to date on the analysis of disruptive events has been limited to a formal Delphi analysis. This work seems to have been well received by NRC but it does not accommodate the analysis of multiple events or that of a long-term evolution of the geohydrologic system. Current BWIP plans in this area will accommodate the analysis of system behavior over a 10,000 year period, which will satisfy EPA requirements. The latest DOE siting guidelines, though, specify time periods (for analysis) of 100,000 years and longer. We recommend that BWIP re-examine performance assessment plans in light of the latter requirements.

Most of the PNL findings agree with those of other reviewers of BWIP. The technical questions have been for the most part discussed with the RHO staff. The PNL reviewers were generally impressed with the quality of the BWIP technical staff and their evident commitment to the challenging task they face.

While there has been excellent progress in BWIP, particularly in the past year, PNL is convinced that the technical questions identified must be resolved before it will be possible to show with reasonable assurance that the Hanford site is adequate for disposal of nuclear waste.

CONTENTS

1.0 INTRODUCTION

At the request of the U.S. Department of Energy, Richland Operations Office, the Pacific Northwest Laboratory (PNL) has reviewed the technical bases relative to the ability of Hanford basalt to meet siting guidelines for waste repositories. As directed, the PNL review considered scientific, engineering, and related aspects regarding the use of the Hanford Site as a repository for high-level and transuranic nuclear wastes. We compared the information from several sources with the siting guidelines directed by the National Waste Policy Act of 1982 and currently being prepared by the Department of Energy (DOE).

Sources of information used for the comparison included the Basalt Waste Isolation Project (BWIP) Site Characterization Report (SCR) and numerous comments made by the NRC, USGS and others on information presented in the SCR. Additional information was obtained by reviewing RHO/BWIP documents (see bibliography). Also, the review involved many valuable discussions with BWIP staff and consultants, who were most cooperative. In some cases, those discussions involved detail that is not available in referenceable form. We have identified in the bibliography those items for which the only reference is material gathered from meetings. Information received after October 14, 1983, was not considered in this review.

The August 1, 1983, draft of the DOE siting guidelines was used by PNL as the basis to identify specific questions on the ability of Hanford basalt to serve as a nuclear waste repository. These were incorporated with questions that had been documented in reviews by others which PNL felt had merit. The August draft of the guidelines has subsequently been revised and most certainly will undergo additional revision. We have attempted to remain current with changes in the guidelines as they have developed. Such an activity has not been totally successful and in the interest of maintaining a consistent baseline we considered only the August draft for guidance.

The PNL study was restricted to examining only scientific, engineering and related aspects relevant to locating a nuclear waste repository in Hanford basalts. Such a charter excludes detailed consideration of environmental, socioeconomic and transportation issues. However, cursory examination clearly shows that certain guidelines fall within the category of a "favorable condition." Examples of these guidelines would include site ownership and control, and population density and distribution. Other guidelines such as environmental quality and socioeconomic impacts, will require a more detailed assessment before a determination can be made about the Hanford site.

Our study was also limited to review of the selection process of a reference repository location (RRL) for terminal storage of nuclear wastes in Hanford basalt. The selection of a candidate horizon within the RRL was also reviewed.

We had originally planned, once the questions and issues were identified, to review BWIP plans as presented in a Site Characterization Plan (SCP). The SCP was to be analyzed to determine how it addressed the questions and issues identified by this study. Publication of the SCP, however, has been deferred for some time. Because the SCP is not available, we have relied heavily upon discussions with DOE/BWI and RHO/BWIP staff members to identify activities and plans currently considered by the BWIP.

The SCP will be a living document during preparation in the coming months. Some questions and issues identified at this time will have been resolved, some will have been identified as non-issues, and new issues may well be identified. Therefore, one should not expect a one-to-one correlation between this document and the SCP when it is issued.

PNL approached this study using a team effort that encompassed the pertinent scientific disciplines. This approach maximized the probability of identifying the major technical questions related to use of deep Hanford basalts for a repository. The study conclusions were not bound by time and budget constraints that must be considered by those responsible for management of the BWIP. As a result, no attempt has been made to optimize or prioritize the issues identified in our study. We do, however, believe we have considered and described within this report the major questions relevant to the BWIP. PNL is convinced the BWIP must resolve the identified questions before it will be possible to show with reasonable assurance that the Hanford Site is adequate for disposal of nuclear waste.

We determined that the scope of the review should closely parallel an NRC review (NUREG-0960) that is organized in seven sections. One of those sections addresses QA/QC, a consideration which is beyond the scope of this work, although in a few key areas, QC capability must be developed and as such is treated as a technical question requiring resolution. With this exception, then, the PNL report is organized in the same manner as the NRC's and includes Chapter 2, which discusses geologic and geophysical aspects of the Hanford site basalt flows. Chapters 3 and 4, respectively, address geohydrologic and geochemical considerations of the Hanford site. The response of a waste package containing nuclear waste to a Hanford site basaltic environment is addressed in Chapter 5. Repository engineering, including mining activities and rock mechanics analyses, is included in Chapter 6. Finally, Chapter 7, discusses performance assessment tools and analyses.

2.0 GEOLOGY/GEOPHYSICS

This chapter is focused on geology and geophysics; however, because of the multidisciplinary nature of the Basalt Waste Isolation Project, there is naturally some overlap with geohydrology, rock mechanics, and climatology. In PNL's opinion, the unresolved technical questions identified in this report have been, for the most part, identified previously in various RHO, NRC, and USGS reports. Therefore, the objective of this writeup is to provide a concise summary of these unresolved technical questions, make an attempt at prioritization, and speculate on the potential significance of these topics relative to the draft DOE siting guidelines (U.S. Department of Energy 1983).

This chapter on geology/geophysics is segmented into four sections: 1) Assessment of Hanford Basalt Relative to Draft DOE siting guidelines, 2) Key Unresolved Technical Questions, 3) Assessment of BWIP Plans to Address These Unresolved Technical Questions, and 4) Summary of Findings.

2.1 ASSESSMENT OF HANFORD BASALT RELATIVE TO DRAFT DOE SITING GUIDELINES

Although this chapter focuses on geology and geophysics, the pertinent siting guidelines (U.S. Department of Energy 1983) are dispersed among several other categories in the August 1983 draft. Therefore, all guidelines considered pertinent to geology and geophysics are summarized in this section. The guidelines are quoted verbatim with the DOE paragraph number given in parentheses following the title. In some instances a guideline will be discussed in more than one chapter of this report. For example, a paragraph from the chapter titled "Geohydrology" (960.4-2-1) is discussed here as well as in Chapter 3. We have included the "favorable" and "potentially adverse" conditions that appear to be characteristic of a site in the Cold Creek syncline in the basalts underlying Hanford. It is imperative that the reader realize that both the interpretation of the BWIP siting conditions and the information used for this report to substantiate conclusions are subject to a significant degree of judgment and must be considered preliminary in nature.

2.1.1 DOE Guidelines - Conditions and Processes Affecting Expected Performance

Geohydrology (960.4-2-1)

Qualifying Conditions. "The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The conditions and characteristics of the geologic setting and the use of reasonably available technology shall permit (1) the requirements set forth in 10CFR60.113 for radionuclide releases from the engineered system and (2) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment to be met."

Favorable Conditions. (3) "Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be characterized and modeled with performance-assessment techniques."

The BWIP site may not be able to take credit for this favorable condition because site characterization to an acceptable spatial resolution for near field-modeling appears essentially impossible using surface geophysics, borehole investigations, or exploratory shaft tests. These studies are of extreme importance, but are not of high enough resolution to diffuse safety and performance assessment questions. In other words, the proximity of flow-top breccia, cooling fans, faults and/or shear zones cannot be determined prior to repository construction. The most viable method for characterizing basalt intraflow features in support of performance-assessment analyses may be some form of multi-directional probing in advance of, and subsequent to subsurface excavation of repository tunnels. However, the hydrological significance of such intraflow features is uncertain at this time and therefore it is still conceivable that the hydrologic criteria for this condition may be met (see Section 3.1).

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

The BWIP site will probably suffer from this potentially adverse condition because of the presence of locally thickened flow-top breccia, zones of potentially high vertical permeability formed by emplacement and cooling of the lava flows, (e.g. margins of individual flows, zones formed by interaction of hot basalt and water, and joints formed by cooling but not sealed by secondary mineralization), faults, and shear zones (U.S.G.S., 7/28/83). Any or all of these features could significantly contribute to the difficulty of characterizing or modeling the site groundwater flow systems.

Rock Characteristics (960.4-2-3)

Qualifying Condition. "The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, groundwater, and engineered components. The conditions and processes of the geologic setting and the use of reasonably available technology shall permit (1) the requirements set forth in 10CFR60.113 for radionuclide releases from the engineered barrier system and (2) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment to be met."

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

No credit should be taken for this favorable condition, since both the working thickness and the lateral extent (distance between intraflow anomalies) of the candidate basalt flows are highly uncertain at this time. The lava flows are likely to extend for great distances beyond the RRL, but the intraflow details are uncertain. It seems unlikely that surface geophysics, borehole studies, or even the exploratory shaft results will reduce these uncertainties to the degree necessary to take credit for the repository design flexibility afforded by the thickness or lateral extent of the host rock formation. This is not to infer, however, that a repository cannot be designed and constructed with the potential limitations and uncertainties in mind. Furthermore, having up to four candidate basalt flows may ultimately prove to be of real benefit relative to the question of repository design and construction flexibility.

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

It has been suggested that basalt may suffer from dehydration, diagenesis, volume reduction, and/or mechanical flushing of materials comprising the fracture fillings in the rock mass (USGS, May 6, 1983) However, documented data upon which to base a conclusion are insufficient at this time. See Chapter 6 for a discussion of thermally-induced fractures.

2.1.2 DOE Guidelines - Potentially Disruptive Processes and Events

Climatic Changes (960.4-2-4)

Qualifying Condition. "The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In projecting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting."

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

It is unlikely that BWIP will be able to claim credit for this favorable condition. The Quaternary Period spans essentially the last three million years and the regional and local climate has changed numerous times, with possibly the most dramatic climate being that associated with alpine and continental glaciation that could affect both recharge and hydraulic conductivity conditions. It is important to note, however, that no evidence exists that glaciers have ever reached the Hanford site itself. The closest approach appears to have been the area between Chelan and Coulee City. The geohydrological significance of such dramatic changes relative to the BWIP project is largely unknown. If a new glacial age occurred, it is likely that the quantities of water available for regional groundwater recharge would be significantly increased. One estimate is 0.5 cm to 3.0 cm of incremental recharge per year under the base of the glacier (Bull, 1980). Meltwaters may have additional effects. However, associated increases in localized discharge would be the likely result as opposed to significant changes in regional hydraulic gradients in the deeper basalt groundwater system.

Another issue that may be raised is that the state of induced compressive stress due to ice sheet loading and ground subsidence, which may significantly induce radial and tangential ground stresses beyond the toe of the glacier. This could result in displacements on pre-existing faults and fractures that may then affect hydraulic conductivities. At this time, these issues are still in the realm of speculation. However, there is some evidence that this mechanism may be responsible for the Great Lakes and other lakes marginal to Laurentide ice sheets. The important point is that these uncertainties will make it difficult for BWIP to take credit for the stability of climate in the Quaternary Period.

Potentially Adverse Conditions. (2) "Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the groundwater flux through the host rock sufficient to significantly increase the transport of radionuclides to the accessible environment."

The BWIP site should not suffer from this potentially adverse condition since glaciation is not likely to be a factor in the next 10,000 years. Furthermore, the significance of being in the proximity of continental glaciation is largely unknown and therefore should not be overstated. For example, it is unlikely that Missoula-type flooding will have any geohydrological impact on the deep BWIP site. If performance assessment analysis (see Chapter 7) carries past the first 10,000 years, this glaciaton question may require more attention.

Erosion. (960.4-2-5)

Qualifying Condition. "The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In projecting the likelihood of potentially disruptive erosional processes, the DOE will consider the climatic, tectonic and geomorphic evidence of rates and patterns of errosion in the geologic setting during the Quaternary Period."

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

The BWIP site can obviously take credit for this favorable condition since the target depths range from 815m to 1055m (RHO-BW-ST-28P-Draft, 1983).

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

The BWIP site will be able to take credit for this favorable condition (Underberg, 1983).

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

The BWIP site should be able to take credit for this favorable condition (Underberg, 1983).

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

This potentially adverse condition should not pertain to the BWIP site (Underberg, 1983).

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

This potentially adverse condition should not pertain to the BWIP site (Underberg, 1983).

Tectonics. (960.4-2-7)

Qualifying Condition. "The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In projecting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, stratigraphic, geophysical and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period."

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

It would appear that deformation rates are exceedingly low and that the primary issue is the geohydrological significance of faults and shear zones as previously discussed. Site characterization for the BWIP Project has not progressed to the extent that credit should be taken for this favorable condition. The stratigraphic, structural, and tectonic complexity of the site is such that a multi-year effort will be required to develop a technically defensible site characterization baseline upon which such a radionuclide transport prediction can be based.

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

Since the proposed BWIP site is located in the Yakima Fold Belt and evidence of active folding, faulting, uplift, and subsidence during the Quaternary Period exists, it might appear that BWIP would suffer from this potentially adverse condition. However, questions remain as to the definition of the geologic setting. It would be premature to conclude that this is a potentially adverse condition for the BWIP site just because folding and faulting occurred in the vicinity of the RRL during the Quaternary Period. The RRL is located in the Cold Creek Syncline, between two anticlinal folds.

Furthermore, although the stratigraphy and structure below the candidate host basalt formations are not well known, current data indicate that gradual subsidence is the controlling process in the Cold Creek Syncline and that the rates of synclinal and anticlinal (fold) deformation appear extremely low. Eleven years of geodetic surveying have resulted in a spatial and temporal strain rate average of 1.0-2.0 mm/yr. Strain rates based on seismic and geologic data are interpreted to be as low as 0.04mm/yr (SCR, 1982). The trilateration survey results were at the limits of the instrument precision, and therefore the deformation rates based on seismic and geologic data are considered to be more reliable. Continued data gathering (e.g. geologic, seismic and geodetic) is the only way to quantify the strain rate further. Undoubtedly, the major problem will be determining the significance of continued, albiet slow, deformation of the basalts, since baseline hydrologic conditions, especially vertical hydraulic conductivity, are not well understood.

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

At this time, data are insufficient to support conclusions regarding this potentially adverse condition. However, major historical earthquakes do not appear to be symptomatic of the region (although as is always the case, the data base is limited to only the last several tens of years). It is probable that BWIP will be required to assume the recurrence of at least a magnitude 6.5 event located at the closest point on the Rattlesnake-Wallula Lineament (RAW). It is questionable whether such a large event is likely for the RAW. It is also questionable whether such an earthquake would have any real significance to a repository in basalt. The important unknown factors are the seismic energy attenuation properties surrounding the proposed repository site, the potential for strike-slip displacement along the RAW that might induce secondary displacements along smaller (undetected) faults intersecting the repository, the potential hydrological changes due to fault displacements, the vibratory response of the backfill materials relative to the host rock, and the effects of seismicity on shaft seals. Currently, there are no good defensible reasons to conclude that historical earthquakes will be a potentially adverse condition for BWIP.

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

The available data point to a lack of correlation between earthquake locations and known tectonic features. No reason exists to indicate that either the frequency of occurrence or the magnitude of earthquakes may increase in the future. This potentially adverse condition does not seem pertinent to BWIP.

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

This should not be a problem for BWIP since the proposed site has no evidence of higher than usual seismic activity (opposite actually true) or larger than normal earthquakes. The only unique seismic conditions associated with the basalts is the presence of swarms of very low magnitude earthquakes. Displacement on existing fracture planes in the dense interior of basalt flows has been postulated to be the source of swarm earthquakes (Rothe, 1979). Similar deformation in weaker zones (e.g., interflows, flowtops) may occur in an aseismic mode. Currently, the resolution of locating hypocenters is too low to confirm the "dense interior" hypothesis. However, to determine the potential significance of microseismic events occurring in the same dense basalt proposed for the repository, it will be necessary to quantify the range of frequencies, vibrational energies, and potential cumulative displacements on the basalt fractures (see Section 2.3 on BWIP plans). This may be particularly important to canister retrievability, given that small, but close, seismic events may result in limited attenuation of energies in the high frequency (i.e., 100 hz) range that may be potentially significant to long tunnels and canister holes. It appears, at this time, that microseismic swarm activity may be construed to be a potentially adverse condition for BWIP. However, there are insufficient data to derive a conclusion.

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

Landslides and large-scale surface-water impoundments are distinct possibilities in the Pasco Basin. However, it seems unlikely that such events could significantly affect a deep repository.

(6) "Potential for tectonic deformations (uplift, subsidence, folding, or faulting) that could adversely affect the regional groundwater flow system."

Slow tectonic deformations are apparently ongoing in the Yakima Fold Belt and elsewhere in the region, but data are insufficient for qualifying and quantifying the potential effect(s) positive or negative, on the regional groundwater flow system. However, tectonic deformations can significantly affect groundwater systems, as witnessed subsequent to the recent Idaho earthquake. Such evidence cannot be extrapolated, however, since faults have been shown many times to be either water flow conduits or water flow barriers. Thus, there is great uncertainty in the area of tectonic deformation and vertical hydraulic conductivity and lateral flow barriers. Because of these uncertainties and the presence of substantial groundwater at the currently proposed BWIP site, it is possible that BWIP will suffer from this potentially adverse condition. Definite conclusions are premature, however.

Human Resources. (960.4-2-8-1)

Qualifying Condition. "The site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including groundwater suitable for human consumption without treatment or crop irrigation, present at or near the site will not be likely to lead to interference activities that would cause the requirements specified in Section 960.4-1 not to be met."

Favorable Condition. "No known natural resources that have or could have in the foreseeable future a value great enough to be considered an extractable resource."

The BWIP site will not likely be able to claim credit for this favorable condition because of the known presence of potentially valuable groundwater resources (although high flouride content may make the water of much less value) and the possible presence of natural gas in the sub-basalt strata.

Potentially Adverse Conditions. (1) "Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or (ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting."

Although natural gas has been found in the Grande Ronde below the RRL, there is considerable uncertainty as to its source. If it is proved to be coming from a structural trap below Cold Creek Syncline, that could conceivably make the site an above-average exploration target. If it is, it is not likely to be of commercial potential. Much uncertainty concerning naturally occurring materials in the Pasco Basin still exists; however, it appears that the BWIP site may suffer from this potentially adverse condition.

(2) "Evidence of significant subsurface mining or extraction for resources within the site if it could affect containment or isolation."

No evidence exists to indicate any subsurface mining within the RRL site.

(3) "Evidence of drilling within the site for any purpose other than repository-site characterization to a depth sufficient to affect containment and isolation."

There is no evidence of anomalous drilling within the RRL site.

(4) "Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources."

Presumably the natural gas resource, if any, and the groundwater resource at the BWIP site are not disproportionately concentrated at the site.

(5) "Potential for foreseeable human activities, such as groundwater withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale

surface-water impoundments, that could adversely change portions of the groundwater flow system important to waste isolation."

There appears to be reasonable potential for several of the aforementioned activities to occur in the future at or near the BWIP site. However, the existing baseline hydrology is still too uncertain to permit prediction of the potential beneficial or adverse changes, if any, due to such activities.

2.1.3 DOE Guidelines - Ease and Cost of Construction, Operation, and Closure

Rock Characteristics. (960.5-2-9)

Qualifying Condition. "The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of the host rock will be suitable to accommodate the underground facility; (2) the repository construction, operation, and closure will not cause undue hazard to personnel; and, (3) the requirements specified in Section 960.5-1(3) will be met."

Favorable Conditions. (1) "A host rock that is suitable for repository construction, operation, and closure, and is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility."

Because of the uncertainties in the working thickness and lateral extent between potential intraflow anomalies, it appears that BWIP will not be able to take credit for this favorable condition.

Potentially Adverse Conditions. (1) "A host rock that is suitable for repository construction, operation, and closure, but is so thin or laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility."

The thickness and lateral extent of the competent positions of the candidate basalt flows are not known. Moreover, acceptable characterization to ensure mining safety and performance assessment predictions may be essentially impossible using surface geophysics, borehole exploration or the exploratory shaft. Therefore, it appears that the BWIP site may exhibit this potentially adverse condition. It should be noted, however, that having up to four candidate basalt flows may ultimately prove to be of real benefit relative to the question of repository design and construction flexibility.

(4) "Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation."

Data on thermally induced fracturing and the hydration and dehydration of mineral components are insufficient to allow firm conclusions concerning this potentially adverse condition. See Chapter 6 for a discussion of thermal stresses.

(5) "Existing faults, shear zones, pressurized brine pockets, dissolution effects or other stratigraphic or structural features that could adversely affect safety because of water inflow or construction problems."

Given the apparent difficulties in characterizing faults, shear zones, brecciated regions, and pillowed zones, it will be critical to develop acceptable methods for multi-directional probing of the wall rock in advance of mining operations (see Section 2.3 on BWIP plans). It should be anticipated that uncontrolled penetration of a high permeability zone with water pressures in the range of 1500 psi might result in catastrophic mechanical flushing of the high permeability materials and subsequent flooding. It appears that the BWIP site may suffer from this potentially adverse condition.

<u>Tectonics</u>. (960.5-2-11)

<u>Qualifying Condition</u>. "The site shall be located in a geologic setting in which the effects of expected tectonic phenomena and igneous activity will not affect repository construction, operation, and closure, such that the requirements specified in Section 960.5-1(3) will be met."

<u>Favorable Condition</u>. "The nature and rates of faulting, if any, within the geologic setting will not result in unacceptable hazards from earthquakes to repository construction, operation, and closure."

One area of concern is the potential impact of seismicity on the retrievability of canisters from long horizontal boreholes. These boreholes presumably will intersect pre-existing fractures. Displacement on these fractures in response to some seismic forcing functions is simply not known. Another area of concern is the potential for undetected faults obscured by the sediments overlying the basalts. Because of uncertainty surrounding these questions, the BWIP site will not likely be able to take credit for this potentially favorable condition. This conclusion may change as more data are collected, however.

Potentially Adverse Conditions. (1) "Evidence of active faulting within the geologic setting."

No evidence of active faulting within the geologic setting has been found. Nevertheless, there is some question as to whether site characterization techniques employed to date would detect the presence of active faults buried beneath the mantle of surficial sediments (USGS, May 6, 1983).

(2) "Historical earthquakes or man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits."

Data upon which to base a conclusion are insufficient, but this is not likely to be a problem for BWIP since historical earthquakes have been relatively small in magnitude and underground mines are usually devoid of the soil amplification factor often characteristic of surface buildings.

(3) "Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity."

There are no indications that this is a potentially adverse condition at the BWIP site since there appears to be little meaningful correlation between seismicity and known structures in the vicinity of RRL.

2.2 UNRESOLVED TECHNICAL QUESTIONS

The unresolved technical questions presented in this section do not represent an exhaustive list, but are the issues considered key at this time. As is always the case in such projects, future investigations may result in modifications, additions, and deletions in this tabulation. The issues presented in this report include: (1) intraflow stratigraphy, (2) mineral stability, (3) sub-basalt stratigraphy and lithology, (4) geological structure and tectonics, (5) near- and far-field seismicity, (6) glaciation, and (7) natural resources and the presence of methane.

2.2.1 Intraflow Stratigraphy

One unresolved technical question is the thickness and lateral extent of the candidate basalt flows. This particular question has gained significant attention since drilling RRL2. The brecciated flow-top for the Umtanum was found to be 148 ft, which nominally represents 64% of the total flow thickness of 197 to 231 ft. The conclusion was that localized thickening or thinning in the flow-top and related fanning joints occur in the reference repository location. Several stratigraphic features that may be encountered during the construction of the miles of tunnels for a repository include: "(1) locally thickened flow-top breccia (i.e., the partially welded broken rock formed in the upper part of a flow by explosion or flowage of a partly congealed basalt flow), (2) zones of potentially high vertical permeability formed by emplacement and cooling of the lava flows (e.g., margins of individual flows, zones formed by interaction of hot basalt and water, and joints formed by cooling but not sealed by secondary mineralization), and (3) faults, particularly the strike-slip variety and shear zones" (USGS, 7/28/83). Although Figure 3-29 of the SCR (1982) is likely an extreme example, it is reproduced here to lend perspective on this intraflow stratigraphy question (Figure 2.1). Examples of intraflow structural and stratigraphic discontinuities in the flow are depicted in this photograph of the Emerson Nipple outcrop.

It is difficult to predict the probability of encountering one or more of these potentially pressurized (1500 psi), water-bearing zones at depth; and the regional paleogeology would support the assertion that the probabilities may vary significantly from flow to flow. Based upon a limited analysis of basalt outcrops, the USGS staff suggest that the chance of encountering such intraflow anomalies might be on the order of 5 to 25% for the Umtanum flow and somewhat less for the Cohasset (USGS, 7/28/83). Regardless of the range of

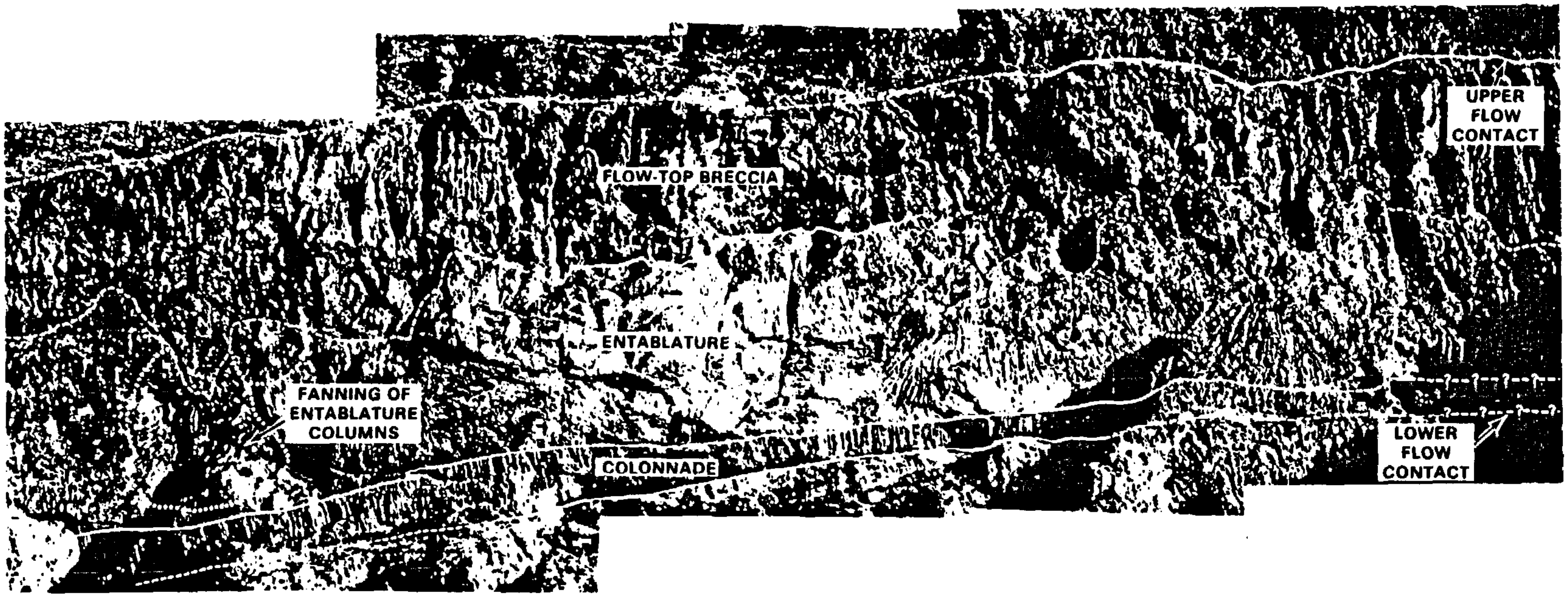


FIGURE 2.1. Small-Scale Structural and Stratigraphic Discontinuities in the Umtanum, Flow at the Emerson Nipple Section. (Source: SCR Figure 3-29, page 2.5-30).

estimates, it seems clear that there is a reasonable possibility of encountering intraflow discontinuities during repository construction. Detailed contingency plans should be established to deal with the possibility of mining into a high pressure, high permeability water-bearing zone (see Section 2.3 on BWIP plans).

The potential consequences associated with encountering an intraflow anomaly are themselves based upon speculation. One possible scenario is that the combination of high water pressures and weak, unconsolidated materials could result in significant flooding. Therefore, it is possible that such features may significantly reduce the flexibility in designing and/or constructing the repository. At the very least, contingency plans should be developed to deal with such discontinuities (e.g., detection, avoidance, control, and remedial action plans and techniques) (see Section 2.3 on BWIP plans).

Even if these anomalous zones are not explicitly encountered during construction, their proximity to the repository, coupled with the potential thermal/mechanical effects induced by excavation and elevated temperature waste emplacement (disturbed rock zone), might result in an interconnection being developed. Another potential problem is that the unpredictability and nonuniformity of the intraflow stratigraphy might make near-field performance assessment characterization and subsequent predictive modeling more difficult and uncertain.

A fundamental question is what, if anything, can be done in the next few years to improve the characterization of the deep intraflow stratigraphy. The things that can and are being done will be discussed in the next section of this report. However, it is important to note that all parties involved (e.g., BWIP, USGS, PNL, and NRC) apparently agree, in principle, that adequate spatial characterization of the intraflow stratigraphy of a deep candidate basalt flow is not amenable to remote techniques like surface geophysics, a high-density borehole program, or even exploratory shaft experimentation.

The apparent conclusion is that the only way to handle potential intraflow discontinuities is via in situ, multidirectional probing (e.g., small-diameter drill-holes, radar, seismic) into the rock during construction. Additional probing, especially above and below the tunnels, may be required for near-field performance assessment characterization and modeling.

2.2.2 Mineral Stability

Uncertainty remains about the effects of temperature on the chemical and physical stability of zeolite and smectite minerals thought to be the main infilling materials for fractures and cooling joints. The primary concern appears to be the scenario of dehydration, diagenesis, volume reduction, and mechanical flushing. However, due to the poucity of data available during this review, no conclusions are possible concerning the realism of this scenario or the potential significance on performance assessment.

2.2.3 Stratigraphy and Lithology Below the Repository

Originally it was assumed that the thickness of the entire basalt sequence in the Pasco Basin was relatively uniform and that basalt extended for many thousands of feet below the proposed repository depth at the RRL. Indeed, this may still, for all practical purposes, be the case. However, additional investigations like magnetotelluric surveys (Halpin, 1982) have revealed that significant zones of relatively thin basalt may exist in the Pasco Basin, and therefore the thickness between the repository and the sub-basalt stratigraphy may be substantially less than originally thought. There are other reasons for needing to know the stratigraphy and lithology below the repository. For example, understanding of the ambient hydrochemistry may require knowledge of the mineralogy and hydrochemistry of the thick sequence of sediments below the basalts. In addition, the presence of methane in the Grande Ronde water samples in Cold Creek Syncline, plus the intensive oil company exploration in the vicinity of the Hanford site, may intensify the need for more information about the deeper stratigraphy and lithology. Finally, geophysical data (e.g., magnetotelluric, magnetic, gravity, seismic reflection and seismic refraction) appear to be the primary tools for the development of a tectonic model(s). It will remain to be seen if the uncertainties inherent in the interpretation of these data sets can be maintained within acceptable limits without more downhole calibration.

2.2.4 Geological Structure and Tectonics

This section includes a description of example structural features, a discussion of the potential significance of the structural/tectonics issues, and a presentation of the perceived difficulties in characterizing structure and developing a tectonic model(s) for the BWIP site.

In this report, structure is loosely defined to be any deviations from a relatively flat system. The bumps and valleys can have many causes, and deformation may or may not be currently ongoing. An important point is that the surface topography may not be representative of subsurface structure. To lend perspective to this unresolved technical question, two magnetotelluric crossections are presented in Figures 2.2 and 2.3 (Halpin, 1982). These are two crossections of the original data interpretation. Significant uncertainties are associated with the interpretation of these data; and these crossections are shown simply to lend perspective.

The reader is cautioned not to derive premature conclusions from these interpreted crossections. For example, the block faulting depicted in the figures is a subject of considerable controversy and may or may not actually exist. Consequently, no locations are provided in the figures, though the crossections are essentially contained on the Hanford site. The various layers depicted in the crossections generally refer to: (1) the relatively conductive sediments plus the upper brecciated basalt flowtop overlying the uppermost basalt layer; (2) the relatively resistive sequence of basalts; (3) the relatively conductive layer below the basalts, inferred to be sedimentary material; and (4) the lowest resistive layer, generally inferred to be a crystalline basement rock.

There are tremendous difficulties and uncertainties associated with characterizing the deep stratigraphy and structure as depicted in the figures and subsequently correlating this with surface or near-surface features. The primary methods for characterization are: 1) geophysical analyses (e.g., magnetotelluric, gravity, magnetic, seismic reflection, and seismic refraction) and 2) geological extrapolations from available outcrops. For example, the magnetotelluric data shown in the figures may have a resolution of 10 to 20% (Price, 9/18/83). However, this assumption has not and apparently cannot be

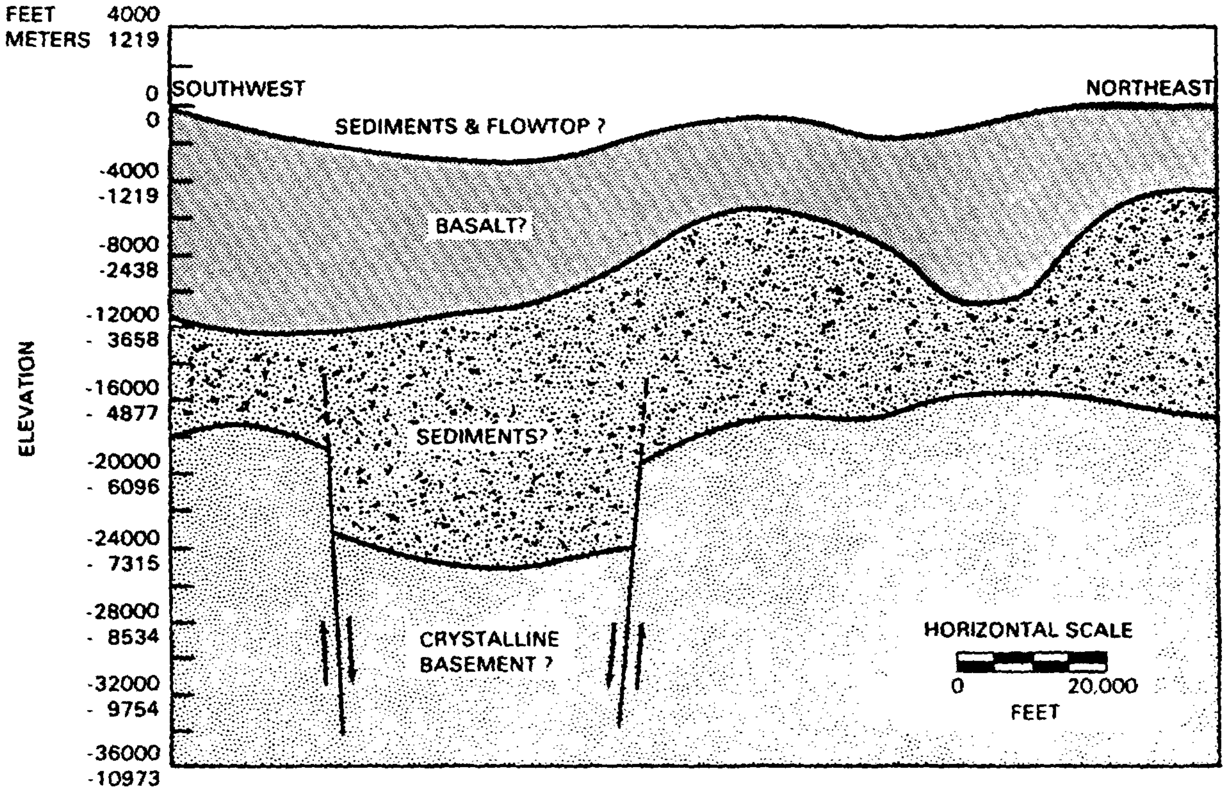


FIGURE 2.2. S-W/N-E Stratigraphic Crossection as Inferred from Initial Interpretation of Magnetotelluric Survey Data (after Halpin, 1982)

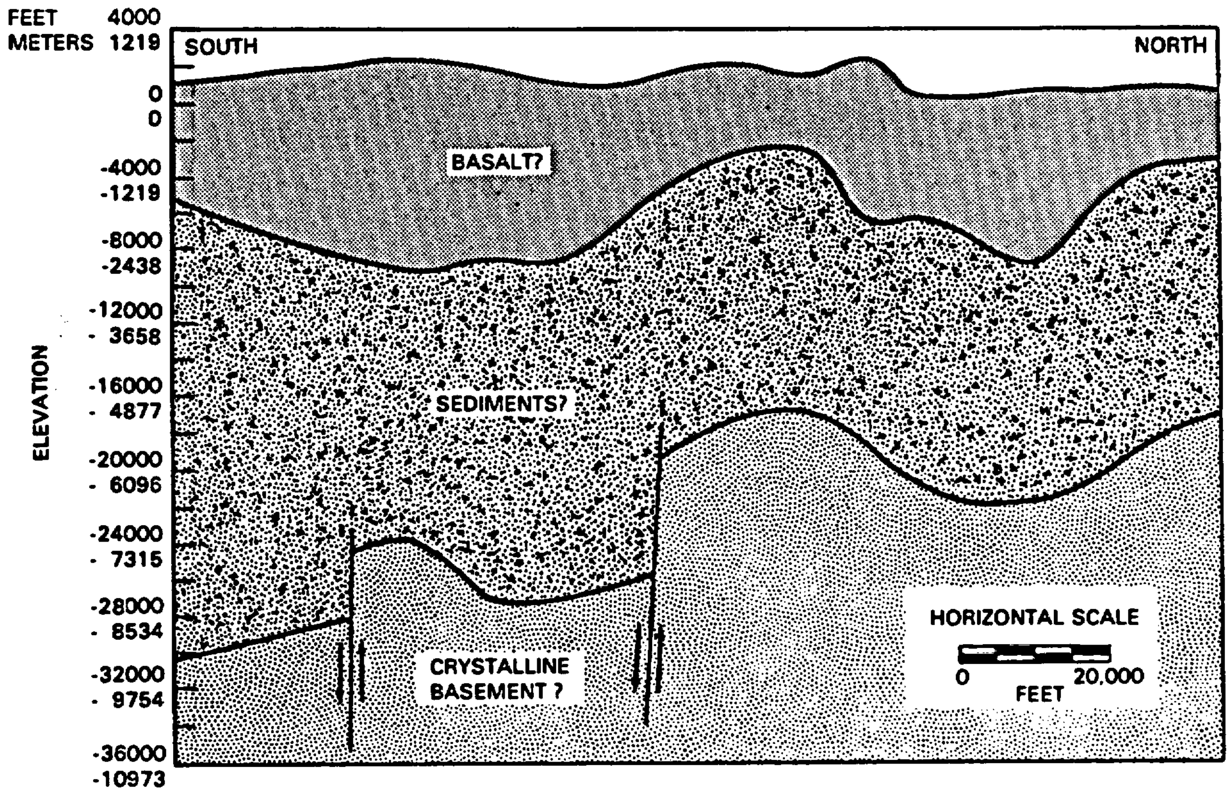


FIGURE 2.3. N/S Stratigraphic Crossection as Inferred from Initial Interpretation of Magnetotellingic Survey Data (after Halpin, 1982).

validated for basalt at this time because geophysical techniques have not been calibrated or tested for sensitivity at a basalt site. Furthermore, the magnetotelluric interpretation presented in the figures was based upon the assumption of lateral continuity of the electric resistance of the inferred sediments below the basalt. An alternative assumption is to fix the continuous lateral resistivity of the basalts and allow the value of the sediments to float in a constrained manner. This alternative interpretation (which was in draft format and not available for this report) appears to reduce significantly the vertical relief at the base of the basalt sequence (basalt/sediment interface), typically smoothing across extremely thick or thin areas of the basalt. More dramatic structure is thus transferred to the interface between the sediment/crystalline basement.

The difficulty of employing geophysical techniques at a basalt (and for that matter other non-sedimentary geological formations) site must not be underestimated. Near surface high velocity layers, fluctuating magnetic alignments in the basalts, high energy attenuation characteristics, and the lack of deep borehole control are just examples of the difficulties facing the BWIP geophysics staff. The point to be made is that there are currently large uncertainties associated with the geophysical data sets.

Given the major uncertainties in the geophysical data sets, coupled with the unavailability of sub-basalt borehole information, and the apparently significant ambiguities associated with extrapolating geological information from the margins of the Columbia Plateau (Price, 10/14/83), it appears that one of the major unresolved technical questions is the conceptual model(s) of the stratigraphy and structure, correlation of surface and subsurface features, and identification of the tectonic (dynamic) nature of the basalts and deeper formations. Development of such a conceptual model(s) will require a major, multi-year effort. Furthermore, if the uncertainties in the geophysical data cannot be reduced to acceptable and technically defensible limits, future BWIP investigations may require a deep sub-basalt borehole program.

