Basalt Waste Isolation Project Annual Report - Fiscal Year 1979

MASTER

**Staff
Basalt Waste Isolation Project**

November 1979

Prepared for the United States
Department of Energy
Under Contract DE-AC06-77RL01030

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Rockwell International

**Rockwell Hanford Operations
Energy Systems Group
Richland, WA 99352**

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PRELIMINARY REPORT

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Informal Report

BASALT WASTE ISOLATION PROJECT
ANNUAL REPORT - FISCAL YEAR 1979

Staff

Basalt Waste Isolation Project

November 1979

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P R E F A C E

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 basalt feasibility study. Geologic exploration of Columbia Plateau basalts was needed to determine the feasibility of commercial nuclear waste disposal.

In September 1977, the National Waste Terminal Storage Program was restructured. While emphasis was still on a salt repository, additional funds were given to support investigation of two U.S. Department of Energy sites--Hanford and Nevada. The Hanford project 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. The Basalt Waste Isolation Project is integrated with other programs of the Office of Nuclear Waste Isolation (Battelle Memorial Institute) as part of the overall National Waste Terminal Storage Program.

The Basalt Waste Isolation Project of Rockwell Hanford Operations is aimed at examining the feasibility and providing the technology to design and construct a geologic repository for storage of radioactive waste in basalt formations beneath and within the Hanford Site. This facility will be designed to meet the federal responsibility for custody and permanent isolation of commercial radioactive wastes in the United States. Programmatic emphasis at present is in assessing site suitability by fiscal year 1981. The Basalt Waste Isolation Project is part of the National Waste Terminal Storage Program.

The Basalt Waste Isolation Project is divided into seven areas:

- *Systems Integration encompasses the definition of technical criteria, planning, and systems analysis, as well as repository siting and mine model development;*
- *Geosciences encompasses all geologic studies needed for basalt qualification, repository siting, and conceptual design;*

- *Hydrologic Studies includes all tests required to define any existing ground-water flow systems and obtain the hydrologic information needed for basalt qualification, repository siting, and conceptual design;*
- *Engineered Barriers includes the thermal assessment of the repository environment and the effect of waste form and other engineered barriers on repository feasibility and effectiveness;*
- *Near-Surface Test Facility construction involves the construction of a Near-Surface Test Facility for in situ testing of the thermo-mechanical behavior of basalt;*
- *Engineering Testing involves the conduct of tests to obtain laboratory and in situ engineering properties necessary for conceptual design and basalt qualification; and,*
- *Repository Engineering involves the preconceptual and conceptual design of a repository in basalt. If a decision is made to proceed with a repository in basalt, detailed design and construction will begin at appropriate times.*

This annual report summarizes key investigations in these seven areas. The last section of the report lists documents issued during fiscal years 1978 and 1979. As new investigations proceed, results will be documented and issued shortly thereafter.

The organization of the Basalt Waste Isolation Project is shown on the following page. The project is conducted through the effort of the Rockwell Hanford Operations' staff presently consisting of 241 professionals and 95 subcontractors representing a cross section of professionals throughout the scientific community.

The Basalt Waste Isolation Project is conducted under an open-information policy designed to establish and maintain credibility with the news media and the public.

The information program objectives can be divided into three key areas:

- *To keep the public, interested individuals and groups, program participants, and other associated organizations and individuals informed about the activities of the Basalt Waste Isolation Project;*
- *To provide timely information to news media, appropriate public officials, and concerned segments of the public to assure understanding and permit accurate news coverage of the waste isolation activities; and,*
- *To provide information assistance to news media representatives upon request, and to make reasonable and timely arrangements for visits to work sites and facilities by interested groups and individuals.*

Organization of the Basalt Waste Isolation Project.

The mission of the Basalt Waste Isolation Project information program is to disseminate updated scientific and technical information on all aspects of the Basalt Waste Isolation Project to the public at large in understandable terms through:

- *Press releases, press briefings, and press seminars;*
- *Brochures, booklets, pamphlets, fact sheets, briefing books, press kits, and information packets;*
- *Testimony, briefings, and seminars;*
- *Public information meetings, technical society meetings, and the annual Basalt Waste Isolation Project meeting; and,*
- *Audio-visual media (slide, videotape, film presentations).*

To assure coordination and overall public information continuity, the Office of Nuclear Waste Isolation receives on a regular basis input, data, and prepared materials for inclusion in the "Nuclear Waste Isolation" newsletter. The newsletter covers all elements of the National Waste Terminal Storage Program. Also supplied on a regular basis is updated photograph and slide material for inclusion in the National Waste Terminal Storage Program Album.

In response to an objective of the National Waste Terminal Storage Program requiring significant public involvement in the Basalt Waste Isolation Project, the U.S. Department of Energy and Rockwell Hanford Operations held three public meetings on the project in Richland and Seattle, Washington and Portland, Oregon in fiscal year 1979.

During fiscal year 1979, a visual documentation program was initiated. On a regular basis, the various activities undertaken by the project have been visually recorded to provide a permanent videotape and photographic record of the work progress. This visual record is of particular importance in construction activities such as the Near-Surface Test Facility to depict problem areas encountered and resolved. This visual documentation has also been incorporated into a 22-minute videotape feature with narration outlining the project. The videotape has been utilized by members of the staff to inform various groups and media representatives about the project.

In response to queries from the public, media, scientific, and other groups and agencies about the project, an information packet has been generated. The packet includes:

- *A four-color bi-fold Basalt Waste Isolation Project brochure;*
- *Current press releases on the Basalt Waste Isolation Project;*
- *A Basalt Waste Isolation Project fact sheet;*

- *A Near-Surface Test Facility fact sheet; and,*
- *Project photographs.*

During fiscal year 1980, a Visitor Briefing Center will be established at the Near-Surface Test Facility to accommodate media, governmental, and other group visits to the site. The center will be equipped with a demonstration and display area, a conference room equipped with full audio-visual capabilities, and a mine-safety equipment change area.

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CHAPTER I - SYSTEMS INTEGRATION

CHAPTER I - SYSTEMS INTEGRATION

SUMMARY

The systems integration program involves the definition of studies required as part of the assessment of the feasibility of basalt as a repository medium for nuclear waste storage. These studies include the planning of demonstration facilities, as well as the specification of scientific studies to be undertaken for and during the licensing process. In addition, the systems integration program is responsible for utilizing the results of ongoing research and development insofar as needed to identify potential repository sites in basalt and assess the feasibility of nuclear waste storage in basalt. Thus, the systems integration program is responsible for integrating all research and development studies and preparing the information needed for licensing a nuclear waste repository in basalt.

During fiscal year 1979:

- Technical requirements for evaluation of a basalt site as a nuclear waste repository were identified;
- A site identification program was carried forth;
- A demonstration program for the in situ definition of heat and heat plus radiation effects on the basalt was designed;
- Extensive engineering modeling of hypothetical repository systems was conducted;
- A long-term risk assessment program was initiated; and,
- An Office of Licensing was established to document and coordinate all information needed for use in the licensing process for a nuclear waste repository in basalt.

Technical requirements for identifying a site in basalt as a potential nuclear waste repository have been in a developing phase for the last few years. In an attempt to formalize these requirements, the systems integration program developed a preliminary listing of site identification and radiological requirements to be used to direct the site identification program. These preliminary technical requirements are discussed in this chapter and are compatible with National Waste Terminal Storage Program guidelines as developed to date. When the U.S. Nuclear Regulatory Commission develops Title 10, Code of Federal Regulations, Chapter 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," technical requirements will be re-addressed to assure they are compatible with these guidelines.

An integral part of the Basalt Waste Isolation Project is the selection of a site which could successfully support the development of a radioactive waste repository. The first phase of selecting a site was completed this fiscal year; it consisted of identifying a small number of potential sites for further evaluation.

The site identification process consisted of three activities:

- Definition of objectives and establishment of guidelines which form the basis for candidate site identification;
- Development of a screening process to identify candidate sites starting with the relatively large study area and progressively concentrating on smaller and smaller areas with a higher potential for containing suitable sites; and,
- Development of a ranking process to preferentially order candidate sites based on a decision analysis approach.

In order to assess the feasibility of utilizing basalt as a possible rock type for nuclear waste storage, the staff of the Basalt Waste Isolation Project has proposed that a series of in situ tests be conducted in a Near-Surface Test Facility in the Columbia Plateau basalts. These in situ tests are designed to provide information to assist in the design, construction, and licensing of a nuclear waste repository in basalt. The in situ testing to be conducted at the Near-Surface Test Facility is but one aspect of the larger Basalt Waste Isolation Project and is supported by laboratory testing of rock, waste-rock interaction, and alteration products, as well as field studies in borehole plugging, hydrologic, and site-specific tests at depth in the proposed repository horizon.

The in situ tests are grouped in two categories; identification and demonstration tests. The identification tests utilize electric heaters to simulate nuclear waste material and are designed to meet the technical objectives of the program. The demonstration tests, some of which utilize nuclear waste material as the thermal sources, are designed to demonstrate that the electric heaters indeed are representative of the nuclear waste.

Over the past year, the University of Minnesota, with Dames & Moore's Advanced Technology Group as subcontractor, has been supporting Rockwell Hanford Operations in three areas relating to numerical modeling of rock stresses within a nuclear waste repository in basalt. These areas are:

- Conceptual repository design;
- Analysis of the proposed Near-Surface Test Facility; and,
- Development of computer models for repository design.

During fiscal year 1979, a long-term risk assessment program was initiated. This program consists of the development of a multiple barriers model, the development of release scenarios, and the preliminary assessment of transport model capabilities. The emphasis on this program is in the use of the flexible models prepared to receive data that become available as site selection, repository design, and other project study areas progress.

An Office of Licensing was established during fiscal year 1979 to document all available and pertinent information about the Columbia River Basalt in a format suitable for use in the licensing process. As a part of this effort, detailed safety and environmental report formats were developed. Detailed schedules for preparation of the Preapplication Site Review Report were developed. Writing has started and drafts will be completed next fiscal year.

TECHNICAL REQUIREMENTS FOR QUALIFYING A BASALT
SITE FOR A NUCLEAR WASTE
REPOSITORY

R. E. Isaacson, R. E. Johnson, R. A. Deju
Rockwell Hanford Operations
Richland, Washington 99352

Technical requirements for identifying a site in basalt for a potential nuclear waste repository have been in an evolving development phase since the question was first asked whether or not basalt might be suitable for the final storage and disposal of nuclear waste arising from the nuclear defense program. Some of the initial questions that arose were: What is the isolation potential of the basalts? Does water move through the rocks? At what rate? Will radionuclides be transported into the biosphere? Can the wastes be converted into a form that will be essentially insoluble? What waste forms will provide assurance that chemical reactions between the waste, the host rock, and water in the rock will not increase the solubility and transport rates of radionuclides? What effect will heat arising from the radioactive decay of the waste have on the rocks and hydrology? Such questions were interwoven into, and were an integral part of, the preliminary program to evaluate the feasibility of storing nuclear waste in basalt.

Today, these questions are being studied and, on a preliminary basis, shaped into requirements which will be formalized into regulations and documents specifically directed toward the identification of sites for nuclear waste repositories. Siting criteria are being developed concurrently with the regulatory development of the U.S. Nuclear Regulatory Commission rules and regulations and U.S. Environmental Protection Agency criteria and guidelines. Both the National Waste Terminal Storage Program and basalt criteria will be compatible with these federal regulations.

The U.S. Nuclear Regulatory Commission is currently developing Title 10, Code of Federal Regulations, Chapter 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories."

BASIC REQUIREMENTS

Preliminary site identification requirements are based on radiological standards and technical and socioeconomic site suitability factors.

A fundamental goal for disposal of radioactive waste is isolation; that is, maintaining the waste sufficiently separate from the biosphere so that radiological exposure never exceeds codified standards. During operation of a repository, containment will be provided by engineered barriers and natural barriers enhanced by institutional controls. Post-closure isolation of long-lived radioactive wastes will be provided by passive, engineered and existing, natural barriers. Institutional control, the extent and duration of which are not determined, will be

implemented to monitor repository performance with regard to isolation and provide necessary administrative controls.

Radiation protection requirements for radioactive waste should be based on an assessment of the benefits versus consequences and risks to individuals and populations. The risk assessments should examine the following factors:

- The potential for radionuclide transport from buried waste;
- The efficacy of the alternate methods considered for protection relative to the efficacy of the recommended method(s);
- The potential for adverse health effects on individuals and populations using computer models of the storage system;
- The period for which a commitment of land and of water and mineral resources is deemed necessary to mitigate any postulated consequences;
- The persistence of the potential for environmental and health effects when such residues may influence the choice of a protection option;
- The probabilities of release of radioactive material to the environment due to feature(s) of natural or engineered barriers, loss of institutional controls, etc.; and,
- The uncertainties in these assessments and their sensitivity to the parameters and the models used.

The impact of postulated consequences must be equal to or less than codified guidelines. The design for radiation protection should be such that no further modifications for risk reduction are technically, economically, and socially necessary. Risks associated with the selected method of control, to any generation, should be no greater than those limits already known to the current generation.

Radiological standards are established by the U.S. Environmental Protection Agency to limit the hazards to man and to the environment that could result from a proposed activity such that may be promulgated by a nuclear waste repository. Thus, the siting process requires an early identification of radiological standards against which a tentative repository site in basalt can be modeled. Since such standards have not been issued, preliminary radiological requirements are based on existing information from the U.S. Department of Energy, the U.S. Environmental Protection Agency, and the U.S. Nuclear Regulatory Commission.

PRELIMINARY SITE IDENTIFICATION REQUIREMENTS

In the studies, requirements have been identified that will isolate harmful quantities of nuclear wastes from the biosphere and contribute to an assurance of acceptable public health and safety at all times.

These requirements can be restated in a number of ways, expanded in detail, and used as program guidelines subject to formally issued U.S. Nuclear Regulatory Commission criteria.

The principal requirements have been grouped according to discipline and include radiological, engineering, hydrologic, geochemical, geologic, and socioeconomic considerations.

RADIOLOGICAL REQUIREMENTS

National Environmental Policy Act Compliance

All activities in the waste management area shall be conducted in compliance with the National Environmental Policy Act and other relevant environmental protection statutes and regulations.

As Low As Reasonably Achievable Occupational Exposure

The occupational exposure from the repository above-ground facilities shall be as low as reasonably achievable occupational exposure. The occupational exposure from the repository below-ground facilities shall be as low as reasonably achievable occupational exposure. The occupational exposure from the decommissioning activities shall be as low as reasonably achievable occupational exposure.

As Low As Reasonably Achievable Environmental Exposure

The exposure to the environment/biota from the repository shall be as low as reasonably achievable occupational exposure and consider both operational and post-closure conditions. Concentration levels to the biota of specific nuclides shall be less than those specified in Title 10, Code of Federal Regulations, Chapter 20, Appendix B; the exposures to any individual shall not be greater than 0.5 rem per year. The annual dose equivalent shall not exceed a 25-millirem average to all individuals of a contiguous population group (whole body dose) and be compatible with requirements of the U.S. Environmental Protection Agency as implemented by the U.S. Nuclear Regulatory Commission.

Monitoring of Environs for the Potential Contamination by Radioactive Materials

Active monitoring shall be maintained at the repository during the operational period and the continuation of monitoring shall be investigated for the post-closure period.

Determination of Exclusion Area Boundaries

Boundaries shall be established around the repository and its related facilities to control occupancy and thus ensure that contaminant concentrations at the exclusion area boundary due to an accident do not result in consequences greater than the guidelines established by Title 10, Code of Federal Regulations, Chapter 100 and recommended in American National Standards Institute Standard N287.

ENGINEERING REQUIREMENTS

Retrievability

The rock properties of the repository basalt horizon and the surrounding area and the design configuration of the repository shall be such that radioactive waste can be retrieved from storage for a time sufficiently long to prove the suitability of the storage mode.

Resource Considerations

A repository should be sited in an area not known to contain significant valuable resources that may be attractive to present or future generations seeking those resources.

Rock Stresses

The rock of the repository horizon and the surrounding area should not be under a state of stress that could jeopardize the construction, operation, and post-operational integrity of the repository.

Rock Properties

The thermal and mechanical properties of the repository basalt horizon shall be such as to ensure the integrity of the repository during construction, operation, and post-operation phases.

Exploration and Testing

Exploration and testing techniques used in the selection and/or development of the repository site should be such that their potential impact on the long-term effectiveness of the repository will not be significant.

Transportation Considerations

A potential repository site should be located to minimize the risk associated with the transportation of the radioactive waste to the site.

HYDROLOGIC REQUIREMENTS

Hydrologic Analysis

Analysis of the repository system must demonstrate that ground water will not transport radionuclides to the biosphere in excess of codified quantities under all credible conditions. Such an analysis must include considerations of potential, credible events and processes disruptive to the repository.

Proximity to Dams

Areas in which a repository may adversely affect potentially usable water-bearing sources or which may be affected by existing major dams should be avoided.

Shaft Emplacement Tunnel Plugging

The geologic system of a repository should be such that it can be plugged and sealed at repository closure to ensure that the overall hydrogeologic system will continue to function satisfactorily.

Water Content of Rock

The water content of the host rock shall be such that water will not be liberated by radioactive heat or undergo chemical reactions on a scale large enough to compromise the integrity of geologic isolation.

GEOCHEMICAL REQUIREMENTS

Multiple Barriers

The repository should encompass a system of multiple, naturally occurring, and engineered materials that serve as reliable barriers to transport of hazardous amounts of radionuclides to the biosphere.

Waste Form and Engineered Barriers

Waste form and canister materials (engineered barriers) should be selected which will not chemically react or dissolve, individually or in combination, with the repository rock in such a way as to compromise the operational safety or geologic containment of the repository. Any reactions which could occur should not sufficiently degrade the isolation potential through increased mobility of the radionuclides present in the waste.

Radiation and Heat Effects

Radiation and radioactive decay heat should not reach levels high enough to produce physical and chemical reactions in the repository rock or in any barrier that would compromise the geologic containment.

GEOLOGIC REQUIREMENTS

Repository Depth

The repository should be at a depth sufficient to separate it from surficial processes and other credible events that might cause a breach of the repository containment.

Rock Body Size

The thickness, lateral extent, and shape of the specific body of rock in which a repository is to be constructed should be adequate to allow room for the repository and provide a sufficient buffer zone around the repository.

Tectonic Stability

The repository and buffer zone should lie within a structurally stable geologic block.

Proximity to Faults

Faults, along which recurrent rupture could occur, should not be present within the repository buffer zone.

Proximity to Volcanic Activity

Areas with abnormally high geothermal gradients or with evidence of relatively recent volcanic activity should be sufficiently distant to provide an acceptable risk.

Surface Characteristics

The repository site and its buffer surroundings shall possess surface characteristics which are compatible with waste disposal.

SOCIOECONOMIC REQUIREMENTS

Ownership

The repository site shall be located on land for which the federal government can obtain ownership, can control access to the repository site, and can obtain ownership of all needed surface and subsurface rights to assure that activities at the site will not cause unacceptable adverse impacts to repository performance.

Socioeconomic Considerations

A potential repository site should be located such that negative socioeconomic impacts resulting from the construction and operation of the repository can be minimized.

Government Considerations

A potential repository site should be located such that it is in conformance with existing legal requirements and is acceptable by jurisdictional agencies.

REPOSITORY SITE IDENTIFICATION

D. R. St. Laurent
Rockwell Hanford Operations
Richland, Washington 99352

An integral part of the Basalt Waste Isolation Project is the selection of a site which could successfully support the development of a radioactive waste repository. The first phase of selecting a site was completed this fiscal year. It consisted of identifying a small number of potential sites for further evaluation.

A rigorous, structured program will be followed to ensure that any site selected for a repository meets the licensing and environmental requirements of the United States Government. Each step in the siting process is a logical progression that begins with identifying prospective sites using a screening process, determining a limited number of sites for further investigation, evaluating and characterizing the sites, determining the suitability of the sites, selecting a site, and, finally, intensively characterizing the selected site to examine whether or not it meets licensing criteria.

SCOPE OF WORK

In September 1978, Woodward-Clyde Consultants was awarded a contract to assist the Basalt Waste Isolation Project in the site identification study. The goal of the site identification study in fiscal year 1979 was to identify whether or not any suitable candidate sites of approximately 10 square miles (16 square kilometers) could be found within the Hanford Site. To enable an investigation of the entire Hanford Site, the siting process was applied to a somewhat larger surrounding area, the Pasco Basin. Conditions that exist outside the boundary of the Hanford Site that could influence the siting of a repository within the Hanford Site were also considered.

The site identification process consisted of three activities:

- Definition of objectives and establishment of guidelines which form the basis for candidate site identification;
- Development of a screening process to identify candidate sites starting with the relatively large study area and progressively concentrating on smaller and smaller areas with a higher potential for containing suitable sites; and,
- Development of a ranking process to preferentially order candidate sites based on a decision analysis approach.

OBJECTIVES OF THE SITING STUDY

The objectives of the siting study are to assure public health and safety, mitigate adverse environmental and socioeconomic impacts, and minimize system cost. For each objective, appropriate considerations were identified that express areas of concern, such as earthquake ground motion, the existence of culturally important areas, or site preparation costs, respectively. Guidelines were established to represent specific levels of achievement under each consideration and to delineate progressively smaller siting areas that may be suitable for locating a repository. Figure 1 is a schematic representation of objectives, considerations, and guidelines.

GUIDELINE DEVELOPMENT

Guidelines were of two types; inclusionary and classifying. The inclusionary guidelines established or interpreted minimum levels of a parameter based on regulatory or statute requirements, technological limitations, or gross economic considerations. For example, areas which lie outside of national parks and monuments were included for further study in response to a statute or regulation which prohibits developments such as a repository in national parks. This guideline also recognized concerns in consideration of culturally important areas. Those areas interpreted as subject to moderate to low earthquake ground motion were included for further study. This guideline was responsive to gross economic considerations and, in part, to technological limitations that recognized the concerns in consideration of earthquake ground motion.

Classifying guidelines were those for which a finite numerical level of a parameter was not required, but which provided bases for differentiating siting areas. For example, the subjective evaluation of distance to ground-water discharge areas was used to differentiate siting areas and to guide professional judgments, although no desirable minimum distance was established.

In developing the screening guidelines, separate time frames were utilized for the surface and subsurface facilities. It was assumed that the process of construction and operation of surface facilities will extend over a period of 60 years. For the subsurface facilities, an isolation period of 10,000 years was utilized based on the studies that the health hazard of high-level radioactive waste decreases significantly in that period of time.⁽¹⁾

SCREENING PROCESS

The screening process utilized the inclusionary and classifying guidelines in several steps to identify areas for further study (Figure 2). Three basic screening steps were used to successively

FIGURE 1. Schematic Representation of Objectives, Considerations, and Screening Guidelines.

FIGURE 2. Steps in Screening Process.

reduce the Pasco Basin screening area and to identify nine candidate sites within the Hanford Site (Figure 3). The boundaries of sites shown in Figure 3 are schematic and each includes approximately 10 square miles (16 square kilometers) of area. The boundaries will be defined more accurately after additional information on the geology, hydrology, thermo-mechanical properties, and other conditions in surface and subsurface areas becomes available.

REFERENCES

1. U.S. Nuclear Regulatory Commission, Proposed Statement of General Policy: Licensing Procedures for Geologic Repositories for High-Level Radioactive Wastes, Federal Register 78-53869 through 78-53822, Washington, D.C., 1978.

FIGURE 3. Study Area and Candidate Sites.

THE TEST PLAN FOR IN SITU DEMONSTRATION

A. D. Krug
 Rockwell Hanford Operations
 Richland, Washington 99352

In order to assess the feasibility of utilizing basalt as a possible rock type for nuclear waste storage, the Basalt Waste Isolation Project has proposed that a series of in situ tests be conducted in a Near-Surface Test Facility in the Columbia Plateau basalts. These in situ tests are designed to provide information to assist in the design, construction, and licensing of a nuclear waste repository in basalt. The in situ testing to be conducted at the Near-Surface Test Facility is but one aspect of the larger Basalt Waste Isolation Project and is supported by laboratory testing of rock, waste rock interaction, and alteration products, as well as field studies in borehole plugging and hydrology and site-specific tests at depth in the proposed repository horizon.

The in situ tests are developed in two phases. The initial tests (Phase I) utilize electric heaters to simulate nuclear waste material and are designed to meet the technical objectives of the program. Phase II tests, some of which utilize nuclear waste material as the thermal sources, are designed to resolve less technical questions; however, they should demonstrate that the electric heaters indeed are representative of the nuclear waste.

The objectives of the test program planned for the Near-Surface Test Facility are to:

- Measure thermomechanical rock properties:

- Uniquely measure properties as functions of stress, temperature, rock quality, orientation, and size;

- Verify magnitude of properties and phenomena under complex geometries and boundary conditions; e.g., simulated heater experiments;

- Characterize rock properties for generalization of Near-Surface Test Facility conditions to other sites;

- Determine thermomechanical rock mass response under operating, accelerated, and overload conditions:

- Determine the maximum heat load per waste canister;

- Investigate rock/liner/overpack interaction; and,

- Demonstrate the thermomechanical behavior of basalt under the range of conditions possible with alternate waste forms, various canister placement configurations, and waste loading density;

- Provide verification and validation of predictive analysis:
 - Provide response from experiments for verification and validation of thermomechanical computer models for repository design and licensing;
- Evaluate the thermomechanical radiation interaction and radiation impact on rock mass response:
 - Evaluate the radiation effect, geomechanical changes, and radiolysis resulting from waste emplacement in the basalt;
 - Evaluate the changes in the waste form resulting from storage in the basalt rock mass under repository operating conditions; and,
 - Verify that in situ response of basalt is analogous to laboratory and predictive model simulation;
- Determine the construction impact on rock mass properties:
 - Evaluate the effect construction imposes on the thermomechanical response of basalt to applied heat.

Additionally the Near-Surface Test Facility will provide the opportunity to verify and demonstrate the ability to store actual spent fuel. This will include demonstration of handling, safe emplacement, storage, and retrieval of spent fuel in basalt in a simulated repository environment.

The objectives of the Near-Surface Test Facility test program can be met by a variety of characterization and test activities. Four groups of such tests are proposed for the Near-Surface Test Facility:

- Jointed block tests;
- Full-scale electric heater tests;
- Room-scale tests (accelerated room-scale); and,
- Single spent fuel canister tests.

These tests are supported by geologic site characterization (prior, during, and after the test), in situ stress measurements (hydrofracturing and overcoring) in the test horizons, and standard laboratory tests on rock properties from cores taken in the test area. The initial tests (jointed block, full-scale electric heater, and accelerated room scale) are for identification purposes and are being conducted in Phase I of the test program. The later tests, incorporating spent fuel, are proposed for demonstration purposes and are to be part of the Phase II portion of the test program. A simplified layout of the Near-Surface Test Facility (Figure 1) identifies in general terms the locations of the tests.

FIGURE 1. Tentative Layout of Near-Surface Test Facility Tests.

A series of jointed block tests is planned to provide in situ material property data on basalt. This is input to the numerical analysis which will be used to predict the rock mass response for the Near-Surface Test Facility tests and for repository design. These tests will be conducted in a variety of orientations and in varying rock types. The information will be used to characterize and extend the Near-Surface Test Facility data to other sites and rock conditions. In these tests, a block of basalt up to 6.5 feet (2 meters) square and 16.4 feet (5 meters) in length is to be outlined by drilling. Flatjacks are to be installed, surrounding the block, so that the confining pressure can be controlled. Figure 2 is a schematic of the basic test concept. These tests are intended to uniquely measure various thermomechanical properties (heat conductivity, coefficient of linear expansion, and rock deformability) to be determined by energizing a number of thermal sources (placed in boreholes in and around the block) and monitoring power levels, temperatures, and heat fluxes. The dependence of these properties on pressure and temperature can be determined. A uniform distribution of heat sources is required to maintain the block at a constant temperature for measurement of the coefficient of linear thermal expansion and rock deformability. The rock mass deformability can be determined as a function of temperature and pressure in a likewise manner.

Two full-scale electric heater tests are planned for the first phase of the test program. These are designed to simulate operating conditions and overload conditions around a single canister of spent fuel. This is accomplished by placing electric heaters in a borehole in full-size canisters. Canister field temperatures, stresses, and displacements are to be measured under varying thermal load conditions. The evaluation of decrepitation and non-linear deformation under load and overload conditions, the verification and/or modification of mathematical models, the determination of the effects and response of joints and fractures to temperature and thermally induced stress, and the validation of in situ thermal conductivity and expansion coefficients are required for preliminary thermomechanical qualification of basalt. The full-scale electric heater, used in Full-Scale Electric Heater Tests #1 and #2, is shown in Figure 3. At a later stage, additional full-scale electric heater tests, with canisters in non-vertical orientations, may be introduced.

The temperature and stresses around excavations in basalt under a variety of possible repository configurations are to be evaluated in an accelerated room-scale test (Figure 4). This test goes beyond canister-scale analysis of the full-scale electric heater test and considers the interaction of thermally induced stresses with room excavation. This provides room-scale rock mass strength information. It would be impractical to perform a full-scale, real time experiment to evaluate room-scale rock mass strengths and temperature limits. But because of the expected independence of basalt response to the loading path, an accelerated room-scale test is practical. Temperatures and stresses experienced in 25 to 50 years in the repository (for some configurations) are to be examined in this test. This test involves placing heaters in the floor, sidewalls, and roof of the test room. This would allow temperatures in

FIGURE 2. Layout of Typical Jointed Block Test.

FIGURE 3. Typical Full-Scale Electric Heater.

FIGURE 4. Layout of Accelerated Room Scale Test.

the room and surrounding rocks to achieve levels similar to those proposed in repository design. Thus, predictive analysis of room performance in the various conditions of thermal loading can be made from the knowledge of room behavior under accelerated loading. At a later stage, an operating-scale room test may be introduced to investigate stresses and temperatures associated with the early (0 to 5 years) life of the repository.

Single-canister spent fuel tests are planned in order to validate the use of electric heaters as spent fuel simulators and to provide a data base for the thermomechanical and radiation response of basalt. Two tests, utilizing different aged fuel, will provide information at differing radiation thermal load conditions. These tests will consist of individual canisters located in lined and instrumented test holes in the floor of the Phase II test room.

The Near-Surface Test Facility is presently under construction, with Phase I construction nearing completion. The Phase I test program is scheduled to begin in mid-1980 with the full-scale heater tests. Planning for Phase II is under way, with the startup for these tests anticipated in late 1981.

Initial planning of test activity at the Near-Surface Test Facility has concentrated on the thermomechanical qualification of basalt as a repository medium. The Near-Surface Test Facility is, however, a multipurpose test facility and planning is under way to broaden the use of the facility for tests of borehole plugging, liner studies, backfill and overpack material studies, and construction methods analysis.

ENGINEERING MODELING OF HYPOTHETICAL REPOSITORY SYSTEMS

C. M. St. John
University of Minnesota
Minneapolis, Minnesota 55455

Over the past year, the University of Minnesota, with Dames & Moore's Advanced Technology Group as subcontractor, has been working in three areas relating to numerical modeling of rock stresses within a nuclear waste repository in basalt. These areas are:

- Conceptual repository design;
- Analysis of the proposed Near-Surface Test Facility; and,
- Development of computer models for repository design.

This report summarizes activities in the first of these areas. In the long run, the other activities also contribute to the design, as their objectives are to improve and validate the computer models that form the bases for the studies.

PROBLEM BREAKDOWN

When discussing engineering modeling, it is convenient to break down the whole problem into a number of components. These reflect the scale on which the problem is considered and the level of detail that is sought during numerical modeling. Three scales were chosen:

- Canister scale;
- Room scale; and,
- Repository scale.

Clearly, there is overlap, since the behavior of the rock immediately around the canister could have impact directly on room stability, and the stability of rooms determines to what extent the properties of a previously stable rock mass are modified by the excavations necessary during repository construction. Despite these overlaps, each scale will be considered in turn.

CANISTER SCALE

On the canister scale, the effects of expected variations in the waste form have been examined. In particular, waste age, the effect of concentration of heat within the central portion of the canister, and the importance of direct gamma radiation heating of the basalt have been considered. Waste age has a significant effect on temperatures, but this can be controlled by the appropriate choice of initial loading of the canister. Non-uniform heat generation from the waste is smoothed because of

the high conductivity of the steel of the canister and the lining. Gamma heating is also of limited significance as the penetration is small, only about 4 to 6 inches (10 to 15 centimeters).

