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Basalt Waste Isolation Project Quarterly Report

**July 1, 1980
through
September 30, 1980**

**R. A. Deju
Director, Basalt Waste
Isolation Project**

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QUARTERLY REPORT**

**JULY 1, 1980
THROUGH
SEPTEMBER 30, 1980**

R. A. Deju

**Director
Basalt Waste Isolation Project**

November 1980



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ABSTRACT

This report addresses the technical progress for the Basalt Waste Isolation Project for the fourth quarter of fiscal year 1980. The organization of the report follows the current work breakdown structure for the technical areas of the project. The major highlights for the quarter are provided below.

Systems Integration completed a Technical Baseline Control Plan and submitted it to the U.S. Department of Energy-Richland Operations Office; implementation of the plan was initiated within the Basalt Waste Isolation Project on August 15, 1980. Through the site evaluation activity, a location in the western Cold Creek syncline area was identified as the reference repository location. An alternate site in the central Cold Creek syncline area was also identified. Full-Scale Heater Tests #1 and #2 were started on July 1, 1980 at the Near-Surface Test Facility. The tests are progressing satisfactorily; temperature, stress, and deformation data are being accumulated and analyzed. The development and documentation of three rock mechanics computer codes were completed during this reporting period. HEFF and MINAQ are boundary element-based codes intended for analysis of plane stress and thermomechanical problems; BETA is a finite element model intended for thermomechanical analysis in cases where the geometry may be expressed in plane or cylindrical coordinates. Several environmental documents were prepared and submitted to the U.S. Department of Energy-Richland Operations Office during this quarter.

In Geosciences, reconnaissance geologic mapping of the Columbia Plateau of Oregon resulted in the discovery of the westernmost-known Grande Ronde Basalt source area. Such mapping also showed the need to give formation status to suprabasalt sediments in four structural basins in Oregon and to include these formations as units of a new group termed "Dalles." Detailed field mapping determined that thinning of the Grande Ronde Basalt-Sentinel Bluffs member at Sentinel Gap is due to the presence of a paleostructural high, rather than to faulting. Such mapping also showed that surface fissures in the Snively Basin area of Rattlesnake Mountain are due to landsliding; recent landsliding was probably caused by a higher than normal precipitation during the winter and spring of 1980. New trenches at Gable Mountain revealed offsets in sediments that are interpreted to be of Quaternary age; possible causes of these offsets include tectonic faulting and movement induced by the effects of glaciofluvial flooding. A study of the intraflow variations in the Umtanum flow indicates that flow-top breccia is thickest in areas where the total flow is thickest and that tiering does not occur in areas of paleotopographic lows where the flow has ponded. A review of geologic, seismologic, and geodetic data indicates a preliminary rate of deformation in the Pasco Basin of 1 millimeter per year. An analysis of samples from the 3,246-meter-deep well (Rattlesnake Hills Well #1) suggests that the entire section penetrated is Grande Ronde Basalt; the possibility is being examined that this thick Grande Ronde section (the thickest on the Columbia Plateau) is due to structural rather than to stratigraphic

causes. The results of seismic reflection and multilevel aeromagnetic surveys were received and used to screen areas in the Cold Creek syncline during the reference repository location selection process. No unusual seismic activity was reported during the quarter. Installation of a six-station, portable seismic network was completed; the network will be used to monitor micro-earthquake activity in the Pasco Basin.

In Hydrology, three studies were completed and documented in the regional hydrology effort. In the first report, comparison of 1975 and 1979 LANDSAT classification data reveals that irrigated agricultural land increased approximately 20% over the period of study. The second report summarizes refined meteorological data for the Pasco Basin. A third regional hydrology report examines the potential for future water development in the Pasco Basin.

In the hydrological numerical model studies, both far- and near-field modeling studies were conducted. Preliminary far-field model results suggest that groundwater travel times to the Columbia River from the Umtanum flow in the Cold Creek syncline are on the order of 50,000 to 150,000 years. Vertical travel times account for the largest percentage of these travel times, and the ratio of vertical to horizontal permeabilities appears to play a significant role in determining groundwater flow patterns. For the near-field studies, a parametric and sensitivity analysis was completed for a hypothetical repository in the Umtanum flow. Two-dimensional simulations were performed for time periods up to 250,000 years following repository closure. Some of the major findings were that buoyancy velocities are an important variable, all radionuclides considered were contained in a small region about the repository following a 70,000-year period, and simulations over a 250,000-year period indicated that only ^{129}I would potentially migrate upward to the Wanapum Basalt just outside the Grande Ronde strata.

Selected radionuclide release scenario studies were also carried out during the quarter. Preparation of a report documenting the results of these analyses has been initiated.

In the hydrology field studies, 20 intervals were hydrologically tested in new boreholes, with an additional two intervals in existing boreholes. Reported transmissivities fall within previously reported values. Hydraulic head and hydrochemistry data suggest the absence of significant vertical groundwater movement. Of particular significance is the apparent absence of groundwater mixing between aquifers in the Saddle Mountains and Wanapum Basalts within the Cold Creek structural area.

Five hundred-sixty meters of borehole were cored in Boreholes DC-12, -14, and -15.

Engineered Barrier activities supporting the development of engineered barrier systems for emplacement in basalt continued during the quarter. The initial characterization of reference Umtanum basalt collected from outcroppings at the Hanford Site indicated nearly identical mineralogy when compared to basalt samples taken from Borehole DC-2 drilled earlier in the central Pasco Basin to a depth in excess of

900 meters. This substantiates the use of reference basalt in hydrothermal and sorption experiments supporting barrier system development. Advanced hydrothermal tests have yielded initial data that confirm results of earlier scoping tests; i.e., basalt is an effective barrier to radionuclide migration. In tests in which simulated spent fuel, basalt, and Hanford groundwater are reacted at 300°C, the concentration of uranium in solution was 2 ± 1.4 micrograms per milliliter after 4 weeks of exposure. In the absence of basalt, the concentration of uranium was 71 ± 1 micrograms per milliliter after a like period of time. Results obtained to date from advanced hydrothermal tests incorporating simulated supercalcine, basalt, and groundwater indicate that at a basalt-to-water ratio of 10:1, the solution pH exhibits a slow decrease to 7.8 after 385 hours, as opposed to pH depression to as low as 4.0 predicted from basalt/seawater experiments conducted elsewhere. Sorption chemistry studies were continued to determine the distribution ratios (K_d 's) for key radionuclides between basalt and simulated groundwater. The results of static tests have led to several conclusions: the geologic materials having a higher surface area (e.g., the secondary mineralization, 650 square meters per gram) usually have a higher radionuclide sorption capacity (K_d value) than those materials with lower surface areas (e.g., the basalts, ~20 square meters per gram) temperature effects on K_d between 23° and 60°C are relatively minor; and radionuclides such as technetium, neptunium, or iodine, which normally occur in an anionic or neutral form are sorbed relatively poorly by these geologic materials under oxic conditions. For radionuclides exhibiting more than one stable oxidation state (selenium, technetium, neptunium, plutonium, and uranium) little or no enhanced sorption onto basalt and fracture mineralization has been observed under slightly anoxic conditions. A computer code for calculating and plotting stable solids and solution concentrations as a function of pH and Eh (or oxygen fugacity) was developed. Calculations made using this code have shown that under likely repository conditions uranium is not more soluble than about 3×10^{-9} moles per liter. This is below the recommended concentration specified for drinking water in Title 10, Code of Federal Regulations, Part 20 for all uranium isotopes and their daughters (including ^{226}Ra). Thus, the extreme insolubility of uranium in a repository in basalt should inhibit the dissolution and transport rates of the major components of spent fuel to innocuous levels.

The draft of a report was completed which presents data from the literature on corrosion of cast irons, carbon steels, and titanium alloys, and evaluation of the data with respect to the Grande Ronde groundwater. The procedures for corrosion testing of candidate canister and overpack materials were defined. Procurement of candidate alloys for corrosion tests is essentially complete, and specimens were prepared for the first tests. Structural loads on engineered barrier systems emplaced in basalt were estimated. The test plan for the shallow borehole plugging test was revised, and the candidate test site was selected to be on Gable Mountain near the Near-Surface Test Facility. A study of fracturing and grouting in shafts constructed in basalt was initiated to evaluate the extent of fracturing around large openings and the ability to effectively seal them.

All Phase I Near-Surface Test Facility equipment was received and installed this quarter. The drilling contractor mobilized for the Phase II drilling on September 23 and 24, 1980, and bids were received September 25, 1980 for the Phase II facility work--other than drilling. The Phase II Title II drawings were completed August 15, 1980.

During this quarter, effort focused on two general areas in Engineering Testing: collection and verification of data from the two Full-Scale Heater Tests, which started July 1, 1980; and initiation of activities to support the Phase II tests of spent fuel and vitrified high-level waste. Data are being collected, recorded, and analyzed by the Rock Mechanics staff. The tests have operated smoothly thus far. Planning for the emplacement of nuclear waste is proceeding to meet the test start date of January 1982. The tests will use two canisters, each containing one pressurized water reactor spent-fuel assembly and one canister of vitrified high-level waste.

Repository conceptual design by Kaiser Engineers/Parsons Brinckerhoff continued during the quarter with emphasis on developing the concepts selected during the previous quarter. Kaiser Engineers/Parsons Brinckerhoff completed a draft revision of a report on the functional design criteria for a nuclear waste repository in basalt (Project B-301). Review of the draft document by the U.S. Department of Energy, the Office of Nuclear Waste Isolation, and Rockwell Hanford Operations is in progress. Kaiser Engineers/Parsons Brinckerhoff initiated a study of defense high-level waste and commercial high-level waste storage during September 1980 in support of the on-going nuclear waste repository in basalt conceptual design. The current design concept is based on the receipt and storage of commercial spent fuel and low-level transuranic waste. The new study will evaluate the impact on repository conceptual design of the following waste receipt scenarios:

- Receive and store Hanford defense high-level waste in addition to commercial spent fuel and low-level transuranic waste.
- Receive and store Hanford defense high-level waste, commercial high-level waste in a quantity equivalent to the commercial spent fuel received in the current design basis, and low-level transuranic waste.

During the quarter, work on the Exploratory Shaft Test Facility was limited to acquisition of comments on the test plan and completion of the preconceptual design report. The test plan was transmitted May 22, 1980 for review by participants in the National Waste Terminal Storage program. When the review is complete, a revised test plan will be prepared. The preconceptual design report was released September 30, 1980 as a system design description with supporting studies covering areas of major technical interest.

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INTRODUCTION

In February 1976, the U.S. Energy Research and Development Administration (currently the U.S. Department of Energy) expanded the commercial radioactive waste management programs and established the National Waste Terminal Storage Program. Its mission was to provide multiple facilities in various deep geologic formations within the United States. The Office of Waste Isolation was established within the Union Carbide Corporation-Nuclear Division to provide program management of the National Waste Terminal Storage Program. The overall program consisted of investigating a number of geologic rock types to determine their suitability for terminal storage of radioactive waste. Basalts, such as the Columbia Plateau basalts, which underlie a large portion of the Pacific Northwest and the Hanford Site, were selected for initial geologic reconnaissance. Atlantic Richfield Hanford Company was asked in May 1976, by the Office of Waste Isolation, to plan and execute a geologic exploration of Columbia Plateau basalts to determine the feasibility of utilizing those formations as a site for disposal of commercial nuclear waste.

In September 1977, the National Waste Terminal Storage Program was restructured. Additional funds were given to support investigations of two U.S. Department of Energy sites--Hanford and Nevada. The Hanford program is presently the responsibility of the U.S. Department of Energy-Richland Operations Office. Rockwell Hanford Operations (successor to Atlantic Richfield Hanford Company) is the prime contractor responsible for this work. The Basalt Waste Isolation Project within Rockwell Hanford Operations has been chartered with the responsibility of conducting these investigations. These investigations are part of a national program being integrated for the U.S. Department of Energy by the Office of Nuclear Waste Isolation of Battelle Memorial Institute.

The overall Basalt Waste Isolation Project is divided into the following principal work areas:

- Systems Integration
- Geosciences
- Hydrology
- Engineered Barriers
- Near-Surface Test Facility
- Engineering Testing
- Repository Studies.

Summaries of major accomplishments for each of these areas are reported in the following sections.

SYSTEMS INTEGRATION

The objective of Systems Integration is to consolidate all research activities leading to the identification, characterization, and licensing of a site for potential use as a nuclear waste repository in basalt within the Hanford Site. The scope of work includes reviewing research, test, and design activities; providing thermomechanical computer models, conducting trade-off studies; performing data analyses and interpretation; and establishing the technical basis and criteria for site selection, licensing, and design of the repository and ancillary facilities.

The Systems Integration end function is divided into three major activities:

- Project Management
- Systems Integration
- Safety and Environmental Documentation.

During the fourth quarter of fiscal year 1980, work has progressed in all three activities.

PROJECT MANAGEMENT

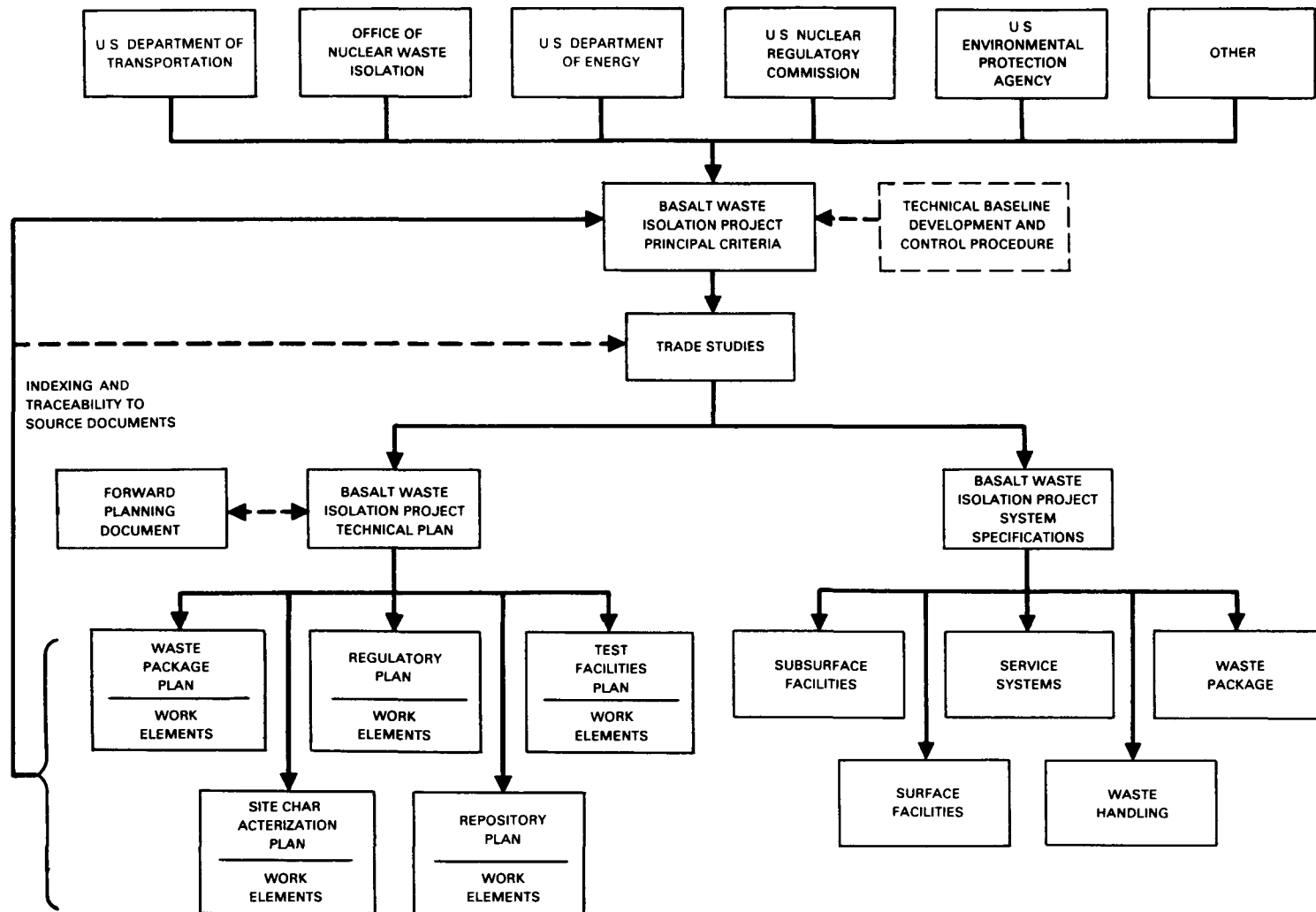
The project management activity is concerned with the management of the Systems Integration end function; specifically in the preparation and control of schedules, preparation of budgets and work packages, control of program costs, and overall guidance of the technical activities.

SYSTEMS INTEGRATION

Technical Criteria

A Technical Baseline Control Plan was submitted to the U.S. Department of Energy-Richland Operations Office and implemented within the Basalt Waste Isolation Project on August 15, 1980. This plan uses the classical systems engineering approach to provide visibility, traceability, and efficient management control of the technical baseline.

The technical baseline is controlled by the logic mechanism shown in Figure 1. It defines what has to be done to meet the program objectives through the principal criteria document and the system specifications and how we plan to meet the program objectives through the Basalt Waste Isolation Project technical plans. In addition, a computerized traceability and index system provides visibility for effective management control.



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FIGURE 1. Basalt Waste Isolation Project Technical Logic Mechanism Network.

Site Evaluation

Based on the current results of repository siting work, the A-H site, located in the western part of the Cold Creek syncline area (Figure 2), has been designated as the reference repository location (formerly called the preferred site). Site J, located in the central Cold Creek syncline area, is the alternate site. The identification of the preferred and alternate sites was made by ranking using a dominance analysis technique. The reference repository location is the combination of sites A and H. These two sites rated within 3% of one another in ranking. Site J ranked second and is the alternate location; site C ranked a close third. The second and third ranked sites fell 30 to 35% below sites A and H, thus indicating a clear preference for the A-H site. The identification of the reference repository location and alternate was carried out by a committee consisting of technical personnel from Rockwell Hanford Operations and Woodward-Clyde Consultants, San Francisco, California, under the guidance of Woodward-Clyde Consultants. The committee considered ten sites in the Cold Creek syncline area. The ten candidate sites are located in the Cold Creek syncline close to the 200 East and 200 West Areas. Seven (A, B, C, D, E, F, and G) of the ten sites had been identified by Woodward-Clyde Consultants in fiscal year 1979; three (H, J, and K) of the ten sites were identified by Rockwell Hanford Operations' geologists and geophysicists in mid-fiscal year 1980 based on new seismic reflection and aeromagnetic data and interpretations, and were submitted to the committee for consideration. The ten sites were evaluated and ranked using available information on the geology, hydrology, tectonics, ecology, and socioeconomics of the Hanford Site and vicinity. A report documenting these siting studies is being prepared.

Systems and Test Analysis

Full-Scale Heater Tests #1 and #2, which are part of the Near-Surface Test Facility test program, were started up on July 1, 1980. These tests will provide a data base on the response of basalt to thermal loading similar to that which might be expected in a deep geologic nuclear waste repository. The second phase of this canister-scale (very near field) test program will begin in fiscal year 1982 when canisters of spent fuel and vitrified waste are placed in the Near-Surface Test Facility.

Full-Scale Heater Test #1 is comprised of a main heater (in a full-size canister) surrounded by eight peripheral heaters (of smaller diameter). The peripheral heaters were operated at the 0.25-kilowatt level during this quarter, with the main heater turned on to the 1.0-kilowatt level after 30 days. The peripheral heaters were used to raise the rock mass temperature in the vicinity of the canister closer to that which would be found at depth. The main heater was operated at 1.0 kilowatt to approximate the thermal load of a single 5-year-old, pressurized water reactor spent fuel assembly. Later in the test, power levels to the main and peripheral heaters will be increased to test higher than expected thermal loading, as well as to simulate the effects of neighboring canisters in a repository.

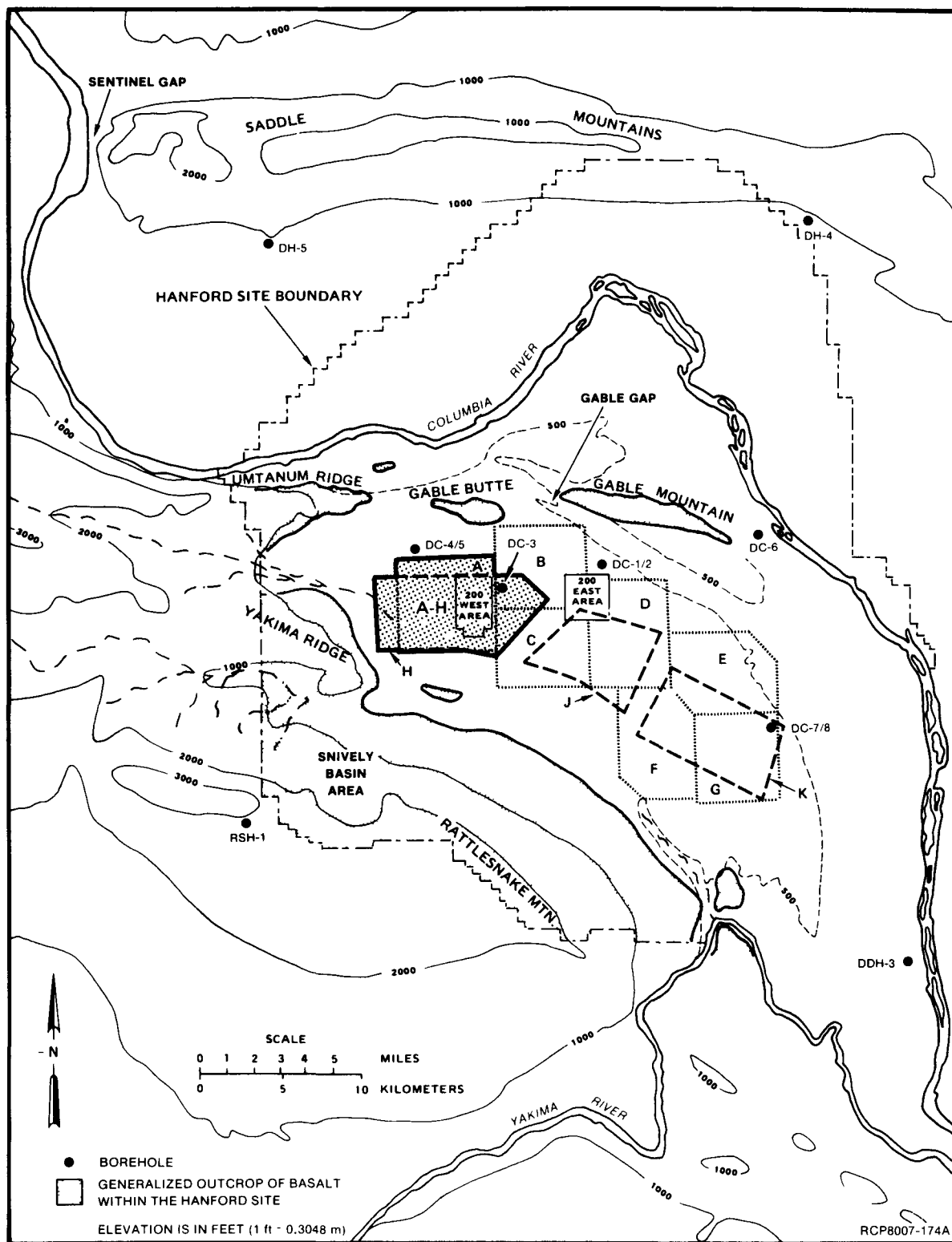


FIGURE 2. Index Map--Northern Pasco Basin and Hanford Site.

Full-Scale Heater Test #2 is comprised of a main heater (in a full-size canister) without peripheral heaters. It was operated at the 1.0-kilowatt level during this quarter. Eventually, this heater will be powered up to 5.0 kilowatts in order to evaluate the effects of extreme conditions upon the basalt in the vicinity of the canister.

Thermocouples, extensometers, U.S. Bureau of Mines deformation gauges, and IRAD gauges have been placed in a series in boreholes surrounding the test canisters to determine temperatures, displacements, and stress within the rock mass. Analysis of the test data is under way, but formal results are not available at this time. Preliminary temperature measurements suggest that the principal mode of heat transfer within the very near field is by heat conduction and that temperatures are largely unaffected by surface convection. Laboratory measurements of thermal properties appear to provide reasonable input to the thermal models. The results of the thermal modeling of heat conduction using finite element modeling are in reasonable agreement with measured temperatures given uncertainties in source-power levels, rock thermal properties, source-power radiation, and convective-heat transport from the floor.

Engineering Model Development

During this fiscal year, the University of Minnesota, Minneapolis, Minnesota, is documenting the models developed or modified for Rockwell Hanford Operations under previous subcontracts. User's manuals for TEMP3D, STRES3D, and DIFFUS2 have been discussed in previous quarterly reports. Three additional codes, BETA (formerly ALPHA), HEFF, and MINAQ (formerly SALTY), are discussed in this report.

HEFF and MINAQ are boundary element-based codes intended for analysis of plane-stress and thermomechanical problems. Both of these codes are indirect formulations: HEFF uses the "fictitious force" method and MINAQ the "fictitious displacement" or displacement-discontinuity method.

HEFF may be used to compute temperatures, stresses, and displacements around excavations in a rock mass where heat sources are embedded. The rock mass is assumed to be linearly elastic, isotropic, and homogeneous. Heat sources may be constant or decay exponentially.

The major limitation of HEFF concerns the method used to calculate the temperature and thermal stress fields. Use is made of the analytical solution for infinite line sources; these sources are assumed to extend in and out of the plane or section of the problem analyzed. These solutions do not take into account the presence of the excavation and are, therefore, in error in the immediate vicinity of any excavation. In practice, this error amounts to satisfying the stress boundary conditions around the excavation but not the temperature boundary conditions. The condition analyzed, therefore, corresponds closely to a hypothetical case of an excavation filled with a soft backfill with thermal properties identical to the host rock.

The other limitations of HEFF are the needs to assume idealized material behavior, to ignore the out-of-plane dimension, and to disregard discontinuities within the rock mass.

MINAQ is based on the displacement-discontinuity method. This code is similar to HEFF, but it differs in two important respects:

- It can only be used to represent a single excavation horizon which consists of a series of excavations separated by pillars. Only the widths of excavations and pillars are specifically represented by the model. Excavation shape is not represented and no detailed information regarding stresses around the excavations can be obtained.
- Unlike HEFF, MINAQ can be used to represent specific discontinuities passing through the rock mass. Such discontinuities behave in a nonlinear manner, even though the remainder of the rock mass must be treated as linear.

Like HEFF, MINAQ is limited by the use of analytical solutions for describing the response of the rock mass to thermal loading. Since MINAQ is intended for use in cases where the scale of individual excavations is relatively small, this limitation is less significant than for HEFF. Use of MINAQ to solve problems on a repository scale requires that the free surface above the repository be explicitly recognized. That free surface is made to satisfy two conditions: that it is isothermal and traction free.

BETA is a finite element model intended for thermomechanical analysis in cases where the geometry may be treated as being plane or axisymmetric. The calculation process is split into two independent but linked parts, thereby enabling thermal or mechanical analysis to be performed alone. The mechanical analysis is handled using eight-node, isoparametric, quadrilateral elements. Material behavior is assumed to be linear and isotropic, but up to seven different material types are used. Loading conditions include nodal point loading, distributed boundary loading, body forces, and initial stress, as well as thermal stress. The latter may be calculated automatically by the thermal section of the program that uses an explicit computational scheme, dividing each quadrilateral into six triangular elements. Thermal loading is defined in terms of either a source strength per unit area or energy input at a node. The characteristics of such a heat source are described by up to ten exponentially decaying components. Thermal boundary conditions can be either isothermal or adiabatic.

A significant limitation of BETA is common to all purely differential models. It derives from the necessity to discretize the entire region of concern. The practical consequence is that arbitrary boundaries for a domain, which may be semi-infinite or, for practical purposes, infinite, must be defined. Incorrect choice of these boundaries, as well as poor discretization of the problem domain, will adversely affect the results

of the analysis. In this respect, BETA differs fundamentally from the analytical code, STRES3D, and the boundary element codes, HEFF and MINAQ.

SAFETY AND ENVIRONMENTAL DOCUMENTATION

An environmental protection evaluation for seven boreholes was prepared and submitted to the U.S. Department of Energy-Richland Operations Office on July 11, 1980. The environmental protection evaluation was subsequently rewritten to include only the shallow boreholes (RRL-1 through RRL-6) per a request from the U.S. Department of Energy-Richland Operations Office. On September 2, 1980, the revised environmental protection evaluation was transmitted to the U.S. Department of Energy. A second environmental protection evaluation covering Boreholes DC-16, -17, and -18 will be submitted as soon as the final borehole locations are determined.

Two draft environmental assessment reports were submitted to the U.S. Department of Energy-Richland Operations Office on September 12, 1980. One of the reports discusses the potential environmental impacts associated with the screening or narrowing of the area under consideration. The other report discusses the environmental impacts associated with site characterization activities, such as borehole drilling.

GEOSCIENCES

The purpose of the Geosciences' studies is to gather basic data on local and regional geology to support the identification of a reference repository site in basalt. The studies emphasize reconnaissance field investigations in that portion of the Columbia Plateau underlain by Columbia River basalt (Figure 3) and detailed field work within the Pasco Basin of the Columbia Plateau where the Hanford Site is located (Figure 2).

The Geosciences end function is divided into four major activities:

- Project Management
- Geology
- Geophysics
- Seismic Monitoring.

During the fourth quarter of fiscal year 1980, work has progressed in all four major activities.

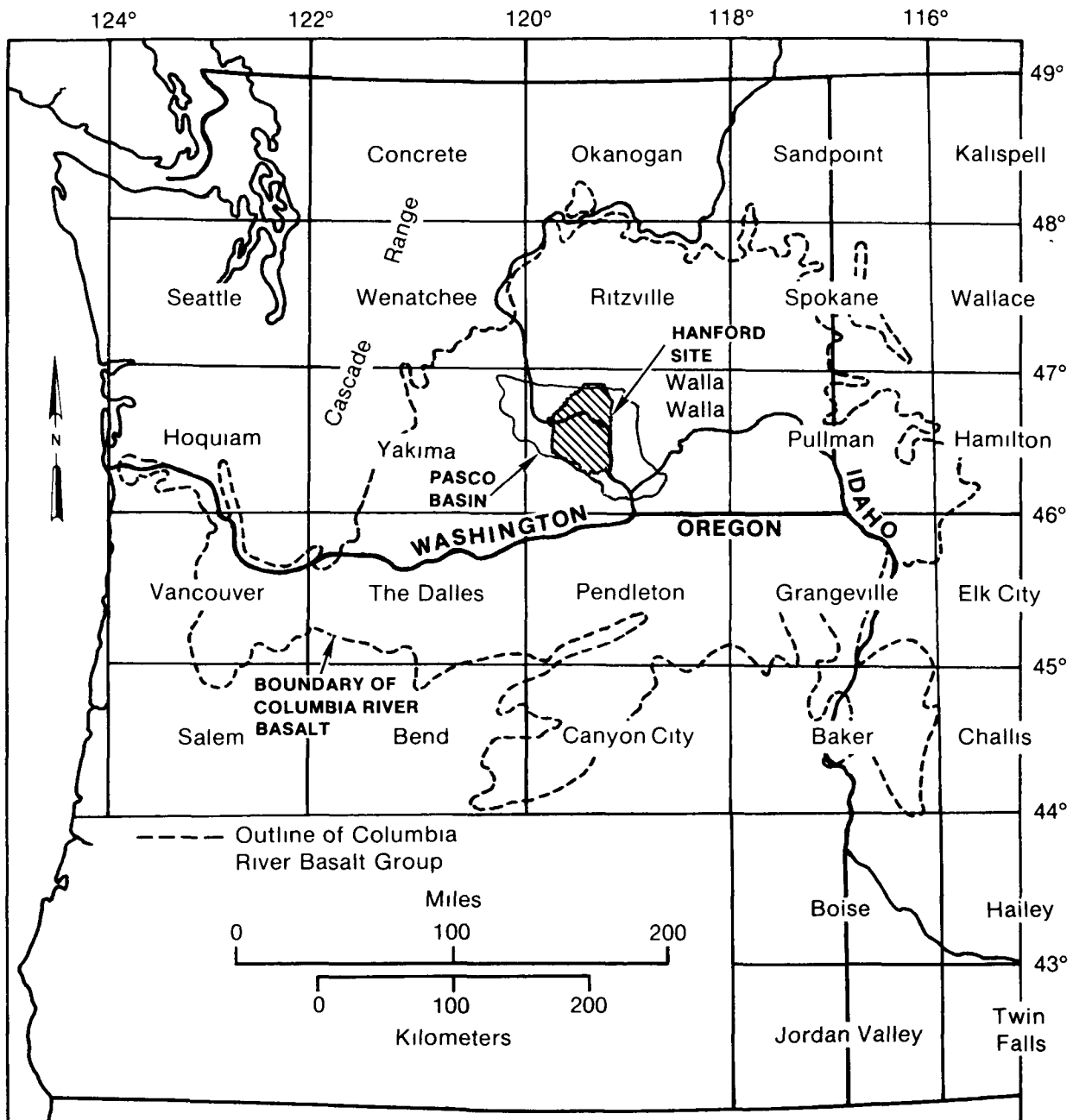
PROJECT MANAGEMENT

The project management activity is concerned with the management of the Geosciences end function; specifically in the preparation and control of schedules, preparation of budgets and work packages, control of program costs, and overall guidance of the technical activities.