In the categories of structure and tectonics, some specific unresolved issues include the assessment of currently identified geological and/or geophysical features within or near the RRL (e.g., N-85, Nancy Linear, the

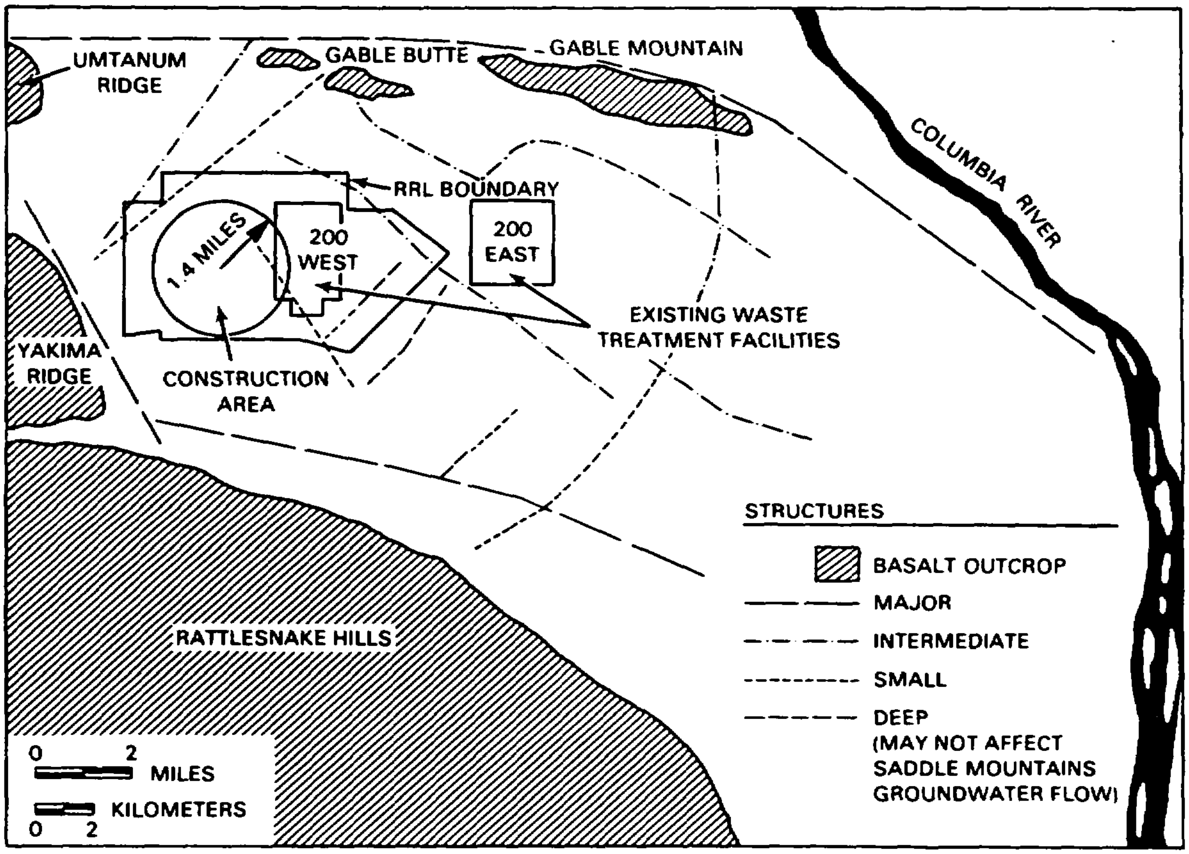
Hydrologic Barrier anomaly, the CLEW-RAW-SNIVELY feature and especially any structures splaying into the RRL; the eastward extension of the Yakima Ridge; North-South Columbia River feature; the PUG zone of 30 aeromagnetic anomalies; and Umtanum Ridge) (Price, 8/18/83). One possible rendition of at least some of these features is shown in Figure 2.4. Another question is the degree of mechanical coupling or decoupling between the basalts and the crystalline basement (Caggiano, 1983). The potential for strike-slip faults not directly associated with folds has been identified as an important question by the USGS (USGS, May 6, 1983). Finally, the apparently anomalous east-west trend of the Yakima Fold Belt, which contains the RRL, appears to be an important unresolved question (Caggiano and Duncan, 1983).

The BWIP staff provided the following description of the geological or geophysical features thought to require resolution in the next several years. It is important to recognize that these identified geological and geophysical anomalies are not necessarily structures. The geological or geophysical anomalies described below are considered to be the unresolved features of primary importance at this time (Price, 8/18/83). This should not be construed to mean that other currently identified anomalies or new ones found in the future are unimportant.

"The feature N-85 is an aeromagnetic and gravity anomaly located within the RRL. Based upon the present data set, N-85 cannot be adequately addressed. Additional geophysical data may or may not help. Even an elaborate drilling program may never reveal its source since the geophysical signature(s) is relatively weak."

"The Yakima Barricade Area contains both the Nancy linear and the Hydrologic Barrier anomaly. This area is important because of the anomalous hydrologic heads that have been observed and because many of the aeromagnetic anomalies trend into the RRL."

"The northern extension of the RAW past Snively Basin, the Hanson Creek anomaly and the Hog Ranch/N-S gravity gradient are all features that remain unresolved and warrant investigation. Of particular importance is the potential for structures splaying off the aforementioned features into the RRL."



KNOWN AND INFERRED STRUCTURES, EXISTING FACILITIES, AND CONSTRUCTION AREA

FIGURE 2.4. Working Draft Geophysical Feature Map (ST-14)

"The eastward extension of Yakima Ridge has been traced by gravity, aeromagnetics, and ground magnetics. Several crosscutting anomalies have been detected (primarily NW trending). Two N-W trending, aeromagnetic features are also located within the RRL. These anomalies, D-218 and N512, have weak aeromagnetic signatures, but because N-512 is also detected via bouguer gravity and both features are located near the proposed site for the exploratory shaft, their identity should be resolved."

"The N-S straight section of the Columbia River has been observed on several geophysical data sets. The simple fact that such a long straight section of the river exists probably warrants further investigation. The N-232 aeromagnetic feature and a parallel trending N-E gravity anomaly both trend into the RRL and therefore require further investigation."

"The PUG is an informal name for over 30 aeromagnetic anomalies that are arranged in a peculiar geometric pattern. A N-W trending series of anomalies at the northern boundary of the RRL, the PUG cross-cuts the Cold Creek Syncline and therefore warrants further resolution."

"The last near-field feature warranting investigation currently is the Umtanum Ridge. This area has been selected by the BWIP staff primarily because it has potential to be a good area to investigate the relationship of the basement structure to those structures observed at the ground surface. As mentioned earlier, the lack of such subsurface/surface structural correlation information is the main obstruction in the development of a tectonic model(s)." (Price, 8/18/83)

The geophysical anomalies described above are all within or very near the RRL. Greater understanding is also needed of the more regional statigraphy, structure, and tectonic setting to a better understand the near-field features.

Another example of a specific unresolved technical question is the assessment of the ages, rock types and structures within the total region and especially below the basalt in the Pasco Basin. Such information is essential in assessing the tectonic stability of any site. Unfortunately, it appears difficult to reduce the ambiguity associated with extrapolation of geological information from the plateau margins. These difficulties and uncertainties associated with geophysical techniques have already been discussed.

A third unresolved problem is the degree of mechanical coupling or decoupling between the basalts and the presumably crystalline basement. In other words, what role does the thick sequence of sediments inferred to exist between the basalt and the crystalline basement play in controlling the tectonics of the area? This appears to be an important aspect of the current controversy surrounding the thin versus thick skin conceptual models for the Columbia Plateau. Mechanically weak sediments may behave as an inelastic, aseismic body, thus effectively decoupling the relatively rigid basalts from the rigid and potentially block-faulted basement rocks. Although BWIP staff have conducted workshops to address these questions, no conclusion or even favored hypothesis is currently available.

A fourth specific technical question is the potential for strike-slip faults not directly associated with folds. The USGS staff point out that on the Columbia Plateau, linear zones of steeply dipping faults and shear zones clearly transect folds. "The problem is that these features may have little or no surface expression and may be essentially impossible to detect with geophysical methods or a borehole program. In view of their length and Cenozoic age, they should be considered in the site characterization because of their potential hydrologic significance and in evaluating ground motion related to seismic activity. Detection of such zones will likely require multi-directional probing in advance of mining operations." (USGS/BWIP Tables of Dispositions and Responses).

The fifth question is the apparently anomalous nature of the Yakima Fold Belt that contains the RRL. " By way of clarification, the Yakima Fold Belt issue stems from the fact that the similarity of structural trends in plateau and older rocks suggests a general relationship of plateau structures to structures in areas marginal to the plateau. The similarity of trends and style of folding and faulting between rocks along the margins of the plateau and rocks beyond the plateau margin suggests that deformation of the plateau has been similar to that in the region. Such regional deformation probably affected rocks in the central Columbia Plateau also and may reflect the movement of lithospheric plates or crustal blocks. An exception is the east-west trend of folds and faults in the Yakima Fold Belt, a trend not seen in major structures surrounding the plateau." (Caggiano, 1983)

One question that should be asked is what is the real significance of the unresolved structural and tectonic questions? Furthermore, to what degree must the questions be ultimately resolved to ensure that the site can be licensed? It seems clear that given the complexity of the Hanford basalt, these technical questions will have to be resolved in an iterative fashion between DOE and NRC.

The aforementioned unresolved technical questions in the areas of structure and tectonics could potentially have significance in the following areas: (1) interpreting seismic information and developing a model(s) upon which to base predictions of future seismic activity, (2) developing a conceptual groundwater model(s) which includes some understanding of the relationship between structures (e.g. anticlines, synclines, faults) and hydraulic conductivities and potentials, (3) identifying the existence of structural or stratigraphic traps combined with source sediments to address the issue of natural gas from both the resouce potential and mine safety perspectives, (4) characterizing and predicting strain (deformation) rates, (5) understanding current in situ stress conditions and identifying alternative sites, if any, should stress/strain conditions at the RRL prove unacceptable, and (6) defining any other constraints on the repository design and operation that may be caused by structural or tectonic factors.

2.2.5 Near and Far-field Seismicity

Near-field seismicity generally refers to micro-earthquake swarms in the Pasco Basin. Displacement on fractures and joints in the "dense" interior of various basalt flows has been postulated as the source of the swarm earthquakes (Rothe, 1978). The hypothesis is that the dense interiors are significantly stronger, mechanically, and therefore support the buildup of stresses to levels that result in small but numerous earthquakes as the stresses are relieved on pre-existing fracture planes. Conversely, the weaker interbed sedimentary zones and brecciated basalt zones tend to deform (strain) aseismically. The depth of micro-earthquake swarms may be correlated with the dense flow interiors; however, current data on event locations is not of sufficient spatial resolution to permit final conclusions to be derived. If these earthquake swarms are occurring in the same basalt flow interiors that are being proposed to host the repository, then it is important to consider this near-field seismicity relative to performance assessment. This may especially be true during the operational and canister retrieval phases of the repository. Estimates should be made for the range of frequencies, energies, and cumulative displacements on joints and fractures potentially intersecting tunnels. Furthermore, the concept alternative considering 200 foot-long horizontal canister emplacement holes are especially important. Small, but close seismic events may also result in high-frequency (e.g., 100 hz) vibrations that could be of importance given the lack of attenuation due to short distances and the size of the underground workings (see Section 2.3 on BWIP plans).

With respect to large earthquakes, the greatest uncertainties appear to be in identifying energy attenuation characteristics between potential structures like the RAW and the proposed location for the RRL, and identifying the small velocity structure in the vicinity of the RRL. Based on the results of other projects like WPPS and Skagit/Hanford, it may be necessary for BWIP to accept an earthquake as large as magnitude 6.5. However, the capability of the pertinent structure to generate this large an earthquake is still very uncertain and subject of some controversy. Because it is controversial issue, it is probably easier for BWIP to just accept the proposed magnitude unless repository design problems result. The connection between the earthquake and potential consequences is the major unresolved technical question. For example, what impact might an earthquake have on a repository prior to backfilling (e.g., strike-slip displacement along secondary faults potentially intersecting the repository, seismically-induced changes in the hydraulic conductivities or gradients, shear or dilational displacement on fractures and cooling joints intersecting tunnels and boreholes). Differential vibratory response between the host rock and the filling/sealing materials may be a source of concern, subsequent to backfilling and sealing the access shafts. Seal failure should be considered and analyzed for potential performance assessment impacts.

2.2.6 Glaciation

No evidence is available to indicate that the Pasco Basin has ever been overlain by glacial ice. Furthermore, it seems highly unlikely that continental glaciation will play any role in the first 10,000 year increment pertinent to the BWIP project (Bull, 1980). However, because the DOE Siting Guidelines refer to the assessment of climatic changes during the Quaternary Period, and because continental glaciation (Okanogan Lobe) advanced at least 30 miles across the Waterville Plateau (approximately where Chelan and Coulee City are located) (McKee, 1972); and because the Pasco Basin has been exposed to several large post-glacial floods, it seems prudent to consider the unresolved technical questions associated with glaciation.

Two issues of potential concern are: 1) glacial-induced changes in the regional groundwater recharge conditions and 2) stress-induced changes in hydraulic conductivities. A distinct possibility exists that substantially greater amounts of water will be available for recharge in the future. (Bull, 1980). However, it seems that the likely consequence will be the creation of numerous surface streams as opposed to any significant changes in the relative hydraulic potentials for the regional groundwater system. The hydrology group should determine whether or not the potential for increased recharge is a significant unresolved question.

Stress-induced change in hydraulic conductivities should also be considered, especially for pre-existing zones of weakness (e.g., fracture zones, faults). Stresses are greatest just beyond the edge of the ice sheet. The radial and tangential stresses beyond the toe of a continental ice lobes are apparently large enough to induce fracturing (Brotchie and Silvester, 1969). "Fracturing, thus caused, may be responsible for the initiation of the Great Lakes and other lakes marginal to the Laurentide ice sheet. Some of the lakes are radial to the ice sheet, and others are tangential." (Bull, 1980). "Faults along the coast of Maine, probably initiated by ice-sheet margin stresses, are still active due to isostatic rebound" (Rand and Gerber, 1978). Wheather or not the groundwater system pertinent to the BWIP site might be affected by glacial-induced effects remains totally uncertain.

2.2.7 Natural Resources

The apparent vertical undulations in the basalt/sediment interface (i.e., zones of thin basalt shown on magnetotelluric surveys), the possibility of stratigraphic or structural traps at the base of the basalt, the discovery of 60% methane saturated waters in the Grande Ronde formation in the Cold Creek Syncline, and the amount of natural gas exploration in the immediate vicinity of the Hanford site lead one to speculate about the possibility of natural gas below the RRL as a potentially valuable resource. If so, methane and groundwater might comprise the list of primary resources pertinent to the BWIP site.

Another factor to consider is mine safety, especially during the canister retrievable period when certain rooms and tunnels might be closed off from large volume air circulation. If the methane is only dissolved in the groundwater (i.e., no two-phase flow), then the amount of methane to be introduced into a room should be controlled primarily by the rate of water inflow and any diffusion/degassing activity in the connecting fractures. Contingency plans and designs should be made in the event that methane in unventilated boreholes and rooms should ultimately pose any problems.

Another consideration is the source(s) of the gas. If the source is primarily biological production within the Grande Ronde formation itself, then an effective upper limit to the amount of methane available may exist. In other words, the source may be rapidly played out as was possibly the case for the old gas fields on Rattlesnake Mountain. If however, the source is thermo-catalytic conversion and/or biological activity at deeper horizons, then the gas problem, if any, may last for a substantial period of time. No answers are available at this time. However, the alledged existence of several thousands of feet of presumably hydrocarbon-containing sediments below the basalts is justification for making natural gas an unresolved technical question.

2.3 ASSESSMENT OF BWIP PLANS TO ADDRESS TECHNICAL QUESTIONS

The most general assessment that can be made of BWIP plans is that this is a classic example of a very technically competent and hardworking staff faced with the difficult and challenging assignment of developing a conceptual model(s) for a complex geological and hydrological area.

2.3.1 Intraflow Stratigraphy

This question involves the thickness and lateral extent of the dense interior (intraflow structure) of any candidate basalt flow. The major concern is the unpredictable nature of : 1) locally thickened flow-top breccia, 2) zones of potentially high vertical permeability formed by emplacement and cooling of the lava flows (e.g., flow margins, canyon fills, cooling joints), and 3) faults and shear zones. Several parties concerned (e.g., USGS, PNL, and NRC) apparently agree that adequate spatial characterization of the intraflow stratigraphy of a deep candidate basalt flow cannot be determined by surface geophysics, borehole drilling, or even during the exploratory shaft phase of the project. These are all very important studies, but possibly the only way to handle this potential mine safety and design flexibility problem adequately will be underground multidirectional probing into the rock during construction. Subsequent probing, especially above and below the tunnels, will be necessary for near-field performance assessment characterization and modeling.

The response provided by the BWIP staff to this unresolved technical question is as follows: "BWIP is addressing the problem of detecting structural and stratigraphic zones which may be significant to the safety and performance assessment of a repository by developing anomaly detection instrumentation for use underground. These studies are being carried out, along with other instrument development studies, by the Engineering Development Department. Geoscience staff members are serving as technical liaisons on the anomaly detection studies." (Price, 10/14/83)

Underground anomaly detection schemes are apparently being addressed by Lawrence Berkeley Laboratories and a draft report is in review by BWIP staff. Conclusions from this study are that in situ seismic and radar exploration methods, along with pilot drillholes, are likely to provide the most significant data for detection of discontinuities which might be encountered underground. Since discontinuity detection in basalt is essentially a new technology, Woodward-Clyde Consultants have been contracted to develop test plans for anomaly detection instrument development and testing. This study will be followed by design, development, and testing of methods and instruments identified in previous studies. The developed techniques will presumably be used for probing in all directions from the underground opening thus covering the performance assessment characterization issue.

"In addition, analog studies are also being conducted to provide data on tectonic and primary intraflow structures from areas where the basalt flows are exposed. These data will aid in assessing the type of structures and the likelihood of their presence in the RRL." (Price, 10/14/83)

It appears that the BWIP staff have adequately recognized the complexity of the intraflow stratigraphy question and are conducting studies in the two most promising areas, namely instrumentation for underground multidirectional probing and analog studies at available outcrops. It must be emphasized however, that because of the lack of experience in applying anomaly detection methods to basalt, significant uncertainty exists as to whether or not the proposed probing methods will work adequately. Underground tests are required. Furthermore, some instrument development and improved in-field processing techniques will be required. Since the Lawrence Berkeley Laboratory report was still in draft form and not available for PNL review, this report does not reflect its contents. Therefore, the specific status of this unresolved technical issue is still somewhat unclear.

2.3.2 Mineral Stability

This question involves the uncertainty concerning the effects of temperature on the chemical and physical stability of zeolites and smectite minerals thought to be the primary infilling materials for fractures and cooling joints. The concern is that thermal degradation, combined with high differential water pressures around the mine, might result in mechanical flushing of the secondary minerals and subsequent changes in hydraulic conductivity.

The geology/geophysics group was unable to provide any reference materials or investigation plans concerning this question. From discussion with BWIP, it appears that their position is as follows: conclusions cannot be drawn at this time about the potential for temperature induced mineral changes, subsequent increases in fracture permeability, radionuclide retardation properties, or mechanical stability of the fracture filling materials; in any case, the volume of rock that will be exposed to elevated temperatures is so small that it is unlikely that dehydration scenarios are of great importance in overall repository performance. (Price, 10/14/83). PNL's opinion is that this conclusion is premature considering the poucity of information. This remains an unresolved technical question until further data are provided for review.

2.3.3 Stratigraphy and Lithology Below the Repository

This unresolved technical question is tied closely to structure and tectonics and therefore the discussion is presented below.

2.3.4 Geological Structure and Tectonics

Given the aforementioned uncertainties in the geophysical data sets (e.g., magnetotelluric, gravity, magnetic, seismic reflection and refraction), the unavailability of deep borehole information, and the apparent inability to extrapolate geological information from the margins of the Columbia Plateau, it appears that one of the unresolved technical questions is the development of a conceptual model of the local and regional structure, correlation of surface and subsurface features, and the tectonic nature of the basalts and deeper formations.

The BWIP staff have indicated the following plans relative to the uncertainties in sub-basalt stratigraphy, structure, and tectonics: "1) Armold Orange, Emeralds Exploration, is and will continue to work closely with the BWIP staff to examine the quality of the magnetotelluric data. A close look at data quality and interpretive limitations of BWIP's data set, supported by resmoothing and reinversion of some of the data, are part of this effort. An assessment of additional magnetotelluric data needs is being made and may include a non-exclusive survey and several Hanford site stations, 2) a long off-set refraction survey will be performed by the U.S. Geological Survey under an interagency agreement with the Department of Energy. This will provide subsurface information based on different physical parameters for comparison with the crustal structure interpreted from magnetotelluric data,
3) information from boreholes through the basalt (i.e., Shell Rosa Gap, Shell

Whiskey Dick, and Shell-ARCO Saddle Mountains Wells) will be used for MT interpretations as it becomes publicly available, 4) additional regional gravity data are being obtained through the State of Washington and the USGS. These data will be used in the ongoing MT interpretation, additional seismic parameter data (e.g., sonic logs, vertical seismic profiling) will be obtained to provide calibration of exploration seismic data." (Price, 10/14/83).

In general, BWIP argues that extrapolation of geological information from the basalt plateau margins (regardless of the ambiguity), combined with multiple remote sensing techniques (e.g., magnetotillurić, magnetic gravity, seismic refraction and reflection, earthquake surveillance and geophysical sensitivity studies) will likely be sufficient to proceed with structural/tectonic model development. Based upon the results of these analyses, a recommendation will be made on the need for deep sub-basalt boreholes in the Pasco Basin. This appears to be a lotical and responsible approach to a very difficult geological/geophysical problem.

The forgoing BWIP plans have been reviewed in consideration of some specific unresolved issues such as: 1) assessment of currently identified geological and/or geophysical features within or near the RRL, 2) identification of the ages, rock types, and structures beneath the basalt, 3) the degree of mechanical coupling or decoupling between the basalts and the crystalline basement, 4) the potential for strike slip faults not directly associated with folds, and 5) the apparently anomalous east-west trend of the Yakima Fold Belt which houses the RRL.

With respect to the investigation of observed geophysical features (which may or may not represent real structures), the BWIP staff have proposed the following approach: "1) integrate all existing geophysical and geological data pertinent to the specific anomaly and identify additional data needs, if required, 2) design investigation around location, trend, hydrologic, and geologic implication of the feature, 3) complete studies such as additional ground surveys, modeling, drilling, and data reprocessing, 4) reevaluate all pertinent data for interpretations, 5) iterate the process as needed, and 6) use consultants to aid in interpretation and evaluation of significance of individual anomalies" (Price, 10/14/83).

BWIP's approach to identification of the ages, rock types, and structures beneath the basalt has been previously discussed and basically involves magnetotelluric investigations, extrapolation of geological information from the plateau margins, and monitoring of deep drilling by the oil companies as the information becomes publicly available.

With respect to characterization of the degree of mechanical coupling or decoupling between the basalts and the crystalline basement, there appears to be no consolidated, focused plan of attack at this time. In general, the same can be said for identifying the potential for strike slip faults not directly associated with folds. The USGS position is that such features are extremely important and cannot be detected from the surface using geophysical techniques or boreholes. Thus, the only recourse is to use probing techniques in advance of mining and subsequent probing for performance assessment analyses and predictions activities. The BWIP staff have responded with the following position. "Horizontal drilling in advance of mining is planned both for the ES and during repository development. The BWIP is currently attempting to predict the occurrence and properties of such zones with the aid of analog studies at synclinal exposures. Methods are also being developed for remote sensing (geophysical methods) in front of the mining face and out from the tunnel during construction of the ES and the repository." (Price, 10/14/83).

With respect to the apparently anomalous east-west trend of the Yakima Fold Belt which houses the RRL, BWIP staff provided the following observations and working hypotheses. "The explanation of the Yakima Fold Belt structural trends is important to the development of a viable tectonic model. Two important aspects are the relationship of the surface structure to the basement structure and the timing of deformation in the Yakima Fold Belt and surrounding area. Studies addressing deep structure, structures trending into the Columbia Plateau, and the timing of deformation in and around the Pasco Basin are ongoing. They are being integrated into a deformation model of the area. More recent field data from the area surrounding the plateau indicate that there is evidence for north-south compression." (Price, 10/14/83)

"Some potential explanations (working hypotheses) include: 1) Yakima fold orientations are related to sub-basalt structure in the central plateau and, in contrast to plateau margins, this structure is east-west. In view of the rotated crustal blocks west of the plateau (suspect terrains), this is possible as a manifestation of east-west structures in such a suspect terrain beneath the central plateau, 2) Yakima folds formed at a different time than northwest- and northeast-trending structures beyond the plateau margins and under a different stress regime, 3) under north-south compression and with an anisotropically layered thick basalt in the central plateau, surface structures in shallow basalts are detached from those beneath along a decollement of unknown depth or dimensions, and 4) northwest- and northeast-trending structures are present in older rocks beyond the plateau and were reactivated under north-south compression. In contrast, such structures were not present in the basalt and so it deformed differently while older rocks continued to be strained along weak zones." (Price, 10/14/83). In PNL's opinion, BWIP staff are doing all that can be reasonably expected in investigating these unresolved technical questions in geological structure and tectonics.

2.3.5 Near- and Far-Field Seismicity

Near-field seismicity refers to the micro-earthquake swarms that may occur in the dense basalts proposed for the repository. The main unresolved technical question is the potential impact of such seismic activity, or more specifically the small stress drops and displacements giving rise to the activity. This is the same unresolved question pertinent to far-field, larger earthquakes. The BWIP Seismic Test Plan appears to outline an excellent program for characterizing the location, size, and frequency of large and small earthquakes in the pertinent areas. It also outlines steps for characterizing the appropriate attenuation properties and small scale velocity structure. This plan in combination with the Seismic Design Task Force seems to embody a good sound approach to the issue of seismicity. The only limitation appears to be in the area of estimating the range of frequencies, vibrational energies, and potential cumulative displacements on joints, fractures, and/or splayed faults potentially intersecting the repository. This may be particularly important to canister retrievability, given that small, but close, seismic events may result in high frequencies (i.e., 100 hz) that could be important for an operating underground repository. All of these estimates require data collection and analysis as outlined in the Seismic Surveillance Test Plan.

The BWIP staff acknowledge the potential effect on retrievability and indicate the following course of action will be taken. "Specific steps for seismic data analysis have not been determined since the analysis of high resolution data from the borehole network requires state of the art interpretive methods which are being developed by Rockwell personnel with input from consultants and review by the NRC and their consultants. Standard interpretive methods will be used and, based on results and BWIP needs, additional methods will be developed. A Seismic Design Task Force, made up of members of Site, Project Integration and Performance Assessment, Engineering Development and Engineering Design Departments, provides the interface between seismology and design." (Price, 10/14/83)

2.3.6 Glaciation

BWIP staff have no plans for addressing glaciation at this time. This is primarily because the current EPA and NRC positions seem to focus on the first 10,000 year period following repository closure. As long as this remains the EPA and NRC position, glaciation is an academic issue. However, BWIP may have to revisit the glaciation question sometime in the future (see Chapter 7). The two potential areas of concern are the effect of continental glaciation on regional recharge, discharge, and hydraulic gradients and stress-induced changes in hydraulic conductivities due to shear and/or dilation displacements on pre-existing or new zones of weakness beyond the toe of the heavy ice mass.

2.3.7 Natural Resources

The key topics are natural gas and potentially mineable groundwater (though high flouride may change the picture). BWIP has no current plans to address either issue except to monitor the activities of the oil companies. BWIP's deep structure investigations are primarily in support of understanding the structural/tectonic setting of the Pasco Basin. However, better delineation of the structure at the basalt/sediment interface might shed some light on the presence of stratigraphic/structural traps for gas beneath the Cold Creek Syncline and the RRL. In addition, BWIP's efforts to identify if the gas is of biological or thermo-catalytic origin may be of some benefit. A mine-gas expert from the Bureau of Mines has also been consulted. At a minimum, BWIP should include consideration of methane in future designs and contingency plans.

2.4 SUMMARY OF FINDINGS

A summary of the findings described in this chapter are:

1. The intraflow stratigraphy of the candidate basalt flows is likely to vary in an unpredictable manner due to a variety of anomalies (e.g., locally thickened flowtop breccia, flow margins, canyon fills, cooling joint patterns, faults, and shear zones). The major problems associated with the intraflow stratigraphy are potential restrictions on the design and construction of the repository, potential flooding of the mine due to an uncontrolled entry into a potentially high-pressure (1500 psi) water-bearing zone, and the difficulties in identifying the proximity, or lack thereof, of these anomalous zones for performance assessment analyses. The main conclusion is that the existence of these anomalous zones cannot be determined from surface geophysical techniques, a borehole drilling program, or even the exploratory shaft. It will require multi-directional probing with boreholes and specialized in situ geophysical techniques in advance of, and subsequent to, actual repository mining operations.

2. Although the BWIP staff have made significant progress, a major unresolved technical question is tectonic characterization of the region surrounding the RRL. The major problems are the uncertainties associated geophysical techniques as applied to basalt (e.g., magnetotelluric, magnetic, gravity, seismic), the ambiguities of extrapolating geological information from the margins of the basaltic mask, and the lack of deep (sub-basalt) borehole information upon which to calibrate other information sources. This unresolved technical area is significant to the questions of relative thinning of the basalt below the repository, natural gas exploration potential, interpretation of ambient hydrochemistry, and development of tectonic model(s) for the region. It appears that BWIP staff are approaching these questions is a very logical and responsible manner.

3. Another unresolved technical question is the potential presence of methane in what is being inferred to be a very thick sequence of sediments below the basalts. The resource question is whether or not the methane observed in the Grande Ronde basalt waters in the Cold

Creek Syncline is from a local, and thereby quickly exhaustible source, or from a much larger and deeper source. The technical questions associated with the methane presence are related to the amount of methane that might be expected to accumulate in an unventilated (closed) segment of the repository and the significance of methane on near-field performance. Additional attention to these methane questions may be necessary.

4. Another unresolved technical question is that of seismicity. This includes the areas of potentially undetected strike-slip faults upon which displacement might result in perturbations to the hydrological system. Vibrational energies associated with earthquakes may also be important depending upon the repository, the size of the event(s), and the energy attenuation characteristics of the intervening geological media. Existing data indicate that relatively large but remote earthquakes are not likely to be particularly significant to an underground facility. What may be of more concern are the earthquake swarms, which are composed of extremely low magnitude events, but which may potentially be located in the same rock zones as the repository. Consideration must be given to the potential hydrological significance of small displacements on fractures in the dense basalts which may give rise to the swarm earthquake activity. Of additional concern is the high frequency energy generated, since, given the short distances involved, attenuation may be low. The concern is focused on retrievability of cannisters in potentially long horizontal boreholes should they be employed.

5. Another unresolved technical question is the thermal stability of minerals filling the fractures in the basalt. These minerals have a controlling influence on water flow and the concern is that high temperatures might result in dehydration, diagenesis, volume changes, and mechanical flushing under the extremely high differential water pressures. Plans should be developed to resolve this question.

6. The last question discussed in this chapter is focused on glaciation. First of all, it is apparently unlikely that continental glaciation will even occur in the first 10,000 year period of

importance to BWIP. Secondly, there is no evidence that glaciation has advanced any closer than Chelan-Coulee City area. Questions remain however, on the potential significance of continental glaciation in the areas of increased regional hydrological gradients and stress-induced displacement on pre-existing or new faults and fractures. There appears to be some evidence, especially in the Great Lakes area, that the radial and tangential stresses beyond the toe (margin) of the heavy ice sheet can lead to fracturing and fault displacements. Such deformation could conceivably affect hydraulic conductivities. Future consideration of these possibilities may be necessary.

7. General areas requiring some attention are data management (e.g., formatting, integration and display) and better documentation of the overall technical plan of attack. With the minor exception of these areas, the BWIP geology/geophysics staff members are doing an admirable and first-class technical job on a very complex geological problem.

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3.0 GEOHYDROLOGY

This chapter is organized in much the same manner as the previous chapter. An assessment of the geohydrology of the Hanford basalt relative to the August 1, 1983 DOE siting guidelines (DOE, 1983) is presented, followed by a discussion of the technical questions relative to geohydrology that have been identified as a result of our review of the BWIP program, the SCR (1982), the SCA (1983), and a variety of SCR review documents prepared by various government agencies and independent bodies. In the process of reviewing the reviews of the SCR and the BWIP program, we have attempted to determine the reasoning which lead the reviewers to their conclusions so that the need and adequacy of the BWIP program plans to answer these could be determined. The remaining sections of this chapter present:

- the major questions relative to performance assessment in the area of geohydrology,
- an assessment of the BWIP plans for addressing the questions identified,
- a summary of the important findings in the area of geohydrology.

3.1 ASSESSMENT OF HANFORD BASALT RELATIVE TO DRAFT DOE SITING GUIDELINES

Some reviewers expressed concern that the DOE did not follow their siting guidelines in selecting Hanford basalts. They felt that Hanford basalt was picked because the DOE owned the land rather than because it was the best location in basalt to site a repository. The reviewers felt this viewpoint changed what should have been a selection task into one of trying to show that the RRL is a suitable site. These reviewers felt that even the selection of the RRL site within Hanford was highly subjective. The August 1, 1983 draft of the DOE siting guidelines put many of these questions to rest. The new draft of the guidelines (pages 23-25) indicates that prior to the passage of the Nuclear Waste Policy Act which "mandated the preparation of the guidelines, the DOE had already identified nine sites as potentially acceptable. As stated in section I.B (of the draft guidelines), the DOE therefore intends to use these nine sites as candidates for the first nominations required by the Act; the screening that led to them did not use the guidelines, per se, but was based on similar principles."

The guidelines go on to say that these original nine sites (tuff, basalt, two bedded salt sites in the Palo Duro Basin in Texas, two salt sites in the Paradox Basin of Utah and three dome salt sites in the Gulf Interior region in Mississippi and Louisiana) will be evaluated and compared according to the guidelines in order to select those acceptable for further study. "Furthermore, primary importance will be given to the postclosure guidelines because they refer to those site conditions or properties that contribute to the principal function of waste isolation and hence to the long term protection of public health and safety. The preclosure guidelines are considered of less importance than the post closure guidelines in this comparison."

To put the geohydrology of Hanford basalts in perspective, an assessment of the basalts relative to the DOE siting guidelines is appropriate. Such an assessment will serve to elucidate which properties of basalt, for this geohydrologic setting, will require the most understanding. The guidelines are subdivided into two sets of factors, "Conditions and Processes Affecting Expected Performance" and "Potentially Disruptive Processes and Events." For each technical guideline in each of these two categories above we have quoted the qualifying condition, favorable conditions, potentially adverse conditions, and, for some guidelines, disqualifying conditions (DOE, 1983).

In the following paragraphs an objective evaluation of the Hanford basalts relative to the draft DOE siting guidelines on geohydrology is presented. It should be recognized, though, that these classifications will be subject to interpretation and scientific judgment.

3.1.1 DOE Guidelines - Postclosure

System Guidelines (960.4-1)

"The geologic repository shall consist of multiple natural and engineered barriers that, when considered in concert, will provide reasonable assurance that after repository closure radioactive wastes will be physically separated from the accessible environment in accordance with the requirements set forth in 10CFR60 and 40CFR191.

The technical guidelines that follow establish conditions that shall be considered in determining compliance with this system guideline. The relative significance of any postclosure technical guideline to the overall system performance is site specific. Therefore, for each technical guideline, determination of compliance or disqualification shall be made in the context of the overall system, considering the favorable and potentially adverse conditions identified at the site.

A site shall be disqualified if its characteristics do not allow reasonable expectation of compliance with this system guideline when considered in conjunction with the engineered barrier system, including those required under 10CFR60.113."

3.1.2 DOE Guidelines - Conditions and Processes Affecting Expected Performance

Geohydrology (960.4-2-1)

Qualifying Condition. "The present and expected geohydrologic setting of the site shall be compatible with waste containment and isolation. The conditions and characteristics of the geologic setting and the use of reasonably available technology shall permit (1) the requirements set forth in 10CFR60.113 for radionuclide releases from the engineered system and (2) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment to be met."

With respect to the geohydrology there is a reasonable expectation that the site can be sufficiently characterized in a hydrological sense to allow performance relative to 10CFR60.113 to be determined. However, for reasons delineated below, this task is regarded as difficult given the geohydrologic setting of the RRL.

Favorable Conditions. (1) "Site conditions that allow the geohydrology at the site to be characterized to the extent that it is likely that the pre-waste-emplacement groundwater travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment is more than 10,000 years."

This favorable condition probably applies to the site. Here, as is the case for many of the geohydrologic questions relative to basalt, the complexity of the basalt hydrologic system is the issue. Solid, objective answers to this question must await further data.

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

(See Chapter 2.)

(3) "Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be characterized and modeled with performance-assessment techniques."

The hydrologic aspect of this criterion probably applies to the site. Again, the main issue is the complexity of the basalt geohydrology. The multi-layered nature of the basalts and potential structural complexities in and around the RRL make this a difficult question to assess fully before the additional data on potentiometric baseline and large scale pump tests become available. (See also 2.1.1.)

(4) "A high effective porosity along the paths of likely radionuclide travel between the host rock and the accessible environment."

This condition does not seem to be applicable to the basalt site. Current understanding of the effective porosities of basalt in the interflow zones, interbeds, and in the dense basalt interiors is limited. Based on our current understanding of the basalts, however, we would not predict a high effective porosity along any of these paths. The likelihood of high effective porosity for the other potential geologic materials is also low.

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

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

This condition is not applicable to the Hanford site. While the immediately surrounding rock if available in sufficient thickness would most likely meet the low conductivity criterion, the interflow zones above and below the host rock could most likely not be categorized as having low hydraulic conductivity.

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

The BWIP site probably does not meet this condition. This condition is presumed to mean that the repository is located within a recharge (or downward moving part of the regional groundwater system) or at least upgradient from the discharge part of the regional groundwater system. In our opinion the RRL, is in a discharge area and this does not satisfy thus favorable condition. However, the database is inconclusive in this respect. New data from the planned potentiometric baseline program should allow this question to be answered.

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

This favorable condition probably applies to the site. Existing data, if taken without further inspection, would indicate that low hydraulic gradients exist. Nevertheless, questions remain concerning the adequacy of the drill and test methods used to determine vertical gradients; also it is not known what effects the long sections of open boreholes within the Grande Ronde might have had on any natural gradients.

<u>Potentially Adverse Conditions</u>. (1) "Expected changes in geohydrologic conditions--such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity, and the groundwater flux through the host rock--sufficient to significantly decrease the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions."

Since the exact effect of changes in the application of irrigation water from surface water sources, irrigation withdrawal and damming of the Columbia and Snake rivers have not been assessed, it is not possible to judge this condition. Withdrawal of water for irrigation could potentially change the groundwater gradients beneath the Hanford site, thus this issue needs to be addressed.

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

This potentially adverse condition pertains to the BWIP site. Potable and irrigation water sources do exist along the flow paths from the host rock to the accessible environment.

Disqualifying Condition. "A site shall be disqualified if there is reasonable expectation that the average pre-emplacement groundwater travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment is less than 1,000 years, unless the characteristics and conditions of the geologic setting , such as capacity for radionuclide retardation and groundwater flux, would limit potential radionuclide transport to the accessible environment to the extent that the requirements specified in Section 960.4-1 could be met."

It does not appear the Hanford site will be disqualified on the basis of this condition. Even though data are scanty and sometimes questionable, there is a reasonable chance that the pre-waste-emplacement groundwater travel time, once appropriate site characterization data is gathered, will be determined to be greater than 1000 years.

In summary, our assessment of the Hanford basalts relative to the geohydrologic considerations in DOE's siting guidelines (DOE, 1983) paints neither a rosy nor completely damning picture. The site probably meets the qualifying condition (960.4-2-1). The site could probably meet four of the potentially favorable conditions but probably does not meet three others. Two potentially adverse conditions apply to the site, while a third does not. We conclude that on the basis of existing data or geohydrologic evidence, the site cannot be disqualified.

3.2 GEOHYDROLOGY-TECHNICAL QUESTIONS

From a geohydrologic perspective, the biggest single question relative to siting a waste repository in basalts is the complexity of the basalt system. The complexity of basalts renders characterization and prediction of performance difficult. A complex hydrologic system like basalt requires more data points and more careful characterization methods than simpler hydrologic systems to achieve the same degree of confidence in system understanding and performance predictions.

Complexity, while more relevant for basalts, is by no means unique to basalts. Because of the depths proposed for siting repositories, all repository sites are likely to face similar difficulties. These siting depths generally mean that multiple, interacting, and deep groundwater flow systems will require characterization and understanding.

At BWIP, complexity problems are compounded by the sheer number of hydrogeologic layers and interacting flow systems. A complex system with large variability is difficult to characterize since a single test which shows low permeability is not sufficient. Many tests are required to produce a statistically significant sample of the probability density functions for important hydrologic parameters, along with spatial correlation functions. Such data are required to develop a spatial distribution of these hydrologic parameters for the various layers. While identification of the number and thickness of basalt layers and interbeds is probably a realizable goal, it is not simple to identify the:

- exact location and hydrologic character of layer pinch outs
- spatial integrity (i.e., the hydrologic confinement properties) of these layers, and

- location and hydrologic character of dikes, faults, and other features (barriers) that could be important to vertical interconnection and travel time predictions.

The wide range in existing permeability measurements illustrates the variability in the local nature of this property. It is this complexity in the stratigraphy and hydrologic properties of the basalt flows that makes the development of a single, unchallengeable conceptual model of the basalt geohydrologic system a very difficult task, given the current state of characterization. Figure 3-29 from page 3.5-30 of the SCR (Figure 2.1 of this report) illustrates graphically the complexities within a single basalt flow.