The behavior of lined boreholes has been examined using an explicit finite difference model capable of simulating material failure according to a Mohr-Coulomb yield criterion. Studies have indicated that stresses in steel liners will be very high if there is direct contact between the basalt and the liner. These high stresses may be controlled by emplacing a weak backfill that isolates the liner from the basalt. When such backfill is used, a thinner liner of steel with a lower yield stress may be used. Figure 1 shows the decrease in borehole radius as a function of external pressure for various lining conditions.

ROOM SCALE

Room-scale analyses have been conducted to demonstrate the differences between the vertical and horizontal emplacement options. In both cases, high stresses are generated normal to the plane containing the canister. Figure 2 shows the temperatures and stresses around a room with horizontally placed canisters. With horizontal emplacement, relatively high horizontal stresses are predicted within the roofs of the emplacement corridors. These would tend to be lessened by the presence of near-vertical jointing typical in basalt flows and also by weakening of the rock around the excavation due to blast damage. Horizontal emplacement will also result in tensile stresses in the sidewalls of the emplacement corridors. These stresses would have little impact on support requirements and also would have little effect on liner behavior or retrievability.

Support methods and excavation methods should be subjects for continuing investigation. These both determine to what extent the original properties of the basalt are modified by the construction of the repository. Major modification will result in increased permeability of the rock around the excavation and provide channels for radionuclide migration, even if the underground openings are effectively backfilled. Furthermore, modifications to the basalt properties have a pronounced effect on the stresses around the excavations and, hence, on the support requirements.

REPOSITORY SCALE

A number of repository-scale studies have been conducted. The simplest of these, carried out using an essentially analytical mode, had the purpose of examining stresses and temperatures around major access tunnels and shafts for a particular repository configuration. For the purposes of the study, the repository was assumed to consist of a series of panels each approximately 650 feet (200 meters) wide and 6,500 feet (2,000 meters) in length. Panels were developed sequentially on either side of a central barrier pillar in which it was assumed that shafts would be located. These analyses indicated that the effect of waste emplacement sequence was insignificant on the scale considered, and that the assumed barrier pillar was of sufficient size to ensure that temperature and stress changes around the shafts and access tunnels were minor.

FIGURE 1. Decrease in Rock Hole Radius as a Function of External Pressure for Various Lining Conditions.

0 3
METERS

0 9.8
FEET

(a)

CONCLUSION

Aspects of engineering design of a repository that have been studied using geotechnical numerical models have been summarized. At the lowest level of detail and largest scale, the problem of prediction of radionuclide migration has been addressed. The release mechanism for the radionuclides will be ground-water flow, so investigation of means of controlling rock mass permeability changes must be a primary objective of such engineering studies. On a shorter time scale, engineering studies are required to assess operational safety and ensure retrievability of isolated waste, should such action prove necessary.

LONG-TERM RISK ASSESSMENT

S. E. Logan
Los Alamos Technical Associates, Inc.
Los Alamos, New Mexico 87544

R. B. Lantz
Intera Environmental Consultants, Inc.
Houston, Texas 77079

The overall objective of the Los Alamos Technical Associates, Inc. subcontract with Rockwell Hanford Operations' Basalt Waste Isolation Project is to provide the risk analysis for the terminal isolation phase of a geologic repository in basalt in support of feasibility studies, design work, and licensing activities.

ASSESSMENT METHOD FOR RADIOACTIVE WASTE MODEL
AND COMPUTER CODE

The Radioactive Waste Management Systems Model and associated computer code, called the Assessment Method for Radioactive Waste,⁽¹⁾ is the vehicle for the risk assessment calculations. This model is basically a computer simulation or systems analysis model (Figure 1). The computer code interfaces component models providing continuous calculations from the Source Term (Inventory at Risk) through a Release Model and two parts of the Environmental Model (Transport to Environment and Environment-to-Man Pathways) obtaining output doses to population. The code does not replace established models that are in use for various segments of the problem, such as air dispersion, geosphere and biosphere transport, environmental pathway analysis, and dosimetry. Instead, most of the calculations within the computer code make use of input arrays and matrices of factors or coefficients obtained from the established models, augmented by the judgments of experts in each discipline. In the original version of the computer code, simplified versions of leaching and ground-water transport models are used internally, but these, as well as the major model sections, are each contained in sub-programs providing for replacement where desired. Output is provided at several stages through the model, giving calculated release quantities, environmental concentrations, and doses to the population.

During fiscal year 1979, work was concentrated on planning, preparation of models, development of release scenarios, and preliminary calculations. The emphasis was on establishing a firm foundation with flexible models prepared to receive data that become available as site selection, repository design, and other project study areas progress. Update of the computer code methodology included provision for a multiple barrier model, as an alternate to the leaching model, and provision for utilizing input from comprehensive ground-water transport codes.

FIGURE 1. Assessment Method for Radioactive Waste--A Simplified Flow Chart.

MULTIPLE BARRIER MODEL

Designs for a nuclear waste repository in basalt provide engineered systems in addition to the natural barrier system intended to provide assurance that radionuclide migration from the repository will be within required limits. The conceptual system includes the following barriers:

- The waste form itself;
- The waste canister and canister fill material;
- Grout/liner material surrounding the canister;
- Host rock (basalt);
- Backfill of placement room; and,
- Plugging of the shafts and other penetrations.

A multiple barrier model (Figure 2) is being developed that simulates the release of radionuclides from the waste form, radionuclide interaction with and transport through the multiple barrier system, and the release of radionuclides from the near field. This model serves two functions:

- To evaluate performance of engineered barrier designs in a stand-alone computer code mode; and,
- To comprise a module for the computer code providing a portion of the release model.

A number of physical and chemical processes must be considered in the multiple barrier model, including hydraulic flow, diffusion, dispersion, advection, dissolution, sorption, precipitation, ion exchange, and complexation. The initial coding to apply these multiple barrier sub-models in a computer simulation has been accomplished with the Los Alamos Systems Analysis code⁽²⁾ developed under the direction of Dr. P. A. Secker at the Los Alamos Scientific Laboratory prior to his joining Los Alamos Technical Associates, Inc.

The Los Alamos Systems Analysis code was designed for modeling and evaluating the transient performance of large-scale continuous systems. The model of the physical system is described mathematically in terms of a coupled set of first-order, usually non-linear, ordinary differential equations with time-dependent inputs. The modeled system may be represented by a set of sub-routines called modules. The model-independent computational main frame of the code, together with a collection of user-coded modules, provides extensive solution capabilities for dynamic systems analyses.

The incorporation of the leaching, transport, and chemistry sub-models into the code provides the stand-alone multiple barrier model

FOR EACH TIME INCREMENT, t :

(1) W obtained from waste form leaching model

(2) $B_U = W * F_B$, where F_B is fraction unretarded by barrier

(3) $A_B = \sum_{i=1}^{t-1} (W_i - B_{U1})$

(4) $B_{BR} = \sum_{i=1}^{t-1} B_{RR1}$

(5) $C_B = \sum_{j=1}^{t-1} \sum_{i=j}^{t-1} (W_j - B_{Uj}) * (1 - \exp(-\lambda * (T_i - T_{i-1})))$, where T = TIME

(6) $R_B = A_B - B_{BR} - C_B$

(7) $B_{RR} = R_B * F_R$,
where F_R is barrier release fraction

(8) $B_R = B_U + B_{RR}$

FIGURE 2. Conceptual Multiple Barrier Model.

that then interfaces with the Assessment Method for Radioactive Waste code by generating near-field release data files to be used in the original code's risk assessment calculations.

RELEASE SCENARIOS

The base case for a given repository design and source term will be with no disruption. This will consider existing hydrology in the deep basalts and, to the extent known, will consider existing higher hydraulic conductivity features such as faults, jointing, basaltic ring structures, breccia formations, and remnant stream beds.

Disruptive events that could potentially result in radionuclide release from a nuclear waste repository in basalt may be divided broadly as follows.

- Disruptive events through repository. This includes faulting, intrusion by man, and volcanic intrusion. Faulting could disrupt the near field and permit increased circulation of water through the repository and vertically interconnect aquifers that would significantly alter the potential pathways to the biosphere. Volcanic effects can range from near-field disruption by magma or volatile intrusion to explosive penetration and transport to the atmosphere.
- Disruptive events at some distance affecting the repository. A severe earthquake at some distance from the repository can cause shaft seal failures. A volcanic intrusion below, but not penetrating, the repository can induce hydrothermal transport from the repository.
- Disruptive events at some distance affecting the transport path. This category of events does not affect the repository directly, but alters pathways for ground-water transport. An example is a fault that interconnects aquifers at some distance from the repository in a way that shortens the pathway to the biosphere.

The initial release scenario selected for model demonstration (in addition to the no-disruption base case) will involve a fault through the repository. Details for this scenario will evolve as hydrology becomes further defined. Follow-on scenarios will be developed during fiscal year 1980.

In addition, there are a number of associated, local conditions potentially affected by climatic changes, glaciation, and other natural processes. Results of a recent study⁽³⁾ are being considered in this work. When results are obtained for multiple repository simulations by the Waste Isolation Safety Assessment Program methodology, the maximum and minimum boundary curves for a multiple simulation envelope can be adapted to Assessment Method for Radioactive Waste code input. In addition, various specific scenarios identified during simulation runs can be used to reinforce or augment release scenarios identified as part of this project.

HYDROLOGY AND GROUND-WATER TRANSPORT

The primary responsibilities in this area include:

- Hydrologic characterization of a potential site in Columbia Plateau basalts;
- Geosphere transport of radionuclides in the far-field area characterized by the initial and modified geosphere state outside the near field; and,
- Near-field hydrologic conditions used as input for the multiple barrier model.

A preliminary conceptual model of the hydrologic system at the Hanford Site has been characterized as four layers. These four layers consist of:

- The upper aquifer;
- The Saddle Mountains Basalt;
- The Wanapum Basalt; and,
- The Grande Ronde Basalt.

Although oversimplified, the calculated potentials in the three-layer basalt unit reasonably agreed with the available U.S. Geological Survey data.

Verification or control of the model simulation is by comparison with:

- The magnitude of the discharge from the basalt units compared to the overall surface discharge rate of the Columbia River; and,
- The more detailed permeability measurements at the Hanford Site.

The above simulation uses potential boundaries at the upstream end; thus, the total flow through the basalt unit depends strongly on the specified permeability of the individual layers. Matching of the measured U.S. Geological Survey potential data in each unit controls the heterogeneity level of the permeability distribution. The overall permeability magnitude, however, is controlled by the few measurement points in the vicinity of the Hanford Site.

There is still substantial uncertainty about the overall permeability level for each basalt flow unit because of limited permeability measurements. Additionally, interpretation of the injectivity tests has been performed by various analytical methods, and this interpretation can differ by two to three orders of magnitude. It is anticipated that work during fiscal year 1980 will try to reduce the uncertainty in the permeability measurements.

A possible scenario for the geosphere state has been evaluated. Radionuclides migrate from the vicinity of the repository located within the Grande Ronde Basalt to eventual discharge in the Columbia River. Pathways, travel times, and complete one-dimensional radionuclide transport calculations were performed for a five-component chain. This chain consisted of the actinide series initiated from ^{242}Pu . The entire chain simulated included:

In this simulation, the five-component chain was initially based upon a unit source for ^{242}Pu . To provide the proper input for the Assessment Method for Radioactive Waste code model, unit sources of the subsequent series nuclides were also run. These include a unit source for ^{238}U , ^{234}U , ^{230}Th , and ^{226}Ra , respectively.

As a consequence of making the calculations in the above manner, Los Alamos Technical Associates, Inc. can utilize the actual source information from their multiple barrier model, scale the results from unit source calculations by Intera Environmental Consultants, Inc., and get a super-position of the end results for any combination of the actinide series present in the initial inventory and releases from the multiple barrier mode.

Work during fiscal year 1980 will concentrate on improving the understanding of the hydrologic flow unit simulation at the Hanford Site in the Columbia River Basalt Group, and evaluating potential release mechanisms for other scenarios.

SUPPORTING ACTIVITIES

Several tasks in this project provide supporting information and input data for the risk assessment calculations. Characterization of the repository and source term relates to release scenarios and transport parameters. Characterization of the region is providing demographic, agricultural, and water usage information. Preliminary air dispersion analyses have been completed that provide for depositions and air concentrations of each radionuclide in each geographic zone associated with unit releases. One task is establishing the time range over which the calculations will be made. The time range must be long enough to include meaningful results, but should not unnecessarily extend into time periods with increasing uncertainty.

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LICENSING APPROACH IN SUPPORT OF THE
BASALT WASTE ISOLATION PROJECT

G. S. Hunt
Rockwell Hanford Operations
Richland, Washington 99352

The Office of Licensing was established to document all available and pertinent information about Columbia River Basalt in a format suitable for use in the licensing process. Licensing is the legal process used by the U.S. Nuclear Regulatory Commission to grant approval to the U.S. Department of Energy to construct, operate, and decommission a waste repository in a geologic medium such as basalt. The licensing process as described by draft U.S. Nuclear Regulatory Commission regulations will maximize public participation in the whole cycle of repository construction, operation, and closure beginning with the site selection process.

As a part of the licensing procedure, detailed safety and environmental formats were developed which will be slightly modified, so that all National Waste Terminal Storage Program participants are presenting data in a similar manner. Detailed schedules for preparation of the Preapplication Site Review Report were developed. Writing has started and drafts will be completed next fiscal year. The Preapplication Site Review Report, containing an executive summary, a safety analysis section, and an environment section, will be used to describe the plan to evaluate whether or not a site in basalt can be found which is a suitable medium for a geologic repository.

The Office of Licensing will prepare the documentation this fiscal year and through fiscal year 1981 needed by the U.S. Department of Energy to aid in their identification and selection of candidate sites for the first, deep, underground geologic repository. Site information will be contained in a report which is currently described as a Preapplication Site Review Report. This report will summarize everything the Basalt Waste Isolation Project knows about the physical characteristics of basalt, emphasizing those characteristics which relate to site selection. The report will also summarize in detail the process used by the Basalt Waste Isolation Project to select a suitable site on the Hanford Site.

The Preapplication Site Review Report is currently scheduled for submission by the U.S. Department of Energy to the U.S. Nuclear Regulatory Commission in September 1981. This schedule is compatible with draft regulations which require the U.S. Nuclear Regulatory Commission's involvement early in the site selection process. The executive summary, which is primarily a description of the site selection process, will be supported by environmental and safety analysis sections. The environmental and safety analysis sections will permit the U.S. Nuclear Regulatory Commission to evaluate the environmental and safety aspects of a repository in basalt. This should permit the widest public review and, hopefully, will facilitate dialogue between the license applicant (the U.S. Department of Energy) and the licensor (the U.S. Nuclear Regulatory Commission).

ACCOMPLISHMENTS IN FISCAL YEAR 1979

Detailed preparation schedules for the executive summary section, the environmental section, and the safety analysis section of the Preapplication Site Review Report were developed to assist preparation of the report next year.

The format and content document for the environmental section was written and revised during the past year. This document provides explicit guidance to the preparers of the environmental section and the safety section of the Preapplication Site Review Report. It is anticipated that this format will be revised slightly in the next few months so that all National Waste Terminal Storage Program contractors will be using the same format.

A similar document outlining the format and content for the safety analysis section was revised. These guidelines will be utilized by the preparers of the safety analysis section of the Preapplication Site Review Report. Further modification of the safety section is anticipated as more guidance from the U.S. Nuclear Regulatory Commission becomes available. When revised, it will be a document which can be used by all U.S. Department of Energy contractors to describe the safety aspects of geologic repositories. This same format will be used when a license application is made for a repository in basalt.

A licensing working group consisting of nuclear waste test facility contractors (Basalt Waste Isolation Project, Office of Nuclear Waste Isolation, and Nevada Test Site) was established this year and will begin to function to coordinate all phases of the licensing effort between the various contractors. This will ensure that all licensing documents have similar format and content, and that design assumptions common to the various geologic media are the same.

PLAN FOR FISCAL YEAR 1980
PREAPPLICATION SITE REVIEW REPORT
SAFETY ANALYSIS SECTION

During the first six months of fiscal year 1980, draft chapters of the safety analysis section of the Preapplication Site Review Report will be prepared. The section will evaluate the safety of the proposed repository, both for the short and long term. In support of this evaluation a long-term risk assessment contract was let to Los Alamos Technical Associates, Inc., Los Alamos, New Mexico. (See paper by Drs. S. E. Logan and R. B. Lantz). Los Alamos Technical Associates, Inc. will utilize advanced computer modeling techniques developed for the U.S. Environmental Protection Agency to analyze the potential for nuclide migration to the biosphere. Results of this effort will provide input for the long-term assessment.

ENVIRONMENTAL SECTION

All chapters of the environmental section of the Preapplication Site Review Report will also have first drafts prepared by March 1980.

Land-use patterns for the Columbia Plateau will be identified to evaluate potential environmental effects.

A cost-benefit study will also be conducted to determine the optimum way of establishing criteria for environmental and occupational exposure to radioactive materials. This study will analyze the effects that changes in the criteria have as a function of both costs and potential benefits. The study will assess the use of probability expressions as a form of presenting environmental and occupational exposure criteria.

EXECUTIVE SUMMARY SECTION

The executive summary section of the Preapplication Site Review Report will be prepared to meet the requirements of Title 10, Code of Federal Regulations, Part 60, paragraph 60.11, which should be finalized early in 1980. The format and content of this section will be developed by May 1980 and the writing of the section will follow.

During fiscal year 1980, it is planned that all of the risk assessment models and interfaces to be used by the Los Alamos Technical Associates, Inc. will be exercised to provide early indications of any problem areas and additional data needs. This effort will use the preconceptual repository design as a basis for safety and environmental analyses.

The far-field and long-term radioactive dose to man will be estimated using the Waste Isolation Safety Assessment Program with input from the Basalt Waste Isolation Project. The Waste Isolation Safety Assessment Program output will be compared to the results of long-term risk assessment being conducted by a Basalt Waste Isolation Project subcontractor and the programs integrated to obtain a valid estimate of the risk to man.

A licensing strategy consulting team will be assembled in fiscal year 1980 to review the outlines, progress, and draft of all sections of the Preapplication Site Review Report. These consultants will be experts in several fields of waste disposal and will have considerable experience in dealing with the public and governmental regulatory agencies such as the U.S. Nuclear Regulatory Commission and the U.S. Environmental Protection Agency.

CHAPTER II - GEOSCIENCES

CHAPTER II - GEOSCIENCES

SUMMARY

The geosciences program is gathering the data required for identification and evaluation of potential repository sites in basalt. These studies will lead to identification of repository target areas, if any, that potentially provide geologic barriers adequate to prevent release of radiocontaminants to the biosphere. If a repository site is successfully identified, geologic studies will thoroughly characterize the area to determine the extensiveness of individual basalt flows, the stability of the region, and the presence or absence of potentially hazardous geologic structures. If the United States Government selects a final site, geologic studies will thoroughly characterize the site and continue to evaluate existing risks and provide adequate information for any safety assessment of the site selected.

During fiscal year 1979:

- An intensive program was carried forth to complete documentation of the geologic characteristics of the Columbia Plateau;
- Extensive geologic field mapping of the Pasco Basin in south-central Washington was completed;
- The seismicity of the Columbia Plateau continued to be monitored using a microseismic network; and,
- Geophysical surveys were conducted to support the field mapping programs.

Regional studies included a literature search, surface geologic mapping, and photolineament analysis. Regional studies have been of a reconnaissance nature and were designed to augment detailed studies conducted concurrently within the Pasco Basin.

The stratigraphy and structure of the Columbia River Basalt Group within Washington State have been defined through the compilation of a regional geologic map at a scale of 1:250,000. The map was produced through a synthesis of previously existing data and new field studies. The map compilation shows that a plateau-wide basalt stratigraphy is present, and that basalt flows throughout the region can be correlated through a combination of chemical, paleomagnetic, and field properties.

Regional geologic mapping studies were supported by an analysis of Landsat satellite imagery and U-2 aerial photography to identify regional and localized surface features of potential significance to the structural geology of the Columbia Plateau. Photolineament maps covering the Washington State portion of the Columbia Plateau were produced as part of this effort. The results of the analysis indicated that structures with distinct topographic reflections are best identified using satellite imagery and aerial photography.

Pasco Basin studies included surface geologic mapping, borehole studies, and geophysical surveys to determine the stratigraphy, structure, and tectonic stability of the Pasco Basin. The Pasco Basin includes the Hanford Site of the U.S. Department of Energy.

The thickness, sequence, and lateral extent of Grande Ronde Basalt flows in the Pasco Basin subsurface have been determined through the use of basin-wide correlations combined with surface mapping and deep core drilling. Basalt unit identifications were made using chemical compositions, paleomagnetism, and borehole geophysical logs. Grande Ronde Basalt flows in the Pasco Basin are subdivided into 2 distinct flows; a lower sequence, informally named the Schwana sequence, and an upper sequence, informally named the Sentinel Bluffs sequence. The Schwana sequence is approximately 2,500 feet (750 meters) thick and consists of at least 15 to 25 separate flows. Overall, the Schwana sequence flows average about 3.5 percent magnesium oxide (low-magnesium oxide chemical type) which occurs only in the southeastern Pasco Basin. The normal-2 and reversed-2 and possibly reversed-2/normal-1 regional magnetostratigraphic horizons have been identified within the Schwana sequence and 5 chemical stratigraphic units have been identified and correlated in the low-magnesium oxide flows. The Sentinel Bluffs sequence averages about 890 feet (247 meters) thick in the central Pasco Basin and consists of 5 to 12 flows. The Sentinel Bluffs sequence flows average about 5 percent magnesium oxide (high-magnesium oxide chemical type) and contain 2 correlative magnetostratigraphic horizons.

The upper Grande Ronde Basalt in the Pasco Basin contains at least two units currently interpreted as individual flows that are laterally continuous throughout the central Pasco Basin and are relatively thick, compared to other flows in the upper Grande Ronde Basalt. One of the thick "through-running" flows, the Umtanum flow, has an anomalously low paleomagnetic inclination and is effectively a marker horizon throughout the Pasco Basin subsurface. Because of their thickness and lateral extent, these flows should be considered as candidate host rocks. The two flows are separated one from another and from overlying and underlying basalt flows by sequences consisting of thinner flows, some of which appear to pinch out within the central Pasco Basin, but are probably laterally extensive across the basin.

The major geologic structures that have deformed the upper Grande Ronde Basalt flows in the Pasco Basin since their emplacement and cooling have been identified. Foremost among these are the Yakima Folds. Individual folds trend east in the northwestern part of the basin and southeast in the southeastern part of the basin. Structural relief decreases to the east, but varies locally because of culmination and depression along the hinge zone of individual folds. Folds are locally faulted along these steep limbs and contain subsidiary folds and faults on their gently dipping limb. Generally, anticlinal hinge zones are more deformed than synclinal hinge zones. Most subsidiary, second-order structures are not parallel to the trend of the first-order structures, but some structures have been identified which cross-cut the structural hinge zones at an oblique angle and might extend down the limbs across synclines. Aeromagnetic surveys have been used to locate and trace buried first-order

and second-order structures on the flanks of first-order folds. Reflection seismic survey results have also revealed second-order structures. Preliminary structure contour maps, structure cross sections, and isopach maps have been prepared. These maps indicate that potential host rock units are at depths of approximately 2,500 to 4,500 feet (762 to 1,372 meters) in the central Pasco Basin, and dips average less than 3 degrees across areas in excess of tens of square miles (kilometers) in the central Pasco Basin subsurface.

The seismicity of eastern Washington continued to be monitored using a microseismic monitoring network. Earthquake activity in the plateau appears to be from two different source depths; shallow, low-magnitude events in small volumes of basalt, and deeper events below basalt that are of low magnitude and generally diffuse. This pattern was determined after a detailed, 10-year earthquake monitoring period.

Geophysical surveys in the Pasco Basin during fiscal year 1979 were designed to meet two objectives; to assist in the general definition of subsurface structures in the central Pasco Basin using standard geophysical surveys performed through subcontractors, and to provide detailed geophysical profiles across specific structures in the Pasco Basin using high-resolution surveys performed by Rockwell Hanford Operations' geophysicists and equipment. Eighty-seven line miles of seismic reflection surveying, extensive magnetotelluric, aeromagnetic, gravity, resistivity, and other techniques were used throughout various areas of the Pasco Basin to support the geophysical mapping effort.

GEOLOGY OF THE COLUMBIA PLATEAU

S. M. Price
Rockwell Hanford Operations
Richland, Washington 99352

Regional geologic studies conducted during fiscal year 1979 included:

- Bibliographic and index map compilation;
- Surface geologic mapping; and,
- Analysis of satellite imagery and aerial photography.

The results of these studies are discussed in a recently completed status report.⁽¹⁾ The following is a summary of information contained in that report.

BIBLIOGRAPHY AND INDEX MAP COMPILATION

An important objective of the regional geologic studies effort was the collection, centralization, and evaluation of all data currently available for the Columbia Plateau (Figure 1). As part of the data compilation process, Columbia Plateau bibliographies were completed for their respective states by the Washington State Department of Natural Resources' Division of Geology and Earth Resources,⁽²⁾ the Idaho State Bureau of Mines and Geology,⁽³⁾ and the Oregon State Department of Geology and Mineral Industries.⁽⁴⁾ Keyed to each bibliography is a set of index maps showing the areal extent and/or locations of specific types of geologic information.

GEOLOGIC MAPPING

A second objective of the regional geologic studies effort was the preparation of a reconnaissance geologic map (at a scale of 1:250,000) of the Columbia Plateau (Figure 1). During fiscal year 1979, a geologic map of Columbia River Basalt of Washington (east of the Cascade Range, Figure 1) was completed by personnel of the U.S. Geological Survey.⁽⁵⁾ In addition, a surficial geologic map of late Cenozoic sediments overlying the basalt of this area was completed by personnel of the Washington State Department of Natural Resources' Division of Geology and Earth Resources.⁽⁶⁾ Significant stratigraphic and structural information shown on these maps is summarized below.

STRATIGRAPHY

The regional Columbia River Basalt map portrays the outcrop extent of 4 formations, 14 members, and several informally named magnetostratigraphic units designated in Figure 2.⁽⁷⁾ The oldest of the four formations (Imnaha Basalt) crops out only within the southeastern part of the map area. Imnaha Basalt is conformably overlain by Grande Ronde Basalt.

FIGURE 1. Outcrop Extent of the Columbia River Basalt Group (shaded area).

Series	Group	Sub-group	Formation	Member	K-Ar age (m.y.)	Magnetic polarity				
M I O C E N E	Upper Miocene	COLUMBIA RIVER BASALT GROUP	YAKIMA BASALT SUBGROUP	Saddle Mountains Basalt	Lower Monumental Member	6 ³	N			
					////////// erosional unconformity //////////					
					Ice Harbor Member					
					basalt of Goose Island	8.5 ³	N			
					basalt of Martindale	8.5 ³	R			
					basalt of Basin City	8.5 ³	N			
					////////// erosional unconformity //////////					
					Buford Member		R			
					Elephant Mountain Member	10.5 ³	N,T			
					////////// erosional unconformity //////////					
	Pomona Member				12 ³	R				
	////////// erosional unconformity //////////									
	Esquatzel Member					N				
	////////// erosional unconformity //////////									
	Weissenfels Ridge Member									
	basalt of Slippery Creek					N				
	basalt of Lewiston Orchards					N				
	Asotin Member					N				
	////////// local erosional unconformity //////////									
	Wilbur Creek Member					N				
	Umatilla Member				N					
	////////// local erosional unconformity //////////									
	Middle Miocene						Wanapum	Priest Rapids Member		R ₃
								Roza Member		T,R ₃
								Frenchman Springs Member		N ₂
							Basalt	Eckler Mountain Member		
								basalt of Shumaker Creek		N ₂
								basalt of Dodge		N ₂
								basalt of Robinette Mountain		N ₂
							Grande Ronde Basalt		14-16.5 ²	
										R ₂
							Lower Miocene			
	?									
						R ₁				
				Imnaha Basalt ⁴						
						T				
						N				
		R ?								

¹ Information in parentheses refers to Picture Gorge Basalt

² Data mostly from Watkins and Baski (1974)⁽⁸⁾

³ Data from McKee and Others (1977)⁽⁹⁾

⁴ The Imnaha and Picture Gorge Basalts are nowhere known to be in contact. Interpretation of preliminary magnetostratigraphic data suggests that the Imnaha is older

N=Normal R=Reversed T=Transitional

FIGURE 2. Regional Columbia River Basalt Group Stratigraphic Nomenclature.

The Grande Ronde Basalt is the most voluminous unit of the Columbia River Basalt Group and virtually underlies most of the Columbia Plateau. The known thickness of Grande Ronde Basalt ranges from tens of feet (meters) along the margins of the Columbia Plateau, to more than 3,000 feet (1,000 meters) within the Pasco Basin.⁽¹⁾ The thickest exposures of the sequence, comprised of 30 to 40 flows, are located in southeastern Washington.

Grande Ronde Basalt flows have a continuous range in chemical composition within a field defined as Grande Ronde chemical type.⁽⁷⁾ Within localized areas of the plateau, chemical "breaks" between sequences of flows having low-magnesium oxide and high-magnesium oxide Grande Ronde chemistries have been used for correlation and mapping purposes. However, the only known, mappable "regional" subdivisions of Grande Ronde Basalt are four magnetostratigraphic units. These units, listed in ascending order, are termed reversed-one, normal-one, reversed-two, and normal-two (Figure 2). Exposures of Grande Ronde Basalt within the map area primarily belong to the two upper magnetic intervals, reversed-two and normal-two. Magnetostratigraphic units shown on the map provide an important framework for more detailed study of Grande Ronde Basalt stratigraphy.

Grande Ronde Basalt is overlain by Wanapum Basalt (Figure 2), a formation which defines the plateau surface throughout much of the map area. The four recognized Wanapum Basalt members have a relatively high iron oxide and titanium dioxide content in comparison to Grande Ronde Basalt.⁽⁷⁾ Source dikes for three of the four Wanapum Basalt members were identified during regional mapping.

The Saddle Mountains Basalt is the youngest formation of the Columbia River Basalt Group and is comprised of 10 recognized members (Figure 2) having distinctive chemistries. Feeder dikes for these members are located in the southeastern and south-central portions of the map area. The period of Saddle Mountains Basalt extrusion was marked by waning volcanism, the development of thick sedimentary units between flows, and accelerated folding and canyon cutting.⁽⁷⁾ Hence, the mapped distribution of Saddle Mountains Basalt members and intercalated sediments serves as an important framework for assessing the structural development of the plateau.

Late Cenozoic sediments of Washington were divided into 18 map units (Figure 3). The most extensive of these units includes the Pliocene suprabasalt Ellensburg and Ringold Formations, the Pleistocene catastrophic flood deposits, and Pleistocene to Recent loess deposits.⁽⁶⁾

The suprabasalt Ellensburg Formation includes poorly lithified clastic and volcanoclastic sediments which occur within the western portion of the Columbia Plateau. The Ringold Formation crops out within the central portion of the map area and includes an upper sand and silt facies and a lower conglomerate facies. Paleontologic⁽¹⁰⁾ and paleomagnetic⁽¹¹⁾ data suggest that the upper Ringold facies was deposited between three and five million years before present. The Ringold Formation may be in part time correlative with the uppermost Ellensburg Formation.