GEOLOGY

Geology activities that produced significant results during the fourth quarter of fiscal year 1980 include the following:

- Reconnaissance and detailed geologic mapping of Columbia River basalt and post-basalt sedimentary and volcanic rocks
- Photolineament mapping
- Structural analysis of Yakima folds
- Analysis of intraflow structures
- Assistance in selecting a reference repository location
- Tectonic studies
- Economic resource studies.



NAMES OF ARMY MAP SERVICE 1° X 2° QUADRANGLE MAPS (1:250,000 SCALE) ARE SHOWN

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FIGURE 3. Index Map--Region.

During fiscal year 1980, geologic mapping of approximately 70% of the Columbia River basalt of Oregon was completed by personnel of the U.S. Geological Survey, Western Division. This work, combined with work carried out by the U.S. Geological Survey, Western Division during fiscal years 1978 and 1979, has produced basalt mapping of approximately 90% of the Columbia Plateau.

Mapping of Columbia River basalt in Oregon was oriented toward completion of the area closest to the Pasco Basin, i.e., that area covered by the Pendleton and The Dalles 1- by 2-degree quadrangles (Figure 3). Field work to complete the Pendleton 1- by 2-degree quadrangle was concentrated in its southwest corner. Such work revealed that the contact between the Columbia River basalt and all older rocks is quite irregular, reflecting the hilly topography inundated by the basalt. Exposures of the Picture Gorge Basalt (Figure 4), the oldest basalt formation in the area, have been traced 15 kilometers north of the axis of the Blue Mountains uplift (which trends northeast across the Pendleton 1- by 2-degree quadrangle, Figure 3). Most of the Picture Gorge Basalt is best assigned to the N_1 magnetostratigraphic unit, with only the uppermost flows belonging to the R_2 (Figure 4). The Picture Gorge-Grande Ronde Basalt contact appears to be in the lower part of the R_2 (Figure 4). There is no evidence of a major time break or deformation between the Picture Gorge Basalt and overlying Grande Ronde Basalt. Younger flows in the area, in addition to the R_2 Grande Ronde Basalt, include the N_2 Grande Ronde and Wanapum Basalts, primarily the Frenchman Springs Member (Figure 4).

In the extreme southwest corner of the Pendleton 1- by 2-degree quadrangle, two 20-kilometer-long, northwest-trending linear vent systems occur. These systems probably fed two or more R_2 Grande Ronde Basalt flows. The western system, containing one dike and elongate cones or ramparts as much as 200 meters high, is the westernmost source yet found for the Yakima Basalt Subgroup (Figure 4). Discovery of this complex enhances the possibility that Grande Ronde Basalt feeder dikes may be present within the Pasco Basin.

Many northwest-trending topographic lineaments cut the southwest quarter of the Pendleton 1- by 2-degree quadrangle. These lineaments are probably faults, but tectonic breccia or stratigraphic offsets cannot always be shown. In some places, vertical displacements can be documented, and on a few fault planes, subhorizontal slickensides indicative of strike-slip movement occur. However, the sense of offset--right or left lateral--is not evident. The locations of at least three thrust faults have also been determined in the area.

Within The Dalles 1- by 2-degree quadrangle, N_1 through N_2 Grande Ronde Basalt flows, and possibly older R_1 Grande Ronde Basalt flows, are exposed (Figure 4). Based on chemistry, N_2 Grande Ronde Basalt flows are divisible into an older low-magnesium oxide and a younger high-magnesium oxide sequence. Thinning of the high-magnesium oxide sequence to the south of the Columbia River is indicative of broad basining in Grande Ronde time; thinning of this sequence from east to west presumably

Series	Group	Subgroup	Formation	Member	K-Ar age (m.y.)	Magnetic polarity
MIOCENE	UPPER MIOCENE	COLUMBIA RIVER BASALT GROUP	YAKIMA BASALT SUBGROUP	Lower Monumental Member	6	N
	MIDDLE MIOCENE			Erosional unconformity		
LOWER MIOCENE			SADDLE MOUNTAINS BASALT	Ice Harbor Member		
				Basalt of Goose Island	8.5	N
				Basalt of Martindale	8.5	R
				Basalt of Basin City	8.5	N
				Erosional unconformity		
				Burford Member		R
				Elephant Mountain Member	10.5	N.T
				Erosional unconformity		
				Pomona Member	12	R
				Erosional unconformity		
				Esquatzel Member		N
				Erosional unconformity		
				Weisenfels Ridge Member		N
				Basalt of Slippery Creek		
				Basalt of Lewiston Orchards		N
				Asotin Member		N
				Local erosional unconformity		
				Wilbur Creek Member		N
				Umatilla Member		N
				Local erosional unconformity		
				Priest Rapids Member		R ₃
				Roza Member		R ₃ T
				Frenchman Springs Member		N
				Eckler Mountain Member		N ₂
				Basalt of Shumaker Creek		N ₂
				Basalt of Dodge		N ₂
				Basalt of Robinette Mountain		N ₂
				14-16.5		N ₂
				(14.6-15.8)		N ₁
				Basalt of Dayville Basalt of Monument Mountain Basalt of Twickenham		R ₂
						R ₁
						R ₁
						T
						N ₀
						R ₀ ?

☐ Ellensburg Formation

RCF8011-7

FIGURE 4. Regional Columbia River Basalt Group Stratigraphic Nomenclature.

reflects Cascadian uplift. A plagioclase-phyric unit, termed the "winter water flow," occurs at the top of the N₂ low-magnesium oxide sequence; one flow of this type has been observed in virtually every part of The Dalles 1- by 2-degree quadrangle. Distribution of the "winter water flow," in relationship to underlying Grande Ronde Basalt flows, indicates that a pre-Grande Ronde Basalt topographic or structural high existed in the vicinity of The Dalles, Oregon. In the eastern half of the quadrangle, the rapid thinning of the Frenchman Springs Member to the south of the Columbia River appears to be tectonic, as is the distribution of the Roza and Priest Rapids Members (Wanapum Basalt, Figure 4) that appear to be confined to synclinal areas.

Structures in The Dalles 1- by 2-degree quadrangle include numerous, high-angle, northwest-trending faults. Within the western third of the quadrangle, most of these faults have minor vertical separations and frequently display subhorizontal slickensides. Within the central and eastern parts of the quadrangle, doubly plunging anticlines occur along the strike of these northwest-trending faults. The axes of major folds within this area are primarily oriented northeast to east-west. In places, overturned beds and high-angle reverse and thrust faults are associated with these folds. The most important north-south structural trend in the area is the main Hood River fault (located in the western third of The Dalles 1- by 2-degree quadrangle, Figure 3). The vertical separation across this fault appears to be at least 300 meters.

Reconnaissance geologic mapping of approximately 60% of the suprabasalt sediments and volcanic rocks of Oregon was completed by Oregon Department of Geology and Mineral Industries' personnel during fiscal year 1980. Work by the Oregon Department of Geology and Mineral Industries, combined with work completed by the Washington Department of Natural Resources, Division of Geology and Earth Resources, and Idaho Bureau of Mines and Geology during fiscal years 1978 and 1979, has produced maps covering approximately 80% of the suprabasalt sedimentary and volcanic rocks of the Columbia Plateau. Work by the Oregon Department of Geology and Mineral Industries included the completion of field mapping for 53 selected 7.5-minute quadrangles and compilation and photogeologic mapping of one hundred twenty-seven 7.5-minute quadrangles, all in the Pendleton and The Dalles 1- by 2-degree quadrangles (Figure 3). A preliminary map legend of 21 units includes three volcanic rock units, an undifferentiated pre-Columbia River basalt unit, and 17 Miocene to Holocene sedimentary units. Results include a proposal that the Dalles Formation be raised to group status and include the Tygh Valley, Chenoweth, Alkali Canyon, and McKay formations of the Tygh, The Dalles, Arlington-Boardman, and Agency Basins, respectively. These discrete basins are separated by broad basalt anticlines, and the sediments which occupy each basin can be mapped as individual suprabasalt formations. It is proposed that these basins represent separate, localized, tectonic deformations.

During this quarter, photolineament maps covering most of Oregon and Idaho were completed by Pacific Northwest Laboratory personnel. This work, combined with previous work carried out by Pacific Northwest Laboratory, has produced photolineament maps covering approximately 90% of the

Columbia Plateau. These maps are based on an analysis of LANDSAT, Skylab, and U-2 photography; photolineaments recorded on these maps are coded as to imagery association and as to interpreted origin (i.e., topographic, drainage alignments, tonal discontinuities, and cultural features). Initial draft copies of these maps were issued to regional field personnel to aid in their reconnaissance geologic mapping work. In turn, field personnel have conducted a review of these maps and have provided input that will be used to evaluate the relationship between structures observed in the field and mapped photolineaments. Digitizing has also been initiated that will enable a statistical analysis of photolineament types and trends to be carried out during fiscal year 1981.

Continued field mapping in the Pasco Basin area has focused on the distribution and thickness of basalt flows to better understand the geologic history of the basin and on follow-up work in Snively Basin (Figure 5). Previous mapping indicated that the Grande Ronde Basalt-Sentinel Bluffs member thinned dramatically at Sentinel Gap. The possibility that this thinning was caused by faulting is now considered unlikely, based on the results of recent field work which suggest that thinning of the basalt pile against the Hog Ranch structure is the most likely explanation. Also, recent work shows a similar situation along Umtanum Ridge (Figure 5). Distribution of Wanapum and Saddle Mountains Basalts indicates that structures in the Pasco Basin were active by late Wanapum time, and most were active by early Wanapum time.

Numerous surface fissures have been discovered in the loess and colluvium near Benson Spring in the Snively Basin area of Rattlesnake Mountain. The fissures range in length from <3 to 140 meters with vertical displacement of up to 48 centimeters. Mapping of individual fissures indicates that they are spatially related to a large, old landslide that has moved down-dip, evidently on the Mabton interbed. The fissures offset a firebreak that was plowed across the landslide in 1976 indicating very recent movement of the landslide. The cause of the recent movement is not known; both tectonic and nontectonic causes have been considered. Current opinion is that the recent landsliding is probably not caused by erosional undercutting, irrigation, or earthquake motion, but probably is caused by the double-the-normal amount of precipitation on the Hanford Site from January through May 1980.

Detailed geologic studies in the vicinity of Gable Mountain (Figure 5) are being carried out by Golder Associates of Seattle, Washington, under the sponsorship of the Northwest Energy Service Company. Trenching across the central Gable Mountain fault has revealed the offset of sediments which are interpreted by Golder Associates to be of Quaternary age. Personnel in the Rockwell Hanford Operations' Geosciences Group have been closely following the trenching and trench logging being conducted by Golder Associates and providing technical input. The current trench exposures appear to support tectonic faulting as a viable interpretation, although alternative causes (such as movement induced by the effects of glaciofluvial flooding) are also possible. Work to qualify the origin, age, and significance of the offsets in sediments at Gable Mountain is continuing.

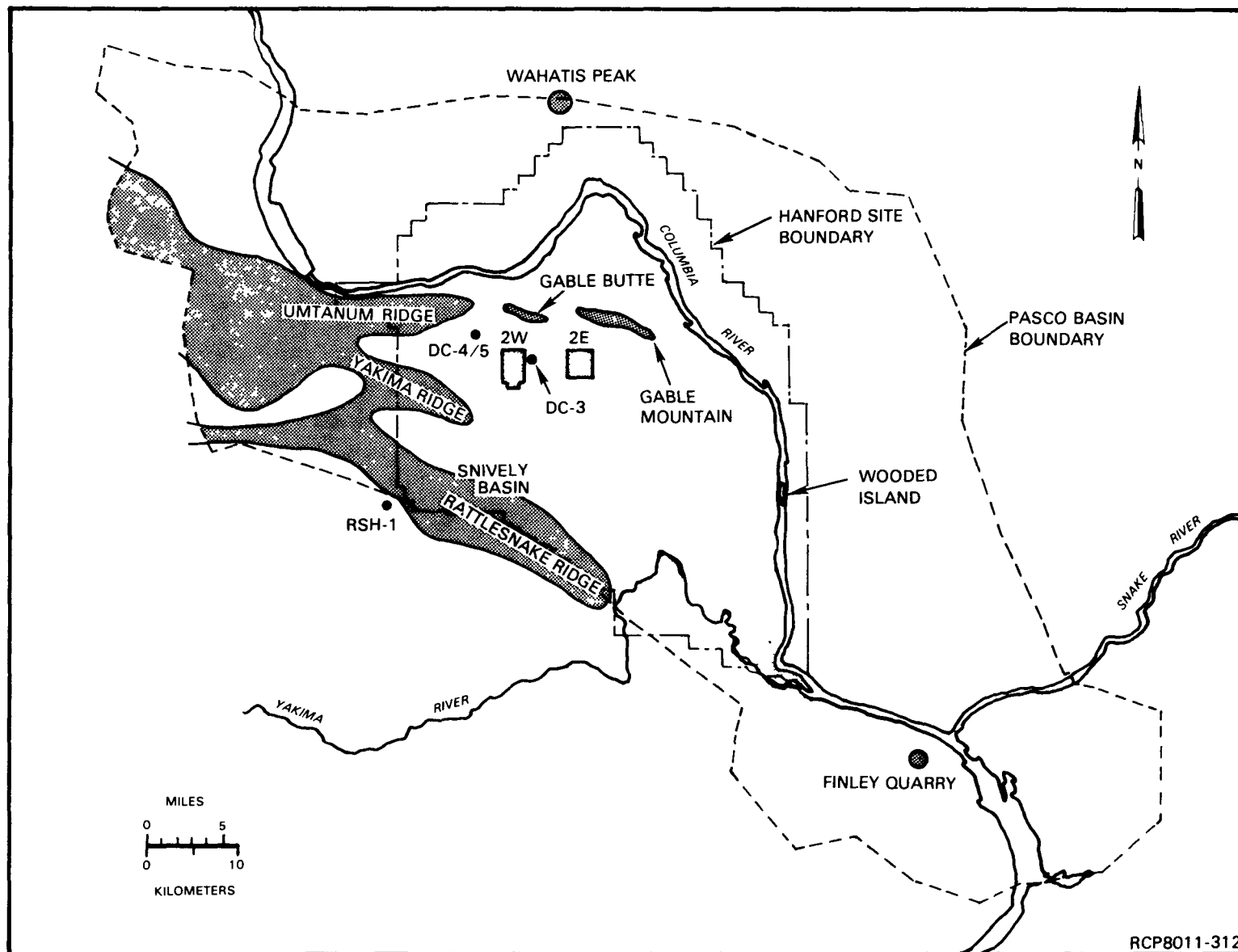


FIGURE 5. Pasco Basin Location Map.

Interpretation and prediction of variations in intraflow structures in the Pasco Basin subsurface are important goals of the continuing lithologic studies of the Grande Ronde Basalt and specifically of the Umtanum flow, which is currently the prime candidate for a repository host rock. Qualitative mesoscopic and petrographic differences have been shown to indicate the position of the entablature-colonnade contacts and the presence or absence of tiering within the entablature. Current petrographic studies are aimed at quantifying these textural relationships. Preliminary work shows significant relationships between average opaque mineral volume percent versus position within the flow and average perimeter per opaque mineral grain versus position within the flow. Several other quantifiable petrographic parameters are currently being investigated. Lateral variations in the Umtanum flow in the Pasco Basin subsurface have been studied by using a fence diagram (Figure 6) showing intraflow structures interpreted to be present in seven of the Pasco Basin deep boreholes. Lateral variations have been schematically represented between adjacent boreholes and the two surface sections. The Umtanum flow-top breccia correlates well with total flow thickness; that is, the flow-top breccia is thickest in areas where the total flow is thickest. No pillow zones were observed in the Umtanum flow in any of the boreholes or surface sections, suggesting that pillow zones (if present) encountered at depth within the Pasco Basin would be of very limited lateral extent. The Umtanum flow is thickest in the west-central portion of the basin and appears to thin to the north and northeast. In contrast, tiering within the Umtanum flow appears to be restricted to Borehole DH-5 and to the southeastern portion of the basin. This suggests that the presence or absence of tiering may be influenced by geographic location, topography, or proximity to vent areas. In fact, because areas where the flow is thickest tend not to be tiered might indicate that tiering does not occur in areas of paleotopographic lows where the flow has ponded. The relationships described above have been used in repository siting studies.

Tectonic studies during the quarter included the review of geologic and geophysical data by Shannon & Wilson, Inc., Seattle, Washington. The results of this review were used to prepare north-south and east-west cross sections which model the crust through the Columbia Plateau and Pasco Basin. In addition, a literature review of hypotheses on regional tectonics was completed by Shannon & Wilson, Inc. and a preferred preliminary tectonic model for the Columbia Plateau presented. The completion of this work, along with a review of available in situ stress data (see RHO-BWI-80-100 3Q), represents an initial step toward an assessment of the tectonic stability of the Pasco Basin.

A review of available geological, historical, and instrumental data by Rockwell Hanford Operations served as the basis of a preliminary assessment of the relative rate of deformation in the Pasco Basin. Available data indicate that deformation of the Columbia River basalt began as early as 14 million years ago and progressed at a rate of less than 1 millimeter per year. Deformation, once localized, has apparently continued along the same trends and zones initially developed during the Miocene. Historical seismicity indicates that moderate-size earthquakes

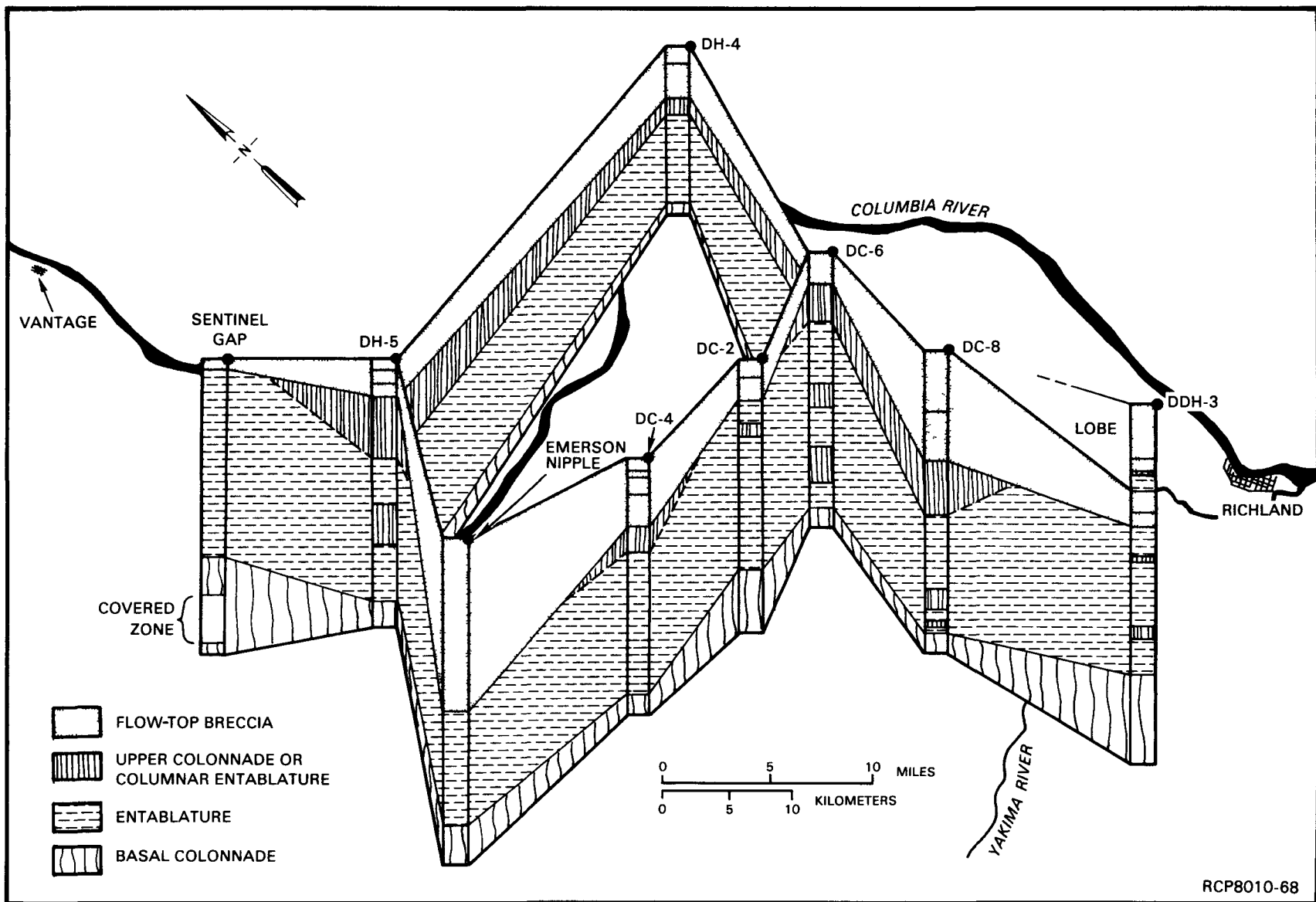


FIGURE 6. Fence Diagram for the Umtanum Flow.

(less than magnitude 6) are infrequent and separated by periods of relatively low-level, diffuse stress release. Instrumental records of earthquakes reveal no concentrated stress release along mapped geologic structures or along planar zones. Focal mechanism solutions indicate rupture occurs on steeply dipping planes of varying orientation in volumetrically restricted zones in basalt and in broad zones below basalt under nearly horizontal, north-south compression. Measurement of strain with dilatation arrays in the Pasco Basin indicate strain of less than 1 millimeter per year. Available data currently support a model of slow, ongoing deformation. Such a model can provide preliminary upper bounds for estimates of earthquake size, recurrence, and fault displacement, all of which are necessary for risk assessment.

A baseline survey of 12 new geodetic monuments, set during the previous quarter, was made using a two-color laser interferometer. The monuments are positioned in four triangular arrays across known faults, and were surveyed by Terra Technology, Inc., Redmond, Washington, to a precision of 1 part in 10 million. Periodic surveys of the monuments will be used to detect possible seismic movement on the faults.

An inventory of major mineral resources within 322 kilometers of the Hanford Site and a preliminary assessment of discovery and development potential of mineral resources within 100 kilometers of the Hanford Site were completed. The study suggests that coal and high-unit-value mineral development potential above, within, and beneath the flood basalts of the Pasco Basin is negligible. Oil and natural gas occurrence and development potential in sediments within the flood basalt sequence in the Pasco Basin are judged to be small. Oil and gas development potential in sediments postulated to underlie flood basalts at depths in excess of 3,000 meters in the Pasco Basin is essentially unknown. Any such potential would be well below projected repository depths of 900 to 1,500 meters. Studies are continuing of compositions of interbed carbonaceous matter and carbon isotope/hydrocarbon gas ratios for natural gas detected in hydrologic test holes in the Pasco Basin.

Through the courtesy of Shell Oil Company, Rockwell Hanford Operations has received approximately 750 samples of well cuttings from Rattlesnake Hills Well #1 (RSH-1) (Figure 5), a petroleum exploration well drilled in 1956. These cuttings were collected at 3- and 6-meter intervals during the drilling of RSH-1 and cover the drilled section between 6.7 and 3,250 meters. One hundred sixty-five of the samples have been analyzed for major oxides. These analyses suggest that the entire section penetrated by RSH-1 is Grande Ronde Basalt. Confirmation is pending the results of trace element and strontium isotope analyses. This result implies a much thicker section of Grande Ronde Basalt in RSH-1 than anywhere else on the Columbia Plateau. However, structure may have also caused the sequence penetrated by RSH-1 to have been repeated. Work to determine the origin of the thick Grande Ronde section is continuing.

In addition to the above activities, five abstracts were accepted for presentation at the 1980 national meeting of the Geological Society of America.

GEOPHYSICS

Results of seismic reflection, multilevel aeromagnetic, and magnetotelluric surveys were received from subcontractors during the quarter. The fiscal year 1980 seismic reflection work (Figure 7) was completed by Seismograph Service Corporation, Tulsa, Oklahoma. The major portion of the results included two-dimensional modeling, depth conversion, and limited reprocessing of data collected during fiscal year 1979. Interpretations of the fiscal year 1980 survey data were presented on seismic reflection sections (profiles) and on a time-contour map derived from reflections from the top-of-basalt surface (see RHO-BWI-80-100 3Q for summary descriptions of each reflection line). The new reflection data and the preliminary results of aeromagnetic surveys were used to screen areas in the Cold Creek syncline during the reference repository location selection process.

The main part of additional subcontractor work was to generate two-dimensional seismic reflection models by computer methods. These two-dimensional models illustrate the seismic reflection response to known, suspected, and theoretical geologic conditions of lithologies and structural features. Approximately ten models were generated to illustrate some of the following features:

- Erosional channels in the upper basalt
- Offset basalt layers with several different ranges of offsets
- Facies changes in sediments above the basalt sequence
- Stratigraphic variations within the basalt
- Structural folds within the basalt (anticlines and monoclines).

A seismic model example is shown in Figure 8. These seismic models are being used to further interpret and evaluate the seismic reflection surveys. The computer modeling has shown that several geophysical methods are generally necessary to provide the resolution needed to characterize a site.

Reprocessing of selected fiscal year 1979 seismic reflection survey data was carried out using new techniques and refinements to improve the resolution of the data. Results of the reprocessing show that several specialized, seismic data-processing techniques, such as gain-controlled cross correlation of VIBROSEIS data, and spatial filtering can be used to increase the frequency content to resolve thinner layers in the basalt beneath the Hanford Site. The reprocessing results have also suggested that more velocity control from boreholes on the Hanford Site and from further studies of the common depth point velocity analyses could improve resolution.

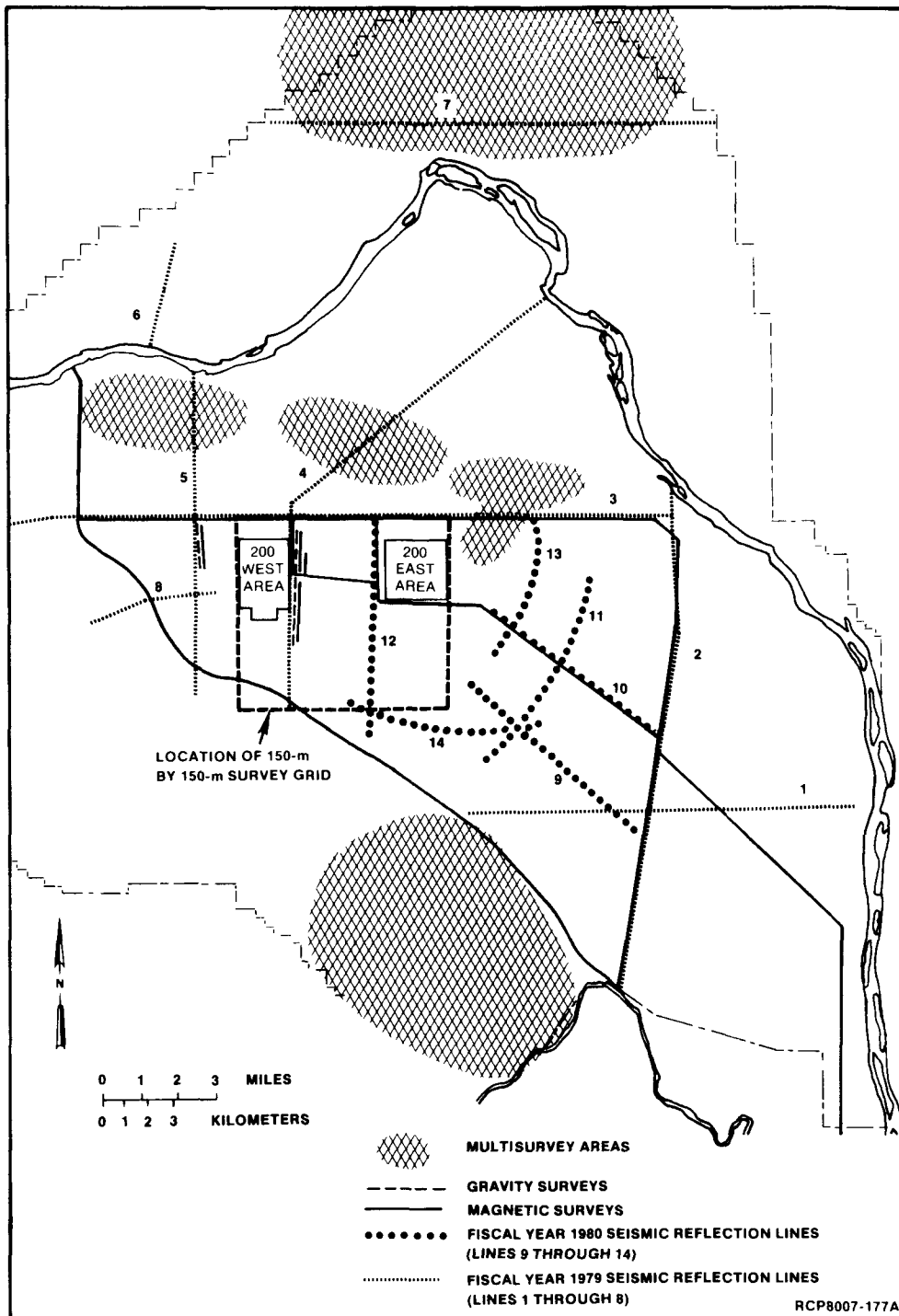


FIGURE 7. Index Map of Geophysical Surveys.

