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Basalt Waste Isolation Project

Annual Report - Fiscal Year 1980

Staff
Basalt Waste Isolation Project

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

Rockwell International

Rockwell Hanford Operations
Energy Systems Group
Richland, WA 99352

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Informal Report

BASALT WASTE ISOLATION PROJECT
ANNUAL REPORT - FISCAL YEAR 1980

Staff
Basalt Waste Isolation Project

November 1980

Rockwell International
Rockwell Hanford Operations
Energy Systems Group
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BASALT WASTE ISOLATION PROJECT ANNUAL REPORT
FISCAL YEAR 1980

The Basalt Waste Isolation Project is one of the components of the National Waste Terminal Storage Program. As such, the Basalt Waste Isolation Project is chartered with the responsibility of assessing the feasibility of using the deep basalts beneath the Hanford Site as a medium for the disposal of nuclear waste. The Basalt Waste Isolation Project has made great progress in a number of areas during fiscal year 1980. During this fiscal year, we consolidated the information available in the fields of geology and hydrology of the Columbia Plateau and issued two reports summarizing this information. Both of these reports have been given broad distribution to assure adequate peer review and comments.

In addition, during the year we consolidated the information on engineered barriers and prepared a report summarizing the research to date on waste package development and design of borehole seals. The waste package studies, when combined with the hydrologic integration, revealed that even under extreme disruptive conditions, a repository in basalt with appropriately designed waste packages can serve as an excellent barrier for containment of radionuclides for the long periods of time required for waste isolation (see papers by Baca, Arnett, and Wood in this report).

During fiscal year 1980, the first two heater tests at the Near-Surface Test Facility were initiated. On July 1, 1980, both tests were started and have been successfully operated to this date. The papers on the Near-Surface Test Facility section of this report present the results of the equipment installed and the preliminary results of the testing.

In October 1979, the U.S. Department of Energy selected the joint venture of Kaiser Engineers/Parsons Brinckerhoff Quade & Douglas, Inc. to be the architect-engineer to produce a conceptual design of a repository in basalt. During the year, this design has progressed and concept selection has now been completed. The papers by Ritchie and Turner in this report give further details on the studies to date.

This annual report presents a summary of the highlights of the work completed during fiscal year 1980. It is intended to supplement and summarize the nearly 200 papers and reports that we have distributed to date as a part of the Basalt Waste Isolation Project studies. A full listing of these reports is contained at the end of this report. Copies of any of these documents may be obtained from the National Technical Information Service, Springfield, Virginia, 22161

During fiscal year 1981, we expect to continue the studies described in this report and expand in a number of areas including more extensive hydrologic modeling under worst-case scenarios and additional geotechnical studies. A Jointed Block Test is being started at the Near-Surface Test Facility and plans for an exploratory shaft test facility are being developed. It is expected that these studies will serve as the basis for the feasibility assessment of using the basalts beneath the Hanford Site for terminal storage of nuclear waste.

Readers who have any questions or inquiries about the Basalt Waste Isolation Project or who desire further information on the subject should write to R. A. Deju, Director, Basalt Waste Isolation Project, P.O. Box 800, Rockwell Hanford Operations, Richland, Washington, 99352.

R. A. Deju, Director
Basalt Waste Isolation Project

December 1980

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CHAPTER I

SYSTEMS AND REGULATORY AND INSTITUTIONAL ACTIVITIES

OVERVIEW OF SYSTEMS STUDIES

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The Systems program of the Basalt Waste Isolation Project involves system studies as part of the assessment of the feasibility of basalt as a repository medium for nuclear waste storage. These studies include the planning as well as the requirements for scientific studies to be undertaken. The Systems Integration program is responsible for utilizing the results of ongoing research and development to identify potential repository sites in basalt and assess the feasibility of storing nuclear waste in basalt, integrating all Basalt Waste Isolation Project research and development studies, and preparing the information needed for qualification of a nuclear waste repository in basalt.

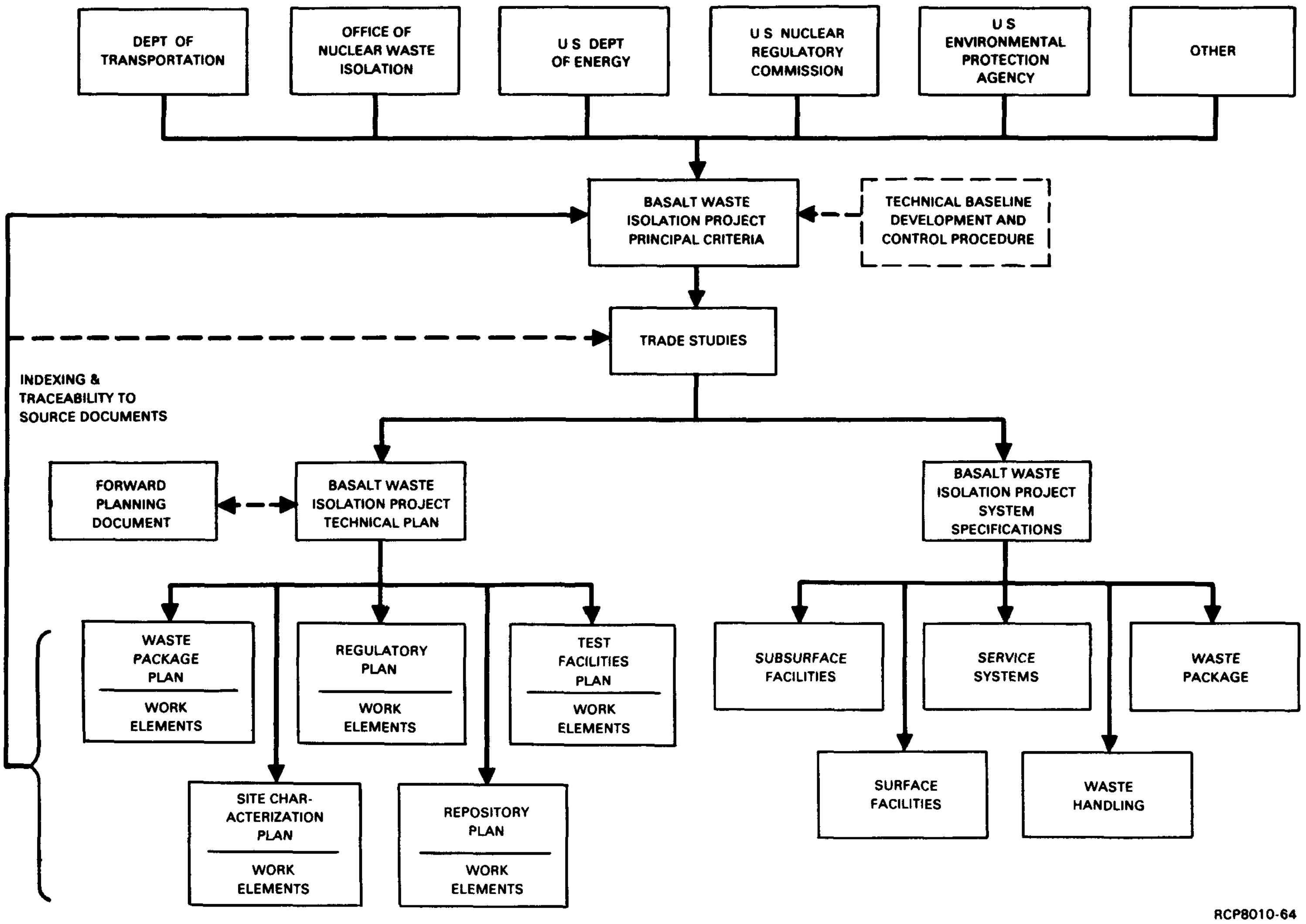
During fiscal year 1980, the following major activities were completed:

- Issued technical baseline control plan for the Basalt Waste Isolation Project
- Identified reference repository location for a nuclear waste repository in basalt
- Reviewed National Waste Terminal Storage Program documents
- Prepared preliminary socioeconomic assessment report of a nuclear waste repository in basalt.

TECHNICAL BASELINE CONTROL PLAN

Efficient management control of the Basalt Waste Isolation Project dictates that control of the technical baseline be enhanced. The technical baseline is a tool which defines and controls technical requirements, specifications, criteria, documents, and drawings needed to meet Basalt Waste Isolation Project objectives. Control, traceability, and visibility are emphasized; therefore, Rockwell Hanford Operations introduced and implemented the classical Systems Engineering (integrated engineering process) approach to technical baselining.

The Systems Engineering approach provides work or task control, visibility, and traceability to assure that all aspects of engineering logic have been applied to the project and that all project aspects are documented. Technical baseline control is maintained through the Technical Logic Mechanism Network (Figure 1), which identifies three primary technical baseline documents. These documents, the Basalt Waste Isolation Project principal criteria document, the Basalt Waste Isolation



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

Project technical plan, and the Basalt Waste Isolation Project systems specifications, identify what has to be done in the program to meet our objectives, and how we plan to do it.

The principal criteria document identifies all criteria, regulations, and requirements imposed on the project by federal, state, local, coordinating, and other governmental agencies. The Basalt Waste Isolation Project technical plan identifies how we plan to accomplish these objectives. Each element of work or task necessary to meet a requirement or satisfy a criteria is identified through end function technical plans and logic networks.

The Basalt Waste Isolation Project systems specifications (Figure 2) define the quantitative technical performance requirements derived from the principal criteria for the design, construction, and operation of a repository in basalt. The systems specifications specify design parameters, criteria, and constraints for a system or subsystem; support the principal criteria document concerning what has to be done to complete a nuclear waste repository in basalt; identify what each element of work or tasks will ultimately have to support; and ensure that all work performed is logically supportive of the end product.

Management visibility of the overall technical baseline is aided by a traceability and indexing system. Each element of work or task performed must be done for a specific purpose; to meet a criteria, requirement, regulation, or specification. Visibility is accomplished through a computerized numerical code, which identifies each item of work to each specific criteria or specification in the principal criteria document and systems specification. Management control of the technical baseline utilizes and is achieved through a configuration management change control process and is integrated throughout the project via a forward planning document with the master project schedule and fiscal year budget.

REFERENCE REPOSITORY LOCATION

An integral part of the Basalt Waste Isolation Project is the selection of a site which could successfully support the development of a nuclear waste repository in basalt. In fiscal year 1979, 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 Hanford Site and progressively concentrating on smaller and smaller areas
- Development of a ranking process to preferentially rank candidate sites based on a decision-analysis approach

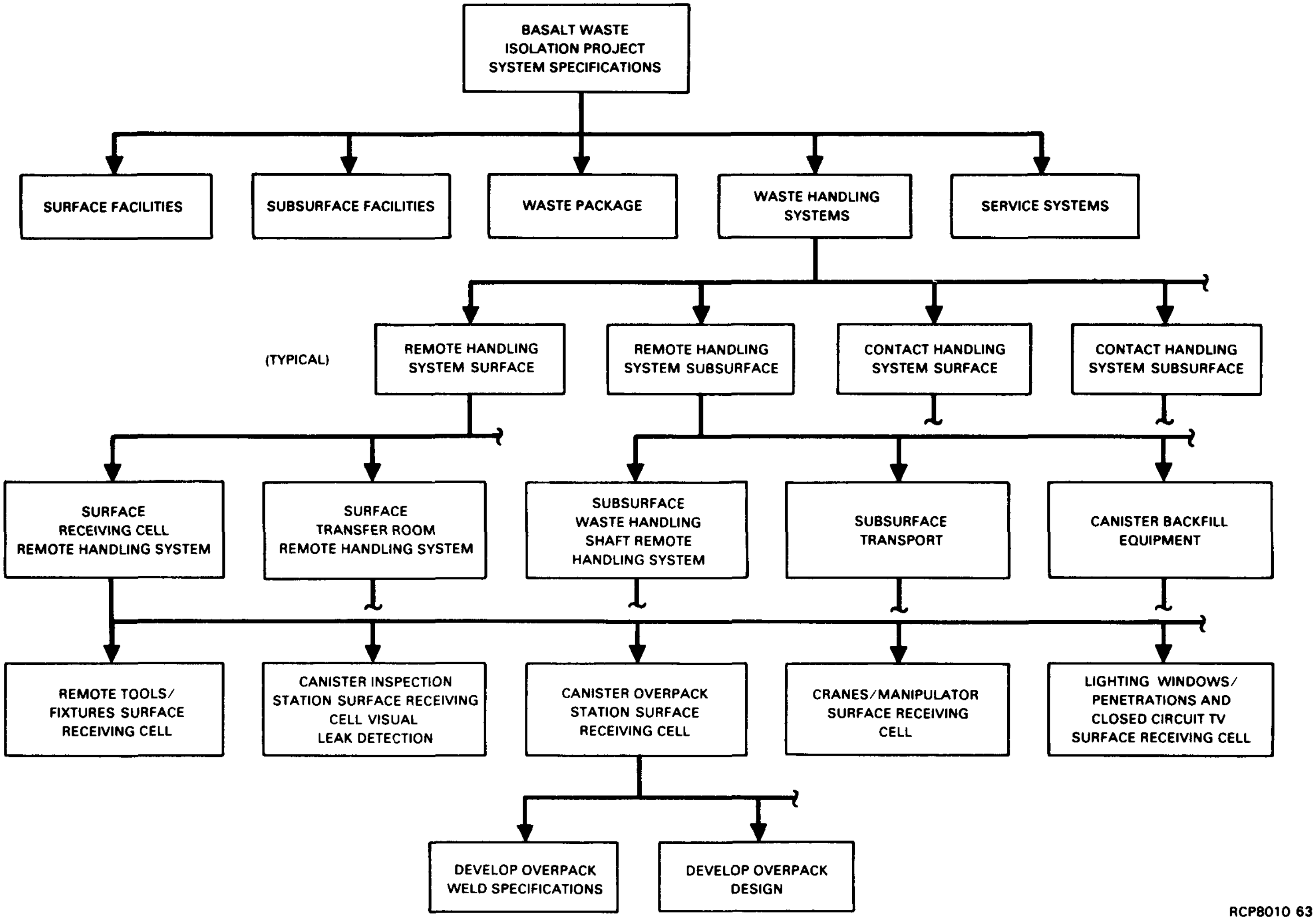


FIGURE 2. Basalt Waste Isolation Project Specifications.