CORRELATION OF MAP UNITS

DESCRIPTION OF UNITS

- Qd** DUNE SAND - Active and stabilized dunes of predominantly fine to medium sand. mostly quartz and basalt grains reworked from older sedimentary deposits.
- Qa** ALLUVIUM - Primarily stream deposits of silt, sand, and gravel in floodplains, terraces, and valley bottoms. Includes local lacustrine, paludal, and eolian deposits in depressions.
- Qaf** ALLUVIAL FAN DEPOSITS - Primarily unconsolidated sand and gravel on alluvial fans. Surface is relatively un dissected and exhibits little or no petrocalcic soil development (caliche).
- Qc** COLLUVIUM - Primarily angular to subangular basaltic debris accumulated at the base of steep slopes and cliffs. Includes talus and talus cones formed by active and inactive rockfall.
- Qls** LANDSLIDE DEPOSITS - Unstratified and poorly sorted clay, silt, sand, and gravel deposited by rotational and translational slides and flows.
- Ql** LOESS - Loess deposits consisting of eolian silt and fine sand up to 246 feet (75 meters) in thickness. Generally not mapped where less than approximately 6.5 feet (2 meters) thick. Locally contains multiple petrocalcic horizons and tephra beds.
- Qafo** OLDER ALLUVIAL FAN DEPOSITS - Primarily semi-consolidated gravel or fanglomerate. Surface of fans is dissected and capped by well-developed petrocalcic soils (caliche).
- Qfs** CATASTROPHIC FLOOD SLACKWATER SEDIMENTS - Rhythmically bedded and graded silt, sand, and gravel deposited by lower energy slackwaters or catastrophic floods and (or) surges of catastrophic floods. Includes the Touchet beds.
- Qfg** CATASTROPHIC FLOOD GRAVELS - Predominantly coarse gravel and sand deposited by higher energy waters of catastrophic floods.
- Qtb** TERRACE AND BAR DEPOSITS, UNDIFFERENTIATED - Glaciofluvial, fluvial, and ice-contact stratified silt, sand, and gravel deposits of various lithologies in terraces and bars in the valleys of the Columbia, Okanogan, and Spokane Rivers and tributaries. Includes deposits of the Great Terrace.
- Qgl** GLACIOLACUSTRINE TERRACE DEPOSITS - Silt, sand, and gravel deposited in glacial lakes that formed along the Columbia, Okanogan, and Spokane Rivers and their tributaries. Includes deposits of the Nespelem Terrace. Surface of the terraces may exhibit local modifications by fluvial and catastrophic floodwaters.
- Qgd** GLACIAL DEPOSITS - Till, outwash, and ice-contact stratified deposits in moraines, till plains, and melt-water channels and terraces.
- Qt** TIETON ANDESITE - Andesitic flow of the lower Naches River drainage.
- Qtgt** GRAVEL OF THE TERRACE REMNANTS - Gravel and coarse sand in remnants of high fluvial terraces and alluvial fans within the Yakima River drainage basin. Includes the Cowiche gravel. Age uncertain, but may be in part correlative with Thorp Gravel, Ellensburg Formation, Ringold Formation, and gravels of ancestral Columbia River (Tc).
- Tt** THORP GRAVEL - Fluvial (?) gravel in dissected high terraces and alluvial fans in the Kittitas Valley. Probably correlative with the upper Ringold Formation.
- Tr** RINGOLD FORMATION - Fluvial and lacustrine clay, silt, sand, conglomerate, and fanglomerate of diverse composition. Includes a cap of thick, well-developed petrocalcic soil (caliche). May be correlative with the uppermost Ellensburg Formation.
- Tc** GRAVEL OF ANCESTRAL COLUMBIA RIVER - Predominantly well-rounded pebble gravel. Columbia River provenance indicated by a dominance of quartzite pebbles.
- Te** ELLENSBURG FORMATION - Primarily weakly lithified fluvial and lahatic deposits. Base undefined. Mapped only where they overlie the Yakima Basalt Subgroup. Dominated by dacitic, andesitic, and pumiceous clasts.
- Ty** YAKIMA BASALT SUBGROUP - Lava flows of the Saddle Mountains, Wanapum, and Grande Ronde Formations. Includes sedimentary interbeds of the Ellensburg and Latah Formations, local colluvium, caliche, and widespread, thin loess.
- pm** PRE-MIOCENE ROCKS, UNDIFFERENTIATED - Primarily Precambrian through Mesozoic metamorphic and plutonic rocks, and early Tertiary sedimentary and volcanic rocks.

FIGURE 3. Regional Late Cenozoic Sediments Stratigraphic Nomenclature.

During Pleistocene glaciation, eastern Washington was subjected to a number of catastrophic floods which resulted from the breakup of ice dams impounding glacial lakes in Idaho, Montana, and northeastern Washington. The central and eastern portions of the map area are dominated by erosional features and sedimentary deposits resulting from these floods. Most surficial flood deposits are thought to be associated with the last major flood, dated at approximately 13,000 years before present.⁽¹²⁾

The eastern portion of the map area is covered by eolian loess deposits which include at least four distinct units. Three Pleistocene units and a younger late Wisconsinan to Recent loess have been correlated with glacial events in the region.⁽¹³⁾

STRUCTURE

In general, the map area can be subdivided into three informal structural subprovinces--the Yakima Fold Belt subprovince, the Palouse subprovince, and the Blue Mountains subprovince. The Yakima Fold Belt subprovince is characterized by east-west-trending, asymmetrical anticlinal ridges and intervening synclinal valleys. Available data indicate that the formation of these folds began in late Grande Ronde time, but was most pronounced after late Saddle Mountains time. Although supra-basalt Ellensburg and Ringold sediments were involved in the folding process, younger sedimentary units are generally undeformed.

The Palouse subprovince is underlain by basalt flows with a regional dip of less than five degrees to the southwest. The dip is a reflection of regional westward tilting which occurred throughout most of the period of basalt extrusion. Also present within the subprovince are broad folds having tens of feet (meters) of amplitude.

The Blue Mountains subprovince is essentially a broad, northeast-trending, anticlinal arch which was uplifted during Miocene-Pliocene time. Only the extreme northeast extension of the Blue Mountains subprovince is located within the map area.

ANALYSIS OF SATELLITE IMAGERY AND AERIAL PHOTOGRAPHY

A third objective of the regional geologic studies effort was to conduct an analysis of available satellite imagery and aerial photography in order to identify regional and localized surface features of potential significance to the geology of the Columbia Plateau. During fiscal year 1979, photolineament maps (scale 1:250,000) covering the Columbia Plateau of eastern Washington were completed by Pacific Northwest Laboratory personnel.⁽¹⁴⁾ These maps were based primarily on an analysis of Landsat imagery and U-2 photography acquired during fiscal year 1978. Photolineaments recorded on the maps are coded as to imagery association and as to interpreted origin (i.e., topographic, drainage alignments, tonal discontinuities, and cultural features).

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GEOLOGY OF THE PASCO BASIN

C. W. Myers
Rockwell Hanford Operations
Richland, Washington 99352

Geologic studies in the Pasco Basin during fiscal year 1979 included surface mapping of basalt and sediments, analysis of core from deep core holes, and completion of several geophysical surveys. Results of these studies are summarized herein.

STRUCTURE

The Yakima Folds (Figures 1 and 2) trend east-west in the northwestern part of the Pasco Basin and northwest in the southeastern part of the basin. Structural relief on the folds decreases toward the east. In general, the anticlines are asymmetric, open to tight, and eroded into sharp to rounded ridges separated by broad, alluviated valleys developed in the synclines. The sense of fold asymmetry is such that the steeper limb of an anticline is usually the north limb; however, the reverse is true locally. Overturning and thrusting were observed in some hinge zones and shorter limbs. Culminations and depressions are common along fold hinges and produce variations in structural relief and plunging hinge lines. The maximum fold amplitude observed is approximately 3,000 feet (915 meters). Wavelengths vary from 3 to 12 miles (5 to 20 kilometers). In places, each major fold within the Pasco Basin has smaller, subsidiary folds and faults on its limbs or in its hinge regions. The Wahluke and Cold Creek synclines are two major synclines in the northwestern Pasco Basin. The Wahluke syncline lies between the Saddle Mountains structure and the Umtanum Ridge-Gable Mountain structure. The Cold Creek syncline is between the Umtanum Ridge-Gable Mountain structure and the Yakima Ridge structure.

BASALT STRATIGRAPHY

Grande Ronde Basalt flows in the Pasco Basin are subdivided into 2 distinct sequences of flows; a lower sequence, informally named the Schwana sequence, and an upper sequence, informally named the Sentinel Bluffs sequence (Figure 3). The Schwana sequence is at least 2,500 feet (750 meters) thick and consists of at least 15 to 25 separate flows. Overall, the Schwana sequence flows average about 3.5 percent magnesium oxide (low-magnesium oxide chemical type), except for a thin sequence of low-potassium oxide flows which averages 5 to 6 percent magnesium oxide (very high-magnesium chemical type). The normal 1-2/reversed-2 and possible reversed 1-2/normal 1-1 regional magnetostratigraphic horizon has been identified within the Schwana sequence, and 5 chemical-stratigraphic units have been identified and correlated within the Schwana sequence. The Sentinel Bluffs sequence averages about 890 feet (270 meters) thick in the central Pasco Basin and consists of 5 to 12 flows. The Sentinel Bluffs sequence flows average about 5 percent magnesium oxide (high-magnesium oxide chemical type) and contain 2 correlative magnetostratigraphic horizons.

FIGURE 1. Generalized Geology Map of the Pasco Basin.

FIGURE 2. Generalized Structure Cross Section.

FIGURE 3. Interpretation of Rock-Stratigraphic Units, Central Pasco Basin.

The Umtanum flow averages about 200 feet (60 meters) total thickness across the central Pasco Basin (Figure 2). The flow top is typically a 25- to 50-foot (8- to 15-meter) thick rubble, but locally a thicker flow-top breccia is developed. The flow interior of the Umtanum flow is typically 150 to 175 feet (46 to 54 meters) thick, with the lower 10 to 60 feet (3 to 18 meters) consisting of colonnade and the central 100 to 150 feet (31 to 46 meters) consisting of entablature. Tiered colonnade and entablature have been observed.

TECTONICS

Deformation is localized along Yakima Folds trends and northwest-trending structures. Deformation was generally subdued through Wanapum time and became more pronounced after late Saddle Mountains time. The extent of involvement of Ringold sediments in the deformation appears to decrease from lower to upper Ringold units, suggesting that deformation continued into Ringold time, possibly at a reduced rate. Upper Ringold sediments (less than 3.5 million years) along the White Bluffs appear to be only slightly tilted, but here they overlie relatively gently dipping basalt. No direct evidence of Quaternary sediments offset by tectonic faults has been found in the Pasco Basin.

SEISMICITY OF THE COLUMBIA PLATEAU

S. D. Malone
 Geophysics Program
 University of Washington
 Seattle, Washington 98195

The following is a brief summary of the University of Washington technical reports on eastern Washington seismic studies.(1)

Before discussing the details of the seismicity of eastern Washington, it is necessary to describe the velocity structure. Since the accuracy of earthquake locations depends closely on the accuracy of the velocity structure used to locate them, considerable effort has been spent investigating it. It is also of use in the interpretation of the tectonics of the region.

Over the past several years, studies of different parts of the Columbia Plateau and adjacent areas have developed velocity models which differ significantly from one another. The current state of these studies is summarized in Table 1.

TABLE 1. Summary of Velocity Structures.

Central V_p^*	Plateau Focal/ Depth (km)	Northern Plateau		Central Cascades		Puget Sound	
		V_p	h	V_p	h	V_p	h
3.7	0.0	5.1	0.0	5.1	0.0	5.36	0.0
4.7	0.8	6.05	0.5	0.0	0.0	6.61	10.0
5.15	1.2	7.2	19.0	6.4	18.0	6.70	16.0
6.05	7.5	8.0	24.5	6.8	22.0	6.91	22.0
7.2	19.0			7.9	38.0	7.11	32.0
8.0	28.0					7.16	35.0
						6.87	38.0
						7.75	41.0

* V_p = Compressional wave velocity in kilometer per second (1 kilometer = 0.62 mile).

In summary, the structural studies indicate there are significant differences in the velocity models between the central basin and the northern plateau (north of 47 degrees north). A significantly different structure also exists in the Cascade Range and still another in western Washington. Thus far, no significant difference is found across the feature known as the Olympic-Wallowa Lineament, although the data are not extensive to the southwest of it. Hopefully, with the recent addition of new stations in the southern Cascades, there will be confirmation of this preliminary interpretation.

GENERAL SEISMICITY

Historically, the Columbia Plateau has been an area of moderate to low seismicity. The historical record⁽²⁾ shows that an area just to the south of Lake Chelan has had a number of felt earthquakes. The central basin has had only a few reported events, all less than Modified Mercalli intensity V, while there have been several larger events along the Washington-Oregon border area; in particular, the Walla Walla, Washington and Milton-Freewater, Oregon area. The largest earthquake in eastern Washington was the 1936 Modified Mercalli intensity VII event in this area.

In 1969, a local earthquake monitoring network was installed by the U.S. Geological Survey in the central part of the plateau. This network underwent several expansion phases and was taken over by the University of Washington in 1975. The present network includes 36 telemetered stations extending from Pendleton, Oregon in the south, to Winthrop, Washington in the north. Recent additions to this array in the central and southern Cascades mean coverage is fairly uniform for locating earthquakes down to coda length magnitude (M_L) of 2.0 over most of the state.

This complete earthquake catalog now goes from April 1969 to June 1979 and contains 2,587 events, of which 345 are known or suspected blasts and 2,242 are earthquakes. Some of these events fall outside the boundaries of the eastern Washington network, but are still included in the catalog; there are 113 of these, leaving 2,129 earthquakes of some interest to this project. A temporal analysis of this 10-year catalog has been run to explicitly quantify the characteristics of the seismicity. It should be remembered that the network array location sensitivity has not been the same over this period.

Most of the earthquakes in the Columbia Plateau province located in the last 10 years can be grouped in the following categories:

- Earthquakes which occur within the basalt stratigraphy and which exhibit very strong swarm characteristics in both space and time; and,
- Earthquakes which occur below the basalt and which have temporal or spatial characteristics which do not exhibit any swarm tendencies.

To study the swarm characteristics, events in a 1.4 degree of latitude by a 1.6 degree of longitude were selected. These events are plotted in Figure 1. Only the best located events are plotted in this figure, those with time residuals of less than 1.2 miles (2.0 kilometers). The very obvious spatial clustering of these events is evident in this figure. Arbitrary boundaries have been drawn around what are called individual "swarm areas." Those sub-regions are labeled with a two-letter designator for identifying the individual areas. In drawing the boundaries, an attempt was made to include only enough area to encompass all the earthquakes in a group.

To examine the temporal clustering of events within swarm areas, plots have been made of the number of events per unit time versus time. The 10-year period of the catalog is divided into 1,000 equal intervals

CENTER OF MAP IS 46.50 DEGREES NORTH, 119.40 DEGREES WEST.

MAGNITUDE KEY ◯ 0.0 ○ 1.5 ○ 3.0

FIGURE 1. Well Located Shallow Earthquakes 1969-1979.

of about 3.5 days each, and the number of events occurring within a swarm area for each interval is plotted in a histogram manner. Examples of such plots are shown in Figure 2, which illustrates the difference between a typical swarm area (Wooded Island), events which fall in no swarm area, and events which occur below the basalt (deep events). There is a total of 1,699 earthquakes in these plots; 1,192 occur within 1 of the 13 selected swarm areas, 300 are shallow, but not in a swarm area, and 207 are deeper than 4 miles (6 kilometers) and these are lumped together in their own category. Thus, over 75 percent of the shallow earthquakes occurring in the last 10 years in this area occur as swarms in only 5 percent of the area.

FOCAL MECHANISMS

Events deeper than 4 miles (6 kilometers) do not cluster temporally or spatially as do the shallow events in the basalt. They occur in a broad, generally north-south band and exhibit many of the temporal characteristics of events near Lake Chelan; i.e., they occur as isolated events or in traditional main-shock/aftershock sequences rather than swarms.

Because of the shallow nature of the majority of the activity and the station distribution, it has been difficult to obtain well-constrained fault plane solutions for many events. At present, there are 12 solutions obtained using various techniques. A summary of these solutions is given in Table 2.

TABLE 2. Summary of Focal Mechanisms.

<u>Location</u>	<u>P-Axis</u>		<u>T-Axis</u>		<u>Comment</u>
	<u>Az</u>	<u>Dip</u>	<u>Az</u>	<u>Dip</u>	
	(degrees)		(degrees)		
Eltopia	168	2	80	55	Composite
Eltopia	170	8	380	28	Composite
Eltopia	183	2	130	88	Composite
Royal	180	5	350	88	Composite
Royal	353	25	143	69	Composite
Wallula	327	2	121	62	Composite
Ellensburg	324	23	203	52	Deep event
Chelan	321	3	58	58	Well controlled
Chief Joseph	129	3	24	68	Single event
Walla Walla	104	2	185	78	Poorly controlled
Midway	216	4	85	83	Two deep events
Horse Heaven Hills	324	0	229	78	Deep event

Of primary interest in this table is the common direction of the maximum stress direction, "P." The average azimuth is north 158 degrees east with a very shallow dip. This characteristic stress pattern seems to be similar over most of the northwest. There appears to be no evidence for major through-going fault structures, but, rather, the earthquakes seem to occur in response to a uniform stress field acting on small structures within the basalts.

FIGURE 2. Histogram Plotting of Events Occurring in Various Swarm Areas.

CURRENT PROJECT

There are several projects which are currently under way of interest to the waste isolation effort.

- Southern Cascade array expansion--The new stations in the southern Cascades along with some additional stations soon to be installed as part of a geothermal research project will be used for additional velocity structure studies.
- Down-Hole Project--A three-component, deep borehole seismic system including preamps has been acquired and is presently being tested in well DC-3 within the Hanford Site.
- On-Line Computer System--A real-time computer recording system is being implemented and should be operational in the near future.
- Regional Shear Wave Structure--A surface wave study is being conducted to determine the regional shear wave structure across the Cascades, using three long-period seismic systems.

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HIGHLIGHTS OF THE PROGRAM FOR REGIONAL MAPPING OF THE COLUMBIA RIVER BASALT GROUP

D. A. Swanson
U.S. Geological Survey
Menlo Park, California 94025

A reconnaissance geologic map (scale 1:250,000) of the Columbia River Basalt Group in eastern Washington and northern Idaho was completed during fiscal year 1979. Preliminary structure contour maps on the top of the Grande Ronde and Wanapum Basalts in eastern Washington were prepared. The geologic and structure contour maps will be released as U.S. Geological Survey open-file reports in late 1979. Geologic mapping is nearing completion in northeastern Oregon, and the main thrust of field work in fiscal year 1980 will be preparation of a map of the Columbia River Basalt Group in much of eastern Oregon and adjacent Idaho.

Mapping was conducted by full-time and temporary personnel of the U.S. Geological Survey. Nine geologists were involved in mapping areas throughout the Columbia Plateau; seven of these were active in fiscal year 1979. The stratigraphic nomenclature used in the mapping is as shown in Figure 2 of the paper by Dr. S. M. Price, and locations mentioned in the text are included in Figure 1 of this paper.

Personnel of the U.S. Geological Survey mapped along the western margin of the Columbia River Basalt Group from Cowiche Creek south to the Columbia River at White Salmon and westward through the Columbia Gorge to Cape Horn. Grande Ronde Basalt (both normal-2 and reversed-2) is the dominant stratigraphic unit. Flows are commonly pillowed, testifying to the presence of abundant water in rivers and lakes near the margin of the plateau. Invasive flows are common in micaceous and tuffaceous sedimentary interbeds. Major faults offset magnetic contacts and the Grande Ronde-Frenchman Springs contact.

Most of the faults are associated with anticlinal ridges. Vertical displacement of nearly 900 feet (300 meters) occurs on the Baldy fault northwest of Husum. Right-lateral displacement along several northwest-trending faults and lineaments is suggested by the en echelon arrangement of small anticlines along an extension of the Simcoe uplift southeast of Camas Prairie. The Frenchman Springs Member occurs north of Surveyors Creek, a tributary of the Klickitat River, and in the Columbia Gorge northwest of Cape Horn, and these two occurrences considerably extend the previously known limits of the member.

Personnel of the U.S. Geological Survey mapped the eastern half of The Dalles quadrangle and adjoining parts of the Yakima quadrangle in Washington. Both the Pomona and Umatilla Members and a flow of Lolo chemical type in the Priest Rapids Member pinch out toward the west within a 3.0- to 5.5-mile (5- to 9-kilometer) wide zone extending northwest from Rock Creek into the Yakima Indian Reservation. The Mabton Member of the Ellensburg Formation thins from east to west in this zone. The Selah Member thins near the Columbia Hills from 300 feet (100 meters) near

FIGURE 1. Location Index Map.

Sundale to 9 feet (3 meters) at Rock Creek. Another zone of stratigraphic change extends northeast from a point 5 miles (8 kilometers) north of Klickitat. The Roza Member lenses out against a possible extension of the Bingen anticline, and a Priest Rapids flow ends on the south flank of the Grayback Mountain anticline. Intracanyon flows of the Frenchman Springs Member partly fill a canyon eroded into a structural high, possibly in reversed-2 Grande Ronde Basalt north of Grayback Mountain. Thrust faults occur on both the northeast-trending Columbia Hills and Simcoe-Bickleton anticlinal ridges; they are associated with numerous low- and high-angle faults. A thrust crossing Rock and Chapman Creeks has a heave of 1 mile (1.6 kilometers) and a throw of only 750 feet (250 meters) and locally cuts gravel of The Dalles Formation. Structural relief on Grayback Mountain is at least 2,400 feet (800 meters); a thrust on the south side of the structure has a heave of at least 2,400 feet (800 meters) and a throw of more than 1,200 feet (400 meters). Many high-angle faults with northwest trends cross the area. The 3 largest fault systems with such a trend, the Arlington-Shutler Butte, Luna Butte, and Laurel, cross the Columbia Hills and extend into Oregon. They seem to be wrench structures in which narrow, doubly plunging anticlines and associated faults with variable senses of offset combine to form a continuous structure. The northwest structures apparently post-date the northeast-trending anticlinal uplifts, as their geometry is more clearly defined, appearing to interfere with the northeast structures, and their traces are remarkably straight. The Arlington-Shutler Butte and Luna Butte faults appear to cut Simcoe Mountains flows locally. One of the splays of the Luna Butte fault may be Quaternary, as it cuts an alluvial fan and possibly a landslide deposit between Rock Creek and Luna Butte.

The Horse Heaven Hills west of the Mabton-Bickleton road was also mapped by the U.S. Geological Survey. Thrusting occurs east of the road and roadcuts, but none was recognized west of the road. High-angle, normal faults with small displacements occur along the crest of the otherwise rather simple asymmetric anticline. The oldest flows exposed in the structure are in the Frenchman Springs Member; Roza, Priest Rapids, Umatilla, Pomona, and Elephant Mountain Members capped by Snipes Mountain conglomerate are all present. Possible right-lateral faults occur at the west end of the ridge.

Work continued by a geologist for Central Washington University in the area between the Columbia River and Yakima, concentrating on the Yakima Indian Reservation. Grande Ronde Basalt (reversed-2 and normal-2) and many representatives of Wanapum and Saddle Mountains Basalts are present. Within normal-2, the chemical break from low-magnesium oxide flows to high-magnesium oxide flows is sharp in all analyzed sections. Jointing and lithologic differences commonly allow the chemical break to be mapped in the field. The uppermost low-magnesium oxide flows are somewhat plagioclase-phyric south of the Simcoe-Horse Heaven ridge. The Frenchman Springs Member has its present western margin along a south-southwest line from Tampico to Grayback Mountain, but an outlier in the upper Klickitat drainage suggests that the member originally covered much of the upper Toppenish Creek Basin. The Roza Member has an irregular

western margin, possibly reflecting early structurally controlled topography along Toppenish and Ahtanum Ridges; in general, the margin follows a southwest trend from Yakima to near Mosier, Oregon. The Priest Rapids Member has a similar distribution as the Roza, but commonly extends 0.5 to 2.0 miles (1 to 3 kilometers) farther west. The western margin of the Umatilla Member was mapped between Wiley City and the area just east of Status Pass; the Umatilla fills an ancient canyon eroded into the Priest Rapids on lower Logy Creek. The Pomona Member has a western limit similar to that of the Umatilla on the Yakima Indian Reservation. The Pomona, however, extends farther west (south of the reservation) and is interbedded with The Dalles Formation southwest of Celilo, Oregon, proving time equivalency of the Ellensburg and The Dalles Formations. The Pomona forms a 300-foot (100-meter) thick intracanyon flow just south of Wiley City, probably within a valley of the ancestral Columbia River. The western margin of the Elephant Mountain Member was mapped from Black Rock Valley past Elephant Mountain to Toppenish Mountain and from there due south to just east of Roosevelt. Mapping of the Snipes Mountain conglomerate delineates the post-Elephant Mountain course of the ancestral Columbia River between the Yakima Valley and Hood River, Oregon, and earlier courses along Yakima Ridge were also recognized. Many faults, particularly of thrust and strike-slip nature, were mapped or interpreted. Thrust faults occur along the following anticlinal ridges: Toppenish; Ahtanum-Rattlesnake; Ortley; Columbia Hills; and, Whiskey Dick-Frenchman Hills. Strike-slip faults mostly trend northwest to north and have right-lateral movement. Young surface ruptures occur in three zones along the crest and north slope of Toppenish Ridge; these ruptures cut deposits interpreted as correlative with the Touchet beds, elsewhere dated at about 12,000 years old.

The U.S. Geological Survey completed mapping in the Grand Coulee area and on the Colville Indian Reservation. Grande Ronde Basalt (normal-2 and reversed-2) underlies the entire area. Frenchman Springs and Roza Members occur in Grand Coulee, but pinch out south of the Columbia River. The Priest Rapids Member extends across the river and occurs extensively on the reservation, particularly on the Omak Plateau. Small thrust faults were documented along the Coulee monocline, but in general the area is structurally simple. A previously reported structure, the Barker Canyon monocline, was found to be non-existent.

The U.S. Geological Survey completed geologic mapping in the Clearwater Embayment of Idaho. Four new and fairly extensive (39-square mile [100-square kilometer]) units in the Saddle Mountains Basalt were recognized. At least 3 are younger than a possible correlative of the Pomona Member. The 4 units are in the Canyon Creek, Craigmont, Ferdinand, and Grangeville areas, respectively, and do not all occur in the same section. In the Grande Ronde Basalt, reversed-2 is the youngest unit present; it very gradually pinches out along a northwest-trending line midway across the embayment. Normal-2 and reversed-1 units extend across the embayment, but both pinch out between Orofino and Little Green Mountain where the Priest Rapids Member rests directly on Imhaha Basalt. The Maggie Creek flow of Bend is the sole representative of normal-1 in the Stites area, where a local accumulation of reversed-2 flows, presumably near vents, also occurs. A source for the oldest intracanyon flow along the Snake River may be present in the upper reaches of the North

Fork of the Clearwater River; if so, this flow of Frenchman Springs major-element composition must have followed an ancestral Clearwater valley into the Lewiston area. The same may be true for a possible correlative of the Wilbur Creek Member. The dominant structural trend in the embayment is northwest, expressed generally by normal faults with displacements of less than 150 feet (40 meters) down to the southwest. However, faults with major displacement (greater than 300 feet [100 meters]) are significantly off this trend; these faults are the Limekiln, Mt. Idaho, Stites, and Cottonwood. Initiation of the Limekiln fault and uplift of the Craigmont Plateau occurred between reversed-2 and Priest Rapids time, as indicated by stratigraphic and distributional relations. The Mt. Idaho fault south of Grangeville was probably activated at about the same time.

Mapping by a geologist of Washington State University continued in northeastern Oregon and adjacent Idaho. Stratigraphic relations among several Saddle Mountains flows were clarified in the Minam-Palmer Junction-Elgin area. Some evidence suggests that northwest-trending, normal faulting took place in this area before Umatilla time, but after the eruption of olivine-rich flows informally named the Levi flows. Between the Imnaha and Salmon Rivers, flows of Imnaha Basalt and Grande Ronde Basalt (reversed-1, normal-1, reversed-2) dip gently northwestward, steepening to 5 degrees near the Salmon River and the west rim of Hells Canyon. A major fault trends south-southwest from Whitebird; the east side is downthrown 1,200 feet (600 meters) at Whitebird and more than 3,000 feet (1,000 meters) at Riggins. Reversed-2 Grande Ronde dies out just west of the fault. Two post-Grande Ronde flows lie unconformably on reversed-2 and normal-1 in this area. South of Hat Point, reversed-2 dies out. Near Cloverdale, the northwest dip changes to a gentle south dip of about 2 degrees, which extends south and east into the Wild Horse Creek area. The Imnaha Basalt thickens to 1,710 feet (570 meters), but reversed-1 retains its maximum thickness of 1,200 feet (400 meters). The southwest margin of the Hat Point block is complex, as the basalt is faulted and tilted southwest up to 15 degrees, producing the Halfway Basin. Faults are small, vertical, and trend northwest, with the north-east sides downthrown. Many of the faults curve and north- and north-east-trending faults are abundant. These structures may continue into the Weiser Embayment. A thick volcaniclastic deposit and a small, eroded cone occur near the top of normal-1 in the area. Many dikes of Imnaha and Grande Ronde Basalts occur south of Hat Point.

Mapping by a geologist of Oregon State University continued in the complex area of the Grande Ronde graben and Wallowa Mountains. Grande Ronde Basalt (all 4 magnetostratigraphic units) and several informal younger units, including a variety of andesite flows and 1 local basanite flow, occur in the area. The non-basalt flows are of Columbia River Basalt age, as krypton-argon ages of them range from about 10 to 13 million years. Five vents, 4 of which are aligned, have been mapped west of the graben. These vents consist of breccia pipes containing fragments both older and younger than the wallrock at the level of present exposure. The vents are younger than the andesite, which occurs at clasts in the vent breccia. A dike at least 5 miles (8 kilometers) long is spatially associated with the vents, but no related lava flow has been recognized. Fourteen normal faults, generally trending north-northwest,

have been mapped within an area extending 8 miles (13 kilometers) west of the west escarpment of the Grande Ronde graben, and at least 5 faults occur along the northward extension of the graben.

In summary, field work during fiscal year 1979 continued that of the previous year and greatly extended regional map coverage of the Columbia River Basalt Group. This work has not only delineated a wealth of important volcanologic, stratigraphic, and paleogeographic relations, but has also provided significant new insights and interpretations into the tectonic history of the region.

GEOPHYSICAL SURVEYS IN THE PASCO BASIN

R. C. Edwards
Rockwell Hanford Operations
Richland, Washington 99352

Geophysical surveys in the Pasco Basin during fiscal year 1979 were designed to meet two objectives; assist in the general definition of subsurface structures in the central Pasco Basin using standard geophysical surveys performed through subcontractors, and provide detailed geophysical profiles across specific structures in the Pasco Basin using high-resolution surveys performed by Rockwell Hanford Operations' geophysicists and equipment.

Figure 1 shows the location of geophysical surveys completed or in progress. All survey locations chosen were based on the need for detailed data along specific structures and across specific areas.

Standard surveys conducted by subcontractors for Rockwell Hanford Operations consisted of:

- Eighty-seven line-miles (140 line-kilometers) of VIBROSEIS seismic reflection surveying conducted along 8 individual survey routes;
- Twenty-six tensor magnetotelluric survey stations conducted on approximately a 6-square mile (10-square kilometer) grided pattern; and,
- Six hundred square miles (approximately 1,600 square kilometers) of constant elevation (4,000 feet [1,200 meters]), high-resolution aeromagnetic surveying using 0.5-square mile (0.8-square kilometer) loop-ties flight.

High-resolution geophysical surveys conducted by Rockwell Hanford Operations are indicated by hexagons on Figure 1. These surveys are being used to investigate specific structures identified by the Rockwell Hanford Operations' geologic staff or by the results of previous geophysical studies. The surveys have utilized the following methods:

- Gravity surveying with station spacing between 100 and 500 feet (30 and 150 meters);
- Land-born magnetic surveying using both total field and some vertical gradient techniques;
- Resistivity profiling and soundings using Wenner array, Lee array, Schlumberger array, and various dipole arrays;
- Turam electromagnetic survey looking for phase information from buried structures; and,
- High-resolution refraction seismic surveying.

FIGURE 1. Summary of Geophysical Investigations Conducted or in Progress.

Figures 2 and Figure 3 represent examples of geophysical survey results obtained to date; much interpretive work is under way. Figure 2 shows a short segment of a reflection seismic line where it crosses the Gable Butte-Gable Mountain structural trend. Figure 3, another example, is a contour map on the top of geoelectric layer 3, a highly conductive unit which is probably a layer of Mesozoic or early Tertiary sedimentary rocks, but whose exact lithology is unknown. This map was constructed from magnetotelluric data. Seismic reflection, magnetotelluric, and other geophysical data give the geologist a tool to examine the nature and attitude of subsurface strata without penetrating them.