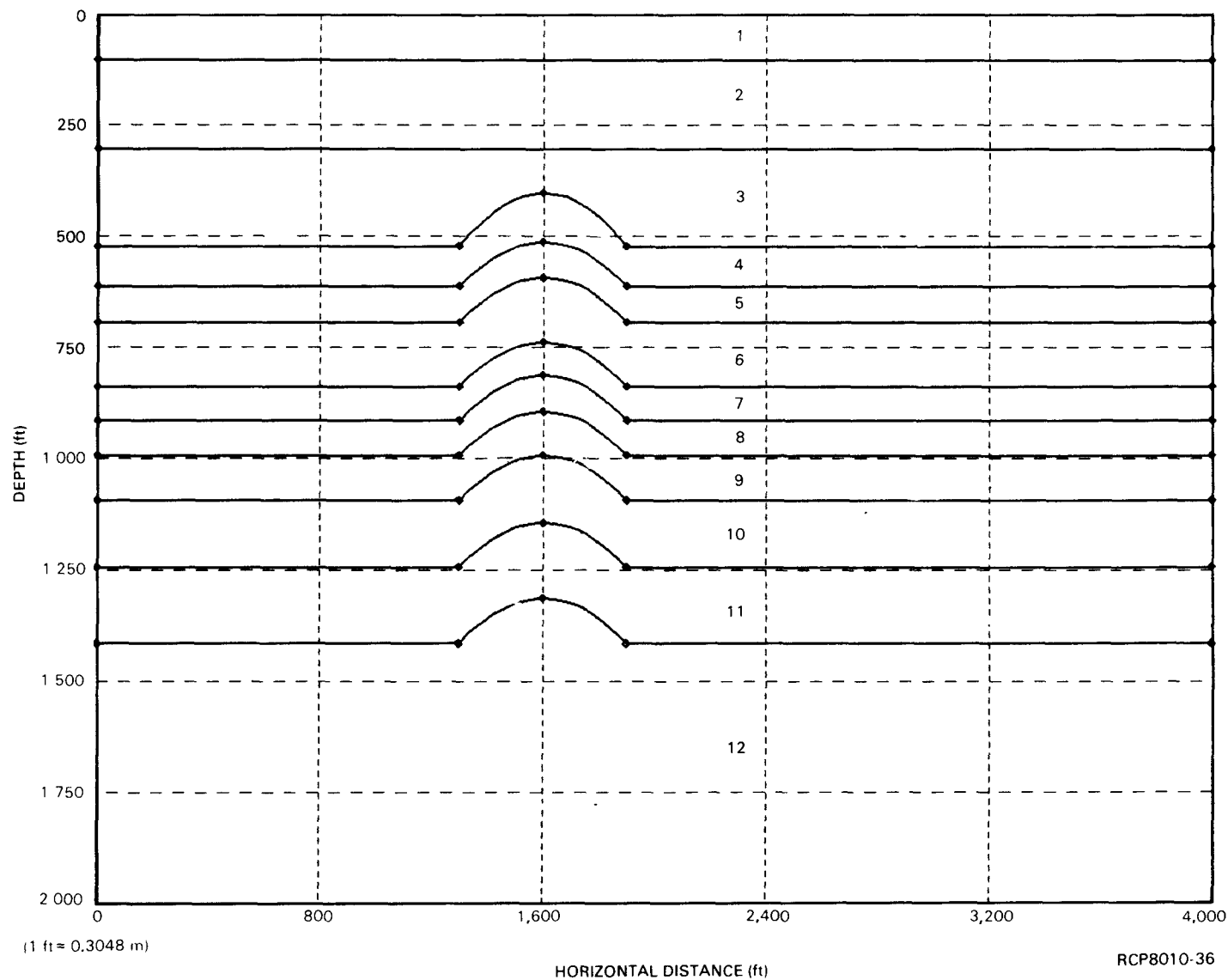
FORMATION	GEOLOGIC LAYER	VELOCITY (ft/sec)	DENSITY (g/cm ³)	LAYER NUMBER	DEPTH (ft BGS)
HANFORD FORMATION	ALLUVIUM	2,500	1.9	1	— 250 —
	PASCO GRAVELS	7,000	2.34	2	
RINGOLD FORMATION	(UPPER) (MIDDLE) (LOWER) RINGOLD	10,000	2.45	3	— 500 —
SADDLE MOUNTAINS BASALT	ELEPHANT MOUNTAIN MEMBER	11,000	2.85	4	— 750 —
	RATTLESNAKE RIDGE INTERBED	6,000	1.94	5	
	POMONA MEMBER	11,000	2.85	6	— 1,000 —
	SELAH INTERBED	6,000	2.23	7	
	ESQUATZEL MEMBER	12,000	2.83	8	— 1,250 —
	COLD CREEK INTERBED	7,500	2.11	9	
	UMATILLA MEMBER	11,500	2.71	10	— 1,500 —
	MABTON INTERBED	6,500	2.2	11	
WANAPUM BASALT	(UNDIFFERENTIATED)	12,000	2.8	12	— 1,750 —

(1 ft = 0.3048 m)

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(a) Geologic Model Layer Parameters and Identification.

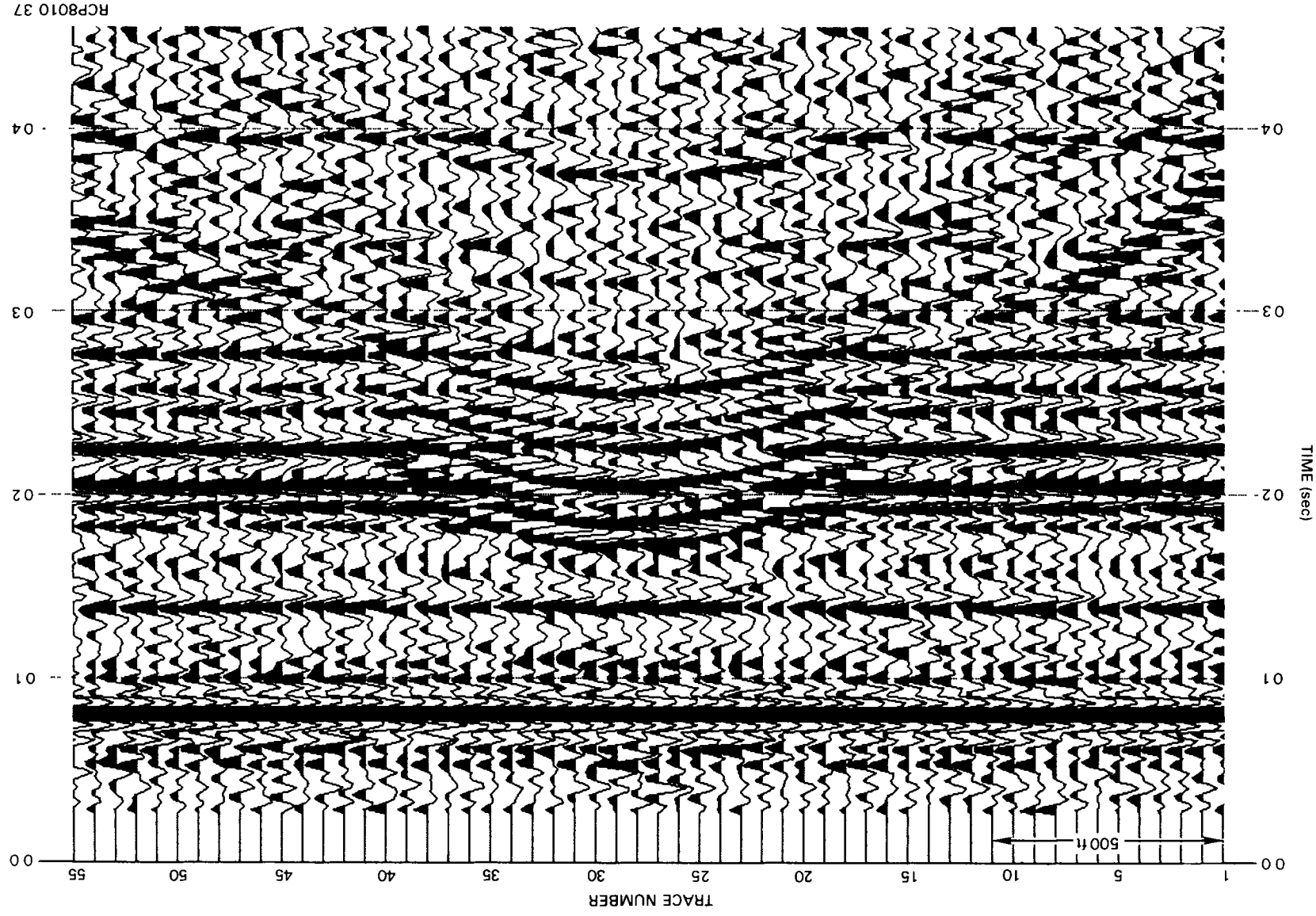
FIGURE 8. Two-Dimensional Synthetic Reflection Model.



(b) Geologic Model.

FIGURE 8. (continued)

RHO-BWI-80-100 4Q



(c) Seismic Response.
FIGURE 8. (continued)

Interpretive data sets for all five levels of the multilevel aeromagnetic survey have been received from Aero Services, Houston, Texas. A preliminary review of these results has not revealed any significant, previously unknown subsurface features. Integration of multilevel aeromagnetic survey results with other geophysical and geologic data is under way.

The magnetotelluric survey results were received from Argonaut Enterprises, Denver, Colorado. An initial review of these results showed some differences between Argonaut Enterprises' data and magnetotelluric data collected by a previous subcontractor. A "third party" review is currently being arranged to evaluate these differences. Additional magnetotelluric surveying will be delayed until this review is completed.

Ground surveys by in-house geophysical personnel continued during the fourth quarter in the Finley Quarry, Gable Mountain, and Yakima Ridge areas (Figure 5). Interpretations of geophysical data on the Finley Quarry and Gable Mountain-Gable Butte areas were started during the fourth quarter and should be completed during the first quarter of fiscal year 1981.

Work to support an in-house gridded gravity survey continued during the quarter (Figure 7). Monumenting of 30% of a 150-meter by 150-meter (approximate) grid in the 200 West and 200 East Areas was completed. Monumenting was prioritized to ensure early coverage of the reference repository site area. Collection of gravity data in the reference repository location area was initiated during the quarter.

Improvements in capabilities for in-house processing of geophysical data have continued. Interactive computer programs have been written for, or converted to, off-line computer terminals so that gravity and magnetic profiles can now be quickly analyzed and plotted on local off-line facilities. A seismic-reflection data-processing software system is presently being installed on a local, centralized computer facility. This software will allow further analysis of subcontractor seismic data, development of seismic models, and processing of limited amounts of in-house seismic data.

SEISMIC MONITORING

Routine seismic monitoring in the eastern portion of Washington State continued by the University of Washington, Seattle, Washington; no unusual activity was reported during the fourth quarter. The annual technical report was received; however, the report does not contain any Hanford Site earthquake location data for events recorded after December 1979 because of the effort to monitor the seismicity associated with the activation of Mount St. Helens. The rate of earthquake activity at Mount St. Helens is no longer extreme, and work to compile data for the last half of fiscal year 1980 is currently under way.

The new on-line computer system is now fully operational at the University of Washington. This system records telemetered seismic data from the 38 eastern Washington stations and 45 western Washington stations. Each seismic channel is digitized, and information can be recorded on tape in multiplexed form for any period when the computer has determined that a seismic event is in progress. These tapes are processed off-line with the help of another computer that has a variety of programs for displaying, analyzing, plotting, and archiving the data.

Installation of the Rockwell Hanford Operations' portable seismic network has been completed. All six of the three-component seismometers are now in the field and transmitting back to a central recording center. The stations are presently located at:

- Rattlesnake Ridge
- Gable Mountain
- Wooded Island
- Wahatis Peak
- DC-5 surface
- DC-5 at a depth of 1,065 meters.

The electronics for the telemetry links have been redesigned for high-frequency fidelity and higher dynamic range. The network will be used to monitor microearthquake swarm activity in the Pasco Basin. As such, the network configurations will be altered as activity in the area changes.

The borehole seismometer experiment is continuing. Hydrologic testing needs during this quarter required that the instrument be moved from Borehole DC-3 to Borehole DC-5 (Figure 5). However, the collection of data at the DC-5 locality has been delayed because of instrument malfunction. Possible causes of this malfunction are currently being evaluated. At least part of the instrument failure has resulted from electrical noise at DC-5 caused by overhead power lines. Plans to reposition the seismometer package in DC-3 are being pursued.

HYDROLOGY

The Hydrology end function provides criteria and evaluation techniques for hydrologic assessment of potential repository sites. Study of the groundwater regime underlying the Columbia Plateau is important, since the groundwater pathway affords the most likely avenue of contact between repository-stored wastes and the biosphere. Hydrologic studies have emphasized the development of a data base to characterize the groundwater system underlying the plateau and modeling of the flow system to evaluate the potential for radionuclide transport to the biosphere. The hydrologic studies include reconnaissance regional studies over the Columbia Plateau and intensive local studies within the Pasco Basin where the Hanford Site is located.

The Hydrology end function is divided into four major activities:

- Project Management
- Hydrology
- Testing Support
- Drilling Support.

During the fourth quarter of fiscal year 1980, work has progressed in all four activities.

PROJECT MANAGEMENT

The project management activity is concerned with the management of the Hydrology end function; specifically in the preparation and control of schedules, preparation of budgets and work packages, control of program costs, and overall guidance of the technical activities.

HYDROLOGY

Two Basalt Waste Isolation Project-funded studies were completed by the Pacific Northwest Laboratory. The first was the fiscal year 1980 final report on remote sensing within the Columbia Plateau. The report dealt with comparison of 1979 digital LANDSAT data against the corresponding 1975 LANDSAT data to observe trends in land use for developing projections for scenario analyses. The distribution of irrigated agricultural lands was compared and revealed that within the approximate 103,600-square-kilometer area represented by the LANDSAT scenes, 9,184 square kilometers were used for irrigated agriculture in 1975 as compared with 11,088 square kilometers in 1979. This represents a net increase of about 20% in irrigated agriculture. These statistics and the corresponding digital information represent an important contribution to the fiscal year 1981 regional investigations which will focus on anthropogenic groundwater dynamics.

The second report focused on the compilation and evaluation of data at all meteorologic stations within and adjacent to the Pasco Basin and the preparation of maps showing the distribution of parameters (i.e., precipitation for various seasons). These data represent considerable refinement over corresponding parameters used in the general water budget computation for the Pasco Basin as part of the regional surface water study. These data will assist in substantially improving recharge estimates used in far-field modeling.

Another study completed this quarter was the preliminary Pasco Basin water resource-use study. This study summarized past and present water-use activities and administrative stations within the Pasco Basin, explored the potential for future water development, and suggested development scenarios that may be appropriate for future scenario studies. Both surface water- and groundwater-use were examined. It was concluded that groundwater resource development is an important consideration with respect to human intrusion scenarios.

During this quarter, the far-field modeling work was directed to selection and analysis of hydrologic release scenarios. Numerous generic scenarios were reviewed and evaluated for potential application to the Columbia River basalt. On the basis of the site-specific characteristics (geology, seismicity, hydrology, etc.) of the Hanford Site, a set of scenarios was chosen that is of interest from the standpoint of (1) technical plausibility and/or (2) perceived risk. Five particular scenarios studied in detail consisted of:

- Base conditions for a vertical profile through the Columbia River basalt and a hypothetical repository in the Umtanum flow of the Grande Ronde Basalt
- Development of a fault in the vicinity of the waste repository that could create a direct hydraulic pathway to the major aquifers in the upper formations
- Occurrence of microearthquake swarms that may induce fracturing of the host rock
- Movement of magma in the deep basalts which perturbs the natural geothermal gradient and may induce a convective phenomenon around the repository
- Degradation of the borehole seals causing hydraulic interconnection between the repository and the upper aquifers.

As part of this release scenario work, a member of the Hydrology Group staff participated in the international Workshop on Radionuclide Release Scenarios for Geologic Repositories organized by the European OECD/Nuclear Energy Agency, Paris, France. A technical paper on a radionuclide release scenario selection process for a potential basalt repository was presented at the workshop by R. C. Arnett. A complete discussion of the

analysis, findings, and conclusions of this scenario work will be documented in a forthcoming technical report. In addition to the analysis of scenarios, the report contains a set of baseline hydrologic data for subsequent consequence analysis.

In parallel with the release scenario work, efforts continued in the calibration of the three-dimensional groundwater model for the Pasco Basin. The calibration of the numerical model, RHAFÉ, is being performed by manually adjusting the permeability estimates and running the model to achieve a "best fit" between measured and calculated hydraulic heads. In subsequent work, the model calibration will be automated using a "parameter estimation" technique. These preliminary groundwater flow simulations for the Pasco Basin generally suggest the following observations:

- Travel times (both horizontal and vertical) from the Umtanum flow (within the Cold Creek syncline) to the Columbia River are on the order of 50,000 to 150,000 years.
- Groundwater flow vertically through the basalts accounts for the major part of the travel time; whereas, horizontal flow through the interbeds appears to account for about 10% of the travel-time estimates.
- The ratio of vertical to horizontal permeabilities appears to play a significant role in determining the calculated groundwater flow patterns.

These particular observations are limited under the specific technical bases and assumptions of the present conceptual and mathematical models.

In the area of near-field modeling, work was completed in assembling and interfacing a suite of numerical models for the coupled analysis of hydrological/geomechanical processes. A technical paper was prepared which describes the numerical models and simulation methodology. This paper was presented at the Second Workshop on Thermomechanical/Hydrochemical Modeling for Hardrock Waste Repository, which was sponsored by the Office of Nuclear Waste Isolation and Lawrence Berkeley Laboratory. From the technical discussions in the modeling session, the attendees generally agreed that "double porosity" models provide the most practical approach to simulation of groundwater flow in fractured-porous media; this approach is currently being used in the Basalt Waste Isolation Project near-field models.

A comprehensive parametric and sensitivity analysis study was completed for a hypothetical repository in the Umtanum flow. The study was performed to assess the basic waste isolation characteristics of the Columbia River basalt. The near-field numerical models were used in conjunction with a decision tree framework that provided a logical and systematic approach to determine conservative estimates of waste migration. Two-dimensional computer simulations for a vertical cross section were made using geologic and hydrologic data for the Columbia River basalts. A waste inventory equivalent to one-half the projection for the United States' commercial nuclear power industry by the year 2000 was assumed.

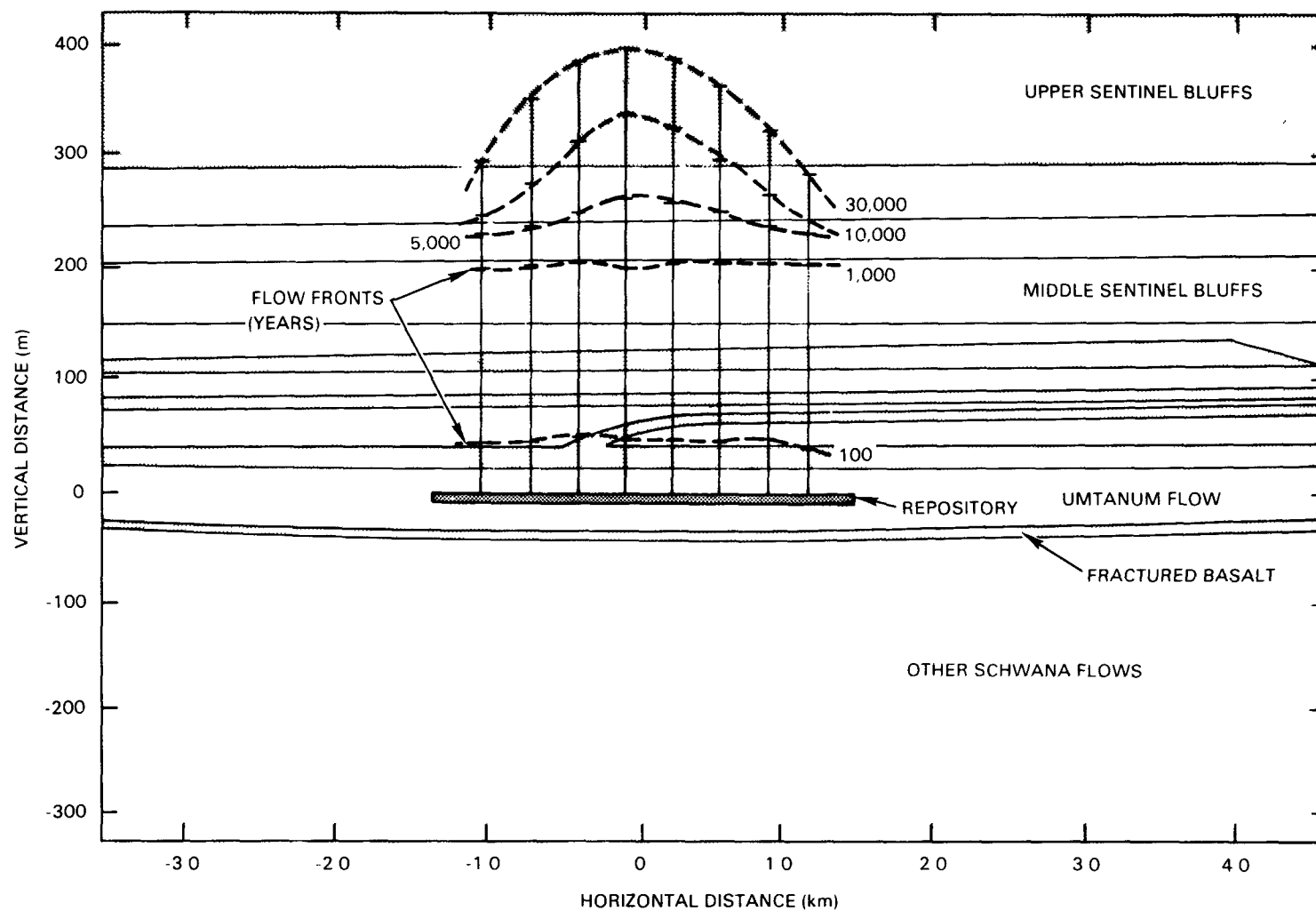
Simulations for various radionuclides (activation and fission products, actinides) were performed for time periods up to 250,000 years after closure. Sample results from this study are shown in Figures 9 and 10. Some of the major findings of the study are:

- With regard to groundwater flow, buoyancy velocities generated by the high temperatures in the vicinity of the repository are much greater than those produced by the natural hydraulic gradients.
- In the case of nuclide migration, transport of dissolved radionuclide during the peak thermal period would significantly influence the overall rate and extent of radionuclide transport.
- Simulations over a 70,000-year period after closure indicate that all radionuclides considered would be contained in a small region around the repository and within the bounds of the Grande Ronde Formation.
- Simulations over a 250,000-year period indicate that only ^{129}I would potentially migrate into the Wanapum Formation because of its relatively large initial inventory, long half-life, and low-sorption properties in basalt.

Overall, these theoretical analyses suggest that a basaltic rock environment can provide a high degree of waste isolation over long-term periods, under the condition that no initiating events occur that create a direct pathway from the repository to the upper aquifers in the Saddle Mountains and Wanapum Formations.

In a second near-field modeling study, an analysis was performed for a set of "postulated" release scenarios. The scenarios considered were: (1) fault zone, (2) microearthquake swarm, and (3) magma movement in the deep basalts. In the first scenario, it is assumed that a fault zone develops adjacent to a hypothetical repository in the Umtanum flow. In the case of the microearthquake scenario, it is assumed that the permeability and porosity of the host rock are altered by induced fracturing. For the third scenario, it is assumed that natural convection becomes a significant driving force for upward migration of nuclides.

Numerical models originally developed for thermomechanical/hydrological analysis were used to evaluate the release scenarios. In this limited consequence analysis, the study focused on evaluating the significance of postulated release events for a hypothetical repository in the Umtanum flow. The computer simulations of groundwater flow, heat transfer, and nuclide transport were performed for a 50,000-year period. Sample results from this initial scenario analysis are presented in Figures 11 and 12. Figure 11 illustrates the temperature patterns around the repository at 1,000 and 50,000 years after closure; Figure 12 depicts the technetium plumes for the base case, assuming very low sorption and the fault scenario but using nominal values for the sorption coefficient. In both cases, the extent of the waste migration is relatively small.



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FIGURE 9. Pathline and Travel Time Calculations for Baseline Conditions.

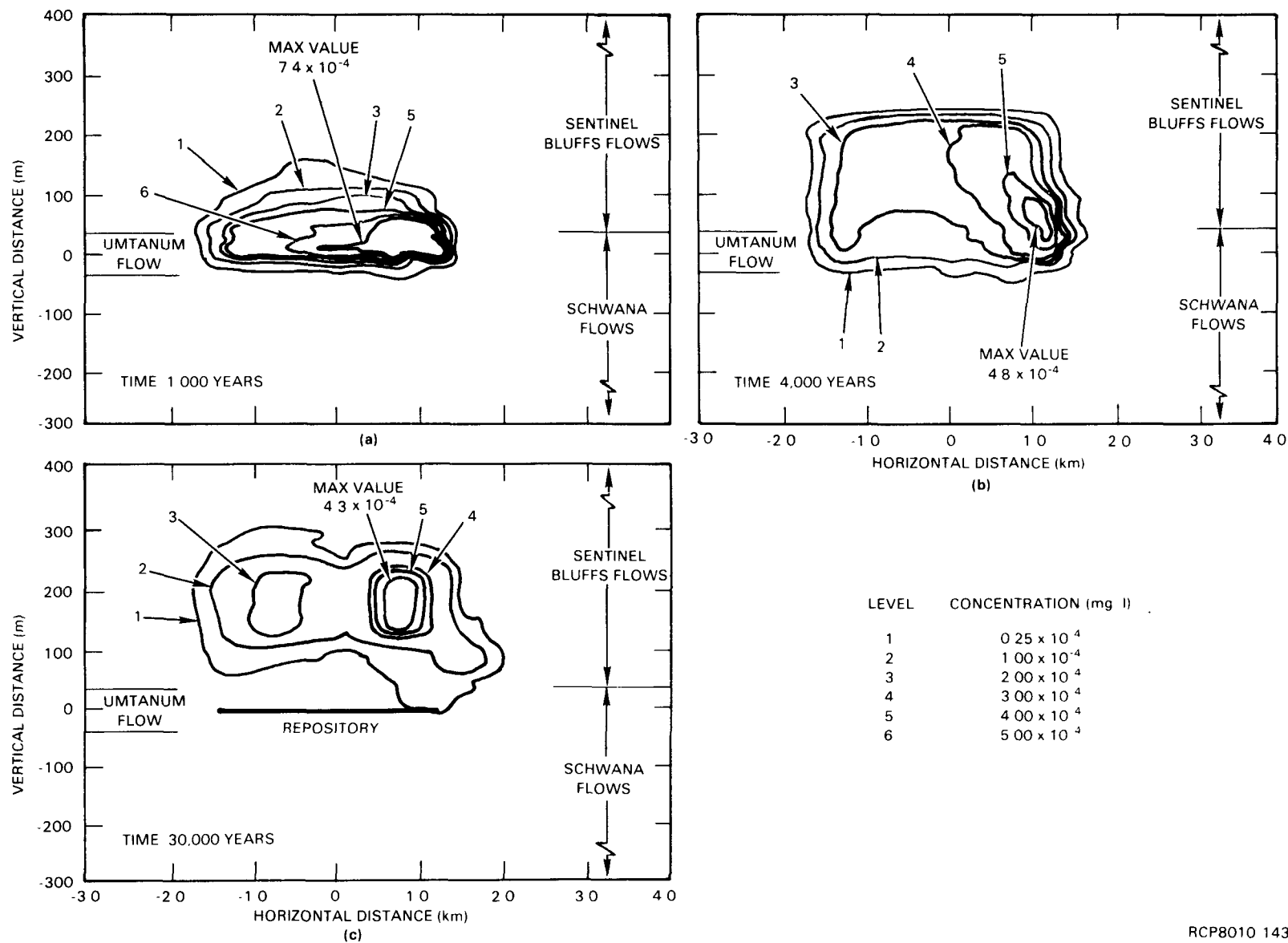
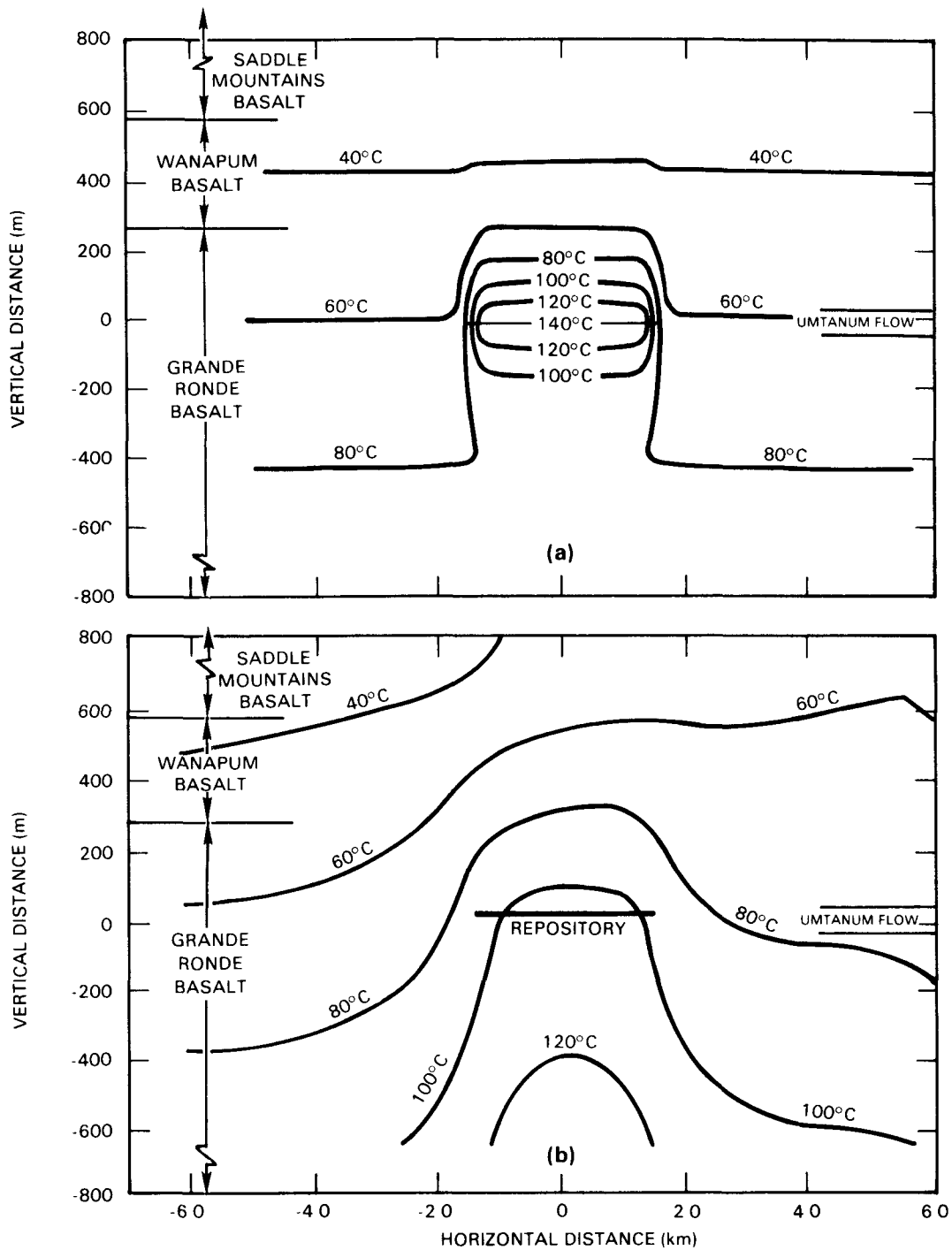


FIGURE 10. Iodine-129 Contours for Baseline Conditions.

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FIGURE 11. Simulations of Temperature Patterns at (a) 1,000 Years and (b) 50,000 Years in the Near Field.