During fiscal year 1980, the work, in part, consisted of developing a ranking data base of appropriate scope and detail that could be utilized for ranking and, thereby, narrowing the candidate areas identified during fiscal year 1979 (Figure 3) site identification process. Fiscal year 1980 site ranking activities led to the identification of a reference repository location which will be investigated in greater detail (as designated in Figure 3). Details of the identification process are discussed by Myers and Bielefeld in the geosciences section of this report.

DOCUMENTS REVIEW

Numerous draft documents are received for review by the Basalt Waste Isolation Project from the Office of Nuclear Waste Isolation, the U.S. Department of Energy-Richland Operations Office, the U.S. Department of Energy-Headquarters, the U.S. Nuclear Regulatory Commission, and other governmental agencies of the National Waste Terminal Storage Program. This review process provides consistency in the technical approaches and document formats between the Basalt Waste Isolation Project and other National Waste Terminal Storage Program activities.

SOCIOECONOMIC ASSESSMENT

Based on preconceptual design information, an investigation was initiated into potential socioeconomic impacts associated with the development of a nuclear waste repository on the Hanford Site. The study examines existing baseline socioeconomic data for surrounding communities and examines possible impacts and mitigation strategies.

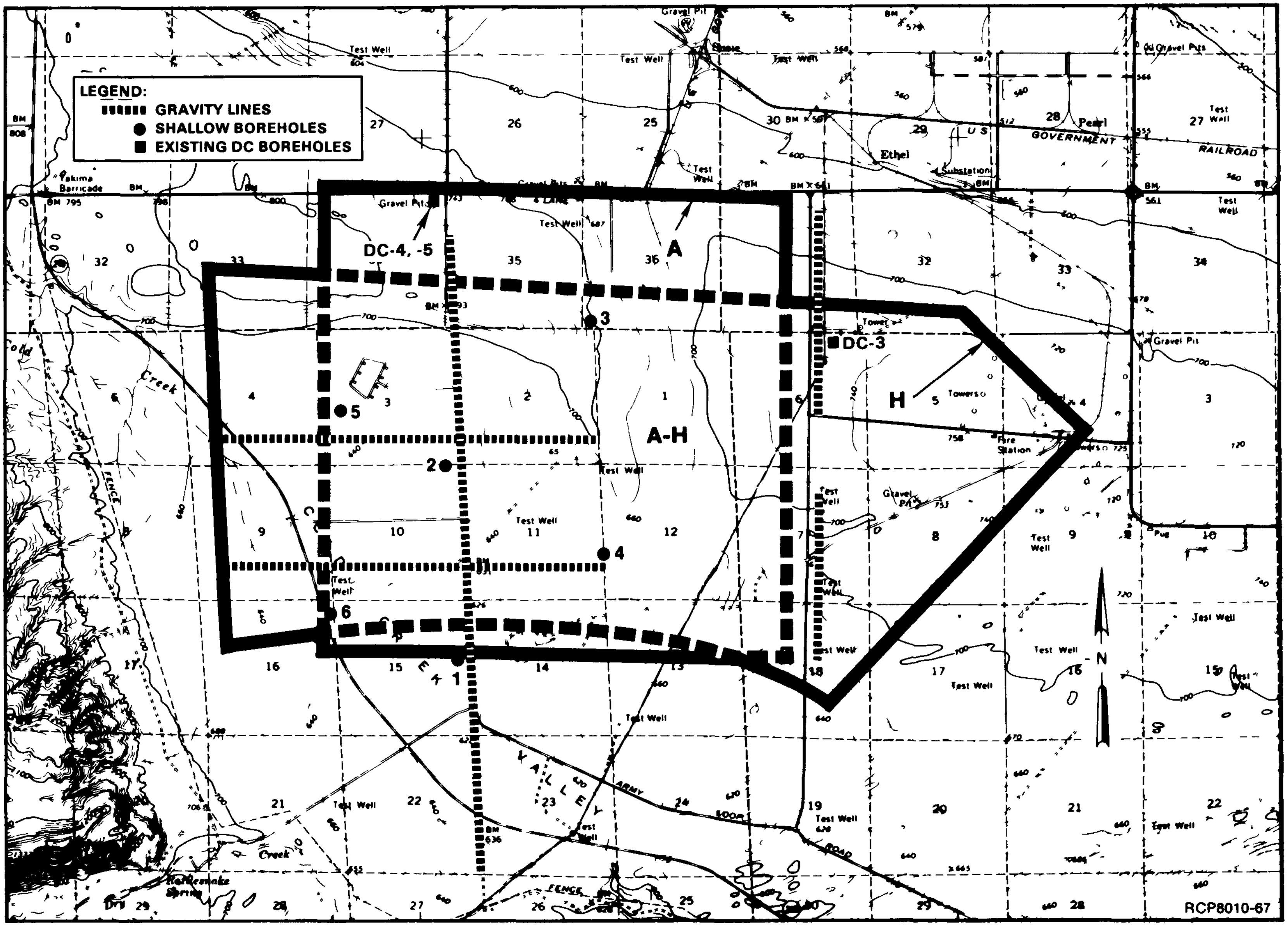


FIGURE 3. Reference Repository Location, Site A-H.

OVERVIEW OF REGULATORY AND INSTITUTIONAL STUDIES

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This paper provides an overview of the activities that have taken place in fiscal year 1980 within the Basalt Waste Isolation Project that are significant to licensing. Several documents have been prepared this year which will aid the licensing efforts for the Basalt Waste Isolation Project.