The results obtained during the fiscal year 1979 geophysical surveys will aid the more intensified geophysical effort during the next few years for detailing candidate sites. The surveys will continue to use the above-mentioned techniques and other methods determined to be valuable in defining subsurface conditions.

Results of fiscal year 1978 geophysical surveys and preliminary results from fiscal year 1979 surveys have been integrated with results of geological studies.⁽¹⁾

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FIGURE 2. Reflection Seismic Section, Gable Mountain-Gable Butte Area.

FIGURE 3. Contour Map, Top of Goelectric Layer 3;
Magnetotelluric Data, Pasco Basin.

MAGNETOSTRATIGRAPHY OF THE GRANDE RONDE BASALT,
PASCO BASIN AND PRELIMINARY INVESTIGATION
OF THE MAGNETOSTRATIGRAPHY OF THE
RINGOLD FORMATION, WASHINGTON

D. R. Packer
Woodward-Clyde Consultants
San Francisco, California 94111

An important objective of the geologic studies conducted as part of the Basalt Waste Isolation Project is to evaluate the stratigraphic relations of the basalt flows in the upper Grande Ronde Basalt portion of the Columbia River Basalt. Previous paleomagnetic analyses of the Columbia River Basalt flows have resulted in the correlation of these sequences and have been reported by several researchers.⁽¹⁻⁴⁾

Magnetostratigraphy has been successfully applied to correlating portions of the upper Grande Ronde Basalt sequences which contain thick, internally dense flows and are currently being considered as potential repository host rocks. Whole-rock, major-element, chemical analyses have identified two sequences of basalt flows, Sentinel Bluffs and Schwana, as distinguishable on the basis of pronounced differences in the concentrations of several major elements, mainly magnesium. The paleomagnetic properties of the upper Grande Ronde Basalt flows exposed in Sentinel Gap were examined.⁽⁵⁾ That study⁽⁵⁾ indicated that the upper Grande Ronde Basalt at Sentinel Gap contains at least one polarity reversal and possesses significant differences in the inclination of the natural remanent magnetism direction.

Work was extended on the Grande Ronde Basalt from surface exposures to samples obtained from drilled cores as deep as several thousand feet (meters).⁽⁶⁾ That study correlated three magnetostratigraphic units through the upper Grande Ronde Basalt of the Pasco Basin subsurface on the basis of inclination variations and located a polarity reversal in one core hole, DH-5.⁽⁶⁾ That study established the feasibility of correlating flows of the Grande Ronde Basalt throughout the Pasco Basin using magnetostratigraphy and established preliminary magnetostratigraphic polarity boundaries and units having distinctly different inclinations that could be used for correlation.

The present studies were undertaken to evaluate in greater detail the paleomagnetic characteristics of magnetostratigraphy in the Grande Ronde Basalt sequence and correlate between selected core holes within the Pasco Basin. In addition, the paleomagnetic characteristics of selected portions of Saddle Mountains and Wanapum Basalt sequences in the Pasco Basin were evaluated. These sequences also possess variations in inclinations and polarity that make them suitable for magnetostratigraphic correlation using core hole samples in a manner similar to that for the Grande Ronde Basalt.

Results from 940 samples using approximately 7 samples per flow from 10 cores were analyzed. The cores were oriented with respect to up direction.

Results of the paleomagnetic measurements of samples from the holes sampled show four magnetic correlation lines between adjacent flows in holes that have distinctly different mean stratigraphic inclinations, and two magnetic polarity boundaries that can be used for magnetic correlation in the Grande Ronde Basalt in the Pasco Basin. The results of paleomagnetic measurements from the Wanapum and Saddle Mountains Basalts indicate that the potential for magnetostratigraphic correlation in these sequences is also good.

RINGOLD FORMATION

The Ringold Formation, because of its thickness, extent, and age, is an excellent unit in which to detect and date the deformation that has occurred since deposition of the basalt. The three facies of the Ringold Formation are present in and around the Pasco Basin and will be referred to as the upper, middle, and lower Ringold units. These units are based on the occurrence of clay, silt, sand, and ash in the upper unit, sandy conglomerate in the middle unit, and the "blue clay," consisting of clay, sand, and silt, in the lower unit. In the Pasco Basin, the fluvial and lacustrine nature of the Ringold Formation makes lithologic correlation of units over as few as several miles (kilometers) difficult, particularly in drilled holes. The age of the Ringold Formation is not fully known, although several authors have discussed the age of the upper Ringold unit on the basis of sparse fossil evidence. A preliminary investigation of the magnetostratigraphy of the upper Ringold unit exposed at White Bluffs was conducted for United Engineers and Constructors.⁽⁷⁾ That study concluded that both normal and reverse magnetic polarities were present in the upper Ringold unit and that paleomagnetism could be useful in the dating and correlation of these units.

One objective of the study conducted for Rockwell Hanford Operations was to investigate the paleomagnetism of the upper Ringold unit exposed at one location in the White Bluffs in enough detail to resolve, with reasonable confidence, the magnetostratigraphy of the rock units sampled. The other objective was to evaluate, in a preliminary manner, the magnetostratigraphy of the subsurface Ringold Formation in the Pasco Basin and at selected exposures outside the Pasco Basin. Two hundred ninety-four paleomagnetic samples were collected and measured during the study, 146 from outcrops in the Pasco Basin, 54 from outcrops outside the basin, and 94 from subsurface sections.

These studies reached the following conclusions:

- The magnetostratigraphy of the upper Ringold unit exposed in the White Bluffs at the Parsons Canyon-Ringold Flat sections has a 65.62-foot (20-meter) thick section of normal magnetic polarity at its base and is overlain by approximately 261 feet (110 meters) of section having reversed magnetic polarity; the caliche and loess that overlie this section have a normal magnetic polarity;

- The samples from the Ringold Formation exposed outside the Pasco Basin have normal and reversed magnetic polarity, magnetization that has predominantly consistent directions between paired samples, and magnetization directions that are generally consistent between adjacent sample horizons; they are thus favorable for paleomagnetic analysis;
- The samples from the subsurface in the Pasco Basin have normal and reversed magnetic polarity, and magnetization that has poor consistency between magnetization directions of paired samples and adjacent horizons;
- The polarity sequence at the Parsons Canyon-Ringold Flat sections and evidence of reversals in other parts of the Ringold Formation suggest that correlation of these units using paleomagnetism is possible; and,
- The reversed magnetic polarity sequence of the upper Ringold unit, if assumed to represent a period longer than 100,000 to 200,000 years, suggests, in conjunction with paleontological evidence, that this reversed sequence is within the Gilbert Reversed Epoch (the Gilbert Reversed Epoch is approximately 3,320,000 to 5,120,000 years of age).

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CHAPTER III - HYDROLOGY

CHAPTER III - HYDROLOGY

SUMMARY

The hydrology program provides hydrologic criteria and evaluation techniques by which potential repository sites can be identified and evaluated. Studies of the ground-water regimes underlying the Columbia Plateau are important, since the ground-water pathway probably affords the most direct contact between the repository and the biosphere. Thus, hydrologic studies have emphasized the gathering of data to characterize the ground-water system underlying the Columbia Plateau and the modeling of data needed to evaluate potential radiocontaminant transport to the biosphere. The hydrology program includes reconnaissance regional studies within the Columbia Plateau and intensive local studies within the Pasco Basin where the Hanford Site is located. The Pasco Basin was selected for detailed study because of its unique structural significance in the region; i.e., the greatest accumulation of basalt rock appears to occur within the Pasco Basin.

During fiscal year 1979:

- Existing ground-water and surface-water data were gathered and compiled to prepare a comprehensive analysis of the hydrology of the Columbia River basalts; and,
- A ground-water modeling program was initiated and preliminary simulations were conducted.

The hydrologic program includes field activities to determine the basic elements of ground-water flow, the ranges of hydraulic conductivity, and storage coefficients for basalts and sedimentary interbeds and the hydrochemistry of basalt ground waters and spring waters.

Approximately 125 spring sites were identified during fiscal year 1979 in the Rattlesnake Hills west of the Hanford Site. Detailed hydrochemical and isotopic data were collected at 23 of these sites.

During fiscal year 1979, ground-water samples were acquired and analyzed from 16 well and 8 spring locations identified within the Hanford Site. Existing water quality data were also analyzed from 7 wells in the north part of the Pasco Basin. Permeability tests and hydraulic heads were measured in the Rattlesnake Ridge, Cold Creek, Selah, and Mabton interbeds of the Saddle Mountains Basalt in boreholes DB-13 and DC-14, and in the Priest Rapids Member of the Wanapum Basalt in boreholes DB-12, 699-52-111, 699-52-115, and 699-53-103. Head and permeability measurements were also acquired in the Vantage interbed of the Wanapum Basalt in a dual borehole site located 1 mile (1.6 kilometers) northwest of the 200 West Area of the Hanford Site.

Within the Grande Ronde Basalt, 23 head measurements and 9 permeability tests were completed in separate interflows at 3 well sites located within the Hanford Site.

In the modeling area during fiscal year 1979:

- Reviewed and documented porous media ground-water flows and radionuclide transport theory and models applicable to Columbia River basalts;
- Performed preliminary review of fracture flow theory and modeling from the standpoint of Columbia River Basalt hydrologic analysis needs;
- Performed preliminary near-field model simulations of flow and radionuclide transport;
- Performed far-field model simulations of ground-water flow in deep basalts of the Pasco Basin;
- Initiated mathematical and numerical verification of selected flow and transport models; and,
- An initial set of ground-water flow model input data was assembled for the Pasco Basin (these data include geographic descriptions, hydraulic heads, hydraulic conductivities, storage coefficients, and boundary and initial conditions).

The results of the preliminary modeling work lead to the following generalizations:

- The flow fields established in the near field by hydraulic gradients across the system boundaries are strongly influenced by the presence and hydraulic properties of the repository;
- A repository backfilled with a permeable material such as gravel or crushed rock will induce a near-field flow system with a converging-diverging pattern at steady-state;
- A near-field flow system becomes independent of the repository characteristics at a certain level of permeability contrast;
- In a converging-diverging flow regime, the near-field contaminant plume exhibits a fanning-out pattern at the ends of the repository and a constriction at the center; and,
- The rate and extent of waste migration in a basalt environment are relatively small for mobile, long-lived nuclides.

DATA AVAILABLE FOR PASCO BASIN GROUND-WATER STUDIES

F. A. Spane, Jr.
Rockwell Hanford Operations
Richland, Washington 99352

Hydrologic data of varying quality and quantity are available for ground-water studies of formations within the Columbia River Basalt Group in the Pasco Basin. Most of the hydrologic data to date have been collected for the uppermost formation, the Saddle Mountains Basalt. In addition, data are not distributed uniformly throughout the basin. Data generally are more abundant and for specific aquifer systems within the Hanford Site, while hydrologic information for the remainder of the Pasco Basin is limited to isolated wells which are completed in multiple aquifer horizons. Therefore, data obtained for areas outside of Hanford are composite in nature and can be utilized only in a qualitative manner.

Hydrologic data available for ground-water studies can be grouped into three major categories. They include:

- Measurements of hydraulic head;
- Hydraulic property determinations; and,
- Hydrochemical analyses.

HYDRAULIC HEAD MEASUREMENTS

Where sufficient areal and vertical hydraulic head measurements are available, a general description of the flow dynamics; e.g., areas of recharge and discharge, ground-water flow pattern, etc., within specific geohydrologic units can be obtained. Table 1 lists the number of well sites where head measurements are available for individual aquifer systems within basalt formations at Hanford. As shown, the Saddle Mountains Basalt has the most areal hydraulic head measurements for formations of the Columbia River Basalt Group. In contrast, the Grande Ronde Basalt which has the fewest areal head measurements has the most sites where vertical head distributions are recorded.

In the basin area outside of Hanford, head measurements are limited to domestic and irrigation wells which are commonly completed in multiple aquifer horizons within the Saddle Mountains and upper Wanapum Basalts. Because of their composite character, head measurements can be utilized only to delineate areal potentiometric patterns. Approximately 93 potentiometric measurements are reported for the Saddle Mountains and Wanapum Basalts in the data files of the Washington State Department of Ecology. These measurements are of unknown quality, since they represent individual measurements taken over an extended time period; i.e., over the past 30 years by a multitude of individuals and agencies. No measurements are reported for the Grande Ronde Basalt.

TABLE 1. Hydrologic Data Available for Formations of the
Columbia River Basalt Group at Hanford.

<u>Hydrologic Data</u>	<u>Saddle Mountains (Well Sites)</u>	<u>Wanapum (Well Sites)</u>	<u>Grande Ronde (Well Sites)</u>
Hydraulic Head			
Areal	15	6	4
Vertical	3	2	4
Hydrologic Properties			
Hydraulic Conductivity	17	6	4
Storage Coefficient	0	4	4
Porosity	0	0	4
Hydrochemical Data			
Major Inorganic	14	7	4
Trace Element	14	7	4
Radioisotopic	14	5	4

HYDRAULIC PROPERTIES

Areal and vertical hydraulic property information for the various geologic formations is required to adequately model the ground-water flow systems within the Columbia River Basalt Group. Hydrologic property determinations which are reported at Hanford are primarily for hydraulic conductivity and storage coefficient. Only a few measurements are available for porosity.

The hydraulic properties were determined in situ by aquifer test procedures; e.g., air-lift and turbine pumping tests, injection and withdrawal tests, etc., and, in a few instances, by laboratory techniques.

Table 1 lists the distribution of hydraulic property determinations for formations at Hanford. As indicated, most hydraulic conductivity measurements are for the Grande Ronde Basalt. These measurements, however, are areally limited to four well sites. Storage coefficient measurements are available only for the Wanapum and Grande Ronde Basalts. Porosity measurements, which were estimated from borehole geophysical logs, are reported only for the Grande Ronde Basalt.

Outside of Hanford, meager information concerning hydraulic properties of basalt aquifers is available. This is primarily limited to 21 entries of specific capacity data listed on driller's logs for the area. These data are for composite aquifers within the Saddle Mountains and upper Wanapum Basalts and, by their nature, are very qualitative.

HYDROCHEMICAL DATA

In ideal situations, hydrochemical data can be utilized to provide hydrologic information concerning ground-water flow systems. Together with isotopic analyses, such data can evaluate and/or determine the:

- Origin and source of ground water;
- Areal ground-water flow patterns;
- Residence and travel time;
- Hydrochemical classification;
- Rock and ground-water reactions; and,
- Aquifer intercommunication.

However, the lack of extensive areal and vertical hydrochemical and isotopic data within the Pasco Basin precludes their use in quantitatively defining the hydrologic characteristics of ground-water flow systems within the Columbia River basalts.

Table 1 gives the distribution of hydrochemical data available for basalt formations at Hanford. As shown, most available hydrochemical data to date are for ground-water samples collected from wells completed in the Saddle Mountains Basalt. These data include analyses for major ions, trace elements, and selected water-quality parameters; i.e., silica, alkalinity, specific electrical conductivity, temperature, and pH. Only limited information is available for selected stable and radioactive isotopes. Radioisotopic data include $^2\text{H}^1\text{H}$, $^{18}\text{O}/^{16}\text{O}$, $^{13}\text{C}/^{12}\text{C}$, ^3H , and ^{14}C .

In the basin area outside of Hanford, hydrochemical data are available for composite samples from aquifers within the Saddle Mountains and Wanapum Basalts. The data are limited to major inorganic and selected trace element analyses. No radioisotopic determinations have been reported.

CURRENT AND FUTURE STUDIES

The basic thrust of current and future field hydrologic investigations in the Pasco Basin is toward the acquisition of new down-hole data. Studies conducted during fiscal year 1979 revealed that minimal data are available outside the Hanford Site upon which to base a hydrologic assessment of the Columbia River basalts; this is particularly true for the Wanapum and Grande Ronde Basalts.

During fiscal year 1980, hydrologic activities will be centering upon:

- Measurement and monitoring of hydraulic head measurements for existing wells completed in various formations of the Columbia River Basalt Group--Information obtained from this investigation will provide an updated potentiometric map for the Saddle Mountains Basalt within the Pasco Basin, produce an initial potentiometric map for the Wanapum and Grande Ronde Basalts at Hanford, and supply data which can be used to determine diurnal, seasonal, and regional responses of the various aquifer systems;
- Determination of hydraulic properties for geologic formations within existing wells and proposed boreholes--The hydraulic properties determined and testing techniques utilized are shown in Figure 1; locations of the research wells at Hanford which are being tested are shown in Figure 2; in addition to these wells, a selected number of existing wells outside of Hanford will be tested in various horizons of the Saddle Mountains and Wanapum Basalts;
- Characterization of the hydrochemical and isotopic content of ground water within the Columbia River basalts--Accompanying the hydraulic property testing program, an extensive hydrochemical sampling program was initiated; besides selected ground-water zones from wells mentioned above, sampling of springs in the surrounding tributary

METHODS OF TESTING	STATIC HEAD	HORIZONTAL PERMEABILITY	VERTICAL PERMEABILITY	STORAGE COEFFICIENT	EFFECTIVE POROSITY	DISPERSIVITY
<u>WATER POTENTIAL</u>						
Single Well	•					
Dual Well	•					
<u>PUMPING TEST</u>						
Single Well		•		•		
Dual Well		•	•	•		
<u>SLUG WITHDRAWAL TESTS</u>						
Single Well		•		•		
Dual Well		•	•	•		
<u>SLUG AND CONTINUOUS INJECTION TESTS</u>						
Single Well		•		•		
Dual Well		•	•	•		
<u>TRACER TESTS</u>						
Dual Well		•	•		•	•

FIGURE 1. Hydraulic Property Determinations from Various Testing Techniques Utilized during the Fiscal Year 1980 Field Program.

FIGURE 2. Hydrologic Testing Sites--Fiscal Year 1980.

areas of the Pasco Basin was initiated; data obtained on major inorganic and trace element chemistry, isotopic composition, and ground-water ages will provide insight into ground-water flow patterns, interactions, and residence times for aquifer systems within the Pasco Basin;

- Evaluation of borehole geophysical logs--In the past, many different logs have been acquired, but have not been fully interpreted to obtain quantitative information concerning hydrologic properties; the borehole logs will be analyzed to evaluate the following parameters--moisture content, porosity, relative permeability, and in-hole ground-water movement.

Starting in fiscal year 1981, a two-phase approach will begin in field testing. First, down-hole testing will take place in those boreholes cored within or near the primary reporting sites selected in fiscal year 1980. These data are designed to evaluate the hydrology of the potential repository sites and to integrate this into the known Hanford hydrologic setting. Secondly, coring and testing will begin outside Hanford to study the overall basalt hydrology of the Pasco Basin. Major questions requiring resolution in this area are:

- The areal and stratigraphic distribution of hydrologic properties, especially hydraulic heads and permeabilities, and of ground-water chemistries;
- Inter-aquifer communication both within the Columbia River basalts and between them and the overlying unconfined aquifer and rivers;
- Ground-water recharge and discharge areas for the Wanapum and Grande Ronde Basalts; and,
- Fracture hydrology of the specific basalt flows(s) at the site(s) selected for possible repository development.

GROUND-WATER HYDROLOGY OF THE COLUMBIA RIVER BASALTS
OF THE PASCO BASIN AND VICINITY

R. E. Gephart
Rockwell Hanford Operations
Richland, Washington 99352

This paper addresses three aspects of the basalt hydrology of the Pasco Basin and vicinity. They are:

- The basic elements of ground-water flow;
- The ranges of hydraulic conductivity and storage coefficients reported for basalts and sedimentary interbeds; and,
- The hydrochemistry of basalt ground water and spring waters.

ELEMENTS OF THE GROUND-WATER FLOW SYSTEM

Within the Pasco Basin, the Columbia River Basalt Group is composed of the Saddle Mountains, Wanapum, and Grande Ronde Basalts. Confined aquifers exist in some of the more permeable interflows and interbeds of these basalts. The dense interiors of many basalt flows act as low-permeable aquitards bordering these confined aquifers.

Recharge to the Saddle Mountains Basalt aquifers is from direct infiltration of precipitation and stream runoff in the Rattlesnake Hills, Yakima Ridge, Umtanum Ridge, and the Saddle Mountains (Figure 1). Figure 2 shows the potentiometric surface for head measurements within the Mabton interbed beneath the Hanford Site. The generalized ground-water flow direction is shown as eastward from areas of recharge. Examination of this figure indicates a pronounced ground-water recharge mound from which water moves radially outward.

Artificial recharge from irrigation in the Columbia Basin Irrigation Project occurs along the eastern and northeastern sections of the Pasco Basin. Scooteney Reservoir is located near the eastern edge of the Saddle Mountains and is probably a major, artificial recharge area.

Ground-water movement is assumed to conform closely to the regional dip of the rock as it travels toward areas of discharge. The major discharge area for Saddle Mountains Basalt ground water is probably the Columbia River between Richland and Wallula Gap in the Horse Heaven Hills. Here, the Saddle Mountains Basalt is in direct contact with the Columbia River beneath Lake Wallula. All hydraulic heads for Saddle Mountains Basalt are greater than the average Lake Wallula elevation of 340 feet (104 meters), so direct discharge to this lake is possible.

Areas of minor discharge are; the Yakima River west of Richland, where the level elevation of the river is 360 to 410 feet (110 to 125 meters), and, the Columbia River north of Umtanum Ridge, which

FIGURE 1. Generalized Location Map for the Pasco Basin and Vicinity.

FIGURE 2. Potentiometric Map for and Inferred Flow Directions of Ground Water within the Mabton Interbed beneath the Hanford Site.

intercepts southward ground-water flow from the western portion of the Saddle Mountains just east of Sentinel Gap.

Recharge from overlying and underlying aquifers can occur locally wherever favorable hydrogeologic and hydraulic head conditions exist. Although the degree of intercommunication and ground-water transfer between aquifers is largely unknown, evidence indicates that the unconfined aquifer and at least the Rattlesnake Ridge confined aquifer system of the Saddle Mountains Basalt are in hydraulic communication beneath portions of the Hanford Site (specifically in the West Lake-Gable Mountain Pond area on the southwest end of Gable Mountain and within paleostream channels which were incised into the basalt). (1,2,3)

Local recharge areas for the Wanapum Basalt aquifers are probably similar to those found within the Saddle Mountains Basalt, particularly along the western and northern boundaries of the Pasco Basin where both of these formations crop out. Thus, beneath the Hanford Site, it is expected that the general shape of the potentiometric surface for the upper Wanapum Basalt aquifers will approximate those given in Figure 2. The Columbia River between Sentinel Gap and Umtanum Ridge is likely a minor recharge area for the Wanapum Basalt (Figure 3).

Along the northwestern section of the Pasco Basin, portions of the Sentinel Bluffs and Schwana sequences of the Grande Ronde Basalt crop out on the northern flank of Umtanum Ridge and within Sentinel Gap. Here, the Columbia River is probably a source of local recharge to the Grande Ronde Basalt. Some local recharge is also expected to occur in the Rattlesnake Hills where this formation lies near ground level.

Extensive outcrops of Wanapum and Grande Ronde Basalts also occur west and north of the Pasco Basin. These exposures are within the Yakima River, Upper Yakima, and Kittitas Basins making up the western portion of the Columbia River Basalt Group. These outcrops, particularly those adjacent to the Cascade Range, probably contribute a major portion of regional recharge to the Wanapum and Grande Ronde Basalts that reaches the Pasco Basin through inter-basin movement (Figure 3).

Wanapum and Grande Ronde Basalts also crop out east of Walla Walla, Washington, in the Walla Walla River Basin, but the recharge of this area probably reaches no farther west than Lake Wallula.

The principal recharge to the Wanapum and Grande Ronde Basalts in the eastern Pasco Basin is from ground-water flow from the Palouse/Snake and Big Bend Basins (Figure 3). The Saddle Mountains Basalt forms the upper basalt formation in the eastern Pasco Basin area, so it receives most of the irrigation recharge from the Columbia Basin Irrigation Project not removed as stream runoff or unconfined aquifer recharge.

Wanapum and Grande Ronde Basalts crop out in the Snake River Gorge upstream from Ice Harbor Dam and also along the fringe of the Columbia Plateau. The Snake River is likely a discharge area for the Wanapum and Grande Ronde Basalts east and southeast of the Pasco Basin. Ground-water

FIGURE 3. Elements of the Wanapum and Grande Ronde Basalt Ground-Water Flow Systems.

discharge from these basalts is also to the Columbia River, probably in Lake Wallula or farther south in the Columbia Gorge where these basalts may be in hydraulic communication with the river. Such communication could occur as a result of vertical leakage in areas structurally deformed or through direct contact between the Columbia River and the basalts.

FLOW SYSTEM CLASSIFICATION

Ground waters present beneath the Pasco Basin are hydraulically influenced by the geohydrologic environment both within and outside the basin. While some aquifers recharge and discharge entirely within the basin, others do not. Table 1 summarizes some of the basic features of the flow systems present.

The shallowest system is the unconfined aquifer lying atop the basalts. It is essentially a local system being of limited areal extent and contained completely within the Pasco Basin.

The confined aquifers of the Saddle Mountains Basalt might also be classified as a local system. Although flow paths are longer than those in the unconfined aquifer, recharge and discharge boundaries remain mostly within the basin, except for some inter-basin ground-water transfer from the Big Bend and Palouse/Snake Basins.

The Wanapum and upper Grande Ronde Basalt aquifers are probably classified as an intermediate system, although the lower Grande Ronde Basalt may be part of a regional system. Both receive recharge from within the basin and from the surrounding plateau; however, their point of discharge is yet unknown.

CONDUCTIVITY AND STORAGE COEFFICIENT VALUES

Table 2 lists the ranges and most frequently reported values for hydraulic conductivity and storage coefficients within Columbia River basalts and sedimentary interbeds of the Ellensburg Formation. Of the 16 conductivity values determined for interbeds, all but 4 are between 10^1 and 10^2 feet per day (10^{-3} and 10^{-2} centimeters per second). No storage coefficients have been calculated for interbeds due to the absence of observation well data. However, because confined conditions exist, values of 10^{-3} to 10^{-5} are expected.⁽²⁾

For simplicity, zones of low-density basalt consisting of vesicular, brecciated, or rubbly rock are labeled as basalt interflows in Table 2. The 43 conductivity values reported range from 10^4 to 10^{-5} feet per day (10^0 to 10^{-9} centimeters per second). The highest conductivities are along a few permeable flow contacts.

Sections of high-density basalt normally correspond to entablature and colonnade flow structures. Conductivities for these zones are labeled under columnar basalts. Horizontal conductivities are between 10^{-3} and 10^{-8} feet per day (10^{-7} and 10^{-12} centimeters per second) with most reported values in the lower range of this spread.

TABLE 1. Basic Features of the Ground-Water Flow Systems Present beneath the Pasco Basin.

<u>Flow System</u>	<u>Geologic Unit</u>	<u>Recharge within the Pasco Basin</u>	<u>Discharge within the Pasco Basin</u>	<u>Ground-Water Contributions from Outside the Pasco Basin</u>
Unconfined Aquifer	Hanford and Ringold Formations	Major	Major	Minor
	Saddle Mountains Basalt	Major	Major	Minor
Confined Aquifers	Wanapum Basalt	Minor	Possible	Major
	Grande Ronde Basalt	Minor	Possible	Major

TABLE 2. Hydrologic Properties for Columbia River Basalts and Associated Sedimentary Interbeds.

<u>Rock Type</u>	<u>Range of Hydraulic Conductivity in Feet/Day (centimeters/second)</u>	<u>Range of Most Frequently Reported Hydraulic Conductivity Values in Feet/Day (centimeters/second)</u>	<u>Storage Coefficient</u>
Sedimentary interbed	10^{-1} - 10^2 (10^{-5} - 10^{-2})	10^1 - 10^2 (10^{-3} - 10^{-2})	10^{-3} - 10^{-5} (c)
Basalt Interflows(a)	10^{-5} - 10^4 (10^{-9} - 10^0)	10^{-1} - 10^{-5} (10^{-5} - 10^{-9})	10^{-3} - 10^{-4}
Basalt Columnar Sections(b)	10^{-3} - 10^{-8} (10^{-7} - 10^{-12})	10^{-5} - 10^{-8} (10^{-9} - 10^{-12})	10^{-5} - 10^{-6}

^aAny basalt zone consisting of vesicular, brecciated, or rubbly basalt.

^bAny basalt zone consisting of moderately fractured basalt of higher density than that reported in a.

^cSee Reference 4.

Storage coefficients for basalt interflows are approximately 2 orders of magnitude larger than those for columnar basalts.

BASALT HYDROCHEMISTRY

Table 3 lists the average and range of major inorganic constituents in ground water for the Columbia River Basalt Group in the Pasco Basin. These data indicate that ground water within the Saddle Mountains and upper Wanapum Basalts are hydrochemically similar and are of a sodium-bicarbonate chemical type. This is graphically shown in Figures 4 and 5. Figure 6 is a map locating the well and spring sites sampled for the chemical analyses. No information is currently available for the lower Wanapum Basalt. The few ground-water samples available from the Grande Ronde Basalt are of a sodium-chloride, bicarbonate chemical type and thus chemically distinct from the other two basalt formations (Figure 7). In addition, comparisons of average chemistries reveal that the Grande Ronde Basalt possesses higher dissolved solids concentrations (particularly chloride, sulfate, fluoride, sodium, and silica) than ground water in the Saddle Mountains or Wanapum Basalts.

These distinct differences in chemical types suggest a lack of hydraulic communication between aquifers in the Saddle Mountains/upper Wanapum Basalts and those in the Grande Ronde Basalt.

The distribution of total dissolved solids and inferred flow directions of ground water within the Mabton interbed beneath the Hanford Site from these data compare favorably with the ground-water flow pattern from the potentiometric map shown in Figure 2.

Trace element concentrations in the Columbia River basalts are low or below detection limits. Those elements most frequently detected in ground water from the Saddle Mountains and upper Wanapum Basalts are aluminum, barium, boron, iron, and strontium. Grande Ronde Basalt waters contain these plus bromine and zinc. Range in trace element concentrations compare reasonably well with published values.⁽³⁾

Available radioisotopic data for Columbia River basalts are limited to a few radionuclides (tritium, 180 , and ^{14}C) and these are mostly from ground water sampled from the Saddle Mountains Basalt. Tritium levels are at detection limits (~ 0.01 tritium units), except when drilling fluid contamination entered the borehole. The areal distribution of 180 data for the Mabton interbed compares reasonably well with the ground-water flow pattern suggested by the potentiometric map in Figure 2; i.e., increased 180 concentrations (-20 to -17 δ^{180} standard mean ocean water) with distance from recharge areas. Carbon-14 data also support this trend.

Oxygen-18 ratios for Grande Ronde Basalt do exhibit isotopically heavier values (-15 to -16 δ^{180} standard mean ocean water) in comparison to values cited for the overlying basalts. The heavier trend may be attributed to greater thermal effects and isotopic exchange which probably occur within the deeper ground-water flow systems.

TABLE 3. Average Composition and Range in Concentration of
Major Chemical Constituents within Ground Water
for Formations of the Columbia River Basalt Group.

	<u>Lower Saddle Mountains Basalt</u>	<u>Upper Wanapum Basalt</u>	<u>Grande Ronde Basalt</u>
<u>ANIONS*</u>			
HCO ₃ ⁻	217 (169-267)	177 (141-216)	75 (66-88)
CO ₃ ⁼	0	0	59 (101-127)
Cl ⁻	20 (4.3-63)	6.6 (3.8-15)	131 (98-148)
SO ₄ ⁼	4.0 (.3-18)	11 (.2-32)	72 (13-108)
NO ₃ ⁻	.5 (.5)	.5 (.1-2.7)	**N.D.
F ⁻	2.2 (.1-8.0)	.7 (.2-2.0)	29 (21-37)
<u>CATIONS*</u>			
Na ⁺	83 (36-122)	34 (17-80)	225 (182-250)
K ⁺	11 (7.7-14)	11 (5.9-19)	2.5 (1.9-3.3)
Ca ⁺⁺	4.7 (.5-22)	17 (1.6-24)	1.1 (.8-1.3)
Mg ⁺⁺	1.8 (1.-12)	8.8 (.2-15)	.7 (.0-2.0)
SiO ₂	69 (56-91)	57 (41-73)	117 (115-121)
Total Dissolved Solids (sum)	413 (344-505)	324 (283-435)	705 (584-826)

*Concentrations in milligrams per liter.