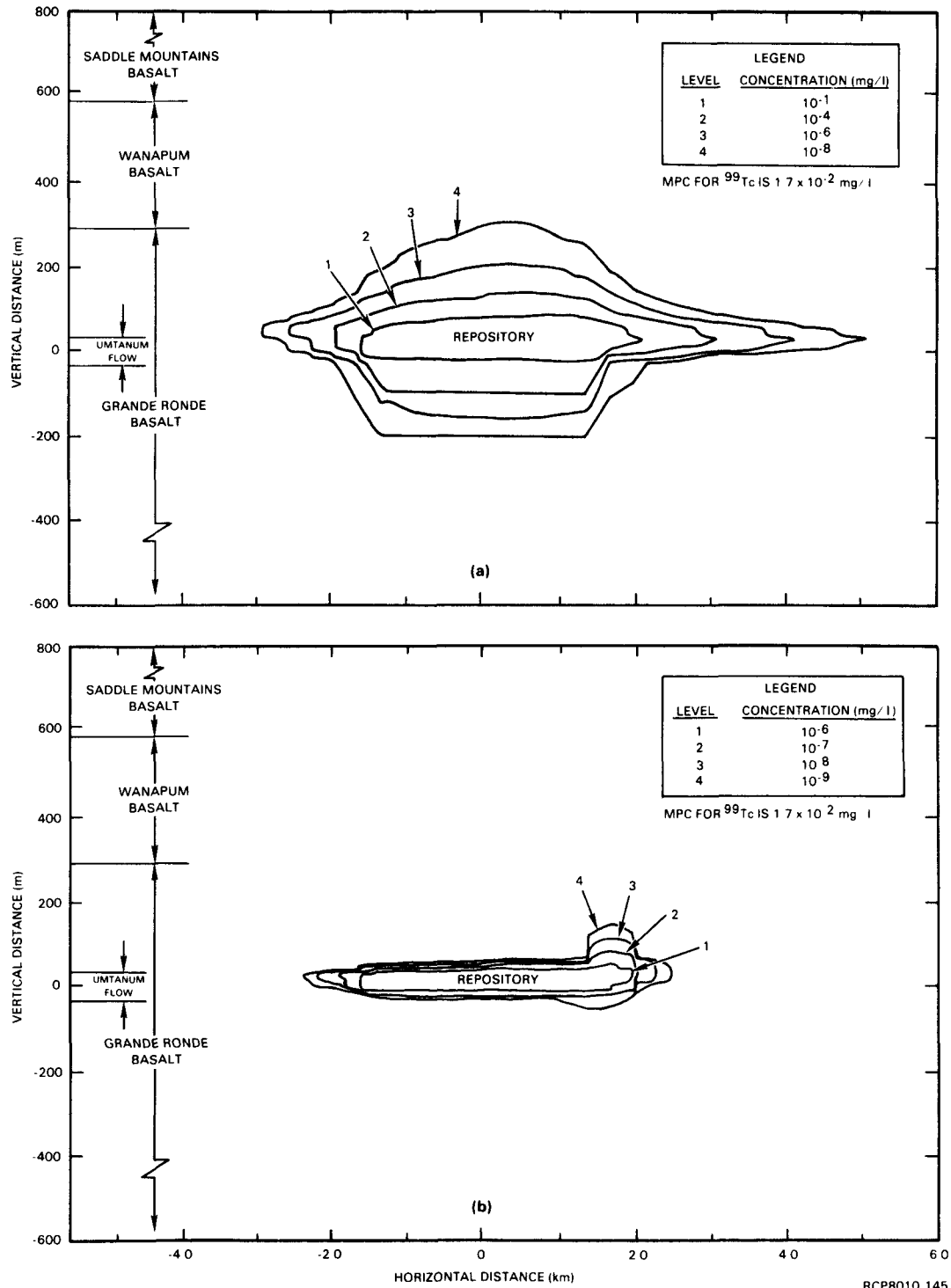


FIGURE 12. Near-Field Simulation Results for Technetium Plumes at 50,000 Years for (a) Base Case Simulation and (b) Fault Zone Scenario.

During this quarter, the Basalt Waste Isolation Project Hydrology Group has made significant progress in assembling and integrating near-field models for repository analysis. Moreover, applications of the numerical models with the available field data have provided the first quantitative indication of the waste isolation capabilities of the Columbia River basalts. To develop confidence in the results of these theoretical analyses, it is important to continue the near-field parametric and sensitivity studies using more detailed geologic and hydrologic data so as to evaluate the significance of descriptive and model uncertainties.

TESTING SUPPORT

During this quarter, emphasis was focused on acquiring new downhole hydraulic parameters and hydrochemical data for groundwater horizons within new and existing boreholes on the Hanford Site. These data were acquired by Rockwell Hanford Operations' staff.

Table 1 lists stratigraphic intervals and transmissivity values determined for selected interbed and interflow zones tested during this quarter. Twenty intervals were hydrologically tested in boreholes now under construction: DC-7, -12, -14, and -15. Two additional horizons were tested at existing borehole DC-6. Transmissivity values shown in Table 1 fall within the range previously reported for these intervals.

Vertical hydraulic head measurements were obtained at four borehole sites which were or are currently being progressively drilled and tested. As an example of these data, Figure 13 depicts the distribution of hydraulic head with depth at Borehole DC-14, which is located in the northern part of the Hanford Site adjacent to the Columbia River. The hydraulic head distribution at DC-14 indicates a:

- Pronounced increase in hydraulic head with depth within the Saddle Mountains Basalt--suggesting a potential discharge area for groundwater within this formation
- Uniform to slight decline in hydraulic head with depth from the lower Saddle Mountains Basalt to the lower Wanapum Basalt--suggesting lateral flow of groundwater within this section
- Significant decline in hydraulic head near the base of the Wanapum Basalt (i.e., lower Frenchman Springs Member).

The pattern of hydraulic head with depth at other borehole sites is summarized in Table 2. Information presented in this table indicates variable vertical hydraulic head patterns for boreholes within the Saddle Mountains Basalt. However, a similar pattern of relatively uniform hydraulic heads with depth for most of the Wanapum Basalt is evident at all boreholes.

TABLE 1. Transmissivity Values for Selected Interflow Zones Tested Between July 1, 1980 and September 30, 1980.

Borehole Number	Stratigraphic Interval	Test Interval (meters below ground surface)	Transmissivity (square meters per day)
DC-6	Grande Ronde	730.3 - 822.0	10^0 - 10^1
	Composite Grande Ronde	688.8 - 1,321.0	10^1
DC-7	Composite Grande Ronde	1,254.0 - 1,526.0	10^{-1} - 10^0
	Grande Ronde	1,472.0 - 1,526.0	10^{-3} - 10^{-2}
	Grande Ronde	1,428.0 - 1,471.0	10^{-1} - 10^0
DC-12	Grande Ronde	734.0 - 745.5	10^{-1}
	Grande Ronde	781.8 - 811.4	10^{-1}
	Grande Ronde	858.9 - 867.2	10^2
DC-14	Frenchman Springs	485.9 - 494.4	10^1 - 10^2
	Frenchman Springs	499.9 - 520.6	10^1
	Frenchman Springs	527.6 - 554.7	10^1 - 10^2
	Frenchman Springs	560.2 - 570.0	10^1 - 10^2
	Frenchman Springs	575.5 - 604.4	10^2
	Vantage Interbed-Grande Ronde	646.2 - 681.2	10^1
	Grande Ronde	721.8 - 728.5	10^{-2}
	Grande Ronde	747.1 - 754.7	10^{-1} - 10^0
DC-15	Frenchman Springs	458.7 - 473.4	10^2
	Frenchman Springs	469.4 - 485.5	10^1 - 10^2
	Frenchman Springs	527.6 - 554.7	10^0 - 10^1
	Frenchman Springs	559.0 - 559.9	10^2
	Frenchman Springs	609.0 - 637.6	*
	Frenchman Springs	639.8 - 670.0	10^{-1}

*Complicating multiphase borehole conditions; data currently under analysis.

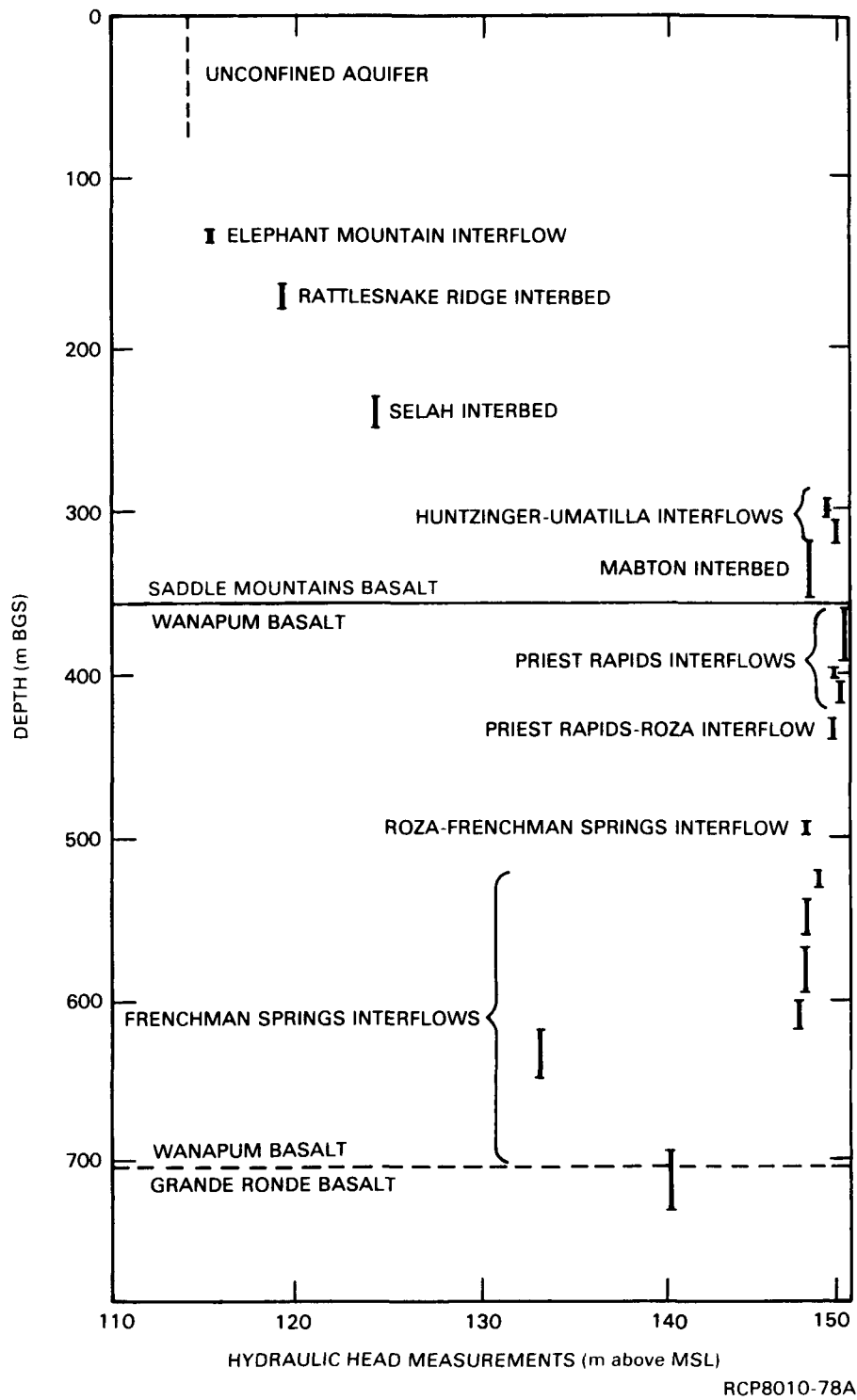


FIGURE 13. Hydraulic Head Measurements within the Saddle Mountains and Wanapum Basalts at Borehole DC-14.

TABLE 2. Vertical Hydraulic Head Patterns within
Columbia River Basalt.

Borehole Number	Saddle Mountains Basalt	Wanapum Basalt	Grande Ronde Basalt
Hydraulic Head - Vertical Distribution			
DC-6			Variable, generally increases with depth
DC-12		Uniform with depth	
DC-14	Increase with depth	Relatively uniform with depth to lower Frenchman Springs Member, then significantly lower	
DC-15	Variable, increases within lower part of formation	Uniform with depth to lower Frenchman Springs Member, then significantly lower	

Hydrochemical data collected at five locations during this quarter provided additional information concerning the hydrology of basalt formations underlying the Hanford Site. General descriptions of vertical hydrochemical patterns for the five sites are summarized in Table 3. The presence of a distinct hydrochemical break between the Saddle Mountains and Wanapum Basalts in the Cold Creek syncline (e.g., borehole DB-15) as shown in Figure 14 is of hydrologic importance. The sharp distinction in chemical type suggests a lack of hydraulic communication and mixing of groundwaters across this formational contact. For boreholes outside the Cold Creek syncline (e.g., DC-14 and -15), no major hydrochemical break was discerned at this boundary. A significant hydrochemical break was noted, however, between the Wanapum and Grande Ronde Basalts at DC-14.

DRILLING SUPPORT

Drilling accomplished during this quarter is shown in Table 4 (see Figure 15 for borehole locations).

TABLE 3. Vertical Hydrochemical Patterns for Groundwater within the Columbia River Basalt.

Borehole Number	Vertical Hydrochemical Patterns
DB-15, DB-13, and DC-12	Significant hydrochemical break near the Saddle Mountains Basalt-Wanapum Basalt contact
DC-14	No hydrochemical break through Saddle Mountains and Wanapum Basalts, major break between Wanapum and Grande Ronde Basalts
DC-15	No significant hydrochemical break; slight increase in chloride and fluoride content below Saddle Mountains Basalt-Wanapum Basalt contact
DC-6	Variation in concentration, but no change in hydrochemical type for Grande Ronde Basalt groundwater.

TABLE 4. Status of Borehole Drilling, End of Fourth Quarter, Fiscal Year 1980.

Well Number	Actual Depth (meters)	Percent Completion	Depth at Completion (meters)
DC-12	863	66	1,326
DC-14	733	53	1,371*
DC-15	670	50	1,326

*DC-14 depth at completion extended from 671 to 1,371 meters.

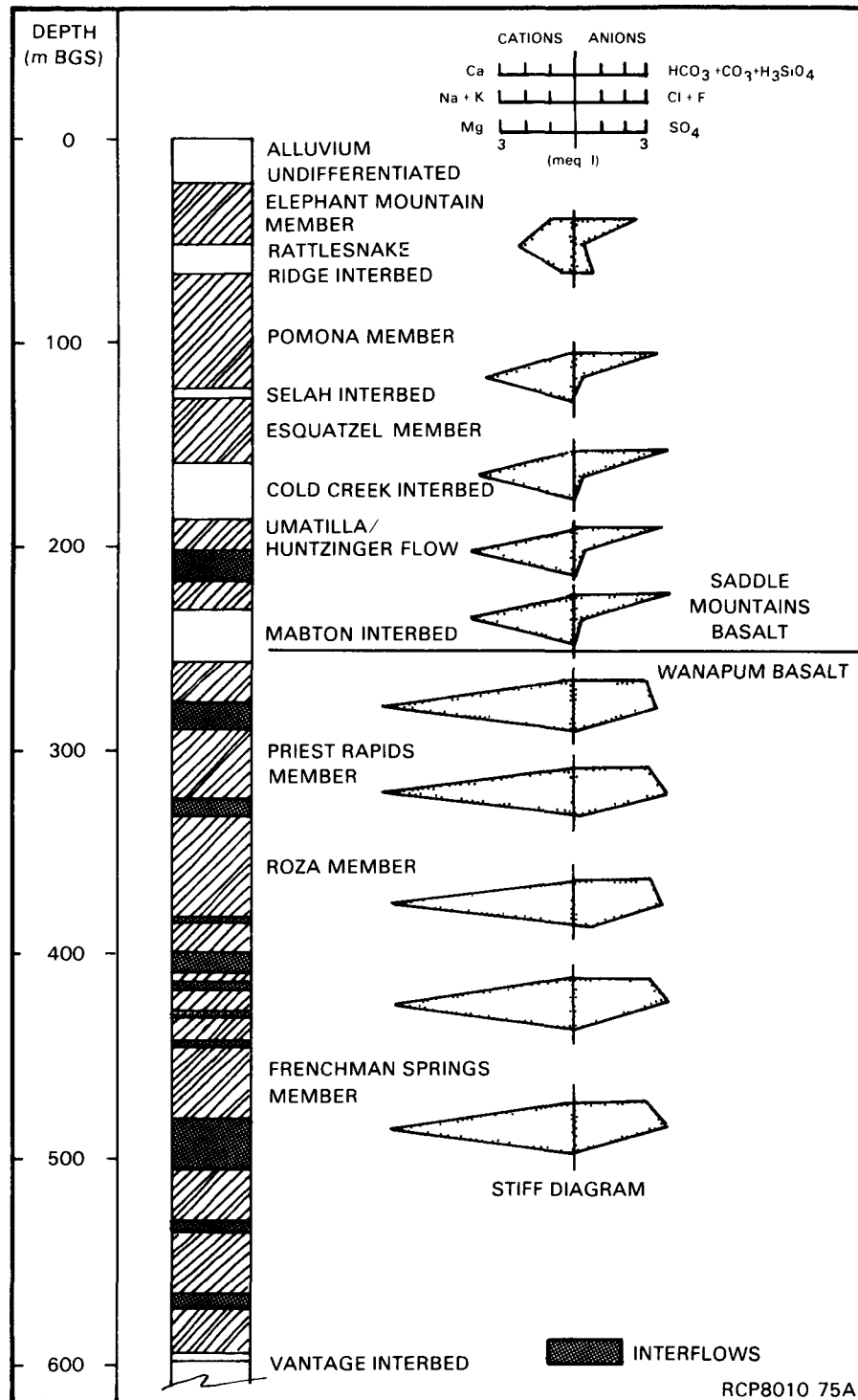


FIGURE 14. Preliminary Hydrogeologic and Hydrochemical Data within the Saddle Mountains and Wanapum Basalts at Borehole DB-15.

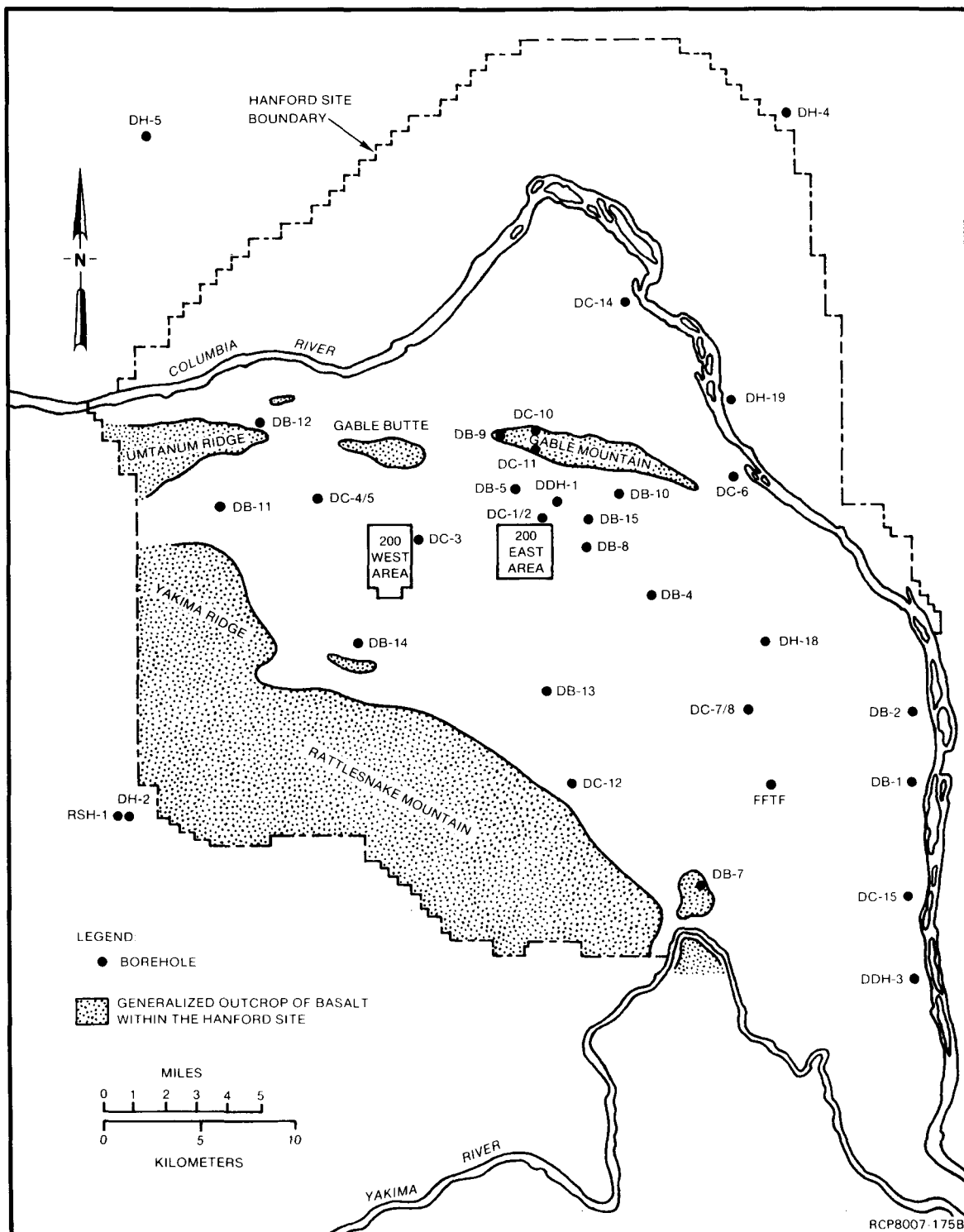


FIGURE 15. Pasco Basin and Vicinity Boreholes.

ENGINEERED BARRIERS

The objective of the Engineered Barriers end function is to specify the engineered and natural barriers that will ensure that nuclear and nonradioactive hazardous materials emplaced in a repository in basalt do not exceed acceptable rates of release to the biosphere. Key activities are the definition of repository conditions under planned operating and potential accident scenarios, review and development of information relevant to radionuclide transport, development and engineering of barrier materials and assemblages, and the acquisition of data necessary to define safe disposal of wastes in a repository in basalt. Program activities have concentrated on specifying and testing natural and man-made materials that can be used to plug boreholes in basalt and that can be used as multiple barriers to surround nuclear waste forms and containers.

The Engineered Barriers end function is divided into three major activities:

- Project Management
- Multiple Barrier Studies
- Borehole Plugging.

During the fourth quarter of fiscal year 1980, work has progressed in all three activities.

PROJECT MANAGEMENT

The project management activity is concerned with the management of the Engineered Barriers end function; specifically in the preparation and control of schedules, preparation of budgets and work packages, control of program costs, and overall guidance of the technical activities.

MULTIPLE BARRIER STUDIES

Emplacement of nuclear wastes in a deep geologic repository may cause both physical and chemical changes in the existing geologic environment. These changes may, in turn, promote detrimental reactions between engineered barrier components, repository host minerals, and the groundwater. Studies of potential interactions between candidate waste forms, canister, overpack, backfill materials, and the basalt in contact with groundwater have continued to meet the objective of designing and developing engineered barrier systems for emplacement in a repository located in basalt. These studies deal with potential chemical reactions both in the near-field zone (phase transformations, dissolution) and in the far-field zone (solution/precipitation).

Basalt Characterization

Basalt characterization work provides kilogram quantities of fully characterized reference basalt for use in hydrothermal and sorption studies scoped to support design and development of engineered barrier systems for emplacement in a repository constructed in basalt. The initial characterization of reference Umtanum basalt previously collected from outcroppings at the Hanford Site has been completed and reported (RHO-BWI-80-100 3Q). The work has continued this quarter to include the characterization of basalt samples taken from the core of Borehole DC-2 drilled earlier to a depth in excess of 900 meters in the central Pasco Basin. The samples taken at depth have been compared to outcrop reference samples and determined to be mineralogically similar to ensure that they are representative of those found at the potential repository horizon.

Comparison of the two basalts shows that the major silicate phases and mesostasis* in both are nearly identical (see Tables 5 and 6). The clinopyroxenes, pigeonite, and augite show the chemical variations normally found in basaltic rocks. Most pyroxene is in the augite compositional range, with the exception of minor pigeonite, subcalcic augite, and ferroaugite. Pigeonite is less abundant than augite. Plagioclase is the most abundant silicate mineral in all reference and DC-2-equivalent samples and is very constant in composition (49 to 51% anorthite). The major opaque phase in all Umtanum samples is titaniferous magnetite which is nearly constant in composition for all samples with 29 to 32% TiO₂.

TABLE 5. Composition of Major Silicate Minerals in Reference (RUC,1) and DC-2 (DC-2,UC, 963 meters) Umtanum Colonnade.

	Pigeonite		Augite				Plagioclase			
	RUC,1 *(1)	DC-2,UC (1)	RUC,1 (5) σ		DC-2,UC (3) σ		RUC,1 (9) σ		DC-2,UC (7) σ	
SiO ₂	50.78	51.39	50.11	0.35	49.82	0.34	56.33	1.85	57.34	2.44
TiO ₂	0.59	0.52	1.05	0.19	0.94	0.18	0.11	0.02	0.09	0.01
Al ₂ O ₃	0.90	0.80	2.53	0.60	1.71	0.61	26.97	1.20	26.62	1.89
Cr ₂ O ₃	0.05	0.05	0.05	--	0.05	--	N.D.	--	N.D.	--
FeO	24.52	21.66	15.56	1.86	16.11	0.52	0.79	0.09	0.84	0.07
MnO	0.67	0.50	0.36	0.01	0.39	--	N.D.	--	N.D.	--
MgO	17.76	20.42	15.45	0.74	14.83	1.24	0.09	0.04	0.06	0.02
CaO	5.91	4.81	15.31	1.68	15.03	1.10	9.43	1.38	9.38	2.15
Na ₂ O	0.07	0.09	0.27	0.04	0.23	0.02	5.28	0.59	5.05	0.55
K ₂ O	N.D.	N.D.	N.D.	--	N.D.	--	0.69	0.32	0.78	0.37
P ₂ O ₅	N.D.	N.D.	N.D.	--	N.D.	--	N.D.	--	N.D.	--
TOTAL	101.25	100.24	100.69		99.11		99.69		100.16	
mol%	En 50 Fs 38 Wo 12	En 57 Fs 34 Wo 9	En 44 Fs 25 Wo 31		En 43 Fs 26 Wo 31		An 49 Ab 47 Or 4		An 50 Ab 45 Or 5	

N.D. = Not Detected

*() = Number of Analyses

*Mesostasis is defined as the interstitial material between the larger mineral grains in a microcrystalline rock as a microcrystalline groundmass.

TABLE 6. Composition of Major Silicate Minerals in Reference (RUE,1) and DC-2 (DC-2,UE, 954.4 meters) Umtanum Entablature.

	Pigeonite			Augite				Plagioclase			
	RUE,1 *(3)	σ	DC-2,UE (1)	RUE,1 (5)	σ	DC-2,UE (4)	σ	RUE,1 (9)	σ	DC-2,UE (5)	σ
SiO ₂	50.90	0.78	51.48	49.42	1.82	50.09	0.43	55.51	1.22	56.11	0.67
TiO ₂	0.58	0.10	0.61	1.15	0.57	0.94	0.16	0.11	0.03	0.13	0.02
Al ₂ O ₃	0.82	0.15	0.72	1.89	0.55	2.03	0.46	27.15	0.78	26.64	0.59
Cr ₂ O ₃	0.05	--	0.05	0.05	--	0.05	--	N.D.	--	N.D.	--
FeO	23.47	1.09	22.51	17.94	2.68	15.25	0.99	0.70	0.14	0.90	0.06
MnO	0.53	--	0.48	0.46	0.06	0.48	--	N.D.	--	N.D.	--
MgO	19.09	1.48	18.10	13.89	1.77	14.78	1.24	0.11	0.02	0.08	0.02
CaO	5.16	0.94	6.27	15.18	1.04	15.05	1.54	9.67	0.19	9.76	0.64
Na ₂ O	0.07	0.02	0.09	0.25	0.02	0.28	0.04	4.97	0.47	5.09	0.27
K ₂ O	N.D.	--	N.D.	N.D.	--	N.D.	--	0.68	0.13	0.71	0.14
P ₂ O ₅	N.D.	--	N.D.	N.D.	--	N.D.	--	N.D.	--	N.D.	--
TOTAL	100.67		100.31	100.23		98.95		98.90		99.42	
mol%	En 53 Fs 37 Wo 10		En 51 Fs 36 Wo 13	En 40 Fs 29 Wo 31		En 43 Fs 25 Wo 32		An 51 Ab 44 Or 5		An 51 Ab 45 Or 4	

N.D. = Not Detected

*() = Number of Analyses

Broad beam analyses of mesostasis in the reference and core basalt samples are presented in Table 7. Colonnade mesostasis appears very similar in composition in both materials for all major oxides, with the exception of the alkalis. Potassium is higher in the reference colonnade and lower in Na₂O relative to the DC-2 equivalent. In general, mesostasis in the colonnade is higher in K₂O and lower in Na₂O and FeO, similar in composition to fractionated rhyolitic glass. The entablature mesostasis is more variable in composition; the reference material apparently contains more microcrystalline magnetite (high-FeO) relative to the DC-2 equivalent.

TABLE 7. Composition of Mesostasis in Reference and DC-2 Umtanum Basalt.

	(RUC,1)		(DC-2,UC)		(RUE,1)		(DC-3,UE)	
	*(7)	σ	(7)	σ	(5)	σ	(7)	σ
SiO ₂	72.20	1.49	72.88	1.20	61.22	1.78	69.37	0.87
TiO ₂	0.69	0.14	0.82	0.13	1.53	0.60	0.86	0.14
Al ₂ O ₃	12.47	1.44	12.71	0.60	12.49	0.63	13.74	0.43
Cr ₂ O ₃	N.D.	--	N.D.	--	N.D.	--	N.D.	--
FeO	1.59	0.16	2.16	0.34	10.49	1.08	4.49	0.88
MnO	0.05	--	0.05	--	0.16	0.02	0.05	--
MgO	0.05	--	N.D.	--	0.59	0.13	0.05	--
CaO	0.51	0.19	0.62	0.20	3.87	0.47	1.90	0.24
Na ₂ O	4.01	0.45	6.62	1.10	7.14	0.37	7.45	0.10
K ₂ O	6.47	0.27	4.07	1.04	2.68	0.30	2.74	0.24
P ₂ O ₅	0.12	0.09	0.10	0.43	0.62	0.02	0.36	0.11
TOTAL	98.16		100.03		100.79		101.01	

N.D. = Not Detected

* = Number of Analyses

Textural differences noted between reference Umtanum colonnade and entablature are consistent with DC-2 equivalent samples. Entablature in both materials is characterized by abundant mesostasis and titaniferous magnetite dendrites; whereas colonnade typically appears more coarsely crystalline and contains larger equant opaque grains and less mesostasis (Figure 16). These differences are usually reflected in the composition of the mesostasis (Table 7), with entablature mesostasis containing higher iron (i.e., microcrystalline magnetite) relative to colonnade; whereas the high-K colonnade "glass" appears more highly fractionated.

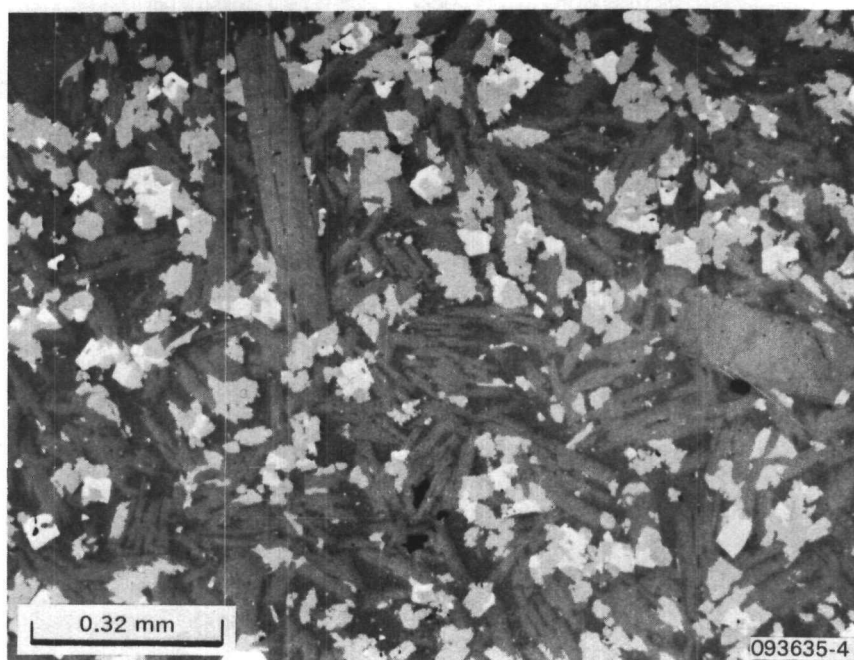
Preliminary studies of DC-2 Umtanum flow-top breccia samples suggest that preferential dissolution of mesostasis by groundwater may be restricted to this relatively porous zone. Reflected light photomicrographs of DC-2 and reference entablature and colonnade samples exhibit very little dissolution pitting; whereas a DC-2 flow-top sample shows dissolution and vesicle filling with silica, euhedral clinoptilolite, and clay [Figure 17(a)]. Precipitation of secondary minerals takes place below this zone, where entablature and colonnade fissures and vesicles appear sealed [Figure 17(b)].