The overiding hydrologic question is embodied in the following:

"Can the uncertainties in the understanding of the system, hydrologic model predictions and data base be reduced (by testing) so that compliance with NRC draft criteria for pre-waste emplacement groundwater travel times be defensibly demonstrated?"

In the rest of this section we will present the major questions relative to geohydrology that have been identified in the course of this review process. These questions can generally be categorized under the following headings:

- General
- Existing Field Data And Acquisition Methods, and
- Conceptual Modeling And Performance Assessment.

The BWIP plans for addressing these issues, as we currently understand them (without having access to the SCP, which is in preparation) will be covered in a later section of this chapter.

3.2.1 General

Data Access Procedures

Outside qualified reviewers felt that in general, the SCR did not present data in a manner that was conducive to independent technical review as dictated by NWPA (U.S.G.S., 1983 and Shaw, 1983). Many reviewers of BWIP work have expressed concerns about the release of field data. These reviewers would like access to the raw field data; they complain that interpretations of the data are presented, as opposed to the actual data. This is an important question since it relates to the testing methodology itself. (See Section 3.2.2.)

Averages

Averages rather than ranges were used in calculations in the SCR.

Brecciated Zones

Why has only one of the highly brecciated zones been tested?

Deep Drilling

Should data on the geology below the basalts be collected to clarify the questions regarding geochemical anomalies; the nature and source of the tectonic forces acting in the region; the source of the methane in the Grande Ronde of the RRL-2; and the possibility of hydrocarbon resource potential.

3.2.2 Existing Field Data and Acquisition Methods

Drill and Test Procedure

Representativeness of the hydrologic parameters measured by the drill and test procedures utilized in the BWIP field program have been questioned by a number of reviewers and in particular the USGS. Reviewers question the validity of this procedure in determining potentials, gradients, representative conductivities, and chemistry. The questions raised regarding the drill and test procedure are as follows:

1. In light of existing USGS data on basalt wells outside the Hanford area, which have taken from 3 months to a year or more to reach an equilibrium value, was enough time taken for heads to reach equilibrium? The USGS has also pointed out that a comparison of the DC-1 head and inferred gradient data obtained during drilling (in much the same manner as utilized in the drill and test program) disagree with the potentials obtained from the long-term DC-1 piezometer data. The direction and magnitude of gradients also disagree.
2. What effects does the mud have on chemistry and conductivity measurements in light of the USGS analysis, which indicates that for at least 50% of the tests mud may have been present in the formation?

3. Was the duration of the pump tests adequate to determine the hydraulic conductivity of a spatially-large-enough volume of aquifer material?

4. How does the lack of observation wells affect the quality of the measurements?

To put these issues regarding the drill and test procedure into perspective, let us examine some of the reasoning that gives rise to these questions.

The existing BWIP drill and test procedure consists of setting up on the hole and drilling, for the most part by mud rotary techniques, down to the first interval to be tested. The upper part of the formation is cased and sealed down to the first interval to be tested. The interval to be tested is then pumped initially to clean up the hole. The water levels are then allowed to recover until "equilibrium" is reached. This determination is made by plotting the observed water level with time. The time varies, depending on the properties of the interval, but is typically in the range of a few days. The hole is then pumped further until tracer measurements in the recovered water indicate that the majority of the mud that can be removed has been (the drilling mud was spiked with fluorescein dye). At this time, the hydraulic conductivity testing is begun (duration 8 hours to a day or so). At the completion of the test, the water level is tracked until the potential recovers to near the initial water levels. When the hydraulic conductivity test is completed, the hole is pumped further to insure that a representative chemistry sample is obtained. Both the dye levels in the pumped waters and the tritium content (drilling fluid comes from the Columbia River, which has elevated tritium levels) is tracked. At this point the chemistry samples are taken and the interval and hole is plugged with cement. After the cement is hardened, the interval is drilled through and the hole is deepened to the next interval to be tested and the process is repeated. This entire procedure, depending on the depth and number of intervals tested, takes from nine months to more than a year. The influence of drilling mud on geochemical sampling is discussed in Section 4.2.1.

It is the total time for this procedure, as well as the length of time allowed for equilibrium, the use of mud, and the duration of the conductivity tests, that give rise to the challenges. In order for the drill and test data to yield valid information relative to vertical potential distributions, directions of flow, and magnitude of vertical gradients, one must make two apriori assumptions.

First, the groundwater system is in steady state (i.e., the potentials must be assumed to be temporally invariant at that location, at least over a time frame of 9 months to one year). If the system were indeed responding to annual transients associated with pumping and irrigation, or to longer term trends related to overpumping (gradual decline) or surface water irrigation (gradual rise), then the direction and magnitude of the vertical gradient would be biased in an unknown manner.

Second, intervals to be tested are well confined areally. Otherwise the drilling fluid injection and water removal for hydraulic testing and chemistry sampling could affect the heads in deeper units yet to be tested. One could argue that since more water is removed than drilling fluid injected, the drill and test procedure could bias any measures of vertical gradient in a non-conservative manner. The procedure has the ability to produce a drawdown front ahead of it that would lower the observed head in the deeper and as yet untested units. On the other hand, if careful control were exercised to avoid this problem, then hydraulic conductivity measurements would be spot (i.e., very limited scale) measurements of hydraulic conductivity, of limited use for near or far field performance assessment.

Questions relative to the drill and test procedure alluded to above are concerned with the representativeness of the hydraulic conductivities determined by this procedure and with the details of the procedure itself. The USGS has raised questions regarding effects of the use of loss-of-circulation material, the loss of as much as 100 percent of the drilling fluid, and the failure to remove all the drilling mud before hydraulic conductivity testing.

Along these same lines, the question arises as to why so many of the conductivity values determined are similar to those of clay. Other questions about hydraulic conductivity measurements relate to the duration of these tests and thus the scale of the measurements. The large variability in the determined values (seven orders of magnitude for the Grande Ronde, eight for the

Wanapum and six for the Saddle Mountains basalts) makes one question whether the duration of the tests was long enough to sample the conductivity of a volume of aquifer rock large enough to be useful for performance assessment modeling in the far field. The values determined from the short duration test may not be adequate because of the limited scale of the measurement. One generally expects the variability to decrease with the scale of the measurement. The conductivities from drill and test procedures are of limited scale. They show more variability and do not measure the global ability of the basalts to conduct water horizontally or vertically. As an example of the inadequacy of these measures, RHO and NRC could not with any certainty address the adequacy of the spatial distributions proposed for the design of large-scale, multiple-well interference tests, even in light of all the available hydraulic conductivity testing that had gone on to date. They felt that data were insufficient to determine how close wells in the RRL area would have to be to show useful interference effects.

Given the questions regarding the drill and test procedure, how good are previously collected drill and test data and how can they be validated?

Vertical Permeability

Another important question is the lack of understanding and measurements of vertical permeability in the basalt hydrologic system. Understanding of both the nature and magnitude of the vertical permeability is essential in developing a defensible estimate of pre-emplacement groundwater travel times. The magnitude of the vertical permeability and the nature of the vertical interconnection between the (typically) more transmissive horizontal interflows and/or interbeds must be demonstrated or developed from field measurements. Without this data an unacceptable uncertainty in pre-emplacement groundwater travel times and performance assessment predictions of radionuclide migration will result. BWIP must be able to develop a defensible field testing program that will distinguish the relative importance of that portion of the vertical permeability which might result from:

- short circuits consisting of distributed vertical conduits associated with large fractures, dikes, faults, overlapping flows or other hydrologic features;

- small quantities of water moving through many small, uniformly distributed vertical fractures of the colonade and entablature;
- the confinement of the silts and clays prevalent in some interbeds, which separate some of the basalt flows.

The uniformly distributed leakance type of interconnection that arises from either the silts and clays of the interbeds or distributed small fractures within the colonade and entablature would yield a more dispersive path with a much lower effective vertical permeability than interconnection of the conduit type. From a far-field performance assessment point of view, interconnection of the conduit type would yield a high permeability and less dispersive path from the breached repository to the surface.

For these reasons, there is a need to understand the nature of the "hydrologic barrier" west of the RRL and the variety of potential structural and hydrologic analomies identified within and around the RRL.

Two scales for measuring vertical permeability are important:

- repository scale, for which characterization of the "good" rock and its variability are important to primary containment within the repository host rock and estimates of near-field performance, and
- regional scale, for the far-field modeling of pre-waste emplacement travel times discussed above.

<u>Effective Porosity and Dispersivity</u>

Several additional tests aimed at characterization of effective porosity and dispersivity are needed. Only one effective porosity and dispersivity test has been run so far; this test yielded what might best be described as a questionable low value for effective porosity (1.0E-4). Several of the reviewers point out that the value determined in this single test was ignored in the performance assessment modeling.

<u>Regional Flow System Characterization and Potentiometric Baseline</u>

The USGS (USGS, 1983) has stated (and we agree) that development of a data base on the Pasco Basin hydrologic system sufficient to develop an understanding of the regional flow system is a key component to understanding the

RRL hydrologic system and to the overall reduction of uncertainties regarding flow paths and travel times from the repository horizon to the accessible environment. If one looks at the potentiometric measurements within and around the RRL, the potentiometric variation and gradients based on existing data appear to be small. However, considering the uncertainty that these areally-restricted data create both in terms of interpreted regional direction of flow, it becomes apparent that using an inverse technique for a larger region such as the Pasco Basin will establish the RRL boundary conditions with a higher degree of uncertainty.

To understand the regional flow system, researchers will have to collect baseline data on the spatial and temporal variations of potentials, recharge, aquifer stress (pumping, Hanford disposal and irrigation application). They will also have to collect, assemble, and analyze pump test and specific capacity data for the Pasco Basin. The USGS suggests that at least three years of baseline potentiometric data collection may be required before any significant stresses within the Hanford area, such as might be caused by the large scale pump tests or ES construction, would be detected. This issue needs to be addressed by additional studies and comparisons of recent hydrographs with historical hydrographs.

Other questions relative to the collection of baseline potentiometric data which need to be resolved include:

- What are the effects on the unconfined water table of starting up Purex and shutting down U pond? Would these affect the baseline data collection operation being planned near the RRL? If the baselining operation could be affected, then methods for delaying or minimizing these effects need to be investigated.
- What effect do the open boreholes in the Grande Ronde have on vertical gradients that may have naturally existed? What effect will these boreholes have on the baseline data set if they are not plugged or packered off? How long must one wait following plugging for effects of the wells to be eliminated?

3.2.3 Conceptual Modeling and Performance Assessment

Reviewers point out that various conceptual models are consistent with existing data. Even so, only one RHO model, which PNL and others find lacking, was used in performance assessment, although historical information on other preliminary modeling efforts was presented. The non-conservative nature of the RHO conceptual model as presented in the SCR arises from the assumption that vertical mixing is lacking. This assumption is based on an observation of low vertical gradients and distinct groundwater chemistry, which was felt to preclude mixing between the basalt interflow zones and discharge of the deeper basalts through upper hydrologic systems and eventually the alluvium and river. But as Shaw (1983) points out, in a discharge area such as the Pasco Basin, hydrologists more often interpret small vertical gradients between the various hydrologic units as an indication of reasonable vertical communication, as opposed to little vertical communication as assumed by RHO. The USGS points out that upward movement of ground water can occur any place where gradients support it. They point out that the leaky nature of basalt formations within the Columbia Plateau is well documented, as evidenced by the response of deeper basalt units to irrigation and pumping. Discharge from deeper basalts to major streams can and does occur where the basalt is not in contact with the surface streams. Significant quantities of water can move vertically (even through very tight confining layers) when the large area over which small vertical gradients exist is considered.

RHO's use of hydrochemistry data to interpret hydrology as opposed to supporting hydrologic interpretations was criticized by all reviewers. PNL concurs with the other reviewers in this matter. The generally accepted approach is that water chemistry data alone are not sufficient to develop a conceptual model of a hydrologic system. However, isotopic and chemistry data should be predictable based on the conceptual hydrologic model. This subject is discussed in some depth in Section 4.2.1.

As alluded to in the discussions regarding the drill and test procedures, PNL and other reviewers believe that questionable duration and scale of the hydraulic conductivity tests conducted thus far are partially responsible for the large variability in the hydraulic parameters reported (from six to eight orders of magnitude for the interflow zones alone; eleven orders of magnitude if the flow interiors are included). As Shaw (1983) points out, the variability in hydraulic conductivity measured for basalts is greater than for any other rock type presented in the SCR (Figure 5.27, page 5.1-48). The large variability in the hydraulic conductivity measurements makes us question the use of these values in performance assessment models. In any event we cannot support the 90 and 97.5 percent confidence limits for hydraulic conductivity values alluded to in the SCR on page 12.4-8 and used in travel time predictions. Questions also arise concerning the data, conceptual model and analysis methodology that could give rise to the probabilistic assessment of travel time published in RHO-BW-ST-28P-Draft (1983; pages I-311 through I-314). The estimates published there indicate that travel times from the four candidate horizons have been determined to be greater than 5000 years with a 95% probability.

In their review of the BWIP SCR, the NRC attempted to demonstrate the futility of making premature predictions of groundwater travel time. The NRC took a very simple approach in selecting their conceptual model as part of their review process. They indicated that the current data base on the Hanford basalts could not allow one to distinguish between:

- uniformly distributed vertical permeability and strictly vertical movement;
- vertical conduits and strictly vertical movement;
- strictly horizontal movement; and
- combinations of the above.

They used these various conceptual models over the wide range of permeabilities measured and came up with travel times from 20 to over a million years for the range of travel times from the repository horizon to the accessible environment. They do not believe that these are realistic estimates for travel time or travel time ranges, but were attempting to show the futility of making premature estimates of travel time given the current state of system characterization. In subsequent meetings between BWIP and NRC on Performance Assessment Review, the NRC indicated to RHO that they damage their credibility and the credibility of the program by continuing to publish estimates of groundwater travel time before adequate site characterization data are available.

In the performance assessment area a key question relates to understanding of the system and the development of a defensible conceptual model for groundwater. Based on the available data, more than one conceptual model may currently be developed and defended. Data must be collected to define RRL model boundary conditions and to define the effect that hydrologic barriers and other anomalies within the RRL have on groundwater flow. Using these data, a defensible conceptual model can hopefully be constructed. As part of this process, there will be a need to understand the regional flow system, as alluded to earlier, so that the effects of changes outside of the Pasco Basin will have on the RRL site can be ascertained. Questions about man's ability to influence groundwater flow directions and gradients, thus decreasing travel time, will need to be answered.

What is a conservative assumption? RHO indicated in the SCR that they will use a conservative approach to address the uncertainty question to avoid some of the difficulties associated with this developing technology in the area of hydrology. The use of a "conservative approach" to address uncertainty is not, however, without controversy. There was much discussion by various reviewers relative to RHO's selection and use of conservative conceptual models, and parameters. The treatment of uncertainties in performance assessment looms as a real issue, not only in the BWIP program, but also throughout the NWTS program. This issue will be addressed in the next section.

3.3 PERFORMANCE ASSESSMENT ISSUES RELATIVE TO GEOHYDROLOGY

This section describes some potentially important performance assessment questions that were identified as a result of this review process and work on another project for the DOE. These important questions surfaced as a result of attending the DOE/NRC Workshop on Performance Assessment for the Basalt Waste Isolation Project held in September 1983. The major areas of concern relate to the type of assessment NRC currently indicates it will require of BWIP at licensing relative to both the NRC rule (10CFR60.112(c)) and the EPA standard (40CFR191.13(a,b)).

Another area of concern that warrants investigation is NRC's developing stance regarding data analysis and interpretation: "Available data must be evaluated in light of accepted physical principles." NRC's stance on this issue needs to be pursued, at least in the area of geohydrology, since many of the parameters necessary to characterize hydrologic systems cannot be measured with a "meter" or "ruler." Effective porosity, permeability, aquifer boundaries, and recharge must be determined indirectly by data analysis techniques from other directly measurable quantities (e.g., drawdown at observation or pumping wells). The potential problem in this area is that NRC seems to be saying that "accepted physical principles" means "the way it has traditionally been done" and that new and potentially better methods of data analysis will not be accepted. NRC has indicated, if one reads between the lines, that they will only accept traditional analysis results of the large-scale pump tests being planned at BWIP. The basalts are complex and violate nearly every assumption of the traditional pump test analysis techniques, as do many hydrologic systems. Better analysis can and has been performed in other hydrologic settings by using models that account for the stratigraphy, system heterogeneities, direct interconnections between layers, and non-uniformities affecting the spread of the drawdown cone emanating from the pumped well. These types of analyses would be disallowed if one follows what appears to be NRC's current course regarding accepted data analysis and interpretation techniques. This is an extremely important issue relative to the analysis and interpretation of the large scale pump test planned for the RRL area. BWIP needs to clarify NRC's intent and challenge it if necessary to preclude an arbitrary ruling which would negate use of new technology and existing modeling techniques. We feel that the best available, defensible technology needs to be used.

3.3.1 Risk Assessment

Neither BWIP nor NWTS performance assessment methodology in general embraces the risk assessment methodology being proposed for use by NRC for post closure performance assessment of the geologic isolation system. No mention of a full risk assessment approach was made in any of the NWTS performance assessment plans we have reviewed. There are many reasons to question the validity of risk assessment methodology for geologic systems, since this methodology has traditionally only been associated with short-term, active, event-dominated systems (such as reactors). It is not clear that degradation and failure of relatively passive geologic waste isolation systems over geologic time periods can adequately be addressed by this approach. Geologic changes are generally related to the interactions between time sequences of slow continuous processes and discrete events (on a geologic time scale). Indications given to BWIP at the performance assessment review meeting in September are that NRC will require a full risk assessment type of support to demonstrate compliance with the release limits given by EPA (Table 2, appendix to 40CFR191). The implications of this type of performance assessment requirement need to be fully investigated by DOE and BWIP since, according to our knowledge, none of the sites has envisioned the need for this kind of assessment to demonstrate compliance with the EPA standards. Such an approach could mask what we really know about a site behind a myriad of complex summations of multiplications of potentially meaningless probabilities by estimates of consequences of likely and highly unlikely events to arrive at a risk assessment. An obvious danger is that real safety and uncertainty issues might take a back seat, and that the risk response function, which is much more arbitrary and less meaningful (owing to the way in which most, if not all, of the probabilities are likely to be chosen), would drive the decision process without a full investigation of its components. This is much akin to the way in which EPA release limits were set in the first place. These limits, according to an earlier PNL analysis of the EPA standards, resulted from consequence estimates based on release from brine pockets, and the driving probability which made this release scenario of concern was based on an erroneous estimate of drilling frequency for salt. Another danger, alluded to earlier, is that event-driven risk assessment approaches typically ignore interactions between slow, chronic system changes unless they alone can result in failure. Earlier NWTS work with geologic simulation models indicated that interactions and time sequencing between slow, geologic processes cannot be ignored when trying to assess long-term performance of a geologic isolation system. The NRC position of requiring a full risk assessment should be challenged, as appropriate, and resolved.

3.3.2 Approach to Assessment of Sensitivity and Uncertainty

In the area of assessing sensitivity and uncertainty, we find that NRC has chosen to use new, developing and untested methods. We must caution that the NRC's approach, which calls for the use of Monte Carlo techniques via Latin Hypercube sampling, has some inherent shortcomings that could potentially cause difficulties in licensing BWIP or any other site. The current NRC supported methodology is not well suited for systems for which parameters are correlated. It contains no constraints for limiting "realizations" for parameter distributions to that subset which produces "realizations" of potential distributions within the realm of observations. It should also be noted that uncertainty in boundary conditions, recharge, conceptual models, stratigraphy, which are all sources of uncertainty, are not being addressed in a systematic way by either BWIP or NRC.

The problems with the particular uncertainty and sensitivity approach being proposed for use by NRC are more subtle than those associated with the use of risk assessment, but no less important. It is well recognized in the scientific community that there is a great deal of uncertainty associated with characterizing and fully understanding groundwater flow and transport in deep geohydrologic systems. Part of this uncertainty is due to the difficulties and costs involved with characterization of deep hydrologic systems; another part results from trying to avoid a "swiss cheese" effect, which certainly could occur if complete characterization were attempted.

The major hydrologic problems in the area of sensitivity and uncertainty, however, are related to the attempt by NRC to move too quickly from the fully deterministic approach to newer, less fully developed, understood and untested methods, which are the subject of much ongoing research. Traditionally, groundwater models have been applied to relatively near-surface hydrologic systems, where more complete characterization is still possible, even though expensive. Models of these systems and sensitivity or uncertainty studies on these types of systems have been deterministic, for the most part. In a deterministic modeling and uncertainty approach, the data on the system is collected and interpreted, a conceptual model(s) of the system is developed, spatial distributions of parameters are inferred, a code(s) is selected, and the system is modeled. Model predictions are compared to observations and less certain parameters and parameter distributions are modified as needed (within the range of uncertainty for that parameter) to obtain better agreement between model predictions and observations. Once the model is calibrated (an "acceptable" match between model predictions and observations is obtained), sensitivity studies are performed for each of the major parameters and parameter distributions to attempt to determine the most sensitive parameters. The information from these sensitivity studies can then be used to guide further field activities aimed at reducing the uncertainty in these parameters or to obtain some estimate of bounds for model predictions. As a final step in this deterministic process, one would then like to subject the system to a different state of stress than was present during the time when the calibration data set was obtained. A comparison between the model predictions for this new state of system stress and the field observations of real system response can then serve to validate the site model and provide further estimates for uncertainty bounds for model predictions.

A fully calibrated and validated deterministic model, such as described above, is hard to achieve and the geohydrologic community is beginning to recognize some problems with this approach, even though it has been successfully applied to many real systems. Anyone who has performed one of these deterministic analyses is aware that there is nothing unique about the spatial distribution of parameters used to describe observed system response. In fact, there are probably an infinite number of "similar" spatial distributions of parameters (generally referred to as "realizations" of the system), which can give rise to the same observables. Considering the uncertainty associated with the system response observations and the fact that we can only observe response and measure parameters in the real system at points in a continuous groundwater system, we must realize that any inference of spatial distribution from these point observations involves interpretation. In addition, each spatial distribution, within this myriad of possible spatially varying parameter distributions or "realizations," can also give rise to the same probability density function for the parameter and with the same kind of spatial correlation functions.

It is this knowledge which has given rise to the new work in the area we'll call "stochastic hydrology." NRC has attempted to move headlong into "stochastic hydrology" to better account for uncertainty. This trend could cause great difficulties in siting and licensing a repository. This new area of technology, if not approached properly, could cause difficulty not only in licensing a potentially adequate site, but also in the licensing of a potentially unacceptable site.

First attempts in the area of "stochastic hydrology," which ignored the spatial correlation aspects important to groundwater systems, produced some erroneous conclusions. Spatial correlation attempts to account for the fact that, depending on the system being studied, the permeability near an observation of high (or low) permeability is not completely independent of its neighboring values. In fact, for a given hydrologic system, the value of permeability at the nearby location will have a greater probability of also being a higher (or lower) value (i.e., the spatial distribution of permeability cannot be randomly assigned spatially based solely on a probability density function developed from the measurements of permeability).

Let us now look at the methodology NRC is currently following in the area of sensitivity and uncertainty. At the recent BWIP meeting, the NRC indicated that it was going to require a full probabilistic assessment of travel time in order to demonstrate compliance with the requirements of 10CFR60: "The geologic repository shall be located so that the pre-waste emplacement groundwater travel times through the far field to the accessible environment are at least 1000 years."

Because NRC and BWIP have only deterministic tools, the approach to stochastic hydrology and uncertainty must be of the multiple realization or Monte Carlo type and any systematic approach to sensitivity would most likely be of the adjoint type. NRC is embracing a Monte Carlo approach to the determination of a probabilistic assessment of travel time without recognizing the full implications of such an approach. Monte Carlo consists of forming "n" random "realizations" of the input parameter distributions and running the deterministic model "n" times to come up with an estimate of the probability density function for travel time. This completely Monte Carlo approach, while more general, will be expensive at the very least.

Another approach, which involves "Latin Hypercube sampling," is being embraced by NRC. This approach can reduce the work quite considerably, but it has one potential drawback. While the general Monte Carlo can account for spatial and temporal correlation between input parameters, Latin Hypercube sampling is most appropriate for the case where there is no correlation assumed between input variables (Iman and Conover, 1980). Correlation between input variables, important to the estimation of travel time, does most certainly exist. While there may be no recognizable correlation between effective porosity and permeability in general a correlation certainly exists between permeability and porosity in a specific geohydrologic setting and medium. Assumption of a lack of correlation would most certainly associate the lowest porosity with the highest permeability. When this is done, travel time will be grossly underestimated. It should be noted that while the current Latin Hypercube approach supported by NRC does not account for this important correlation between parameters, a more sophisticated approach could be developed.

Another area of concern we have about NRC's proposed statistical and stochastic methods include their use of a developing untested technology for which estimates of hydrologic system performance are unreliable. Let us examine the current use Monte Carlo, perturbation-based or adjoint techniques. None of these methods really contains constraint mechanisms to limit the "possible realizations" of hydrologic systems to the realm of reality. In the Monte Carlo (Latin Hypercube) and perturbation methods, the realm of sampled "realizations" is constrained only by the measurements of the parameters themselves and the statistics and correlations that can be inferred by geostatistical methods such as kriging. As a result, system "realizations" for parameter distributions such as conductivity can be produced, which when coupled with recharge and boundary conditions, produce distributions for potentials that are nowhere near the observed range for the system. Of all the data we gather in the field, potential distributions are the best; yet, these initial attempts at addressing uncertainty completely ignore this information.

The technology for addressing uncertainty in hydrologic systems is in its infancy. Methods of the future will eventually contain hooks for constraining the sampled "realizations" to head distributions within the uncertainty bounds for potentials. Future methods of determining uncertainty will certainly constrain the sampled "realizations" to those which give rise to potential distributions within the range of observations. If we only use the uncertainty data associated with permeability and porosity and ignore the constraints that the observed potential distributions place on travel time uncertainty, we will be in error and we may not be conservative. Most of the current concern with respect to research in uncertainty methodology is in the area of conductivity distributions. Uncertainty in boundary conditions, recharge, conceptual models, and stratigraphy are all sources of uncertainty which must be addressed in some way.

BWIP should challenge NRC current position regarding uncertainty and sensitivity and work jointly with NRC to determine the best possible approach for quantifying uncertainty in groundwater systems. BWIP and NRC should be careful in their selection of methodology for addressing uncertainty and examine each proposed new approach for potential shortcomings.

3.3.3 Traditional "Convective Dispersive Transport Equation"

Another area of potential concern to BWIP is the rapidly growing awareness in the scientific community that the traditional "convective dispersive transport equation" is deficient in correctly describing transport in a geohydrologic system. If NRC follows its current course, it will certainly require some kind of new contaminant transport assessment before the first repository is licensed. Both EPA and NRC have or have had active research programs in this area. BWIP should maintain an awareness of what work is being performed in this field and how the attitude of the scientific community is changing.

3.4 ASSESSMENT OF PLANS TO ADDRESS ISSUES

Many of the issues alluded to in this review have already been identified in previous reviews by the NRC, USGS, Golder and Associates (for the State of Washington), the Yakima Indian Nation, and other reviews of the SCR and the BWIP program. As a result of earlier reviews, the RHO-BWIP team is already aware of and has embarked on a course of action to address concerns that have been identified. The BWIP plans for remaining issues will be covered in the

SCP document, now in preparation. We have attempted to make a preliminary assessment of BWIP plans for addressing these issues via verbal communication with appropriate BWIP staff.

3.4.1 General

Since the publication of the SCR and the subsequent issuance of various reviews by the NRC (SCA), the USGS, and others, the BWIP team has been involved in several meetings with the NRC and USGS. The purpose of these meetings was to develop consensus plans for addressing the various issues. BWIP's extensive cooperation in these efforts was commended by the USGS in its letter to R. Morgan (July 28, 1983). Their desire to get on with the process of addressing the issues and proceeding with development of consensus plans for site characterization was also obvious at the DOE/NRC Meeting on Hydrology Testing (July 11-15) and at the various Interagency Hydrology Working Group meetings, held since these reviews.

Data Access Procedures

BWIP is in the process of supplementing their previously available data packages, interval reports program and drilling and testing quarterly reports with a new system for advising NRC and other affected parties, on a monthly basis, of new project test data. In addition, the site characterization data reports in the engineering release system will be placed in the public reading room and will be provided, as requested, to NRC and other affected parties. NRC and other affected parties will receive a monthly status report of additions to the engineering release system dealing with site characterization activities. BWIP is also in the process of implementing a computerized data base for geohydrologic data.

Averages

BWIP has indicated verbally that it will begin to address performance assessment with Monte Carlo and stochastic models (small perturbation approach). As pointed out in the previous section, the use of uncertainty methodology (Monte Carlo, Latin Hypercube, or current small perturbation stochastic methods) needs to be approached with great caution.

Brecciated Zones

BWIP has tested one zone of tectonic breccia at RRL-6 and obtained a value for hydraulic conductivity in the intermediate range between those encountered for flow tops and the dense interior. We know of no other plans to test other brecciated zones. Certainly the existing data on permeability of brecciated zones need to be supplemented.

Deep Drilling

BWIP has no plans for deep drilling at the current time. This subject should be reassessed sometime in the future in light of the rumors regarding developable gas reserves in the Saddle Mountains and the needs of a credible tectonic model (see Chapter 2).

3.4.2 Existing Field Data and Acquisition Methods

Drill and Test Procedure

The BWIP hydrology staff has been developing consensus plans to obtain the necessary data for characterizing the site and for evaluating the usefulness of the existing drill and test data. The plans and programs that are under way appear adequate for addressing these issues based on our current understanding. As data from these programs is developed, the need for additional tests may become obvious. Such tests could provide even more valuable additional evidence to support or refute the data and methodology. One, however, must recognize that no matter how conclusive the results of these tests appear, the data obtained via the drill and test operations will suffer some loss in credibility.

BWIP plans involve programs (some of which are already under way) to evaluate the following questions:

1. Was there enough time for equilibrium to be reached? Is the system in steady state?

   The BWIP plan for addressing these issues revolves around the drilling (air rotary) of three well complexes where multiple-level piezometers can be installed surrounding the RRL; the installation of multiple-level peizometer nests in the Grande Ronde in RRL 14 and

RRL 2; and the subsequent development of a baseline data set for potentials. From this baseline data set, the questions regarding the "steady state" issue can be answered directly. If the system is in steady state, the data can be used to interpolate values for the other boreholes that were installed via drill and test methods in and around the RRL site.

2. What effects does mud have on the chemical sampling and the hydraulic conductivity? BWIP has two programs currently implemented to address these issues. These are discussed further in Chapter 4.

At DC-14, a flowing well, a program to address the chemistry issue has been implemented. The program involves development of a temporal baseline data set on the chemistry from this interval. Subsequent to the establishment of this baseline data set, mud will be injected into the interval and the return to baseline conditions will be documented.

The program at DB-2 (an air rotary hole) is aimed at addressing the issue relative to the effect of mud on hydraulic conductivity measurements. This test will be conducted in the flow interior where the effects from plugging with mud should be most prevalent. This hole will be tested clean (without mud) and then retested after mud has been injected to simulate the drill and test procedure.

This same kind of test may also be needed on a flow top. In addition, BWIP should also consider a longer-term test on a flow top to address the variability question raised by a number of qualified reviewers. Testing the flow top over a much longer period while the hole is clean, having an observation well at distance, and repeating the test after injection of mud or loss of circulation material would serve to address this "scale" issue relative to hydraulic conductivity testing. A short duration test like that used in the drill and test procedure could be used for the repeat test.

Vertical Permeability

The questions here are related to determination of the magnitude and nature of vertical permeability. BWIP's current plans address these questions directly and appear adequate given our current state of understanding.

Work in geophysics is planned to attempt to get a better understanding of the nature of the "hydrologic barrier" to the west of the RRL. These efforts involve the areas discussed below.

1. Determining the character of the overlying sediments so that the magnetic data can be reinterpreted.
2. Drilling a line of closely spaced holes to the top of basalt across the suspected location of the barrier in order to determine if there are any analomies in the top of the basalt surface.
3. If the location of the barrier can be sufficiently identified spatially then an attempt would be made to drill through it with deviated drilling techniques.

We were told additional efforts are being undertaken to better define the other potential geohydrologic anomalies in and around the RRL which have been identified by geophysical methods.

An initial test to quantify the vertical permeability has recently been completed. This was a ratio test to determine the vertical permeability of the basalt flow interiors and was conducted at DC 4 and 5. While difficulties related to the setting of a packer negate the assignment of quantitative value to the magnitude of the vertical permeability, some qualitative feel for the transmissive properties can be made. A ~500 psi overpressurization developed during emplacement of a packer in a 48-ft-long interval of basalt interior took 8 weeks to dissipate. Plans for additional tests are under way for 1984. The test being considered is a cross hole test which was described by S.P. Neuman (University of Arizona) at an Interagency Hydrology Working Group meeting in December of 1982. After testing this method the relative value of these two methods will be evaluated and further tests will be planned.

BWIP is also planning to perform the large scale interference (pump) tests in the RRL area, after a potentiometric baseline has been collected. These tests should develop a clearer understanding of the larger scale permeability both horizontally and vertically and should provide invaluable information relative to the nature and magnitude of vertical permeability within the basalts in the RRL area. The USGS was initially backing these tests as providing fairly conclusive data relative to vertical permeability, but recently they have been indicating that these tests might not provide as conclusive a data set on the magnitude and nature of vertical permeability as had been previously thought. We feel, as do BWIP and NRC staff, that these tests will provide the type of information necessary for site characterization and for greatly reducing the uncertainty associated with evaluation of pre-emplacement groundwater travel times.

Effective Porosity and Dispersivity. Thus far only one field tracer experiment to determine effective porosity has been conducted. This test was conducted at DC 7 and 8 in the McCoy Canyon flow top. Some controversy was associated with interpretation of the results; this centered around the selection of the "appropriate effective interval length" to use in backing out a quantitative value for effective porosity from the empirical parameter used in the analysis of field observations. If the full packer interval is used, then a questionable low value in the range of 1.0E-4 is calculated. The uncertainty in this analysis approach needs to be resolved or a different analysis methodology selected. Additional tests of flow top effective porosity are contemplated in conjunction with other test programs. Tests of flow interior effective porosities are planned for the ES facility.

Regional Flow System Characterization and Potentiometric Baseline. BWIP currently has an existing monitoring program, which includes some 11 wells, completed mostly in the Priest Rapids and Mabton zones. The BWIP staff is also involved in an active planning program with the Interagency Hydrology Working Group. Their purpose here is to define an appropriate distribution of existing basalt wells outside the Hanford project but within the Pasco Basin, in addition to the wells within the Hanford Project that can be monitored to develop a potentiometric baseline. Using the potentiometric baseline, scientists could answer the "steady state" question and develop a data base on potentials sufficient to provide a defensible understanding of the regional groundwater flow system. BWIP is also in the process of developing a plan for installing bridge plugs in the deep boreholes that are currently open throughout the Grande Ronde.

Conceptual Modeling and Performance Assessment. The performance assessment staff have selected what appears to be an appropriate set of geohydrologic flow and transport tools and is in the process of documenting, baselining, and benchmarking these codes according to NRC standards. Personnel are beginning to study a variety of plausible conceptual models, as opposed to the single conceptual model approach. In Section 3.4.1 we allude to the problems we foresee with trying to adopt the NRC approach for development of a probabilistic assessment of travel time and we strongly caution the performance assessment staff from developing premature estimates of groundwater travel time before all the data are in.

The BWIP staff are actively involved with and supportive of the Interagency Hydrology Working Group of the USGS, BWIP and PNL. This group is working to develop a defensible understanding of the regional (Pasco Basin) groundwater flow system. We believe this effort is essential and should be continued.

3.5 SUMMARY OF GEOHYDROLOGIC FINDINGS

Our assessment of the Hanford basalts in the RRL area in relation to the draft DOE siting guidelines leads us to conclude that from a geohydrologic perspective, these basalts are neither completely optimum nor inadequate. These basalts satisfy the guidelines qualifying condition (960.4-2-1). Of the seven potentially favorable conditions, (960.4-2-1-(1) through (5)i-iii), the basalts could probably meet four and would probably not meet the other three. Of the three potentially adverse conditions (960.4-2-1-(1) through (3)), two of these conditions apply to the basalts while the third does not.

From a geohydrologic perspective, the biggest single issue relative to siting a waste repository in basalts is the complexity of the basalt geohydrologic system. The complexity of the basalts causes difficulties in characterizing and predicting performance. We conclude that a complex hydrologic system like basalt will require more data points and more careful characterization methods than simpler hydrologic systems to achieve the degree of confidence necessary to make the required performance predictions.

The problem of complexity, while more relevant for basalts, is by no means unique to basalts. The complexity issue is one that all repository sites are likely to face owing to the depths proposed for siting repositories. At BWIP this problem is greater, however, because of the extensive number of hydrogeologic layers and interacting flow systems. While identification of the number and thickness of basalt layers and interbeds is probably possible, it may not be as simple to identify the:

- exact location and hydrologic character of layer pinch outs,
- spatial integrity (i.e., the hydrologic confinement properties) of these layers, and
- the location and hydrologic character of dikes, faults, and other features (barriers) that could be important to vertical interconnection and travel time predictions.

The wide range in existing permeability measurements illustrates the variability in the local nature of this property, at least. It is this complexity in the stratigraphy and hydrologic properties of the basalt flows that makes the development of a single, unchallengeable conceptual model of the basalt geohydrologic system a difficult task.

The overriding hydrologic issue for the Hanford basalts is thus embodied in the following question: "Can the uncertainties in the understanding of the system, hydrologic model predictions and data base be reduced (by testing) so that compliance with NRC draft criteria for pre-waste emplacement groundwater travel times can be defensibly demonstrated?" Our examination of the existing geohydrologic data leads us to conclude that in spite of the complexity of the

Hanford basalts, these basalts can probably be characterized well enough to provide the required evaluation relative to the other media and sites under study.

Until all the information on potentiometric baseline, large scale pump tests, and other necessary regional and local site characterization data are available, there can be no defensible estimate of groundwater travel time with the appropriate uncertainty bounds. We do, however, feel there is a reasonable probability that once the site characterization data have been gathered and analyzed, the pre-emplacement groundwater travel time will be determined to be in excess of 1000 years.

The BWIP program for selection, baselining and benchmarking of performance assessment codes appears to be well-organized and progressing on schedule.

3.6 REFERENCES

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4.0 GEOCHEMISTRY

This chapter discusses geochemical technical questions identified in 1) hydrogeochemical analysis of the existing groundwater regimes in support of conceptual hydrologic model development, and 2) far-field nuclide transport. A third area, geochemical interactions among the waste package components, rock and groundwater, is discussed within Chapter 5.0, Waste Package.

4.1 ASSESSMENT OF HANFORD BASALT RELATIVE TO DRAFT DOE SITING GUIDELINES

Section 960.4-2-2 of the draft siting guidelines (U.S. Department of Energy, August 1983) contains qualitative statements on what constitutes favorable and potentially adverse geochemical conditions as well as listing qualifying conditions that must be met by each site. The following discussion first quotes discrete pieces of the guidelines and then discusses our assessment of the Hanford basalt for each point within the guidelines.

Geochemistry (960.4-2-2)

Qualifying Conditions. "The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, the groundwater, and engineered components, the conditions and processes of the geologic setting and the use of reasonably available technology shall permit (1) the requirements set forth in 10CFR60.113 for radionuclide releases from the engineered barrier system and (2) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment to be met."

With the data available today on the chemical interactions between basalt rock and its alteration products, groundwater and engineered components and the hydrologic data on flow paths and travel times, it is not possible to state unequivocably that requirements in 10CFR60.113 and Section 960.4-1 will be met. However, we can state that preliminary performance assessment analyses presented in the SCR, although open to criticism for lack of sufficient data, show that technology is available to permit such an evaluation to be performed.

Further, BWIP plans in the area of geochemistry should provide the types of data necessary to perform such an evaluation.

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

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

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

4) "A combination of pre-waste-emplacement geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository to be dissolved into the groundwater flow system."

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

In general, the Hanford basalt has geochemical attributes that lead us to conclude that it meets most of these favorable conditions. The Columbia River basalt has several favorable geochemical attributes such as neutral to slightly basic pH and an apparent low redox condition with a large source of FeII minerals that should be capable of maintaining reducing conditions. Both the neutral to slightly alkaline pH and reducing conditions are favorable in that they generally promote radionuclide precipitation and adsorption and minimize canister corrosion. The deep Hanford groundwaters do not generally exhibit high concentrations of inorganic complexing ligands that would tend to increase solubility. The high fluoride ion content in Grande Ronde basalt groundwater is suspected by Cleveland, Rees and Nash (1983) to form stable complexes with PuIV. Cleveland, Rees and Nash infer that higher than expected (when compared to similar granite, tuff and shale systems) plutonium solution concentrations observed in their basalt-groundwater suspensions could be the result of the high fluoride content (30 ppm). As the granite, tuff and shale systems all had much lower fluoride concentrations, they suggest that fluoride may be causing the higher solution concentration. No further experiments were performed to investigate the hypothesis (such as adding fluoride to the other rock systems or removing the fluoride from the basalt groundwater). Early, Jacobs and Drenes (1983) and SCA (1983), using thermodynamic modeling calculations, do not predict that the observed fluoride concentrations would significantly increase plutonium solution concentrations. These differing views will require further study.

Appreciable amounts of dissolved organic ligands do not appear to be in the deep basalt groundwaters; thus, organic complexation is not currently considered a problem. On the other hand, the recently measured high methane content found in samples of the Grande Ronde basalt flow within the Cold Creek syncline groundwater merits further consideration. Dissolved methane itself probably does not constitute a problem as an organic ligand for radionuclides, but upon radiolysis of methane, the potential for the formation of stronger complexing agents must be considered. The high methane contents also could be an adverse condition for mine safety and could designate the presence of valuable resources. These aspects are discussed in Chapters 6 and 2, respectively.