**N.D. = Not Detected.

○ Spring issuing from the Saddle Mountains Basalt

• Well sample from the Mabton interbed of the Saddle Mountains Basalt

➡ Increasing flow distance from areas of recharge

FIGURE 4. Chemical Composition of Springs and Ground Water Sampled from the Saddle Mountains Basalt.

o Spring issuing from the upper Wanapum Basalt

· Well sample from upper Wanapum Basalt
outside of Cold Creek syncline

x Well sample from upper Wanapum Basalt
within Cold Creek syncline

➡ Increasing flow distance from areas of recharge

FIGURE 5. Chemical Composition of Springs and Ground Water Sampled from the Upper Wanapum Basalt.

FIGURE 6. Ground-Water Sampling Sites.

PERCENT REACTING VALUES (equivalents)

- GROUND-WATER SAMPLE FROM GRANDE RONDE BASALT IMMEDIATELY BELOW UMTANUM UNIT, AT WELL DC-1
- ▲ COMPOSITE GROUND-WATER SAMPLE FROM GRANDE RONDE BASALT PRIMARILY FROM 600 FEET (183 METERS) BELOW UMTANUM UNIT, AT WELL DC-6

FIGURE 7. Chemical Composition of Ground Water Sampled from the Grande Ronde Basalt.

SPRING HYDROCHEMISTRY

Approximately 125 spring sites were identified during fiscal year 1979 in the Rattlesnake Hills west of the Hanford Site. Detailed hydrochemical and isotopic data were collected at 23 of these sites.

On an average, spring waters possess a low total dissolved solids content (<350 milligrams per liter) with the principal chemical constituents being bicarbonate, silica, calcium, and sulfate. Trilinear plots (Figures 4 and 5) of the hydrochemical data suggest an overall uniformity in composition (principally a calcium-bicarbonate chemical type). Concentration levels for trace elements such as aluminum, barium, boron, and iron are low or below detection limits.

Tritium concentrations of generally between 5 and 50 pico curies per liter suggest recent spring water origin. Deuterium and ^{18}O data indicate that the spring waters are of meteoric origin with no major alteration or mixing with ground water of different origins.

Springs issue from the basalt whenever a local decrease in the conductivity of the rock forces ground water to the surface. In the Rattlesnake Hills, springs exist throughout the entire elevation range of exposed basalt.

FISCAL YEAR 1979 FIELD WORK

During fiscal year 1979, ground-water samples were acquired and analyzed from the 16 well and 8 spring locations identified within the Hanford Site on Figure 2. Existing water quality data were also analyzed from 7 wells in the north Pasco Basin. Permeability tests and hydraulic heads were measured in the Rattlesnake Ridge, Cold Creek, Selah and Mabton interbeds of the Saddle Mountains Basalt in boreholes DB-13 and DC-14, and in the Priest Rapids Member of the Wanapum Basalt in boreholes DB-12, 699-52-111, 699-52-115, and 699-53-103. Head and permeability measurements were also acquired in the Vantage interbed of the Wanapum Basalt in the dual borehole site located 1 mile (1.6 kilometers) northwest of the 200 West Area of the Hanford Site.

Within the Grande Ronde Basalt, 23 head measurements and 9 permeability tests were completed in separate interflows at 3 well sites located within the Hanford Site.

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GROUND-WATER MODELING--AN OVERVIEW

R. C. Arnett
Rockwell Hanford Operations
Richland, Washington 99352

An adequate assessment of the hydrologic regime for a subsurface radioactive waste repository requires knowledge of ground-water flow dynamics along all potential flowpaths leading to the biosphere. Basically, all the subsurface hydrologic data gathering and analysis are designed to:

- Identify all potential flowpaths from a repository site to the biosphere;
- Predict the range of velocities and, therefore, the travel time of radioactive contaminant movement along those paths;
- Predict, with acceptable certainty, the concentration and distribution of radionuclides at the biosphere arrival location(s); and,
- Provide input to biotic transport and dosimetry models.

To address the above goals, it is necessary to adequately define the subsurface hydrologic regime and apply such definitions in a dynamic manner by means of a set of analogs or models. The fundamental steps in the hydrologic analysis process of moving from an initial system identification to an impact assessment is presented in Figure 1.

FUNDAMENTAL CONCEPTS

The basic phenomena involved with possible radionuclide transport through the ground-water flow system are convective flow, hydrodynamic dispersion (including diffusion), radioactive decay, and chemical interactions such as radionuclide sorption on the rock matrix. In creating the mathematical analog of the system, the distribution of ground-water potential energy is represented by a single equation (for single-phase flow), often referred to as the ground-water flow equation. The movement of solutes such as radionuclides within the ground water is represented by a transport equation which includes terms for convective velocity, dispersion, decay, and chemical interactions. The influence of a thermal source is represented by the heat transport equation where the heat field influences the ground-water flow field and vice versa. In such a case, it is necessary to solve the energy balance equation and the ground-water equation in coupled fashion. The convective velocity is obtained from the ground-water potential energy distribution by means of a governing relationship such as Darcy's law. Thus, the results of the flow equation are used to determine the convective velocity field for the transport equation.

FIGURE 1. Fundamental Steps in the Hydrologic Analysis Process.

Away from the immediate vicinity of the waste canisters, it can be assumed, in most cases, that transport factors do not influence the potential energy distribution. In practical terms, this means that the fluid velocity field can be determined over the entire simulation period and the resultant information preserved and input to the transport model at a later time. The prediction of the flow field and contaminant movement is a sequential operation under this assumption.

NEAR FIELD

The important physical processes occurring within the near-field zone are often highly interdependent, as shown graphically in Figure 2. A comprehensive analysis of simultaneous fluid flow, stress, heat, and radionuclide transport is limited by the fact that an integrated computer simulation methodology does not yet exist. Nevertheless, there is a broad set of computational models which will be useful in near-field simulations. A list of representative computational models is presented in Table 1. These models vary in complexity in terms of the processes modeled. In most cases, these models are designed to be used conjunctively, rather than by themselves.

FAR FIELD

The heat transport and stress field influences are, by definition, insignificant in the far-field ground-water system, so that the physical processes reduce to a simulation of the ground-water flow field which feeds into radionuclide transport modeling. The output of the ground-water transport model may be used directly to formulate a system description and risk assessment or as input to biotic transport and dose models. The relationship is shown in Figure 3.

As in the near-field models, far-field model analysis is best served by a suite of models, each of which have certain strengths and limitations depending upon the mathematical formulation, assumptions, numerical method, and convenience. Table 2 is a brief summary of a set of representative far-field models which appear to have capabilities useful in the Basalt Waste Isolation Project. Ongoing model development by various public and private organizations is expected to result in improvements and a general advance in modeling capability.

VERIFICATION

One of the necessary steps in modeling is to verify the numerical algorithm of the computer code. One means of accomplishing this is to compare the numerical model against analytical solutions. Figure 4 shows a comparison of the Rockwell Hanford Finite Element (RHAFE) numerical model to an analytical solution of leaky aquifer flow.⁽¹⁾

The three-dimensional Rockwell Hanford Finite Element numerical model is being applied to the Pasco Basin system. The initial finite element network for the basin is shown in Figure 5. The finite element method permits irregular node spacing. This capability is used to locate the model nodes at actual well sites in many cases. In this way, the

FIGURE 2. Relationship of Processes and Properties in Near Field.

TABLE 2. Computational Models for Far-Field Analysis.

Fluid Flow	Radionuclide Transport
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TABLE 1. Computational Models for Near-Field Analysis.

Model Name	Reference	Approach			Fluid Flow		Stress				Heat		Radionuclide		
		PM	CO	NC	IS	NI	IS	NI	LI	NL	AD	DS	S	MC	DC
GWTherm/ Damswel	2	X				X		X	X			X		X	
STEALTH	3	X				X		X		X	X	X			
MERCER	4	X				X					X	X			
DUGUID	5		X		X		X		X						
GALE	6			X	X		X		X						
WILSON	7			X	X		X								
TERZAGHI	8	X			X										
SWIFT	9	X				X					X	X	X	X	X
FECTRA	-	X	X										X		
CHAINT	-	X	X										X	X	X

PM - Porous Media
 CO - Continuum Fracture
 NC - Non-continuum Fracture Flow
 IS - Isothermal
 NI - Non-isothermal
 LI - Linear Properties

NL - Non-linear Properties
 AD - Advection
 DS - Dispersion
 S - Single
 MC - Multi-component
 DC - Decay Chains

FIGURE 4. Comparison of Rockwell Hanford Finite Element Numerical Model and Hantush Analytical Model.

FIGURE 5. Preliminary Finite Element Network for the Pasco Basin.

measurements at actual well sites can be directly input to the model without spatial interpolation. In a similar fashion, the model results can be checked against measurements in the calibration process. The finite element model was initially applied to the Pasco Basin in a simple, one-layer situation. More recently, four-layer definition has been input to the model.

Preliminary model analysis is under way to incorporate more realistic definition into the model input and to obtain estimates of the possible radionuclide travel times to the biosphere in the deep basalt system of the Pasco Basin.

FISCAL YEAR 1979 ACCOMPLISHMENTS

During fiscal year 1979:

- Reviewed and documented porous media ground-water flow and radionuclide transport theory and models applicable to Columbia River basalts.
- Performed preliminary review of fracture flow theory and modeling from the standpoint of Columbia River Basalt hydrologic analysis needs.
- Performed preliminary, near-field model simulations of flow and radionuclide transport.
- Performed simple, far-field model simulations of ground water in deep basalts of the Pasco Basin.
- Initiated mathematical and numerical verification of selected models.
- Assembled an initial set of ground-water flow model input data for the Pasco Basin. These data included geographic descriptions, hydraulic heads, hydraulic conductivities, storage coefficients, and boundary and initial conditions.
- Reviewed and documented the basic theory of uncertainty applicable to ground-water modeling.
- Assembled several useful "data models;" i.e., parameter estimation, Kriging.

FISCAL YEAR 1980 PLANNED EFFORT

In order to meet programmatic requirements during fiscal year 1980, the following hydrologic modeling studies will be completed.

- Update the Pasco Basin model input to include at least four layers.

- Update the hydrologic data base to be used in support of model calibration, verification, and parameter estimation. Prepare up-to-date documentation of data used in modeling studies.
- Perform initial calibration of Pasco Basin model and document results.
- Perform near- and far-field scenario analyses using the computational models to estimate ground-water travel times, arrival locations, and possible radionuclide concentrations at the biosphere.
- Conduct sensitivity and parameter estimation analyses to determine the range of reasonable conditions and parameters to be used in modeling studies. This effort is to be closely coordinated with field hydrologists and other technical contributors to the Basalt Waste Isolation Project.
- Prepare documentation on porous media models including theory, numerical techniques, user information, and results of code verification and baseline testing.
- Acquire, test, and evaluate selected fracture media models as needed for coupled flow, heat transport, rock stress and strain, and contaminant transport. Document review of basalt fracture flow theory and models.
- Provide positive feedback to field hydrologists and others in designing optimum data collection efforts. The data modeling efforts are expected to be particularly useful in this regard.

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PRELIMINARY MODEL SIMULATIONS

R. G. Baca
Rockwell Hanford Operations
Richland, Washington 99352

The isolation of spent fuel in a nuclear waste repository is dependent on such basic factors as longevity of the spent fuel container, waste form leach resistance, and barrier effectiveness of the geologic media. Long-term isolation of the radionuclide wastes, however, is ultimately dependent on the performance of the geologic medium as a natural barrier. To examine the fundamental relationships between the hydrologic and transport characteristics of a basalt system and to test existing computer codes, a series of computer simulations were undertaken. The computer simulations presented here are based on a hypothetical release scenario considering ground-water intrusion and leaching over a 50,000-year period. An analysis of the transport processes occurring in the near-field zone is performed to evaluate the rate and extent of waste migration from a generic, hypothetical nuclear waste repository in basalt.

MODELING METHODOLOGY

The modeling methodology used in this preliminary transport analysis is based on computer simulations obtained with the Sandia Waste Isolation Flow and Transport model.⁽¹⁾ Two-dimensional simulations are performed which consider flow and transport processes within a vertical cross section. Three key radionuclides are modeled consisting of: ^{14}C , ^{99}Tc , and ^{129}I . These particular radionuclides were selected because other modeling studies^(2,3) have consistently shown that these radionuclide species contribute a significant portion to the overall dose risk for a geologic repository and generally exhibit low to non-sorbing characteristics in basalt (i.e., more mobile nuclides).

A simple, conceptual model was adopted for the physical system consisting of 6 major layers, 2 of which represent confined aquifers (Figure 1). This conceptual model and the hydraulic characterization of the strata are consistent with the data recently used in thermomechanical modeling of a nuclear waste repository in basalt by the University of Minnesota.⁽⁴⁾ The hydrologic boundary conditions are based on a gradient of 7.92 feet per mile (1.5 meters per kilometer), which creates a flow field from left to right. The specific hydraulic properties used in this conceptual model are listed in Table 1. The hydraulic conductivity and porosity values are derived from the data collected for the Columbia Plateau basalts at Hanford.⁽⁵⁾ This particular conceptual model is not intended to realistically portray all of the significant hydrologic characteristics of the Columbia Plateau basalts; rather, it is simplified so as to promote the development of a fundamental understanding of the dominant transport processes.

FIGURE 1. Conceptual Model for a Nuclear Waste Repository in Basalt Media.⁽⁴⁾

TABLE 1. Hydraulic Properties for Conceptual Model.

<u>Rock Layer</u>	<u>Thickness (meters)</u>	<u>Hydraulic Conductivity (meters per second)</u>	<u>Effective Porosity (cubic meter per cubic meter)</u>	<u>Bulk Density (kilogram per cubic meter)</u>
Sediments	300	1×10^{-6}	0.10	1,800
Basalt	400	1×10^{-9}	2.5×10^{-3}	2,900
Sandstone	4	1×10^{-6}	0.10	1,930
Basalt	482	1×10^{-9}	2.5×10^{-3}	2,900
Fractured Basalt	4	1×10^{-6}	0.10	1,930
Basalt	1,818	1×10^{-9}	2.5×10^{-3}	2,900

Projections for the wastes generated by the entire United States' nuclear power industry through the year 2000 are used as a basis to quantify the waste inventory for these radionuclides; the actual data used are shown in Table 2 along with nuclide parameters. Transport parameters were assigned the following values:

Longitudinal Dispersivity, D	250.0 feet (76.0 meters)
Lateral Dispersivity, D_t	25.0 feet (7.6 meters)
Molecular Diffusivity, D_d	8.6×10^{-6} feet per second (8.0×10^{-7} square meters per second)
Tortuosity Factor, T	10.

TABLE 2. Waste Inventory and Nuclide Parameters.

<u>Element</u>	<u>Half Life (years)</u>	<u>Specific Activity (curies per gram)</u>	<u>Initial Inventory (gram)</u>	<u>Source of Estimate</u>
^{14}C	5730.	4.46	2.31×10^5	PNL*
^{99}Tc	2.1×10^5	1.72×10^{-2}	6.99×10^{11}	ORNL**
^{129}I	1.7×10^7	1.63×10^{-4}	4.93×10^7	PNL

*Pacific Northwest Laboratory.

**Oak Ridge National Laboratory.

These dispersivities are representative of values estimated for the unconfined aquifer at Hanford (6) and used in previous ground-water modeling studies.(7) These values are 1 and 2 orders of magnitude higher than those values cited in the literature for crystalline rock.(8) Consequently, the assigned values should tend to enhance the overall rate of migration.

In specifying the hypothetical release scenario, the following set of very conservative conditions is assumed to exist:

- Repository contains the entire year 2000 spent fuel inventory and has been backfilled;
- All boreholes and shafts have been plugged and sealed;
- Ground water completely fills the repository immediately after closure; i.e., instantaneous resaturation phase; and,
- The waste form is completely leached in 10,000 years.

In addition to these primary assumptions, the effects of the thermal field are neglected and it is assumed that all strata behave as porous media.

MODEL APPLICATIONS

The physical presence of the repository within its host medium can have some impact on the natural flow patterns. In turn, alterations on the flow paths affect the patterns of waste migration. To evaluate the importance of the repository characteristics on flow and transport, two model applications were made. The hydraulic properties assigned to the repository system were varied so as to represent two different backfill materials. The first case, for example, assumes that the properties of the backfill are the same as those of the intact dense basalt strata. In the second case, however, it is assumed that the backfill material is similar to a coarse gravel or crushed rock. Data used in these cases are listed in Table 3.

TABLE 3. Hydraulic Properties for Backfill Material.

<u>Case</u>	<u>Material</u>	<u>Hydraulic Conductivity (K)* (meters per second)</u>	<u>Effective Porosity (cubic meter per cubic meter)</u>
1	Basalt	1×10^{-9}	2.5×10^{-3}
2	Gravel	$1 \times 10^{+0}$	0.45

*Note: $K \text{ (meters per second)} \times 2.84 \times 10^5 = K \text{ (feet per day)}$.

To apply the Sandia Waste Isolation Flow and Transport computer model, a finite-difference grid system was constructed to represent the near-field simulation area (Figure 2). A fine-grid network was specified in the immediate vicinity of the repository where the concentration gradients would be the greatest. For each grid block of the computational network, the computer model provides a numerical solution to the governing flow and transport equations. Primary computer output consists of pressure, Darcian flow velocities, and radionuclide concentrations for successively larger increments of time.

Case 1 - Repository with Basalt Backfill

In Case 1, the repository is assumed to have the same hydraulic properties of its host medium. Consequently, the unidirectional flow patterns are established with flow from left to right. By virtue of the low-hydraulic conductivity of basalt, the Darcian flow velocities in the horizontal direction achieve a steady-state magnitude of about 7×10^{-7} feet per day (2.5×10^{-12} meters per second). This relatively low-flow velocity suggests that dispersion; i.e., macroscopic mixing, will tend to be the dominant transport mechanism since advection will be very small. This observation is confirmed in the contour plots shown in Figure 3 (a, b, and c) for time equal to 50,000 years after closure. The contours for the various radionuclides show that the repository behaves as a finite line source; as a result, the primary direction of waste migration is normal to the longest axis of the repository. As illustrated in the time history plot, Figure 4, only ^{129}I exceeds the maximum permissible concentration level at a location of 65 feet (20 meters) above the center point of the repository; beyond 164 feet (50 meters), the ^{129}I concentrations are significantly below the maximum permissible concentration.

The primary observation that can be made for this case is that the rate of waste migration is so small that the radionuclides do not reach the major water-bearing zones in the sandstone and fractured basalt layers after 50,000 years. In the case of ^{99}Tc and ^{14}C , it is likely that these two components eventually decay away before reaching the confined aquifers; whereas, the ^{129}I could potentially reach those zones, but at trace levels. Longer term simulations would be needed to confirm this observation.

Case 2 - Repository with Gravel Backfill

For Case 2, the repository system is assigned hydraulic properties which are typical of gravel or crushed rock.⁽⁹⁾ The sharp contrast in hydraulic conductivity and porosity between the repository and the host medium produces a significant alteration of the unidirectional flow field. Steady-state flow patterns show a converging-diverging flow zone around the repository. This indicates that the repository is, in a sense, drawing the water toward it. The maximum horizontal (Darcian) velocity through the repository system, for example, increases to about 0.9×10^{-3} feet per day (3.2×10^{-9} meters per second).

FIGURE 2. Computational Network for Near-Field Simulation.

FIGURE 3a. Case 1-Concentration Contours at 50,000 Years, Technetium-99.

FIGURE 3b. Case 1-Concentration Contours at 50,000 Years, Carbon-14.

FIGURE 3c. Case 1-Concentration Contours at 50,000 Years, Iodine-129.

Figure 4. Case 1-Concentration Histories for a Point above Repository.

Higher velocities and complex flow fields significantly enhance the effects of hydrodynamic dispersion which, in turn, spreads the contaminant plumes. This effect is illustrated in the contour plots shown in Figure 5 (a, b, and c) for 50,000 years. In the vicinity of the repository, the rate and extent of radionuclide migration have increased substantially from that observed for Case 1. The contours exhibit a unique spreading effect, which manifests itself in a "fanning out" of the plume at the ends of the repository while constricting at the center. This effect is better explained by the steady-state pressure contours and flow lines which are shown in Figure 6.

It is interesting to note that ^{99}Tc which possesses the largest initial inventory, 6.69×10^{11} grams, exhibits the least spreading after 50,000 years; whereas, ^{129}I spreads the most. This is explained by the differences in sorption properties; i.e., retardation effects (see Table 3). The contour plots also show that, after 50,000 years, only trace levels of ^{129}I reach the fractured basalt layer where they are further diluted, but spread horizontally. The ^{14}C plume in Figure 5(b) shows a lesser degree of spreading than ^{129}I , although they possess the same sorption properties in basalt; since ^{14}C has a shorter half-life (5,730 years) than ^{129}I , the dispersion effects on the ^{14}C plume are offset by the decay process.

Closure

A basalt environment, such as the Columbia River Basalt Group, is characterized by a collection of strata which generally exhibit sharp contrasts in their dimensions and, more importantly, in their hydraulic properties. These particular aspects uniquely determine the nature and mechanics of flow and transport in a basalt environment. The relatively simple conceptual model used in the simulations of a hypothetical, geologic repository provide a basis for building a quantitative understanding of these phenomena.

From the three simulations presented herein, the following major generalizations can be made.

Fluid Flow

- The flow fields established in the near field by hydraulic gradients across the system boundaries are strongly influenced by the presence and hydraulic properties of the repository.
- A repository backfilled with a permeable material such as gravel or crushed rock will induce a near-field flow system with a converging-diverging pattern at steady-state.
- The near-field flow system becomes independent of the repository characteristics at a certain level of permeability contrast.

Nuclide Transport

- The transport of mobile nuclides in dense, intact basalt is dominated by hydrodynamic dispersion.

FIGURE 5a. Case 2-Concentration Contours at 50,000 Years, Technetium-99.

FIGURE 5b. Case 2-Concentration Contours at 50,000 Years, Carbon-14.

FIGURE 5c. Case 2-Concentration Contours at 50,000 Years, Iodine-129.

* 1 MPa $\approx$ 145 psi

FIGURE 6. Steady-State Pressure Contours and Flow Lines.

- In a converging-diverging flow regime, the near-field contaminant plume exhibits a fanning-out pattern at the ends of the repository and a constriction at the center.
- The rate and extent of waste migration in a basalt environment are relatively small for mobile, long-lived nuclides.

It should be kept in mind that these generalizations are limited by the scope of the conceptual model and the definition of the release scenario adopted for this preliminary transport analysis.

With regard to nuclear waste isolation and system performance, these simulation results indicate that the hypothetical basalt system is highly effective as a natural barrier to waste migration. This conclusion and its significance are further amplified when one reflects on the conservative basis of the release scenario; e.g., repository contains the entire spent fuel inventory for the year 2000, immediate ground-water intrusion after closure, waste form is completely leached in 10,000 years, and high dispersion characteristics. Since the nuclides modeled in this analysis represent the most mobile nuclides in the spent fuel inventory, they provide an upper bound for the behavior of less mobile species such as the actinide elements. Recent simulations of major actinide chains; e.g., uranium series, neptunium series, and actinium series for the same period of waste isolation (50,000 years), have confirmed this conclusion.

The results of this recent study demonstrate the value of detailed simulations in providing insight to complex processes. Moreover, these results illustrate the capability of existing models to simulate ground-water transport of radionuclides over long periods of time. Future transport modeling studies will extend the current analysis to evaluate longer term waste isolation periods such as 500,000 to 1,000,000 years. In addition, the level of detail and complexity of the conceptual model will be increased. Other processes influencing the waste migration patterns will be considered such as simultaneous heat transport and rock stress and strain.

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CHAPTER IV - ENGINEERED BARRIERS

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SUMMARY

The emplacement of nuclear waste in the geologic repository may cause physicochemical perturbations to the surrounding environment. The engineering barriers program attempts to identify, from a physicochemical standpoint, the features of various barriers to transport of radioactive contaminants. The program evaluates four potential barriers: the waste; the rock; the container; and, the overpack. In addition, a borehole plugging system is being designed as a final barrier once the repository is sealed and abandoned. To assess the effectiveness of such a multiple barrier system, one examines chemical changes which could lead to chemical reactions, both at the canister (phase transformation/ dissolution) and outside the repository (dissolution/precipitation and sorption/desorption).

During fiscal year 1979:

- A multiple barriers study program including the experimental and theoretical characterization of the chemical environment of a potential waste repository was initiated; and,
- A borehole plugging program involving selection, testing, demonstration, and evaluation of materials for plugging man-made openings--boreholes, shafts, and tunnels--in a nuclear waste repository excavated in Columbia Plateau basalt was initiated.

The multiple barriers activity is comprised of four subdivisions: characterization; emplacement environment; waste/barrier/rock interactions; and, barrier optimization. Tasks in these subactivities were intended to yield reliable requisite source term input to the hydrologic and radionuclide transport models being developed. Such computer codes were used to assess the effectiveness of various engineered and natural barrier assemblages for preventing release of intolerable amounts of various radionuclides to the biosphere.

The major part of the laboratory work in the multiple barriers activity is concentrated in the hydrothermal, geochemistry, and sorption chemistry tasks. These studies serve as the focal point to assess and demonstrate the performance of natural and engineered barriers under both near- and far-field conditions. The Pennsylvania State University scientists, under contract with Rockwell Hanford Operations, have for some time now been studying hydrothermal interactions of non-radioactive waste forms, Columbia Plateau basalts, and synthetic Hanford ground water. When completed, these tests will provide a baseline for formulating and conducting hydrothermal tests with radioactive waste forms. Rockwell Hanford Operations and Pacific Northwest Laboratory are conducting far-field sorption tests.

The borehole plugging study is being conducted by Woodward-Clyde Consultants as part of the Basalt Waste Isolation Project of Rockwell Hanford Operations. The objectives of this study are to: (a) characterize the natural environment within shafts, tunnels, or borings which penetrate the geologic units at or near a repository in basalt; (b) to identify candidate plugging materials which are compatible with the existing or anticipated environmental conditions; (c) to review methods of placement for plug materials or systems; and, (d) to provide a preconceptual design for a plug system in man-made openings (boreholes, shafts, and tunnels excavated during repository construction) that will assure containment of radioactive waste products after closure of the repository. The specific purpose of the plug system will be to prevent the migration of harmful amounts of radioactive waste to the biosphere. Work completed to date has addressed characterization of the plugging environment, identification of candidate plugging materials, selection of several candidate materials for further physical and chemical testing, and identification of techniques which may be suitable for placement of the various plug materials.

TECHNICAL OVERVIEW OF THE MULTIPLE
BARRIERS PROGRAM

W. W. Schulz
Rockwell Hanford Operations
Richland, Washington 99352

The Engineered Barriers Project of the Basalt Waste Isolation Project comprises both the borehole plugging activity and the multiple barriers activity. As its name implies, the former study involves selection, testing, demonstration, and evaluation of materials for plugging man-made openings--boreholes, shafts, and tunnels--in a nuclear waste repository excavated in Columbia Plateau basalt. A separate paper by Mr. H. Ewoldsen of Woodward-Clyde Consultants discusses the details and current status of the borehole plugging activity.

The goal of the multiple barriers activity is to specify engineered barrier systems for each candidate high-level waste form (e.g., canister, overpack, backfill, etc.) which, acting in concert with natural geologic barriers, will prevent migration of unacceptable amounts of radionuclides to the biosphere. Several highly important experimental characterization, hydrothermal, and sorption tasks must be successfully completed to achieve this goal. Following a brief resume of the multiple barriers concept, this overview highlights the various tasks including their organization, their interactions with one another, and their contribution to the goals and objectives of the multiple barriers activity. This review concludes with a listing and discussion of some of the significant technical milestones achieved thus far. Much more technical detail is provided in other papers in this report as authored by Drs. B. E. Scheetz and G. S. Barney.

MULTIPLE BARRIERS CONCEPT/SYSTEMS

Figure 1, adapted from a recent Sandia Laboratories publication,(1) illustrates the now familiar multiple barriers concept for disposal of spent fuel or high-level nuclear waste in a geologic repository. In this system, the high-level waste form or spent fuel in its container is encapsulated in a suitable metallic or ceramic canister; in some cases, the resulting assembly may be sealed (overpacked) in a second metallic container. Waste canisters are inserted into holes drilled into the repository floor or walls and the holes are subsequently backfilled with materials; e.g., clay minerals for sorbing mobile radionuclides and/or intrusive ground water. The waste form-canister-overpack-backfill "package" makes up the engineered barriers. The final barriers in this defense-in-depth system are the natural geologic strata. For a repository excavated in Columbia Plateau basalts, the natural barriers include both fresh and altered basalts, secondary minerals which fill vugs, and interbed material.

FIGURE 1. Generalized Multiple Barriers Concept for Geologic Nuclear Waste Disposal Storage.

The multiple barriers approach has been widely accepted in the United States by governmental agencies^(2,3) and by the scientific community as an important and useful means of guarding against unacceptable release of radionuclides to the biosphere. Suitability and applicability of a multiple barriers system to long-term United States' high-level defense waste has recently been recommended and endorsed.⁽¹⁾ Most recently (November 1979) in two position papers,^(4,5) the U.S. Nuclear Regulatory Commission has stated that multiple barrier specifications and criteria will be included in a forthcoming federal regulation (Title 10, Code of Federal Regulations, Chapter 60) controlling disposal and/or storage of nuclear waste in geologic repositories. Acceptance of the multiple barriers approach represents a departure from previous philosophy of storage in the United States which had placed great emphasis on the primary barrier of the geologic host rock in containment of radionuclides. Adoption of the multiple barriers approach recognizes the uncertainty in predicting long-term geologic changes and also the complex geochemical mechanism which occurs at depths.

Pioneering Swedish scientists⁽⁶⁾ established a significant benchmark in barrier development and concepts with their studies of copper, lead-lined titanium, and α -alumina canisters and bentonite-quartz backfill materials. Braithwaite and Magnani⁽⁷⁾ in the United States have recently evaluated various metals and alloys as potential materials for construction of nuclear waste canisters and overpacks.

MULTIPLE BARRIERS ACTIVITY--ORGANIZATION AND TASKS

The multiple barriers approach to geologic storage of nuclear wastes is fairly new. A compendium which lists reliable and time-tested engineered barriers and assemblages has not yet been published. The Swedish studies and the generic barrier investigations provide useful guidelines for barrier selection. There still exists, however, a need to organize and conduct extensive laboratory work to select, test, and evaluate engineered barrier components which are specifically tailored for use in a nuclear waste repository sited in the Columbia Plateau. The multiple barriers activity of the Basalt Waste Isolation Project is organized (Figure 2) to meet this site-specific need.

The multiple barriers activity comprises four major subdivisions: characterization; emplacement environment; waste/barrier/rock interactions; and, barrier optimization. Tasks in these subactivities are intended to yield reliable requisite source term input to the hydrologic and radionuclide transport models being developed by members of the Hydrology Group. These computer codes, as discussed in the paper by Drs. S. E. Logan and R. B. Lantz, will be used to assess the effectiveness of various engineered and natural barrier assemblages for preventing release of intolerable amounts of various radionuclides to the biosphere.

As indicated in Figure 2, the characterization tasks are concerned with acquiring a detailed knowledge of the natural barriers; e.g., basalt, secondary minerals and interbed materials, and ground waters, with which

FIGURE 2. Major Tasks of the Multiple Barriers Activity.

the engineered barrier materials will complement and/or interact. Much useful data about basalts and ground water will come from work of the Geosciences and Hydrology Groups of the Basalt Waste Isolation Project. Additional information about these materials required for specification of engineered barriers will be obtained as part of the multiple barriers activity. An important task of the characterization subactivity is to document, from literature sources, chemical and physical properties of various high-level waste forms. Such information is necessary to meet the goal of specifying at least one satisfactory barrier assemblage for each candidate waste form. Currently, the candidate waste forms are spent fuel, glass, and supercalcine; other waste forms will be added to this list as necessary.