These results verify that the reference basalt collected from the outcropping at Umtanum Ridge on the Hanford Site is sufficiently similar to that found at the potential repository horizon to qualify it for use in experimental studies. The textural studies also confirm that vesicles and fissures are frequently filled in the entablature and colonnade, and dissolution of mesostasis normally does not occur in these zones.

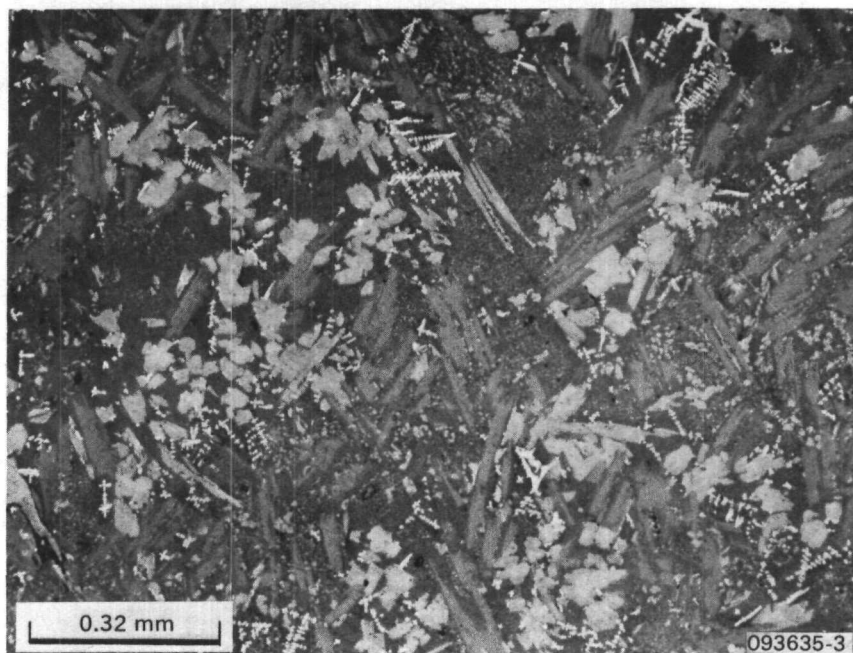
Hydrothermal Chemistry

The objective of the hydrothermal chemistry studies is to assess the performance of selected waste forms and candidate barrier materials under conditions appropriate to a repository constructed in basalt at the Hanford Site. Toward this end, scoping tests were begun in 1977. These early tests were intended to give a qualitative measure of waste form performance and to target areas for detailed quantitative research. This phase of the hydrothermal chemistry program has been successfully completed.

One of the important results of the scoping tests has been to rank selected waste forms in terms of performance. Results of tests conducted in the range of 200° to 300°C, using simulated waste forms and groundwater, indicate that the most leach-resistant waste form studied is supercalcine (SPC-4). Supercalcine's performance is followed by borosilicate glass and then simulated spent fuel. These results affect engineered barrier design because the more leachable waste forms require more extensive engineered barrier systems to achieve equal system performance.

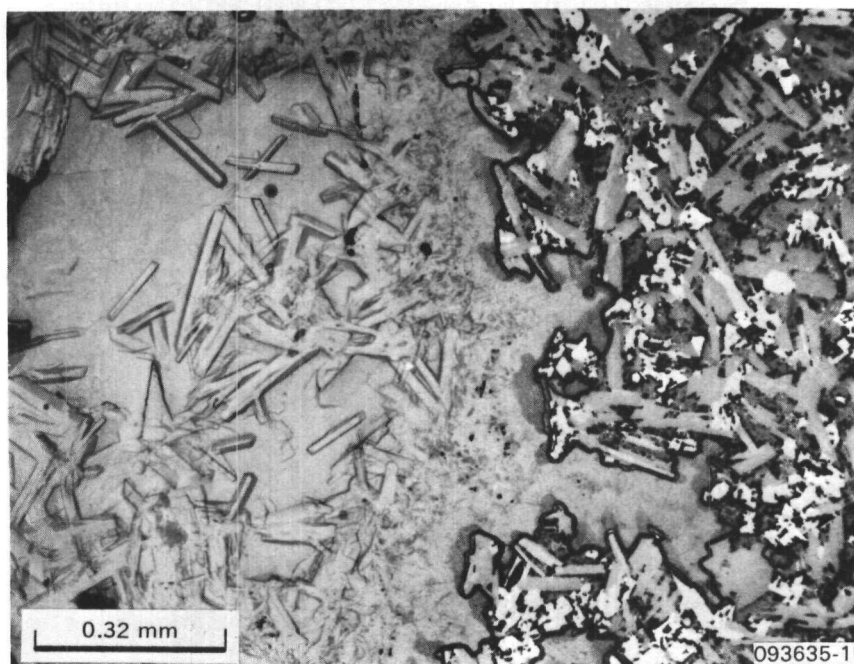


(a)

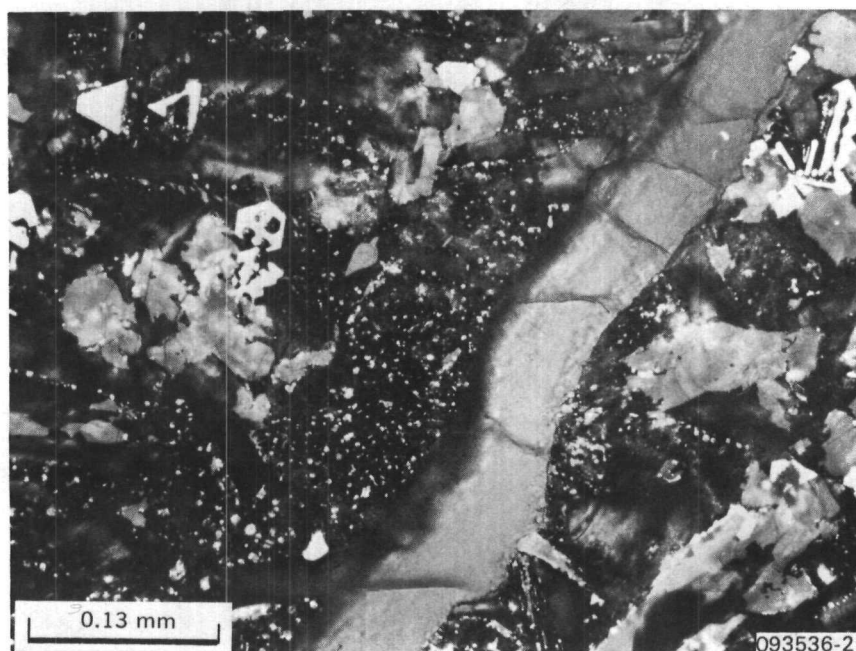


(b)

FIGURE 16. Reflected Light Photomicrographs of (a) Reference Umtanum Colonnade (RUE,1) and (b) Reference Umtanum Entablature (RUE,1). Note the greater volume percent mesostasis (dark-gray) in entablature relative to colonnade and the lack of dissolution pitting in both samples. White phase = titaniferous magnetite; light gray = clinopyroxene; medium-gray = plagioclase; and dark-gray = mesostasis.



(a)



(b)

FIGURE 17. Reflected Light Photomicrographs of (a) Umtanum Flow-Top Sample (DC-2,UFT) and (b) DC-2 Umtanum Entablature Sample (DC-2,UE). Note the dissolution of mesostasis between crystals in basalt clasts (right side) and secondary mineral vesicle filling (left side) in Figure 17(a). Figure 17(b) is an oil immersion reflected light photomicrograph, which shows clinophilolite fracture filling.

Another important result obtained from the scoping tests is that basalt is an effective barrier to radionuclide migration. This occurs by two mechanisms. The first mechanism is chemical reaction. New solid phases are formed which remove radionuclides from groundwater. Important stable phases produced by reaction of simulated waste with basalt include pollucite ($\text{CsAlSi}_2\text{O}_6 \cdot n\text{H}_2\text{O}$), powellite [$\text{Ca}, \text{Ba}(\text{MoO}_4)$], and perhaps weeksite [$(\text{K}, \text{Cs})_2(\text{UO}_2)_2(\text{Si}_2\text{O}_5)_3 \cdot 4\text{H}_2\text{O}$] or haweeite [$\text{Ca}(\text{UO}_2)_2(\text{Si}_2\text{O}_5)_3 \cdot n\text{H}_2\text{O}$].

The second mechanism is reduction. Basalt imposes extremely anoxic conditions in the groundwater which stabilizes the insoluble tetravalent transuranic oxides. Thus, uraninite (UO_2), rather than schoepite ($\text{UO}_3 \cdot 3\text{H}_2\text{O}$), is the stable phase in the repository environment. This is a significant result because it implies that uranium cannot be dissolved by Hanford groundwater in amounts exceeding maximum permissible concentrations.

The combined effect of both mechanisms can be illustrated by the following example. Over the range 200° to 300°C , nearly all the cesium, rubidium, and molybdenum and a significant percentage of the uranium can be dissolved by water. However, when a mass of basalt equal to the mass of waste is added to the experiment, no cesium, rubidium, molybdenum, or uranium can be detected in the test solutions. This result remains to be verified, however, by careful quantitative experimentation.

In the advanced hydrothermal testing initiated this quarter, emphasis has been placed on accurate determination of steady-state solution composition. Data from these tests will provide the basis for detailed conceptual designs of engineered barrier waste packages. These experiments differ from the scoping studies, in that more sophisticated equipment is being used. Inert autoclaves have been fabricated from which solutions may be extracted for analysis during the experiment. This development permits accurate profiling of changes in solution composition and pH.

Initial results from the advanced tests have confirmed the fact that solution compositions reported from the scoping tests cannot be used quantitatively. (Many of the scoping tests were compromised by the occurrence of precipitation during autoclave cool down at the termination of the test run). The new data confirm the earlier conclusion that basalt is an effective barrier to radionuclide migration. For example, at 300°C , 71 ± 1 micrograms per milliliter of uranium are dissolved from spent fuel in the absence of basalt. After 4 weeks, at 300°C , when basalt is present, hydrothermal solutions contain only 2 ± 1.4 micrograms per milliliter uranium.

Perhaps more significant is the profile of hydrothermal solution pH. Early Basalt Waste Isolation Project predictions of hydrothermal solution pH have been based on basalt reacted with natural waters which resulted in severe pH depressions at temperatures above $\sim 200^\circ\text{C}$. This depression was temporary and resulted from smectite (i.e., magnesium-rich clay) precipitation. Since smectites are experimental products of simulated Columbia River basalt/Hanford groundwater interactions, the concern is

that the pH of flowing hydrothermal solutions entering a repository in basalt may reach as low as 4.0 pH as the result of the same reactions. Such acidic waters would be corrosive to barrier and waste material.

The results obtained to date from advanced hydrothermal experiments incorporating simulated supercalcine, basalt, and groundwater indicate that these concerns may be unwarranted. Using a groundwater to basalt ratio of 10:1 at 300°C, the solution analysis shows no evidence of severe pH depression after 385 exposure hours. Rather, the pH has slowly decreased to a present value of 7.8 (Figure 18). The experiment will be continued until a steady-state pH is reached. The present trend, however, is inconsistent with a steady approach to a pH value, which is controlled by the dissociation of silicic acid. (The expected value for the pH at 300°C would be 6.5 under this condition).

In addition, it is felt that these results do not follow the trend observed earlier because of the low-magnesium content of Hanford groundwater and because of the slugged dissolution of basalt glass. If these results are verified by quantitative basalt-water experiments, then it can be concluded that repository pH is unlikely to be lower than that imposed by silicic acid dissociation.

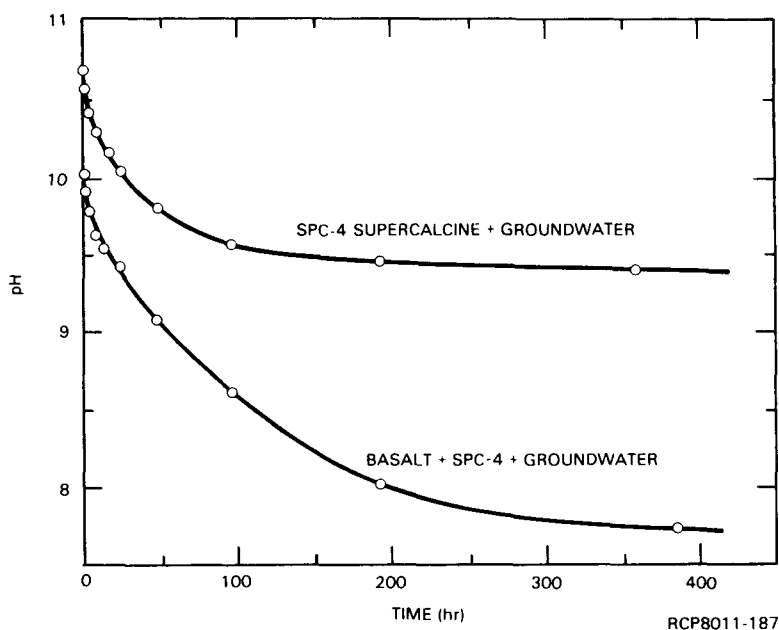


FIGURE 18. Effect of the Presence of Basalt on Solution pH in Simulated Supercalcine/Basalt/Hanford Groundwater Reaction Studies.

Most experiments planned by the Basalt Waste Isolation Project use simulated wastes. However, testing with actual waste materials is necessary to obtain a license for repository construction, and such testing requires the use of a hot cell facility. Accordingly, preliminary efforts to reserve hot cell facilities have begun. Feasibility studies are

currently being performed by Atomics International, Division of Rockwell International, and by EG&G, Inc., Idaho Falls, Idaho. Progress reports from these contractors indicate that hydrothermal testing may be conducted at either facility.

Sorption Chemistry

The objective of the sorption chemistry studies is to obtain distribution ratios (K_d 's) for the key radionuclides under conditions which simulate those that exist in the groundwater flowpath from a repository constructed in basalt to the biosphere. The distribution ratio is defined as the ratio of the activity sorbed onto the solid phase to the activity in the aqueous phase. These distribution ratios, along with other relevant chemical and physical data, will be used to evaluate the ability of the geohydrologic system and the candidate engineered barriers materials to prevent the transport of radionuclides to the biosphere.

The distribution ratio is an empirical parameter and can be dependent on many system parameters, including: solution composition; solid composition; radionuclide species and concentration; and system Eh, pH, temperature, and pressure. Radionuclide distribution ratios have been determined using an equilibrium batch technique between representative geologic materials from the Hanford Site and synthetic groundwaters which simulate actual Hanford groundwaters. The geologic materials include Umtanum, Flow E, and Pomona basalts; secondary mineralization from the Pomona basalt, and an interbed tuff from the Ellensburg formation. The groundwater formulations used in the K_d determinations are given in Table 8 and the results of the static experiments at 25° and 60°C are

TABLE 8. Synthetic Groundwater Formulations.

Constituents	Concentration (milligrams per liter)	
	Groundwater #1	Groundwater #2
Na ⁺	30.7	225
K ⁺	9.0	2.5
Ca ²⁺	6.5	1.06
Mg ²⁺	1.0	0.07
Cl ⁻	14.4	131
CO ₃ ²⁻	0	59
HCO ₃ ⁻	81.5	75
F ⁻	0	29
SO ₄ ²⁻	11.1	72
SiO ₂	25	108
pH	8.0	10.0

presented in Tables 9 and 10, respectively. Several conclusions may be shown from these data: the geologic materials having a higher surface area (e.g., the secondary mineralization, 650 square meters per gram) usually have a higher radionuclide sorption capacity (K_d value) than those materials with lower surface areas (e.g., the basalts, ~20 square meters per gram); temperature effects on K_d between 23° and 60°C are relatively minor; and radionuclides which normally occur in an anionic or neutral form such as technetium, neptunium, or iodine are relatively poorly sorbed by these geologic materials under oxic conditions.

Distribution ratios for uranium, cesium, strontium, technetium, and neptunium have been determined between the basalts and secondary mineralization and the two groundwater formulations given in Table 8. The results of these experiments are presented in Table 11. Only uranium shows a significant difference in K_d values: the sorption of uranium from groundwater #2 is approximately an order of magnitude less than the sorption of uranium from groundwater #1 for the basalts. This is probably due to the fact the groundwater #2 contains greater amounts of carbonate and is higher in pH than groundwater #1, which leads to higher uranium anionic (uranyl carbonate) complexing levels. (Groundwater #2 is representative of groundwaters at the repository depth, Grande Ronde Basalt; groundwater #1 is representative of groundwaters in the upper Wanapum Basalt and lower Saddle Mountains Basalt).

The concentrations of the radionuclides in the groundwater can be expected to vary with time because of changes in the thermal and physiochemical conditions in and near the repository. The radionuclide K_d value is sensitive to changes in the radionuclide concentration. Experiments have been conducted to determine K_d values over a radionuclide concentration range determined by factors such as radionuclide solubility, specific activity, and the lower analytical detection limit. The cesium and strontium isotherm results have been reported previously. Neptunium distribution ratios generally show a slight increase with decreasing radionuclide concentration over the concentration range investigated (10^{-5} to 10^{-8} molar) for the basalts and the tuff. Neptunium sorption onto the fracture mineralization does not show a concentration dependence over this concentration range. Technetium sorbed only onto the Umtanum basalt in any measurable amount, and results indicate that the technetium concentration has little effect on the sorption behavior of technetium. Sorption isotherm experiments to determine the radionuclide concentration effects on K_d values are under way for other key radionuclides.

Radionuclide distribution ratios also can be affected greatly by Eh and pH conditions in the environment. Repository conditions are expected to vary in pH from approximately 6 to 10 and in Eh from -0.5 volt (10^{-68} atmospheres O_2) to +0.5 volt (10^{-7} atmospheres O_2). Radionuclide distribution ratios have been determined under slightly anoxic conditions for those radionuclides that exhibit more than one stable oxidation state (selenium, technetium, neptunium, plutonium, uranium). An oxygen concentration of 7.87×10^{-7} atmospheres was obtained that simulates the possible repository conditions immediately following repository

TABLE 9. Radionuclide Distribution Ratios between Synthetic Groundwater and Representative Geologic Materials.^a

Radionuclide	23°C, K _d (milliliters per gram)					
	Initial ^b Concentration	Umtanum ^c Basalt	Flow EC ^c Basalt	Pomona ^c Basalt	Secondary ^c Mineralization	Tuff ^d
⁷⁵ Se	2.63 x 10 ⁻¹³	5.4 ± 1.3	1.2 ± 0.3	2.4 ± 0.7	7.6 ± 0.3	--
⁸⁵ Sr	5.54 x 10 ⁻¹²	105 ± 4	91 ± 5	121 ± 9	274 ± 16	--
	1.23 x 10 ⁻¹⁰	--	--	--	--	541 ± 127
⁹⁹ Tc	6.55 x 10 ⁻⁸	2.68 ± 21.9	0	0	0	--
	1.59 x 10 ⁻⁹	--	--	--	--	0
¹²⁵ I	4.24 x 10 ⁻¹⁴	6.8 ± 1.3	1.0 ± 0.4	2.0 ± 1.0	14.0 ± 1.8	--
	3.06 x 10 ⁻¹³	--	--	--	--	2.6 ± 0.5
¹³⁷ Cs	8.76 x 10 ⁻¹⁰	705 ± 18	278 ± 6	1,685 ± 245	11,000	--
	1.59 x 10 ⁻⁷	--	--	--	--	3,052 ± 184
²²⁶ Ra	8.42 x 10 ⁻¹⁰	187 ± 24	127 ± 21	158 ± 5	339 ± 94	--
²³⁷ Np	6.47 x 10 ⁻⁸	30.0 ± 13.0	4.1 ± 0.9	9.8 ± 0.5	36.9 ± 7.5	--
	2.03 x 10 ⁻⁸	--	--	--	--	25 ± 3
²⁴¹ Am	2.09 x 10 ⁻¹⁰	277 ± 103	622 ± 180	696 ± 93	1,355 ± 152	--
	5.72 x 10 ⁻¹⁰	--	--	--	--	355 ± 183
²⁴¹ Pu	1.62 x 10 ⁻¹¹	102 ± 97	165 ± 16	267 ± 18	2,572 ± 341	--
²³³ U	2.15 x 10 ⁻⁸	56 ± 11	13 ± 1	16 ± 2	147 ± 70	--

^aValues reported are the average of three replicates ± one standard deviation.

^bConcentrations in moles per liter.

^cContact time 50 days, synthetic groundwater #1, 1 gram solid to 10 milliliters of solution.

^dContact time 30 days, synthetic groundwater #2, 5 gram solid to 30 milliliters of solution.

TABLE 10. Radionuclide Distribution Ratios between Synthetic Groundwater and Representative Geologic Materials.^a

Radionuclide	60°C, K _d (milliliters per gram)					
	Initial ^b Concentration	Umtanum ^c Basalt	Flow EC Basalt	Pomona ^c Basalt	Secondary ^c Mineralization	Tuff ^d
⁷⁵ Se	2.63 x 10 ⁻¹³	0	1.0 ± 0.1	0	0	--
⁸⁵ Sr	5.54 x 10 ⁻¹² 1.10 x 10 ⁻¹¹	122 ± 3 --	104 ± 1 --	130 ± 4 --	339 ± 5 --	-- 244 ± 70
⁹⁹ Tc	6.55 x 10 ⁻⁸ 1.59 x 10 ⁻⁹	25.5 ± 5.2 --	0 --	0 --	0 --	-- 0
¹²⁵ I	4.24 x 10 ⁻¹⁴ 3.06 x 10 ⁻¹⁴	0 --	0 --	0 --	0 --	-- 2.4 ± 0.6
¹³⁷ Cs	8.76 x 10 ⁻¹⁰ 1.50 x 10 ⁻⁸	463 ± 5 --	187 ± 6 --	747 ± 37 --	1,432 ± 695 --	-- 554 ± 40
²²⁶ Ra	8.42 x 10 ⁻¹⁰	360 ± 69	313 ± 50	399 ± 80	351 ± 55	--
²³⁷ Np	6.47 x 10 ⁻⁸ 2.03 x 10 ⁻⁸	31.2 ± 4.7 --	8.3 ± 0.5 --	12.1 ± 3.2 --	53.5 ± 18.8 --	-- 25 ± 22
²⁴¹ Am	2.09 x 10 ⁻¹⁰ 7.31 x 10 ⁻¹²	236 ± 98 --	400 ± 245 --	717 ± 3 --	1,489 ± 350 --	-- 189 ± 55
²⁴¹ Pu	1.62 x 10 ⁻¹¹	353 ± 224	300 ± 26	700 ± 108	3,328 ± 609	--
²³³ U	2.15 x 10 ⁻⁸	103 ± 12	52 ± 5	116 ± 22	1,356 ± 48	--

^aValues reported are the average of three replicates ± one standard deviation.

^bConcentrations in moles per liter.

^cContact time 50 days, synthetic groundwater #1, 1 gram solid to 10 milliliters of solution.

^dContact time 30 days, synthetic groundwater #2, 5 gram solid to 30 milliliters of solution.

TABLE 11. Effect of Groundwater Composition on Radionuclide K_d Values.^a

Radionuclide	23°C, K_d (milliliters per gram)					
	Initial Concentration ^b	Groundwater ^c	Umtanum Basalt	Flow E Basalt	Pomona Basalt	Secondary Mineralization
²³³ U	8.16×10^{-9}	#1	56 ± 11	13 ± 1	16 ± 2	147 ± 70
		#2	2.8 ± 0.9	1.0 ± 0.2	0.9 ± 0.2	72 ± 2
¹³⁷ Cs	10^{-9}	#1	$1,112 \pm 183$	460 ± 74	$1,643 \pm 420$	$12,000$
		#2	$1,032 \pm 151$	558 ± 88	$2,063 \pm 173$	$9,795 \pm 3,976$
⁸⁵ Sr	10^{-10}	#1	161 ± 35	216 ± 59	152 ± 14	451 ± 103
		#2	138 ± 13	143 ± 20	188 ± 41	249 ± 49
⁹⁹ Tc	6.55×10^{-8}	#1	5.6 ± 3.5	0	0	0
		#2	1.3 ± 0.4	0	0	0
²³⁷ Np	6.7×10^{-8}	#1	13 ± 1	7 ± 1	9 ± 1	75 ± 38
		#2	7 ± 3	0.5 ± 0.1	52 ± 16	157 ± 40

^aValues reported are the average of three replicates \pm one standard deviation; contact time of 54 to 62 days; 1 gram solid to 10 milliliters of solution.

^bConcentrations in moles per liter.

^cCompositions for groundwater #1 and groundwater #2 are given in Table 8.

closure. A comparison of the radionuclide K_d values obtained under oxic and slightly anoxic conditions is presented in Table 12. Little or no enhanced sorption of these isotopes onto the basalt and fracture mineralization is apparent under the slightly anoxic conditions. However, there would almost certainly be observable effects on these radionuclide K_d values if the oxygen partial pressure approached the equilibrium value of 10^{-68} atmospheres of O_2 predicted for the sealed repository.

The need for radionuclide distribution measurements under controlled Eh and pH conditions has prompted the investigation of several Eh-pH control systems. Several Eh poisoning agents and pH buffers have been tested for use in radionuclide sorption experiments. Quinhydrone has been found to be a potential Eh poisoning agent for systems with pH values less than 7.5. The quinhydrone would poison the system at an oxygen fugacity of approximately 10^{-36} atmospheres of O_2 at 25°C. Ferroin was tested as a potential Eh poisoning agent, but was found to interfere with radionuclide sorption onto the geologic materials. Sodium sulfite and hydrazine are presently being investigated as potential Eh poisoning agents for the basalt/groundwater system at higher pH values than are possible with quinhydrone.

Near-Field Modeling

The objective of the near-field modeling work is to determine the release rates of key radionuclides within a repository located in basalt. Included in this work is the thermalchemical modeling of the near-field environment, which involves the coupling of algorithms describing fluid flow, waste form and barrier dissolution, radionuclide precipitation, and surface sorption. Modeling activities in this quarter have centered around developing an adequate theory to describe sorption in a complex system and a review of solubility data for actinide compounds.

The conventional retarded flow approximation treats sorption of migrating ions as if they were all at infinite dilution on the solid surface. This leads to the equation:

$$R = 1 + K_d \frac{\rho}{\phi} \quad (1)$$

where

R is the ratio of nuclide velocity to fluid velocity

K_d is the amount sorbed divided by amount in solution and

ρ and ϕ are density and porosity of the rock, respectively.

TABLE 12. Effect of Oxygen Fugacity on Radionuclide K_d Values.^a

Radionuclide	23°C K_d (milliliters per gram)				
	fO_2 Conditions ^b	Umtanum Basalt	Flow E Basalt	Pomona Basalt	Secondary Mineralization
⁷⁵ Se	0	5.4 ± 1.3	1.2 ± 0.3	2.4 ± 0.7	7.6 ± 0.3
	A	16.8 ± 4.0	1.0 ± 0.6	0	3.3 ± 0.3
⁹⁹ Tc	0	26.8 ± 21.9	0	0	0
	A	$4,489 \pm 3,165$	2.5 ± 1.7	0	0
²³⁷ Np	0	30 ± 13	4.1 ± 0.9	9.8 ± 0.5	36.9 ± 7.5
	A	148 ± 27	11.2 ± 10.9	11.9 ± 2.5	79 ± 10
²⁴¹ Pu	0	102 ± 97	165 ± 16	267 ± 18	$2,572 \pm 341$
	A	$5,190 \pm 3,290$	51.6 ± 14.4	70.8 ± 51.1	415 ± 178
²³³ U	0	2.8 ± 0.9	1.0 ± 0.2	0.9 ± 0.2	72 ± 2
	A	9.3 ± 1.0	1.6 ± 0.7	2.0 ± 0.9	108 ± 23

^aValues reported are the average of three replicates \pm one standard deviation. Contact time of 50 to 53 days, using groundwater #1 and 1 gram solid to 10 milliliters of solution, except for ²³³U where groundwater #2 was used.

^b0 = 0.2 atmosphere O_2 ; A = 7.9×10^{-7} atmospheres O_2

This equation does not strictly apply if there is a major component of the solution that interacts with the surface or if the migrating radio-nuclide is present in more than trace quantities. A migration model that takes account of the interactions between different ions has been developed and a code written for the case of three competing components. In the general case, the retardation factor for element j , R_j is given by:

$$R_j = 1 + R_j^{\circ} \quad (2)$$

and the sorption parameter R_j° by:

$$R_j^{\circ} = \frac{[S_j]}{[C_j]} \left[1 - \frac{n_j^2 [S_j]}{\sum_{\ell=1}^n n_{\ell}^2 [S_{\ell}]} \right] \quad (3)$$

In this expression, $[S_j]$ and $[C_j]$ refer to concentrations of j on the solid surface and in solution, respectively, and n_j is the charge on component j . The expression takes account of the fact that the number of surface sites is finite and that the different ions in solution compete for them. Figure 19 illustrates the effect of site competition for a hypothetical case in which a groundwater contains 10^{-2} moles per liter of sodium which competes with a trace component, cesium, for a limited number of surface sites. The effect of competition is negligible at very low cesium concentrations, but once the cesium starts to fill large numbers of surface sites, K_d becomes progressively lower and the two equations give substantially different results for the retardation factor, R . This phenomenon will have to be considered in advanced near-field models that will be developed to simulate environments relatively rich in radionuclides.

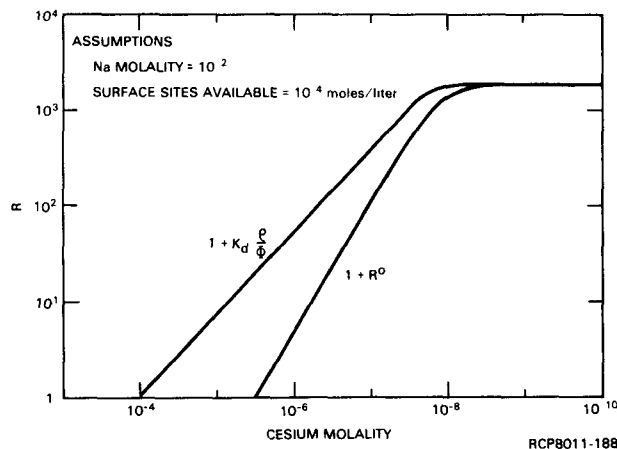


FIGURE 19. Effect of Site Competition (Hypothetical Case) on the Retardation Factor, R , for Cesium.