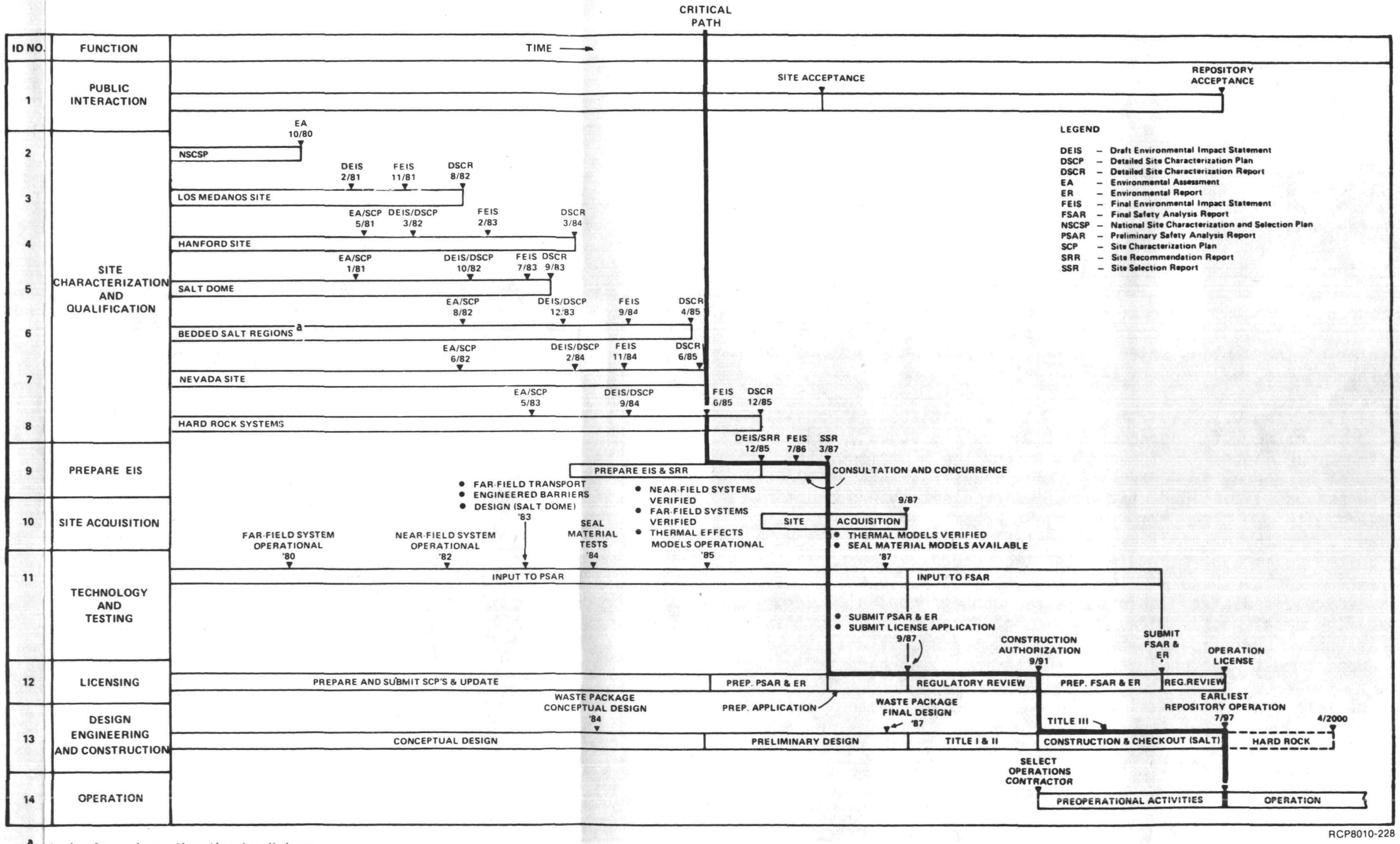
Field and laboratory investigations have been ongoing in the Basalt Waste Isolation Project and are focused toward the following needs:

- Site identification
- Engineered barrier development
- Conceptual repository design.

The status of the various scientific and engineering endeavors has been documented in several reports.(1,2,3)

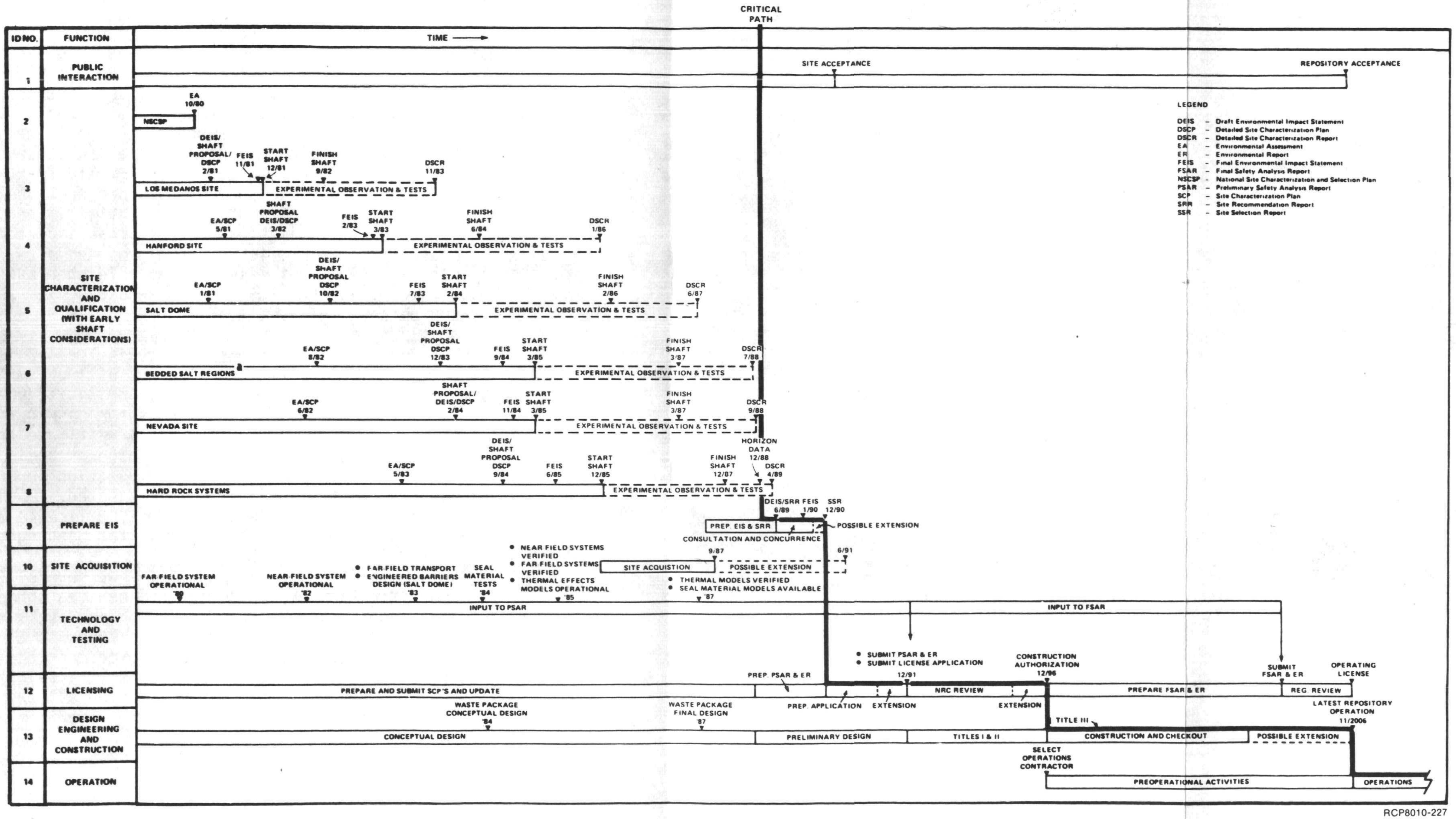
In April 1980, the U.S. Department of Energy submitted its position statement in the matter of proposed rulemaking on the storage and disposal of nuclear waste.(4) In Section III of the statement, the U.S. Department of Energy presented schedules illustrating that the site and media selection, licensing activities, and repository construction can take place within a time frame ranging between 16 and 26 years. Figures 1 and 2 are the National Waste Terminal Storage Program schedules contained in the rulemaking schedule. The two schedules are basically the same, except that in Figure 2 it is assumed that exploratory shaft facilities are required at all selected sites and extended time periods are assumed for certain activities. The important point made by the schedules is that, regardless of whether or not the Basalt Waste Isolation Project must have exploratory shafts for site characterization, a repository can be operational by the end of the year 2006. That date is coincident with the year the first commercial power reactor loses its 40-year license. These schedules call out several milestones appropriate to the Basalt Waste Isolation Project. The schedule calls for public release of the basalt licensing documents starting in May 1981.