Included in the barriers optimization subactivity are the important tasks of testing, demonstrating, evaluating, and, finally, choosing canister, overpack, and backfill materials for use in the Basalt Waste Isolation Project. Available literature covering a broad list of candidate engineered barrier materials is currently being reviewed to choose preliminary reference barriers for laboratory testing. Follow-on hydrothermal reaction tests will be performed with selected canister and overpack materials to measure their resistance to attack by Hanford ground water at expected repository temperature and pressure conditions. Bench-scale studies of backfill materials will initially emphasize their ability to sorb and bind key mobile radionuclides. Hydrothermal behavior and interactions of backfill materials under near-field conditions are important concerns to be determined. Effects of radiation on the physical and chemical properties of the various engineered barriers need to be established. Availability of technology and equipment to satisfactorily emplace single or multiple-component backfill materials will also be addressed.

The major part of the laboratory work in the multiple barriers activity is concentrated in the hydrothermal, geochemistry, and sorption chemistry tasks. These studies serve as the focal point to assess and demonstrate the performance of natural and engineered barriers under both near- and far-field conditions. The Pennsylvania State University scientists, under contract with Rockwell Hanford Operations, have for some time now been studying hydrothermal interactions of non-radioactive waste forms, Columbia Plateau basalts, and synthetic Hanford ground water; status and results of these important tests are presented in a subsequent paper by Dr. B. E. Scheetz. When completed, these tests will provide a baseline for formulating and conducting hydrothermal tests with radioactive waste forms. In a later paper, Dr. G. S. Barney will discuss conditions and results of far-field sorption tests currently being performed by Pacific Northwest Laboratory scientists under contract to Rockwell Hanford Operations.

A basic goal of the near-field radionuclide behavior task is development of thermodynamic data bases and models and computer codes to adequately model the chemical regime in the near-field region of a basalt repository. Evolution of such models and codes will permit realistic, predictive, time-dependent simulations of the several chemical reactions--canister and waste form dissolution, mineral precipitation,

radionuclide sorption--which can or will take place in near-field areas of opened and sealed repositories. Such tools will be highly useful to support and extrapolate results of laboratory-scale hydrothermal tests. More important, the models and codes developed in this task will serve to generate vital and valid source term input to the far-field hydrologic and radionuclide transport codes.

Appropriate data validation technology will be provided under the barrier optimization subactivity. This technology will be used to track and verify the source and authenticity of the characterization, hydrothermal, sorption, and other results produced by the diverse tasks of the multiple barriers activity. These data must be assimilated, correlated, and integrated before their application and role in formulation and specification of reliable and economically tenable engineered barrier systems can be defined. The formidable, but highly essential, job of reviewing and overviewing multiple barrier activity data and programs will be conducted by both in-house experts and outside consultants. This continuing review process will provide the means to ensure that a quality product is delivered on a schedule consistent with overall Basalt Waste Isolation Project needs.

TECHNICAL ACCOMPLISHMENTS AND STATUS

All of the experimental work of the multiple barriers activity completed to date has been performed by outside contractor scientists. Significant progress has been made, as indicated in Table 1, in sorption studies and in non-radioactive hydrothermal testing. Details of this progress will be given in the reports of Drs. Scheetz and Barney. Dr. L. V. Benson and his colleagues at Lawrence Berkeley Laboratory have extensively characterized secondary minerals present in various Columbia Plateau basalt formations; part of this continuing study has already been documented.⁽⁸⁾ Also, as part of their work for the multiple barriers activity, Dr. Benson's team is developing and applying thermodynamic models and computer codes; e.g., Wolery code,⁽⁹⁾ etc., to describe near-field reactions of various radionuclides to form stable minerals. Considerable progress in this latter area has been made in modeling the behavior of uranium, plutonium, strontium, and cesium.

A recent build-up of in-house staff will facilitate and permit necessary program acceleration. Experimental barrier characterization and non-radioactive hydrothermal tests are presently scheduled to continue through fiscal year 1982. These efforts will provide a solid foundation for formulation and conduct of highly important hot cell hydrothermal tests with actual waste forms. Barrier assemblages which survive rigorous static and flow-through radioactive hydrothermal tests will become serious contenders for use in a nuclear waste repository located in basalt. In preparation for the hot cell tests, our current goal is to be able to fully specify by the end of fiscal year 1982 up to three candidate engineered barrier assemblages for each waste form.

TABLE 1. Multiple Barriers Activity--Significant Accomplishments 1977-1979.

- HYDROTHERMAL WASTE/ROCK INTERACTION STUDY
First (non-radioactive) phase completed (The Pennsylvania State University).
- IDENTIFICATION AND DISTRIBUTION (VERTICAL/RADIAL) OF SECONDARY MINERALS
Preliminary study completed and documented (Lawrence Berkeley Laboratory).
- FAR-FIELD SORPTION TESTS
Determined K_d values (25 to 60 degrees centigrade; 1 bar) for distribution of key radionuclides between synthetic ground water and candidate basalt flows (Pacific Northwest Laboratory).
- THERMODYNAMIC MODELING OF MINERALIZATION REACTIONS
Developed model for describing reactions of uranium, plutonium, cesium, and strontium to form stable minerals under repository near-field conditions.
- CANISTERS, OVERPACKS, BACKFILL
Preliminary list compiled of candidate barrier materials for use in a nuclear waste repository in basalt.

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STATUS OF THE STATIC, CLOSED SYSTEM, HYDROTHERMAL ALTERATION
EXPERIMENTS OF SIMULATED NUCLEAR WASTE FORMS

B. E. Scheetz, S. Komarneni, D. K. Smith
Materials Research Laboratory
The Pennsylvania State University
University Park, Pennsylvania 16802

Part of the waste management effort at The Pennsylvania State University has dealt with the stability of candidate waste forms under "worst case" repository conditions. These studies were composed of three different types of experiments, each of which were designed to provide needed data on the stability of the simulated waste forms. The initial studies were performed at 100-degree-centigrade intervals between 100 and 400 degrees centigrade for durations of 1 month with all of the waste forms, both alone and in the presence of basalt. These "scoping" studies established that marked alteration could be anticipated at the higher temperature studies and that between 200 and 300 degrees centigrade, a sharp increase in reactivity was observed. Short-term experiments of only 1-month duration suggested that equilibrium was not achieved.

The second series of experiments, designated "reconnaissance" experiments, were conducted at 100-degree-centigrade intervals up to 300 degrees centigrade for durations up to 1 year. The experiments were designed to look for an approach to equilibrium. For those experiments conducted at temperatures less than 300 degrees centigrade that have been analyzed, equilibrium has not yet been achieved. Hydrothermal treatments at 300 degrees centigrade for up to 6 months have not yet reached an equilibrium phase assemblage. Neither the scoping nor the reconnaissance experiments addressed the partitioning of cations between the solid and liquid components of the hydrothermal system.

Detailed studies were conducted at temperatures up to 300 degrees centigrade for up to 6 months with each of the waste forms alone and in the presence of basalt. Analyses of the liquid phase as well as the solid products from the experiments were completed. The importance of the solution analyses at the lower temperatures must be emphasized in light of the limited alteration that was observed. The behavior of each of the waste forms will be discussed in detail.

Spent fuel elements were prepared for the hydrothermal experiments.⁽¹⁾ The spent fuel elements formulation was susceptible to leaching in these experiments even at 100 degrees centigrade (Table 1). Nearly 9 percent of the total available cesium was detected in solution at 100 degrees centigrade along with about 6 percent of the strontium and 7 percent of the molybdenum. At 200 and 300 degrees centigrade, nearly 100 percent of the cesium was detected in solution. Under similar experimental conditions, but in the presence of basalt, only about 2 to 4 percent of the cesium was detected in solution at 200 degrees centigrade after up to 4 months of hydrothermal treatment (Table 2).

TABLE 1. Average Concentrations and Percentages
Extracted for Selected Cations of Each
of the Three Waste Forms.

<u>Waste Form</u>	<u>PNL 76-68 Glass</u>		<u>Supercalcine SPC-4</u>		<u>Spent Fuel Elements</u>	
<u>Waste Loading</u>	<u>33%</u>		<u>70%</u>		<u>100%</u>	
	<u>pg/ml</u>	<u>%</u>	<u>pg/ml</u>	<u>%</u>	<u>pg/ml</u>	<u>%</u>
	100°C					
Cesium	2	0.2	20.5	0.3	24	8.9
Strontium	0.5	0.5	1.3	0.04	5.4	5.9
Molybdenum	11	0.9	31	0.6	24	6.8
	200°C					
Cesium	3.3	0.3	8.5	0.2	363	100
Strontium	60	-	0.5	0.005	1	1.1
Molybdenum	68	4.4	72	1.3	308	87
	300°C					
Cesium	48	4.9	17.5	0.4	265	94
Strontium	1.3	0.4	1.6	0.05	ND	-
Molybdenum	1,100	72	387	7.1	190	64

Averages represent the results of multiple experiments of 1, 2, 3, and 4 weeks duration at 300 bars; water-to-solids ratio is 1:10.

TABLE 2. Percentages Extracted for Selected Cations of Each
of the Three Waste Forms in the
Presence of Basalt.

<u>Waste Form</u>	<u>PNL 76-68 Glass</u>	<u>Supercalcine SPC-4</u>	<u>Spent Fuel Element</u>
	<u>%</u>	<u>%</u>	<u>%</u>
	100°C		
Cesium	2.6	ND	-
Strontium	0.4	0.3	-
Molybdenum	2.5	0.4	-
	200°C*		
Cesium	2	0.3	1
Strontium	ND	0.1	ND
Molybdenum	2.5	1.8	ND
	300°C*		
Cesium	22	0.4	ND
Strontium	0.4	0.1	ND
Molybdenum	70	0.5	ND

*Experimental duration: 4 months at 300 bars.

The alteration of supercalcine in parallel experiments to the spent fuel elements released 0.3 percent of the total available cesium into solution at 100 degrees centigrade along with 0.6 percent of the molybdenum and 0.04 percent of the strontium. At 200 degrees centigrade, 0.2 percent of the cesium was detected in solution along with 1.3 percent of the molybdenum and a trace amount of strontium. Sodium appears in solution at 20 percent of the total available in the original solids. The amount of cesium detectable in solution at 300 degrees centigrade increased to 0.4 percent of the total, while molybdenum increased to 7.1 percent and strontium increased to 0.05 percent. Sodium substantially increased to 80 percent of the total available in the original solid. When supercalcine was treated hydrothermally in the presence of basalt, the values for cesium, molybdenum, and strontium were generally lower at all temperatures. (Sodium that exhibited a large release into solution at 300 degrees centigrade was present at about 8 percent of the total available in the original solid.)

Pacific Northwest Laboratory 76-68 simulated waste glass was the third waste form that was hydrothermally treated under similar conditions as supercalcine and spent fuel elements (Table 1). At 100 degrees centigrade, 0.2 percent of the total available cesium was detected in solution, 0.9 percent of the molybdenum, and 0.5 percent of the strontium. The percentages in solution increase only slightly at 200 degrees centigrade to 0.3 percent of the cesium, 4.4 percent of the molybdenum, and no detectable strontium. However, at 300 degrees centigrade, 4.9 percent of the cesium was detected in solution, along with 72 percent of the molybdenum, and 0.4 percent of the strontium. In addition, those components of the glass-forming network, boron and silicon, are present at 88 percent and 5 percent, respectively.⁽²⁾

Glass in the presence of basalt (Table 2) exhibits a release of 2.6 percent of the total cesium into solution at 100 degrees centigrade, along with 2.5 percent of the molybdenum, and 0.4 percent of the strontium. At 200 degrees centigrade, the values for the concentrations of cesium, molybdenum, and strontium do not change significantly. Experiments conducted at 300 degrees centigrade, however, had analyses for cesium in solution as high as 22 percent of the total of the cesium in the original solids, 70 percent of the molybdenum, and 0.4 percent of the strontium. At the higher temperature in the glass-forming element, boron is present at 88 percent of the original present in the solid, while silicon was detected only at 1 percent of the original amount.

Characterization of the solid alteration products from these experiments was performed with the aid of a scanning electron microscope. No phases could be recognized in the spent fuel elements and spent fuel elements/basalt experiments that could not be accounted for in the original starting materials. Two different types of alteration products were observed in the supercalcine and supercalcine/basalt experiments. The first represented a dissociation of the pollucite and scheelite phases in the original waste form followed by a precipitation of similar phases (pollucite and scheelite), but with different bulk chemical compositions. The second type of alteration product observed consisted of

phases that were not present in the original phase assemblage of the waste form. These phases included two unidentified phases, one a barium-aluminosilicate and the other a potassium-aluminosilicate. At 300 degrees centigrade, glass and glass/basalt mixtures exhibited extensive alteration. For the most part, those phases formed in the presence of basalt were the same as the phases formed as the alteration products of glass alone. Two exceptions to this statement were noted. The pyroxene formed in the presence of basalt appears to contain more reduced iron than the pyroxene that formed in the alteration of the glass alone. This difference was manifested in the dark body color of the acmite-augite compound. The final difference recognized was the formation of quartz when glass altered in the presence of basalt.

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AN OVERVIEW OF SORPTION STUDIES

G. S. Barney
Rockwell Hanford Operations
Richland, Washington 99352

The most likely mechanism for transport of non-gaseous radionuclides from a nuclear waste repository is dissolution of the waste form and transport of fission products and actinides in ground water. Migration of the dissolved radionuclides will be retarded by sorption on the overpack, backfill, basalt, secondary minerals, interbed materials, or sediments in the flow path of the contaminated ground water. The most useful measure of the ability of these materials to retard migration is the distribution ratio (K_d) which is defined as the ratio of the activity sorbed on the solid to that in solution (not necessarily at equilibrium). Values of K_d along with other relevant parameters (permeability, leach rate, radioactive decay, etc.) will be used to model radionuclide transport.

SORPTION PARAMETERS

The objective of these sorption studies is to obtain K_d values of key radionuclides under conditions which exist in the ground-water flow path. Values of K_d for trace amounts of radionuclides in a geologic environment are controlled by a large number of variables. Those variables which have been identified thus far include the following:

- Composition of the solid phase (elemental composition, phase composition);
- Physical characteristics of the solid phase (surface area, particle size, porosity);
- Chemical reactivity of the solid phase (cation and anion exchange capacity, solubility, hydrolysis and other reactions with the liquid phase, sorption isotherms);
- Composition of the liquid phase (cation and anion concentrations, pH, Eh, colloid concentration);
- Identification of the chemical species and concentration of the radionuclide sorbed;
- Time;
- Temperature and pressure; and,
- Radiation.

In addition to providing essential information for modeling radionuclide migration, sorption data will be used to determine the needs and priorities for development of engineered barriers for specific radionuclides. Overpack and backfill materials may be designed to retard migration of a radionuclide that is identified as being mobile in the geologic environment.

SORPTION METHODOLOGY

Experimental techniques can have a large effect on measured K_d values. Careful separation of solids and liquid is essential to prevent error due to the presence of colloids and radiocolloids. Variations in technique and their effects on K_d measurement are listed in Table 1.

TABLE 1. Effects of Various Experimental Procedures on K_d Measurement.

<u>Procedure</u>	<u>Effect on K_d Measurement</u>
1. Addition of tracers: a. in solution; b. dry.	Tracer solution may alter ground-water composition. Dry tracer compound will have minimum effect on ground-water composition.
2. Filtration of spiked ground water.	Filtration will eliminate any precipitated tracer; i.e., $\text{Pu}(\text{OH})_4$.
3. Pre-equilibration of ground water with geologic material.	Avoids changes in ground-water composition due to sorption of macrocomponents.
4. Equilibration in various containers.	Tracers sorb more strongly onto some container materials than others.
5. Crushing and sieving of the geologic materials.	May change the surface area and the number of sorption sites.
6. Solid-liquid separation after equilibration: a. centrifugation; b. filtration; c. ultrafiltration.	May leave solids in solution. May leave colloids in solution and may sorb tracer on filter. May sorb tracer on filter.

Table 1 (continued)

<u>Procedure</u>	<u>Effect on K_d Measurement</u>
7. Equilibration of various tracer/solution/solid.	If sorption isotherm is non-linear, these ratios will affect K_d .
8. Measurement of container wall sorption.	May be important for radionuclides which tend to precipitate.
9. Agitation during equilibration.	Vigorous agitation may produce fines due to abrasion of solid surfaces.

KEY RADIONUCLIDES

Radionuclides have been identified which pose the greatest potential threat to mankind during storage of radioactive wastes in a deep repository. The criteria used for selection of these radionuclides are as follows:

- Amount of radionuclide present in irradiated uranium fuel;
- Half-life;
- Probable physical and chemical forms;
- Biological half-life;
- Known sorption properties; and,
- Leach rate from waste form.

Combining all these criteria, the following list of elements appears to be of greatest importance:

Actinides

Neptunium
Uranium
Radium
Americium
Plutonium

Fission Products

Iodine
Cesium
Technetium
Selenium
Strontium
Tin
Europium

REVIEW OF SORPTION DATA

Radionuclide sorption on crushed basalt at room temperature has been studied by a number of researchers. Radionuclide sorption kinetics have been studied;⁽¹⁾ some radionuclides are sorbed very slowly by crushed basalt and other rocks. Neptunium sorption from synthetic ground-water solution continued even after 218 days of equilibration. Strontium sorption required about 75 days and cesium about 10 days to reach a constant concentration. These slow reactions are probably due to changes in the composition of the solution and rock surface with time. The basalt slowly dissolves during contact with ground water and eventually colloidal particles are formed which contain silicon, iron, calcium, and aluminum. Radionuclides such as cesium, strontium, neptunium, americium, and plutonium are strongly sorbed onto these colloids.

Cesium sorption on basalt has been shown to be strongly influenced by cesium concentration in solution.⁽²⁾ Values of K_d increase as the tracer concentration decreases. This is due to the non-linearity of the sorption isotherm in the concentration range 10^{-10} to 10^{-5} million cesium.

The presence of oxygen in ground-water solutions during equilibration with basalt and other igneous rocks has been shown to strongly affect sorption of certain radionuclides. When oxygen is excluded during equilibration of ground water with basalt from Sentinel Gap, sorption of technetium and neptunium is drastically increased.⁽³⁾ The relatively mobile species TcO_4^- and NpO_2^+ , which are stable in solutions in contact with the atmosphere, are reduced to immobile TcO_2 and NpO_2 by Fe(II) in the basalt. Other radionuclide species that might reasonably be affected by Fe(II) reduction include UO_2^{2+} , SeO_4^{2-} , and $Sn(OH)_6^{2-}$.

Sorption of selenium, strontium, technitium, iodine, cesium, radium, neptunium, uranium, americium, and plutonium on samples of crushed basalt from three different flows (the Umtanum, Flow E, and Pomona basalts) has been studied.⁽⁴⁾ For identical particle sizes, sorption varied significantly for the different sources of basalt. For example, cesium sorption increased in the order Flow E < Umtanum < Pomona. The approximate order of increasing sorption for the radionuclides was $I \approx U < Se < Tc < Np < Ra < Sr < Pu < Am < Cs$. Values of K_d ranged from 0 milliliter per gram for iodine and uranium to about 2,000 milliliters per gram for cesium after equilibration for 83 days. These measurements were made in the presence of atmospheric oxygen. In a reducing environment, the order of increasing sorption could change.

The effects of temperature on sorption have also been studied.⁽⁴⁾ Sorption was measured at three temperatures: 23; 60; and, 150 degrees centigrade. Values for iodine, neptunium, and uranium remain nearly constant over this temperature range. Values for cesium and americium decreased as the temperature increased; and selenium and strontium increased as the temperature increased. Sorption appears to rise and fall in response to presently unknown reactions between the solution, rocks, and radionuclide.

In addition to the batch sorption experiments outlined above, several column experiments have been described.^(2,5) The movements of plutonium in ground-water solution through fissures in basalt were modeled by construction of an artificial fissure in a sample of basalt from the Experimental Breeder Reactor II site. The top of the fissure was spiked with plutonium, and water was pumped through at a slow, steady rate. The fissure was then scanned for alpha activity. Two peaks were observed, one due to a tightly bound plutonium species on the fissure surface and a second peak representing a more mobile form of plutonium. Rock columns were also made of granulated basalt. Cesium-spiked solutions were passed through the columns and the effluent was sampled and analyzed for the tracer. A significant fraction of the cesium is held up in the rock columns after passage of the main cesium peak. This effect may be due to diffusion of cesium into intergranular sites in the bulk of the rock material and appears to be very significant in the retardation of cesium in flowing ground water.

Preliminary studies of radionuclide sorption on secondary minerals found in basalt formations have been reported.⁽⁴⁾ Secondary minerals are expected to influence migration since ground-water flow paths such as fissures are lined with these minerals. The mineral sample used in this work was obtained from a large vug in the Near-Surface Test Facility excavation. The principal constituent was a smectite clay. Only short-term sorption data are available at present; however, K_d values for strontium and cesium tend to be higher than for basalts, probably because of the high cation exchange capacity and surface area of the clay.

Interbed materials such as sandstone, tuff, and fractured basalt are the major water-bearing layers in the Hanford formation. Contaminated ground-water flow paths will eventually include these porous materials. Their sorption properties are, therefore, significant in modeling radionuclide migration. Sorption studies using these materials are just beginning and no data are yet available on Hanford Site-specific samples.

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PROGRESS SUMMARY--BOREHOLE PLUGGING STUDY

Hans Ewoldsen
Woodward-Clyde Consultants
San Francisco, California 94111

The borehole plugging study is directed and managed by Woodward-Clyde Consultants as part of the Basalt Waste Isolation Project of Rockwell Hanford Operations. The objectives of this study are to: (a) characterize the natural environment within shafts, tunnels, or borings which penetrate the geologic units at or near a repository in basalt; (b) to identify candidate plugging materials which are compatible with the existing or anticipated environmental conditions; (c) to review methods of placement for plug materials or systems; and, (d) to provide a preconceptual design for a plug system in man-made openings (boreholes, shafts, and tunnels excavated during repository construction) that will assure containment of radioactive waste products after closure of the repository. The specific purpose of the plug system will be to prevent the migration of harmful amounts of radioactive waste to the biosphere. Work completed to date has addressed characterization of the plugging environment, identification of candidate plugging materials, selection of several candidate materials for further physical and chemical testing, and identification of techniques which may be suitable for placement of the various plug materials.

Review of present preconceptual repository design information indicates that numerous shafts, tunnels, and borings will require plugging. The anticipated maximum diameter of any opening is approximately 33 feet (10.06 meters), with a minimum diameter of several inches (centimeters). It is anticipated that the borehole plug system will require plugging of openings throughout the basalt flow sequence at and overlying the repository. This will provide redundancy and protection from unanticipated horizontal or vertical flow along natural fractures.

The plugging environment will include individual basalt flows which range from a few to more than 200 feet (60.96 meters) thick and are separated from adjacent flows by porous interflow zones and occasionally by sedimentary interbeds. Basalt flows in the Columbia Plateau are essentially fractured throughout their thickness. Fractures occur along vertical planes in the colonnade and as fanning fractures in the entablature. Subhorizontal, slightly undulatory planes occur within some flows, particularly along contacts between the entablature and colonnade. Flow tops generally are less dense and have more irregular borehole walls than the dense, interior parts of the flow. Plugging will have to consider all types of fractures, including radial and tangential stress relief or construction blasting fractures which may develop in the vicinity of all man-made openings.

Porous zones within the sequence are expected to be saturated with ground water of high pH, with calcium, magnesium, sodium, chloride, and carbonate the most dominant contained ions. Potentiometric data from

wells are presently unclear and will require careful analysis before it is possible to quantify the system. The hydraulic conductivity within the interbeds and the basalt must be assessed. Temperatures near the repository may approach 392 degrees Fahrenheit (200 degrees centigrade); far from the repository, the temperature should be on the order of 122 to 131 degrees Fahrenheit (50 to 55 degrees centigrade). The selection of candidate plug materials is one of the most critical steps in the development of a borehole plug system. Materials to be used in plugs influence and are influenced by the types of possible placement machines and overall potential plug designs that can be used. Some plug systems may or may not be feasible to construct, and existing placement equipment may have to be redesigned or new machinery developed to handle the combination of materials under consideration for plugs.

In general, no single material will satisfy all the requirements of plug design in the geologic environment at the Hanford Site, so material selection schemes must examine and rate a variety of somewhat unrelated chemical, physical, environmental, and data-availability factors in an evaluation of candidate materials.

Several major considerations help to limit the large number of potential plug materials. In general, the materials should be compatible with the natural geologic environment at repository depths on the Hanford Site. They should also be compatible with alterations to this environment produced by the excavation and drilling of shafts, tunnels, and boreholes. In addition, it would be desirable to have plug materials which have a documented history of survival through time approaching the 10,000-year containment life span of the repository. This constraint greatly diminishes the immediate acceptability of many man-made materials.

A screening process has been used to identify materials with a high probability for successful use in plugs and a high potential for meeting criteria that may be applied to plug systems. The selection process takes into consideration these factors and a mix of other physical, chemical, and technological parameters considered significant to an evaluation of candidate plug materials.

Over 70 candidate materials were initially identified, including one or more from the following categories: igneous and metamorphic rocks; sedimentary materials; minerals; native elements; natural organic materials; pozzolans and fly ashes; processed metals; ceramics; glasses; synthetic resins; silicones; organic colloids; polymers; cements; and, asphalts.

From the initial candidate materials, approximately ten have been selected for further study and testing as preferred candidate materials. These include basalt, smectite clays, clinoptilolite, portland cements, hydrothermal cements, and others. Further phases of the study will consider the merits of these materials singly and as multi-material systems, eventually leading to the preconceptual design of one or more plug systems for field testing.

CHAPTER V - NEAR-SURFACE TEST FACILITY

CHAPTER V - NEAR-SURFACE TEST FACILITY

SUMMARY

The Near-Surface Test Facility is being designed as a facility for in situ examination of the behavior of an entire basalt rock mass composed of rooms embedded in the central portion of a basalt flow. These in situ tests include experiments with electric heaters, followed by experiments with spent fuel when the combined effect of heat and radiation will be examined.

Approximately 3,000 feet of tunnels and test rooms were constructed in Gable Mountain on the Hanford Site. The construction activities cover the facility construction, as well as all equipment installation for both the heater and spent fuel tests.

During fiscal year 1979:

- Construction of the tunnels and all drilled holes for the heater test were completed; and,
- Design of the bottom loading transporter for the spent fuel tests was nearly completed.

In May 1978, bids were opened for the construction of the underground portion of the Near-Surface Test Facility to be built within Gable Mountain on the Hanford Site. The contract was awarded to the Genstar Construction Company of Bellevue, Washington. The work started in July 1978 and the excavation was completed in June 1979. The site work was administered by J. A. Jones Construction Services Company and inspected by Vitro Engineering Corporation.

After completion of the excavation, six 8-inch (20-centimeter) diameter utility holes and eight 12-inch (30-centimeter) diameter ventilation holes were drilled by Carman Water Wells Incorporated from the surface into the West Access Tunnel and the Spent Fuel Test Room, respectively. A total of 168 holes varying in diameter between 1.5 and 18 inches (3.8 and 45 centimeters) were rotary drilled in the Heater Test Room and the Extensometer Room to accommodate instruments for the test program. The drilling was performed by Continental Drilling Corporation.

The design of the bottom loading transporter was performed in accordance with the functions and design criteria as developed for the Near-Surface Test Facility. The bottom loading transporter design and many of its features were based on existing liquid metal fast breeder reactor plant technology. The Clinch River breeder reactor plus transporter, floor valves, cold trap casks, and auxiliary handling machine hoist and grapple, and the Fermi fuel transporter were consistent with the Near-Surface Test Facility objectives and bottom loading transporter requirements.

CONSTRUCTION OF THE NEAR-SURFACE TEST FACILITY: A HISTORICAL PERSPECTIVE

H. A. Zweifel
Rockwell Hanford Operations
Richland, Washington 99352

D. E. Hansen
Jenny Geotechnical Corporation
Bellevue, Washington 98009

L. G. Eriksson
AB Ingenjörsgologi
Stockholm, Sweden

In May 1978, bids were opened for the construction of the underground portion of the Near-Surface Test Facility to be built within Gable Mountain on the Hanford Site. The contract was awarded to Genstar Construction Company of Bellevue, Washington; ten bids were received. The site work started in July 1978 and the excavation was completed in June 1979. The site work was administered by J. A. Jones Construction Services Company and inspected by Vitro Engineering Corporation.

DESIGN

The contract comprised the Phase I facility design for heater tests and the Phase II facility design for spent fuel tests. The required excavation consisted of 3 open cuts leading to the 3 parallel tunnels (East Access, West Access, and Spent Fuel) running north-south (Figure 1). The East Access Tunnel was connected at the bottom by a vertical raise and the Heater Test Room was connected to the West Access Tunnel. The Extensometer Room is to the west from the access tunnel parallel, deeper, and 40 feet (12.5 meters) north of the Heater Test Room. The West Access and Spent Fuel Tunnels are respectively extended by a 60-foot (18.5-meter) long Transfer Room connected at the bottom by the Spent Fuel Test Room.

INVESTIGATIONS

Explorations for the facility consisted of 2 diamond-bit drilled core holes; 1 near the center of the facility and 1 at the northern base of Gable Mountain. However, the location at Gable Mountain provided extensive outcrops exposing the units through which the excavations would penetrate. During the construction, 6 exploratory holes, varying in length between 50 to 80 feet (15 to 24 meters), were drilled into the rock above the crowns of the Transfer Rooms and the Heater Test Room to verify the thickness of competent rock. Two of the holes were cored. Geologic site characterization was continuously performed by Rockwell Hanford Operations' geologists and geologic surveillance (design verification) was regularly performed by the Rockwell Hanford Operations' senior mining engineer.

FIGURE 1. Near-Surface Test Facility.

GEOLOGY

The open cuts and portals for the 3 access tunnels are constructed in the Elephant Mountain Member with columns normally greater than 2 feet (0.6 meter) in diameter. The columnar jointing is quite wavy, providing good interlocking between individual blocks. The next unit penetrated by the access tunnels was the Rattlesnake Ridge interbed. It consists of a poorly cemented sandstone with siltstone and mudstone units and is approximately 20 feet (6.1 meters) thick. The final unit penetrated by the access tunnels and the test rooms was the Pomona Member. The test rooms were constructed within the entablature of this flow. The Pomona basalt is tightly jointed, with excellent interlocking, and columns approximately 6 inches (15 centimeters) in diameter. All units dip slightly to the northeast. Only small quantities of water were encountered, as was expected in any of the units.

EXCAVATION

OPEN CUTS

Construction began in July 1978 and consisted of excavating 3 open cuts for the tunnel portals. The cuts were excavated by air trac drills and blasting. The perimeters of the excavations were pre-split; however, very few, if any, line holes can be seen today. The walls were draped with mesh and, in addition, the immediate portal areas were rock bolted and shotcreted. The rock over the crown of the tunnel portals was pre-supported with Number 10 rebars fully encapsulated with polyester resin, and eventually portal support structures in concrete were built. The excavated material which was high-quality, clean rock was used to construct a work and access area immediately north of the open cuts. The maximum height of the fill was approximately 25 feet (7.6 meters). The material was placed with a large Terex Loader and spread with a Caterpillar D-8 dozer. This equipment also provided the compactive effort which produced a high-quality rock fill. Eventually, tunnel spoil was added to the fill and it also produced high-quality rock fill. Tunnel excavation progress is depicted in Figure 2.