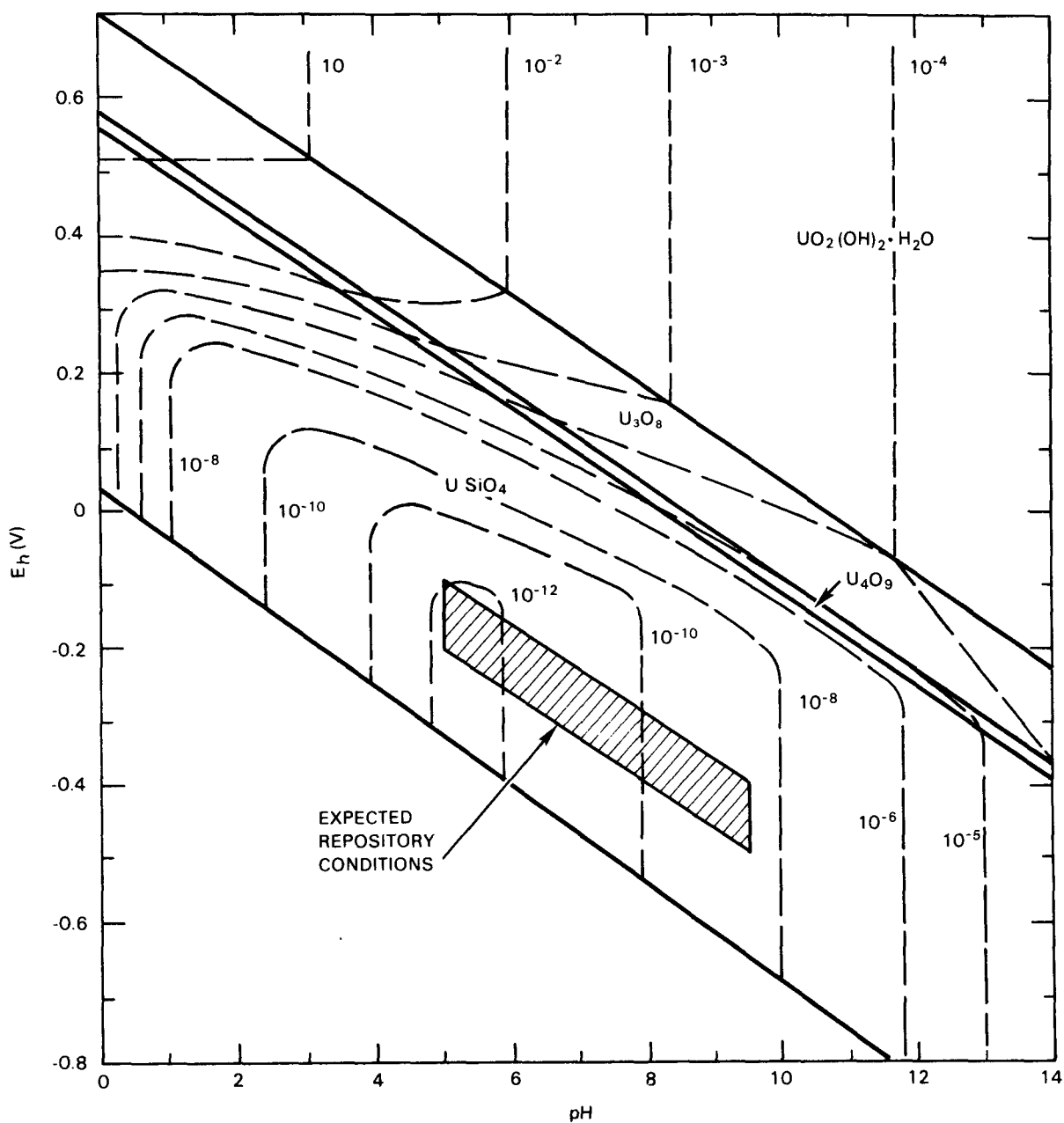
A review of thermodynamic data for uranium and plutonium has led to the conclusion that, under reducing conditions, these elements will be extremely insoluble in Hanford groundwater. Reducing conditions are anticipated to occur soon after repository closure when air introduced during operations has been consumed by the host basalt. A code to calculate and plot stable solids and solution concentrations as a function of pH and Eh (or oxygen fugacity) has been developed during the quarter. Figure 20 shows the calculated solubility of uranium at 65°C in groundwater from the Grande Ronde Basalt horizon. Under likely repository conditions (indicated by the shaded region in Figure 20), uranium should not be more soluble than about 3×10^{-9} moles per liter. This is below the recommended concentration guide values for drinking water (Title 10, Code of Federal Regulations, Part 20) for all uranium isotopes and their daughters (including ^{226}Ra). Thus, the extreme insolubility of uranium in a repository in basalt should provide rigid constraints on the dissolution and transport rates of the major components of spent fuel.

Canister/Overpack Materials Evaluation

The objective of the canister/overpack materials evaluation task is to identify and characterize, by corrosion and mechanical property testing, materials that would be suitable candidates for long-lived engineered barrier system components for emplacement in a repository located in basalt. A study in support of this task and preparation for corrosion screening tests has continued during the quarter.

A survey of the literature for existing corrosion information on cast irons, carbon steels, and titanium alloys has been completed. The report, which presents the data and its evaluation with respect to the Grande Ronde Basalt groundwater environment, has been drafted. The conclusions are as follows:

- The uniform corrosion of low-alloy titanium in a basalt environment is expected to be extremely low. A linear extrapolation of general corrosion rates and an added corrosion allowance suggest that 1/8- to 1/4-inch-thick wall would give a life of 1,000 years. This is a conservative estimate, since the corrosion rates are expected to be logarithmic with time rather than linear. Pitting and crevice corrosion are concluded to be unlikely corrosion modes in basalt groundwaters. Stress corrosion cracking is also unlikely to occur in the commercial purity titanium alloy and the low-palladium or molybdenum alloyed titanium.
- Low-alloy cast irons can be used as barrier metals provided the environment surrounding the metal keeps the alloy in the passive range. The solubility of the corrosion product and the semi-permeable nature of the oxide film allows significant uniform corrosion over long times. A linear extrapolation of high-temperature corrosion rates on carbon steels and corrosion rates of cast irons in soils yields values for metal penetration of 5 to 6.5 centimeters after 1,000 years.



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FIGURE 20. Calculated Solubility of Uranium at 65°C in Grande Ronde Basalt Groundwater.

Studies have been initiated to define the time dependence of environmental variables related to corrosion rates during the canister/overpack design life. The results of this work will identify the range of experimental variables for canister/overpack materials corrosion tests used to evaluate the performance of these engineered barriers components.

The test procedure for corrosion screening tests of candidate canister/overpack materials has been defined. The procedure consists of the exposure in autoclaves of stressed and unstressed coupons to simulated Grande Ronde Basalt groundwater. Important considerations were control of oxygen fugacity of the water, methods of monitoring the effectiveness of water chemistry control, and material corrosion in progress. The test variables for the screening tests are hydrogen ion concentration (pH) and oxygen fugacity. Three levels of pH have been selected:

- The reference pH (9.92 at 25°C) representing the "equilibrium" condition for the repository groundwater
- A pH (9.6 at 25°C) representing an expected variability of the "equilibrium" condition
- A pH (7.5 at 25°C) representing a non-equilibrium condition which is predicted for the first few thousand hours of the overpack design life.

The oxygen fugacities selected for the tests are the low-oxygen (10-50 atmospheres at 250°C) condition and the high-oxygen (equilibrium with air at 1 atmosphere) condition which will prevail during the repository operation period.

Procurement of materials for the corrosion tests is essentially complete, and specimens have been prepared for the first tests. The autoclave system has been assembled and checked for operability, and specimen assemblies are being prepared to initiate the first tests.

As an aid to the evaluation of engineered barrier system design concepts, preliminary estimates have been made of mechanical loads on barrier systems under conditions expected in a repository constructed in basalt. The estimated loads are summarized in Table 13. As more information becomes available on backfill properties and site-specific repository conditions, the magnitude of these predicted loads may change considerably.

TABLE 13. Estimated Mechanical Loads on Waste Packages Emplaced in Basalt.

Loading Mechanism	Stress (atmospheres)
Lithostatic and hydrostatic	
Vertical	100 - 200
Horizontal	50 - 450
Clay swelling	~20
Rock movement	
Faulting (low probability)	2 - 4
Steam pressure	Less than lithostatic pressure

BOREHOLE PLUGGING

The objective of the borehole plugging activity is to devise a plugging system to seal boreholes, shafts, and tunnels associated with a repository in basalt. Several types of plugging materials, plug emplacement machinery types and techniques, and monitoring instrumentation are undergoing study. An integrated series of field tests leading to licensable repository seals for a repository in basalt is being planned. The Shallow Borehole Plugging Test Plan discussed previously (RHO-BWI-80-100 3Q) has been revised, and several sites on Gable Butte and Gable Mountain were evaluated as possible sites for the test on the basis of the following criteria:

- Presence of undisturbed rock, similar to proposed repository horizon rocks, near the surface and above the water table
- Accessibility of the site
- Availability of services and facilities
- Minimum requirement for site preparation.

The site selected for the Shallow Borehole Plugging Test is on Gable Mountain near the Near-Surface Test Facility. It is located on the Elephant Mountain flow in an area well removed from the fold axes on the north and south flanks of Gable Mountain. It is located on a relatively flat bench that will require minimum site preparation and is near roads and utilities associated with the Near-Surface Test Facility.

Five small-diameter (Nx) core holes have been drilled to a depth of 46 meters to characterize the candidate area for the Shallow Borehole Plugging Test. The characterization holes penetrated the Elephant Mountain flow, the Rattlesnake Ridge interbed, and the upper portion of the Pomona flow.

The cores have received preliminary characterization and standard geophysical logging (resistivity, natural gamma, and acoustic). Downhole photography (television and 35-millimeter camera) has been carried out for characterization purposes. Preliminary results indicate that several intervals suitable for instrumentation and testing exist within the cored intervals. Determination of the physical properties of the recovered core has been initiated in the laboratories of Woodward-Clyde Consultants, Oakland, California.

A study of fracturing and grouting in shafts constructed in basalt has been initiated. The objective of the study is to evaluate the extent of fracturing around large-diameter openings and its effect on the ability to effectively seal them. The study will also provide assurance that a proposed exploratory test facility shaft can be sealed.

NEAR-SURFACE TEST FACILITY

The Near-Surface Test Facility is a multipurpose test facility for in situ testing in basalt. The Phase I (electric heater) and Phase II (nuclear waste) tests to be conducted in the facility are designed to:

- Qualify basalt as a repository medium
- Provide the basis of design for key repository elements
- Demonstrate placement, storage, and retrieval of canisters containing radioactive material in an underground basalt environment.

The Near-Surface Test Facility is located on the west end of Gable Mountain on the Hanford Site. The facility consists of a computer room and approximately 1,000 meters of underground workings, including access tunnels and test rooms. Work under Phase I developed the electric heater test portion of the facility so that testing may begin in fiscal year 1980. Work in preparation for Phase II testing is scheduled for completion in fiscal year 1982.

The Near-Surface Test Facility Design and Construction end function is divided into nine major activities:

- Project Management
- Design--Phase I
- Construction--Phase I
- Safety and Environmental Analysis--Phase I
- Decommissioning--Phase I
- Design--Phase II
- Construction--Phase II
- Safety and Environmental Analysis--Phase II
- Decommissioning--Phase II.

During the fourth quarter of fiscal year 1980, work has progressed in the project management, Phase I and Phase II construction, and Phase II design activities.

PROJECT MANAGEMENT

The project management activity is concerned with the management of the Near-Surface Test Facility end function; specifically in the preparation and control of schedules, preparation of budgets and work packages, control of program costs, and overall guidance of the technical activities.

CONSTRUCTION - PHASE I AND PHASE II

The Phase I facility equipment installation was completed with installation of the uninterruptible power systems and the telemetry system.

The drilling contractor started mobilizing on September 23, 1980 for the Phase II drilling work.

The Phase II facility installation for the block test area has started.

Procurement of equipment for Phase II is continuing. All identified equipment has been ordered except equipment for the alarm system, which will be ordered during fiscal year 1981.

The Phase II Title II drawings were completed as scheduled on August 15, 1980.

ENGINEERING TESTING

The objectives of the Engineering Testing end function are to design, procure, fabricate, and install equipment and instrumentation to obtain in situ test data during the Near-Surface Test Facility operations. Phase I tests consist of Full-Scale Heater Tests #1 and #2 and Jointed Block Tests #1 and #2. Phase II (nuclear waste) tests consist of Spent Fuel Tests #1 and #2 and a Vitrified Waste Form Test. The test data will be used to establish the engineering feasibility of constructing a repository in basalt and repository design. Rock testing and other miscellaneous special studies are also included as part of this program to assist in meeting the Near-Surface Test Facility objectives.

The Engineering Testing end function is divided into four major activities:

- Project Management
- Engineering Studies
- Phase I
- Phase II.

During the fourth quarter of fiscal year 1980, work has progressed in all four of the activities.

PROJECT MANAGEMENT

The project management activity is responsible for the management of the Engineering Testing end function; specifically in the preparation and control of schedules, preparation of budgets and work packages, control of program costs, and overall guidance of the technical activities.

ENGINEERING STUDIES

During the fourth quarter of fiscal year 1980, two reports were issued. One was the final report on the characterization of the Umtanum flow by the Colorado School of Mines, Golden, Colorado, entitled "Geological Characterization of Drill Holes DC-6, DC-8 and DC-4" (RHO-BWI-C-69). The other was the final report on thermal property tests (such as thermal conductivity, thermal expansion, specific heat and thermal diffusivity) that were conducted by Pacific Northwest Laboratory, Richland, Washington, entitled "Thermal Property Measurements of Pomona Member Basalt from Core Holes DB-5 and DB-15, Hanford Site, Southeastern Washington" (RHO-BWI-C-76).

Foundation Sciences, Inc., Portland, Oregon, has completed laboratory investigations of basalt core from the Full-Scale Heater Tests #1 and #2

areas. Table 14 is a compilation of the results of all the thermomechanical property measurements for the Full-Scale Heater Test #1 area on intact entablature basalt from the Pomona flow. A report discussing these results in greater detail is scheduled to be released early in fiscal year 1981. Table 15 presents preliminary data from the Full-Scale Heater Test #2 area.

Initial analysis indicates that no major differences exist between cores from the two test areas. The only test that showed conflicting results was the apparent porosity test. Different sample sizes used for the two areas may account for the difference in reported values. The larger area/volume ratio in one set of test specimens may have resulted in higher observed porosity values. This possible sample-size phenomenon is currently being studied by Foundation Sciences, Inc. and will be discussed at a later time.

Currently, core from the entablature zones of the Umtanum flow, as well as from the Pomona flow, are undergoing triaxial confinement tests at elevated temperatures and pressures, and an additional set of Umtanum core and a set of core from the Accelerated Room-Scale Test area are being prepared for the basic suite of tests. Results of these tests as well as a full analysis of all of the test areas will be completed in fiscal year 1981.

PHASE I

The Phase I tests provide the design, procurement, fabrication, calibration, installation, checkout, operation, and analysis of heater test equipment in the Near-Surface Test Facility.

The Phase I tests are subdivided into the following subactivities:

- Heaters and Controllers
- Rock Instrumentation
- Data Acquisition System
- Site Characterization
- Test Engineering Support
- Equipment Installation
- Operations.

Work progressed in each of these subactivities, except equipment installation. Since the equipment for the full-scale heater tests was installed in the third quarter, the next planned equipment installation activity will be associated with the block test in the second quarter of fiscal year 1981.

TABLE 14. Reference Thermomechanical Properties, Pomona Flow,*
Full-Scale Heater Test #1 Area.

Item	Range	Mean \pm Std. Dev.	Units	Comments
Density Bulk	2.80 - 2.88	2.85 \pm 0.02	g/cm ³	--
Grain	2.88 - 3.11	3.00 \pm 0.05	g/cm ³	--
Apparent porosity	0.5 - 1.3	0.91 \pm 0.28	%	--
Modulus of rupture	39.0 - 49.6	46.2 \pm 4.4	MPa	--
Brazilian tensile strength	13.4 - 25.3	20.2 \pm 3.4	MPa	--
Young's modulus static	74.5 - 112.4	88.9 \pm 6.9	GPa	Relatively constant from 20 ^o -300 ^o C and 0-13.8 MPa confining pressure.
Dynamic	70.9 - 91.8	82.7 \pm 4.1	GPa	Determined at ambient conditions.
Poisson's ratio static	0.22 - 0.36	0.26 \pm 0.01		Tests conducted over a range of confining pressures from 0-13.8 MPa and 22 ^o C.
Dynamic	0.22 - 0.27	0.25 \pm 0.011		Determined at ambient conditions.
Compressive (P) wave velocity	5.56 - 6.10	5.90 \pm 0.13	km/sec	--
Shear (S) wave velocity	3.17 - 3.63	3.38 \pm 0.09	km/sec	--
Thermal diffusivity	4.41 - 7.61	6.3 \pm 0.68	10 ⁻³ cm ² /sec	Temperature (20 ^o -300 ^o C)
Specific heat	(C _S = 0.075 + 2.86 x 10 ⁻² ln T)		cal/g- ^o C	Temperature (70 ^o -350 ^o C)
Thermal conductivity	(K = 4.39 + 3.95 x 10 ⁻³ T)		**mcal/cm-sec- ^o C	Temperature (20 ^o -300 ^o C)

TABLE 14. (Continued)

Item	Range	Mean + Std. Dev.	Units	Comments
Coefficient of thermal expansion	$(\alpha = 5.1 + 2.2 \times 10^{-3} T)$		$10^{-6}/^{\circ}\text{C}$	Temperature (70° - 300°C)
Compressive strength	266.1 - 413.7	356.5 ± 43.4	MPa	Temperature = 22°C Confining Stress = 0 MPa
	404.0 - 441.3	422.7 ± 26.2	MPa	Temperature = 22°C Confining Stress = 3.45 MPa
	342.7 - 478.5	408.9 ± 61.4	MPa	Temperature = 22°C Confining Stress = 6.9 MPa
	469.5 - 502.6	485.4 ± 16.5	MPa	Temperature = 22°C Confining Stress = 13.8 MPa
Empirical relation for failure stress as a function of confining pressure for the above strength data: $\sigma_1 = 357.8 + 8.7 \sigma_3$, where σ_1 is the axial stress at failure, σ_3 is the confining pressure, and 357.8 MPa is the uniaxial compressive strength. The linear failure envelope developed from these data indicates that the angle of internal friction is $52^{\circ} \pm 3^{\circ}$ and the shear strength is approximately 57.3 MPa.				
	319.2 - 410.9	364.7 ± 64.8	MPa	Temperature = 150°C Confining Stress = 0.69 MPa
	273.7 - 291.0	280.6 ± 9.0	MPa	Temperature = 300°C Confining Stress = 0.69 MPa
Insufficient data have been acquired to develop empirical relationships for compressive strength as a function of temperature. However, a generally decreasing trend is seen in the data.				

*The properties of the Pomona flow presented in this table are based upon laboratory investigations of intact entablature basalt collected from the area of Full-Scale Heater Test #1 at the Near-Surface Test Facility.

**mcal = millicalorie.

TABLE 15. Reference Thermomechanical Properties, Pomona Flow,*
Full-Scale Heater Test #2 Area.

Item	Range	Mean + Std. Dev.	Units	Comments
Density Bulk	2.77 - 2.94	2.85 \pm 0.02	g/cm ³	--
Grain	2.85 - 3.12	2.98 \pm 0.11	g/cm ³	--
Apparent porosity	0.1 - 0.56	0.27 \pm 0.14	%	--
Modulus of rupture	31.4 - 54.7	46.6 \pm 8.2	MPa	--
Brazilian tensile strength	17.0 - 21.7	19.4 \pm 1.7	MPa	--
Young's modulus static	79.3 - 92.4	87.6 \pm 3.9	GPa	Relatively constant from 20 ^o -300 ^o C and 0-13.8 MPa confining pressure.
Dynamic	71.0 - 87.2	82.2 \pm 3.6	GPa	Determined at ambient conditions.
Poisson's ratio static	***			
Dynamic	0.21 - 0.30	0.26 \pm 0.026		Determined at ambient conditions.
Compressive (P) wave velocity	5.63 - 6.29	5.92 \pm 0.16	km/sec	--
Shear (S) wave velocity	3.07 - 3.51	3.39 \pm 0.08	km/sec	--
Thermal diffusivity	3.85 - 7.88	5.66 \pm 0.99	10 ⁻³ cm ² /sec	Temperature (20 ^o -300 ^o C)
Specific heat	***		cal/g- ^o C	Temperature (70 ^o -350 ^o C)
Thermal conductivity	***		**mcal/cm-sec- ^o C	Temperature (20 ^o -300 ^o C)
Coefficient of thermal expansion	***		10 ⁻⁶ / ^o C	Temperature (70 ^o -300 ^o C)

TABLE 15. (Continued)

Item	Range	Mean + Std. Dev.	Units	Comments
Compressive strength	296.5 - 380.6	347.5 \pm 35.8	MPa	Temperature = 22°C Confining Stress = 0 MPa
	409.6 - 420.6	415.1 \pm 8.3	MPa	Temperature = 22°C Confining Stress = 3.45 MPa
	***		MPa	Temperature = 22°C Confining Stress = 6.9 MPa
	433.7 - 525.4	479.9 \pm 64.8	MPa	Temperature = 22°C Confining Stress = 13.8 MPa
Empirical relation for failure stress as a function of confining pressure for the above strength data: $\sigma_1 = 362.7 + 9.2 \sigma_3$, where σ_1 is the axial stress at failure, σ_3 is the confining pressure, and 362.7 MPa is the uniaxial compressive strength. The linear failure envelope developed from these data indicates that the angle of internal friction is 54 degrees \pm 3 degrees and the shear strength is approximately 59.3 MPa.				
	317.8	317.8	MPa	Temperature = 150°C Confining Stress = 0.69 MPa
	***		MPa	Temperature = 300°C Confining Stress = 0.69 MPa
Insufficient data have been acquired to develop empirical relationships for compressive strength as a function of temperature.				

*The properties of the Pomona flow presented in this table are based upon laboratory investigations of intact entablature basalt collected from the area of Full-Scale Heater Test #2 at the Near-Surface Test Facility.

**mcal = millicalorie.

***Data not available at this time.

Heaters and Controllers

Dewatering/desteaming modules were fabricated, tested, and placed in operation at Full-Scale Heater Tests #1 and #2 Areas. The dewatering/desteaming modules were operated to remove water from heater and instrumentation boreholes with depths of 5.5 to 7 meters.

A 1.27-millimeter-diameter by 7-meter-long borescope was procured to observe the main heater borehole walls for Full-Scale Heater Tests #1 and #2. Observations will identify rock decrepitation and rock fracturing for use in rock characterization. This information will be used in test analysis of the Near-Surface Test Facility.

Rock Instrumentation

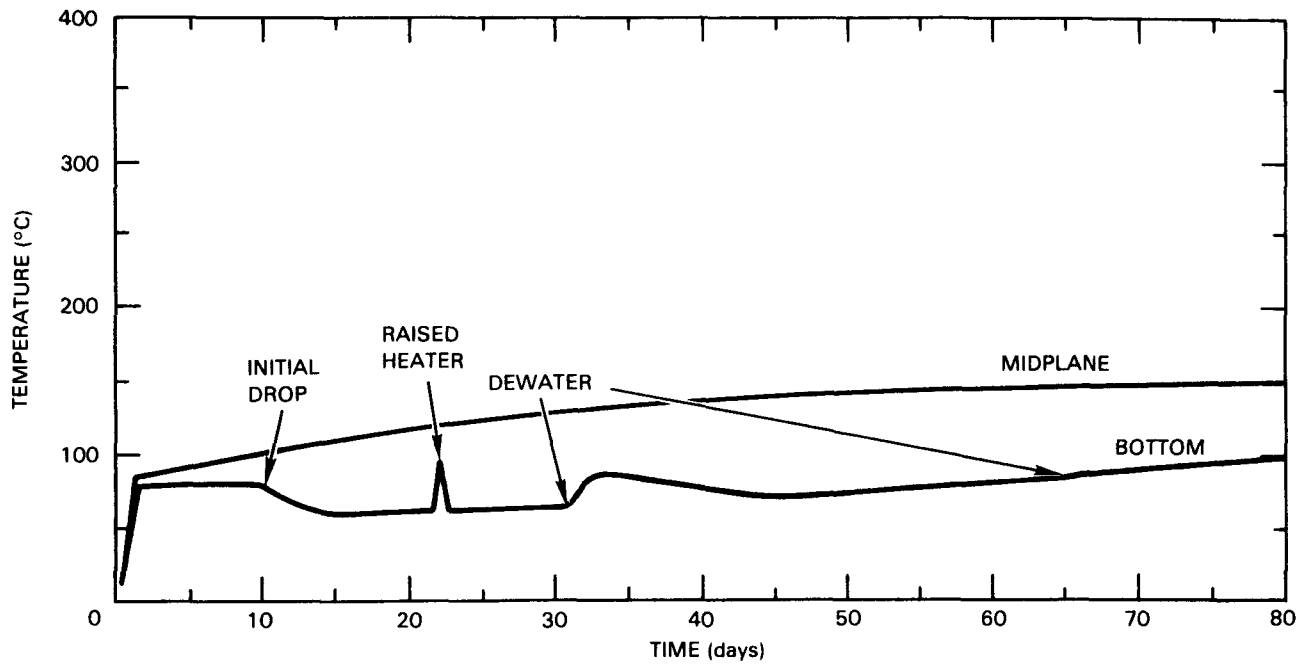
Water migration into peripheral heater boreholes results in degrading the outputs of the heater, type-K thermocouples. A water vaporization-condensation cycle within the lower portion of the heater borehole produces a characteristic indicated temperature drop as shown in Figure 21. The heater was elevated about 30 centimeters, calculated to be well above the borehole water level, and the expected rise in sensor response was observed. Subsequent dewatering of the heater boreholes resulted in the temperature rise as seen on the time history plot. By day 75, all of the peripheral heaters had achieved temperatures near or above 100°C and condensation had stopped.

The specific heat (0.48 calorie per gram-°C) for steam compares favorably with the specific heat (0.24 calorie per gram-°K) of air and will, therefore, not degrade the temperature measurements from thermocouples in a steam environment.

The increased temperatures experienced from rock heating have caused increases in extensometer anchor hydraulic bladder pressures. Figure 22 shows a pressure versus time plot of extensometer 1E04 anchors E01, E02, and E03. During a portion of the heating period, anchor E01 had to be pressure adjusted every day to maintain the pressure within specified limits of 10.3 megaPascals to 12.4 megaPascals.

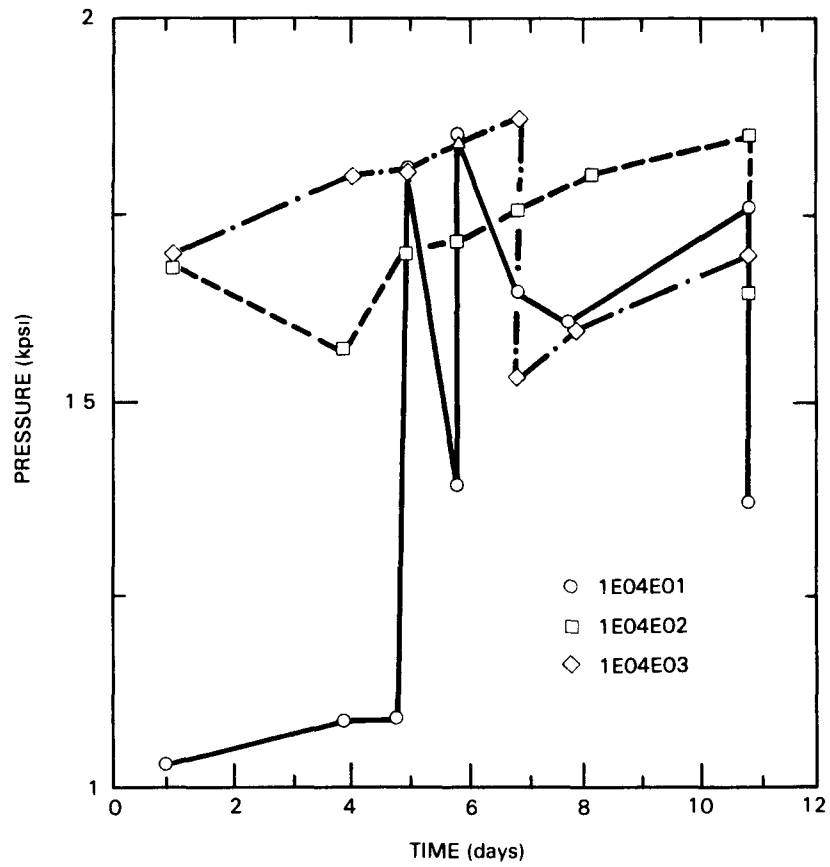
Two vibrating wire stressmeters have shown evidence of failure, as seen in Figure 23. The failure pattern for these sensors is usually observed as an anomalous variation or loss of output. Adjustments and modifications to the monitoring electronics have resulted in a higher degree of confidence in these gauges.

Borehole deformation gauge 2U03 was replaced when the output for two sensing axes became erratic. Since this is a soft gauge (i.e., no embedment into the rock is needed), replacement is comparatively simple and no instrument set time is required.



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FIGURE 21. Heater (1H04) Temperature Time History.



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FIGURE 22. Extensometer (1E04) Pressure Time History.

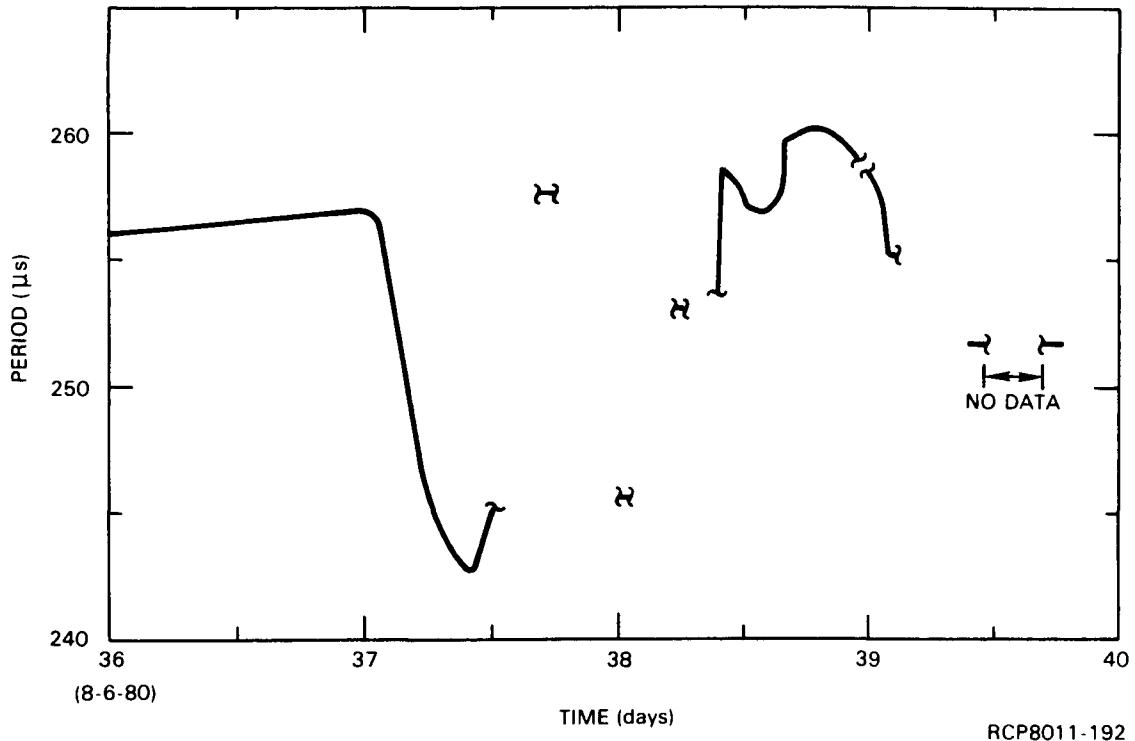


FIGURE 23. Vibrating Wire Stressmeter (1C02C02) Output Raw Data.

Instrument characterization studies continued. These studies are intended to establish instrument response to temperature, displacement, and stress so that the basalt rock response data can be extracted. The characterization data gained from these studies will be integrated into the computer algorithms to facilitate analysis of basalt response to thermal and mechanical perturbations.

The rock instrumentation system baseline conversion algorithms were written this quarter. These algorithms are used to convert the instrument electrical signals to a rock displacement or stress measurement. Summaries of these three algorithms follow and cover the:

- U.S. Bureau of Mines' borehole deformation gauge
- IRAD vibrating wire stressmeter
- Multiple position borehole extensometer.

The equation to convert the measured voltage to a displacement for a given axis of a U.S. Bureau of Mines' gauge is:

$$DM_t = 2.54 \times 10^{-2} \times [K7 + 4.22644 \times 10^{-4} \times (T_t - T_c)] \times [(10 \times VM_t)/VPS_t - (10 \times VM_i)/VPS_i] \quad (4)$$

where,

- DM_t is the measured U.S. Bureau of Mines' gauge axis movement
- K_7 is the calibration constant
- T_t is the temperature of the U.S. Bureau of Mines' gauge at the time of evaluation (t)
- T_c is the temperature of the U.S. Bureau of Mines' gauge at the time of calibration (c)
- VM_t is the U.S. Bureau of Mines' gauge axis output voltage at the time of evaluation (t) in millivolts
- VPS_t is the U.S. Bureau of Mines' gauge axis power supply voltage at the time of evaluation (t)
- VM_i is the U.S. Bureau of Mines' gauge axis output voltage at the time of initialization (i) in millivolts
- VPS_i is the U.S. Bureau of Mines' gauge axis power supply voltage at the time of initialization (i).

All lengths are in millimeters, voltages in volts, and temperatures in $^{\circ}C$ unless otherwise noted.