The first licensing document is the Site Characterization Plan. The objective of the Site Characterization Plan is two-fold; first, to present the information needed to narrow the focus of investigation from an area (Hanford Site) of approximately 1,480 square kilometers to a location (Cold Creek syncline) of approximately 180 square kilometers, and, second, to discuss the plan for site characterization to support site selection and banking. An Environmental Assessment was prepared to parallel the Site Characterization Plan. The Environmental Assessment discusses the potential environmental impacts associated with the



[a] Bedded salt regions other than Los Medanos.

FIGURE 1. Summary Logic Network Activities Leading to Geologic Repository Operation (Reference Schedule).(4)



[a] Bedded salt regions other than Los Medanos.

FIGURE 2. Summary Logic Network Activities Leading to Geologic Repository Operation. (Extended Duration for Characterization, Licensing, and Construction).(4)

screening or narrowing of the area under consideration, as well as the physical activities associated with site characterization such as borehole drilling. The Environmental Assessment is also currently in the review and approval cycle. These two documents fulfill the May 1981 milestone shown on Figures 1 and 2.

The next milestone, as shown on Figures 1 and 2, is the Detailed Site Characterization Plan and the accompanying National Environmental Policy Act document, the Draft Environmental Impact Statement for site banking. The approach and purpose of the Detailed Site Characterization Plan is close to that of the Site Characterization Plan just discussed. It will present the information in support of identification of a preferred site and the plan for detailed characterization in support of site qualification. The Draft Environmental Impact Statement for site banking will address and evaluate the potential impacts of banking or reserving the site. It will also evaluate the potential impacts of the detailed site characterization activities and the impacts of construction, operation, and closure of a repository on the proposed site. Based on the level of repository design that will be available when the document is prepared, bounding calculations may have to be used. The approach will be adequate for the purpose intended.

The next milestone shown on Figures 1 and 2 is the Detailed Site Characterization Report. This report will present all the characterization information that will support or assist the decision to construct a repository on a basalt site. As shown on Figures 1 and 2, the National Waste Terminal Storage Program will investigate and characterize sites in several different rock types. Each effort should culminate in the issuance of a Detailed Site Characterization Report. From this library of reports, the first site will be selected. Once a site is selected and documented in a site selection report, a license application will be prepared and submitted for a license for construction.

This brief overview illustrates that several factors must be taken into consideration when planning a licensing schedule for such a complex program. As mentioned, the federal government's current program will bring several sites in different rock types to a common level before going forth with a licensing application. In addition, several National Environmental Policy Act documents and site selection reports must be developed. Our current program has taken all these considerations into account in our planning and scheduling efforts.

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2. R. E. Gephart, R. C. Arnett, R. G. Baca, L. S. Leonhart, and F. A. Spane, Jr., Hydrologic Studies within the Columbia Plateau, Washington, An Integration of Current Knowledge, RHO-BWI-ST-5, Rockwell Hanford Operations, Richland, Washington, 1979.

3. M. J. Smith, G. J. Anttonen, G. S. Barney, W. E. Coons, F. N. Hodges, R. G. Johnston, J. D. Kaser, R. M. Manabe, S. C. McCarel, E. L. Moore, A. F. Noonan, J. E. O'Rourke, W. W. Schulz, C. L. Taylor, B. J. Wood, and M. I. Wood, Engineered Barrier Development for a Nuclear Waste Repository in Basalt, An Integration of Current Knowledge, RHO-BWI-ST-7, Rockwell Hanford Operations, Richland, Washington, 1980.

4. Statement of Position of the United States Department of Energy in the Matter of Proposed Rulemaking on the Storage and Disposal of Nuclear Waste (Waste Confidence Rulemaking), DOE/NE-0007, U.S. Department of Energy, Washington, D.C., April 15, 1980.

BASALT SITE QUALIFICATION--COMPARISON OF NATIONAL WASTE TERMINAL STORAGE CRITERIA AND REGULATORY REQUIREMENTS

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To establish a licensed repository for nuclear wastes in basalt, the U.S. Department of Energy intends to comply with all parts (technical criteria and administrative procedures) of the regulatory process. Licensing requirements and good engineering practices require that project development, research, and engineering be done in a traceable manner. The licensing requirements which are now in draft form invoke Title 10, Code of Federal Regulations, Part 50, Appendix B(1) on all license applications. These regulations require traceability. A significant element for supporting this process is the preparation of a technical baseline for the Basalt Waste Isolation Project. The baseline supports the establishment of configuration control methodology and serves as a basis to develop the repository system specifications and the study programs aimed at assessing the feasibility of nuclear waste disposal in a basalt environment.