EAST ACCESS TUNNEL

The tunnel was turned under on September 29, 1978 and was completed to a total length of 641 feet (195 meters) on March 8, 1979. Although the opening dimensions were originally 8 x 8 feet (2.5 x 2.5 meters), the contractor requested and received permission to drive the opening as a 10 x 10-foot (3.1 x 3.1-meter) tunnel. The tunnel was advanced full face using jack-leg drills until the Rattlesnake Ridge interbed was passed. After passing the interbed, the rounds were drilled with a Joy ACM-II 2-boom jumbo and rounds varied between 6 to 10 feet (1.8 to 3.1 meters). This equipment and a Gardner Denver 3-boom jumbo were used to drill the blast holes in the facility. Initial tunnel support for the first 30 feet (9.2 meters) of the Elephant Mountain basalt was steel sets. Rock bolts of Number 10 rebar, fully encapsulated in polyester resin, were contemplated for use to support the remaining basalt portions of the

100 FEET $\approx$ 30.48 METERS; 1 YARD $\approx$ 0.914 METERS

FIGURE 2. Construction of the Near-Surface Test Facility: Tunnel Excavation Progress.

excavation. Rock bolts and mesh were used for a distance of 70 feet (21.4 meters). This area was later covered with shotcrete when all excavation was completed. Two small rock falls occurred when the contractor was following the excavation by as much as 28 feet (8.5 meters) with the rock bolt and mesh support. After the rock fall, steel sets were installed for support for about 50 feet (15.3 meters). The remainder of the Elephant Mountain basalt was supported with rock bolts, mesh, shotcrete, and, in special cases, rock spiles. Rock spiles are rebars fully encapsulated in polyester resin and installed at the face drilled at an angle of 30 degrees to the direction of the heading. The rock spiles pre-support rock before the rock is mined out and were instrumental in controlling overbreak in the Elephant Mountain basalt. The Rattlesnake Ridge interbed is supported by a combination of rock spiles, split sets, mesh, and, finally, shotcrete. Because of various difficulties with the shotcrete it was not applied until the interbed had been penetrated by the tunnel. Eventually, the invert in each access tunnel was covered with concrete and drainage holes were drilled in the ribs. Support in the Pomona basalt is primarily by shotcrete, except where augmented by rock bolts at the intersection with the Extensometer Room.

EXTENSOMETER ROOM

A ramp was driven up from the East Access Tunnel as steeply as possible until the crown of the Extensometer Room was reached. Then a top heading was driven the full 164-foot (50-meter) length of the room followed by bench removal using horizontal blast holes to reach the final cross section (14 x 21 feet [4.3 x 6.4 meters]). Muck (blasted rock) removal for all of the tunnels and test rooms was by EIMCO Load-Haul-Dump units. The room was supported by shotcrete in the arch. To accommodate the drilling for instrumentation holes, shotcrete was applied on the south wall and the invert was covered with concrete (Figure 3).

WEST ACCESS TUNNEL

The tunnel was turned under on October 22, 1978 and was completed to a total length of 734 feet (224 meters) on April 6, 1979, of which the last 60 feet (18.3 meters) is a section of the East Transfer Room. The tunnel cross section is 15 x 15 feet (4.6 x 4.6 meters) and round lengths varied from 6 to 10 feet (1.8 to 3.1 meters). Initial tunnel support for the first 45 feet (13.7 meters) is by steel sets followed by 25 feet (7.6 meters) supported with rock bolts and mesh. The next 210 feet (64 meters) through the remainder of the Elephant Mountain basalt and into the upper portion of the Rattlesnake Ridge interbed is supported by steel sets augmented with rock spiles and shotcrete. The remainder of the interbed is primarily supported with shotcrete in combination with rock spiles, split sets, mesh, and concrete on the invert. Support in the Pomona basalt is primarily by shotcrete, except where augmented by rock bolts at the intersection with the Heater Test Room.

FIGURE 3. Extensometer Room.

HEATER TEST ROOM

Excavation of the test room was performed by the top heading and bench method for the 23 x 23-foot (7 x 7-meter) portion and full face through the 17 x 17-foot (5.2 x 5.2-meter) portion after the bench was excavated by horizontal drilling and blasting. Construction began on April 10, 1979 and was completed to a total length of 359 feet (118 meters) on May 21, 1979. Roof support was primarily provided by shotcrete, except where augmented with rock bolts for the first 45 feet (13.7 meters) from the intersection with the West Access Tunnel, and the walls are unsupported, allowing continuous geologic surveillance. The raise connecting the East Access Tunnel was excavated after completion of the Heater Test Room.

SPENT FUEL ACCESS TUNNEL

The tunnel was turned under on November 8, 1978 and was completed to a total length of 730 feet (223 meters) on April 16, 1979, of which the last 60 feet (18.5 meters) is a section of the West Transfer Room. The tunnel cross section, 15 x 15 feet (4.6 x 4.6 meters), was advanced and supported in the same manner as the West Access Tunnel.

TRANSFER ROOMS

Excavation for the transfer rooms was performed by a heading in consecutive sequence with and the same size as the respective access tunnel (Figure 4). Being the largest opening in the facility with a cross section of 32 x 39 feet (9.8 x 12.0 meters), additional heading and bench excavation was required. After completion of the "Spent Fuel Test Room heading," careful excavation of the remainder of the arch immediately supported by shotcrete, welded wire fabric, split sets, and rock bolts was followed by the bench removal. Round lengths were approximately 6 feet (1.8 meters) for the top heading and 10 feet (3.1 meters) for the bench removal.

SPENT FUEL TEST ROOM

The room, cross section 16 x 28 feet (4.9 x 8.6 meters), was excavated by the heading and bench method in a manner similar to the west section of the Heater Test Room. The bench was excavated after completion of the Transfer Rooms, thus being the last excavated part of the underground facility. The excavation was completed on June 30, 1979. Support was provided by shotcrete augmented by rock bolts at the intersections with the Transfer Rooms and with a short transition section of rock spiles at the east end in the ventilation hole area.

DRILLING

After completion of the excavation, six 8-inch (20-centimeter) diameter utility holes and eight 12-inch (30-centimeter) diameter ventilation holes were drilled by Carman Water Wells Incorporated from

FIGURE 4. Transfer Room.

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the surface into the West Access Tunnel and the Spent Fuel Test Room, respectively. A total of 168 holes varying in diameter between 1.50 inches (3.8 centimeters) and 18 inches (45 centimeters) were rotary drilled in the Heater Test Room and the Extensometer Room to accommodate instruments for the test program (Figure 5). The drilling was performed by Continental Drilling Corporation.

FIGURE 5. Core Drilling in the Extensometer Room.

DESIGN AND FABRICATION OF THE BOTTOM LOADING TRANSPORTER

G. M. Young
Rockwell Hanford Operations
Richland, Washington 99352

The design of the bottom loading transporter was performed in accordance with the functions and design criteria as developed for the Near-Surface Test Facility. The bottom loading transporter design and many of the design features were based on existing liquid metal fast breeder reactor plant technology. The Clinch River breeder reactor plant transporter, floor valves, cold trap casks, and auxiliary handling machine hoist and grapple, and the Fermi fuel transporter were consistent with the Near-Surface Test Facility objectives and bottom loading transporter requirements.

Title I (preliminary) design of the Near-Surface Test Facility bottom loading transporter cask was initiated March 5, 1979 by the Energy Systems Group of Rockwell International, Canoga Park, California. This work was completed April 27, 1979.

Title II (final) design is being conducted by Rockwell Hanford Operations, Research and Engineering, Mechanical Technology Group.

The following key requirements have dictated the bottom loading transporter size, performance characteristics, functions, and inter-relationship with other components and the Near-Surface Test Facility:

- The bottom loading transporter shall have the capability to remove an uncontaminated canister of radioactive waste from the transfer room storage, transport it to the test room, and deposit the canister into a test hole;
- At the beginning and ending of the canister transfer operation, the bottom loading transporter shall remove, hold, and reinstall the shipping cask cover and test hole concrete shield plug;
- The bottom loading transporter shall have the capability of transporting and installing a test hole liner into a test hole;
- Component size capability--the maximum dimension for all components that each hoist handles is:

Grapple Hoist (Waste Canister)

Length	178 inches (4.52 meters)
Diameter	12.75 inches (32.38 centimeters)

Auxiliary Hoist

Length 196 inches maximum (4.978 meters) test hole liner
 Diameter 27 inches maximum (68.58 centimeters) shield plug;

- Grapple Load Capacity
 3,000 pounds pull (net) (1,361 kilograms);
- Auxiliary Hoist Capacity
 15,000 pounds pull;
- The atmosphere within a test hole and shipping cask is air; and,
- Shielding capability:

The waste contained in a canister emits a maximum gamma dose rate of 2,500 roentgens per hour and a neutron dose rate of 970 millirems per hour measured 1 foot (3 meters) from the canister center line. Shielding shall be provided which will limit the radiation exposure to not exceed 250 millirems per quarter to personnel involved in the canister transfer operation. The dose rate at the surface of the bottom loading transporter cask containing a canister shall not exceed 50 millirems per hour.

DESIGN DESCRIPTION

The bottom loading transporter (Figure 1) is a floor rail-mounted, motorized carrier which supports a bolt-on shielded cask with internal air atmosphere and radiation shielding. It transfers canistered radioactive waste between the transfer room shipping cask interim storage hole and the test room test holes within the Near-Surface Test Facility (Figure 2).

The Near-Surface Test Facility is a research facility to evaluate the suitability of basalt as a repository for canistered radioactive waste materials. The design and function of the transporter is to support this test program. In brief, the operation for placing a canister in storage in a test hole (Figure 3) begins with unloading the shipping cask from a highway trailer by the overhead crane in the transfer room. The shipping cask impact limiter lid is removed and the shipping cask is placed vertically in the transfer room interim storage hole. The bottom loading transporter is moved over the interim storage hole and the shipping cask lid is removed by the transporter auxiliary crane. After repositioning the transporter so that the transporter cask aligns with the shipping cask, the cask closure gate is opened and the radioactive waste canister is withdrawn from the shipping cask up into the transporter cask by the cask hoist and grapple. The transporter closure gate is then closed and the shipping cask lid is returned to the shipping cask. The transporter is then electrically power driven from the transfer room to the proper

FIGURE 1. Bottom Loading Transporter.

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FIGURE 3. Sequence of Bottom Loading Transporter Operations.

test hole in the test room. The test hole (Figure 4) concrete shield plug is removed by the transporter auxiliary hoist. The transporter is then repositioned to place the transporter cask over the test hole, the closure gate opened, and the radioactive waste canister lowered into the test hole by the grapple. After repositioning the transporter to place the shield plug over the test hole, the shield plug is lowered to close the test hole. The operation is complete when the emptied shipping cask is transferred from the transfer room interim storage hole to the highway trailer.

By reversing the transfer procedure, the canisters can be removed when the testing program is completed.

The transporter has a maximum height of 21 feet 2.5 inches (6.46 meters) measured from the top of the floor rail to the top of the grapple drive housing. The carrier covers a floor area of 8 feet 7 inches (2.61 meters) by 17 feet 3 inches (5.25 meters). The laden weight of the transporter is approximately 110,000 pounds (49,895 kilograms).

Except for the hands-on operation of the carrier index pins, transporter machine mechanisms are powered electrically and manually operated by means of an on-board console. In case of power failure or malfunction, manual overrides permit operations to continue. Instrumentation with panel displays are provided to monitor grapple position and load. The transporter will receive electrical power via a reeled umbilical cable that connects to the Near-Surface Test Facility service located in the test tunnel.

Shielding design features of the bottom loading transporter provide for the limiting of dose rate exposure during the 4 radiation exposure transfer periods to the required amount of 50 millirems per hour or less. These periods are: (a) opened shipping cask; (b) canister transfer in and out of cask; (c) transport canister; and, (d) deposit canister in an open test hole. During any 1 of the 4 periods identified, only the operator and observer shall be permitted in the area, and their position is restricted to being on the bottom loading transporter working platform.

Fabrication of the bottom loading transporter has not been started at this time; however, special considerations concerning assembly and installation have been identified.

The bottom loading transporter will initially be assembled and operationally tested at the manufacturer's facility, partially disassembled into modules, and shipped to the Near-Surface Test Facility site. For the operation testing at the manufacturer's facilities, only the gate portion of the closure gate assembly will be filled with lead shot. Except for the closure gate assembly, all other assemblies utilizing lead shot for shielding will be filled for checkout, then drained for shipment, and then refilled after installation of the bottom loading transporter on the transfer room floor rails. The assembled carrier

FIGURE 4. Test Hole with Liner, Canister, and Plug.

shall be shipped as one module with the operator's platform intact, including the power distribution panel and control console. The retaining guide assembly, cask assembly, and grapple drive assembly will have been removed from the carrier.

CHAPTER VI - ENGINEERING TESTING

CHAPTER VI - ENGINEERING TESTING

SUMMARY

The Engineering Testing Program includes the definition of the engineering properties of basalt and development of technology required for all test programs to be conducted within the Near-Surface Test Facility. These tests include heater tests and spent fuel tests. Results from the heater tests will provide data on borehole decrepitation, thermal stability, structural integrity, temperature and displacement fields, and the influence of fractures and joints upon in situ basalt properties. These studies will provide the basis for the design of key repository elements such as canister storage, borehole criteria, borehole liner performance, acceptable waste canister power levels, storage borehole array criteria, and repository step-loading evaluation. An equally important aspect of the in situ testing program is the development and verification of design models simulating the performance of a repository. A second series of tests will analyze the behavior of a repository in basalt where an array of spent fuel canisters is emplaced.

During fiscal year 1979, a testing program was under way to test the thermal, mechanical, and physical properties of the basalt flows of the Columbia Plateau. The program had two major objectives:

- Compare thermal and mechanical rock properties of a deep flow to those of near-surface flows; and,
- Compare thermal and mechanical rock properties within a single, deep flow at three different locations to check for variances within a flow.

As part of the preparation for the in situ tests at the Near-Surface Test Facility, design and fabrication activities were under way to provide the heaters, controllers, and rock instrumentation needed in the conduct of the tests. In order to monitor thermal stresses and profiles, various rock instruments will be used; e.g., extensometers, borehole deformation gauges, stress meters, and thermocouples.

Some of the tests planned within the Near-Surface Test Facility involve the use of electric heaters to simulate the temperatures and stress conditions around single canisters of nuclear waste materials. Full-Scale Heater Test #1 will simulate the temperatures, thermally induced stresses, and gross thermal loading expected in an actual repository in basalt for a single canister of spent fuel. Full-Scale Heater Test #2 will be used to determine the ultimate heat absorption capacity of a basalt borehole and the effects of high, local, thermally induced stresses.

Main heating units, approximately the size of a waste canister, will be placed in vertical boreholes to simulate conditions appropriate for a gross thermal load of 25 watts per square meter. Full-Scale Heater Test #1 will use peripheral heaters arranged in a circle around the main heater and placed in vertical boreholes to simulate the heating effect of nearby canisters.

ENGINEERING PROPERTIES OF BASALT

C. DeFigh-Price
Rockwell Hanford Operations
Richland, Washington 99352

The thermal, mechanical, and physical properties of the deep basalt flows of the Columbia Plateau must be measured for use in designing a radioactive waste repository in basalt.(1-6)

This year's rock testing program had two major objectives:

- Compare thermal and mechanical rock properties of a deep flow to those of near-surface flows; and,
- Compare thermal and mechanical rock properties within a single, deep flow at three different locations to check for variances within a flow.

Since basalt is a highly jointed rock, the mechanical properties of the mass will be mainly controlled by the jointing. The laboratory testing program for basalt properties is designed to test both intact and jointed cores. A broad range of basic engineering tests was conducted on three test holes on the Hanford Site in the Umtanum flow, at depths from 3,000 to 3,300 feet (915 to 1,010 meters). Figure 1 shows the 3 test hole locations and Table 1 lists the tests performed. Table 2 gives a summary of average values of various key design properties for deep basalts, near-surface basalts, and ranges for average basalts world-wide.

There was some variation between the 3 deep core sets. The results from the first and third sets of cores (from holes DC-6 and DC-4, respectively) were very close. The second core group (from hole DC-8) varied significantly from the first and third groups. For the third set of cores, the variation of strength properties with depth was not as significant. For the first and third sets, there was a uniform decrease in compressive strength and modulus of elasticity with increasing temperature. Post-failure compressive strength increases up to 3 times with high confining pressure, indicating joint mending.

The second set of cores (DC-8) showed significant lower strengths than the first and third sets, but had a higher hardness. Young's modulus of elasticity averaged 50 percent lower than for the first and third sets. The range of property values from all 3 drill holes was comparable. The deep flow basalt cores showed, on the average, significantly less anisotropy than the near-surface basalts tested in fiscal year 1978.

Thermal diffusivity, an important design property when determining maximum allowable heat loading in a repository, varies with temperature and sample density. Testing for the thermal diffusivity of the near-surface basalt flows at Hanford shows significant deviations (Figure 2). So far, two laboratories have performed tests, and a third laboratory

FIGURE 1. Test Holes.

TABLE 1. Fiscal Year 1979 Laboratory Testing Program
for Basalt Cores.

Core Sample Characterization.

Uniaxial Compressive Strength.

Brazilian Tensile Strength.

Triaxial Compressive Strength:

Confining pressures to 10,150 pounds per square inch (70 megapascals);
temperatures up to 932 degrees Fahrenheit (500 degrees centigrade).

Modulus of Rupture.

Static Elastic Properties:

Young's Modulus of Elasticity;

Poisson's Ratio;

Cohesion;

Internal Friction Angle.

Dynamic Wave Velocity:

Compression Wave;

Shear Wave.

Density:

Bulk and Grain.

Porosity.

Thermal Expansion over Range of 68 to 932 degrees Fahrenheit (20 to 500
degrees centigrade).

Thermal Conductivity over Range of 68 to 932 degrees Fahrenheit (20 to
500 degrees centigrade).

Specific Heat over Range of 68 to 932 degrees Fahrenheit (20 to 500
degrees centigrade).

Creep.

TABLE 2. Table of Values for Basalt Intact Core.

<u>Property</u>	<u>Units</u>	<u>Umtanum Basalt Ranges(1,2,3,)</u>	<u>Pomona Basalt Ranges(6)</u>	<u>Range for Average Basalts(1)</u>
Bulk Density	lb/ft ³ (gm/cm ³)	110 to 176 (1.77 to 2.82)	168 to 179 (2.69 to 2.87)	150 to 194 (2.4 to 3.1)
Thermal Conductivity	BTU/in-sec-°F (cal/cm-sec-°C)	*	1.70 to 2.15 x 10 ⁻¹⁵ (3.03 to 3.84 x 10 ⁻³)	1.88 to 5.60 x 10 ⁻⁵ (3.35 to 10 x 10 ⁻³)
Specific Heat	BTU/lb-°F (cal/gm-°C)	*	0.289 to 0.585 (0.288 to 0.585)	0.23 to 0.25 (0.23 to 0.25)
Thermal Expansion Coefficient	/°F (/°C)	3.8 to 6.6 x 10 ⁻⁶ (6.77 to 11.96 x 10 ⁻⁶)	3.6 to 3.7 x 10 ⁻⁶ (6.5 to 6.7 x 10 ⁻⁶)	1.6 to 6.4 x 10 ⁻⁶ (2.9 to 11.6 x 10 ⁻⁶)
Young's Modulus (Static)	psi (MPa)	0.69 to 22.6 x 10 ⁶ (4.76 to 155.8)	9.29 to 12.40 x 10 ⁶ (64 to 85.5)	8.85 to 16.25 x 10 ⁶ (61 to 112)
Poisson's Ratio	-	0.024 to 1.560	0.191 to 0.286	0.22 to 0.28
Uniaxial Compressive Strength	psi (MPa)	0.246 to 12.736 x 10 ⁴ (17 to 878)	3.60 to 5.48 x 10 ⁴ (248 to 378)	0 to 5.8 x 10 ⁴ (0 to 400)
Angle of Internal Friction (Intact)	X	36.4 to 52.3	*	46 to 60
Tensile Strength	psi (MPa)	*	2.18 to 4.13 x 10 ³ (15.0 to 28.5)	0 to 3.33 x 10 ³ (0 to 23)

*Not available.

FIGURE 2. Temperature in Degrees Fahrenheit (Degrees Centigrade) Effect of Temperature on Thermal Diffusivity, Pomona Flow.

performed identical tests on near-surface basalt samples as an independent test in the last quarter of fiscal year 1979. This is to determine whether the deviations are due to different testing methods or possible significant density variations.

The basic conclusions from the basalt thermal and mechanical testing to date are that:

- There can be significant variation of engineering properties relative to a detailed repository design within one flow or between flows;
- There is good correlation between density and strength properties--the higher the density, the greater the compressive strength; and,
- Some design values are out of the range expected for basalt (Table 2); this could be due to the "poker-chip" jointing of many of the samples tested in 1979, as compared to the near-surface Columbia Plateau basalt flow tested in 1978. Also, the limited amount of core available required using core samples with joints, chips, etc., rather than solid samples. The ranges for basalt world wide are not based on a large data base, which could be another reason some of the values fall out of range.

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DESIGN AND FABRICATION OF ROCK INSTRUMENTATION
FOR THE NEAR-SURFACE TEST FACILITY

D. J. Dodds
Foundation Sciences, Inc.
Portland, Oregon 97205

R. J. Blanchard
Rockwell Hanford Operations
Richland, Washington 99352

Rockwell Hanford Operations, in the conduct of their in situ test program at the Near-Surface Test Facility at Richland, Washington, is monitoring the thermal-mechanical response of basalt when it is subjected to simulated heat loads expected in an actual nuclear waste repository in basalt. In order to monitor thermal stresses and profiles, various rock instruments are being used; e.g., extensometers, borehole deformation gages, stress meters, and thermocouples.

The design, fabrication, testing, and assembly of the instrument assemblies are under the direction of Foundation Sciences, Inc., Portland, Oregon. Foundation Sciences, Inc. has performed design studies on each of the four instrument types to determine if and what modifications would be required to satisfy the environmental parameters expected during testing at the Near-Surface Test Facility. Each instrument assembly is required to meet the following parameters.

- Borehole:

Temperature 41 to 392 degrees Fahrenheit (5 to 200 degrees centigrade);

Humidity - Possible dripping water.

- Test Room:

Temperature 50 to 100 degree Fahrenheit (10 to 38 degrees centigrade);

Humidity - Possible dripping water.

- Instrument Enclosure:

Temperature 68 ± 40 degrees Fahrenheit (20 ± 4.5 degrees centigrade);

Humidity - 75 percent relative humidity.

Preliminary designs of the instrument assemblies were reviewed with personnel of other agencies doing similar tests including Lawrence Berkeley Laboratory, Lawrence Livermore Laboratory, and Sandia Laboratories. Suggestions from these sources were incorporated into the final instrument designs.

THERMOCOUPLES

The temperature of the basalt during the test will be monitored by packages of thermocouples designated as Assembly R. Assembly R consists of five type E, Teflon-insulated thermocouples (Figure 1) attached to a flexible tube. The tube also serves as a grout tube. The assemblies are installed in vertical boreholes and grouted into place to assure permanent positioning of the thermocouple-measuring junctions and to provide thermal coupling between the basalt and the measuring junctions. Grouting also eliminates the need for dewatering tubes.

The thermocouple-measuring junctions are attached securely with Kapton tape to a 35-foot (10.67-meter) flexible tube at distances of 4.10 feet (1.25 meters), 9.02 feet (2.75 meters), 13.94 feet (4.25 meters), 18.87 feet (5.75 meters), and 23.79 feet (7.25 meters) from the theoretical collar. The theoretical collar is clearly marked on the tube allowing approximately 11 feet (3.35 meters) to protude from the borehole to facilitate grouting. The thermocouple leads are continuous from the measuring junction to the data acquisition system and are bundled and labeled with the appropriate cable designation.

Each assembly is coiled and crated to avoid sharp bending of the thermocouple wires, which may cause changes in the resistance of the wire.

Two basic modifications to the thermocouple assembly have been incorporated to provide: easier installation; better sensor-rock coupling; waterproofing; decrease in retort action; complete access to instruments for repairs or replacement; and, the ability to produce temperature profiles of the entire hole. These modifications include installing the thermocouples in individual Teflon tubes and filling the borehole with grout.

The following battery of tests was performed on the thermocouples to assure they meet the requirements of the test program:

<u>Test Description</u>	<u>Number of Instruments Tested</u>
X-Ray Examination	161
Calibration Verification	10
Support Tube Response	2
Tape Adhesion Testing	3

EXTENSOMETERS

An extensometer is an instrument which is designed to measure movement of a point or points in an earth or rock mass relative to a known location. Measurements are made along the axis of the instrument.

The major components of an extensometer assembly are the anchors, the connecting rods or cables, the rod or cable tensioning system, and the measuring system.

Model CSLT(R) multiple position borehole extensometers supplied by Terrametrics, Inc., Golden, Colorado (as shown in Figure 2) will be utilized to measure rock deformation at the Near-Surface Test Facility. The multiple position borehole extensometers will be installed in vertical and horizontal, 3-inch (8-centimeter) nominal diameter boreholes with the first 3.28 feet (1 meter), enlarged to a nominal diameter of 4.5 inches (11.4 centimeters). Instruments with 4 anchor positions will be installed in the vertical holes and instruments with 3 anchor positions will be installed in the horizontal holes. Thermocouples will be attached to the anchor-measuring rods at 5 locations to provide a method of monitoring the thermal gradient along the length of each assembly. Also, the thermocouple data will be used to correct the extensometer data for the thermal expansion of the Super Invar measuring rod.

The anchors (Figure 3) selected for use on this project are Terrametrics, Model HG. They consist of a soft copper bladder wrapped around and attached to a zinc-plated steel mandrel. Upon insertion of the anchor into position in the borehole, the bladder is inflated by application of 1,750 pounds per square inch (12.25 megapascals) of hydraulic pressure. Depending upon requisite accuracy, the borehole may or may not be grouted to lend additional stability to the anchor system.

Three basic modifications to the extensometer assembly provide better waterproofing and a more stable head configuration. These modifications consist of:

- Adding a branch Y to the anchor string to allow the thermocouple leads and any water inside the anchor conduit to exit prior to the head assembly;
- Adding additional waterproofing and sealant to the head assembly; and,
- Removing the manifold support assembly from the head assembly and supporting it independently on the rock surface.

The following battery of tests was performed on the extensometers.

<u>Test Description</u>	<u>Number of Instruments Tested</u>	<u>Number of Tests</u>
Anchor Creep	3	3
Direct Current Linear Variable Differential Transformer Calibration (Figure 3)	83	2

VI-15

RHO-BMI-79-100

FIGURE 2. Multiple Position Borehole Extensometer.

FIGURE 3. Extensometer Anchor.

<u>Test Description</u>	<u>Number of Instruments Tested</u>	<u>Number of Tests</u>
Rod Expansion	2	1
Long-Term Stability	6	1
Anchor System Inertia	1	1
Coupling Expansion	3	2

The anchor creep test showed that (Figure 4):

- The anchors tested moved when heated and crept under constant temperature;
- In all cases, the heat-up movement was greater than constant temperature movement;
- Maximum movement was approximately 0.00078 inch (0.02 millimeter);
- Movement could be in or out of the hole; and,
- Grout within the hole did not reduce creep.

More tests are needed to establish more reliable anchorage and the adequacy of the grouting results.

All direct current linear variable differential transformers showed good linearity and repeatability.

The long-term stability test showed (Figure 5):

- All direct current linear variable differential transformers showed greater instability due to heat-up compared with constant temperature instability;
- Maximum constant temperature instability was 14 millivolts; the average was 6 millivolts; and,
- The instability band was horizontal in all cases except one.

The anchor inertia test showed that:

- All movement of the anchor was not sensed by the direct current linear variable differential transformer;
- Maximum adjustment was 0.0006 inch (0.015 millimeter) per volt; average was 0.0004 inch (0.010 millimeter) per volt; and,
- Minimum stick slip phenomenon was noted.

The conclusions from the rod testing are as follows:

FIGURE 5. Anchor Creep Test Results.

VI-1A

FIGURE 5. Long-Term Stability Test.

- Invar rod expansion is nonlinear over the temperature range expected at the Near-Surface Test Facility; and,
- Upon cycling, permanent, thermally induced strain was noted in all rods tested.

IRAD MANUFACTURING COMPANY GAGES

The IRAD Manufacturing Company vibrating stress meter (gage) (Figure 6) consists of a hollow steel, cylindrical body with a highly tensioned steel wire clamped diametrically across the center of the cylinder. The period of vibration of the tensioned wire is monitored electronically with IRAD Manufacturing Company Gage Model MB-6 Readout Meter or their Model MA-2 Datalogger.

To measure in situ stress changes, the stress meter is tightly wedged in a borehole by means of a sliding wedge and platen assembly. A stress change in the surrounding rock deforms the steel cylinder. This deformation produces changes in the tension and period of the vibrating wire. With proper calibration, changes in the period of the vibrating wire can be related to stress change in the rock mass.

Vibration of the wire within the IRAD Manufacturing Company vibrating wire stress meter is initiated by a voltage pulse containing a spectrum of frequencies spanning the natural frequency range of the wire in the meter being read.

Two modifications were made to the standard IRAD Manufacturing Company vibrating stress meter to provide more stable output and better reliability. These modifications are: improved swedging procedure for attaching the vibrating wire to the stress meter body; and, heat treatment of the epoxy plug to minimize water leakage into the stress meter.

The tests performed on the stress meters are as follows:

<u>Test Description</u>	<u>Number of Instruments Tested</u>
Reload Determination	18
Elevated Temperature Stability	1
Differential Thermal Expansion	1
Long-Term Stability	2
Submergence Test	2

FIGURE 6. IRAD Manufacturing Company Gage (with setting tool).

The following are the major results from the testing:

- Calibration is dependent upon material modulus;
- Calibration curves fit second-order polynomial;
- All IRAD Manufacturing Company stress meters (gages) need to be calibrated individually (different preload--different calibration curve);
- One cycle is needed to seal (hysteresis on first cycle);
- Gage output is dependent on temperature; and,
- Fifty percent failure rate on submergence tests.

U.S. BUREAU OF MINES' BOREHOLE DEFORMATION GAGE

The U.S. Bureau of Mines' borehole deformation gage is a device used for measuring changes in borehole diameter along 3 axes, spaced 60 degrees apart (Figure 7). The change in diameter of the borehole is measured with strain gages which are used for each axis. One 350-ohm strain gage is attached to each side of each cantilever near the fixed end of the cantilever. The 4 strain gages associated with each axial component (2 gages connected to each of 2 cantilevers) are wired in a full Wheatstone bridge configuration. Changes in borehole diameter produce deflection of cantilevers through O-ring-sealed pistons which are in contact with the borehole wall. When the cantilevers are deflected (straining the strain gages), a resistance imbalance occurs in the Wheatstone bridge which changes the output voltage. Bridge excitation voltage and output voltage are measured with a digital voltmeter and are related to borehole deformation.

Four basic modifications were made to the U.S. Bureau of Mines' borehole deformation gage to increase its water resistance, to provide better gage stability, and to provide easier access of equipment down the drill hole. The additional waterproofing consisted of silicone rubber-impregnated cable, tapered Teflon packing bushing, and a room temperature vulcanizing rubber seal for each individual conductor in the cable. The method of attaching the strain gages to the cantilevers was altered to minimize drift. Finally, longer pistons and shoulders were added to the gage body to enable the gage to be installed in a large hole, thereby providing more clearance for the equipment and cables to be placed in the hole.

The following tests were performed on the U.S. Bureau of Mines' borehole deformation gage.

FIGURE 7. U.S. Bureau of Mines' Borehole Deformation Gage.

<u>Test Description</u>	<u>Number of Instruments Tested</u>
Measurement Axis Range	14
Zero Displacement	14
Temperature Offset	14
Stress Agreement	2
Long-Term Stability	2
Sensitivity	14

The major results and conclusions from these tests are as follows:

- Full displacement should be 30 millivolts at 0.030 inch (0.76 millimeter) deflection; and,
- Calibration curves are constant, linear, and repeatable.

HEATERS AND CONTROLLERS

M. R. Kasper, Jr.
Rockwell Hanford Operations
Richland, Washington 99352

Some of the tests planned within the Near-Surface Test Facility involve the use of electric heaters to simulate the temperatures and stress conditions around single canisters of nuclear waste material. Full-Scale Heater Test #1 will simulate the temperatures, thermally induced stresses, and gross thermal loading expected in an actual repository in basalt for a single canister of spent fuel. Full-Scale Heater Test #2 will be used to determine the ultimate heat absorption capacity of a basalt borehole and the effects of high, local, thermally induced stresses.

Main heating units, approximately the size of a waste canister, will be placed in vertical boreholes to simulate conditions appropriate for a gross thermal load of 25 watts per square meter. Full-Scale Heater Test #1 will use peripheral heaters arranged in a circle around the main heater and placed in vertical boreholes to simulate the heating effects of nearby canisters.

MAIN HEATERS

Main heater units have been fabricated for Full-Scale Heater Tests #1 and #2 (Figure 1). Each unit consists of 4 U-shaped calrods placed equidistantly in a 10-inch (25.4-centimeter) diameter, schedule 10S stainless steel canister. The canisters, in turn, are each placed in a 14-inch (35.6-centimeter) outer diameter schedule 10 carbon steel liner, which will be placed in 18-foot (5.5-meter) vertical boreholes in the basalt.