The probable error for the U.S. Bureau of Mines' gauge axis movement measurement is estimated to be in the range of $\pm 8.22\%$.

The equation for converting the change in IRAD gauge period to a change in stress is:

$$DS_t = 8.119 \times 10^8 \times (1/\{P_i \times [1.250 \times 10^{-3} \times (T_t - T_i) + 1]\}^2 - 1/P_t^2) \quad (5)$$

where

- DS_t is the change in rock stress (in megaPascals) measured by the IRAD gauge at time of evaluation (t)
- P_i is the period (in seconds, as received from the IRAD scanner) of the IRAD gauge at the time of initialization (i)
- T_t is the temperature (in $^{\circ}C$) of the IRAD gauge at the time of evaluation (t)
- T_i is the temperature (in $^{\circ}C$) of the IRAD gauge at the time of initialization (i)
- P_t is the period (in seconds, as received from the IRAD scanner) of the IRAD gauge at the time of evaluation (t).

The period and temperature measurements are obtained from the data loggers by the data acquisition system.

The probable error for the IRAD gauge cannot be determined using the data available because only one gauge was used in the testing program and, therefore, no comparisons are possible.

The following algorithm to convert the extensometer electrical signal to an anchor displacement is in two parts. Part 1 is done once per assembly using the longest rod as its basis. Part 2 is done for each rod of the assembly and calculates the individual rod movement.

Part 1. At intervals of 0.02 meter or less (ΔL), calculate L_n using:

$$L_n = (n + 0.5) \times L \quad (n = 0, 1, 2, \dots) \quad (6)$$

Using a thermocouple-to-thermocouple curve fit of the form:

$$T = T_{\text{base}} + K1 \times \text{EXP} [K2 \times (L - L_{c1})^2] \quad (7)$$

Note: L_{c1} is 4.3 meters for vertical extensometer assemblies, 9.72 meters for horizontal Full-Scale Heater Test #1 extensometer assemblies, and 10.14 meters for horizontal Full-Scale Heater Test #2 extensometer assemblies. Calculate T_n by inserting L_n in the proper curve fit.

Note: The curve fit generated by T04 and T05 is used from the location of the extensometer head assembly to the location of T04, while the curve fit generated by T02 and T01 is used from the location of T02 to the location of the end of the longest rod. All other locations will use the curve fit generated by the thermocouples that are immediately adjacent to that location.

Calculate TS_n using:

$$TS_n = \frac{6.5 \times 10^{-12} \times (T_n^{3.5})}{[1 + (T_n/210)^2]^{0.65}} \quad (8)$$

Part 2. Calculate the thermal expansion for a rod using the rod length (L_{rod}) and:

$$TE_{\text{rod-t}} = \Delta L \times \left(\sum_{n=0}^k TS_n \right) \quad (9)$$

where

k is an integer, and:

$$\frac{L_{rod}}{\Delta L} \geq k > \frac{L_{rod}}{\Delta L} - 1 \quad (10)$$

Then the measured rock movement (DM_t) is:

$$DM_t = 25.4 \times K7 \times [(10 \times VM_t/VPS_t) - (10 \times VM_i/VPS_i)] \\ - TE_{rod-t} + TE_{rod-i} \quad (11)$$

where

ΔL	is the segment length
n	is the segment identifier
L_n	is the location of n^{th} segment centerline
T	is the temperature along the rod
T_{base}	is the asymptote temperature for temperature curve fit
K1, K2	is the constants for the temperature curve fit
L	is the length along the rod
L_{c1}	is the location of the perpendicular to the centerline of the heated length of the main heater
T_n	is the calculated temperature at the n^{th} segment centerline
T01, T02, T04, T05	are the thermocouples for the given extensometer assembly with the full identifier of XEXXTOX; for example, 1E03T02 would be T02
TS_n	is the thermal strain for the n^{th} segment
TE_{rod-t}	is the thermal expansion of the rod being evaluated at the time of evaluation (t)
L_{rod}	is the length of the rod being evaluated
DM_t	is the measured rock movement in millimeters at the time of evaluation (t)
K7	is the calibration constant

VM_t	is the direct current linear voltage differential transformer output voltage at the time of evaluation (t)
VPS_t	is the direct current linear voltage differential transformer power supply voltage at the time of evaluation (t)
VM_i	is the direct current linear voltage differential transformer output voltage at initialization
VPS_i	is the direct current linear voltage differential transformer power supply at initialization
TE_{rod-i}	is the thermal expansion of the rod being evaluated calculated at initialization.

All lengths are in meters, voltages in volts, and temperatures in $^{\circ}C$ unless otherwise noted.

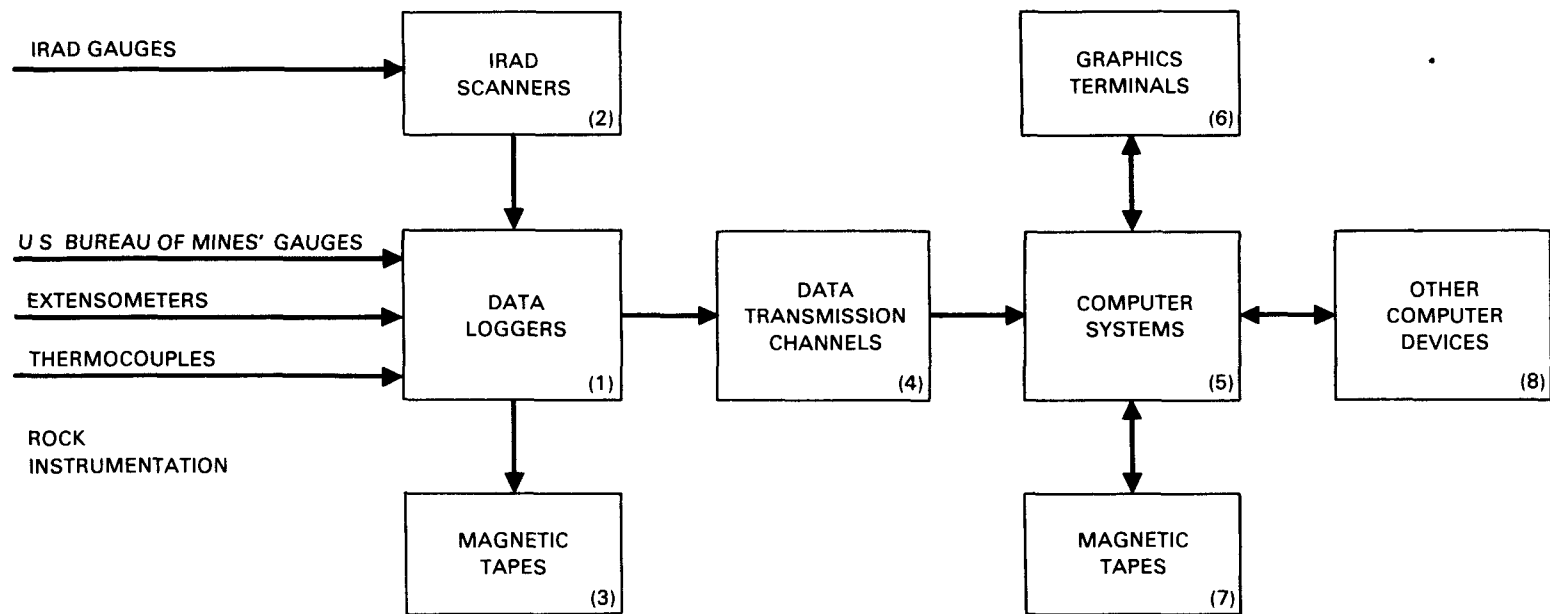
The probable error for the extensometer anchor movement measurement is $\pm 14.33\%$. The probable error is the average error between the converted output and the actual rock response.

Data Acquisition System

The data acquisition system has been completed and is fully operational. The data acquisition system is an automated surveillance and information system which records and processes Near-Surface Test Facility instrument responses and theoretical data. On-line analytical reports in a wide variety are produced for engineering and scientific purposes.

Three months' experience with the system has shown it to be a reliable and stable system. Most failures that have occurred were traced to training or hardware problems. The software itself has been found to be internally consistent and highly reliable.

System Description. The data acquisition system is depicted in Figure 24. Data loggers (block 1) receive analog signals from U.S. Bureau of Mines' gauges, extensometers, and thermocouples and digital signals from IRAD gauges via a scanner (block 2). The sensor responses are read at half-hourly intervals and these data are written to magnetic tapes (block 3) and input through data transmission channels (block 4) to the computer (block 5). The computer processes the data to provide plots on the graphics terminals (block 6), data on magnetic tapes (block 7), and produces other hard-copy and video outputs (block 8). The system is capable of monitoring a maximum of 1,018 sensors. Currently, approximately 900 sensors are active. Four Fluke Model 2240-B data loggers, four Columbia Model 300-C tape drives, four graphics terminals, various other output devices, and two Data General M600 computers complete the system.



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FIGURE 24. Simplified Diagram of the Data Acquisition System.

The system has been designed with redundant data loggers to minimize the probability of data loss. Raw data from each sensor are simultaneously recorded on two independent magnetic tapes. At any time that one of the two available computers is operational, information recovery software can be started by a programmer to insert the data into on-line files. On-line files allow the data to be readily examined. This information recovery software provides the capability to restore the files to a complete state in the event of a total or intermittent failure of the data acquisition system components.

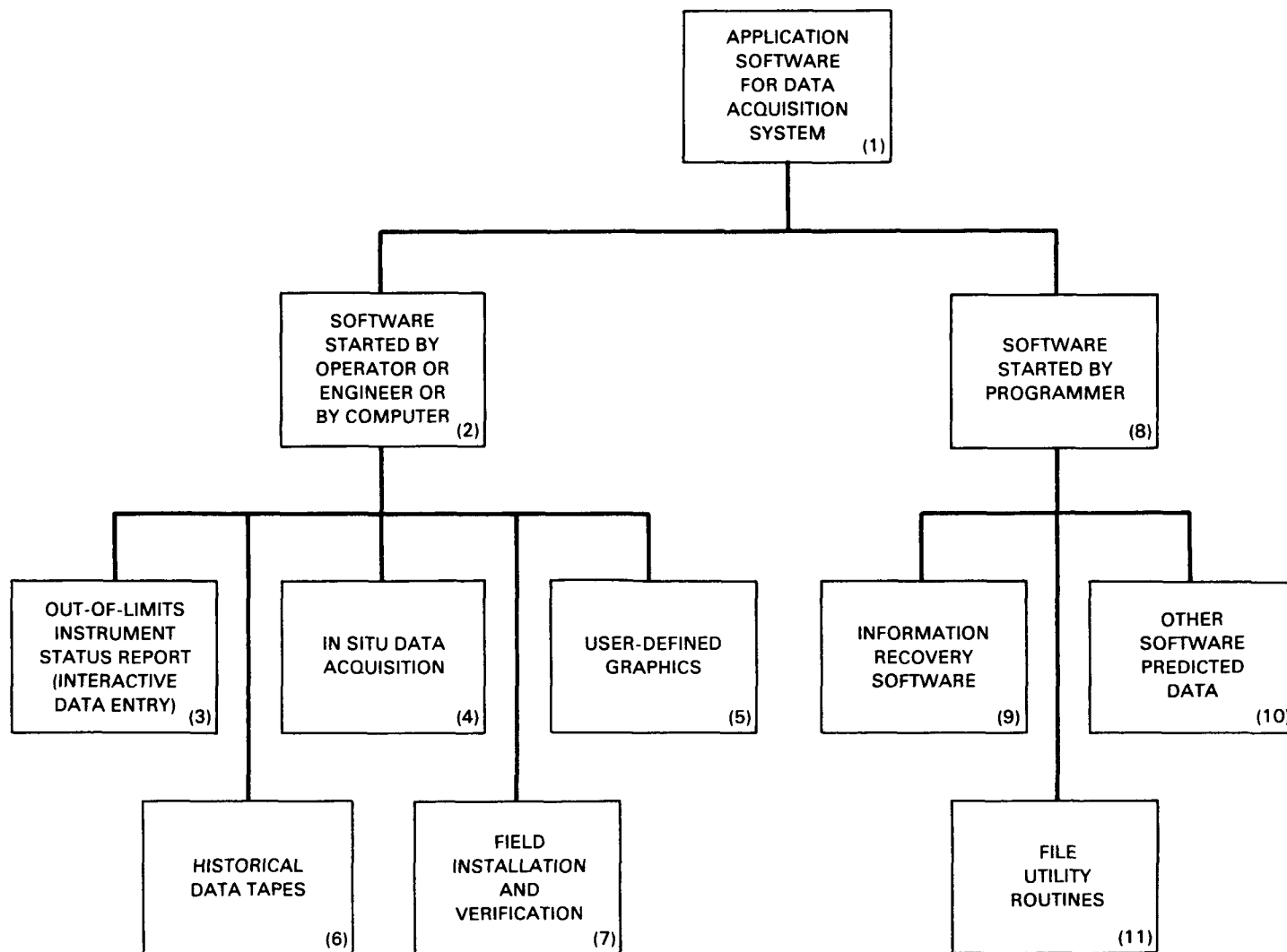
Each data logger is equipped with a magnetic tape cassette recorder to independently record all scan data. The tape cassettes are collected on a daily basis and retained indefinitely.

Data analysis indicates that all instrument data have been recorded and processed in accordance with the test designs and system specifications.

The basic software structure is shown in Figure 25 and is described as follows. (Only major modules activated this quarter are discussed. Full descriptions of the software appear in earlier quarterly reports and are summarized in the annual report.)

- The historical data tapes module (block 6) stores historical data on tape for permanent retention. The module consists of:
 1. Raw/converted data
 2. Smooth data
 3. Test analysis data
 4. Out-of-limits data.
- The information recovery module (block 9) is a "catch up" subsystem that fills in data gaps in the files in the event of computer failure.
- The out-of-limits report (block 3) provides rock instrumentation history.
- The graphics module (block 5) has been enhanced to provide user options rather than predefined plots.
- Reports of a wide variety, including instrument readings and out-of-limits history, are available.
- The predicted data module (block 10) reads, interpolates, and plots predicted data.

The system has been formally accepted as an operational system. This was done by conducting carefully controlled acceptance tests on essential system functions. The data acquisition system users' manuals and operators' manuals have been issued.



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FIGURE 25. Simplified Diagram of Software for the Data Acquisition System.

The existing data acquisition system will continually operate as the surveillance and information system in support of Full-Scale Heater Tests #1 and #2. Because of its success and capabilities, it will also serve as the model and standard for new systems soon to be developed to support other Near-Surface Test Facility research.

Site Characterization

The Phase I geologic site characterization report for the Near-Surface Test Facility will be released at the beginning of the first quarter of fiscal year 1981. The report is a description of the geology and characterization of the rock mass in the area of Full-Scale Heater Tests #1 and #2. The characterization consisted of core logging of the instrument boreholes, detailed joint mapping, impression packer surveys, geologic mapping, and analysis of these data.

The main conclusions are that the basalt in which the heater tests are taking place contains three sets of joints delineated by their degree of dip, each set with apertures averaging 0.25 millimeter and having no preferred orientation. Although the joint frequencies in the study area exceed thirteen per meter, the rock can be rated as "good" in accordance with standard engineering rock mass classifications.

Test Engineering Support

Data verification from Full-Scale Heater Tests #1 and #2 has been concentrated in three main areas:

- Rock instrumentation performance, including conversion of instrument output to engineering units
- Data acquisition system hardware and software performance
- Localized test conditions.

The following rock instrumentation is used to monitor the thermo-mechanical data from the two tests.

Temperature - Thermocouples

Stress - U.S. Bureau of Mines' borehole deformation gauges
- IRAD vibrating wire stressmeters

Displacement - Multiple position borehole extensometer.

Predicted and actual temperature trends for Full-Scale Heater Test #1 thermocouples are generally in agreement. However, actual temperatures at the mid-plane of the main heater and at higher elevations within the rock mass are all lower than predicted values. Thermocouples at a depth

of 2.6 meters below the theoretical collar (i.e., $Z = 0$ plane) show the greatest discrepancy; actual values at this depth are approximately 61°C , 0.5 meter from the centerline of the main heater, and average 18°C lower than expected. This trend differs from thermocouples at lower elevations which generally exhibit temperatures higher than predicted values.

Actual and predicted temperatures for thermocouples 1U10T01 ($Z = -4.8$ meters, $r = 1.47$ meters) and 1U10T02 ($Z = -3.5$ meters, $r = 1.47$ meters) are compared and plotted as a function of time in Figure 26. A preliminary analysis suggests that differences between predicted and measured temperatures may be explained by thermal conductivity differences between intact (unfractured) basalt and in situ basalt because of the presence of discontinuities, dehydration of infilling material at elevated temperatures, and nonuniformity in the initial temperatures at the start of the test.

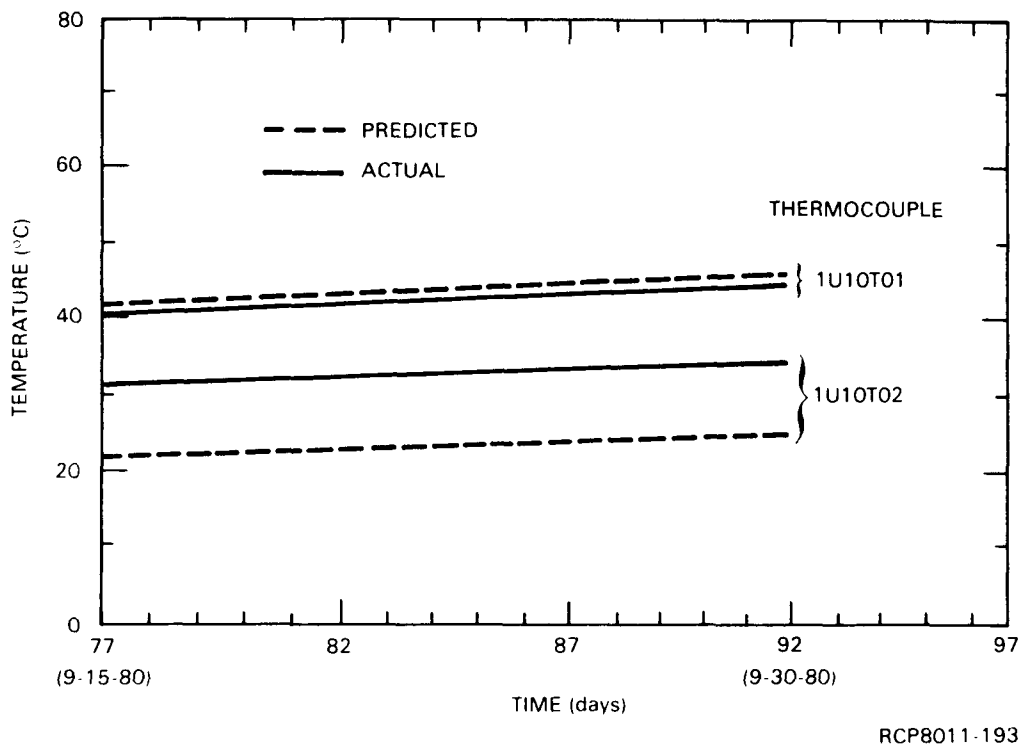


FIGURE 26. Full-Scale Heater Test #1 Temperature for Thermocouples 1U10T01 and 1U10T02.

Predicted and actual temperatures in Full-Scale Heater Test #2 are in substantial agreement. However, actual temperatures near the mid-plane of the heater show the greatest deviation from predicted values and are generally 6°C lower than expected. An isotherm plot of actual temperatures obtained from thermocouples at the heater mid-plane is shown in Figure 27.

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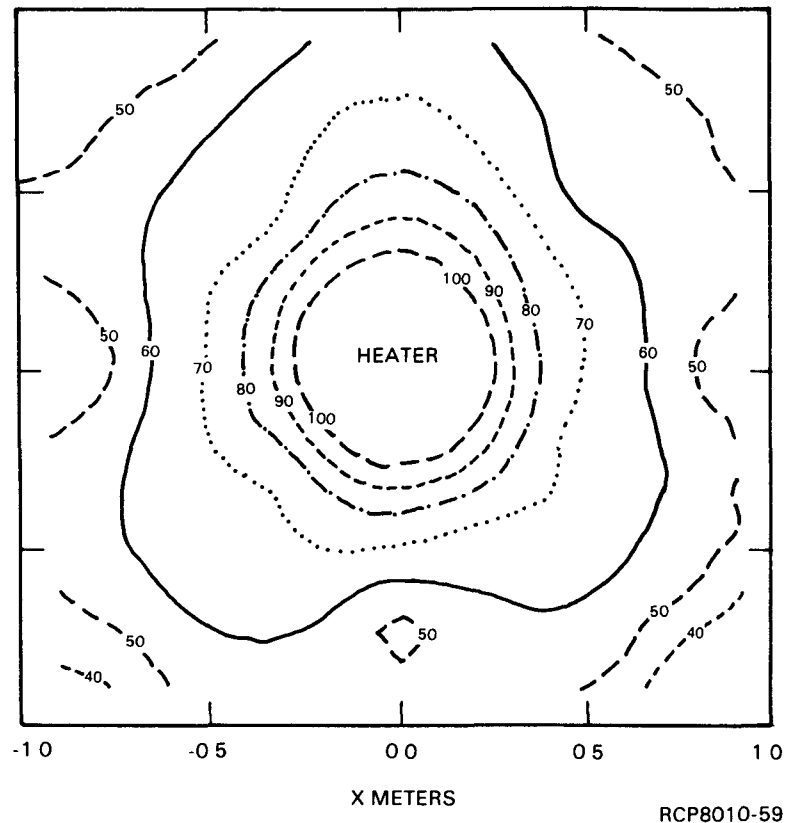
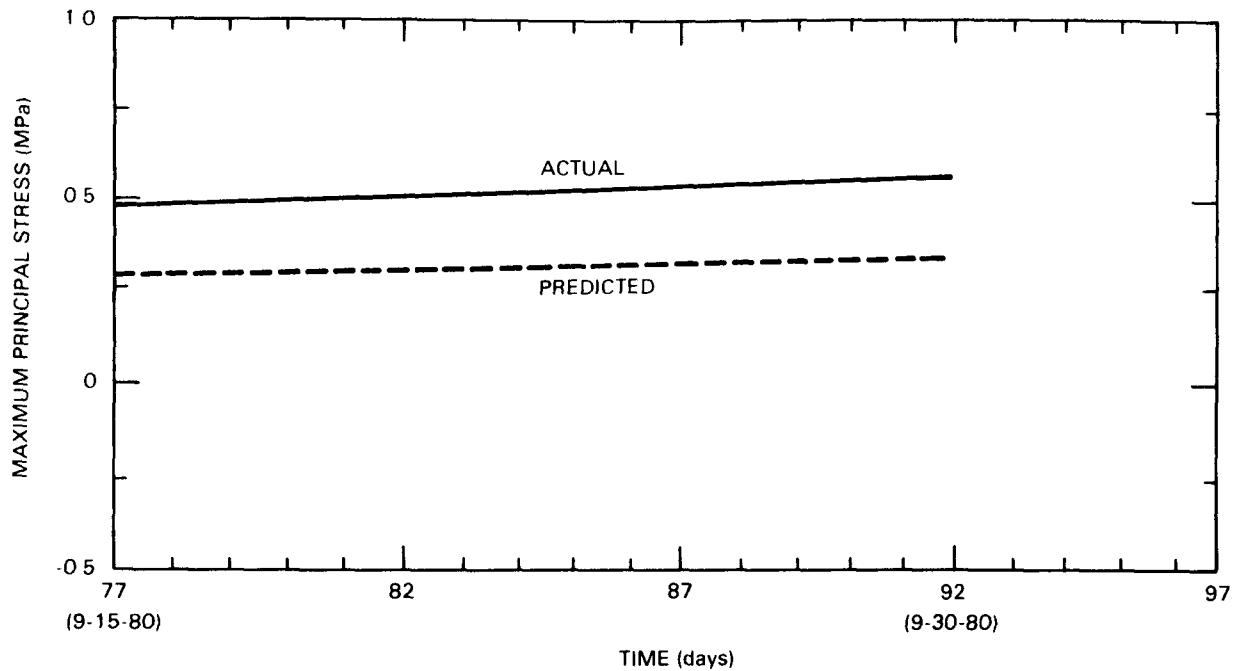


FIGURE 27. Isotherm Plot of Actual Temperature ($^{\circ}\text{C}$), Midplane of Full-Scale Heater Test #2 Main Heater.

Analysis of stress measurements from the U.S. Bureau of Mines' gauges indicates that valid data are being acquired. For U.S. Bureau of Mines' gauge 1U10, located in a Full-Scale Heater Test #1 horizontal borehole, actual and predicted maximum principal stresses are compared and plotted as a function of time in Figure 28. The maximum principal stress is compressive acting in a tangential direction.

Numerical modeling and analysis were axisymmetrical about the main heater. Therefore, the predictions require that the component of tangential-vertical shearing stresses be equal to zero. This result is confirmed by the actual data which indicate that the angle or the direction cosine between the major principal stress and the tangential direction is small in the tangential plane. Both the predicted and actual maximum stresses are increasing with time at approximately the same rate.



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FIGURE 28. Full-Scale Heater Test #1 Stress for U.S. Bureau of Mines' Gauge 1U10.

For extensometer 1E01E01, located in a vertical borehole in Full-Scale Heater Test #1, actual and predicted relative displacements are compared and plotted as a function of time in Figure 29. Preliminary analysis is based on the original algorithm programmed into the data acquisition system; the revised algorithm will be used when software changes are implemented. Relative displacement is movement measured between the extensometer anchor and the borehole collar. The anchor point and borehole collar are located on opposite sides of the main heater mid-plane. A reduction in relative displacement is considered positive and an increase in relative displacement is negative.

A negative displacement which increases with time is predicted. The actual measured displacement is negative and increases very slightly with time. Since the predicted temperature is only 20°C at the anchor point, most of the movement would be reflected by vertical displacement of the tunnel floor which represents a stress-free surface. As shown, no significant displacements have been observed at this early stage of the test.

Operation of the data acquisition system has been excellent to date. Conversion algorithms and algorithm constants are continuously reviewed as the test progresses and the software program updated on a periodic basis. The first major update was initiated at the end of this reporting period.

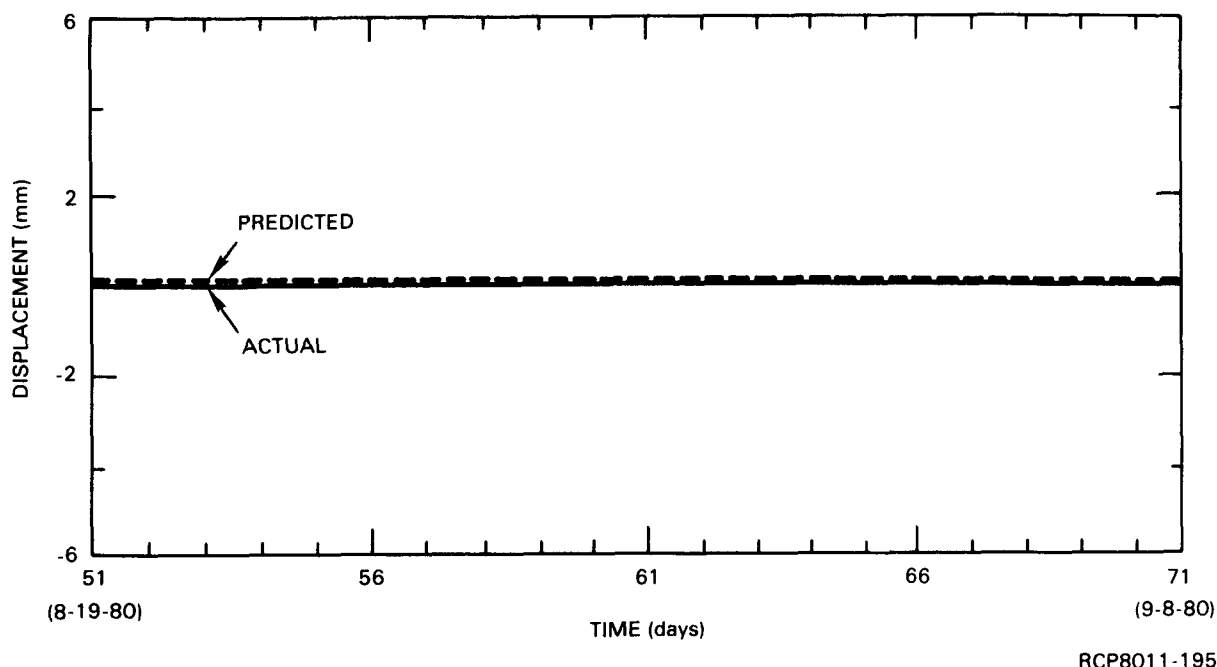


FIGURE 29. Full-Scale Heater Test #2 Displacements Extensometer Anchor 1E01E01.

The following test instruments have been identified as inoperative during this quarter: one thermocouple, one U.S. Bureau of Mines' gauge, and four IRAD gauges. One of the malfunctioning IRAD gauges and the U.S. Bureau of Mines' gauge were replaced.

A complete set of borehole photographs was obtained with the bore-scope during the reporting period prior to the increase in heater-power levels and subsequent rise in temperatures. A preliminary analysis, made on the basis of visual inspection, indicates no change in the appearance of the rock surface.

Water seepage has been detected in the vertical boreholes. Water was removed from seven of the instrument boreholes; amounts varied from 40 to 750 milliliters. The presence of this water has had no apparent effect on instrument performance to date. The eight Full-Scale Heater Test #1 peripheral heaters were also dewatered. The amounts removed varied from 80 to 330 milliliters per hole. Water in the heater holes does affect heater performance and will reduce the heating effect. A daily pump-out of water from neighboring boreholes has been instituted in an attempt to alleviate this problem. The source of the water is under investigation.

Operations

The Phase I heater tests, Full-Scale Heater Tests #1 and #2, were initiated on July 1, 1980. Thirty days later step two of the test program was initiated. Step three was initiated on September 29, 1980.

Full-Scale Heater Test #1 was initiated by turning each of the eight peripheral heaters on and adjusting each power level to 0.25 kilowatt (step 1). Step 2, 30 days later, consisted of turning on power to the main heater and slowly adjusting the power level of each of the four heater elements comprising the main heater to 0.25 kilowatt, for a total main heater power of 1.0 kilowatt. Step 3, at 90 days, consisted of raising the power level of each peripheral heater to 0.50 kilowatt. See Table 16.

TABLE 16. Power Levels for Heater Tests

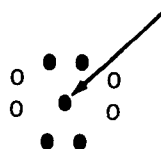
Full-Scale Heater Test #1				Full-Scale Heater Test #2
Time (days)	Step	Central Power (kilowatt)	Peripheral Power (kilowatt)	Central Power (kilowatt)
0 - 30	1	0	0.25	1.00
30 - 90	2	1.00	0.25	1.00
90 - 210	3	1.00	0.50	3.00
210 - 420	4	2.00	1.00	5.00
420 - 510	5	2.00	1.00	5.00
510 - 540	6**	2.00	1.00*	5.00
540 - 720	7	2.00	1.00*	0**
720 - 900	8***	0	0	5.00

*Four peripheral heaters only, other four reduced to zero.

**Step 6 heater removal for borehole inspection.

***Cool down.

CENTRAL HEATER



o - Cold during Steps 5, 6, and 7

● - 0.25 kilowatt during Steps 5, 6, and 7

Plan View of Heaters in Full-Scale Heater Test #1

Full-Scale Heater Test #2 was initiated by turning on the main heater and adjusting the power level to 0.25 kilowatt of each of the four heater elements comprising the main heater (a total main heater power of

1.0 kilowatt). After 90 days, the power level of each heater element was raised to 0.75 kilowatt, for a total main heater power of 3.0 kilowatts (see Table 16).

Twenty-four-hour-shift coverage to support Full-Scale Heater Tests #1 and #2 was initiated on June 30, 1980. Around-the-clock coverage was necessary because the telemetry system for off-shift monitoring of critical functions by substation personnel was not complete. Single shift coverage was initiated on July 28, 1980, when the telemetry system was completed and functionally checked.