We suggest that the attributes discussed in the last two paragraphs allow one to rate the basalt geochemical conditions as favorable per cited favorable conditions 2 and 4, provided the volumetric flow rate of water in the host rock does not override the geochemical attributes.

The nature of the solution alteration processes occurring in the Hanford basalt aquifers, basalt primary minerals interacting with the waters to form secondary minerals, appears to be a favorable condition in regard to radionuclide adsorption. The predominate secondary minerals, clays, zeolites and hydrous iron oxides, have large adsorption affinities compared to the primary minerals of the basalt (see for example Barney and Anderson 1979; Barney and Brown 1980, 1981). The rock alteration reactions also cause fractures to in-fill with reaction products such that the fractures can be completely filled, resulting in reduced permeabilities. This occurs because the alteration phases have a less dense structure and thus take up more volume than the primary minerals. Such reactions might favorably impact potential radionuclide migration. Therefore, in regards to favorable conditions 1 and 3, basalt rock alteration is a favorable process.

The available BWIP retardation factors in the SCR and topical reports (e.g., Ames and McGarrah 1980a,b; Ames, McGarrah and Walker (1981) for expected repository reducing conditions show values greater than 10 for most important radionuclides excepting perhaps iodine.

The DOE guidelines also list the three potentially adverse conditions.

Potentially Adverse Conditions. 1) "Groundwater conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered barrier systems to the extent that containment would be compromised."

2) "Geochemical processes or conditions that could reduce the sorption of radionuclides, degrade the rock strength, or adversely affect the performance of the engineered barrier system."

3) "For disposal in the saturated zone, pre-waste-emplacement groundwater conditions in the host rock that are chemically oxidizing."

In general, Hanford basalt does not meet any of these adverse conditions. As will be discussed later, the pre-waste-emplacement groundwater is reducing with regards to most of the important radionuclides and represents a fluid not particularly adverse in terms of complexing radionuclides or enhancing uniform corrosion. As our knowledge of localized corrosion in the basalt environment is scarce, no appraisal is offered herein. More details on localized corrosion are given in Chapter 5, Waste Package.

The effects of colloids cannot be addressed at present for any of the five stated favorable conditions and three adverse conditions. BWIP staff are currently collecting data on colloids in laboratory experiments. Other unresolved concerns include high fluoride concentration in the deep groundwaters and the high methane content in the deep waters within the Cold Creek syncline. The former may increase the solubility of some radionuclides (e.g., Pu) somewhat; the latter, upon radiolysis, might allow formation of significant quantities of soluble organic chelators and deserves immediate attention.

In summary, given the data available today and our current understanding of radionuclide retardation processes, the Hanford basalts exhibit several favorable geochemical attributes for siting a repository. Further, except for the impact of the high methane content, current BWIP studies have the potential to produce the data needed to resolve the other geochemical concerns in a timely fashion. No potentially adverse conditions can be demonstrated from available geochemical data. The DOE guidelines for geochemistry contain no disqualifying conditions for site selection.

4.2 UNRESOLVED TECHNICAL QUESTIONS

As indicated in the introduction, unresolved technical questions for geochemistry occur in hydrogeochemical analysis of groundwater and far-field radionuclide transport. We decided to include any technical reports published since the SCR to evaluate whether a particular question was in fact still unresolved. In other words, our set of questions excludes some concerns by other critics who had only the SCR for a resource. BWIP's plans and status to date (both the plans and status have been reflected best in recent face-to-face meetings) indicate that most of the difficulties are being addressed in scientifically defensible fashion. Specific details and judgments of the progress toward closure of the geochemical unresolved questions occurs in Section 4.3 and 4.4 for hydrogeochemical analysis of groundwater and far-field radionuclide transport, respectively. Geochemical questions on the waste package are discussed in Chapter 5.

4.2.1 Unresolved Technical Questions - Hydrogeochemical Analysis of Existing Groundwater

For this topic, five general technical concerns have been identified: 1) procedure documentation, 2) data storage/management, 3) data adequacy, 4) data interpretation, and 5) reporting. Each general concern includes several specific issues addressed in Section 4.3. Summaries on the individual technical concerns are found in Section 4.5.

4.2.2 Unresolved Technical Questions - Far-Field Radionuclide Transport

For this topic, two general technical areas, solubility and adsorption, can be identified for which issues have been raised by critics of the SCR (1982). These two processes change the migration potential of radionuclides when compared with the groundwater itself. Knowledge of these two processes and their impact on each radionuclide forms the heart of the geochemical aspects of performance assessment and consequence analysis. Specific technical questions that pertain to predicting Hanford basalt solubility constraints on radionuclide migration include 1) determination of redox potential (Eh), 2) determination of complex formation, 3) determination of controlling solid for each radionuclide, 4) determination of temperature effects and 5) effects of colloids. Specific technical questions that pertain to predicting the retardation of radionuclide migration by adsorption processes include 1) control of Eh, 2) solid adsorbents studied, 3) effects of colloids, 4) radionuclides studied and 5) types of data collected. There are also two technical concerns common to both solubility and adsorption. The first is the rationale used to extrapolate the relatively short-term and small scale laboratory experiments to allow prediction of long-term, far-field performance assessment. The second deals with radionuclide transport code verification/validation. All of these questions and concerns are discussed in Section 4.4 and a brief summary of our findings is found in Section 4.5.

4.3 STATUS OF UNRESOLVED QUESTIONS ON THE HYDROGEOCHEMICAL ANALYSIS OF EXISTING GROUNDWATER

4.3.1 Procedure Documentation

Several reviewers were concerned that the SCR did not contain details on well sampling procedures, sample preservation techniques, chemical analysis procedures, and quality control. As the licensing procedure is to be in the legal arena, much more rigorous documentation than normally prepared for research activities will be necessary.

Procedures are needed for 1) sampling of surface water, well water, and rock and sediment core for geochemical analysis, 2) sample volume requirements and preservation, 3) chemical analysis for each constituent, 4) quality control for each measurement technique, and 5) quality assurance for each well sample.

During discussions with BWIP Site Department personnel on October 11, 1983, we were shown a copy of RHO-BWI-MA-4, Basalt Operating Procedures, a manual that documents all facets of site characterization, including geochemistry. A spot-check of the selected procedures dealing with geochemistry leads us to conclude that the manual gives adequate detail and further, the specific techniques used are judged to be technically appropriate for the areas of sample collection, sample preservation, sample analysis and quality assurance. We use the term quality assurance to refer to the system whereby BWIP assures itself (and the licensing entities) that the results reported do, in fact, refer to the sample that was collected. Most of the procedures have been updated or are new since the SCR, and conform with other standards or accepted practices endorsed by such bodies as the Environmental Protection Agency, United States Geological Survey, American Society for Testing and Materials and American Public Health Association. The overall manual, RHO-BWI-MA-4, is updated frequently and each particular revision has its own date, required update frequency and sign-off responsibilities specified.

Although quality assurance was excluded from the scope of PNL's review of the BWIP project, we make the following observations because quality is an important attribute in judging the usefulness of a chemical analysis. Our observations are incomplete and perhaps not accurate in that no discussions were held with BWIP/RHO QA staff. The written procedures and verbal discussions with the BWIP Site Department Staff lead us to recommend that more detail and attention be paid to quality control, especially with regard to analyses performed by BWIP subcontractors. We use the term quality control to refer to those actions taken by BWIP to ensure that the measurements performed in the laboratory are accurate. Verbal assurances were given that RHO analytical labs use classical quality control charts, rely upon available EPA and USGS standard water samples and NBS or equivalent rock and sediment samples, participate in interlaboratory comparison (round-robin) exercises and use blind duplicate samples to maintain quality control.

Quality assurance and control clauses are a formal part of BWIP subcontracts and RHO quality engineers periodically visit the subcontractors. At times, BWIP technical staff also join the quality engineers in the appraisal process. Despite such activities, it was not clear to us that instructions for sending subcontractors blind duplicate samples or some other appropriate quality control activity had been documented and understood by the BWIP site staff who use the subcontractor's results. Neither did we see any documented criteria or protocol for acting upon suspicious findings. For example, one BWIP scientist has been studying $^{2}H/^{1}H$ ratios in Hanford groundwaters. The analyses are performed by an outside subcontractor. A sample of tap water is sent to the subcontractor with each batch of groundwater samples as a quality control check. For one report period, the scientist observed a distinct change in the reported $\delta^{2}H$ (delta ^{2}H is a convention for quantifying the $^{2}H/^{1}H$ ratio of a particular sample versus an internationally agreed upon standard) for the tap water of 13^{o}/oo (^{o}/oo = parts per thousand). He questioned the subcontractor and was later informed that the lab reviewed the work and discovered a calibration error. Corrected values for that set of data were then sent to the scientist. (No mention was made as to whether a formal report was filed with RHO Subcontracts or Quality Assurance.)

We did not see or sense that documented guidance exists for the individual scientists to determine when and how to act upon a suspected quality control problem. For example, what if the jump in the $\delta^{2}H$ had only been 5^{o}/oo; should the scientist have done anything? (Note the analytical precision of this analyses is 2^{o}/oo; Dave Graham, RHO, personal communication.) Is it documented anywhere that it <u>is</u> the responsibility of the scientist to initiate action? Perhaps formal procedures exist within the BWIP program and the QA organization for dealing with these matters, but it was outside our purview to review BWIP's QA Department.

4.3.2 Data Storage/Management

Several reviewers (e.g., USGS, NRC and Golder and Associates) were concerned that the SCR reported only ranges and mean values for most chemical analyses and did not list individual analyses. Such summary reporting made independent review difficult. Much effort was expended by the USGS reviewers to collate information into a systematic form, such as tables by borehole or by aquifer formation. Upon creating tables, the USGS reviewers found numerous discrepancies within the SCR (1982) where data were reported as one value on one page or table and then reported as another value on a different page or table.

The large quantity of available geochemical data would best be handled with a computer-based data management system. Currently, BWIP geochemical well data are not conveniently stored. The recent data are stored in laboratory notebooks at the Materials Test Laboratory in 200E. The main site users are located in downtown Richland. An existing computer data base includes some data for each aquifer formation for each borehole, typically a recent analysis. Older data, duplicate data (from replicate analyses on the same sample), and very new data are being computerized at an unspecified rate. The existing data management system allows sorting and retrieving, but has no provisions for even simple graphics, such as forming X-Y plots of two variables or simple statistics such as determining means. It appears that most of the recent geochemical water and solids characterization data are stored in notebooks, topical reports and on borehole logs spread among several individuals. No discussions focused on the availability of historical data.

BWIP staff are acutely aware of the deficiencies in their geochemical data storage and management capabilities. A program-wide data base team has been formed to ascertain the overall BWIP needs in the area of data base management. Based upon identified needs, this team will select from commercially available software systems or subcontract for creation of a compatible system. The decision point is for the spring of 1984. We consider the need to centralize, conveniently store, retrieve and analyze the geochemical data as a significant problem impeding the reporting of the data.

4.3.3 Data Adequacy

USGS reviewers feel that a repository site geochemical model and a regional geochemical model are both needed to characterize the site, but neither are possible based on data available in the SCR (1982).

Critics have claimed that the data are inadequate for two reasons. First, sample coverage of the areal extent of the Pasco Basin and Columbia Plateau is insufficient. Sample coverage for the various aquifers/formations such as the shallow unconfined aquifer, aquifers below the Grande Ronde basalt flow, basalt interbeds and recharge zones is also insufficient. Second, chemical analyses are incomplete and potentially inaccurate (biased). Specific details are given below for each type of inadequacy.

Sample Coverage

The surface and bore-hole water data presented in the SCR have been judged as insufficient for developing a readily defensible geochemical model of the existing groundwater systems. The areal distribution of the surface water, and especially well sampling points, has been judged as being too sparse. The critics, especially the USGS, have given specific recommendations on where additional geochemical data should be collected. USGS (Robertson, 1983) suggests that geochemical data collection needs to be expanded beyond the Pasco Basin (Hanford site) and that temporal and spatial variations must be monitored. The USGS also states that more data are needed on precipitation, surface waters (including the Columbia River) and shallow aquifers. They particularly wish to see ^{2}H and ^{18}O isotope analyses performed, as these represent conservative tracers of the various water formations and are a key tool used to decipher groundwater evolution. The USGS (Robertson, 1983) recommends a minimum of ten new boreholes be drilled in the vicinity of the RRL. In particular, USGS states bore holes are needed 1) southwest of the Cold Creek syncline to investigate a potential local recharge zone 2) to delineate both boundaries of the Cold Creek syncline 3) across a suspected hydrologic barrier northwest of the RRL location and 4) downgradient from the RRL. BWIP has completed some new wells (DC-16 Cluster, RRL-2 and McGee) since the SCR, is currently drilling DC-19, 20 and 22 and plans a few additional wells such as

DC-18. Some of these wells will provide data to address the points that USGS raised on the hydrology of the Cold Creek syncline.

Though BWIP staff and the USGS resolved some issues related to the scarcity of sampling points, BWIP staff acknowledged that the USGS still feels that more wells are necessary within the Cold Creek syncline and that more data must be collected outside the Pasco Basin to allow conceptualization of a regional hydrologic model that could provide estimates of the boundary conditions for the Pasco Basin hydrologic model. BWIP staff indicated during the October 11 meeting that they differ with the USGS on the size of the region and effort that should be allocated to obtain an accurate geochemical regional model. The BWIP's current effort is geared at looking closely at the Pasco Basin and not at the entire Columbia Plateau. BWIP has no current plans to drill new boreholes outside the Pasco Basin, but plans on acquiring existing USGS data where available to produce a more regional geochemical picture. More meetings with the USGS and the Hydrology Overview Committee may influence future actions. We agree with USGS that a regional conceptual hydrologic model will prove necessary to bound the local Pasco Basin model. The regional model, in our opinion, will be essential because of the high level of complexity extant in the hydrologic system of the Pasco Basin basalt formations. Focusing solely upon the Pasco Basin will not allow unequivocal interpretations; thus, the bounding values afforded by a regional model seem essential. Geochemical interpretations will likely play a key role in development of both the regional and local hydrologic models. Thus, the need for more wells for geochemical sampling should be given a high priority and fiscal support.

During the October 11 meeting, BWIP staff described available geochemical data on temporal variation of water samples. Data are available from springs on the Hanford site and wells within the Mabton interbed (DB-1,2,4,5,7,9), Priest Rapids basalt flow and the Wanapum formation (McGee well) and Grand Ronde formation (DC-14 and DC-6). No significant seasonal variation in chemical composition has been observed in the well samples. Samples taken in the springs over several years show no significant changes in base-flow chemistry (samples from each early summer). Spring samples taken after a substantial rain storm do show chemical similarity with precipitation itself, reflecting the influence of surface runoff and fracture flow. If BWIP would document these data to facilitate independent review, it may be possible to close out the concern on temporal variations in chemical data.

The distinct chemical nature of the Grand Ronde waters within the Cold Creek syncline (elevated salt content, compared to other nearby basalt flows, and high fluoride and methane contents) suggests that borehole(s) should be completed below the Grande Ronde formation within the Cold Creek syncline to investigate the chemical signature of deeper waters. Boreholes would also help scientists interpret whether there is upward leakage into the Grand Ronde basalt flow. Knowledge of the origin and extent of the methane found in the Grand Ronde water is necessary to aid in assessment of mine safety discussed in Chapter 6. Further knowledge of the stratigraphy below the Grand Ronde basalt formation is needed to aid in interpretation of available seismic data as discussed in Chapter 2.

In the area of rock and sediment characterization, reviewers expressed concern that solids characterization of the interbed, basalt flow tops and fractures was lacking in the SCR, especially for identification of the accessory and secondary minerals. Some additional data on mineralogy have been reported in RHO-BW-ST-28P-Draft (1983), but BWIP has recognized that more data are needed. During the October 11 meeting, we were given a two-page listing of deliverables that the BWIP solids characterization team is committed to providing the BWIP Site Department in the near future. By September 1984 the following samples will be characterized (for minerals present with a semiquantitative description of percent by weight) at a minimum Mabton interbed (19 samples), flow top and interior Cohasset basalt (5 samples), McCoy Canyon (2 samples), Umtanum Flow (2 samples), flow top of basalt directly under the Cohasset flow (8 samples) and Grande Ronde and lower Frenchman Springs fracture and vug fillings (15 samples). Characterization of some samples will concentrate on identification of secondary minerals and glassy mesostasis components. In addition, sulfides, Fe-Ti oxides and any other phase identified in the Grande Ronde basalt flows that may control Eh will be studied. Such characterization should provide enough data over the next year to conclude whether additional mineralogic characterization work is necessary. These data will support reaction path geochemical modeling, far-field radionuclide transport testing and waste package interactions testing as well as site characterization.

To our knowledge, chloride, fluoride and boron contents within the rocks have not been reported; such analyses would be useful in unraveling the source of distinctly saline (compared to other reported Hanford waters) Grande Ronde waters. As an alternative to these analyses, water samples from below the Grande Ronde formation should be obtained to provide data to interpret the anomalous fluoride content and high boron and chloride contents found in the Grande Ronde formation waters.

Chemical Analyses

A particular concern was voiced that BWIP's procedures for collecting gas samples were deficient. During our October 11 meeting, discussions led us to conclude that the current collection techniques have been improved. BWIP staff ordered hardware to fabricate a state-of-the-art system that will allow downhole at pressure and temperature sampling. This hardware will further improve their gas collection capabilities. The current technique involves collecting a water sample in a gas-tight container at the well-head. The technique operates best on artesian wells but is probably only semiquantitative because of pressure relief, which allows two-phase flow during sampling. Therefore, it is questionable to attempt quantitative calculations back to a concentration dissolved in solution. In the SCR (1982) the data are given in % of total gas collected not as dissolved concentrations. Gases currently being analyzed by a subcontractor include hydrogen, oxygen, nitrogen, carbon dioxide, carbon monoxide, helium, argon and methane. We recommended that dissolved hydrogen sulfide also be measured, as this gas is a key redox-sensitive parameter (useful in evaluating Eh) and forms very strong complexes and insoluble compounds with numerous trace metals and radionuclides. Thus, knowledge of dissolved hydrogen sulfide concentrations is necessary to predict solubility limits. The methylene blue colorimetric procedure described by APHA (1981) or Plumb (1981) is recommended.

As mentioned previously, isotopic analyses especially ^{2}H and ^{18}O, are very useful tools to aid the development of the conceptual geochemical model. Stable and radioactive isotope data provide a means of distinguishing, categorizing, and dating groundwater, thereby supplementing standard analytical measurements that specify the composition of the solution. The isotopic data can also be used in generating and testing conceptual reaction models of the groundwater-rock system. Typically, several reaction models can be generated that will satisfy the chemical mass balance constraints on the system. The isotope balances along the assumed flow path can be used to eliminate improbable reaction schemes and further define the geochemical model. An accurate geochemical model can in turn be used to evaluate constraints imposed by the geochemical data on the conceptual hydrologic models.

BWIP's current isotope analyses for all well samples include the stable isotope ratios $^{2}H/^{1}H$, $^{18}O/^{16}O$, $^{34}S/^{32}S$ and $^{13}C/^{12}C$. Radioisotope analyses include ^{3}H, ^{14}C and ^{36}Cl. Some of these data have been collected on selected samples since the late 1970s and results were presented in the SCR. BWIP is currently evaluating a proposal to measure the disequilibrium ratios of the natural decay chains for ^{238}U, ^{235}U and ^{232}Th. We judge the current activities and plans adequate in terms of completeness in isotopes measured and appropriateness of analytical techniques used. The interpretation of the data is the subject of the next subsection.

Reviewers have expressed concern that many of the water analyses reported in the SCR may be inaccurate because of drilling-mud contamination. BWIP has a mud contamination experiment in progress in borehole DC-14. BWIP staff remarked that drilling-mud recovery has been most difficult in the Grande Ronde basalt formation (in which DC-14 is open); therefore, the test should represent a worst case where drilling mud might significantly bias results. Ten thousand gallons of drilling mud slurry were pumped into the borehole. Water is continually being removed from the well (4 gal/min) and the water chemistry is being measured on selected aliquots and compared with expected baseline values. At present, 1.2 million gallons of water have been removed. The data analysis is ongoing and preliminary conclusions are that the major cation and anion constituents rapidly reach steady state concentrations similar to baseline. Some of the trace constituents have not yet reached baseline values. Tritium, injected in the drilling mud slurry (Columbia River water is used for mud makeup), and ^{14}C present naturally in the organic polymer based drilling mud, appear to be sensitive tracers for determining when the bulk of the mud slurry has been removed. In general, BWIP staff feel that their past analyses have not been significantly biased by drilling mud, with the exception of a few trace constituents, especially ^{14}C. We can offer no opinion because we have not seen the data. The data collected from DC-14 should allow definitive statements about the volumes (versus mud used) that must be removed prior to sampling for each important constituent. It is possible that once BWIP staff document the findings from the DC-14 test, this issue may be closed, but our generalized discussions allow us few objective data. We eagerly await documentation of the data.

4.3.4 Data Interpretation

Critics of the SCR voiced much concern in the interpretation of the $^{13}C/^{12}C$ stable isotope data, ^{14}C data, and the proposed conceptual geochemical model. Each of these specific issues is discussed below. A further unresolved issue is the origin of the high fluoride content in the Grande Ronde formation groundwater. BWIP currently does not have an unequivocal explanation for the 30 ppm fluoride levels. In one hydrothermal experiment (11 days at 300°C) in which basalt was reacted with deionized water, a steady state fluoride value of 18 ppm was obtained. This suggests to BWIP staff that the fluoride could be leached from the glass mesostasis of the basalt. No specifics on basalt-to-water ratio were given during the discussion. No plans to identify the origin of the fluoride were offered during the October 11 meeting. At present the origin of the fluoride requires additional study, but the basalt rock may be the source.

^{13}C Data Interpretation

The USGS review (Robertson, May 1983) disagreed with the BWIP interpretation of the $\delta^{13}C$ data in regards to the origin of the methane observed in well waters. Since publication of the SCR, BWIP staff have collected more data, improved gas collection techniques, and discovered high methane concentrations within the Grande Ronde formation groundwaters in the vicinity of the RRL.

During discussions on October 11, the current BWIP interpretation was presented. BWIP has measured the $\delta^{13}C$ for both the methane gas (degassed from the water samples) and bicarbonate/carbonate content in the groundwater. For the methane gas on a per mil basis ($^{o}/oo$), it has been found that methane formed by microbial degradation of organic matter under anaerobic conditions yields $\delta^{13}C(^{o}/oo)$ values more negative than -55 ±5. On the other hand, the $\delta^{13}C(^{o}/oo)$ values for the inorganic carbon system in microbially-induced methane-rich groundwater are expected to be enriched relative to normal groundwaters. The ^{12}C is metabolized by the microbes, forming organic carbon (i.e. CH_4), while the remaining inorganic carbon (CO_2^{2-}, HCO_3^-, etc.) becomes enriched in the ^{13}C. For heat-induced systems, the groundwater inorganic carbon $\delta^{13}C(^{o}/oo)$ value should not deviate positively from normal groundwater environments (-15 to -10).

Current data show that methane in the lower Saddle Mountain and Wanapum formations have $\delta^{13}C$ values as low as $-88^{o}/oo$ (DC-15 borehole), well into the microbial region, while the comparable groundwater carbonate $\delta^{13}C$ values are typically positive, 0 to $+15^{o}/oo$ (see Table 5-39 in SCR, 1982). On the other hand, Grande Ronde formation waters within the RRL area that are rich in methane give methane $\delta^{13}C(^{o}/oo)$ values close to the boundary values between microbial versus thermal generated methane and the groundwater carbonate $\delta^{13}C$ values range from -2 to +17. This suggests that the methane in the Grande Ronde formation within the Cold Creek syncline could have a thermal origin, but the methane in the upper formations seems to be unequivocally biological in origin. The inorganic carbon data for the Grande Ronde formation on waters suggest some enrichment in $\delta^{13}C$ from biological activity; therefore, the methane may be a mixture. As the thermal process usually requires temperatures near or above 100°C, the $\delta^{13}C$ data could be used to support upward migration of deeper waters into the Grande Ronde formation in the vicinity of the RRL. The data from shallower formations and outside the Cold Creek syncline suggest that vertical leakage of thermally produced methane is not occurring in these areas. We feel that criticisms may be partially resolved upon publication of BWIP's new data and interpretation. We also recommend measurement of the chemical composition of waters in formations below to Grande Ronde basalt flows in the vicinity of the RRL.

^{14}C Data Interpretation

Several reviewers were concerned that the groundwater ages that BWIP calculated from the ^{14}C data were incorrect because correction factors for carbon that had been introduced by dissolution of old carbonate minerals were inappropriately used. BWIP staff have also found that drilling mud contamination and the low total carbon content of the deep Hanford groundwaters confounds accurate measurement. BWIP staff currently do not rely upon ^{14}C dating to give absolute values for water age, but do find ^{14}C data useful for giving qualitative information on relative ages, water flow direction and possibly for flagging drilling mud contamination problems. BWIP is investigating other radioactive isotopes to calculate groundwater ages more defensibly. Thus, the ^{14}C technical issue should dissipate once the current philosophy is conveyed to the technical critics.

Conceptual Geochemical Model

Several critics strongly disagreed with simplified statements in the SCR summary that left an impression that BWIP claims that the aquifers in each formation are isolated and that all water flow is horizontal within the formations. In other words, critics felt that vertical communication (leakage) between the aquifers does occur. The SCR (1982; Chapter 5) contains a technical discussion that concludes that vertical leakage between certain aquifers at certain regions within the Pasco Basin does occur. The main technical issue appears to us to revolve around the extent of leakage. The PNL assessment of BWIP plans to quantify vertical leakage and its significance is discussed in Chapter 3. The question of vertical leakage would also be by water chemistry measurements on water samples taken below the Grande Ronde basalt flows.

4.3.5 Reporting

The lack of technical reports that document the available hydrogeochemical data and their interpretation has provoked much of the concern and negative reviews on this area of the BWIP project. BWIP Site Department staff members are acutely aware of this problem and have increased staff in hopes of improving performance. Frustration levels are high among the technical staff, whose time has been occupied with rebutting the aforementioned reviews, generating further plans and justifying current and past activities. We discussed the importance of technical report preparation during our October 11 meeting but were given no specifics on when the Site Department planned to solve this problem. The amount of data already collected and that being collected currently creates a challenge that gets more difficult with time. The aforementioned data storage/management issue is tied very closely with this reporting issue and both deserve immediate attention.

Besides the SCR, the only two technical reports offered to our review team that included data on hydrogeochemistry was the Repository Horizon Identification Report (RHO-BW-ST-28P-Draft, 1983) and Graham's report (1983) on the ^{2}H and ^{18}O data collected on precipitation samples (64) around Rattlesnake Hills.

4.4 STATUS OF UNRESOLVED QUESTIONS ON FAR-FIELD RADIONUCLIDE TRANSPORT (PERFORMANCE ASSESSMENT)

4.4.1 Solubility

Redox Potential (E_h)

In the SCR (1982), BWIP relied quite heavily upon arguments with respect to solubility constraints on dissolved radionuclides to evaluate potential impacts of siting a repository in basalt. Within the NRC's analysis (SCA, 1983), especially Appendix U, issues were raised that criticized BWIP's discussion of solubility of radionuclides in the SCR. Solubility constraints for several important radionuclides (e.g., Pu, Np, U, Tc, Se) can be very sensitive to the redox conditions chosen. Within the SCR, BWIP used a theoretical approach based upon thermodynamic calculations to bound expected Eh conditions. Their key assumptions were that iron-bearing minerals in the basalt control the oxygen fugacity, which in turn is related to Eh. Three calculations were performed using different iron-bearing mineral assemblages: 1) hematite-magnetite, 2) magnetite-fayalite, and 3) magnetite-pyrite. At the repository's ambient temperature and pH (51-58°C and 9.5 respectively), the three calculations yield an Eh range of -0.43 to -0.53 volts. Within the SCR (1982), the discussions remain somewhat hypothetical because little data are presented to show that either of the mineral pairs are known to be redox potential buffers at temperatures as low as 60°C. (Their buffering capabilities are much better known and understood at higher temperatures.) Further, it is not clear that BWIP has identified hematite or fayalite as being present in the basalt or interbed formations.

Actual field measurements with a platinum electrode (shown in Table 5-31 in the SCR (1982) yield values of +0.21 to -0.22 volts. BWIP quotes several references that suggest that platinum electrode measurements in low dissolved solids (unpoised) groundwaters are often subject to large errors. Thus BWIP feels the thermodynamic calculations more correctly reflect expected conditions. Several critics have attacked the theoretical calculations (e.g., Schweitzer and Davis 1983) as unconvincing. They note that some of the phase assemblages selected are known to occur together outside their calculated equilibrium Eh ranges and BWIP has not proven that these minerals control the iron chemistry of the Hanford groundwaters.

The USGS (Robertson, July 28, 1983) suggest that the FeII - FeOOH couple may control the Eh in the basalts, and that such a couple could result in Eh values as high as +0.1 volts. BWIP staff have countered (M. J. Smith, September 21, 1983) that mineralogic characterization of numerous basalt samples that include secondary phases, has failed to show the presence of FeOOH (geothite is an FeIII mineral). The present data suggest that only mixed FeII - FeIII minerals are found, which implies a more reducing environment (see Benson and Teague, 1982). It should be noted that Benson and Teague dealt with a rather limited number of cores and samples, they call their valence state (FeII vs. FeIII) apportioning "a crude approximation" and that some mineral polymorphs of FeOOH may be poorly crystalline and not identifiable by instrumentation used by Benson and Teague.

Currently, BWIP staff suggest that the most likely redox controlling couple involves the dissolution of an iron-pyroxene component (not a separate phase) in either the basalt glassy mesostasis and/or crystalline pyroxene phase. BWIP has adopted an ideal solid solution model, assigning the activity of components to be equal to the mole fraction of these components in their respective solid phases. Using the following equation and designated activities (in parentheses under each component) for the solid components at pH values between 9 and 10 and ambient temperature 50°C, the calculated Eh value is -0.42 to -0.48 volts. Specifics on Gibbs free energies of formation and temperature corrections used in these calculations were not supplied to PNL.

$$3FeSiO_{3(s)} + H_2O \rightleftharpoons Fe_3O_{4(s)} + 3SiO_{2(am)} + 2H^+ + 2e^-$$

designated activities	(0.03)	(0.3)	(1.0)

At the October 11 meeting with the BWIP Site Department, we discussed current Pt electrode field measurements. BWIP observes a stable electrode response at values between -0.1 and -0.3 volts at the surface in an air-tight sample cell where well water flows directly out of the well head with minimal exposure to air. This can be compared to the range +0.21 to -0.22 reported in the SCR for deep groundwater samples measured in the field, but not necessarily within an air-tight sample cell.

It should be stressed that BWIP staff do not put emphasis on any one of the many theoretical calculations, actual electrode measurement or direct observation of redox-sensitive solids and solution species in field and laboratory tests. Rather, BWIP staff rely on the convergence of all these techniques to a narrow range of Eh values to support their contention of reducing conditions. BWIP staff also believe that no matter what Eh is measured or calculated, each redox-sensitive radionuclide must still be demonstrated to be responsive to the controlling (buffering) reaction. The reaction of each multivalent radionuclide within the systems to be studied in the laboratory will be determined by measuring actual valence-state distributions. Measurement of valence-state distribution is often very difficult due to very low total concentrations available or the low percentage of one valence-state compared to the other. In all but a few instances direct measurement may yield only qualitative results, such as plutonium is predominately in a reduced form, as opposed to a quantitative statement like the plutonium valence-state distribution was found to be PuIII = 3%, PuIV = 93% and PuV = 4%.

For hydrothermal conditions, BWIP has used AsIII/AsV as an indicator of redox, is developing a teflon diffusion cell to allow measurement of the partial pressure of hydrogen and is attempting to develop a high temperature Eh electrode for use in experiments performed in autoclaves. More discussions of these techniques are found in Chapter 5. BWIP has tried and has indicated plans to continue to attempt actual solution redox couple measurements to ascertain ambient groundwater Eh values. To date, couples tried [SO_4/S^{2-}, FeII/FeIII and AsIII/AsV] have been mostly unsuccessful because concentrations were below detection limits or in the case iron contamination from the well pipes is suspected. BWIP claims to have data on the SOIV/SII couple that support their claim of reducing conditions.

From viewgraphs presented at a September 6-7 meeting with the Waste Package Department, it appears that arsenic speciation data measured in hydrothermal experiments, preliminary H_2 diffusion data and data on glass leaching in the presence of basalt suggest that at higher temperatures (150-300°C), the basalt acts as a reducing agent. Even at room temperature, Bondietti and Francis (1979) and Meyer et al. (1983) have shown basalt can reduce Tc and Np to lower oxidation states. Rai, Serne and Moore (1980) suggest that basalt can also reduce PuVI solution species. All three reports show these radionuclides readily adsorb or become incorporated into the rock.

The preponderance of evidence leads us to conclude that unaltered basalt will generate an environment capable of reducing such radionuclides as Pu, Np, Tc and Se. But two situations warrant further investigation before the Eh issue can be completely resolved. Most of the hypothetical radionuclide flow path will be through old fractures that have been coated with alteration products. These products might inhibit the Fe^{2+}-rich basalt and glassy groundmass from controlling Eh. As mentioned, BWIP staff have indicated that mineralogic characterization of interbed, flow top and weathering products is a major thrust in the coming year. Preliminary data suggest that the alteration products are mixed FeII - FeIII minerals, which should exhibit some reducing capacity. We recommend that experiments be planned to quantify the reducing power of weathering products. Some data may be gleaned from ongoing nuclide adsorption studies. The effect of radiolysis in the waste package environment on Eh will be discussed in Chapter 5.

Complexes

The very brief technical discussions on solubility within Chapter 6 of the SCR do not attempt to evaluate the importance of considering complex formation. Writers of the SCR relied upon the assumption that actinide oxides and hydroxides are the only controlling solids and that hydrolysis species predominate in solution. NRC (SCA, 1983) devoted most of Appendix U to illustrate that the SCR seriously underestimated the solubility of actinides in basalt groundwaters. We concur that solubility discussions within the SCR were too simplistic and not defensible in light of knowledge available to the scientific community at the time that the SCR was written. Since the SCR, BWIP has published two technical reports that give a more in-depth treatment to probable solubilities for important radionuclides in basalt groundwaters (Early et al. 1982 and Early Jacobs and Drewes 1983). These two documents (one a technical report and the other a proceedings article using the same data) are much more defensible and address most of the NRC's concerns. The documents also identify limitations and data that need more attention prior to making defensible quantitative predictions for safety assessment exercises.

The two BWIP reports in fact agree with many of the NRC calculations given in Appendix U. Both institutions agree upon the controlling solid phase for Am, Np, Pu, probable predominate solution species for Am and Pu, and estimated solution concentrations for Am and Pu for a range of Eh conditions (NRC +0.21 and -0.22 volts and Early et al. -0.6 to 0.0 volts) at repository pH values and 25°C.

The NRC calculations choose uraninite (UO_2) as the controlling solid under reducing conditions and schoepite [$UO_2(OH)_2\ H_2O$] under oxidizing conditions. BWIP calculations suggest coffinite ($USiO_4$) controls the solubility under both sets of conditions (Eh -0.6 to 0.0 volts) as the measured Si concentrations in the groundwater are high. The NRC also includes a species, UCO_3^{2+}, that is not universally accepted as existing (see for example Langmuir, 1978). The resultant uranium calculations expected for the Grande Ronde basalt groundwaters differ between the NRC and Early's work because of these choices. The NRC calculations show uranium concentrations of 10^{-5} to 10^{-6}M (caused by the predominance of the UCO_3^{2+} species), while Early's calculations give results of 10^{-8} to 10^{-9}M. BWIP also remarks that available groundwater analyses of uranium agree with Early's predictions.

A similar discrepancy is found in Np calculations, where NRC assumes the existence of a $NpCO_3^{2+}$ species based upon analogy to a PuIV carbonate species. The stability constant for PuIV carbonate, $PuCO_3^{2+}$, has been estimated from data collected by Moskvin and Gel'man (1958). Lemire and Tremaine (1980) have reviewed the data and estimate a $\log_{10} K_1$ of <41 for the complex, but do not put much confidence in the existence of the complex. A recent review by Kerrisk (1982) points out flaws in Moskvin and Gel'man's assumptions and makes an independent estimate of log K that argues for a value of only 10. Using such a value would greatly lower the estimated maximum solubility-limited concentrations of the Pu (by both NRC and BWIP). Since the NRC used a model that assumed the existence of UCO_3^{2+} and $NpCO_3^{2+}$ species with stability constants (log K = 41), Kerrisk's argument would also significantly lower the NRC predicted solubilities of U and Np and bring them close to BWIP estimates based on the works of Early et al. (1982, 1983). NRC states in Appendix U that their calculations "are not intended to represent an accurate assessment of the solubility limits of U, Np, Pu and Am solids" but rather to "illustrate that the lack of consideration of important complexes can result in serious underestimates of solubility." The major point that can be made is that BWIP, since the SCR, has documented a more defensible capability to estimate solubility limits that acknowledges the effects of complexation. Thus the NRC criticisms have been addressed by recent BWIP work. Nevertheless, the importance of carbonate complexes for actinides remains an issue requiring experimental data. The issue is important for all nuclear waste management options and is being studied by various researchers in the U.S., Sweden and France.

In terms of the companion need to measure the existing range of complexing ligands within the groundwater, BWIP's current activities are fairly complete. We do recommend some effort to measure the phosphate concentration in some representative groundwaters. Phosphate can form some relatively insoluble compounds with many of the important radionuclides.

Solid Phase Controls

Determination of the more likely solid phases that could control the concentration of each radionuclide is a task addressed in the Chapter 5, Waste Package, because it is in the near-field region that such controls would occur. The NRC (SCA, 1983) comments on page U-7 that BWIP's choice of hydroxide and oxide as the controlling solids for the transuranics resulting from the leaching of borosilicate glass waste forms may not be adequate is not supported by any evidence. On the other hand, Rai and Strickert (1980) and Rai, Strickert and McVay (1982) suggest that at room temperature, Np and Pu solution concentrations resulting from dissolution of borosilicate glass, PNL 76-68, are controlled by their respective oxides. It is acknowledged that the experiments were also done in the presence of air as opposed to expected repository reducing conditions and that no basalt was present. Our recommendations for additional experiments of this type are presented in Chapter 5.

Temperature

Temperature effects on solubility calculations will be discussed in Chapter 5, but we shall state herein that BWIP's effort does include some empirical studies that provide data jointly on temperature effects (up to 150°C) on adsorption and solubility. The BWIP Waste Package Department has released draft plans on the Barrier Materials Test Plan (SD-BWI-TP-022-Draft, 1983) suggesting that they will rely upon empirical studies at higher temperatures to determine radionuclide steady-state solution concentrations. (See Chapter 5 for additional details and our recommendations for supplemental experiments.)

Colloids

The effects of colloids on radionuclide transport processes and predictions is currently being studied through empirical flow-through column experiments. Once some observations are available, BWIP staff plan to make decisions on the need for additional study of colloids. In a strict sense, colloids should not affect solubility itself because only true solution species should be considered. However, colloids can affect the transport of radionuclides in solution, adsorption and release from waste forms. More discussions on BWIP's colloid investigations follow in the subsection on adsorption.

4.4.2 Adsorption

Adsorption represents an important radionuclide attenuation mechanism, perhaps the most important mechanism that mitigates radionuclide migration in the far-field. Adsorption is strongly dependent on the type of solid adsorbent present, its available surface area and electrical charge distribution, as well as groundwater composition, pH and Eh. Adsorption, solution complexation, precipitation-dissolution and redox reactions are all interrelated such that a complete understanding of adsorption cannot ignore the other reactions.

Typically adsorption is studied in the laboratory using two common techniques, static batch and dynamic column experiments. BWIP has documented many results and the effects of the aforementioned variables on radionuclide adsorption constants. [See, for example, Ames and McGarrah 1980a, 1980b; Ames et al. 1981, 1982, 1983; Salter et al. 1981; and Barney 1982.]

In general, our review allows us to conclude that the BWIP effort in adsorption is technically sound and that verbally discussed future plans should resolve outstanding issues. The few outstanding issues are summarized below.

Redox Potential (Eh)

The expected far-field redox conditions are reducing compared to conditions found in the laboratory; therefore, some sort of control must be attempted to create a laboratory system that is reducing and similar to the deep repository environment. BWIP and others have used controlled atmosphere chambers and addition of reducing agents or buffers. Most of the reported BWIP data (see references above) that represents reducing conditions was obtained using the reagent hydrazine. Some critics are concerned that the addition of significant amounts of this reagent could bias the observed sorption values. In our opinion, BWIP should perform some complementary experiments using the controlled chambers and/or other reagents. A specific document that compares the results using various approaches would help clear up this issue. As with Eh measurement itself, the most convincing arguments to establish the validity of adsorption constants for reducing conditions would be based on the convergence of results using several different techniques.

Solids

Reviewers expressed some concern that BWIP's coverage of solids neglected flow top, interbed and fracture filling materials. Numerous BWIP documents are available on the adsorption characteristics of interbed materials and minerals known to predominate in the fracture fillings (see Salter et al., 1981, Barney, 1982, and Ames et al., 1982 and 1983). Current and future far-field adsorption plans suggest that BWIP will continue to emphasize such materials and include flow top materials, which is appropriate given that these materials contain the water in which transport would occur.