The main heater calrod sheath is Incoloy 800 with a nominal diameter of 0.475 inch (1.2 centimeters) and the maximum sheath temperature in free air of 1,550 degrees Fahrenheit (843 degrees centigrade). Each rod is approximately 114 inches (2.9 meters) long and has a design life of 3 years at a power rating of 5 kilowatts (208 volts, 60 hertz).

Six thermocouples are attached to each main heater canister. The thermocouples are in pairs approximately 180 degrees apart and are positioned at the top, midway, and bottom of each canister. In addition, a dewatering tube, a desteaming tube, and 4 borescope tubes are attached to the outside of the canister. A second desteaming tube is positioned inside the canister.

The four heating elements in a main heater unit may be controlled separately.

FIGURE 1. Typical Main Heater.

PERIPHERAL HEATERS

Eight peripheral heaters have been fabricated for Full-Scale Heater Test #1. The peripheral heaters are straight calrods which are placed in 0.75-inch (1.9-centimeter) schedule 40 carbon steel liners.

The peripheral calrod sheath is Incoloy 800 with a nominal 0.315-inch (0.8-centimeter) outer diameter and the maximum sheath temperature in free air of 1,250 degrees Fahrenheit (677 degrees centigrade). Each rod is approximately 180 inches (4.6 meters) long, with a design life of 3 years at a power rating of 1.5 kilowatts (208 volts, 60 hertz).

Six thermocouples are attached to each peripheral heater in pairs approximately 180 degrees apart. The thermocouples are placed at the top, midway, and bottom of each peripheral heater.

A separate controller will be used for each of the peripheral heaters for Full-Scale Heater Test #1; however, in future tests, peripheral heaters may be grouped with each heater in a group operated simultaneously by a single controller.

CONTROLLERS

Separate controllers have been designed for the main heaters and peripheral heaters for the Full-Scale Heater Tests. Operation of the main controllers and the peripheral controllers is the same, however, with the exception of power output capacity. The main controller is designed for 1.5 kilowatts of output.

Voltage output, hence power output, is controlled by a variable transformer (Figure 2). Analog panel meters monitor current output and load voltage (root mean square values). Current and load voltage signals are fed into a watt transducer that produces a signal proportional to power. This signal is conditioned by a buffer amplifier and then fed into a digital panel meter on the front of the controller and out to a data logger in an associated system.

FIGURE 2. Simplified Diagram, Heater Controller.

CHAPTER VII - REPOSITORY

CHAPTER VII - REPOSITORY

SUMMARY

This program involves the preconceptual and conceptual design of a repository in basalt. During fiscal year 1979:

- A preconceptual design for a nuclear waste repository in basalt was completed;
- Functional design criteria for a waste repository were completed; and,
- An architect-engineer firm (Kaiser Engineers/Parsons Brinckerhoff Quade and Douglas, Inc.) was selected to conduct the design for the repository.

The objectives of the preconceptual design effort are to develop a feasible reference design concept utilizing existing technology, establish technical, schedule, and cost baselines for the conceptual design, and recommend alternatives that should be considered in subsequent design. These objectives have been achieved.

The preconceptual design will provide the:

- U.S. Department of Energy with baselines for program management and change control during the conceptual design phase;
- Architect-engineer with functional design criteria and an initial concept from which the conceptual design can be developed and traced;
- Basalt Waste Isolation Project staff with a technical basis for preparation of the site characterization report (until approved conceptual design data are available); and,
- National Waste Terminal Storage Program participants with current data and interface assumptions regarding a nuclear waste repository in basalt.

OVERVIEW: PRECONCEPTUAL DESIGN OF A
NUCLEAR WASTE REPOSITORY IN BASALT

D. A. Turner
Rockwell Hanford Operations
Richland, Washington 99352

The preconceptual design is a product of the ongoing research and development program of the Basalt Waste Isolation Project, Rockwell Hanford Operations, which is under contract to the U.S. Department of Energy to establish the feasibility and provide the technology needed to design and construct a nuclear waste repository in a basalt formation on the Hanford Site.

OBJECTIVES OF PRECONCEPTUAL DESIGN EFFORT

The objectives of the preconceptual design effort are to develop a feasible reference design concept utilizing existing technology, establish technical, schedule, and cost baselines for the conceptual design, and recommend alternatives that should be considered in subsequent design. These objectives have been achieved.

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- National Waste Terminal Storage Program participants with current data and interface assumptions regarding a nuclear waste repository in basalt.

CHRONOLOGY AND METHODOLOGY

The methodology and chronology followed in development of the preconceptual design was in accordance with RHO-CD-132 REV 3, "Basalt Waste Isolation Program Plan," namely:

- Issue Preconceptual Design Guidelines November 14, 1978

Design was initiated based on RHO-BWI-CD-2 REV 1, "Repository Preconceptual Design Guidelines." The guidelines are now superseded by the functional design criteria.

- Complete Planning and Scheduling January 12, 1979

RHO-BWI-CD-22 REV 1, "Preconceptual Design Management Plan," was issued November 10, 1978. Vitro Engineering Corporation commenced working on October 1, 1978 and J. F. T. Agapito and Associates commenced work on November 30, 1978. Work plans were approved January 12, 1979.

- Select Concept March 7, 1979

Based on a review of alternatives, a concept was selected, interfaces defined, and a preliminary work breakdown structure established.

- Develop Design Studies June 5, 1979

Preconceptual design studies were accomplished by project participants according to the following task breakdown.

Vitro Engineering Corporation

Surface facilities preconceptual design study.

Waste handling system preconceptual design study.

(Surface) Service systems preconceptual design study.

J. F. T. Agapito and Associates

Access shafts preconceptual design study.

Subsurface facilities preconceptual design study.

(Subsurface) Service systems preconceptual design study.

These studies developed an expanded data base regarding a nuclear waste repository in basalt. All studies were submitted by June 5, 1979.

- Develop Schedule and Cost Data July 5, 1979

Based on the studies, the project participants developed supporting schedule and cost data. The data were submitted by July 5, 1979.

- Establish Functional Design Criteria September 5, 1979

Based on the expanded data base developed during the preconceptual design effort, the preconceptual design guidelines were revised and superseded by the functional design criteria. These criteria define the functions and design requirements for the repository conceptual design effort to be conducted by an architect-engineer under contract to the U.S. Department of Energy.

- Issue Preconceptual Design Report January 30, 1980

Rockwell Hanford Operations was responsible for integration of the preconceptual design studies and other data into the preconceptual design report. The report was completed in draft form October 30, 1979.

- Award Architect-Engineer Contract for Conceptual Design October 1979

The U.S. Department of Energy awarded a prime contract to the joint venture Kaiser Engineers/Parsons Brinckerhoff Quade and Douglas, Incorporated for the conceptual design with an option for Titles I, II, and III services.

FUNCTIONS OF A NUCLEAR WASTE REPOSITORY

The principal function of the repository is to isolate nuclear waste from the biosphere such that it does not pose a significant threat to public health and safety. The design will include provisions for repository expansion. Nuclear waste forms requiring isolation include:

- Canisters containing spent fuel assemblies from boiling water reactors, pressurized water reactors, and other commercial reactors;
- Canisters containing solidified high-level waste;
- Canisters of solid, intermediate-level waste, such as cladding waste; and,
- Containers of solidified low-level transuranic waste.

The repository would have the ultimate capacity to store a total of 492,000 standard canisters and 88,000 standard containers of radioactive waste. These figures were developed from the assumptions that a nominal 380 gigawatts-electric of commercial nuclear power would be generated in the year 2000 and that there will be no recycle of plutonium or uranium from spent fuel. This forecast provides a conservative basis for repository sizing, budgeting, risk assessment, and license planning during the early design stages and was used in preference to more recent forecasts.

Retrieval capability for stored waste will be maintained for up to 25 years after placement. During this period, the stored wastes and confinement barriers will be extensively monitored to assure safety.

The overall functions of the repository are shown graphically in Figure 1.

REFERENCE PRECONCEPTUAL DESIGN

The repository will be licensed by the U.S. Nuclear Regulatory Commission and will be located on a government site.

A proposed suitable site for a repository will be identified during fiscal year 1981. Until then, design will be based on a hypothetical reference site at Hanford. The hypothetical reference site does not correspond to any specific location, but is a composite based on surface and subsurface observations made at different locations across the Hanford Site and vicinity.

FIGURE 1. Functions, Nuclear Waste Repository in Basalt.

An artist's concept of the reference preconceptual design is shown in Figure 2. Geology could allow the use of a modified concept such as a multi-level repository. A high mountain or a cliff might permit horizontal or inclined access. The major physical components of the repository design are identified in the proposed work breakdown structure shown in Figure 3.

Surface Facilities

The surface facilities provide offsite development, land improvements, facilities for receiving and preparing waste for storage, facilities to support repository operations, and facilities for material storage. The surface facilities constitute the repository interface with the environment and the public.

The operating elements of the repository will occupy about 2 square miles (5.2 square kilometers) of surface area to which access will be limited by an 8-foot (2.4-meter) security fence. Surrounding the developed site will be a restricted area. Based on a surface projection of the subsurface facilities (14 square miles [36 square kilometers]) and a 1.3-mile (2-kilometer) buffer zone, the restricted area will require 45 square miles (117 square kilometers).

Access Shafts

Nuclear waste storage, mining development, maintenance, retrieval operations, and emergency operations require transport between the surface and the subsurface facilities which are separated by approximately 3,000 feet (1,000 meters). The shafts provide the means for this transport. Utilities, services, and ventilation air for the subsurface facilities will also be routed through the shafts.

The preconceptual design has five shafts:

- Waste--26 feet (7.9 meters) inside diameter;
- Basalt--18 feet (5.5 meters);
- Service--23 feet (7.0 meters);
- Mine Air Exhaust--18 feet (5.5 meters); and,
- Waste Air Exhaust--18 feet (5.5 meters).

The thick basalt layers within, above, and below the repository storage horizon will provide isolation of the radioactive waste from the public and the biosphere. The access shafts represent the only penetrations of the natural confinement barrier provided by the basalt.

FIGURE 3. Work Breakdown Structure.

Subsurface Facilities

The subsurface facilities are comprised of storage areas for the waste canisters and containers, connecting tunnels, and mine development and support areas.

To store the nuclear waste, approximately 76 million tons of basalt will be excavated over a 23-year period. This will require a work force of some 3,000 persons.

The storage capacity of the repository will be developed in a time-phased program which requires that subsurface mining operations be conducted concurrently with waste storage operations. The repository would be designed to store commercial nuclear waste generated through the year 2010 and could include provisions for expansion.

Repositories in different geologic media differ primarily in their subsurface features. Consequently, design emphasis was placed on the shafts, subsurface facilities, and subsurface systems. Rock mechanics and other trade studies documenting significant subsurface design features, alternatives considered, and the rationale for selection are contained in the preconceptual design guidelines.

Waste Handling Systems

The repository will receive nuclear waste in standardized canisters and containers, as shown in Figure 4, from a federal packaging facility. The packaged radioactive waste will be received by rail or truck transport. The waste handling system will unload, inspect, and prepare the waste packages for storage. The waste packages will then be transferred through the waste handling shaft to the subsurface facilities, transported to the storage location, and placed into storage. The operation will be reversible to provide retrievability.

Two parallel waste handling lines will be needed; one for remotely handled canisters and one for contact handled containers. Spent fuel canisters will be handled onsite within shield transfer casks. The contact waste drums will be palletized in frames with supports configured identically with canister transfer casks. This will allow commonality of waste handling equipment (except for low-level transuranic waste cargo receiving), palletizing, and contact waste storage.

Service Systems

The service systems are those which provide services to and interface with more than one facility (surface, shaft, and subsurface). The major service systems include bulk materials handling, personnel and material transport, subsurface ventilation, electrical power, communications, water supply, radiological waste management, material disposal, and physical security.

CANISTER

- Spent Fuel
- HLW
- ILW

REFERENCE WASTE CHARACTERISTICS

<u>Canister</u>	<u>Thermal Power</u>	<u>Surface Dose Rate</u>
Spent Fuel	700 W	20,000 rem/hr.
HLW	3100 W	100,000 rem/hr.
ILW-Cladding	450 W	900 rem/hr.
ILW-TRU	5 W	3 rem/hr.
<u>Container</u>		
LLW-TRU	0.7 W	5-10 mrem/hr.

CONTAINER

(55-gallon [208-liter] drum)

- LLW-TRU

FIGURE 4. Standard Waste Canister and Container.

Project Phasing Schedule

The project phasing schedule (Figure 5) shows key milestones. Detailed critical path schedules and studies in the preconceptual design guidelines indicate methods of achieving the schedule.

The repository could begin full-mode operation in 1993, accommodate all commercial nuclear waste generated in the United States through the year 2010, and receive 5-year aged waste to the year 2015. The design allows for incremental development of the subsurface facilities over the period of use and includes provisions for expansion.

1. Start Conceptual Design	10/79	11. Start Title III	5/86
2. Submit Schedule 44 (Design)	4/81	12. Complete Title III	6/92
3. Complete Conceptual Design	9/81	13. Start Long-Lead Procurement	11/83
4. Start Engineering Studies	10/81	14. Complete Long-Lead Procurement	4/90
5. Complete Engineering Studies	9/82	15. Start Construction	5/86
6. Start Title I	10/82	16. Complete Construction	6/91
7. Complete Title I	9/83	17. Start Acceptance Testing	6/91
8. Start Title II	10/83	18. Complete Acceptance Testing	6/92
9. Submit Schedule 44 (Construction)	4/84	19. Start Repository Operations	7/92
10. Complete Title II	3/86		

FIGURE 5. Repository Phasing Schedule.

SURFACE FACILITIES

T. E. Meier
Vitro Engineering Corporation
Richland, Washington 99352

The surface facilities provide offsite development, land improvements, facilities for receiving and preparing waste for storage, facilities to support repository operations, and facilities for material storage. The surface facilities constitute the repository interface with the environment and the public. The master plan, as shown in Figure 1, considered various surface, shaft, and subsurface arrangements to optimize isolation and the interfacing of functions.

The principal functions of the surface facilities are to receive waste destined for the repository, provide facilities to house operations and support functions for the repository, and ship empty casks and retrieved nuclear waste from the repository. The surface facilities include offsite development, land improvements, and waste operations facilities to satisfy these functions.

OFFSITE DEVELOPMENT

Offsite development provides the transportation network, utility tie-ins, remote monitoring stations, and a visitor's center.

LAND IMPROVEMENTS

Land improvements provide the land usage, site preparation, and transportation network for the repository. Approximately 2 square miles (5.2 square kilometers) of land will be required for the surface facility development.

The traffic network considers traffic flow, storage spurs, and transport delivery time for efficient movement of equipment, materials, and supplies. Traffic involving radiological waste material will be segregated from other traffic. The traffic system will meet the requirements for safeguards and security.

WASTE OPERATIONS FACILITIES

The waste operations facilities are those in which radioactive waste is temporarily stored or handled by the surface portions of the waste handling and waste management systems. These facilities receive and ship waste containers and shipping casks. They unload, inspect, overpack (if required), and prepare for storage remotely handled, canistered spent fuel and contact-handled containers of low-level transuranic waste. The facilities to perform these functions are the Receiving and Shipping Facility, the Remote Handling Transfer Facility, the Contact Handling Transfer Facility, and the Waste Shaft Head Facility.

1 REMOTE HANDLING TRANSFER FACILITY	29 AGGREGATE SURFACE PREPARATION
2 CONTACT HANDLING TRANSFER FACILITY	30 VISITORS CENTER
3 CARGO RECEIVING AND SHIPPING FACILITY	31 HELIPAD
4 WASTE SHAFT HEAD FACILITY	32 PATROL HEADQUARTERS
5 SERVICE SHAFT HEAD FACILITY	33 MEDICAL AID
6 PERSONNEL AND MATERIAL ACCESS FACILITY	34 WATER TREATMENT PLANT
7 HOT MAINTENANCE SHOP	35 ELECTRIC POWER SUBSTATION
8 SITE-GENERATED WASTE REDUCTION FACILITY	36 SEWAGE TREATMENT
9 ENGINEERING AND ADMINISTRATIVE OFFICE	37 LANDFILL
10 TRAINING CENTER	38 BASALT SHAFT HEAD FACILITY
11 CAFETERIA	
12 MAINTENANCE SHOPS	
13 GARAGE AND MOTOR POOL	
14 PROTECTIVE EQUIPMENT CLEANING	
15 FIRE STATION	
16 INDUSTRIAL SAFETY CENTER	
17 WAREHOUSE CENTRAL STORES	
18 STORAGE YARD	
19 LINER AND PLUG STORES	
20 BULK MATERIALS STORES	
21 PETROLEUM STORES	
22 EXPLOSIVES MAGAZINE	
23 CONTRACTOR STORES	
24 PERCOLATION-EVAPORATION PONDS	
25 GUARD GATES	
26 MINE AIR EXHAUST SHAFT	
27 WASTE AIR EXHAUST SHAFT	
28 FILTER BUILDING	

FIGURE 1. Site Perspective.

Receiving and Shipping Facility

The Receiving and Shipping Facility will provide the building enclosure and equipment to handle canister shipping casks and low-level transuranic waste containers as follows:

- Receive and inspect up to 22,500 waste shipping casks per year and 4,000 low-level transuranic waste containers per year from both truck and rail carriers;
- Radiologically monitor casks, containers, and the facility;
- Unload and transport casks and containers to the Remote Handling Transfer Facility or the Contact Handling Transfer Facility, respectively;
- Decontaminate exterior surfaces of cargo or carriers and collect any potential contaminated waste; and,
- Load and return empty or full shipping casks on both truck and rail carriers.

Remote Handling Transfer Facility

The Remote Handling Transfer Facility will provide the building enclosure, shielded confinement cells, and equipment to handle the spent fuel canisters and the high-level waste canisters and low-level waste containers as follows:

- Remove canisters from shipping casks, inspect canisters, and prepare canisters for transfer to subsurface storage within a shielded operating cell;
- Permit decontamination, repair, or overpack of canisters within overpack-shielded cells for transfer to subsurface storage;
- Accommodate occasional retrieval of waste from the subsurface; and,
- Collect any potential contaminated waste.

Contact Handling Transfer Facility. The Contact Handling Transfer Facility will provide the building enclosure, confinement, and provision to inspect, repair, if required, and prepare for storage containers of low-level transuranic waste.

PRECONCEPTUAL REPOSITORY DESIGN IN BASALT:
SHAFTS, SUBSURFACE FACILITIES, AND SYSTEMS

M. P. Hardy, W. Heley
J. F. T. Agapito and Associates, Inc.
Grand Junction, Colorado 81501

J. F. T. Agapito and Associates, Inc. undertook three of the tasks related to the preconceptual repository design project: shafts; subsurface facilities; and, subsurface systems. Rockwell Hanford Operations and other subcontractors to Rockwell Hanford Operations covered surface facilities, surface systems, and waste handling system design. To assist in the preparation of the design and cost estimate, several consultants contributed as subcontractors to J. F. T. Agapito and Associates; specifically these were:

- Harrison Western Corporation, shaft design;
- Dr. C. M. St. John, Consultant, ventilation;
- Dr. G. Hocking, Dames & Moore, backfilling and dewatering; and,
- Mr. D. Hansen, Jenny Geotechnical, costs and excavation methods.

The repository design was not site specific, but was founded on a hypothetical site representative of the basalts in the Pasco Basin on the Hanford Site. The subsurface facilities were located in the entablature of a major flow approximately 3,200 feet (1,000 meters) below the surface. Design followed pre-specified criteria and employed a work breakdown structure format.

The repository was designed for an operating life of 23 years at an annual placement rate of 22,500 canisters containing 5-year-old spent fuel from commercial nuclear electric generating plants. In addition, 4,000 drums of low-level or contact waste would be disposed of annually in a separate area. An experimental area was included to allow testing of equipment and placement configurations and to permit personnel training prior to activation of the repository. This experimental area may also function as a test facility prior to completion of the full-scale facility.

The primary objective of the preconceptual design effort was to establish a first cost estimate for construction and operation of a repository in basalt. The costing method adopted was to divide the costs into capital items and operating costs. The facility would be authorized and funded on five-year modules, so the capital cost of the facility includes all fixed assets necessary to initiate operations for the first five years. This includes all surface facilities, shafts, major items of the subsurface systems, and those portions of the subsurface facilities not associated with placement and sealing of the canisters in the storage area.

The subsurface facilities of the repository have been designed to be compatible with retrieval of the canisters for up to 25 years after emplacement. Backfilling of the canister storage rooms is planned before the 25-year retrieval period, but should retrieval be necessary, remining of the backfill and resupport of the storage rooms are practical.

SHAFTS

Five shafts were selected as the minimum practical number necessary to accomplish the functions of separate air intake and exhaust flows for the development and waste handling systems and to provide an independent waste handling shaft. These shafts were multiple function facilities ranging in lined diameter from 18 feet to 26 feet (5.5 to 7.9 meters). All of the shafts were situated along a central corridor to provide isolation from the waste emplacement areas, and all will be approximately 3,300 feet (1,006 meters) in depth.

The primary shaft is the waste transport structure, which is the largest (26 feet [7.9 meters]) shaft of the system and the most complex. It will consist of 2 tower-mounted Koepe hoists to operate 4 carrier units capable of moving the cask-encased fuel canisters to the repository level at the rate of 6 per hour. Each hoist will operate 2 carriers in balance, such that 1 is in the up mode, while the other is down, to permit simultaneous loading and unloading at the surface and repository levels. The shaft will be compartmentalized to permit either hoist to operate independently of the other. A third, small hoist will operate a service cage capable of working in either shaft compartment to provide repair and maintenance access in the shaft. A flow of air sufficient to ventilate the unloading station area at the shaft base will be carried in the ducting to the repository level. Figure 1 is a schematic illustration of the waste shaft.

A basalt transport shaft has been designed to hoist broken basalt to the surface during facility development and to lower backfilling and sealing materials to the repository during decommissioning. This shaft will also serve as the fresh air intake for the waste handling ventilation system, which governs the size to a minimum of 18 feet (5.5 meters) in diameter. A single Koepe hoist will operate 2 bottom dump skips in balance, each with a capacity of 28 tons. The shaft hoisting capability will be approximately 900 tons per hour.

A service or men-and-materials-transport shaft will perform personnel and supply movement between the surface and repository levels. It will be 23 feet (7 meters) in diameter and serve as the fresh air intake to the mining and development ventilation system. This shaft will contain a large cage or platform to safely handle men and bulk materials and will be operated by a Koepe hoist in balance with an adjustable counterweight to handle a large variety of loads. This shaft will also contain utility lines and water intake and discharge for the cooling and dewatering systems. A second small cage will operate as an auxiliary man hoist while the main cage is engaged in material movement.

FIGURE 1. Waste Shaft.

Two other shafts will be constructed in close proximity to exhaust air from the repository. They will be 18 feet (5.5 meters) in diameter and will be connected by ducting at the surface to large filter banks which have the capability of cleaning contaminants from the air before releasing it to the atmosphere. These shafts will also be essential during initial development when the mine air exhaust shaft functions as a men and materials shaft and the waste exhaust functions as a basalt transport shaft. These capabilities will exist as emergency backups throughout the operating life of the repository until they are again reactivated during backfilling and decommissioning.

SUBSURFACE FACILITIES

The subsurface facilities provide space for the transport, placement, and storage of the waste canisters, and access and space for mining activities, supporting systems, and backfilling. Figure 2 shows a cutaway schematic of the subsurface facilities around the central shaft area. Figure 3 shows a plan outline of the repository at full capacity after 23 years of operation, receiving 22,500 canisters per year. The essential features of the subsurface facilities layout are 23 panels each sized to receive 1 full year's supply of spent fuel canisters (22,500). Access to the panels from the service shaft and waste shaft area is via 3 drifts at the north end of the panels. Three return drifts connect the south end of the panels to the air exhaust shafts. These access drifts connect along a central corridor between the 5 shafts. The access to each panel from the 3 main access drifts is via 2 drifts, positioned 1 above the other, that pass through the entire length of the panel to the 3 return drifts. The upper access is on the main storage level and is for mining equipment, borehole preparation equipment, waste transporters, and backfill and sealing equipment; whereas the lower drift on a level below the main repository level is for both a rail haulage system for basalt transportation to the basalt shaft and ventilation return air.

Each panel is separated from its adjoining panels by 330 feet (100 meters) of undisturbed basalt and from the main access and return drifts by 660 feet (200 meters) of undisturbed basalt. These separations are designed to both enhance long-term isolation by minimizing the number of interconnecting paths to the shafts and limit temperature buildup in the accesses during the operational life of the repository.

The three main accesses have the following primary function:

- Men and mining equipment access and mine air intake;
- Rail haulage drift; and,
- Waste transporter, backfill drift, and waste air intake.

FIGURE 2. Subsurface Facilities.

FIGURE 3. Repository Layout, 23 Years.

The return drifts from the storage panels satisfy the following functions:

- Rail haulage return, mine air return, and emergency escape route;
- Waste transporter return; and,
- Waste air return.

The layout is designed so that two independent air supplies ventilate the subsurface facilities. A mine air circuit provides forced air for mining and panel preparation operations. No air is exposed to nuclear waste materials in this circuit. A waste air circuit provides air for the waste transporting and emplacement, monitoring, backfilling, and sealing. The layout of access drifts allows for maximum separation of the two air circuits with a minimum of potential leakage from one circuit to another, which will be from the pressure system toward the exhaust system.

Figure 4 shows the subsurface facilities to be constructed for Module I. At any time, panel development, panel mining, panel preparation, canister placement, and backfilling will be on going simultaneously. A low-level waste storage area and an experimental area will be developed as part of the initial development phase, then continually expanded throughout the life of the repository.

Other facilities constructed as part of the initial development include: nuclear waste unload area; basalt crushing and shaft load area; backfill grinding and mixing plants; warehouse and maintenance area; control rooms for display of monitoring devices; dewatering and pump station; ventilation fan and connections; and, concrete mixing area.

Following the completion of Module I, all panels will have the central access open for inspection and monitoring; whereas the remaining three panels will have stoppings and backfill at the storage area to isolate the storage areas completely from the remainder of the operations. For each subsequent module, the later five steps will be repeated, but in Module V, only three panels will be developed and filled with canisters.

Within the storage panel, placement rooms are mined at right angles to the central in-panel access drift. These rooms are spaced on 394-foot (120-meter) centers with smaller reaming rooms in between (Figure 5). After panel mining, panel preparation consists of construction of the storage holes and insertion of the borehole liners. The storage holes are essentially horizontal connecting the placement and reaming rooms. They are constructed in 2 passes; the first by drilling a pilot hole to the reaming room, then by attaching a backreaming head and pulling the head back to the placement room to enlarge the storage hole to a 22-inch (56-centimeter) diameter. Up to 50 drills will be used to construct the storage holes. A steel liner is then inserted and grouted into position.

FIGURE 4. Repository Layout, Module I.

FIGURE 5. Borehole Arrangement.

The storage holes are placed on an 8.5-foot (2.5-meter) spacing and are designed to accept 6 canisters per hole. This density for 5-year-old waste gives an initial gross thermal load of 158 kilowatts per acre (39 watts per square meter) averaged between canisters, but averaged over the panel this density is 50 kilowatts per acre (12.4 watts per square meter). This loading density gives peak rock temperatures in the range of 302 to 392 degrees Fahrenheit (150 to 200 degrees centigrade) and rock stresses within the adopted rock mechanics design criteria.

Sealing and decommissioning are of primary importance in the acceptability of a repository design. This will be carried out in four stages:

- Stage 1--Backfilling and sealing of the placement and reaming rooms will be accomplished within two years of canister emplacement;
- Stage 2--Backfilling and sealing of the individual panels will be accomplished after the retrieval period has expired, probably after Module V is complete;
- Stage 3--Backfilling and sealing of the main accesses to be accomplished with decommissioning of the facility; and,
- Stage 4--Shaft and borehole plugging and sealing will be accomplished during decommissioning, but may have a significant time lag from Stage 3, as the shafts could be used for undefined repository expansion.

Stages 2, 3, and 4 (above) will be carried out sequentially as Module VI of the repository.

Excavation of the subsurface facilities will utilize conventional drill and blast techniques with a trim round to remove the outer 3 to 4 feet (0.91 to 1.22 meters) of material. All permanent access and return drifts will be bolted and shotcreted during the construction phase with a thick concrete lining applied as the permanent support. The storage rooms will be bolted and shotcreted as necessary. All openings that must remain open longer than 5 years will be bolted, shotcreted, and permanently lined with concrete to ensure long-term stability.

The opening sizes vary with function, but because of the large size of the transporter and casks, the opening sizes are, in general, large for underground projects. The main access and return drifts are generally hexagonal in shape; 24 feet (7.3 meters) wide and 16.5 feet (5 meters) high. Some are smaller. The canister placement rooms are 31.5 feet (9.6 meters) wide to accommodate the transporter in the lateral position during canister placement in the horizontal storage holes and 16.5 feet (5 meters) high.

SUBSURFACE SYSTEMS

The major subsurface systems are ventilation and cooling, basalt handling, material and personnel transport, backfill, electrical, water distribution and dewatering, and monitoring and alarm system. Other subsurface systems not detailed in the preconceptual design effort include fire, communications network, energy conservation, emergency, safeguards and security, and compressed air systems.

The ventilation and cooling system provides air to the working areas at an acceptable temperature, humidity, and quality. Two independent circuits are used to isolate potential contamination in areas in contact with waste containers from the mining and development activities. Both circuits use approximately 650,000 cubic feet per minute (306,800 liters per second) with a head loss of approximately 10 inches (25.4 centimeters) of water pressure. The waste air circuit is under negative pressure relative to atmospheric, so that all leakage will be into this circuit. Surface fans are installed at the waste air exhaust. The mine air circuit is under positive pressure relative to atmospheric; the fans for this circuit are located at the base of the men-and-materials shaft.

Air cooling will be a significant cost in the repository because of the high rock temperatures, expected to be in the 125 to 135 degrees Fahrenheit (52 to 57 degrees centigrade) range, and the high machine horsepower usage in the subsurface. A surface water refrigeration plant will be used to chill all water to approximately 42 degrees Fahrenheit (5.6 degrees centigrade) before entry to the repository. Chilled water will be used at all mining faces and spot air coolers at other working areas. Air conditioned, enclosed cabs will be used on all transport vehicles.

The basalt handling system accepts the broken basalt from the mining and development operations and transports it to the unload/crusher station at the base of the basalt haulage shaft. The primary transport system is an electric rail locomotive system. The rail system is designed for loop haulage with loading primarily from rock passes and chutes from the level above. Seven rock passes will be located along each panel. The trains will dump into a surge pocket which will feed into the primary crusher. The crusher will reduce the basalt to -6 inches (-15 centimeters), then feed either the shaft loading pocket or the crushing and grinding plant for concrete aggregate production or backfill production. The basalt handling system is sized to handle 14,400 tons per day and to supply backfill crushed material at 3,200 tons per day.

Material and personnel transport systems include diesel operated trucks and busses that will run in the mine air circuit between the mine and material shaft and the working area. Approximately 800 people have to be transported per shift; staggered operations will be used whenever possible.

Materials to be transported from the shaft to the working areas include steel borehole liners, drill steel, cutting heads, pipe, electrical cable, lubricants, diesel fuel, and grouting materials. Diesel tractors with flatbed trailers will be the primary transport method.

The backfill transport system will be a conveyor system from the basalt crushing and grinding plant along the waste transporter access drift to the storage panels. Placement in the panels will be by dump truck, grader, compactor, and some pneumatic placement.

The electric system will provide power for the water distribution system, ventilation, lighting, miscellaneous and the electrically operated storage borehole drills. The main feeders will be at 13.8 kilovolts down the men-and-materials shafts with emergency backup power supplied down the mine exhaust shaft. Transformers and load centers are located throughout the facility.

Water distribution and dewatering are interrelated with the ventilation system as it provides cooling at the working faces. Water is used for dust control and flushing during mining and storage hole construction. Mine ground-water inflow is expected to be minimal; the design capacity to prevent flooding was established at 2,000 gallons per minute (7,570 liters per second). Grouting will be used to limit inflows where practical.

APPENDIX

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