Operating procedures for the Near-Surface Test Facility computer were completed this quarter. Basalt Technical Systems Unit personnel have initiated training of Near-Surface Test Facility Operations' technicians. Operations will be assuming full responsibility for computer room activities from Basalt Technical Systems Unit early next quarter.

PHASE II

The Phase II test program consists of placing three nuclear waste canisters in the Near-Surface Test Facility to demonstrate placement and to compare the thermomechanical response data collected to the full-scale heater test data. The Phase II tests are divided into the same activities as listed under Phase I plus an additional subactivity: spent fuel preparation. Most of the effort this quarter was in planning and starting work in the spent fuel area.

Spent Fuel Preparation

Preparation of a vitrified waste form was initiated at Pacific Northwest Laboratory for shipment to the U.S. Department of Energy facilities in Nevada where it will be processed for shipment to the Near-Surface Test Facility in a canister designed for storage purposes. The vitrified waste form and two spent fuel assemblies will be used in the Phase II testing program at the Near-Surface Test Facility.

The purpose of the Phase II test is to evaluate: (1) the packaging and handling techniques for canisters containing spent fuel and vitrified waste and (2) determine the thermomechanical response on basalt for these units at the Near-Surface Test Facility.

These tests will employ two spent fuel assemblies and one vitrified waste form. Each of these units will be inserted into the canister developed for the purpose by Westinghouse-Advanced Energy Systems Division. The loaded canister will then be shipped in approved/licensed casks to the Near-Surface Test Facility where they will be transferred to a bottom loading transporter for emplacement into the floor of the test room. The rock instrumentation, acquisition of data, site characterization, and operations will be similar to the full-scale heater tests.

The present plan is to obtain the spent fuel assemblies from the Turkey Point nuclear reactor operated by Florida Power and Light Company. These assemblies are from a pressurized water reactor built by Westinghouse. One spent fuel assembly will have been 5 years out of reactor at the time of delivery to the Near-Surface Test Facility, with a total burnup of between 26,000 and 33,000 megawatt days per metric ton. This fuel assembly will produce a nominal heat rate of 1 kilowatt at the beginning of Phase II testing. The second fuel assembly will have been 2 years out-of-reactor at the time of delivery to the Near-Surface Test Facility, with burnup similar to the first assembly described above. This second fuel assembly will have a heat generation rate of about 2.4 kilowatts at the beginning of Phase II testing.

The source of the vitrified waste form will be Pacific Northwest Laboratory. The thermal output will be approximately 1 kilowatt, similar to the 5-year-old spent fuel assembly described above.

The final design review for the canister experimental demonstration program was held in Large, Pennsylvania on July 16, 1980, by Westinghouse-Advanced Energy Systems Division. The design review included canister design, welding program, evacuation and backfill, collar, drop test results, seismic test, shipping cask and canister thermal interference study, ultrasonic inspection system, and the grapple program.

REPOSITORY STUDIES

The objective of Repository Studies is to design a repository in Columbia River basalt for the disposal of nuclear waste. A supporting goal is to design and construct an Exploratory Shaft Test Facility on the repository site for detailed site characterization.

The Repository Studies end function is divided into seven major activities:

- Project Management
- Engineering Support
- Repository Design
- Long-Lead Procurement Support
- Construction Manager Selection Support
- Construction
- Site-Specific Tests.

During the fourth quarter of fiscal year 1980, work has progressed in three of these activities: Project Management; Repository Design; and Site-Specific Tests.

PROJECT MANAGEMENT

The project management activity is responsible for the management of the Repository Studies end function; specifically in the preparation and control of schedules, preparation of budgets and work packages, control of program costs, and overall guidance of the technical activities.

Monthly repository conceptual design review meetings were conducted with the U.S. Department of Energy, Office of Nuclear Waste Isolation, Rockwell Hanford Operations, and Kaiser Engineers/Parsons Brinckerhoff. A quarterly review meeting was held during July 1980.

REPOSITORY DESIGN

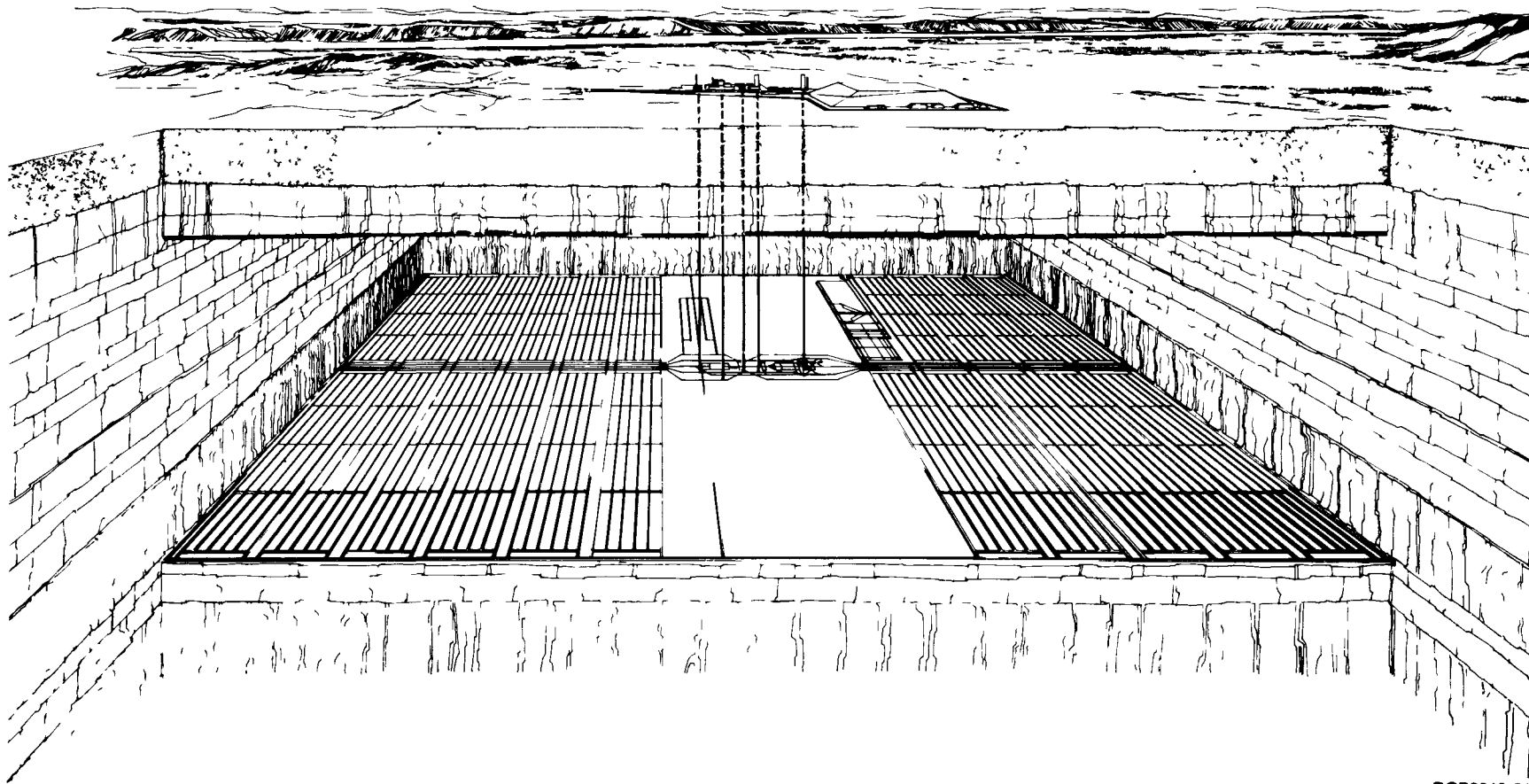
Repository conceptual design work by Kaiser Engineers/Parsons Brinckerhoff continued during the quarter with emphasis on developing the concepts selected during the previous quarter.

Design highlights during the quarter are:

- The surface facility layout was changed to improve security, add a water filtration plant, and move the concrete batch plant from underground to the surface.
- A concept for a machine to perform room and tunnel backfilling was developed.
- A decision was made to construct shaft linings to Quality Assurance Level II. Any shaft collars required for the shaft-sealing system during repository decommissioning will be installed during initial shaft construction to Quality Assurance Level I.
- Analysis of hydrogen gas generation, from radiolytic decomposition of water present in the tailored backfill surrounding the spent fuel package, indicated a potential mechanism for degradation of the titanium overpack. Further study of this potential problem will be conducted during the conceptual design upgrade.
- Review of the repository conceptual design indicated that the present design of the shaft pillar penetrates the shaft below the entablature to accommodate hoist cables and water sumps. Elimination of this potentially undesirable feature will be addressed during the conceptual design upgrade.
- Definition of general criteria for design of the Exploratory Shaft Test Facility continued. The following guidelines were established:
 - The designs for both the Exploratory Shaft Test Facility and the Nuclear Waste Repository in Basalt must be compatible and mutually supportive.
 - The Exploratory Shaft Test Facility shaft will be designed to become a part of the repository, either as an operating repository shaft or as an access to the repository experimental area.

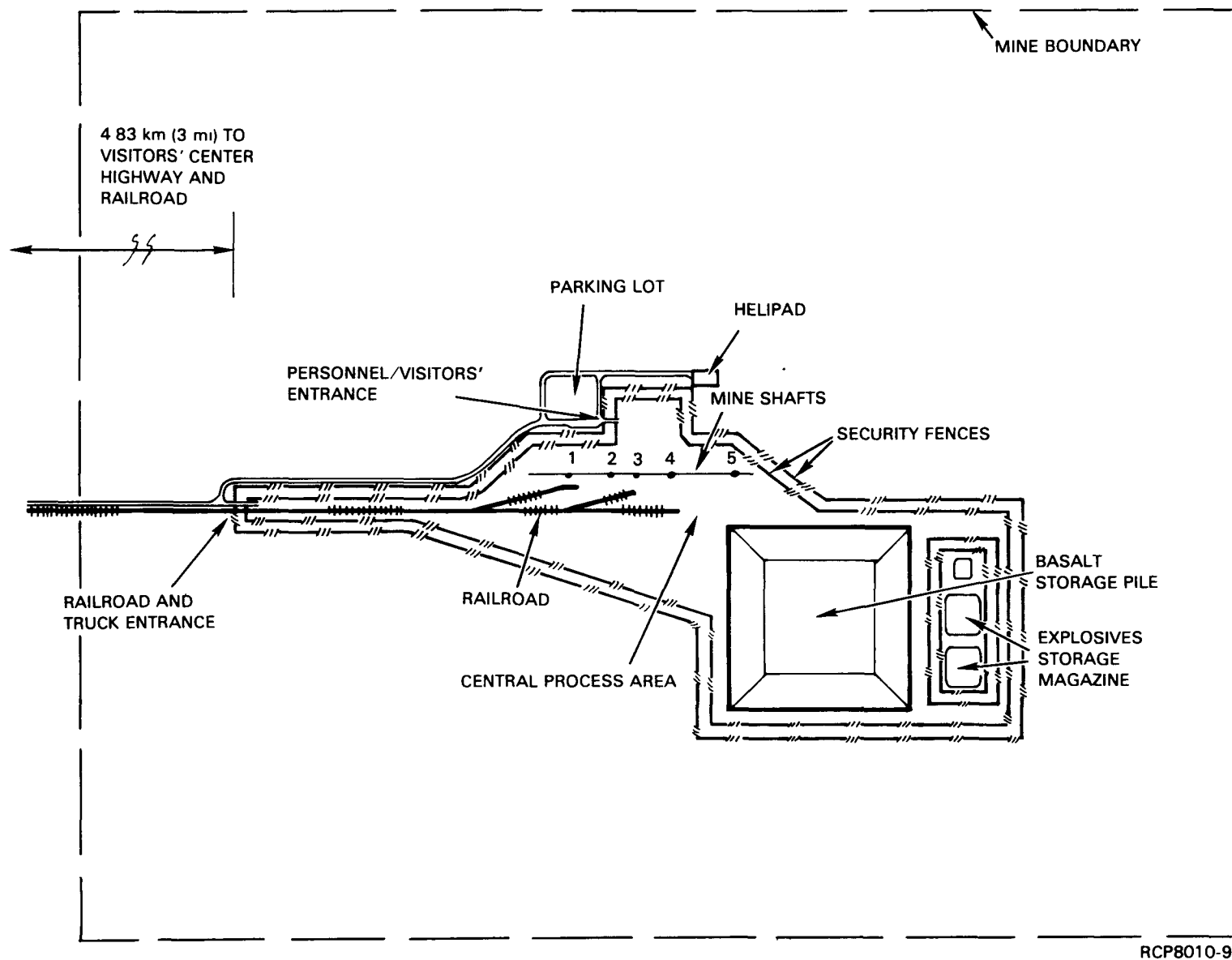
Major elements of the conceptual design of a Nuclear Waste Repository in Basalt are illustrated in Figures 30 through 34.

A significant accomplishment during the reporting period was the completion by Kaiser Engineers/Parsons Brinckerhoff of a draft revision of a report on the functional design criteria for the Nuclear Waste Repository in Basalt (Project B-301). Review of the draft document by the U.S. Department of Energy, the Office of Nuclear Waste Isolation, and Rockwell Hanford Operations is in progress. The revised document will be issued during the next reporting period.



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FIGURE 30. Mine Cutaway and Surface (Perspective).



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FIGURE 31. Surface Facilities Plan.

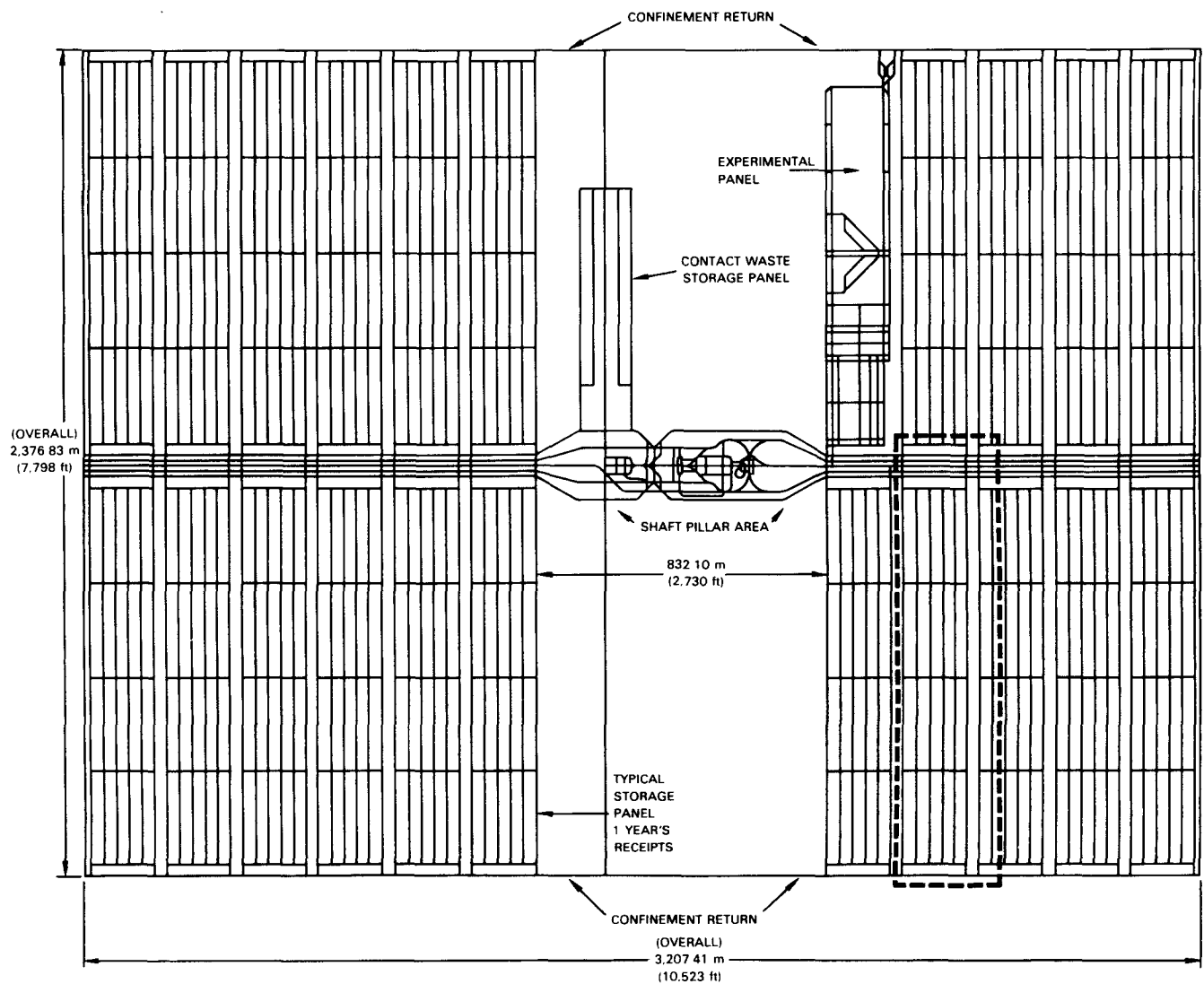


FIGURE 32. Underground Facilities Layout.

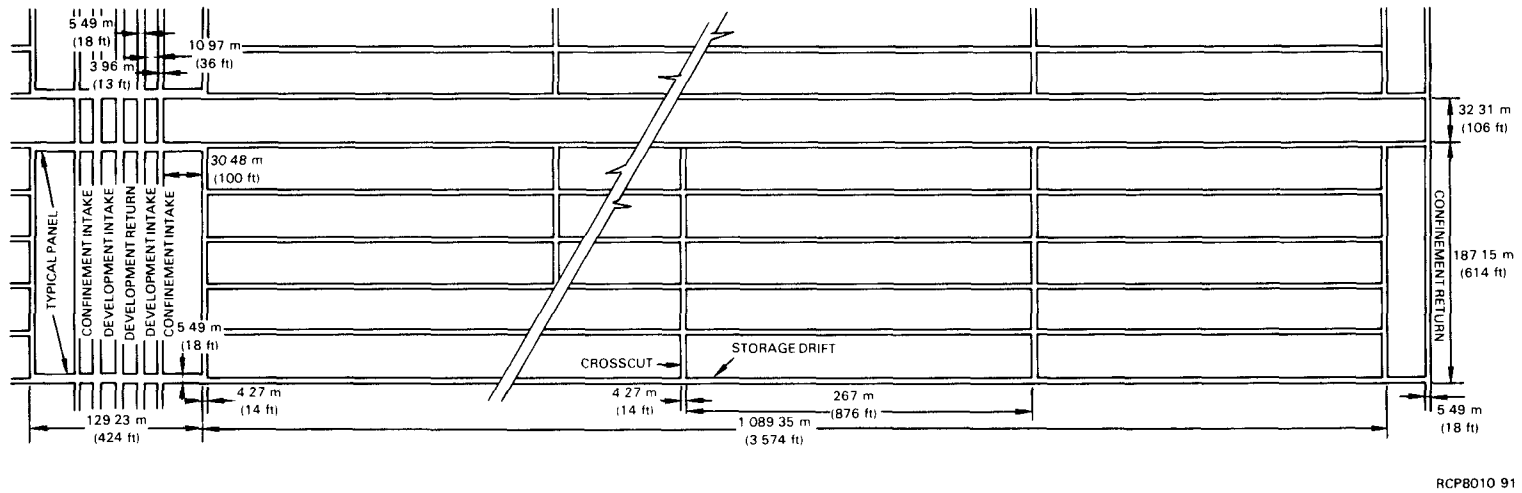


FIGURE 33. Typical Storage Panel.

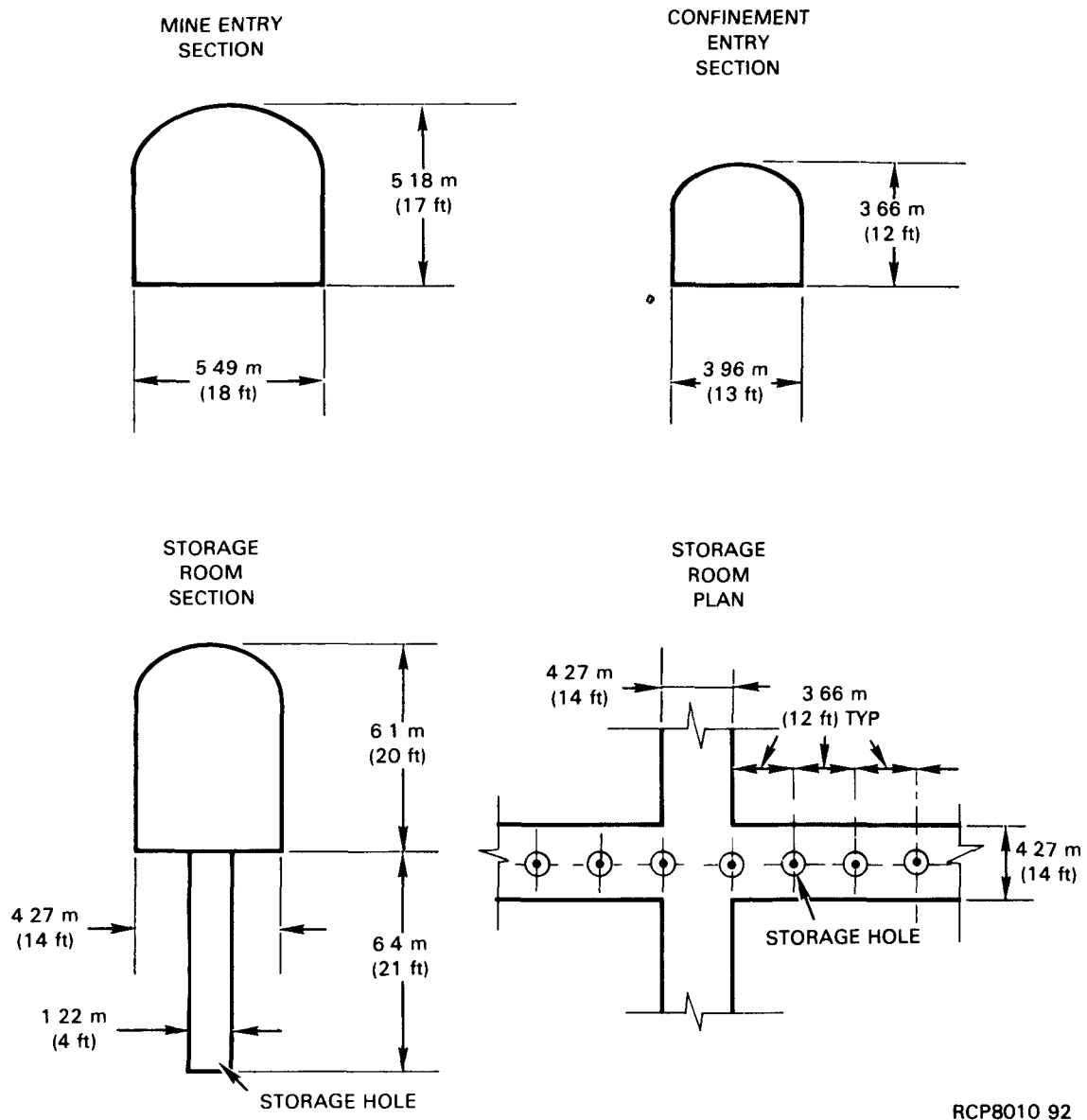


FIGURE 34. Room Cross Sections and Plan.

Kaiser Engineers/Parsons Brinckerhoff initiated a study during September 1980 in support of the on-going Nuclear Waste Repository in Basalt conceptual design. The current design concept is based on the receipt and storage of commercial spent fuel and low-level transuranic waste. The new study will evaluate the impact on repository conceptual design of the following waste receipt scenarios:

- Receive and store Hanford defense high-level waste in addition to commercial spent fuel and low-level transuranic waste.
- Receive and store Hanford defense high-level waste, commercial high-level waste in a quantity equivalent to the commercial spent fuel received in the current design basis, and low-level transuranic waste.

Highlights of this study will be reported during the next reporting period.

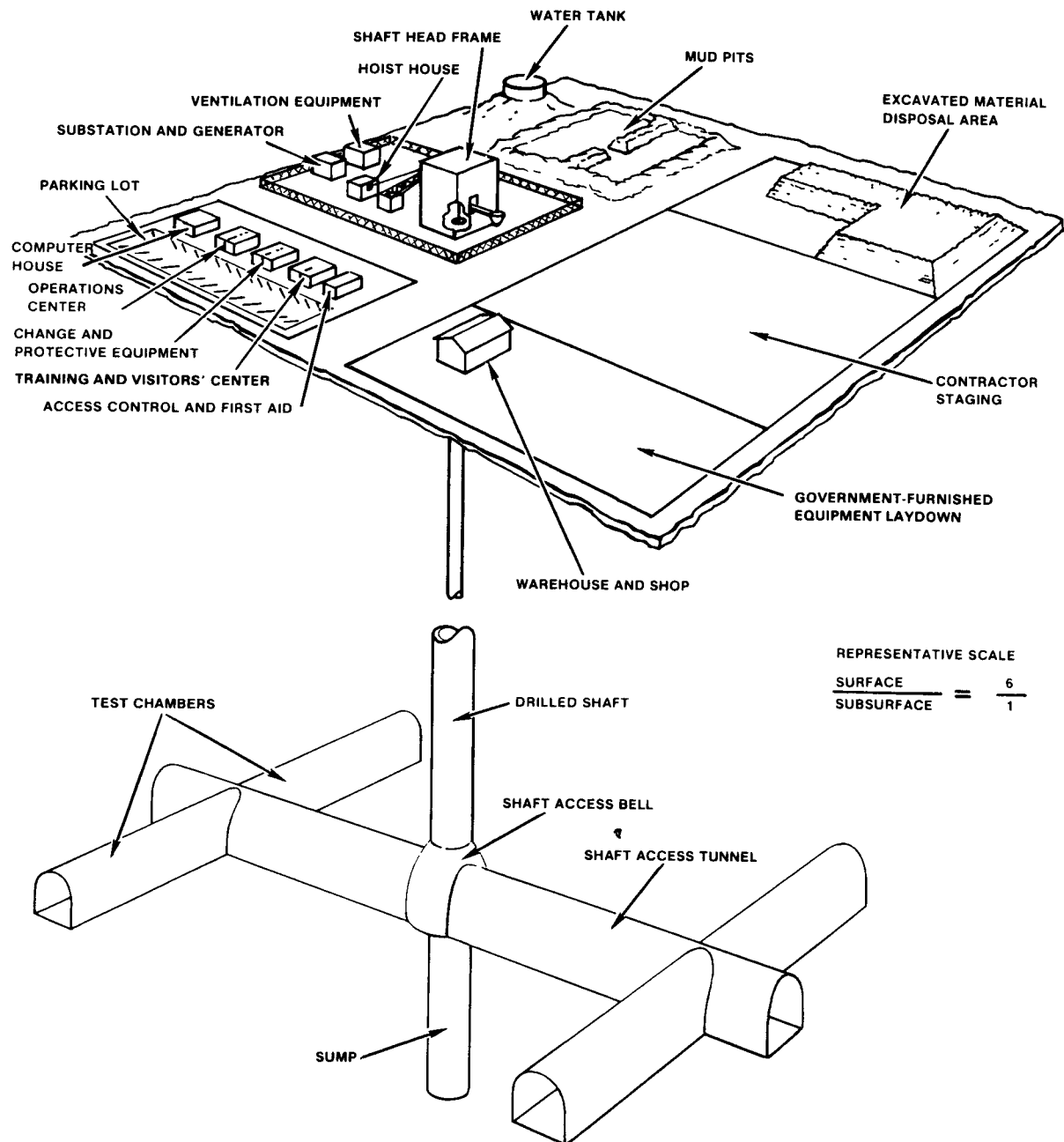
SITE-SPECIFIC TESTS

During this quarter, work on the Exploratory Shaft Test Facility was limited to acquisition of comments on the test plan and completion of the preconceptual design report. The test plan was transmitted May 22, 1980 for review by participants in the National Waste Terminal Storage Program. When the review is complete, a revised test plan will be prepared. The preconceptual design report was released September 30, 1980 as a system design description with supporting studies covering areas of major technical interest. A summary description of the proposed test facility is provided below.

The function of the Exploratory Shaft Test Facility is to provide an access shaft and underground test chambers to perform in situ testing at depth in Columbia River basalts at a reference site for a nuclear waste repository. The objective of a primary test program and reason for construction of the Exploratory Shaft Test Facility at this time is the characterization of the reference repository site. When constructed, the Exploratory Shaft Test Facility will also contain space for certain identified ancillary rock mechanics tests. It is expected that after the currently identified test objectives are achieved, follow-on, in situ testing will be conducted in an expanded facility. The shaft and underground chambers will be constructed so that they are licensable and could be incorporated into a future repository.

A conceptual arrangement and data sheet for the proposed Exploratory Shaft Test Facility are shown in Figure 35 and Table 17.

The surface facilities provide the land improvements, buildings, other structures, and utilities to support construction and test operations. Because of the limited duration of the test program, trailers and temporary construction will be used whenever possible.



RCP8009 108

FIGURE 35. Exploratory Shaft Test Facility in Basalt.

TABLE 17. Exploratory Shaft Test Facility
Preconceptual Design Data Sheet.

Functions	
Initial tests	Primary: Site characterization
Additional tests	Ancillary: Rock mechanics
U.S. Nuclear Regulatory Commission licensing	Requires facility expansion
Ultimate disposition	Licensable
	Incorporate into repository
Surface Facilities	
Site location	Hanford, Washington
Land improvements	8 hectares
Temporary buildings	1,100 square meters
Utility interfaces	1 to 10 kilometers
Drilled Shaft	
Depth	1,140 meters
Finished inside diameter	1.83 meters
Ground support	Grouted steel liner
Excavation	8,000 cubic meters
Steel liner	2,000 metric tons
Construction method	Big hole drilling
Underground Chambers	
Tunnel length	140 meters
Cross section	4.6 x 4.6 meters
Ground support	Rock bolt and mesh
Excavation	2,750 cubic meters
Construction method	Drill and blast
Design basis occupancy	20 persons
Major Systems	
Hoist rating	81 metric tons
Underground ventilation	7 cubic meters per second
Water consumption	91,000 liters per day
Dewatering time	10 minutes
Normal power	5 megavolt-ampere
Facility supervisory data acquisition system	1,000 channels

The shaft will be sunk to the repository candidate storage horizon. Big hole drilling is the preferred method of sinking a deep shaft in the Columbia River basalts based on: (1) available technology, (2) construction safety, (3) isolation enhancement, (4) least cost, and (5) minimum schedule. After drilling, a steel liner will then be floated into position. The area between the liner and the excavation rock will be completely grouted from the drilled depth to the surface. Pipe embedded in the grout will provide passageways for major services. Prior to shaft breakout, the test holes will be drilled through the ports in the liner to assess the grout seal and characterize the near field of the penetrated basalt strata.

At the base of the shaft, underground chambers will be constructed to the minimum requirements necessary to support the in situ testing program. The underground chambers will consist of a shaft access station or "bell," access tunnels penetrating the shaft pillar area, and test chambers or rooms. The "H" layout selected for preconceptual design provides the shortest escape paths to the shaft station bell. The test chambers will allow observation of exposed rock surfaces, drilling of horizontal test holes for near- and far-field characterization of the candidate horizon, and space for ancillary rock mechanics tests.

Underground services and special systems will be provided for operation and maintenance of the underground chambers and will interface with the test systems. The major facility systems include shaft hoist, underground ventilation, water supply, dewatering, electric power, and communications. Normal and redundant services will be provided for essential systems.

The Exploratory Shaft Test Facility preconceptual design was part of a limited effort to develop a feasible reference facility concept using existing technology, to provide the technical basis for functional design criteria (to be prepared later), to assemble schedule and cost data for project planning, and to recommend alternatives that should be considered in subsequent design. Except for completing the test plan and preconceptual design, no other work on the Exploratory Shaft Test Facility is planned at this time.

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RHO-BWI-LD-19 (unclassified), September 1979, R. E. Johnson and R. A. Deju, "Technical Requirements for Qualification of a Potential Nuclear Waste Repository in Basalt"

RHO-BWI-LD-25 (unclassified), April 1980, D. J. Carrell and K. A. Jones, "Environmental Issue Identification for the Basalt Waste Isolation Project"

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