Nuclides

As early as 1980, Barney and Wood documented BWIP's rationale and prioritized the radionuclides for which adsorption data need to be collected. We find the rationale and nuclides studied to be adequate, technically sound and basically in agreement with an independent assessment (Serne and Relyea, 1983).

BWIP staff recognize the dependency of adsorption constants upon radionuclide concentration, groundwater composition and temperature. The BWIP adsorption data cover the effects of radionuclide concentration (via isotherms), temperature effects (25° to in select cases up to 300°, typically to 150°C); and via different reference groundwaters address groundwater composition effects. The groundwaters chosen to date do not include methane or most of the trace constituents. The range of pH and macro cations and anions investigated using the different reference groundwaters is also not as large as some critics, including PNL, would like.

Colloids

BWIP has recently started flow-through column adsorption studies with crushed rock material to supplement past batch experiments. Such column experiments could address important issues that can't easily be studied in batch systems, such as multiple speciation and colloid transport. Results are not documented on preliminary work and future plans for far-field work appear unavailable. For completeness, we suggest that BWIP assess the need to perform flow-through experiments on uncrushed, fractured core material as being used by researchers on other crystalline rock types such as granite in Canada and Sweden and tuff in the United States.

Performance Assessment Issues

The final two issues germane to far-field radionuclide transport are extrapolation of laboratory data for far-field performance assessment and transport code verification/validation. BWIP has no specific plans available in the former. Progress since the SCR includes a two-day workshop held in late August 1983, with tracer field test experts from the United States and Canada. BWIP staff are currently formulating plans for radionuclide field tests. No dates or details about what the plans will include were available in the October 11 meeting.

No specific discussions were held between the PNL geochemistry review team and BWIP Systems Department staff on radionuclide transport code verification/validation. General comments about performance assessment code verification/validation are found in Chapter 7.

4.5 SUMMARY

Comparing the geochemical attributes of the Hanford basalt system to DOE siting guidelines leads us to conclude, with the data and knowledge available, that Hanford basalt has several favorable attributes. Available knowledge and data do not lead us to conclude that there are serious unfavorable attributes. Favorable attributes include pre-emplacement reducing conditions, neutral pH, average radionuclide complexing potential and alteration mineralogy that increases adsorption potential and lowers permeability by filling the fractures. The major unassessed area is the effect of the high methane concentration on radionuclide retention processes. Another technical area needing data is the possibility of colloid formation and the effects of colloids on radionuclide retention. Of these two unresolved questions the impact of methane needs immediate attention.

From our review of the HSCR, SCA and other documents, five general technical areas were identified that need resolution prior to using hydrogeochemical analysis of existing groundwater to aid in the hydrologic flow model. The areas are: 1) procedure documentation, 2) data storage/management, 3) data adequacy, 4) data interpretation, and 5) reporting.

Our review of these five areas leads to the following conclusions. BWIP has adequately documented procedures for sampling waters, rock and sediments, sample preservation and analysis techniques for each constituent. The procedures appear to be technically sound and conform to standard practices of such institutions as EPA, ASTM and APHA. Although not a part of this review, we do suggest that quality control requirements for subcontractors in the area of chemical analyses of waters be reviewed. The current methods of managing the large amounts of geochemical data being produced are weak. The data appear to exist in many cases as hand-written entries in laboratory notebooks. An effort is being made to survey all of BWIP's data management needs. In the spring of 1984 a recommendation will be made to develop a computer-based data management system or to buy an existing software system. The current conditions impede the analysis and timely reporting of the data and may be a key factor causing the poor record on documentation.

The data adequacy area includes two issues, sample coverage and data quality. Reviewers suggest that the areal coverage on the Hanford site is too scarce to develop a geochemical model and that it is necessary to develop a regional model that covers the whole Columbia Plateau. Since the SCR, BWIP has drilled several new wells and has better onsite areal coverage. It is premature to decide whether the current coverage is adequate to develop a Hanford site geochemical model, but, BWIP has added new wells to address many of the data gaps around the RRL area. BWIP also appears to have data that, when documented, could resolve the concern over temporal variation. We agree with the USGS that a comprehensive regional conceptual model will prove necessary to bound the local RRL model. Due to the complexities inherent in the Pasco Basin basalt flows a local model will be difficult to develop; thus, the bounding values afforded by a regional model seem essential.

We also recommend that a well be completed below the Grande Ronde flow within the RRL to provide data on the origin of the methane, high fluoride and total dissolved solids found in the existing groundwater.

The completeness and quality of the well data being collected currently is good and should allay many of the reviewers' concerns. The total dissolved gas analyses especially have improved and should approach state-of-the-art once the at pressure-temperature sampler is fabricated. With documentation of the drilling mud contamination experiment at well DC-14, the impact of drilling mud on past chemical analyses may be defined. We do recommend that hydrogen sulfide and phosphate analyses be included in the chemical analysis activities. There were several areas in data interpretation that received criticism, including the interpretation of ^{13}C data and ^{14}C age dates. The new data on the $^{13}C/^{12}C$ ratio in the methane and groundwater carbonate content suggest that the methane in the Grande Ronde basalt flow within the RRL region may have a different origin than methane found in shallower strata and in the Grande Ronde flow outside the Cold Creek syncline. Documentation of the ^{13}C data may quell the criticisms of the USGS on the origin of methane.

BWIP has determined since publication of the SCR that ^{14}C age dating is not accurate due to ^{14}C in the drilling mud and low total carbon contents in the water that impede precise detection. BWIP is planning to use alternate isotopes in age dating activities and will de-emphasize any past analyses that relied upon ^{14}C.

The biggest problem BWIP has in developing defensible geochemical data is their poor record of publishing. The lack of technical reports that document the available hydrogeochemical data and their interpretation has provoked the most negative comments and led to two detrimental conclusions: either BWIP is hiding potentially damaging information or BWIP is making little progress. Documentation of existing data (a large mass) and that being collected currently creates a challenge that gets more difficult with time. The aforementioned data storage/management problem is tied very closely with this concern and both deserve immediate attention.

Our review of far-field radionuclide transport and performance assessment shows that BWIP staff have made good progress at addressing critic's concerns in the area of solubility and adsorption. Most of the reviewers' concerns centered on the discourse in the SCR on solubility constraints for radionuclides. The discussion in the SCR was, in our opinion, weak and very simplified compared to available knowledge. Since publication of the SCR, BWIP has published a topical report and proceedings article (see Early et al., 1982 and 1983) that demonstrate that BWIP staff are capable of using more acceptable and complete techniques.

Within the solubility area, the SCR was heavily criticized on the choice of a redox value. BWIP staff, in our opinion, are using all the available tools to evaluate the basalt redox potential. In fact, BWIP staff are quite active in funding the development of new techniques. Although there may still be debate on the exact value for Eh, BWIP staff have data that suggest the basalt is reducing. BWIP staff feel the Eh value is in the range of -0.4 volts, but Early et al. have also considered a value as high as 0.0 volts for current solubility constraint predictions to allow critics to see the impact.

BWIP's activities in the area of adsorption have been large and relative to other areas, well documented. Critics have identified three points that warrant attention. The first concern is that most of BWIP's adsorption data for reducing conditions rely upon addition of the reagent hydrazine to produce reducing conditions. Hydrazine may be biasing results. We recommend that BWIP staff perform some experiments using other techniques or reagents to generate reducing conditions and compare the results in a technical report.

Some critics felt that BWIP was neglecting flow top, interbed and fracture filling materials in their adsorption studies. The SCR does not give an accurate picture of the breadth of adsorption work, but a review of published reports and current activities should quell any concerns.

The third concern, the effects of colloids on radionuclide transport, is being addressed by BWIP. The studies have just begun in the last year and have not been documented in publicly available reports. This is the one area that we feel deserves more documentation and perhaps attention in BWIP's far-field radionuclide transport activities.

Two final areas germane to performance assessment have received comment, extrapolation of laboratory data for far-field performance assessment and transport code verification and validation. We received no specific plans for either of these topics. We are aware that BWIP is considering tracer field tests (a two-day workshop with experts from the U.S. and Canada was held in August 1983). General statements on performance assessment code verification and validation are found in Chapter 7.

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5.0 WASTE PACKAGE

The waste package is a functionally discrete repository component consisting of the waste form, the canister, the packing material or backfill, near field geology and the pervading groundwater. Through the agency of the groundwater, the components are chemically and physically interactive with one another. It is appropriate technically and for some discussion purposes to speak in terms of the "waste package" which has historical precedence in the waste management literature and, most pertinently, the BWIP SCR and the derivative NRC Analysis of the SCR.

In organizing the waste package discussion, the integrated waste package concept is only partially applicable. The waste package chapter is long and many technical questions are discussed. Organizationally it is our purpose to conform to the technical review format (technical questions, performance assessment and assessment of BWIP plans to address issues), but also to keep topically related material together without losing the interactive character of the components. Where possible, the waste package is considered with respect to current DOE Guidelines.

One other necessary comment on the organization of Chapter 5 is required. Some redundancy is inevitable. Water chemistry, for example, is a subject of consideration in the discussion of each of the waste package components. To make each of the waste package sections self standing, the same basic water chemistry questions are asked. Our thrust has been consistency at the expense of some redundancy.

5.1 ASSESSMENT OF HANFORD BASALT RELATIVE TO DRAFT DOE SITING GUIDELINES

Guidelines from DOE, EPA and NRC are quoted verbatim. Both the interpretation of the conditions and the data are subject to some degree of judgment.

5.1.1 Guidelines - Conditions and Processes Affecting Expected Performance

The DOE guidelines in essence defer to existing EPA (40CFR191) and NRC guidelines (10CFR60). In particular, DOE states, "A site shall be disqualified if the characteristics that influence radionuclide transport do not allow reasonable expectation of compliance with 40CFR191...[and]...10CFR60." With respect to waste package performance, key points are identified by EPA and NRC.

From EPA: "Disposal systems shall be designed to provide a reasonable expectation that 10,000 years after disposal, reasonably foreseeable releases to accessible environment are less than the quantities calculated (given as limits in table form); and very unlikely releases to accessible environment are less than ten times the quantities calculated (given as limits in table form)."

NRC guidelines are as follows:

"<u>System Performance Objective</u> - Releases of radioactive materials to the accessible environment conform to environmental standards established by the Environmental Protection Agency.

<u>Engineered Barrier Performance</u> - The engineered barrier system shall be designed so that assuming anticipated processes and events (a) containment of HLW will be substantially complete during the period dominated by fission product decay: and (b) any release of radionuclides from the engineered barrier shall be a gradual process:

(a) containment of HLW within the waste packages will be substantially complete for not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository;

(b) the release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure; this requirement does not apply to any radionuclide released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be one part in 100,000 per year of the inventory originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay."

The DOE guidelines specify key favorable and unfavorable conditions; four of these are particularly important with respect to waste package performance. These guidelines have also been discussed in Chapter 4.

Geochemistry (960.4-2-2)

Qualifying Conditions. "The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, the groundwater, and engineered components, the conditions and processes of the geologic setting and the use of reasonably available technology shall permit 1) the requirements set forth in 10CFR60.113 for radionuclide releases from the engineered barrier system and 2) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment to be met."

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

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

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

4) "A combination of pre-waste-emplacement geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository to be dissolved into the groundwater flow system."

5) "Any combination of geochemical and physical retardation processes that would decrease the projected peak cumulative radionuclide releases to the accessible environment by a factor of 10 as compared to those projected on the basis of groundwater travel time without such retardation."

Potentially Adverse Conditions. 1) "Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered barrier system to the extent that containment would be compromised."

2) "Geochemical processes or conditions that could reduce the sorption of radionuclides, degrade the rock strength, or adversely affect the performance of the engineered barrier system."

3) "For disposal in the saturated zone, pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing."

5.1.2 Assessment of Regulatory Guidelines Relative to Hanford

These guidelines of themselves are not sufficiently specific to lead to clear disqualification of any site, based on waste package performance. The NRC requires implicitly that candidate sites demonstrate/evaluate the waste package/repository system in a manner that will allow defensible radionuclide release estimates to times >1000 years into the future. With respect to the waste package, the question is first one of whether or not the site has a seriously detrimental influence. Assuming there is no obvious flaw, the next question is whether or not the BWIP evaluation will likely provide the needed information in a time frame compatible with planned construction/use as a HLW repository.

It is our conclusion that the geochemistry of the Hanford site does not detrimentally influence waste package performance. In general, the prepository (existing) and predicted natural evolution in geochemical conditions are favorable in that they promote precipitation and adsorption of radionuclides. Upon superpositioning the waste package into the existing environment, specific and defensible statements (with documented data) about the effects of the package-induced heat and radiation field cannot as yet be made. On the other hand, basalt rock is known to react to form numerous secondary phases such as zeolites and clays under hydrothermal conditions (e.g., Seyfried and Bischoff, 1979 and 1981 and Apted and Myers, 1982). Both of these types of minerals have large radionuclide adsorption affinities. Further, these minerals are less dense and thus take up more volume than the basalt primary minerals. It is conceivable that these alteration products could plug fractures and impede water flow, another positive attribute. Temperature in general will speed up the natural alteration of the basalt mineralogy.

The knowledge base on radiolysis in geologic environments is small. Should radiolysis promote oxidation of the basalt in the near field, significant amounts of ferric oxyhydroxides and oxides would form. These particular minerals and amorphous substances are well known scavenger and adsorption agents for radionuclides. On the other hand, the site has an unusual characteristic in that groundwater analyses show very high methane concentrations (up to 600 ppm). BWIP does have some work in progress to evaluate potential effects, including radiolysis studies in the presence of methane, that show polyethylene-like solids (colloids) form. The potentially good and bad implications need to be evaluated sooner than planned because of possible large impacts on the subsequent waste package test methodology. It may be, for example, that rock fractures in the near field will be sealed or that the canister or waste form is protectively coated or that organo-metallic compounds form as "alteration phases".

The importance of organic material is well recognized, as embodied in BWIP proposed waste acceptance requirements. Report SD-BWI-CR-018 (1983; see Section 4.4.1.1.7) specifically excludes organic material from the waste package. The concern expressed by BWIP (SD-BWI-CR-018, 1983, pg. 76) is that complexes, polymers, colloids, etc., could form, which "...could seriously complicate the geochemistry of the waste package, host rock, and water environment both with respect to radionuclide transport and to subsequent reactions that could involve the radionuclides." Conditions which inhibit the formation of colloids, organic complexation, etc., are also specifically identified as favorable in DOE Guidelines. These questions have also been clearly identified as issues by NRC.

With regard to completeness of the BWIP evaluation effort on waste package performance, it is our conclusion that the general technical direction is sound. In so far as the experimental program is relatively young and is flexible to the extent that recently identified technical questions are beginning to be addressed, we may conclude that the program can provide the body of information required to show conformation (or not) to DOE, EPA, and NRC Guidelines. The following sections further identify technical questions that have been identified by the BWIP, by NRC, or through our own review. Summary statements from our review concerning the apparent BWIP position/plans concerning these technical questions are also provided. Information will be given on unresolved technical questions, and assessment of plans by BWIP to address the issues for waste form, canister corrosion, backfill and geochemistry. A section on performance assessment issues is also provided for the backfill.

5.2 WASTE FORM

5.2.1 Unresolved Technical Questions

Questions concerning Hanford as a repository site basically deal with how much, when and under what specific chemical conditions water contacts the waste package, and the subsequent release rate from the "disturbed zone," through the geosphere, to the biosphere. A large number of specific technical questions have been identified that have varying degrees of importance. The questions raised by NRC, BWIP and in the present review can be grouped into three general categories concerned with groundwater hydrology, waste form/waste package performance, and geochemistry (mainly far field issues).

Waste form considerations encompass five general technical questions, which overlap to some degree. These are shown in Figure 5.1, along with several other questions; taken together, these questions lead to a decision concerning the acceptability of the site relative to radionuclide releases. In their review, NRC listed twenty-seven (27) issues which can be grouped in these five areas.

1. Does the BWIP approach to evaluation of waste form performance include a reasonable range of hydrologic conditions [flow rate, chemistry]?

2. Does the BWIP approach include an adequate range of near-field geochemistry [composition, pH, Eh, temperature, radiolysis, etc.]?

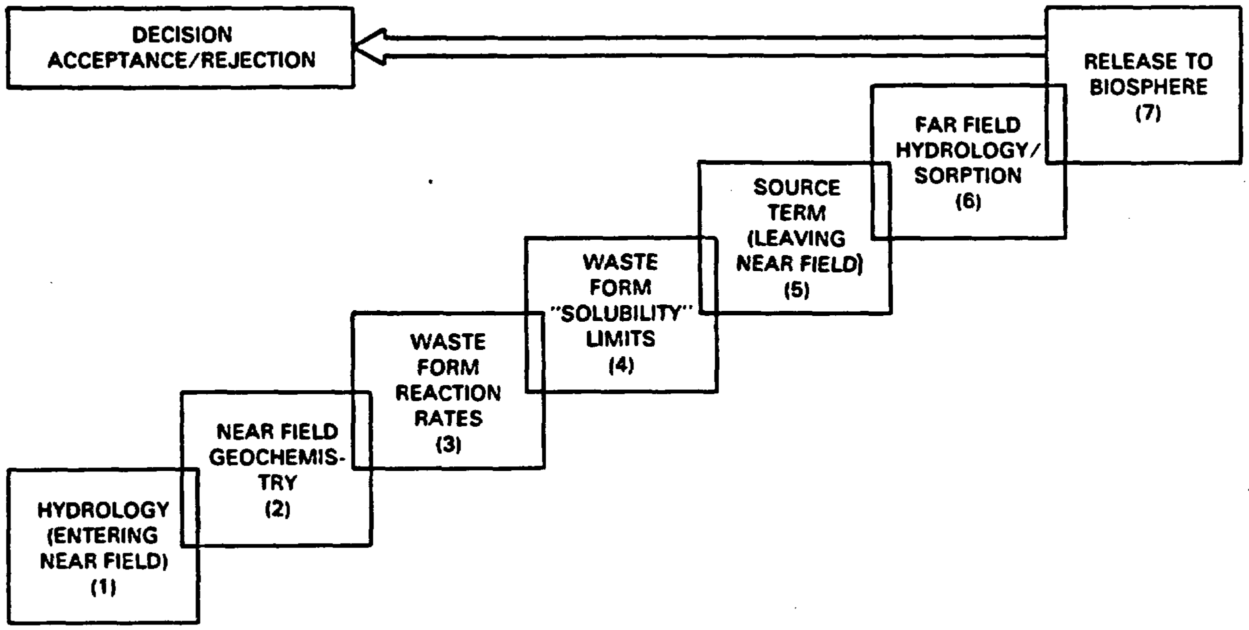

FIGURE 5.1. Issues Concerning Waste Form

3. Can (will) the BWIP evaluation identify an expected range of reaction rates for waste forms [component lifetimes, interactions, other parametric effects]?

4. Can (will) the BWIP evaluation define limiting and probable solution concentrations [including effects of interactions, radiolysis, colloids, etc.]?

5. Can (will) the BWIP evaluation define radionuclide transport out of the near field, providing a "source term" for the far-field evaluation [including radionuclide species identification, near field sorption, etc.]?

As shown in Figure 5.1, these five general questions, if resolved and coupled to defensible, far-field transport models, would provide the technical bases needed to make release estimates, hence allowing decisions to be made concerning the acceptability of Hanford as a repository site. The next section provides a brief review of the BWIP effort related to waste form performance and a discussion of plans and progress in each of the five general areas identified here.

5.2.2 Assessment of BWIP Plans To Address Technical Questions

The BWIP experimental program to evaluate spent fuel and waste glass performance became an increased area of activity in FY1983. A large fraction of the experimental work will come from subcontractor efforts. Temple and Arizona State Universities, Westinghouse-Hanford (HEDL) and the Pacific Northwest Laboratory (PNL) are active subcontractors. The HEDL/PNL work primarily involves evaluation of doped and fully radioactive material. The schedule of work for the next few years is shown in Figure 5.2 (taken from Smith, September 9, 1983). Both static and dynamic experiments will be undertaken, with increasingly complex mixtures of components (and radioactivity) being evaluated as the program matures.

The BWIP approach to evaluating waste forms emphasizes determination of steady state solutions concentrations, tacitly assumed to be related to or equal to true solubilities. These data will be coupled to relatively simple diffusion or diffusion/convection models, as per recommendations of the National Research Council (Pigford, 1983), to give limiting release rates from the near field. BWIP management verbally expressed that kinetic limits would be looked at/used if needed and that leach rate studies already reported or in progress by Savannah River Laboratory (SRL), PNL, etc., should provide the needed information. The BWIP approach is summarized in SD-BWI-TP-022-Draft Section 5.1 (1983) as follows:

> "Measure solubility/steady-state radionuclide concentration; identify, where possible, radionuclide-bearing colloids and hydrothermal alteration products that contribute to solubility-limiting radionuclide release; determine effects of variation in physicochemical parameters on observed solubility/steady state radionuclide concentrations; evaluate the interactive effects of barrier materials on the release rate of radionuclides from the very near-field environment."

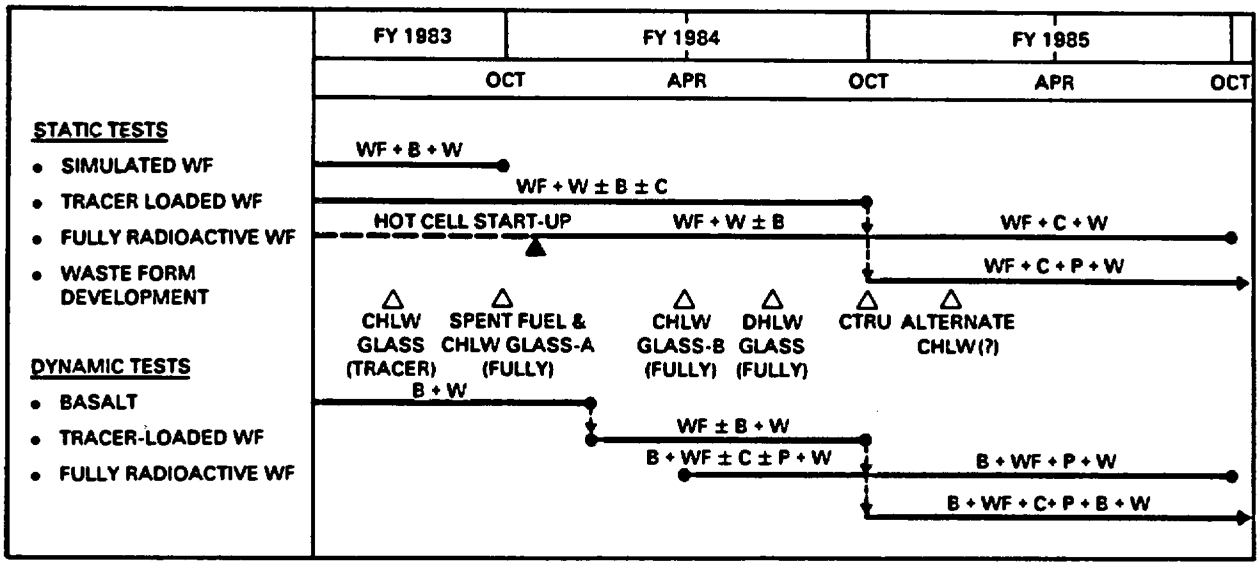

FIGURE 5.2. Schedule for BWIP Waste/Barrier/Rock Interaction Studies (taken from Smith 1983)

WF = waste form
B = basalt
W = groundwater
C = canister
P = packing (backfill)
CHLW = commercial high level waste
DHLW = defense high level waste
CTRU = commercial transuranic waste

BWIP Approach to Evaluation of Waste Form Performance

BWIP does plan to evaluate performance over a reasonable range of groundwater flow rates. The staff have not, to our knowledge, estimated the probable ranges for the rate of water flow through a failed waste package. However, dynamic tests using flow-through columns are planned with an apparatus capable of covering the flow range 0.05 to 10^4 m/yr. By comparison to static tests, it should be possible to interpolate for performance at very low flow rates. We are concerned that only six experiments will be set up. It is not obvious that the number of variables that need to be studied will actually be investigated, since individual experiments will likely require six months or more.

BWIP Approach to Near-Field Geochemistry (Composition, pH, Eh, Temperature, Radiolysis, Etc.)

BWIP has thus far used three different groundwater compositions varying primarily in sodium chloride and sulfate concentrations and having pH = 9.7-10. They plan to evaluate the temperature dependence between 100°C and 250°C, emphasizing 100 and 150°C tests.

Radiolysis is being evaluated as a separate issue and includes methane effects. Additional information will be obtained by study of actual spent fuel and fully radioactive waste glass provided by the Materials Characterization Center.

As will be discussed in more detail in regards to Technical Question 4, we believe BWIP can cover the needed range of conditions, but appears to have embarked on a series of experiments without having undertaken a sensitivity assessment of how important certain factors are. In the near field geochemistry/waste form solubility area, we believe more attention on dissolved gases, especially CH_4/radiation chemistry (gamma and alpha effects), is required very early in the program to justify much of the effort. It is to BWIP's credit that they initiated work in this area early in the program. As a result of that early work, it now appears important to establish or confirm the dissolved gas content in Hanford groundwater. If high methane concentrations are confirmed, it seems necessary to assess combined radiation field/methane effects quickly. The needed studies could be undertaken by a modest redirection of the HEDL/PNL effort.

A second point having to do with the near-field geochemistry is the emphasis on high temperature studies. Although we recognize it may require years to reach steady state at ambient conditions (~60°C), work at this temperature is necessary. While the idea of extrapolating from the 100-250°C work is reasonable and performance at 100°C and above is important, it seems equally important to undertake necessarily long duration studies (5-10 yr experiments should be planned) at the ambient repository temperature.

Identification of Expected Range of Reaction Rates for the Waste Form(s)

BWIP's philosophy is to provide an upper limit or release by establishing steady state "solubility" limits for the radionuclides of importance. They believe, as verbally communicated, that other programs, for example at SRL, will establish kinetic performance in various groundwaters. The BWIP effort will provide some kinetic data near the elemental saturation limits.

It has been verbally communicated that if solubility limits for some elements suggest nonconformance with government criteria, then kinetic limitations will be evaluated to determine if they show conformance. Since certain evidence exists for important kinetic controls (Melnyk et al., 1983), it would seem prudent for BWIP staff to document their interpretation of existing information on the kinetic processes. As discussed with regard to Technical Question 4, kinetics-related questions that can affect apparent solubility limits exist. Without going into great detail here, we believe BWIP-funded studies directed toward definition of waste form leaching kinetics are needed, but have not been identified in the current program. Reliance on studies by others is not likely to be entirely adequate.

Definition of Limiting and Probable Solution Concentrations

We believe that BWIP experimental approach strongly emphasizes determination of steady state solubility limits with good justification. As discussed previously, some effort on leach kinetics is still needed. With regard to determining limiting solution concentrations, the approach being used is good, but needs to be broadened to include a wider range of conditions. Three related areas needing further study/justification are: use of temperature and high surface areas to accelerate the approach to steady state; studies concerning the ratios of near-field components, and effects of leach kinetics on steady state.

Before discussing these areas, it is worth considering the environmental conditions expected in the near field. In this discussion we consider only glass as the reference waste form. The glass will be cast in large (~6 ft tall) canisters that have a diameter of 1-2 ft, depending on heat generation constraints, etc. The glass block will not be monolithic, but will be cracked throughout from thermal shock - having a total surface area 20-50 times greater than the geometric area of the cylinder. Nevertheless, much of the glass will be in the form of fist-sized to football-sized pieces that are tightly intermeshed within the steel canister. Depending on assumptions, the glass could be at temperatures greater than 200°C for decades, falling to near ambient (~60°C) only after 500-1000 yrs. In addition to high temperatures, a high gamma radiation field will exist during the first ~500 yrs. Decay of the transuranium elements will dominate radiation effects at very long times, though effects will be restricted to within or near the glass surface. (The range of a 5 MeV α particle is <100 μm in water.) Evidence is increasing that the Eh and pH of solutions in the near field will be strongly affected, if not controlled, by the radiation fields present.

The canistered glass will be placed in boreholes and surrounded by a packing of bentonite clay and crushed basalt in BWIP's current designs. It can be surmised that bentonite will dominate the groundwater chemistry during whatever might be defined for its lifetime.

Since the repository is in the saturated zone, it must be assumed that resaturation will occur within a few decades of closure. Although current NRC guidelines call for a canister lifetime of 1000 yrs, it is clear that system failure/assessment must be assumed both during the thermal period and after 1000 yrs.

BWIP's studies to date and future plans involve use of high temperatures (100-300°C) and high surface areas (coarse grains - 0.1 to 0.4 mm) to achieve steady state rapidly. Both of these approaches have been successfully used to study simple geologic systems. Special considerations are needed when evaluating waste glass (or spent fuel), since many important constituents are in very dilute concentration. The BWIP approach, in the case of waste form plus basalt studies, is to use Dickson autoclaves with, for example, mass ratios for water/rock/glass = 20/1/1. Steady state concentrations for glass 76-68 are presented in a Rockwell report (Meyers, Apted and Mazer, 1983).

The presence of methane in Hanford groundwater was mentioned previously as a major technical question requiring resolution. It seems highly desirable to undertake solubility studies in the presence of methane and in radiation fields (ideally, performing separate experiments with primarily gamma and primarily alpha radiation). These studies would determine whether or not organic free radicals complex with radionuclides or whether inorganic alteration phases control solubilities. Although six questions related to methane will be resolved in FY1984 by current BWIP plans (Smith, 1983), this key point will not be resolved.

In considering draft BWIP plans (SD-BWI-TP-022-Draft, Chapter 5, 1983), we feel it is important to recognize resource limitations, and recognize that the program is only one year along, at least as a major data producing effort. The program is basically following a reasonable path, moving from less complex to more complex experiments. Because of the complexity of the technical questions and because of the significant advances in understanding of waste form performance that have occurred during the last few years, our primary concerns with the BWIP solubility studies, nevertheless, lead to two generic recommendations:

1. Undertake a broader range of interactive studies with a focus on test parameter - sensitivity studies. For example, what is the best guess for surface area ratios of waste form/rock in the very near field and what effect does a variation by 10^2 have? Why not conduct some experiments at 60°C?

2. Undertake parallel, complex, but as-accurate-as-possible simulations of the very near field. These tests will likely require years of development. Even early results could substantiate current laboratory studies; more importantly, such results would identify needed simpler (and better controlled) parametric studies.

Definition of Radionuclide Transport Out of the Near Field

Current and planned work by BWIP relies on the hypothesis that transport out of the near field can be described by relatively simple convective/ diffusive models and a knowledge of limiting radionuclide solubilities.

Understanding of near-field sorption is a required additional part of this approach, which is similar to recommendations made by the Research Council (Pigford, 1983).

BWIP plans (SD-BWI-TP-022-Draft, 1983) for studies denoted as "fate-of-radionuclides," coupled with other elevated temperature sorption studies and including colloid behavior, can provide the needed information (in addition to previously discussed issues). As discussed in relation to Technical Question 4, questions/recommendations for changes in the current approach would involve 1) broader test parameter - sensitivity studies, and 2) parallel, as-accurate-as-possible simulations of the near field (e.g., close coupled leach/sorption columns). These changes would thus include use of realistic leachates to study near-field sorption.

5.3 CANISTER CORROSION

5.3.1 Unresolved Technical Questions

One approaches the canister corrosion question in a basalt groundwater environment with an impression that a canister life of 1000 years is probably achievable. The basalt saturated groundwaters do not, in tests to date, appear to be particularly aggressive. Canister materials and combinations of materials, more corrosion-resistant than the inexpensive reference materials, are available for a fall-back position. Regardless of the final assessment, favorable or unfavorable, real difficulties will be encountered in providing convincing evidence concerning 1000 year corrosion performance. No applicable precedent on which to model the BWIP corrosion inquiry exists.

Corrosion of heat and radiation generating metal surfaces in high temperature solutions of currently indeterminate composition is a unique problem. While the natural reactors at OKLO may be informative about the migration of radioisotopes underground, they have nothing to say about canister performance. The 1000 year corrosion prediction will rest on defensible descriptions of the evolving corrosion environment as a function of time, experimental determination of the corrosion consequences of the changing environment, and the effects of prior corrosion history on the behavior of the residual canister metal. The description of the changing corrosion environment is perhaps the most difficult element of the program.

Review Scope and Purpose

The BWIP corrosion program review focuses on the present program scope described in the Level IV Canister Corrosion Schedule (Mercado, 1983) and the Barrier Materials Test Plan (SD-BWI-TP-022-Draft, 1983) as interpreted and explained by BWIP staff. This review concerns itself only indirectly with the SCR (1982), primarily with respect to the NRC comments on the SCR.

The purpose of this review is to determine if the BWIP corrosion plan will predict canister corrosion performance in a basalt waste repository.

The Groundwater Corrosion Medium

There is little question about the importance of reliable simulation of repository groundwater and other environmental factors in characterizing canister corrosion. There are differences concerning the measures to be taken to reproduce the corrosion medium satisfactorily.

Preparation. Questions concerning preparation include concentration of soluble species present, definition of the groundwater source term, establishing a justifiable procedure for testing the makeup of groundwater, defining groundwater chemistry under upset conditions, and examining gamma irradiation of methane dissolved in the groundwater.

Corrosion-active species such as the chloride ion are included in soluble constituents. Since the leaching process becomes more rapid as the temperature increases, soluble ion concentrations in heated groundwater might be expected to be higher than in ambient groundwater. The point is of significance for corrosion and needs to be resolved.

Basalt, secondary minerals, backfill material and ions adsorbed or deposited on the near-field surfaces (deposits arising from groundwater boiling) may all contribute to groundwater chemistry. The question then must be considered, how much resultant variation in groundwater chemistry can be expected, and is the range significant to corrosion?

A justifiable procedure for the makeup of groundwater appropriate to each corrosion test temperature is required.

Groundwater chemistry under upset conditions must be defined. For example, groundwater conditions in the case of mechanical or thermally induced failure of the packing barrier should be known.

Gamma irradiation of methane dissolved in the groundwater has been shown to result in formation of a polymeric material, in relatively short, high flux experiments. Further progressive irradiation will lead to various decomposition products, some of which may be corrosion-active. An inventory of the sequence of methane/water irradiation products to be expected in the near field is needed to deal realistically with the corrosion environment. Given the relative abundance of methane (600 ppm), radiation products could be the principal environmental factor in the corrosion process.

Major Environmental Regimes. The repository environment will be subjected to change with time, reflecting the gradual decay of radiation and heat generation, the flooding of the repository and transition from an oxidizing to reducing atmosphere. Within this context of generally gradual change, three significantly different corrosion environments can be defined:

- pre-closure and early post-closure; air-water vapor regime; oxidizing.
- post-closure; flooded, but low pressure. The critical feature is boiling within the engineered barrier or the very near field geology; almost surely oxidizing.
- post-closure; pressurized water; environment reducing.

The first and third phases have been generally recognized. The second phase of indeterminate duration (certainly a period of years) has not been addressed, but should be, because it is this condition in which impregnation of backfill and near-field geology with solids left behind by the evaporating groundwater, will be most important. It is also a period in which boiling and alternating wet-dry metal canister surfaces will occur (if such do ever occur over the canister's history). A realistic chronology of events will be difficult to work out since resaturation of the repository is difficult to predict. The chronology will depend on the repository operational schedule, heat and water removal, and on the timing for introducing packing and backfill.

Mass Transfer Processes

Thermally-induced mass transport associated with the flow of mineralized groundwater up and down a temperature gradient may be a long-term factor in the permeability of the packing material and the near-field geology. Mechanical and adsorptive properties of the packing material may be affected, with unpredictable effects on waste package performance. Mass transfer processes will be most active early in the life of the repository, while canister temperatures and heat generation rates are high and the gradients are still relatively steep.

The expected processes for groundwater moving up the temperature gradient toward the canister would be dissolution of some siliceous materials and deposition of calcium carbonate. Carbonate deposition has been seen in simulated groundwater that was warmed while passing through crushed basalt. Water moving down the gradient away from the canister will cool until, at some point, silica or some more complex species will precipitate. While the analogy is not exact, processes somewhat like those postulated here are responsible for cap rock growth in contained geothermal reservoirs.

The relevance to canister corrosion is this: A repository situation is postulated where the resulting corrosion environment is difficult to predict. In addition, the response of other waste package components to the proposed environment also warrant evaluation. While physical isolation of the waste package by a depositional cocoon around the waste package would certainly be regarded as a favorable development, there are other, possibly, detrimental effects to consider. One possibility is the transformation of the packing/backfill material from a plastic to a rigid mass through the deposition of carbonate or siliceous material. If the resulting mineral impregnated clay is subjected to tensile strains from the thickening corrosion product on the canister, open, unhealed cracks in the packing could result, with unknown effects on corrosion.

Candidate Corrosion Processes

Both uniform and localized corrosion processes may contribute to canister degradation. It is quite likely that over an expected 1000 year service life and an evolving corrosion environment, more than one process is of importance in estimating corrosion behavior. A priori identification of the important corrosion mechanisms may prove to be a problem; it will be even more difficult to make reliable estimates of corrosion rate.

Pitting and Crevice Corrosion. Concerns about localized corrosion processes arise first because localized processes are capable of higher penetration rates than uniform corrosion. In addition, the physical environment of the waste canister appears to be conducive to local corrosion. Pitting and crevice corrosion are clearly associated with a variable chemical environment over a metal surface. This is also true of stress corrosion cracking in a somewhat different context; the presence of tightly packed clay and basalt at the metal surface is a likely prescription for pitting or crevice attack. However, the experimental problem in proceeding from a suspected susceptibility to confirmation of the mechanism and satisfactory estimate of rates is considerable. The groundwater is very complex and a variety of the ions present alone and in combination are potentially capable of producing pitting attack.

Stress Corrosion Cracking. Stress corrosion cracking (SCC) is attributable to specific ions in solution, but requires threshold levels of stress. Several ions potentially present in the groundwater, alone or in combination at groundwater concentration, are capable of initiating SCC under favorable conditions. Again, lacking detailed information on water chemistry at the metal surface as a function of time and temperature, sensitivity of crack initiation and growth to possible chemistry ranges must be established.

Other Local Corrosion Processes. There are other possible localized processes for which electrochemical predictive procedures (or other) are not available. Some possibilities that belong in this category are identified below.

Sulfate reducing bacteria are a possibility in the reducing repository environment.

Prolonged exposure even at modest corrosion rates can produce thick corrosion product layers. Thick corrosion products and the stresses developed in the corrosion product structure have been observed to cause spallation of protective layers and accelerated corrosion. Specimen preconditioning to represent the mid-term corrosion situation should be accommodated in the long-term corrosion tests.

Volume constraint of growing metal oxides probably contributes to accelerated corrosion of carbon steel support plates in PWR steam generators, e.g., SG tube "denting." The extent to which pressure exerted by swelling bentonite in the presence of local ion concentrations might effect canister corrosion is unknown.

There is a final and important consideration in establishing a repository solvent canister corrosion program. There are corrosion mechanisms for which production procedures are not available. Repository corrosion programs must develop means by which such mechanisms can be positively identified.

Models. The program must ultimately look toward the development of a corrosion model based on experimental corrosion data and suitable for prediction of canister performance for 300 - 1000 years. Satisfactory validation of the corrosion model requires confirmation of model predictions by a repository simulation involving the full suite of system variables.

Treatment of Corrosion Variables

The repository is a very complex corrosion environment. Water chemistry, rock and backfill interaction with groundwater, radiation and heat generation, groundwater flow and mass transfer processes, canister materials, fabrication history and state of stress may all affect corrosion processes; most of the variables are subject to change with time. Estimates of the number of independent corrosion variables will differ, but some justification can be made for a number like 18. Coping with this number of variables at two levels (or more than two levels if nonlinear relationships are anticipated) and at several levels of variable interaction leads to very impressive test matrices; so much so that in our estimation, only limited parametric study is possible.

Confirmation of information from a curtailed test matrix would come about from careful simulation studies of the waste package/repository system.

While BWIP has rationally settled on carbon steel as the primary canister material candidate, very little has been done to consider canister design options in dealing with localized corrosion problems implicit in the use of carbon steel. Given that localized corrosion is often of electrochemical origin (e.g., pitting and crevice corrosion), economically practical combinations of materials might be contrived to form a reliable long-lasting defense against these forms of attack.

Waste Package/Repository Simulation

Three major concerns on canister corrosion seem to converge on the need for waste package/repository simulation: approximations of the groundwater chemistry, localized corrosion processes, and predictability of multivariate systems.

a. Good estimations of the groundwater chemistry are needed as a function of temperature. The test solution composition data are needed early in the program so that experimental corrosion mechanisms and rates are meaningful.

b. Evidence is needed on the localized corrosion processes most likely to occur in the repository. The present selection of corrosion processes for study, while reasonable, does not cover all conceivable mechanisms and is (currently) unsupported by experimental evidence.

c. Determining the predictability of multivariable systems may require simulation studies rather than parametric analysis. This requirement is evident when the number of independent variables and the number of interactions that must be considered becomes very large.

The waste package/repository simulation is complicated; analysis from many points of view is needed. Nevertheless, such a simulation does not appear to be impossible; it is needed most early in the program. This is a classic case of last experiment first, but the possible consequences of delay of the simulation tests could be serious.

Canister Design

While the point has been raised elsewhere that it might be more satisfactory to demonstrate canister susceptibility to some form of localized corrosion than to assume it, the possibility of localized corrosion does require accommodation in the canister design. Present calculations of canister corrosion allowance usually include an acceleration factor attributable to local corrosion, such as a pitting factor. Aside from strong suspicions about the transferability of specific localized corrosion "factors" from one system to another, the practice is common and sometimes unavoidable. Often, however, defenses against localized corrosion are practical.