The principal criteria document for the Basalt Waste Isolation Project compiles all principal criteria which serve to guide the various work elements that comprise the Basalt Waste Isolation Project. In writing this document the authors have:

- Reviewed the mission of the National Waste Terminal Storage Program of which the Basalt Waste Isolation Project is a part
- Reviewed the Basalt Waste Isolation Project mission
- Reviewed the confidence rulemaking submission to the U.S. Nuclear Regulatory Commission by the U.S. Department of Energy(2) which expands on the overall mission of the National Waste Terminal Storage Program
- Summarized the National Waste Terminal Storage Program objectives applicable to the Basalt Waste Isolation Project
- Identified technical and regulatory criteria from the U.S. Department of Energy, the U.S. Nuclear Regulatory Commission, the Office of Nuclear Waste Isolation, and other federal and state agencies
- Extracted technical criteria for the Basalt Waste Isolation Project as identified in the above sources
- Consolidated similar criteria from several other sources
- Provided preliminary justifications or interpretations for the criteria that required modification or consolidation

- Listed the sources of the reference materials which provide the basis for the criteria utilized by the Basalt Waste Isolation Project and established traceability to the entire process.

Several federal, state and local regulatory agencies have and will provide criteria (guidelines, regulations, etc.) which have an effect on the Basalt Waste Isolation Project. Some of these criteria have precedence over others and many of them are only in draft form. Additional criteria will probably be promulgated in the future.

Those regulations, which are in draft form, do not have the force of law at present, and yet these draft regulations provide clues as to the content of future regulations. Until the regulations become law, the Basalt Waste Isolation Project has chosen to follow the criteria which appear likely to become law and appear to have direct application to the project. Inclusion of criteria from draft regulations does not imply tacit approval of the regulation by Rockwell Hanford Operations.

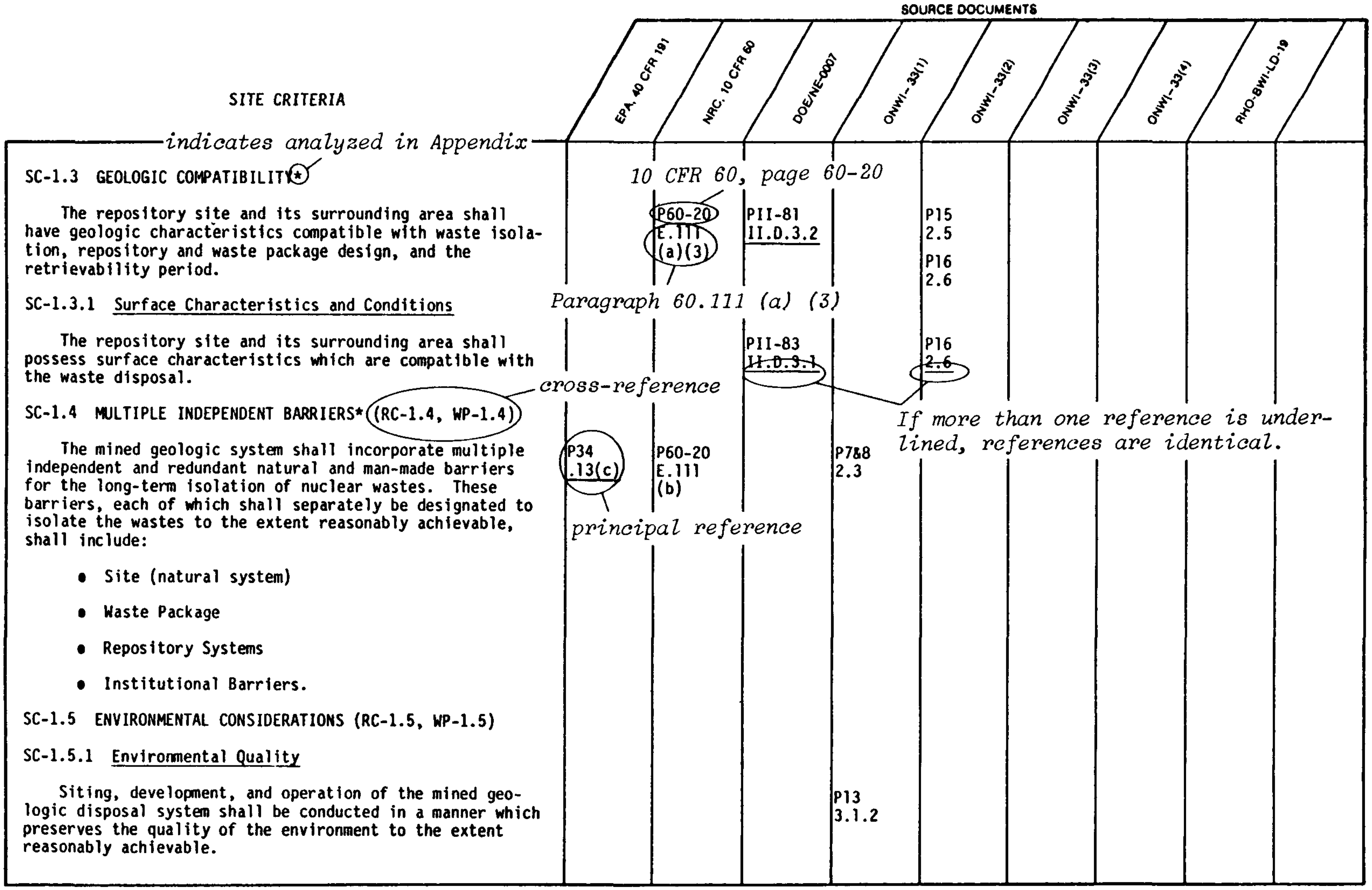
The Office of Nuclear Waste Isolation criteria and procedural requirements documents will be baselines for the National Waste Terminal Storage Program and therefore the Basalt Waste Isolation Project must comply with the criteria that they contain. All other external criteria which can be associated with Office of Nuclear Waste Isolation umbrella-type criteria have been identified in the criteria tables.

The criteria are organized in tables and are separated into five categories which are also the categories of the work breakdown structure. These categories are:

- Site
- Repository
- Waste Package
- Test Facilities
- Regulatory and Institutional.

A typical page from the tables of criteria is shown in Figure 1. Each criterion is identified as being supported from its source document by paragraph and page number. Page numbers are shown to assure that the exact source can be found in a particular draft of the source document. The draft source documents have been assembled and are kept by Rockwell Hanford Operations' configuration management group. As each draft is updated, the criteria document and its appendix can be updated with traceability maintained.