5.3.2 Assessment of BWIP Plans to Address Technical Questions

The documentary evidence regarding the BWIP Canister Corrosion Plan (SD-BWI-TP-022-Draft, 1983) indicates that the program is still in its formative stages. Work to date has been largely literature review, screening tests to select candidate materials, and quantitative assessment of gamma irradiation effects. The detailed studies to identify corrosion mechanisms and estimate corrosion rates are in the planning phases. Subcontracts covering major segments of the BWIP experimental corrosion program have been the recent subject of RFPs. At this point, the planning documents are sufficiently general in the descriptions of tests proposed. Consequently, the detailed information required to estimate the thoroughness and quality of the program is partially lacking.

Having pointed out the difficulties in conducting technical evaluations of a formative program, it should be said the program seems to give good coverage. It seems reasonable that in a year the program will be fleshed out with corroborative detail and many of the present uncertainties resolved. There is time to undertake the orderly development of the corrosion model and little reason to doubt that satisfactory resolution of present uncertainties is possible. It should be recalled that fall back to expensive, but generally corrosion-resistant superalloys is always possible. The comments which follow address specific concerns. It should be noted that a BWIP commitment to address the concerns would not significantly perturb present schedules or planned capabilities. The principal issue, which has to do with the full waste package/

repository simulation, is a matter of timing rather then imposition of a previously unplanned program element.

The Groundwater Corrosion Medium

Preparation. The synthetic groundwater composition appropriate to tests at specified temperatures will be determined by contacting the ambient groundwater with canister metal and packing material. Deviations from the actual repository water composition will be accommodated by determining short-term corrosion rates over a range of each of the obvious corrosion active groundwater constituents. The procedure involves some uncertainties:

- comparability of batch contacting with flow through a column.
- time required to produce representative concentrations of soluble rock constituents, which includes such corrosion-active species as Cl^-. BWIP has followed high temperature leaching studies of crushed basalt to steady state. Chloride ion concentration has been followed. No significant change in the concentration has been observed. Whether the basalt was unusually low in chloride or the chloride is nonleachable for some reason is not known. BWIP staff indicate this question will be looked at further.
- interactions among groundwater constituents. Is it acceptable to ignore concentrations of constituents other than those recognized as corrosion-active?
- whether to initiate pertinent long-term tests prior to the evaluation of methane radiolysis products on corrosion

Verification of the groundwater composition early in the program would seem prudent if considerable corrosion sensitivity to selected ion concentration is shown. Experiments relating groundwater corrosivity to corrosion-active ion concentration are identified in the Barrier Materials Test Plan (SD-BWI-TP-022-Draft, 1983) and the Level 4 Schedule. Depending on the concentration ranges studied, upset conditions will be accommodated.

Major Environmental Regimes. No specific reference is made to a groundwater boiling regime. Since the boiling (heat transfer) mode produces corrosion in many systems, it is worthy of attention in the repository corrosion studies. Both presaturation moist air and postsaturation pressurized water environments are well represented on the corrosion schedules.

Mass Transfer. Generalized reference is made to temperature gradient effects with reference to Appendix 1 of the Barrier Materials Test Plan (SD-BWI-TP-022-Draft, 1983). The applicability of the appended discussion to corrosion-related effects of thermally driven mass transfer is unknown since the appendix is unavailable. Work may be intended in the later, large scale or in situ tests. However, the effects of mass transfer, if any, should be identified early in the program.

BWIP Identification of Canister Corrosion Process(es)

Localized Corrosion Processes. BWIP does not propose the use of detailed waste package/repository simulations to identify canister corrosion mechanisms. To develop the corrosion model and the 1000 year corrosion projection, BWIP proposes to evaluate those processes regarded as most probable or most potentially damaging. In support of this approach, some very good electrochemical diagnostic tests are available for examining pitting and crevice corrosion processes. Accelerated mechanical/environmental tests can be used to look at stress corrosion cracking initiation and crack propagation. Corrosion effects of metallurgical condition and fabrication variables will be examined. BWIP proposes to provide first-rate capability in the conduct of this kind of mechanism inquiry through subcontracted efforts. The fundamental reliability of predictive tests depends in considerable part on reproducing "essential repository features." BWIP proposes to augment the corrosion testing under γ radiation, and to consider the groundwater/packing/canister metal environment as a function of temperature and concentration of the identified corrosion-active species.

BWIP maintains that all potential corrosion mechanisms are being investigated or are in the present plans. To the extent that all corrosion processes could be rationalized to fall under one or the other of "uniform corrosion, pitting, crevice corrosion, intergranular corrosion, stress corrosion cracking, and hydrogen embrittlement," the statement is correct. However, when chemical or physical details are considered in the context of the repository situation, it becomes quite clear that not all readily conceivable mechanisms will be examined. Whether or not corrosion mechanisms of any practical importance to the canister life will be overlooked is impossible to say.

BWIP has recognized the possible presence of sulfate reducing bacteria in candidate BWIP repository horizons. Depending on the results of a BWIP study to determine the presence of bacteria, a corrosion study of the environmental consequences of bacterial action will be organized.

Confirmation of the repository corrosion mechanisms arrived at through diagnostic tests will follow in principle from large scale and in situ tests. The design of these projected facilities and the range of experimental capabilities are unknown. We are concerned that these tests will come late in the program and will provide no guidance for the early phases of the corrosion program.

The Corrosion Model. The means by which BWIP proposes to identify the corrosion environment, the active corrosion mechanism, and the corrosion rate at any time over the projected life of the canister are not clearly stated in the Barrier Materials Test Plan (SD-BWI-TP-022-Draft, 1983). Discussions with BWIP staff have indicated that procedures for producing artificial thick oxides and other features characteristic of metals exposed for long times in groundwater are under study.

Proposed BWIP Treatment of Corrosion Variables

The BWIP philosophy for characterization of the multivariable corrosion system is somewhat different from that proposed in Section 5.3.1. In the first place, only nine system variables are acknowledged (see Table 5.1). Groundwater counts as one variable. Using the nine variable system and applying a Plackett-Burman (P-B) design, a very manageable test matrix is established. It is feasible in this context to undertake a parametric study of the corrosion process without recourse to supplementary waste package/repository simulation.

The proposed use of the Plackett-Burman design raises some questions. Some important qualifications to the applicability of P-B must be recognized:

1. there are no interactions among the variables.

2. Plackett-Burman is only of interest to assess the linear trends in the corrosion response (or other property) with change of the variables under consideration.

It is our analysis that neither of the qualifications are met in the repository corrosion case. Many of the effects of variables are nonlinear, e.g., temperature, time, and repository chemistry (which certainly constitute more than a single variable, as in fact conceded by BWIP in the proposed chemical sensitivity analysis). It is our view that the proposed treatment of the multivariable corrosion system needs additional explanation and justification.

BWIP Plans With Respect to Waste Package/Repository Simulation

BWIP rejects the notion of the detailed waste package/repository simulation on the score that: simulation would require starting with unsaturated packing material of reference design thickness, and, therefore, take a very long time to complete--say 10 years. What is proposed instead is the reproduction of the waste package environment conditions. Packing is presaturated, corresponding to the air/steam operational period and to the post-closure condition. The corrosion tests will be conducted over the potential range of each variable. These laboratory tests will be confirmed by large scale and in situ integral tests and predictive models refined as necessary.

It is important to appreciate that the point at issue is not whether confirmatory simulation testing is done, but when. We firmly believe that the possible confirmation of the corrosion mechanism operator in the repository and the actual groundwater chemistry (s) which will be seen by the converter are of prime importance. Postponing the confirmation of laboratory approximations of groundwater composition and of the repository corrosion environment could negate the value of much of the early corrosion program if the approximations are unsuitable. It is understood that BWIP proposes to test the sensitivity of corrosion to a range of groundwater constituents, but the dimensions of the testing program could be substantial indeed. Without a detailed "sensitivity" test design to consider it is unprofitable to go further.

TABLE 5.1. An Approximation of System Variables

	BWIP List	Reviewer's List
GEOLOGY RELATED		
Rock Chemistry (e.g., Basalt)	--	x
Rock Chemistry of Secondary Minerals	--	x
Surface Condition		
Pore Structure, State of Fissuring or Subdivision	--	x
Preconditioning	--	x
GROUNDWATER CHEMISTRY[a]		
pH		
E_H		
Composition	x	x
Flow	x	x
RADIATION		
Spectrum	--	x
Intensity	x	x
CANISTER/OVERPACK		
Materials		
Composition	x	x
Metallurgical Condition	x	x
Canister Defect Size and Geometry	--	x
Corrosion Products Formed		
BACKFILL/PACKING		
Composition	x	x
Physical Properties		
Preconditioning	x	x
DESIGN FEATURES		
Thermal Input: Decay Heat, Supplemental Electric Heat	--	x
Apparatus Dimensions	--	x
Boundary Temperatures	x	x
TIME	x	x

(a) It is clear that the groundwater chemistry encompasses a number of variables since the proposed R&D program will not provide a positive fix on the composition as a function of temperature.

BWIP Statistical Design

Plackett-Burman designs are closely related to so-called saturated fractional factorial designs. Provided all interactions are negligible, these designs allow unbiased estimation of all linear effects of N-1 factors, from observations taken at N-different sets of test conditions. The saturated fractional factorial designs require that N be a power of 2. However, Plackett and Burman (1946) have obtained designs with the same properties when N is a multiple of four. Below is an example of a Plackett-Burman design for studying N-1 = 11 factors with N = 12 different sets of test conditions. There are two levels of each factor (probably low and high) and these are coded - and +.

Plackett and Burman Design for Study of 11 Factors in 12 Runs

	variable										
run	1	2	3	4	5	6	7	8	9	10	11
1	+	-	+	-	-	-	+	+	+	-	+
2	+	+	-	+	-	-	-	+	+	+	-
3	-	+	+	-	+	-	-	-	+	+	+
4	+	-	+	+	-	+	-	-	-	+	+
5	+	+	-	+	+	-	+	-	-	-	+
6	+	+	+	-	+	+	-	+	-	-	-
7	-	+	+	+	-	+	+	-	+	-	-
8	-	-	+	+	+	-	+	+	-	+	-
9	-	-	-	+	+	+	-	+	+	-	+
10	+	-	-	-	+	+	+	-	+	+	-
11	-	+	-	-	-	+	+	+	-	+	+
12	-	-	-	-	-	-	-	-	-	-	-

It is important to remember in applying these saturated designs that the assumption of no interactions among the N-1 factors is quite strict. If in fact there are interactions, application of a saturated design can lead to erroneous or misleading conclusions about how the factors are affecting the measured or observed response. This is because the linear effects of the N-1 factors are confounded with (i.e., are indistinguishable from) two-way, three-way, and higher-way interactions among the factors.

If several factors interact, then the effect of one of the factors depends on the levels of the other factors. Thus, some factors might not individually have significant linear effects on the measured response. However, when combined with certain levels of other factors, they may interact and strongly affect the response. Thus, if interactions are present, it is possible with the Plackett-Burman design to mistakenly conclude, for example, the Factor 1 has a significant effect but Factors 2 and 3 do not, when, in fact, Factors 1, 2, and 3 interact to strongly affect the response. The result could be an erroneous prediction model, or in the next experiment, Factors 2 and 3 might be ignored or held constant when they really should be studied in combination with Factor 1.

Another limitation of saturated designs is that only linear effects are estimated. There are not enough data (i.e., the factors are not presented at enough levels) to estimate curvature. Thus, if increasing the level of a factor causes the response to follow a curve rather than a line, the extent of this curvature cannot be assessed from a Plackett-Burman design.

We do not propose to argue the merits of the detailed waste package/ repository simulation except to say the geometrical foreshortening of other features of the simulation would be required and would be applied to the backfill as well.

BWIP Program Plans With Respect to Canister Design

The first priority is the evaluation of canisters constructed of a single, inexpensive material such as the carbon steel. If inadequacies are demonstrated, further study of more corrosion-resistant materials would be conducted. While not specifically described in the Level IV Corrosion Schedule or the Barrier Materials Test Plan (SD-BWI-TP-022-Draft, 1983), bimetallic materials would be included in the expanded program. Superalloys constitute a potential last resort material back-up.

5.4 BACKFILL/PACKING

5.4.1 Unresolved Technical Questions

The backfill/packing is a component of the engineered barrier system, as defined in 10CFR60. This material is used to fill the annulus surrounding the canister in the borehole (hereafter referred to as packing), as well as the backfill for tunnels and shafts in the underground facility. A procedure has been specified in the SCR (1982) for each of the packing and backfilling operations; only technical questions related to horizontal borehole packing will be discussed here. Tunnel and shaft backfilling technical questions are covered in Chapter 6.

The packing of the reference waste package conceptual design consists of 0.64 cm (1/4 in.) maximum basalt and bentonite powder (RHO-BWIP/PNL Review Meeting, July 1983). The backfill is blown at 161 km/hr (100 mph) into a 15 cm (6 in.) space surrounding the emplacement canister. The pack density currently specified for the backfill to meet the maximum required permeability (10^{-6} m/sec) is 1.7 g/cm^3 (106 pcf) or 60-70% of theoretical density (RHO-BWIP/PNL Waste Package Meeting, September 1983).

Four backfill technical questions have been identified in the area of waste package. These issues are 1) material segregation during transport, 2) emplacement procedure, 3) need for a structural backfill, and 4) ability to provide quality assurance.

Material Segregation During Transport

The segregation process for particles of differing size, shape, and density can generally be classified into two stages. Penetration of smaller, more angular, and denser particles through the interspaces of the framing particles comprise the first stage; the filling of the voids of the bottom layer with the separated particles forms the second. This segregation process would be expected to occur at each stage of the material handling process (surface to repository level) as defined in the current repository design (SCR, 1982).

Emplacement Procedure

Three major concerns have been identified with the proposed horizontal emplacement scheme:

a) Ability of proposed emplacement procedure to achieve necessary density specified [1.7 g/cm^3 (106 pcf)] for the packing material.

b) Segregation of the packing material during the storage and supply of the particulate materials.

c) Difficulty of achieving the specified density around the canister and pipe supports, especially with a stationary backfill pipe.

Need for a Structural Backfill

The possible need for a structural backfill to prevent collapse of the horizontal borehole opening and increase rock mass permeability has been identified by BWIP (SCR, 1982; Jones, 1982), NRC (1983), and PNL reviewers. This technical issue will be covered in more detail in Chapter 6.

Ability to Provide Quality Assurance

The main problems with the proposed horizontal borehole packing procedure would be in the downhole operation and lack of quality control. These problems would be control of the nozzle to the working face, supplying large volumes of air, and material losses being blown back of the hole with the exhausting air (McGowan et al., 1976).

5.4.2 Performance Assessment Technical Questions Related to Packing

To comply with the proposed Rule (10CFR60) for the 1000 year containment period, the packing material must perform at least one of two primary functions:

- prevention or retardation of fluid flow.
- limitation of radionuclide mobility.

Groundwater flow control will delay the onset of corrosion of the metal container. In the event that there is premature container corrosion or mechanical failure resulting in leaching of radionuclides, the packing must retard the radionuclide migration either by reversible sorptive processes or by irreversible precipitation or fixation. Sodium-bentonite is being considered by BWIP to perform these functions.

A concern has been voiced (e.g., NRC, 1983 and Hydrology and Geology Overview Committee, 1981) that the bentonite clay used in the packing will not be stable at higher temperatures and will lose its favorable geochemical attributes (high adsorption affinity for radionuclides) as well as physical properties (swelling) that create the low permeability characteristics. Bentonite is a hydrous aluminosilicate which forms in nature under conditions of low temperature and pressure, saturated moisture content, intermediate pH (5 to 8) and specific groundwater chemistry (Soo et al., 1983). Bentonite becomes metastable or unstable outside of these relatively narrow limits, therefore, the concerns would seem valid.

BWIP has countered (see rebuttal sections of Hydrology and Geology Overview Committee, 1981) that below temperatures of 300°C (572°F), the bentonite should not significantly change its chemical or physical attributes. Within the draft BMTP (SD-BWI-TP-022-Draft, 1983) additional discussion is presented:

> "Experimental evidence to date also suggests that the conversion of bentonite to illite is not significant because: 1) the potassium required for this reaction is partitioned into other alteration phases in addition to bentonite (e.g., zeolite, Fe-smectite, K-feldspar); 2) the kinetics of smectite conversion to illite appear to be quite slow at expected hydrothermal temperatures (<150°C; Howard and White, 1981); and 3) the source of potassium in the glassy mesostasis of basalt is limited (e.g., 2.5 - 5.5 weight percent K_2O in the Umtanum flow, Allen and Strope, 1983). Consequently, loss of low hydraulic conductivity and swelling potential is not likely to occur. The implication, therefore, is that hydrothermal interaction may improve rather than degrade packing performance with time. Another potential mechanism for packing material degradation is dehydration of bentonite early in the waste package history at peak temperatures. Irreversible loss of structural water in the clay at a sufficiently high temperature could result in loss of swelling capacity and higher

permeability. Recent dehydration experiments show that loss of structural water does not occur at 370°C (698°F) or below even after a year of continuous heating. Thus, the current waste package design temperature limit of 300°C (572°F) will ensure that dehydration will be eliminated as a backfill performance degradation mechanism."

Our review indicates that part of the experimental data that BWIP refers to includes short-term (1 month) hydrothermal tests of bentonite and basalt each contacting groundwater under near-field geochemical conditions (Wood et al., 1982). Additional experiments on the ternary system (basalt/bentonite/groundwater) were conducted for three months at 300°C (572°F) and 300 bars pressure. The water/solids ratio was 10:1 for all experiments (binary and ternary).

Similar solution chemistry trends of the major aqueous species were found in the three systems (basalt-groundwater, betonite-groundwater and basalt bentonite - groundwater) and are characterized by (Wood et al., 1982):

1) Gradual reduction of pH from ~9.75 to a steady state value of ~6.

2) Slight increase in sodium, sulfate, chloride, and fluoride concentrations.

3) Initial increase followed by gradual decrease in silica concentration.

On the other hand, Soo et al. (1983) conclude that a 300°C (572°F) temperature limit for bentonite may be too high and remarked that the Swedes, who have done extensive research on the use of bentonite for packing material, recommend its use for temperatures under 100°C (212°F), while the Canadians are only planning its use below 120°C (248°F). Oversby (1982) also claims that the K^+ concentration observed in basaltic groundwater is high enough to be of concern with respect to its exchange with bentonite, going through a maximum of ~100 ppm at ~200°C (392°F), at elevated temperatures.

The BWIP potassium data (Wood et al., 1982) are high enough to be of concern with respect to its exchange with bentonite at elevated temperatures. We also wish to point out that BWIP reports (Wood et al., 1982) higher K and Al concentrations at 200°C (392°F) than at 300°C (572°F). These arguments/observations would suggest that a lower temperature design limit should be considered.

On the other hand, Wood et al. (1982) found no evidence, within experimental error, for the formation of illite in the bentonite/groundwater binary system. No specific mention was made as to whether or not illite was found in the ternary system, but it is interesting to note the much lower K^+ concentrations observed in the ternary component experiment in comparison to the basalt-groundwater binary system. Based on these experiments and previous experimental work, Combs et al. (1959), Komarnemi and White (1981), Sasaki et al. (1981), and Wood et al. (1982) concluded that sodium-bentonite would remain sufficiently stable up to 300°C (572°F), permitting its use as a packing material.

Further evidence for bentonite stability to temperatures of 300°C (572°F) in hydrothermal tests (up to 90 days) was presented by Couture and Seitz (1983) and Peacor et al. (1983) at a recent NRC Research Program Review of Nuclear Waste Management Research on Geochemistry of HLW Disposal, Reston, Virginia August 30-31, 1983.

From this discussion, we conclude that it appears premature for BWIP to state that under hydrothermal conditions expected in the repository, sodium bentonite would remain sufficiently stable as a packing material. More hydrothermal ternary component tests should be performed at several temperatures and for longer durations to provide valuable data.

We note that such tests have been underway at BWIP (BWIP/PNL Waste Package Meeting, September 1983) and others were started (duration to be 1 year) in August, 1983 at the University of Michigan (Peacor et al., 1983).

5.4.3 Assessment of Plans to Address Issues

The stated objective of the packing testing effort is to "provide sufficient data on the behavior of candidate packing mixtures exposed to the simulated environment of an NWRB to assess their ability to meet packing design and performance requirements" (SD-BWI-TP-022-Draft, 1983). In this effort, the data collected are required 1) to recommend reference packing materials for waste package design, 2) to define design-related thermal mechanical, physical and composition limits, and 3) to predict long-term performance under repository conditions (SD-BWI-TP-022-Draft, 1983).

BWIP has divided the required data into five categories as follows:

1. Groundwater transport characteristics
2. Strength of materials
3. Heat transport characteristics
4. Radionuclide transport characteristics
5. Hydrothermal reactions.

The following discusses BWIP's plan to address technical questions raised earlier in this Chapter.

Material Segregation During Transport

It was apparent during discussions with BWIP (BWIP/PNL Waste Package Meeting, September 1983) that this segregation phenomena had not been identified previously and, hence, plans to address this technical question have not been considered.

Emplacement Procedure

BWIP agrees that many unanswered questions remain on the feasibility of pneumatically emplacing the packing. It is hoped by BWIP, however, that the backfill process development engineering test being conducted by Kaiser Engineers and Parson Brinckerhoff (KE/PB) will resolve many of these questions.

The concept of using pneumatic emplacement techniques were first proposed by Martin (1975). The basic concept is to accelerate soil particles with an air stream so that they impinge the working face of the plug. The densification of the applied soil is dependent upon the impact force and adhesion qualities of the material. It should be noted that soil pellets were used by Martin (1975) and were originally proposed by BWIP (SCR, 1982). BWIP is currently using a "loose" material mix.

Consideration must be given to the proposed scheme of reducing the backfill pipe length during the emplacement process. A pipe length of 33 to 66 m (10 to 20 ft) should be studied. This will yield acceleration of the packing material comparable to that achieved in the repository. Packing characteristics such as density, uniformity, and hydraulic conductivity should be determined.

The bulk density is dependent on the density of the individual particles and a high bulk density may be obtained simply because the particles have a high density rather than because the particles are closely packed (Gray, 1968). Also the particle size distribution of the rock-clay mixture is important. Preliminary test results indicate much higher densities, 1.9 g/cm^3 (119 pcf), than required, 1.7 g/cm^3 (106 pcf). This density is readily achievable with coarse sand (no clay present). With the closeness of specific gravities of the two packing material constituents, this could be misleading. To avoid this difficulty, an expression (packing fraction) involving the ratio of the volume of particles composing the bed (V_p) to the volume of the bed (V_t) may be adopted. In addition, determination of the compositional make-up of the packing material from the canister outward is essential in defining expected packing performance. In the final analysis, the hydraulic conductivity of the packing is probably the critical property that needs to be determined.

Need for a Structural Packing

The need for a structural packing to prevent collapse of the horizontal borehole opening and increase rock mass permeability remains unanswered. It is currently unknown if the backfill needs to meet this criteria.

The strength of the packing will be dependent upon the bentonite-basalt ratio, particle size distribution, and shape and arrangement of particles. The potential exists for exceeding the liquid limit of bentonite by absorption of groundwater, and in turn destroying the strength capability of the packing material. This point should be reviewed by BWIP.

Ability to Provide Quality Assurance

Plans for resolving questions on quality assurance (QA) remain unclear. BWIP staff have considered many alternatives; however, they have found them unacceptable. BWIP staff are relying on "process control" to resolve the QA issue. The backfill process development engineering test being conducted by KE/PB should contribute to resolve this technical question. We believe that

NRC will require some type of positive field testing method during the emplacement process, and efforts should continue in developing such a method.

5.5 GEOCHEMISTRY

5.5.1 Unresolved Technical Questions

Five technical questions have been identified in the area of waste package. Within our assessment we critique 1) geochemistry documents published since the SCR, 2) joint discussions with BWIP's Waste Package Department staff, and 3) Section 5.1 of the draft planning document, Material Barriers Test Plan (SD-BWI-TP-022-Draft, 1983) that was supplied in mid-October for our review. The technical questions are: 1) high temperature solubility determinations, 2) radionuclide source term development, 3) radiolysis effects on near-field geochemistry, 4) adequacy of near-field conditions studied, and 5) measurement/calculation of near-field Eh and pH.

5.5.2 Assessment of Plans to Address Technical Questions

High Temperature Solubility Determinations

It is well known that the data base for solubility of compounds of interest to nuclear waste disposal at higher temperatures is weak. Almost all predictions of radionuclide solubilities are based on simple compounds (e.g., PuO_2, NpO_2) as the controlling solid, at 25°C. Such was the case for BWIP coverage in the SCR [Early et al. (1982, 1983) and the NRC's (1983)]. Because the waste form may in fact be leached at temperatures in the range of 60° - 150°C or at an extreme above 250°C, some understanding of higher temperature solubility is necessary.

BWIP has adopted an empirical approach wherein steady state solution concentrations are determined for the radionuclides in simple static experiments (e.g., basalt-groundwater, waste form-basalt-groundwater) and then the complete system (waste form-canister-packing-basalt-groundwater). BWIP has assumed that once steady-state solution concentrations are obtained, these values can be considered an empirical solubility limit. Attempts will be made to identify the solid alteration products in which each radionuclide resides in hopes of determining the controlling solid. The progression from the simple tests to the total system would allow determination of any deleterious effects of any one component on the overall release of radionuclides. Additionally, the tests would provide valuable data to show whether each of the various components lowers nuclide release via chemical interaction as opposed to physical isolation mechanisms. (These tests address only chemical interactions because the package components are crushed and intimately mixed.) The empirical steady state concentrations versus set temperatures (60°, 90°, 150°, 200°, 300°C) for the overall system would serve as the source term for performance assessment calculations.

Flow-through column experiments will also be performed to investigate the effects of allowing mass transport to remove constituents. BWIP expects that interpolation between the results of the static tests and flow-through column tests (run at higher than expected velocities) will be possible to bound the release rates under an actual breached repository scenario. However, actual flow rates are predicted to be lower than available pumps and laboratory apparatus can maintain.

PNL's major concern with BWIP's plans to rely upon these empirical tests is the need to perform a vast number of experiments to cover potentially important variables such as Eh, pH, and groundwater composition. In addition, there are practical problems in defining when a system is truly in equilibrium (steady-state). What if Al, Fe or Si concentrations are still varying when some set of chosen radionuclides are declared at steady-state? Is it appropriate to stop the experiment, or must one continue monitoring? We question whether critics will ever agree that such an empirical approach can, in a reasonable time frame and within a reasonable amount of tests, determine the effects of variation of physicochemical parameters on observed solubility (steady-state) radionuclide concentrations.

We recommend that BWIP incorporate the use of predictive geochemical modeling (similar to Early et al., 1982, 1983) and solubility experiments on known solid compounds (Rai et al., 1980b, Rai and Ryan, 1982, Rai et al., 1983, Edelstein et al., 1982 and Silva, 1982). One specific addition to the BWIP current empirical plans would be to add a known solid that is suspected of being a potential controlling solid to the BWIP tests after steady-state has been reached. Monitoring the solution concentrations of the system after addition of the known solid would allow one to determine whether prediction based on known systems (pure minerals or simple compounds) are useful. If the concentration of the radionuclide of interest does not change upon addition of the known compound and the known compound is identified in the following solids characterization, it may be argued that the "simple" solid was the original control. If the solution concentration of the nuclide increases at first and then drops back to the previously observed value, it can be argued that some less soluble phase was the original control, but that the simple compound may be used as an upper bound for predictive calculations. Further, it would then be possible to find the controlling solid because of the additional mass of the radionuclide added. If the solution concentration remains higher upon addition of the known compound, the system is allowing two solids to be present. Two solids might be allowed because 1) all of one component (available in the system previously and needed to form the original precipitate) is used up prior to addition of the known solid; 2) adsorption sites had not been saturated in the previous test; or 3) a kinetic problem exists.

Our analysis leads us to conclude that the empirical studies in which a radionuclide is added to solution until no change is observed, as Rockwell proposes, should be supplemented. Any study proposed to be a solubility experiment must by definition identify a controlling solid. Rockwell's approach often will not identify a solid phase because the available instrumentation is not sensitive enough to identify distinct radionuclide-bearing phases in all cases. Addition of an excess of an identifiable phase after reaching steady-state and monitoring changes in solution concentration would help determine solid phase controls.

Rai et al. (1980b and 1982) have used such a technique to identify probable solubility controls for a contaminated soil and actinide-doped borosilicate glass. It could be argued that such "simple" compounds as actinide oxides and hydroxides are the most probable controls that one could observe in time frames possible in laboratory experiments because they easily and rapidly form and would serve as a useful upper bound for long-term performance assessment. Some thermodynamically stable phases might not form in a reasonable time period even at the higher temperatures expected for the waste package. Again one could argue that such slow-forming compounds would lower the solution concentration of the radionuclides over the "simpler," more rapid-forming compounds observable in laboratory experiments. Therefore, work with "simpler" compounds should provide an upper limit value for performance assessment calculations.

Geochemical modeling activities should also be used 1) to evaluate empirical test sensitivity to the various geochemical parameters, 2) to bound the number of empirical studies and maximize their utility, 3) to help address the multitude of "what-if" questions posed by critics and 4) perhaps most importantly, the experimental data via ion speciation and ionic activity product calculations, in hopes of estimating values for missing thermodynamics constants. Such solubility modeling encorporating thermodynamic principles as well as empirical data is endorsed by the National Academy of Sciences (Pigford, 1983) and NRC (1983).

The essence of these recommendations is that BWIP should support all available tools, geochemical computer code predictions, fundamental solubility studies of simple systems and empirical studies on the complex multicomponent waste package. As for Eh determination, it will be the convergence of all these solubility tools to some range of values that will best define radionuclide release from the waste package.

Radionuclide Source Term Development

The heart of BWIP's source term development is the aforementioned progressive empirical laboratory experiments that are called "fate of radionuclide" tests in the Barrier Materials Test Plan (BMTP; SD-BWI-TP-022-Draft, 1983). The philosophy expressed in the BMTP and types of experiments planned (static and flow-through column tests progressing from simulated waste through doped waste finally to fully radioactive waste forms) are practical and address all the major issues: solubility, adsorption, colloids, etc. On the other hand the BMTP lacks specific details on how many tests and what variations in such parameters as pH, Eh, and groundwater composition will be used. The BMTP does specify temperatures and the ratio of solids to solution that will be used in the simpler tests, as well as the ratio of weights of each solid component to be used in the total systems tests, but it does not identify the volume of groundwater in the latter case nor defend the choice of the ratios. For the same reasons as mentioned in the previous subsection heavy reliance upon empiricism alone probably will prove inadequate; too many variables must be considered. We recommend that the computational models (source term) ultimately used for safety assessment be built considering known thermodynamic principles as well as empirical data.

Radiolysis Effects on the Near Field Geochemistry

The BMTP acknowledges the need to investigate the effects of radiolysis. We believe that Rockwell's ongoing and planned experiments should be capable of bounding the effects of radiolysis on the very near-field water Eh and pH. Tests to date (described in the BMTP) on water itself show that Eh can change dramatically under a radiation field, but water has very little buffer capacity to hold the Eh or pH at a set value. Experiments are planned where basalt and package components are also present in the test. It is conceivable that the radiolysis products will react quickly with these solids so that little Eh or pH change will occur. Furthermore, the zone affected by radiolysis is very small compared to the total path-length to the accessible environment; thus, a radiolysis perturbation that could cause different releases in the very near field might be overcome within an insignificant distance.

We would recommend that the radiolysis effects on a basalt groundwater that contains a high methane content receive greater and more immediate attention, especially for tests with all components present. Such bounding work needs to be done prior to designing the specific tests to be performed in the progressive approach of studying each component (waste-form, canister, packing, basalt in the presence of groundwater, then studying two, then three together, etc.).

It is also not clear from review of the BMTP that studies with small masses of actual high level waste glass or spent fuel will create the appropriate radiation field. It is possible that the dose rates will be too small. Specific tests in a ^{60}Co gamma generating apparatus are planned for a few tests, but it is not clear that the number of experiments are adequate to bound the radiolysis issue, especially if the more numerous fully loaded waste package interactions tests generate an unacceptably low radiation field.

Adequacy of Near Field Conditions Studied

Aside from temperature, pressure and in some cases, the solids to solution ratio, the BMTP does not specify exact values or ranges that will be covered. The BWIP philosophy certainly endorses a thorough study of appropriate parameters and processes, but specific details are lacking. The number of variables that need to be studied, controlled, and measured are large; thus, a strictly empirical approach will probably not silence critics. Effort needs to be spent prioritizing and limiting the parameters studied, but most importantly the reasons for dropping some parameters should be documented. Thermodynamic principles and tools (predictive computer codes) and site-specific knowledge should be useful aids in defending the choices.

Measurement/Calculation of Near-Field Eh and pH

As mentioned in Chapter 4, Eh and pH are key parameters that affect solubility and adsorption, the two major processes that control the mobility of radionuclides. (See Chapter 4 for additional details.) The BMTP also reviews approaches and techniques for measuring these parameters at high temperature and pressure. Briefly, BWIP uses or has under investigation the following techniques to measure or calculate pH and Eh. For pH, BWIP will rely upon solution measurement at temperature and pressure via a zirconia pH sensor (10/1/84 goal). BWIP currently uses standard pH electrode measurements at temperatures <100°C and 1 atmosphere pressure, with correction back to temperature and pressure via solution mass balance equations (e.g., see Myers et al., 1983 and Bischoff and Seyfried, 1978).

BWIP will use or investigate the following techniques to measure Eh: 1) measurement of the valence state distribution of dissolved redox couples (e.g., AsIII/AsV); 2) measurement of dissolved oxygen content; 3) use of solid phase redox buffers (e.g., magnetite-hematite) in a metallic membrane porous to hydrogen; 4) use of a teflon membrane that allows hydrogen diffusion and that is placed in the autoclave and connected to an external pressure gauge; and

5) a high temperature/pressure inert metal electrode. The latter two techniques allow Eh monitoring at temperature and pressure.

We conclude that BWIP is attempting numerous techniques to measure or calculate pH and Eh at higher temperatures and pressures and should be commended for the support of subcontractors who are trying to develop practical tools for all members of the geochemical community.

5.6 WASTE PACKAGE COMPONENT INTERACTIONS

5.6.1 Unresolved Technical Questions

The waste form, the container, the packing material, the near-field rock and the groundwater are so interactive that it is common practice to consider them together as the waste package. The interactions among the components have a major influence on waste package performance. Sorting out the details of the interactions is a principal concern in long-term prediction of waste package performance.

Technical Question 1: Are the Appropriate Component Interactions Proposed for the Study?

The possible interactions considering only neighboring solid components are the following:

2	Component Systems	WF/GW, C/GW, P/GW, R/GW
3	Component Systems	WF/C/GW, C/P/GW, P/R/GW
4	Component Systems	WF/C/P/GW, C/P/R/GW
5	Component Systems	WF/C/P/R/GW

where WF = waste form, C = canister, P = packing, GW = groundwater, and R = rock.

Technical Question 2: Are the Component Interactions Being Considered in an Appropriate Sequence?

To judge waste package performance, it is necessary to determine property behavior in a representative repository environment, not a subset of the system components and variables. We believe it is impractical to study a system of 18 variables parametrically, especially when several levels of variable interaction are readily identifiable. The usual approach to complex systems is to study the property of interest in the context of a selected subset of the system parameters. The results are compared with demonstration test data where all the elements of the real system are present. Concurrence is evidence that the important variables have been considered. Nonconcurrence requires that other significant parameters be identified. The essential feature of this procedure is that subset results are confirmed by reference to the full system. In practical terms the need to refer subset data to the full system requires early scheduling of the more complex interaction tests.

Technical Question 3: Are Proposed Analytical and Sampling Techniques Appropriate to Overall Program Needs?

The interaction program deals in trace concentrations of radionuclides which may be subject to change in solubility, complex formation, adsorbence, colloid formation, etc., with minor changes in groundwater composition. Consequently, the program requires the best in analytical chemistry methods--particularly those permitting in situ measurement. For those species and solution properties which are not measurable in the test vessel, sampling methods that don't upset the system or alter the withdrawn solution are required.

Solid phases involved in hydrothermal interaction processes undergo alteration to progressively more stable mineral structures accompanied by modification of the groundwater. Identification of the alteration products and the rates at which these processes take place must be observed and correlated with groundwater chemistry change. Analogous requirements exist for absorption-desorption processes on solid phase surfaces--especially of radionuclides.

State-of-the-art (quite literally that) analytical capabilities are required to support the waste package development program.

Technical Question 4: How is Radionuclide Release Related to Canister Failure Mode?

The mode of canister failure, that is, the geometry and location of the canister penetration at failure, will affect radionuclide release by defining the geometry of the source term. It is expected that the planned canister corrosion studies will define potential failure modes and permit addressing this question.

Technical Question 5: Specific Interaction Test Procedures to be Prepared

Groundwater Composition. BWIP plans to validate batch contacting methods for determining groundwater composition at various temperatures and locations in the near-field repository. Our review was based on the following questions:

- How are representative rock constituents (basalt, secondary minerals, flow top material, etc.) selected for equilibration with water to establish reference groundwater chemistry?
- Are minerals that are selected for equilibration with water preconditioned in any way?
- In testing corrosion sensitivity to groundwater composition, what sort of experimental design is proposed, what water properties or constituents are to be tested, and how are interactions of water constitutents to be considered?

These questions can be summarized: Standard, defensible procedures are required for reference groundwater makeup. In a similar manner with reference to rock: Standard, defensible procedures are required for selecting and preconditioning reference rock material. In a similar method with respect to packing material: Standard, defensible procedures are required for selecting and preconditioning reference packing material.

5.6.2 Assessment of BWIP Plans to Address the Interactions Questions

The draft Barrier Materials Test Plan (SD-BWI-TP-022-Draft, 1983) is descriptive of the interactions program. Related interactions work is covered in the section on waste form (unavailable), corrosion and packing/backfill material. Interactions are a very important part of the BWIP program.

Technical Question 1: BWIP Plans to Address Component Interactions

All of the identified interaction combinations are under study or proposed for study.

Technical Question 2: Sequence of Interaction Tests

The principle dominating the BWIP approach to scheduling interaction testing is to do the simpler experiments, the two component interactions first, progressively moving toward more complex cases. We believe it would be more practical to attempt to explain the repository/waste package system behavior on the strength of these types of tests in conjunction with selected full system interaction demonstration test than attempting to extrapolate full scale results from subsets of the waste package components. Of course, the BWIP program proposes ultimately to perform the full system demonstration. The question is the benefit of the subset interactions. Binary tests are likely to have greater utility in explaining obscurities in the full system simulation than in predicting system behavior. It is essential to initiate complex multicomponent interaction tests along with the simplest binary tests. Otherwise unsuspected interactions whose identification is the purpose of the interaction test program will invalidate the results of the simpler tests. For example, a corrosion test based on a groundwater composition resulting from groundwater/basalt interactions would be of little practical value if the presence of bentonite clay significantly modified the groundwater chemistry. While there is a familiar logic in running simple tests before the complex experiments, uncritical application in waste package system studies is perilous.

Technical Question 3: BWIP Plans to Develop Improved Analytical and Sampling Techniques

There has been clear recognition in the BWIP waste package program of the importance of analytical capabilities adequate to measure the solution chemistry, mineral structure and surface changes important in understanding the system. BWIP has taken the waste repository lead in subcontracting development of state-of-the-art probes and sensors to supplement existing capability.

Technical Question 4: BWIP Plans Radionuclide Release to Canister Failure Mode

It is unclear, first, that BWIP will need to consider the mode of ultimate canister failure as a factor of retarding or limiting radionuclide release and dispersion. However, there appears to be no plan to consider canister failure mode in terms of nuclide release until large scale and in situ tests are undertaken. This effort should be planned.

Technical Question 5: BWIP Plans to Prepare Interaction Test Procedures

While procedures are not discussed in the BMTP (SD-BWI-TP-022-Draft, 1983), we have been assured by BWIP staff that the need for defensible makeup and preconditioning procedures is well understood. It is expected that water chemistry makeup and surface conditioning of rock and backfill/packing will be the subject of Materials Characterization Center (MCC) procedures. MCC will evaluate repository procedures (including BWIP) for inclusion or adaptation as MCC interactions test procedures.

5.7 SUMMARY

The salient observations of the waste package review are summarized in the four statements immediately following. More detailed treatment of the individual waste package components complete the summary.

5.7.1 Waste Package

We see no reason why BWIP should fall short of a technically sound prediction of the waste package behavior given the present staff capabilities and the projected R&D support level.

At this time the BWIP waste package R&D program is insufficiently advanced to justify a conclusive statement, favorable or unfavorable, on the adequacy of the basalt waste package performance.

The waste package program commitment to provide a waste package/repository simulation capability should be given increased emphasis and priority.

The present BWIP waste package test designs to deal with the multivariable, repository/waste package interactions need explanation and perhaps refinement. Available data on thermodynamics-based solubility should be used whenever possible to validate and augment experimental data.

5.7.2 Waste Form

Five broad questions have been identified. Although the BWIP approach is generally well directed, a primary conclusion is that variation in the major parameters/test conditions is not sufficiently broad. The program will provide data of the kind needed, but under a limited (sometimes arbitrary) set of conditions. At this time, none of these questions would obviously lead to disqualification of Hanford as a repository site. The summary comments are as follows:

1. The BWIP approach to evaluation of waste form performance includes a reasonable range of flow rate. Groundwater chemistry is not being varied significantly.

2. The geochemical parameters of groundwater composition, pH, Eh, temperature, radiolysis are important to waste form performance. Of these variables, only temperature is being systematically varied, although ambient temperature 60°C is excluded. A broader approach is needed now.

3. BWIP work related to waste form reaction rates is strongly focused on determination of steady-state solubility limits. Work at other sites is relied upon to supply kinetic information, if needed. A clearly defined in-house effort is needed to insure that program requirements are met.

4. The BWIP evaluation of limiting and probable solution concentration (radionuclides) can meet their objectives, including effects of interactions, radiolysis and colloids. However, the range of sensitivity studies and of complex, near-field simulation studies will require expansion (e.g., waste form + canister + backfill + methane + radiation + flow).

5. The BWIP program to define limiting radionuclide transport out of the near field is intended to provide a source term for the far-field evaluation (including radionuclide species identification, near-field sorption, etc.). The appropriate work is more or less defined, but should include work in the future with more realistic "leachates" to define for example, near-field sorption.

5.7.3 Corrosion

In these summarizing statements about the BWIP program, we have made a conscious attempt not to dwell on the absence of detail. It is appreciated that this program is in its formative period and detail will grow with program maturity. It should also be understood that we concur with most of the generalized plans presently available for consideration. Areas of corrosion concern, some of which may only involve detail not presented in the BMTP (SD-BWI-TP-022-Draft, 1983) or Level IV Corrosion Schedules (Mercado, 1983), are listed in the following:

1. Identification of corrosion process(es) operative under closely simulated repository conditions is required. In simplified laboratory test the possibility exists that departures in the water chemistry and the other process parameters from those in actual repository service could change the corrosion mechanisms.

2. A justifiable generalized procedure is required to define constituents and concentrations for reference, synthetic groundwater to be used for corrosion tests at each test temperature. Early attention to this question is required.

3. The selection of corrosion variables for study, the extent of likely variable interactions and the proposed statistical treatment of corrosion variables needs further explanation.

4. Processes indirectly associated with corrosion need consideration. For example, mass transfer effects, with respect to long-term changes in the chemical and physical properties of the packing.

5. The process for the BWIP predictive model validation (corrosion) is related to large-scale (and) in situ experiments that are not defined in sufficient detail for evaluation.

6. The BWIP corrosion program is handicapped by lack of specific information on the repository design, the emplacement conditions and the canister design objectives. Nevertheless, elaboration of plans for corrosion input to the canister design are needed.

5.7.4 Packing

It is difficult to assess the current state of the packing materials test program critically because a) the project's recent initiation, b) lack of FY1983 results, and c) insufficient details in the Barrier Materials Test Plan (SD-BWI-TP-022-Draft, 1983). We can conclude, though, that as an engineered material and process, the problems associated with the proposed packing emplacement scheme can be overcome. The bottom line should be how long will it take to resolve these problems and at what cost?

Steps toward answering these questions were initiated near the end of FY1983 with KE/PB's backfill process development engineering test. While these tests will help resolve many of the issues posed by NRC (1983), incorporation of the technical questions presented herein have not been identified.

Future physical and mechanical properties tests on the packing material will mock the material matrix as determined by KE/PB's laboratory tests. We feel that this will provide more realistic data on what may be expected in the field. Additional efforts should continue, however, in determining some positive field testing method.

Last, we conclude that adequate measures are being taken by BWIP to understand the expected repository conditions. Questions remain, i.e., showing 10,000 years performance, adequate closure at the seal-rock interface, material segregation, etc., but the BWIP approach gives promise of solving these concerns in the future.

5.7.5 Geochemistry

The Waste Package Plans as represented by Section 5.1 of the BMTP (SD-BWI-TP-022-Draft, 1983) appears to rely too heavily on only one of the available tools, a progression of empirical laboratory experiments from simple binary tests (one package component and groundwater) to complete package simulations with all components. Because the tests are to be run until steady-state solution concentrations are achieved, it does not appear to us that all variables can be investigated over an adequate range of concentrations or conditions in a realistic time frame. Effort needs to be spent prioritizing and limiting variables studied. Thermodynamic principles and tools (ion speciation, solubility and perhaps mass-transfer computer codes) should be used to bound the problem, defend priorities on nuclides and conditions studied, and to help interpret the results of the "fate of radionuclide" tests. Thermodynamics could be used to perform bounding solubility predictions and allow several radionuclides to be dismissed from further study. Thermodynamics could be used to prioritize variables studied such as whether certain complexing ligands must be considered. Thermodynamics could be used with the empirical data to be collected (solution concentrations and solid phase characterization) to develop estimates for or bound missing thermochemical constants ($\log K_r$).

It would also seem wise to perform some of the total package simulation or demonstration tests early in the program to look for unexpected trends or, more positively, to demonstrate system insensitivity to some parameters. The latter activity would be a useful and practical way.

5.7.6 Waste Package Components Interactions

The BWIP waste package development program calls for evaluations of the gamut of potential waste package component interactions.

Large scale demonstrations or in situ tests involving all waste package components are proposed, but late in the program. They should be given greater emphasis and priority.

In support of waste package component interactions studies, a vigorous program to evaluate and adapt state-of-the-art procedures for dilute solution, mineral structure and surface analyses is underway.

Defensible procedures should be developed for preparation of "aged" groundwater and of rock and packing material surfaces for use in interactions testing.

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6.0 REPOSITORY DESIGN

Documents reviewed in the assessment of repository design, underground stability and repository sealing include released publications, draft documents and letter reports. Because a number of the documents were in a draft form, some of the information referred to in this report may have been changed. The reader should therefore be aware of the date of the referenced report for comparison.

The documents were used to address the repository design criteria specified in 10CFR60 and the DOE guidelines. The remainder of this chapter discusses technical questions and the RHO plans for solving them.

6.1 ASSESSMENT OF HANFORD BASALT RELATIVE TO DRAFT DOE SITING GUIDELINES

The following paragraphs were taken from the August, 1983 revision of the DOE siting guidelines. The criteria presented in these guidelines are pertinent to repository design and were used as a basis for evaluating the BWIP design. The following guidelines are again referenced in relevant technical questions in Section 6.2 and are presented here for reference.

System Guidelines (960.5-1)

Ease of Construction, Operation and Closure. "The technical aspects of repository construction, operation, and closure shall be demonstrated to be feasible on the basis of reasonably available technology, and the costs associated therewith shall be demonstrated to be reasonable relative to other available siting options."

The technical difficulties associated with drilling large diameter shafts in the Hanford basalt may prevent the Hanford site from meeting the above guideline. The current nuclear waste repository in basalt (NWRB) engineering design calls for large diameter shafts to be blind drilled to a depth of 3000 to 3900 ft. in the Hanford basalt. Observations of borehole breakout in boreholes DC-15 and RRL-2, and the loss of large volumes of drilling fluid in a well near Ellensburg, Wa., are symptomatic of difficult conditions for shaft construction.

Hydraulic fracturing stress measurements at the Hanford site indicate the horizontal to vertical stress ratio may vary between 2:1 and 2.7:1. Because of the uncertainties associated with the method, the actual stress ratio could be greater or less. A preliminary cost estimate by Kaiser Engineers and Parson Brinckerhoff (KE/PB) indicates the mining costs for repository construction would increase by 260% if the actual stress ratio was 3:1 instead of the assumed 2:1.

Rock Characteristics (960.5-2-9)

Qualifying Condition. "The repository construction, operation, and closure will not cause undue hazard to personnel."

Safety conditions are a source of concern for a repository at Hanford. Current evidence supports the assumption that methane will be encountered at the repository level; however, there is no basis for predicting expected gas concentrations. The current repository design does not address the potential safety problem of gas buildup in isolated sections of the repository during the construction or retrieval phases. PNL recommends the repository ventilation design be made capable of handling both of these contingencies.

Hydraulic fracturing stress measurements in boreholes in the Hanford basalt indicate high horizontal stresses are present. The existence of these stresses is supported by observations of core discing and borehole breakout. If the excavation and thermally induced stresses are sufficiently high, rock burst may occur, presenting safety hazards for construction and repository personnel. There is no way of substantiating this concern until underground openings are developed at proposed repository depths.

Favorable Conditions. (2) "A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation, and closure."

Based on empirical design results, the Hanford basalt will probably not meet the "favorable conditions" outlined above. The empirical design methods indicate a repository at the Hanford site could require from minimal to heavy support to maintain underground opening stability. The support requirements will likely vary within the repository and depend on local conditions. (See 960. 5-2-9-C-3)

Potentially Adverse Conditions. (2) "In-situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility."

In situ conditions at the Hanford site may cause potentially adverse conditions for drilling large diameter shafts for the repository. Hydraulic fracturing results indicate a high horizontal to vertical stress ratio in the inner flows of the Cohassett and Umtanum flows that could result in borehole breakout during shaft construction. Borehole breakout has been observed in small diameter boreholes at the DC-15 and RRL-2 locations. If large volumes of rock were to fall between the cutter head and stabilizers of the drill, the drill could become trapped in the hole. This could result in abandonment of the hole and bit.

Loss of circulation of large volumes of drilling fluid has been observed in drilling boreholes at Hanford and in gas wells in the vicinity of Hanford. If circulation is lost, sloughing of the shaft wall and lodging of the drill bit are possible.

(3) "Geomechanical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure."

Laboratory tests have indicated the uniaxial compressive strength of intact basalt core may decrease with increasing temperature. If high in situ stresses are present, the combination of excavation and thermally induced stresses may cause instability of the repository openings in zones where the rock strength is exceeded. Periodic maintenance would then be required unless the ground support is able to maintain stability.

(4) "Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation."

Analytical analyses by KE/PB indicate the basalt surrounding a repository opening could be subjected to thermomechanical stresses approaching the strength of the rock, and could result in induced fracturing. There is a large amount of uncertainty involved in the results of these analyses because of the lack of data concerning the rock properties, constitutive relationships and boundary conditions. The analyses assumed intact conditions and did not consider fracturing of material in existing joints.

Guideline from 10CFR60.132-e

Additional Design Requirements for the Underground Facility. (2) "Structures required for temporary support of zones 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 containment of wastes."

The lack of written plans and the infancy of the repository sealing program makes it difficult to critique the Hanford site on the basis of the above requirements. The presence of support structures such as steel sets could cause difficulties during the backfilling of the tunnels if the current backfill approach is used. The existence of supports would impair compaction efforts and may create preferential pathways for groundwater movement.

6.2 UNRESOLVED TECHNICAL QUESTIONS

6.2.1 Shaft Drilling and Lining

The NWRB engineering design (SD-BWI-SD-005, 1983) currently calls for large diameter shafts, the largest to be in excess of 20 ft, to be blind drilled to a depth of 3,000 to 3,900 ft in the Hanford basalts. To date, no technological constraints have been identified by RHO that would preclude blind drilling of these shafts. Furthermore, RHO views the possibility of failure in the attempt to drill these shafts as "remote" (RHO-BW-ST-28P, 1983). However, PNL has identified the following unresolved technical questions that may constitute technological restraints with regard to blind drilling shafts at Hanford that are in excess of 12 ft diameter:

- lack of a proven drilling system
- high potential for loss of drilling fluid
- high potential for sloughing, slabbing, and spalling
- liner installation.

Lack of a Proven Drilling System

Conventional shaft drill rigs are large rigs of the type used by the oil industry that have been modified for this purpose. They typically have a rotary torque capacity in the range of 30,000 to 80,000 ft-lb and a hook capacity of 1,500,000 to 2,500,000 lb. Equipped in this manner, these rigs are not capable of drilling deep shafts in a single pass that have diameters much in excess of 12 ft. Shafts of greater diameter have been drilled in sedimentary rock in both the U.S. and Europe using a multiple pass technique; however, the drilling environment was considerably different from that of Hanford (Fenix and Scisson, July 28, 1983). To date, a proven drilling system for drilling a 20 ft diameter shaft to 3,000 (plus) ft in a single pass has not been demonstrated. According to calculations performed independently by PNL and Fenix and Scisson, Inc., a drilling rig capable of drilling such a shaft at Hanford would require a rotary torque capacity of 650,000 ft-lb and a hook load rating of 3,000,000 lb (Enderlin, September 16, 1983; Fenix and Scisson, August 29, 1983). The rotary torque requirement increases rapidly as the shaft diameter is increased. Technology is available to produce a rig of the required capacity. A prototype rig designed specifically to drill shafts up to 20 ft diameter has been built; it failed, however, while drilling a 14 ft diameter hole in Australia. The rig is currently being refurbished and attempts will be made to drill a 20 ft diameter shaft in the future. This rig has a rated torque capacity of 500,000 ft-lb and a hook capacity of 2,000,000 (Fenix and Scisson, July 28, 1983). It is reasonable to assume that the design for this type of rig could be scaled up to satisfy Hanford's requirements.

It has not been demonstrated that it is possible to clean the hole under a 20 ft diameter bit using any of the conventional big hole chip removal techniques. This has always been a major problem facing the shaft drilling industry and is one that rapidly becomes more severe as the diameter of the hole is increased. It is possible that current BWIP sponsored research at Colorado School of Mines on advanced melter design will alleviate both the torque and weight-on-bit requirements. BWIP is also sponsoring important work at LASL on the problem of chip removal.

The drilling technique (single pass or multiple pass) that is to be employed at Hanford for drilling shafts larger than 12 ft in diameter is currently an unresolved technical question.

High Potential For Loss of Drilling Fluid

It is reasonable to assume that loss of circulation will be encountered during shaft drilling at Hanford. Past experience in drilling boreholes at Hanford and in drilling gas wells in the vicinity of Hanford justifies this assumption (Tri-City Herald, November 12, 1981; Morrison-Knudsen August 4, 1983). In the event the circulation system cannot sustain a loss of fluid to the formation, it is quite possible that the hole will slough and lodge the bit. This could result in abandonment of the hole and the bit (Morrison-Knudsen August 11, 1983). Corrective measures become increasingly more difficult as the diameter of the hole increases. There can be no guarantee that the conventional corrective measures developed for the petroleum industry and currently employed in shaft drilling will be effective for 20 ft diameter holes.

Contingency plans have been developed for recovering from a loss of circulation condition while drilling the exploratory shaft (ES) shaft at Hanford, (Morrison-Knudsen, August 4, 1983); however, no contingency plan has been developed for the larger diameter shafts that are planned (Morrison-Knudsen, August 4, 1983). It is reasonable to expect that the experience gained in drilling the ES will be helpful in developing such a plan.

High Potential For Sloughing, Slabbing, and Spalling

There is strong evidence that sloughing and slabbing may occur while drilling through the colonnade and flowtop sections and that spalling may occur while drilling in the intact rock at depth (Morrison-Knudsen, August 4, 1983; August 11, 1983).

A large slough of unconsolidated material from rubble zones or from the interbeds could bury the bit, causing it to become stuck in the hole as well as causing the hole to go out of gauge. A stuck bit could result in abandonment of the hole. An out of gauge hole would have an adverse effect on hole alignment for, if this happens, the drill stabilizers become ineffective.

There is also a distinct possibility that large slabs of columnar basalt could fall from the sidewall and become lodged between the drill assembly and the sidewall, effectively locking the drill assembly in place at the bottom of the hole (Morrison-Knudsen, August 4, 1983; August 11, 1983). Upon reviewing the layout of the downhole drilling assembly (Morrison-Knudsen, June 14, 1982) it becomes apparent that the upper stabilizers would not be capable of breaking up large slabs of rock. PNL could find no evidence of shaft drilling experience in highly stressed columnar basalt such as found at Hanford. There is little direct comparison between the problems encountered while drilling a small diameter exploration hole, where borehole breakout has been encountered at Hanford, and the problems that may be encountered while drilling a large diameter shaft (Morrison-Knudsen, August 11, 1983). PNL was unable to find sufficient data to predict the effect of wall spalling on the shaft drilling operation.

Contingency plans have been prepared. These set forth the remedial action to be taken in the event spalling and/or sloughing occurs while drilling the ES (Morrison-Knudsen, August 4, 1983). No contingency plans have been developed for the larger shafts that are planned at Hanford (Morrison-Knudsen, August 11, 1983).

Liner Installation

Current shaft drilling systems do not drill perfectly vertical holes. Moreover, it is quite reasonable to assume that there will be a slight "dog leg" in the shaft alignment. This condition often poses a serious problem with respect to installing a rigid shell type liner, especially if the shaft is very deep. The more rigid the liner, the more serious the problem. However, there is a tendency for larger diameter bits to drill a straighter hole than a smaller diameter bit. Moreover, the skill and experience of the driller play a major role in drilling a straight hole. There are cases on record where the liner has become bound in the hole during installation (Fenix and Scisson, July 28, 1983). Moreover, the larger the diameter of the liner, the more difficult it becomes to maintain strict vertical alignment of the liner segments while the liner is being assembled and floated into the hole. Of course if the liner also has a "dog leg," this compounds the interference problem. The current shaft design does not provide for casing centralizers, therefore, if the liner touches the wall, the grout tubes are damaged if already installed. If the grout tubes are to be installed after the liner, it becomes impossible to install them. The discontinuous casing lifting lugs would not provide adequate protection for the grout tubes. Moreover, grout is not placed between the liner and the rock in these contact areas. The composite steel and concrete liner being considered for use at Hanford is probably as stiff or stiffer than any liner that has been installed to date and will be about twice the diameter of any other liner installed in this manner. A ring stiffened steel liner, with the rings mounted on the outside of the shell, is also being considered; however, there are significant manufacturing problems with this concept that are yet to be resolved (DeHart, July 29, 1983).

To date, the exact type of liner that will be installed for shafts greater than 12 ft in diameter and the details regarding the installation technique to be employed are unresolved technical questions.

Adequate quality assurance procedures for the concrete core and for grouting the composite liner at the location of the circumferential field welds has not been developed (DeHart, July 29, 1983). Also, current state-of-the-art, grouting control methods are not adequate to guarantee the integrity of grout installed in the shaft/liner annulus.

6.2.2 Underground Ventilation

Chapter 2 discusses the potential sources of methane in the Grande Ronde formation. RHO currently anticipates that only a "trace" of methane will be present in the ventilation circuit and that its presence is not critical to the repository design or situ characterization issues (SD-BWI-TP-007, 1983). We, can find no basis for this assumption.

Ample evidence is available to support the assumption that methane will be encountered at the repository horizon (SD-BWI-TP-007, 1983; SCR). This being the case, it is also reasonable to assume that methane will be carried in the underground ventilation air circuit. If the concentration of methane is of sufficient magnitude, then the repository would be deemed "gassy" and thereafter operated as a gassy mine (30CFR57.21). Under Section 960.5-2-9(c) of the Siting Guidelines, such an operation would be considered a "potentially adverse condition," since operating under these conditions could lead to safety hazards during repository construction and subsequent operation.

Methane repository would be deemed gassy (30CFR57.21) if:

- The State of Washington classified the repository as gassy.
- Flammable gas emanating from the strata has been ignited in the repository.
- A concentration of 0.25% or more, by air analysis, of flammable gas emanating from the strata has been detected not less than 12 in. from the back, face or ribs in any open workings.

Insufficient data are available at this time[a] to predict the expected methane concentrations during various phases of repository construction and operation.

Methane has been produced commercially from wells in the vicinity of the repository situ from depths of 700 ft, 1,000 ft, and 3,600 ft. (RHO-BWI-C-109, 1981). Ongoing exploration through the basalt shield in the vicinity of the Saddle Mountains has recently verified the presence of natural gas below the basalt, at a depth of 12,000 ft from the top of the mountain (Tri-City Herald, September 27, 1983). Based on the foregoing, PNL has concluded that additional effort is required to determine probable gas concentrations to be expected in the repository.

The current repository design does not address the potential problem of gas buildup in isolated sections of the repository during the construction phase (SD-BWI-SD-005, 1983). Likewise, there is no provision for a potential gas buildup during the low-flow retrieval phase. PNL recommends that the repository ventilation designs be modified to insure against these contingencies.

6.2.3 Underground Stability

In Situ Stress

Values of the in situ stress, as measured by the hydraulic fracturing technique, can vary considerably, depending on the interpretation of the hydraulic fracturing data. In the hydraulic fracturing stress equation, the

(a) Letter Gimera to Burnham, November 21, 1983, with attachments.

pore pressure term is questionable because of the impermeable nature of the inner flow basalt. If this term is ignored in the calculation,the estimated horizontal to vertical stress ratio in the RRL-2 region is increased 14 - 17%. Research should be initiated that will provide better understanding of the hydraulic fracturing tests performed in basalt. Until that time, a conservative interpretation of the data is recommended.

Knowledge of the in situ state of stress is necessary for the design of stable underground openings and the understanding of rock mass behavior. A number of hydrofracturing stress measurements have been performed in five basalt flows at the Hanford site. Measurements were made in DC-12 by Kim and Haimson (1982) and at RRL-2 by Rundle (1983). The calculated maximum horizontal principal stress to vertical stress ratio varies between 2.1:1 to 2.7:1 in DC-12 and between 2.2:1 and 2.7:1 in RRL-2.

PNL has pointed out to RHO that the conclusions reached concerning the in situ stress state will vary considerably, depending on the interpretation of the hydrofracturing data. The expression used by RHO to calculate the maximum horizontal principal stress, sigma max, is:

$$\text{Sigma max} = 3\ (Pisi + Ph) - (Pf2 + Ph) - Po \qquad (6.1)$$

where Pisi = shut-in pressure

Ph = hydraulic head

Pf2 = fracture reopening pressure

Po = pore pressure

The pore pressure component takes into consideration the reduction in the effective compressive stress brought about by the hydraulic fracturing fluid that enters the rock pores. While this effect is evident in a porous medium, such as sandstone, it does not seem likely that the effect would be as great in a low porosity rock such as basalt.

If the pore pressure component is ignored, the horizontal to vertical stress ratio is increased by 14 to 17 percent. Differences in the stress ratio become significant when considering excavation costs. A preliminary cost analysis by KE/PB estimated that a repository in basalt with a 3:1 ratio horizontal to vertical stress ratio would cost 265% more than the same repository in basalt with a 2:1 ratio.

6.2.4 Tunnel Design

The use of analytical methods for designing large underground openings is lacking primarily in the difficulty associated in obtaining the necessary input parameters. Currently, the greatest use of the method has been for parametric studies, to examine the influence of different material properties and conditions. A conceptual system design study was conducted by using thermal and excavation analyses (KE/PB, 1982). The linear elastic analyses used in this study are appropriate for some of the tradeoff studies but are insufficient for stability and cost analyses. The analysis uses stress considerations for determining the acceptability of various repository room and waste emplacement configurations. The KE/PB analysis does not consider available data that would allow the analyses to go beyond stress considerations and include stability concerns. Failure criteria, based on laboratory and rock mass classifications systems, are available to analyze beyond simple stress: strength considerations.

The KE/PB design analysis is essentially a stress analysis. The analyses for various opening shapes and waste canister emplacement configurations are based on thermally induced stresses and on an assumed horizontal to vertical stress ratio of 2:1. Once this relation was determined, the pitches that satisfied the design objectives were selected. The stress calculations used simplified elastic and thermoelastic analyses backed by computer checks using the ANSYS finite element program.

The design stability criteria were based primarily on the intact rock strength of basalt. If the calculated maximum tangential stress was below the reduced value of intact strength, the design was considered to be acceptable from a stability standpoint.

While the stress analysis may be adequate as a first approximation, PNL feels that even for the preliminary design phase, the KE/PB analysis may not be comprehensive enough and may understate the difficulty of excavating in Hanford basalts.

An underground opening design that may be acceptable on the basis of stress considerations, may be unacceptable based on stability considerations. The design phase should include failure criteria, such as suggested by Hoek (1980), that can give some indication of the extent of rock failure around the opening. These data can then be used in subsequent analyses to determine the redistribution of stress around the opening and fractured zone and to estimate rock support requirements. The failure criterion proposed by Hoek (1980) is based on theoretical and empirical relationships that consider the principal stresses and the properties and conditions of the rock. The criterion takes into consideration the response of the rock to the full range of stress conditions and is capable of estimating the influence of one or more sets of discontinuities on the behavior of the rock.

It is recognized that KE/PB performed the analysis under considerable time constraints and that the intention of the analyses was to support a conceptual design. PNL recommends, though, that current data be used wherever possible Hydraulic fracturing stress data, available for the trade-off analyses, should more accurately represent the stress conditions. Sufficient rock property data now exist to estimate the parameters needed in Hoek's stability criteria. Necessary parameters can be obtained from triaxial test data using recovered basalt core or can be estimated using the rock mass ratings from classification systems. Use of the failure criteria would permit a stability analysis to be used for cost/support calculations. Other methods, such as empirical design approaches, should be used as a method of checking the results.

6.2.5 Empirical Design Methods

The problems associated with using analytical approaches for tunnel design, (i.e., the inability to furnish the necessary input data for a detailed analysis) are pointed out above. An alternative method is an empirical approach that relates the experience encountered at previous projects to the conditions anticipated at a proposed site. Such an approach has been used by RHO to estimate the ground support requirements for a repository in basalt (RHO-BWI-ST-28-P, July 1983).

The use of empirical design methods by RHO appear to be non-conservative in estimating support requirements for the proposed underground openings. The empirical approaches are based on ratings from a number of the rock mass classification systems. No adjustments were made to the ratings to account for the specific conditions present in the candidate horizons. Because the empirical method is one of the few design methods available, more work is justified in tailoring these approaches for nuclear waste repository design.

The empirical design approach is driven by rock mass classification systems that act as a means of comparing various tunneling and mining projects. The two most popular methods, the Geomechanics Classification (Bieniawski, 1973) and the Q-System (Barton, Lien and Lunde, 1974), were used by RHO to classify the basalt in the candidate basalt flows (RHO-BWI-ST-028-P-Draft July, 1983). The Q-value varies between 8 and 20 for the Cohassett Horizon and 10 and 25 for the Umtanum Horizon. The rock mass rating (RMR) values from the Geomechanics Classification are 66 for both the Cohassett and Umtanum Horizons.

One of the main criticisms of the rock mass classification systems is that some of the parameters are qualitative in nature. The results are somewhat dependent on the experience and interpretation of the engineer doing the work. For this reason, the data base used for the various classification systems should be made available for review for interpretation and discussion. The raw data collected by RHO from the RRL-2 borehole has not been made public in any document at the time of this report.[a] Such an effort is seen as being critical in this case in order to arrive at a consensus by the rock mechanics community.

The support requirements for an underground opening can be estimated using the RMR-rating or the Q-value and corresponding graphs that correlate the rating with a level of rock support (light, medium or heavy support). The support requirements are based on case histories of underground facilities having similar rock mass ratings.

(a) The RHO report, RHO-BWI-ST-52-P, to be released, contains a summary of preliminary results of borehole RRL-2 basalt physical and mechanical property data. The document does not contain information concerning discontinuity parameters, ground water condition, etc., necessary to use rock mass classification systems.

In the RHO-BWI-ST-028P-Draft (1983) document, RHO used a chart developed by Hoek (1981) to estimate support requirements. The chart is a simplified correlation between rock mass quality and the maximum excavation boundary stress. The relationship allows an initial evaluation of the excavation stability to be estimated. This chart is completely different from Hoek's failure criteria. The parameters needed for using Hoek's chart are:

- maximum compressive boundary stress in opening roof or sidewall
- uniaxial compressive strength of the intact rock
- rock mass classification rating(s).

In the analysis, RHO estimated the maximum compressive boundary stress by assuming a horizontal to vertical stress ratio of 2:1 and a stress concentration factor for an elliptical opening. The uniaxial strength was estimated to be 364 MPa, based on the intact strength of Umtanum basalt. The intersection of the parameters is illustrated in Figure 6.1. The conclusions of the analysis were:

> "When only excavation-induced stress is considered, the chart generally recommends 'light support with occasional rockbolts and/or shotcrete and mesh.' Rock core logging has indicated that some portions of the Cohassett have a higher frequency of unhealed fractures than others. These more highly jointed portions would require 'medium support.'" (RHO-BWI-ST-028P-Draft, July, 1983)

PNL has expressed concern that the various rock mass rating parameters had not been adjusted for the specific conditions present in the Hanford basalt. In addition, the intact strength values used did not consider all of the candidate basalts and the uncertainty of the data. PNL provided other support estimates using existing data and the Hoek diagram. The data represented the worst rock strength values and lowest rock mass rating values and resulted in a considerably higher support requirements. The intention of PNL was to demonstrate the range of conditions and attendant conclusions that could be encountered and to encourage a more thorough treatment of the data.

Laubscher and Taylor (1976) and Kendorski et al. (1982) have developed methodologies for adjusting the rock mass rating for various conditions. The conditions include: Number of tunnels (tunnel interactions), Excavation method

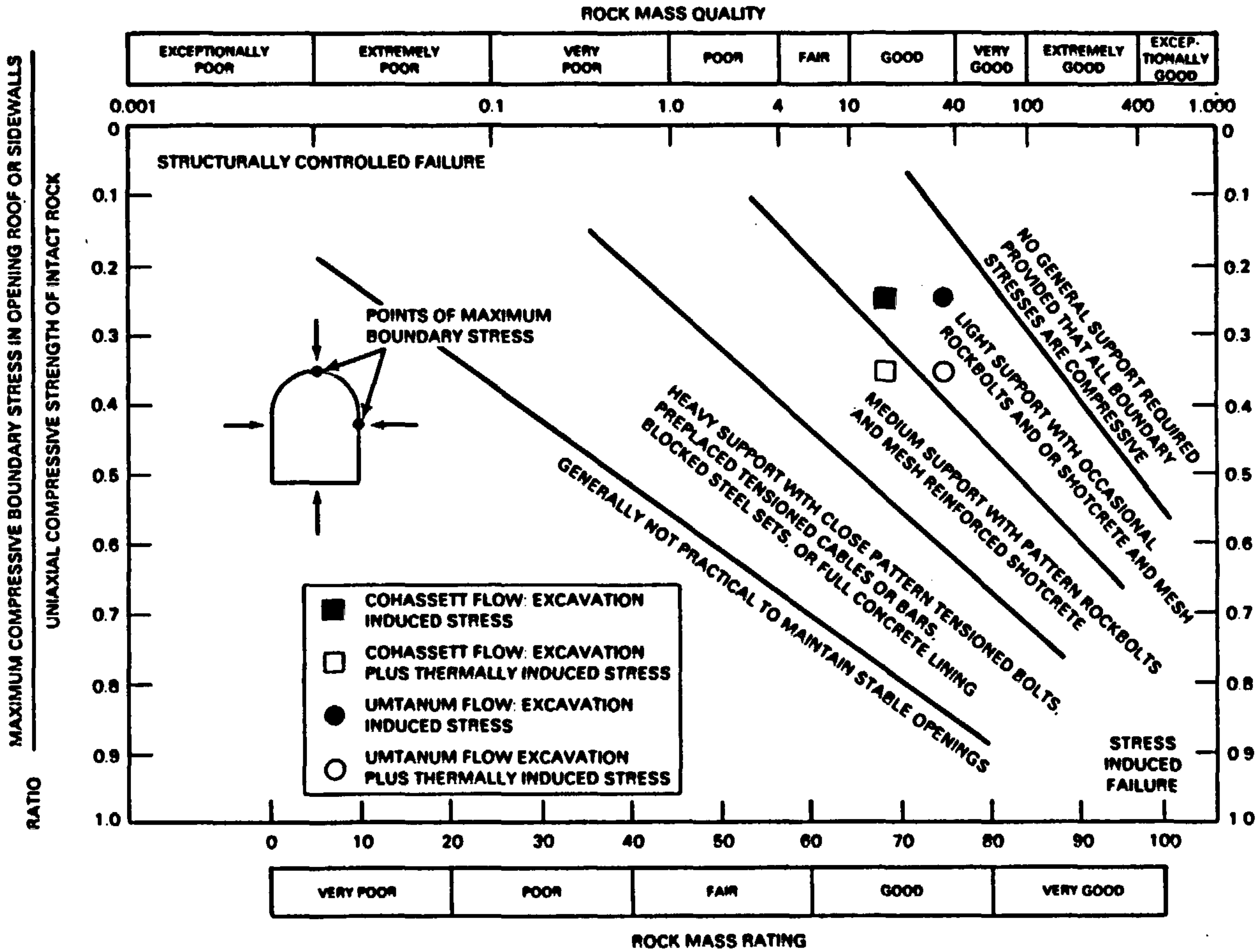

FIGURE 6.1. Approximate Relationship Between Excavation Stability, Rock Mass Quality, or Rock Mass Rating and Maximum Compressive Boundary Stress (after Hoek, 1981)

(blast damage), depth of the excavation, in situ stress, extraction ratio, degree of weathering, and width, location and attitude of major structural discontinuities.

The effect of these adjustments is a lowering of the rock mass rating and a more conservative estimate of the rock support requirements. No evidence has been found that any of the adjustments of the rating system parameters were made by RHO . However, in a later draft of the RHO-BWI-ST-28P-Draft, October 1983) the treatment of the intact strength data was considerably improved by taking a statistical approach to the data. These changes resulted in a more conservative support estimate with a majority of the Cohassett support requirements falling into the "medium support" region when the thermal stresses were added to the excavation induced stress.

There is some evidence that the strength of basalt may decrease with increasing temperature. Parsons Brinckerhoff has reported a decrease in rock strength with increasing temperature and proposed the relationship in Figure 6.2. (Schmidt, 1980, 1981) the chart is based on laboratory strength tests at elevated temperatures performed by the Colorado School of Mines (CSM, 1979,

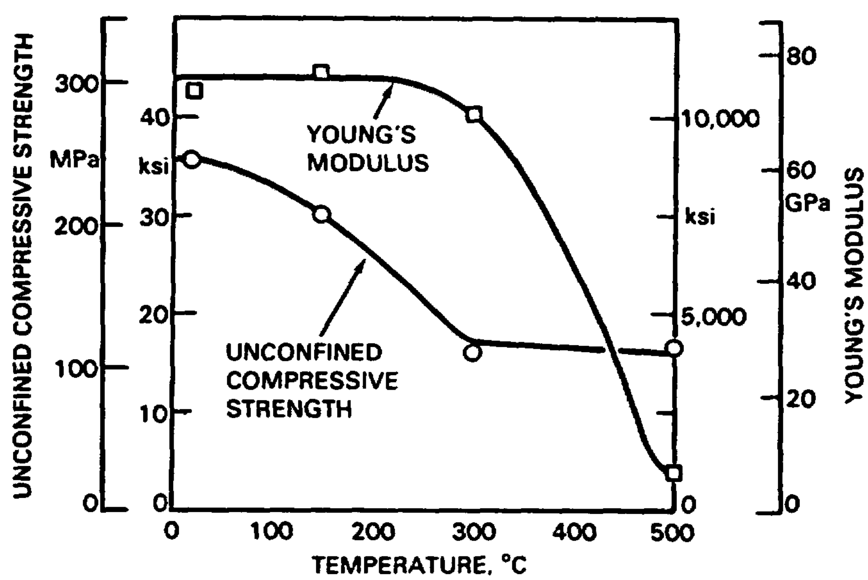

Figure 6.2. Strength and Modulus as Function of Temperature (Schmidt, 1981)

a,b). Foundation Sciences, Inc. (FSI) reported as much as a 50% decrease in intact basalt strength with increasing temperatures (300°C) (RHO-BWI-C-100, 1981). RHO decided to disregard the results due to quality assurance questions regarding the basalt samples used. However, both results indicate a lowering of basalt strength at high temperatures. Referring to Hoek's chart, a lower value of strength results in a greater stress to strength ratio and an increase in the recommended support requirements. Further investigations are necessary to establish the effect elevated temperatures have on the strength of basalt.

Possibly the most significant effect of increased support requirements would be in the cost of constructing the underground repository. PNL performed a simplified cost estimate (Bruno and Young, 1983) to determine the cost implications of going from an underground nuclear waste repository requiring "light-medium support" to a facility requiring "heavy support." The estimates were based on KE/PB's conceptual design analysis (SD-BWI-SD-005, 1983, Vol. I, II, III) and the specific criteria for the degree and cost of ground support for all underground facilities. The conclusions indicated changes in the cost, productivity, construction time and materials handling as follows:

1) total sub surface facility excavation costs increased 48%
2) total repository costs increased 10%
3) productivity (i.e., excavation advance rate) decreased 45% causing an increase in the initial construction period from 8 to 12 years.

The above conclusions were based on limited case histories in mining and civil engineering projects and are not purported to be accurate for the proposed repository design at Hanford. The study was implemented to determine the sensitivity of the various aspects of construction to changes in the support requirements. The KE/PB analyses in support of conceptual system design (KE/PB, 1982) estimated cost increase based on changes in the horizontal to vertical stress ratio. When the ratio was increased from 2:1 to 3:1, repository construction costs increased from $145M to $387M. The increase is significantly higher than the PNL estimate but different assumptions were used. The results exemplify the importance of realistic estimates of rock support requirements for accurate costing and planning of repository construction.

6.2.6 Backfill

Backfilling of underground openings (boreholes and tunnels) and shafts is an integral part of the repository sealing system. The technical questions for the horizontal borehole packing have already been discussed in Chapter 5.

Tunnel Backfilling

The backfill for tunnels consists of bentonite powder and 6.4 cm (2.5 in.) basalt (SCR, 1982). A density of 27.4 kN/m^3 (174 pcf) (water content is 10-15%) is assumed to be achievable for the backfill (Jones, 1982 and SCR, 1982).

The fill is hauled into the room, dumped, and spread by a bulldozer in 0.2 m (8 in.) lifts. Each lift is dampened and compacted mechanically using large equipment before the next lift is started. This sequence continues until the fill reaches half the height of the room, where low-profile equipment will then be used to complete the lift. The remaining 1.5 m (5 ft) of space in the room is backfilled, utilizing a yet-to-be-developed piece of equipment. As currently conceived, this equipment is a traveling shield with hydraulic cylinders for jacking against the walls of the room and a hydraulic ram for compacting the fill (SCR, 1982).

The following technical questions have been identified for tunnel backfilling by the proposed procedure.

Material Segregation During Transport. Material segregation in the proposed material handling from the surface to repository level is common to both horizontal borehole emplacement and tunnel backfilling, and has already been discussed in Chapter 5. Because of the large aggregate size [6.35 cm (2.5 in.)], material segregation during transport will be more severe for the tunnel backfill.

Emplacement Procedure. An unresolved technical question is the proposed emplacement procedure for tunnel backfilling to achieve the necessary density. A review of literature shows that a compressive force of 140 MPa (21,000 psi) was required to obtain a density of 18.4 kN/m^3 (117 pcf) for a bentonite clay-quartz (sand) mixture (Wheelright et al., 1981). It is unlikely that the 92% of theoretical density 27.4 kN/m^3 (174 pcf) can be achieved using the proposed emplacement procedure and equipment. It is theoretically impossible to have 10-15% water content at 27.4 kN/m^3 (174 pcf) packing density. Uniform damping of bentonite mixes generally cannot be achieved and difficulty is often experienced in trying to compact partially wetted bentonite-rock mixtures (Gee et al., 1981; Selig et al., 1982). No testing criteria have been developed for assessing the packing of the specified graded mix. ASTM proctor density tests (ASTM 1557) limit the maximum particle diameter to one fourth to one sixth of the corresponding mold diameter; hence, the larger particles must be scalped and replaced with an equal weight of finer material. Assuming a reasonable compaction density [15.7 to 18.9 kN/m^3 (100 to 120 pcf)] does not guarantee a uniform packing matrix necessary to minimize potential seepage.

Need for a Structural Backfill. The redistribution of stress caused by the proposed opening configuration of the repository design has not yet been fully analyzed. Tunnels should be designed to minimize deformation so that the engineered barrier will reach an equilibrium state without further disturbance of the rock mass. Excessive deformation of the opening could affect disturbed rock zones and support system components, contributing to increased rock mass permeability.

Ability to Provide Quality Assurance (QA). The proposed Rule (10CFR60.152) requires a quality assurance program in accordance with Appendix B of 10CFR 50. Considering the difficulties of material uniformity due to placement segregation, the ability to "wet" the material, and the proposed emplacement scheme, providing QA will be difficult. Satisfactory quality control methods will have to be developed along with the backfilling process.

Shaft Backfilling

The SCR (1982) does not provide detailed information concerning construction and sealing of the repository shafts. Reviewing BWIP's functional design criteria (SD-BWI-FDC-006, 1982), the following design philosophy is posed:

> "The design shall be based on installation of a shaft seal system that includes a redundant series of concrete collars situated in competent basalt flow with compacted sand and bentonite between collar locations. The total length of the shaft seal system shall be a

minimum of 305 m (1000ft). To minimize the potential for groundwater seepage past the collars, the collars shall be keyed into the sides of the shaft beyond the rock zones significantly disturbed by excavation. The lining shall be removed in the areas adjacent to competent basalt flows to eliminate problems associated with shaft liner degradation. The shaft lining shall not be removed within the aquifer zones." (SD-BWI-FDC-006, 1982)

At this time, BWIP is still formulating a conceptual design for shaft backfilling. Hence no particular technical questions can be addressed. NRC's staff of the High-Level Waste Technical Development Branch of the Division of Waste Management has, however, issued a draft technical position addressing the following shaft sealing issues (NRC, 1983):

1) long-term stability of seals
2) designing of shafts with consideration for long-term sealing
3) installation procedures for sealing
4) impact of thermal loading on seals
5) compatibility of seals to host rock
6) maintaining low permeabilities in the sealed area.

The conceptual design for shaft sealing should address all these issues and show how a testing program is being designed to resolve these issues.

6.3. PERFORMANCE ASSESSMENT

The seal system performance assessment approach established by BWIP is based on four assumptions (BWIP Repository Program Overview Meeting, Janaury 20, 1983):

- 1% of contaminants enter the seal system
- instantaneous release from the waste package
- seal system path contribution to EPA $\leq 10^{-3}$
- oxidizing conditions.