The principal criteria document will be maintained by revision and issuance of individual pages as changes are approved. The principal criteria document is the driving mechanism for the Basalt Waste Isolation Project systems specifications and technical plans (Figure 2). The



SITE CRITERIA	SOURCE DOCUMENTS							
	EPA, 40 CFR 191	NRC, 10 CFR 60	DOE/NE-0007	ONWI-33(1)	ONWI-33(2)	ONWI-33(3)	ONWI-33(4)	RHO-BWI-LD-19
SC-1.3 GEOLOGIC COMPATIBILITY* The repository site and its surrounding area shall have geologic characteristics compatible with waste isolation, repository and waste package design, and the retrievability period.		P60-20 E.111 (a)(3)	PII-81 II.D.3.2		P15 2.5 P16 2.6			
SC-1.3.1 Surface Characteristics and Conditions The repository site and its surrounding area shall possess surface characteristics which are compatible with the waste disposal.			PII-83 II.D.3.1		P16 2.6			
SC-1.4 MULTIPLE INDEPENDENT BARRIERS* (RC-1.4, WP-1.4) The mined geologic system shall incorporate multiple independent and redundant natural and man-made barriers for the long-term isolation of nuclear wastes. These barriers, each of which shall separately be designated to isolate the wastes to the extent reasonably achievable, shall include: • Site (natural system) • Waste Package • Repository Systems • Institutional Barriers.	P34 .13(c)	P60-20 E.111 (b)		P7&8 2.3				
SC-1.5 ENVIRONMENTAL CONSIDERATIONS (RC-1.5, WP-1.5)								
SC-1.5.1 Environmental Quality Siting, development, and operation of the mined geologic disposal system shall be conducted in a manner which preserves the quality of the environment to the extent reasonably achievable.				P13 3.1.2				

FIGURE 1. Sample Criteria Table.

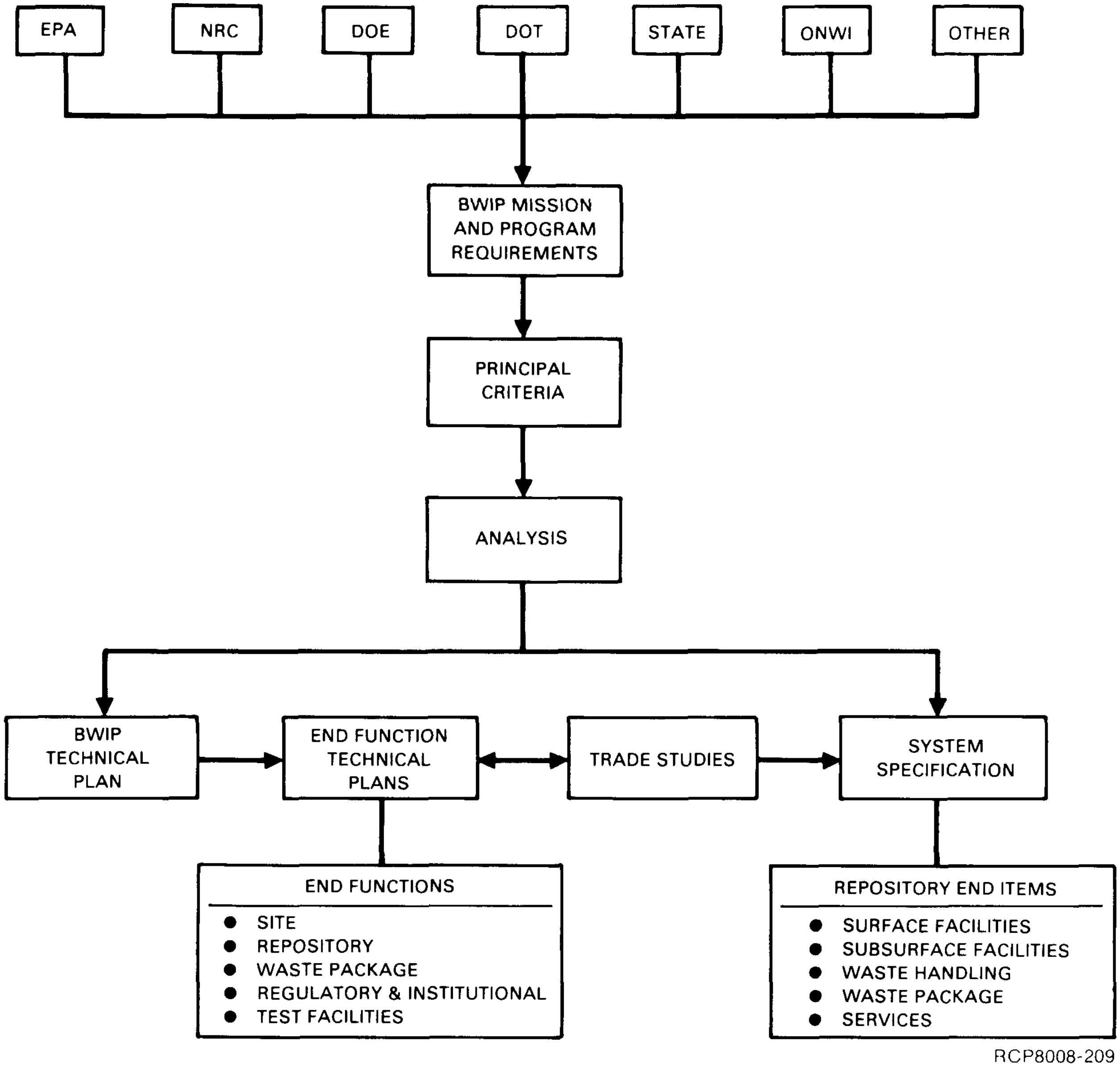


FIGURE 2. Technical Baseline Development.

systems specifications, through a specification tree, convert the criteria into specifications for the design, construction and operation of the repository. The technical plans, through a system of logic networks, specify each work element and work element relationships required to meet the principal criteria document. The ability to trace all elements of the project work, all the way down to the in-house work authorization documents, back to their source requirements is a Basalt Waste Isolation Project management requirement. Accordingly, an indexing system, based upon written Rockwell Hanford Operations procedures, has been developed to assure that all the criteria and procedural requirements are satisfied by some work element within the Basalt Waste Isolation Project.

REFERENCES

1. Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants, Title 10, Code of Federal Regulations, Part 50 (Appendix B), U.S. Nuclear Regulatory Commission, Washington, D.C., January 20, 1975.

2. Statement of Position of the United States Department of Energy in the Matter of Proposed Rulemaking on the Storage and Disposal of Nuclear Waste (Waste Confidence Rulemaking), DOE/NE-0007, U.S. Department of Energy, Washington, D.C., April 15, 1980.

BASALT WASTE ISOLATION PROJECT TECHNICAL BASELINE

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Efficient management control of the Basalt Waste Isolation Project dictates that control of the technical baseline be enhanced. The technical baseline is a tool which defines and controls technical requirements, specifications, criteria, documents, and drawings needed to meet the Basalt Waste Isolation Project objectives. Efficient control, traceability, and visibility are emphasized. To accomplish this, Rockwell Hanford Operations introduced and implemented the classical Systems Engineering (integrated engineering process) approach to technical baselining. This tool has been used successfully by other organizations for more than a decade (e.g., the space program). This tool can be tailored to project control needs regardless of project size. The technical baseline control approach was designed to be in accordance with existing Basalt Waste Isolation Project quality assurance and configuration management Plans.