The seal system performance requirements include: groundwater travel times (to accessible environment) and sorption characteristics that provide required nuclide travel time (T_n) of 500 years water travel time (T_w) with current K_d

estimates. In addition, current allocation analyses will revise performance requirements as understanding of mechanisms and data improve.

With the lack of written material and the infancy of the repository sealing program, it is difficult to critique the performance assessment approach. A number of questions concerning the assumptions may be made:

- Is the 1% of the flow entering the seal system dependent upon the position of the shafts?
- Are the calculations dependent on horizontal or vertical waste package placement?
- Have the data been extrapolated back to reducing conditions at lower temperatures?
- What is the confidence level of the travel time and water quality limits?

6.4 ASSESSMENT OF PLANS TO ADDRESS TECHNICAL QUESTIONS

6.4.1 Integration of Design Activities

A thorough integration of design activities with the multitude of scientific investigations that are being conducted by Rockwell and others is needed in the BWIP. Many of the technical questions below have been discussed elsewhere. They are summarized here only to point out the discrepancies between the design and technical efforts.

Since site selection will be based on a detailed comparison and ranking between sites based on -- "the results of a detailed performance assessment of the proposed repository system against the postclosure and preclosure system guidelines of Sections 960.4 and 960.5 respectively" the proposed repository system must be totally consistent with the technical program. RHO has recently recognized the necessity for achieving this consistency by directing KE/PB to perform some key tradeoff analyses such as shaft optimization, tunnel optimization, and optimization of waste emplacement before proceeding with further design efforts. Likewise, RHO has verbally acknowledged the necessity for incorporating the measured ranges of rock properties, measured in situ stresses, etc., into the functional dlesign criteria (Turner et al., 1983).

Because the initial program followed the requirements of DOE Order 5700, which preceded the Nuclear Waste Act, and because of the nature of conceptual design studies and time constraints), the conceptual design described by the Department of Energy (SCR, 1982) and the "Conceptual System Design Description" (SD-BWI-SD-005, 1983) is out of synchronization or inconsistent with the technical program. A few illustrations of this phenomenon are cited below. It should be emphasized that many of the items mentioned are not of critical concern at this juncture. It is considered essential that these discrepancies be corrected before the SCP is issued.

Methane in Repository

Ample evidence indicates the presence of methane in or below the horizons of interest (SCR Sections 5.1, 5.2.4, 5.1.5.4.4, 6.2.4; SD-BWI-TP-022 Section 5.1.2.1.5) for the repository. Whatever the sourace or transportation mechanism of methane, the probability of finding this gas in the repository during construction or retrieval phases is great.

No recognition of a potential methane problem was found in the repository design documents. The current data do not allow prediction of the expected concentration of methane in the repository. If the ventilation system is inadequate to maintain concentrations below 0.25%, the repository will be automatically designated a "gassy mine" per 30CFR57.21. The implications on the design and operation of the repository could be very great. Whatever the methane concentration proves to be, the ventilation system must be designed to insure against explosive conditions.

Rock Properties

The strength of the intact rock in the repository horizon and, more importantly, the performance of the jointed regimes, will have a profound effect on the design, construction, and cost of a basalt repository. The in situ residual stresses in the basalt will have similar impacts.

Measured in situ stresses are reported in RHO-BWI-ST-28P-Draft (1983). Horizontal to vertical stress ratios in the Grande Ronde formation range from 2.15 to 2.73. A design report (SD-BWI-SD-005, 1983) uses stress ratios of 2.0.

Another design report (BWIP 7866, 1982) dkescribes the impact, which is considerable, of in situ stresses on construction costs. It will be necessary to assure that design bases and estimates reflect the field data.

The same comment can be made for the selection of rock properties to be used in stress calculations. Using a low (2.0) in situ stress ratio and a high (364 MPa) intact rock strength value, the design document (SD-BWI-SD-005, 1983) shows rock strength/crown stress ratios of 2.8. With other reported rock properties and the in situ stress data reported in RHO-BWI-ST-28P-Draft (1983), strength to stress ratios of 1.0-1.2 can be calculated. Interpretations based on these values could lead to considerably different conclusions on the ease and cost of mining Hanford basalt.

Mine Stability

The repository design included in the SCP must contain realistic considerations of stability, safety, and related costs. A collapse of a repository opening could have extremely deleterious effects on the nuclear waste program and we believe that considerations of stability and safety should be more akin to those of civil works than those of conventional mining practice.

The stability analyses performed to date for the conceptual system design (SD-BWI-SD-005, 1983 and BWIP-7866, 1982) use liner elastic stress models. The support calculated in this manner (when high intact rock strengths and low in situ stresses are used) tends to be less than that calculated by rock classification techniques discussed at some length in RHO-BWI-ST-28P-Draft (1983). The design study (BWIP-7866, 1982) acknowledges the simplistic nature of the stress models that are, admittedly, reasonable for conceptual design tradeoff analysis. However, since the calculated support and cost conclusions from the design study impact, and are reflected in many other documents, including the SCR (1982), appropriate updating will be necessary.

Larage Shaft Drilling

The successful completion of the repository access shaft in Hanford basalt is a major construction challenge. Single-pass drilling (which seems to be the most likely method) of a hole this size is on the outer fringe of the state-of-the-art. Since no shafts larger than 14 ft have been drilled in hard rock, the

20 ft hole talked about in the BWIP drilling plans, (see Gimera, 1983) represents a significant advance. Unfortunately, drawing number H-6-6070 in SD-BWI-SD-005 (1983), Vol. II calls for a 22 ft diameter hole. RHO recognizes the implications of this dimension and is funding a KE/PB study of the subject.

6.4.2 Shaft Drilling and Lining

On August 9,1983, PNL conveyed its concerns to RHO regarding the following technical questions (Enderlin, August 9, 1983):

- lack of a proven drilling system
- high potential for loss of drilling fluid
- high potential for sloughing, slabbing, and spalling.

On August 19, 1983, PNL met with DOE, RHO, and its subcontractors to discuss these technical questions and their plans for addressing them (Enderlin, August 25, 1983).

Lack of a Proven Drilling System

As yet, RHO/BWIP has not established their approach to this problem. Consideration is being given to a drilling system capable of drilling shafts up to 20 ft in diameter in a single pass at Hanford and the need to demonstrate a capability for drilling such a shaft. As a result, subcontracts have been awarded to Fenix and Scisson, Inc.(F&S), Colorado School Of Mines (CSM), and Los Alamos Scientific Laboratories (LASL), to perform the required laboratory testing and modeling, and to provide the drilling system specification (Fenix and Scisson, September 29, 1983). PNL has been assigned the task of developing the required test plans. This work is currently in progress and is being conducted in parallel with the Shaft Optimization Studies at KE/PB, which are scheduled to be completed by the end of February 1984. In the event the Shaft Optimization Studies show that the largest shaft diameter can be less than 20 ft, the demonstration test plans will be revised accordingly.

Alternate consideration is being given to an approach wherein Geodril Rig 32 would be modified to drill up to a 20 ft diameter shaft to required depth using a two-pass technique. This approach proposes that the rotary torque capacity of the rig be increased to 400,000 ft-lb and that the height of the substructure be increased. The 12 ft diameter bit currently on site would be used for the first pass. A specially designed reaming bit would be employed to enlarge the hole from 12 ft to 20 ft. A proposal for a test to demonstrate two-pass shaft drilling at Hanford using this rig was submitted to DOE by RHO (Gimera, August 12, 1983). At the request of BWIP, PNL reviewed and commented on this proposal (Burnham, August 25, 1983). Some of the PNL concerns regarding this approach are:

a) A maximum of 400,000 ft-lb of rotary torque would be inadequate for drilling the second pass. Based on calculations using Morlan's equations (Enderlin, September 15, 1983), PNL predicted that at least 185,000 ft-lb of torque would be required to drill the first pass and in excess of 479,000 ft-lb of torque would be required for the second pass. In reviewing the drilling history for a 10 ft diameter shaft drilled in Nevada using Geodril Rig 32, it was noted that peak rotar torque values of 400,000 ft-lb were experienced (Fenix and Scisson, August 11, 1983). This probably explains why the torque table broke down six times during the operation. Therefore, it is reasonable to assume that peak rotary torque values well in excess of 400,000 ft-lb would be experienced at Hanford while drilling the 12 ft diameter hole on the first pass. Peak torque values considerably in excess of the above would be expected in the second (20 ft) pass.

b) The reaming tool to be employed for the second pass is not of a proven design. Bridging or a major slough or slab in the hole below the lower non-rotating stabilizer would seriously impede the performance of the system.

c) The remedial action currently planned for the ES by BWIP for dealing with a major slough, spall, or loss of circulation wherein a cement plug is set on the first pass and then drilled through (SC-BWI-AR-006, June 1982) would be ineffective with a two-pass system, since the cement left in the sidewall would be removed on the second pass.

d) We anticipate that it would require twice the time to drill the shaft using a two-pass technique as it would to drill it in a single pass using a drilling system designed for that purpose, since the penetration rate is expected to be the same for each pass.

High Potential for Loss of Drilling Fluid

Currently no contingency plans have been developed for any shafts other than the exploratory shaft (ES). In reviewing the ES plans for the loss of circulation, one option noted is the addition of lost circulation material.. Where this contingency will not correct the problem, setting a cement plug is planned (SC-BWI-AR-006, June 1982). It is questionable how effective the latter technique would be on shafts 20 ft in diameter. Normally a cement plug is set at the horizon where the problem is encountered and then the shaft is drilled ahead through the plug. This plan calls for equipment capable of placing 40 ft of plug in a 110 in. diameter hole, which would involve placing about 660 to 1320 cu ft of cement in the bottom of the hole. A 20 ft diameter hole would require about 5 times this volume of concrete and may present a logistics problem.

High Potential for Sloughing, Slabbing, and Spalling

Again, contingency plans have been developed for the ES only. In reviewing these plans, it is noted that the remedial action is much the same as described above, where a cement plug is set (Morrison-Knudsen, August 11, 1983). Moreover, this plan concludes that: "An event where the bit became hopelessly stuck would leave essentially one alternative, abandonment of the hole and the drill assembly." PNL fully concurs with the conclusion reached by Morrison-Knudsen. It is recommended that a procedure be developed that would mitigate this potential hazard.

6.4.3 Underground Ventilation

On October 13, 1983, PNL conveyed its concerns regarding the potential for the repository to be classified as a gassy mine and the resulting impact that classification would have on the repository design (Burnham, October 13, 1983).

6.4.4 Underground Stability

In Situ Stress

BWIP acknowledged that certain variables of the test analysis are subject to interpretation, but that an assumption of full pore pressure acting during the tests was made for the report (RHO-BWI-ST-28-P, July, 1983). They stated that in future reports (i.e. the SCP and Hydraulic Fracturing Test Report), a full treatment of the test data both with and without the pore pressure term will be included. In the revised version of document RHO-BWI-ST-28P-Draft (October,1983), BWIP states:

> "It should be noted that there is not universal agreement as to the proper approach to analyzing and interpreting the results of hydraulic fracturing tests. Different investigators may, using the same set of data, arrive at different conclusions and different magnitudes for the stress levels. For purposes of this report, these different approaches were not considered. One consistent approach was used in the analysis and this provides an appropriate basis for assessing the differences in stress levels between the four flows."
> (p I-230).

PNL feels this and other questions regarding hydraulic fracturing parameters deserve close attention. As RHO/BWIP staff points out in the report, hydraulic fracturing is the only acceptable method of measuring the in situ stress at depth from a surface borehole. Also mentioned in the report are the indications from field observations that a high horizontal to vertical stress ratio exists. Core discing has been reported in samples recovered from various flow interiors (Moak, 1981), (Lehnoff, 1982) and borehole breakout (spalling of the borehole wall) was observed in RRL-2 and DC-15 (Rundle, 1983). Both of these conditions are normally associated with brittle rock subjected to high stresses and indicate a potential for possible rock bursts and underground instability.

Stress considerations are important to the overall repository design including orientation, opening shapes and support. Because of the evidence that the candidate horizons are under relative high stress conditions and because of the implications on the construction of a nuclear waste repository, PNL feels that a conservative design approach should be undertaken, at this juncture.

KE/PB developed a conceptual design for the most economical disposal of spent fuel and high level waste (KE/PB, December 1982). The analysis assumed a horizontal to vertical stress ratio of 2:1. Because the 2:1 stress ratio was based on limited data, KE/PB also considered a stress ratio of 3:1. The results of these preliminary analyses indicate that the mining costs increase from $145M to $387M for the case where the stress ratio was 3:1. The significance of the cost difference emphasizes the need for confirming measurements of the in situ basalt stresses.

The questions concerning the interpretation of the hydraulic fracturing test may be answered from the findings of the suite of stress measurements planned at the Exploratory Shaft Test Facility (SD-BWI-TL-006 REVO-0, 1983). Hydraulic fracturing, overcoring and flatjack methods are planned to provide independent checks of the accuracy of the data using principles different from that of hydraulic fracturing.

> "Agreement between hydraulic fracturing and overcoring results would then increase confidence in the accuracy of the repository horizon stress data. Disagreement would be cause for review of test conditions, procedures and results as well as an examination of results of related tests (e.g. flatjack tests) in order to locate the source of conflict. If all results appear to be valid, yet disagreement still exists, the values providing the most conservative approach are to be used for design and analysis."

Because this information will not be available for some time and because stress estimates are necessary for design calculations, PNL recommends the use of conservative assumptions in interpreting hydraulic fracturing results until more definitive data are available.

6.4.5 Tunnel Design

No discussions were held with representatives from KE/PB regarding the heat transfer and stress analyses performed. Discussions with RHO personnel indicated that they were aware of the need for additional work and that planning is underway for a future "design workshop." The workshop would include members from the underground repository design and construction community. The goal of the workshop would be to arrive at an overall design strategy to establish a comprehensive design approach. The input from the members would be ongoing so that any new technology or developments could be incorporated.

6.4.6 Empirical Design Methods

In the October, 1983 revision of RHO-BWI-ST-28P-Draft, RHO's approach to empirical design methods was significantly improved. The input to Hoek's chart considered the entire range of values for rock strength and in situ stress (from hydraulic fracturing measurements).

> "The Cohassett and Umtanum regimes in the charts were determined using the following procedure: the range of the rock mass quality was taken directly from Table I-61. The upper and lower bounds for the Cohassett and Umtanum regimes in the charts were determined using the following procedure: the upper and lower bounds of unconfined compressive stress for the Cohassett and Umtanum entablature structures were computed as the mean compressive strength +2 standard deviations.....The range of the maximum boundary stress in the opening roof was calculated by multiplying the highest and lowest measured values of the horizontal in situ stress in RRL-2 by the roof concentration factor. The roof stress concentration factor was determined to be 1.5 for an elliptical opening with a 2:1 aspect ratio in a 2:1 biaxial stress field...."

The intersection of the parameters on Hoek's chart is illustrated in Figure 6.3. The revised support estimates are:

> (Umtanum) "mostly 'light support with occasional rockbolts and/or shotcrete and mesh'. However, heavier support would be required if flow-top breccia were encountered.....These areas with apparently weaker joints could require 'medium support'."

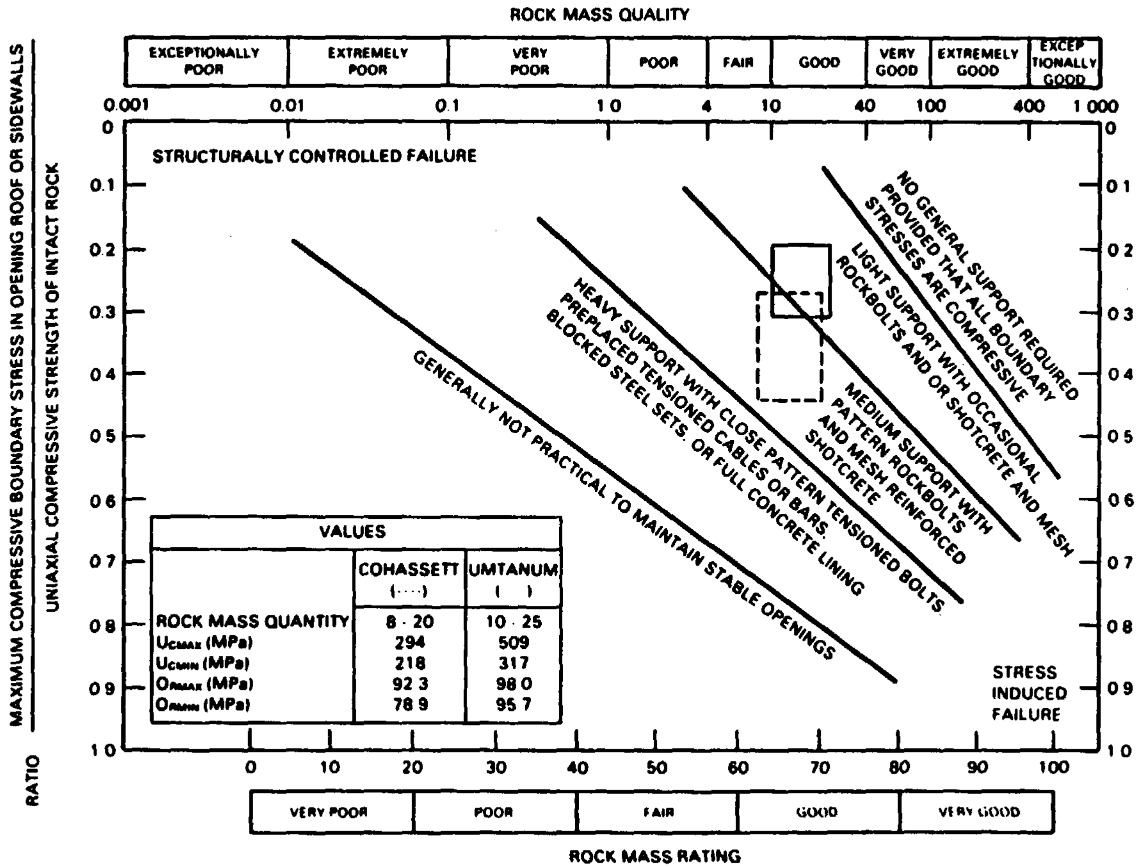

FIGURE 6.3. Approximate Relationship Between Excavation Stability, Rock Mass Quality or Rock Mass-Rating and Maximum Compressive Boundary Stress (after Hoek, 1981)

When the thermally induced stresses are incorporated:

> "The effect of the thermal induced stresses is to require more ground support in both flows. The Cohassett flow may require 'heavy supports' in areas where the heaviest loads occur in the poorest rock. Similar requirements might be expected under thermal stresses in the other candidate horizons, particularly in the Umtanum flow near flow-top breccia and in the Rocky Coulee and McCoy Canyon flows in vescicular zones."

RHO points out the assumption made that the increase in temperature would cause little or no degradation of rock mass quality. RHO also cautioned that the chart was not developed specifically for basalt rock and that the chart contained no observations of ground support in heated rock. Finally, the apparently high likelihood of encountering flow-top breccia (lower compressive strength) in the Umtanum flow is mentioned.

As mentioned previously, the revised treatment is significantly better than the earlier version. However, no mention is made of adjusting the rock mass ratings for the specific conditions in the Hanford basalt (e.g., high stresses). Because of the importance of the empirical approach as a design method and because of the unique importance of a nuclear waste repository, it is recommended that the methodology be adapted to basalt by consultants experienced in developing rock classification and support design methods. The analytical design approach has it own drawbacks and other methods are needed as a means of cross checking the design recommendations.

6.4.7 Backfill

There was a lack of response from BWIP on the technical questions identified in memorandums to J. B. Burnham, (PNL, Program Manager) on Backfilling of Underground Openings (Gates,August 19, 1983) and Shaft Backfilling Technical Issues (Gates,September 23, 1983); hence, no meetings were held and BWIP's plans to address these technical questions are unknown. Further comments on the technical questions are provided:

Tunnel Backfilling

Material Segregation During Transport. M. I. Wood is overseeing the material testing program on the basalt-bentonite clay mixture for Rockwell. Per discussions with him on September 6, 1983, it was learned that plans to address segregation phenomena had not been developed. Some testing of the transport system was in the planning stages in September 1983, but results of these tests are not yet available.

Emplacement Procedure. Factors that influence field compaction results include method of preparation, lift thickness, and compactive effort.

The method of soil preparation prior to compaction is an important factor that generally includes a means of excavating, transporting, and spreading the soil. Also included is a means of adding water. The blending of soil to get homogeneous composition and moisture content within a placed layer is especially important in achieving the specified density and soil performance (Selig et al., 1982). This task is generally done poorly in the field because it is expensive and difficult to achieve, particularly in cohesive soils such as clay and clay-rock mixtures.

The lift or layer thickness significantly affects the density achieved. Generally, the average density decreases as the lift thickness increases (Selig et al., 1982). As each layer is placed and compacted, some additional compaction of underlying layers may also occur. This additional compaction is not usually considered in compaction-control decisions.

For any type of roller, the compactive effort can be changed by varying the magnitude of such parameters as weight, width, contact pressure, and vibration frequency (Selig et al,, 1982). The value of compactive effort applied by field equipment, in comparison with the reference test effort in the laboratory, is generally unknown.

As already stated, it is unlikely that the 92% of theoretical density 27.4 kN/m^3 (174 pcf) can be achieved with conventional earth moving equipment. A more realistic field density would be 15.7 to 18.9 kN/m^3 (100 to 120 pcf)(Gee et al., 1981). Further, the traveling shield, using a "static" press method for the tunnel backfilling operation concept may produce shearing planes at the seal material-basalt interface, as well as at the interface between the basalt-bentonite mixture compacted by conventional methods and the static "press" method.

Need for a Structural Backfill. This topic is covered more thoroughly in Chapter 5. If a structural backfill is required, further importance should be placed on achieving a highly compacted backfill.

Ability to Provide Quality Assurance (QA). Providing QA will be difficult, considering the difficulties of material uniformity due to placement segregation, the ability to "wet" the material, and the proposed emplacement scheme. It is unknown if the traveling shield will be removed periodically so that density measurements can be taken during field placement.

Shaft Backfilling

The following is exerpted (nearly verbatim) from NRC's (1983) draft technical position addressing sealing issues. It is important to note that BWIP's shaft sealing program is in its infancy and hence the lack of written plans preclude a review.

Long-Term Stability of Seals. The performance of the seal system over the life span of the repository continues to be an area of much controversy (D'Appolonia, 1978). NRC is specifying that tests and analyses must be performed by DOE to show that the seal system will perform under adverse conditions for a very long period of time. These methods should include the following.

- Analytical models, based on valid field and laboratory data, that analyze the system's performance over long time periods.
- Analog studies of proposed sealing materials and their longevity in similar environments to the repository, taking into account past experience with such materials.
- Long-term and/or accelerated laboratory testing of sealing materials in simulated repository environments.
- Long-term (3 to 5 years) in situ field testing of sealing materials.

Theoretical geochemical stability analysis of materials over the expected lifetime of the seal system, based on repository environment information.

- Applicable standards such as ASTM E632-81, "Developing Accelerated Tests to Aid Prediction of the Service Life of Building Components and Materials."

Designing of Shafts with Consideration for Long-Term Sealing. The flow of groundwater and transport of radionuclides could occur through the fractured area and around the emplaced seal if the rock units become extensively fractured by either excavation damage or stress redistribution. It is important that the mechanical characteristics of the zone surrounding the opening be understood. Determination of whether damage to the rock units has occurred, the extent of damage, and whether the damage could circumvent the purpose of the seal system must be performed. Areas of concern by NRC in this area are:

- selection of excavation and drilling techniques that inflict minimal damage (fracturing of the rock units)
- quality control of excavation and drilling procedures to assure minimal damage to the rock units
- selection of shaft liners with long-life capabilities
- selection of grout and control of grouting shaft liner to rock units taking into account long-term sealing considerations
- protective excavation, drilling, and reinforcement measures to minimize rock relaxation
- remedial measures to be taken in case excessive excavation and drilling damage has occurred
- installation of grout curtains and cut-off collars effects of stress redistribution resulting from the thermal pulse and subsequent cooling.

Installation Procedures for Sealing. A controlling factor in seal performance could be the placement techniques used in sealing shafts. NRC's concerns in this issue are:

- remedial measures for preparing the opening for sealing (e.g., shaft wall cleaning of residual mud if mud is used during drilling)
- development of technically feasible procedures for placement of seal materials
- adequate quality control to assure proper placement of seals
- field testing of installation procedures.

Impact of Thermal Loading on Seals. Damage to the seal system could result from the thermal loading caused by the emplaced waste. Consideration should be given to:

- chemical stability of seal materials at elevated temperatures
- changes in the stress field of sealed area caused by changes in temperature
- vertical uplift.

Compatibility of Seals to Host Rock. An important consideration in seal design is the compatibility of the physical and chemical characteristics of the seal material and the host rock. Important parameters to consider are:

- physical/mechanical characteristics - compressive strength, creep, stress field, hydrologic data (pressures and flow rates), lithology, rock fractures
- chemical characteristics - mineralogy, phase changes, pH, Eh, groundwater chemistry, rock-groundwater interaction, seal-groundwater interaction, seal-rock interaction.

Maintaining Low Permeabilities in the Sealed Area. The seals are emplaced to reduce to the extent practicable, the potential for creating a preferential pathway for groundwater or radioactive waste. The low permeability area under consideration would include the disturbed zone, the interface between the host rock and the seal, and the seal itself. Areas of NRC concern in this issue are:

- characterizing and sealing (if necessary) the disturbed zone surrounding the shaft

- developing seal materials and a seal system with low permeability and/or high sorptivity.

6.5 SUMMARY OF REPOSITORY DESIGN TECHNICAL QUESTIONS

On the basis of the DOE guidelines related to repository design, and the information reviewed, it is not possible to determine whether the Hanford basalt in the RRL area is either suitable or unsuitable as a site for the disposal of nuclear waste. The basalt exhibits both favorable and unfavorable conditions as outlined in the guidelines; nevertheless, data are insufficient to allow definite conclusions. The exploratory shaft and related test facilities will probably provide answers to many of the repository design concerns in the guidelines. The main concern over the work performed to date in the area of rock mechanics relates to the non-conservative approach taken in some of the design analyses of the underground facility and their interpretation. Recent efforts indicate a more conservative trend.

The Hanford basalt rock conditions may require complex engineering measures in the design and construction of the shafts and the underground facility and in the sealing of boreholes and shafts due to the jointed nature of the basalt and the high horizontal in situ stress. These same "potentially adverse conditions" may cause problems in maintaining stability in the facility during the retrieval period, as well as thermally-induced fractures in the near-field environment.

Current evidence indicates the presence of methane at the repository level, but expected concentrations cannot be predicted with available data. The existing repository design has not addressed the potential safety problem of gas buildup during the construction and retrieval phases.

The cost of developing the underground openings is significantly affected by the in situ stress conditions. If exceptionally high stress conditions are present at Hanford, the site may be prohibitively expensive in comparison with other available sites. The high stresses could also cause rock bursting which would create hazardous conditions for repository personnel. The actual stress state, excavation and support requirements and safety conditions will not be known until the exploratory shaft and related test facilities are completed.

In reviewing the design documents, it appears that RHO staff have often used non-conservative assumptions in their analyses. The high degree of uncertainty of many of the parameters (e.g. in situ stress, rock mass properties, etc.) and the significance of the underground facility warrant a more conservative analysis of the design requirements. Recent indications by RHO suggest that a more conservative approach is now being taken.

The lack of written plans and the infancy of the repository sealing program make critiquing difficult. None of the technical questions identified by PNL or posed by NRC would prohibit construction of a repository in basalt. Failure to address these technical issues could, however, delay completion of the licensing application.

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7.0 REPOSITORY PERFORMANCE ASSESSMENT

Safety and performance assessments include the development, verification, validation, and documentation of technology for analyzing various phenomena that could potentially affect nuclear waste isolation. The assessments include identification of site and design data requirements, recommendations for site characterization, input to siting decisions, and recommendations for potential design modifications directed at improving system performance. The performance analyses are used to identify events and processes affecting the disposal system, to examine their effects upon engineered and natural barriers, and to estimate the probabilities and consequences of the events and processes. This requires realistic projections of the protection that will be provided by all the engineered and natural barriers, including analyses of the likelihood of future human interference and other unplanned events that may cause releases to the accessible environment at a given site.

The performance assessments will include sensitivity analyses of the input parameters to identify the key parameters of the system, and also uncertainty analyses to quantify the confidence limits of the results. Safety and performance analyses are essential to demonstrate compliance with federal regulations governing the safety and performance of nuclear waste repositories. For example, for the pre-closure phase, radiological dose limits are set by 10CFR20 for the plant personnel and by 40CFR191 for the general public. For the post-closure phase, the expected life of waste packages, the maximum annual release of radionuclides from the repository into the geologic media, and the minimum groundwater travel time from the repository to the accessible environment are defined by 10CFR60, and the overall isolation system performance has to meet radionuclide release limits to the accessible environment as specified by 40CFR191. In addition, evaluations have to be provided on the basis of a large number of qualitative objectives and performance criteria defined by the above-listed regulations and by the DOE Siting Guidelines, 10CFR960.

The actual performance analyses conducted for the Hanford site in the SCR are described and evaluated in other chapters of this report. This chapter addresses the overall BWIP approach to performance assessment as evidenced in available reports and in a joint DOE/NRC/BWIP workshop on performance assessment held in Richland, Washington on 29 August to 1 September, 1983 (Deju, April 29, 1983; SD-BWI-PAP-001, 1983; Sagar and Clifton, July, 1983. SCR and SCA) .

7.1 ELEMENT OF PERFORMANCE ASSESSMENT

This section provides an overview of performance assessment to use as a guide in evaluating the overall strategy that BWIP has published. This overview is not derived from BWIP documents; rather it is a PNL perspective derived from participation in the NWTS program, from regulatory criteria, and from presentations at the joint workshop on performance assessment mentioned above.

7.1.1 Performance Assessment Objectives

Because repository performance must be determined for such long periods of time that direct observations or measurements alone will not suffice, performance assessment analyses must be the primary means of making the long-term projections necessary for establishing compliance or non-compliance with regulatory requirements (10CFR60, 40CFR191). Such determinations must be consistent with

60.101(a)(2), which states:

"Proof of the future performance of the engineered barrier systems and the geologic setting over time periods of many hundreds or many thousands of years is not to be had in the ordinary sense of the word. For such long-term objectives and criteria, what is required is reasonable assurance, making allowances for the time period, hazards, and uncertainties involved, that the outcome will be in conformance with those [performance] objectives and criteria."

The objective of performance assessment, then, is to provide the reasonable assurance that the candidate site for repository construction and the proposed engineered repository system comply with regulatory requirements. "Reasonable assurance" is not defined quantitatively:

"The validity of the necessary inferences cannot be reduced, by statistical methods, to quantitative expressions of the level of confidence in predictions of long-term repository performance. Similarly, the Commission will not be able to rigorously determine the probability of occurrence of an outcome that fails to satisfy the performance standards. Available data must be evaluated in the light of accepted physical principles; but, having done so, the Commission must make a judgment whether it has reasonable assurance that the actual performance will conform to the standards the Commission has specified in this rule.

It should also be borne in mind that the fact-finding process is an administrative task for which the terminology of law, not science, is appropriate. The degree of certainty implied by statistical definition has never characterized the administrative process. It is particularly inappropriate where evidence is 'difficult to come by, uncertain or conflicting because it is on the frontiers of scientific knowledge'" (10CFR60 preamble).

The nature of the site evaluation problem is such that compliance cannot be based on a classical probabilistic risk analysis (based on rigorous probability determinations), but must depend in part on expert judgment for such things as conceptual models of the geohydrology, scenarios and their probabilities, estimated parameter values, boundary locations, and uncertainties. To be credible, performance assessment must have as its basis technical conservatism and reliance on currently-available technology, must be based on realistic performance criteria that include the functional requirements of each subsystem, must include realistic uncertainty and sensitivity analyses, and must have integral peer review and updating as technology develops.

The BWIP performance assessment effort is, overall, being pursued in a way that meets these objectives. The only technical question apparent is that BWIP has not addressed methods for introducing the effects of gradual changes of the geologic/hydrologic system that will become important for periods longer than 10,000 years into their scenarios. This question will be discussed in more detail after use of the scenarios and regulatory guidance are outlined.

In PNL's opinion, BWIP lays itself open to criticism by reporting performance assessment calculations that are premature and cannot be technically defended given the current status of geohydrological and geochemical data. For example, the reporting of 95 percent confidence limits (RHO-BW-ST-28P-Draft, 1983) seems clearly inappropriate.

7.1.2 Demonstration of Compliance with 40CFR191

Although not stated explicitly in the draft standard, NRC (as presented in the joint workshop) assumes, based on conversations with EPA, that compliance with the EPA standard will be based on a comparison of the complementary cumulative distribution function (CCDF) of releases from the repository and the standard's criteria.

The CCDF will be constructed from the probability distribution functions for releases from individual scenarios.

The CCDF is a summation of all scenarios imposed on the site by NRC, EPA or others. Each "new" scenario will push the curve a little closer to the EPA limit. It is not difficult to envision that the site proponents will be trying to reduce the number of scenarios considered, while the opponents would increase them to the point that the EPA limit would be violated. Further, as quoted above, the NRC will not attach a numerical confidence estimate to the CCDF; the Commissioners will review each application and make the "reasonable assurance" call. BWIP performance assessment staff are very concerned (as are others in the industry) by this lack of guidance: do they assume "reasonable assurance" means a 50% confidence level, or do they go for 95% to be safe? If they achieve the 95% level, will the NRC require 99%?

The selection and "certification" (by the NRC) of a suite of scenarios is going to be difficult, and may overshadow efforts to characterize the consequences of each scenario. Most of the critical comment that has been leveled at the NWTS site contractors so far has been related to the nuts and bolts of geologic and hydrologic characterization and hydrologic modeling. It appears that this kind of scrutiny will continue, but will be matched by equal or greater attention to "what if?" questions. This will be especially true when the scenario-generation process is opened to the public (see below).

7.1.3 Generation of Scenarios

BWIP has conducted a rigorous Delphi analysis of disruptive events and processes that could affect the Hanford site, and has compiled a set of 45 scenarios for further study. This analysis was received well by the NRC reviewers at the workshop, who added the following cautions:

- The scenario compilation and review process should be opened to the public, and ample time should be allowed for public comment.
- The EPA may require that some "standard" scenarios be addressed even if the Delphi analysis rejected them from serious consideration.

The BWIP Delphi analysis did not (where possible) deal with combined events or with expected long-term evolution of the geohydrologic system.

The ONWI and OCRD approaches to performance assessment have not used the formal Delphi analysis of disruptive events as the fundamental basis for consequence analyses, but have used geologic simulation modeling preceded by workshops on disruptive processes and events less formal than true Delphi analyses. NNWSI has used a fault/event tree analysis to generate their list of scenarios, and supplemented it with some specific geologic simulations.

It is not clear that any of these approaches is going to be adequate for the NRC reviewers. The BWIP approach is a good (probably the best) start and can most readily incorporate a public involvement cycle, but lacks the physically-based inputs and combined-process abilities of geologic simulation modeling (hence has greater uncertainties and no provision for sensitivity analyses). The other approaches lack the initial "legitimacy" that a formal Delphi analysis gives, and have no convenient vehicle for incorporating public review, comment, and input.

7.1.4 General Scenarios For Performance Assessment

The only credible natural mechanism that could bring radionuclides into contact with humans after a well-sited repository has been filled and sealed is groundwater transport. Radionuclide migration could occur under any or all of the following conditions: (1) groundwater transport under expected geologic, hydrologic, and geochemical conditions, including conditions that exist at the time of repository closure and the probable evolution of those conditions during the containment period, and changes in those conditions created by the thermal pulse; (2) groundwater transport under unexpected geohydrologic conditions created by potentially disruptive natural events, which have a small likelihood of occurrence during the hazardous life of the wastes; or (3) by post-closure human activities. Depending on the containment period to be analyzed (see next section), the processes important to evaluating expected system behavior may or may not be similar to those contributing to consideration of potentially disruptive natural events.

It is PNL's judgment that the scenarios to be analyzed in performance assessments should be composed of two parts in the possible case that time periods longer than 10,000 years are considered: (1) a time-varying evolution of the geologic/hydrologic system describing its expected behavior in the presence of on-going processes (including climate change, tectonics, magnetic activity, and erosion) generated by a geologic simulation model; and (2) superimposed events of such small probability that they are not likely to be analyzed adequately by the simulation model. Processes active at a particular site, and low-probability events to be included in potentially-disruptive scenarios should be enumerated by expert consultation, a formal Delphi analysis, and perhaps by regulatory mandate. The formal Delphi analysis may include provisions for public review and comment.

This first phase of analysis will provide a well-documented and peer-reviewable basis for computer simulations of the expected evolution of the geologic/hydrologic system. These simulations, along with cases generated by superimposing low-probability events on the evolving "baseline," should be the scenarios whose outputs (repository release rates, travel times, release rates to the accessible environment, and probabilities) will be evaluated for compliance with regulatory criteria.

7.1.5 Duration of Time Period For Performance Assessment

EPA 40CFR191 (29 Dec 82 Draft) specifies that the performance assessments be performed for a period of 10,000 years after disposal based on the following.

1. Groundwater travels slowly. Assessment of a 10,000-year period "encourages selection of sites where the geochemical properties of the rock parameters can significantly reduce releases of radioactivity through groundwater."

2. Major geologic changes, such as development of a faulting system or a volcanic region, take much longer than 10,000 years. Thus the likelihood and characteristics of geologic events which might disrupt the disposal system are reasonably predictable over this period.

DOE has proposed the philosophy (10CFR960, 1 Aug 83 Draft, page 29) "that the limits specified in Table 2 of 40CFR191 (as finally adopted) should not be exceeded during any 10,000-year period." [Emphasis added] In addition, DOE specifies the conditions which, if present, are favorable to location of a repository.

<u>Geohydrology</u>. (960.4-2-1)

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

<u>Erosion</u>. (960.4-2-5)

<u>Favorable Conditions</u>. (3) "Site conditions such that waste exhumation would not be reasonably expected to occur during the first one million years after repository closure."

These guidelines suggest that the effects of long-term processes and events that cause changes in the hydrologic system (gradients, heads, discharges, and geochemistry) should be analyzed for at least 100,000 years into the future, and those that promote deep erosion (principally tectonics, surface hydrology, glaciation, and changes of sea level) should be analyzed for up to a million years into the future to gain the maximum benefit from performance assessment.

7.2 UNRESOLVED TECHNICAL QUESTIONS

As stated above, this review of the broad scope of performance assessment activities is limited to consideration of the approach to incorporating long-term geologic-hydrologic system development into the overall repository performance evaluation for the following reasons:

- DOE Siting Guidelines (1 Aug 83 Draft) do not consider that a real performance assessment can or will be performed until after site characterization; therefore it is not a question that must be answered in the SCP.
- The other analytical components of a performance assessment (e.g., hydrology, geochemistry) have been addressed in earlier Chapters.

This review is based on the documents listed below in the references, and on the DOE/NRC workshop on BWIP performance assessment. From all of this, the following technical concerns have been identified:

1. It appears that BWIP is basing most of their effort to incorporate effects of ongoing geologic processes on their formal Delphi analysis of scenarios. As was discussed above, such an analysis is an important part of the scenario-generation process and is the only way in which public comment can enter into the process if that becomes necessary. However, the scenarios were all chosen to be single-events (as far as possible) and to the extent possible do not include combined events or gradual changes coupled with rarer disruptive events--according to the presentations in the workshop. It has been the practice in most attempts to generate scenarios to use a formal procedure (fault-tree analysis, geologic simulation modeling, transitional events analysis) to incorporate gradual geologic changes and combinations of events. BWIP currently has no such plan. The BWIP approach is probably adequate if the performance assessment is limited to EPA's 10,000 years. However, it does not satisfy DOE Siting Guidelines (1 Aug 83 draft), which require consideration of successive 10,000- year periods. If the final siting

guidelines require longer analysis periods, modification of the approach will be required.

2. Little attention has been given to the problem of validating the models (as opposed to codes) for BWIP performance assessment analyses. A validation (i.e., comparing model predictions to carefully controlled field experimental results) is probably not possible. However, some intermediate procedures should be identified and pursued.

3. BWIP performance assessment predictions to date have not accounted for the uncertainties in the geohydrology.

7.3 ASSESSMENT OF PLANS TO ADDRESS ISSUES

This review included all available plans, and discussions between the BWIP performance assessment staff and NRC in the workshop. The Performance Assessment Plan should be revised to address the concern shown above unless the DOE Siting Guidelines are changed in the final version and do not require evaluations of periods longer than 10,000 years.

The Site Characterization Plan was not available for this review. It should explicitly outline the interaction between performance assessment modeling and field studies that will result in both a suite of models and a data set for final performance assessment at the end of site characterization.

7.4 SUMMARY OF FINDINGS

BWIP work in performance assessment appears well-directed in general. Progress to date on the analysis of disruptive events has been limited to a formal Delphi analysis, which was well-received by the NRC. However, this analysis does not accommodate the effects of multiple events or of long-term evolution of the geohydrologic system (greater than 10,000 years).

BWIP plans for performance assessment do not contain a provision for evaluating system behavior for a time period longer than about 10,000 years. This time period is in accordance with EPA (draft) and NRC regulatory criteria, but is not adequate for meeting the 1 Aug 83 draft DOE Siting Guidelines, which specify time periods for some analyses of 100,000 and 1,000,000 years. We recommend that BWIP re-examine their performance assessment plans in light of the latter requirements.

7.5 REFERENCES

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