The Systems Engineering approach (Table 1) provides work or task control, visibility, and traceability which are the bases for assuring that all aspects of engineering logic have been applied to the project and that all project aspects are documented. These aspects are:

- Establish program logic
- Prepare program specification
- Prepare technical development plan
- Prepare functional flow block diagrams
- Perform tradeoff studies
- Prepare design requirements and design data sheets
- Prepare schematic diagrams
- Generate layout drawings
- Prepare specification tree
- Prepare system specifications
- Recycle to next level of detail
- Results in complete detail specifications and drawings.

TABLE 1. Systems Engineering Approach.

The Method Operating on a Set of Approved Basic Inputs to Arrive at Desired Endpoint		
Requires	Provides	Assures
Long-Range Plan	Functional analysis-functional flow diagrams	Complete detailed specifications and drawings
Overall Program Logic	Allocation of requirements-schematic diagrams, general layout drawings, design data sheets, specifications	
Program Specification		
Preliminary Development Plan	Optimum solution-trade (tradeoff) study reports	

Control of the Basalt Waste Isolation Project technical baseline is maintained through the Technical Logic Network (Figure 1 in the section by Gurley and Alford), which identifies three primary technical baseline documents. These documents are a vital part of the Basalt Waste Isolation Project technical baseline control system:

- Basalt Waste Isolation Project principal criteria document
- Basalt Waste Isolation Project technical plan
- Basalt Waste Isolation Project system specifications.

They identify what has to be done to meet the objectives of the project and how it is planned to do it. These are the driving plans for the project.

The principal criteria document contains and identifies all criteria, regulations, and requirements imposed on the project by federal, state, local, and other governmental agencies. These requirements have been reviewed, analyzed, interpreted, and categorized into groupings consistent with the project work breakdown structure and the Basalt Waste Isolation Project functional organization. This document defines what has to be done to meet the project objectives.

The Basalt Waste Isolation Project technical plan identifies how we plan to accomplish these objectives. Each element of work or task necessary to meet a requirement or satisfy a criteria is identified through end function (as defined via the work breakdown structure) technical plans and logic networks, which form the basis of the Basalt Waste Isolation Project technical plan. The end functions are identified as:

- Waste package
- Site characterization

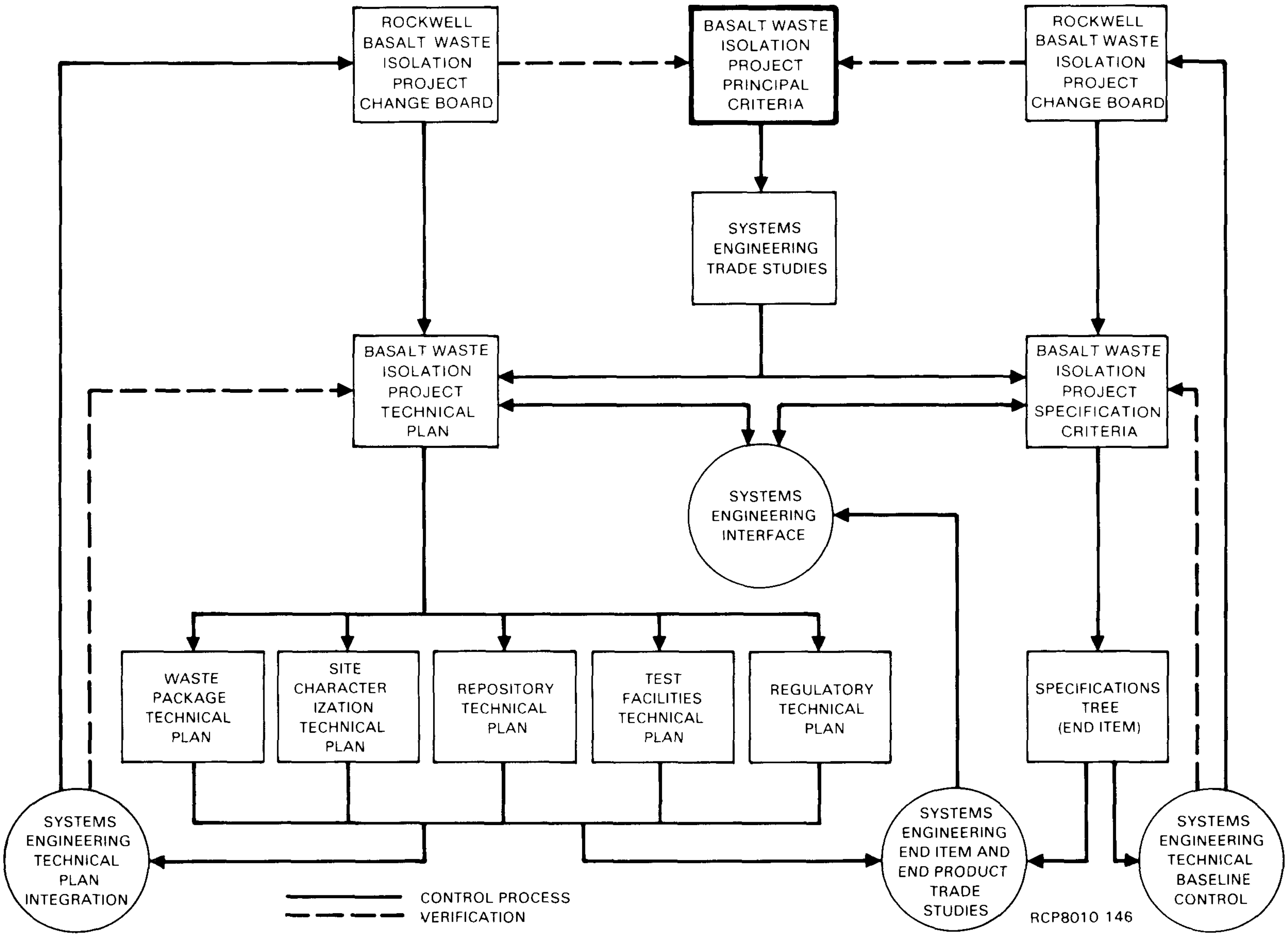

FIGURE 1. Systems Engineering Technical Control.

- Repository
- Regulatory
- Test facilities.

The Basalt Waste Isolation Project technical plan provides a complete overview of the technical rationale being utilized and the justification for the specific work element or task necessary to meet program objectives. It is a compilation and summarization of the end function technical plans.

In addition to these two documents, Rockwell Hanford Operations has prepared Basalt Waste Isolation system specifications which define the quantitative technical performance requirements derived from the principal criteria for the design, construction, and operation of a repository in basalt. The systems specifications specify design parameters, criteria, and constraints for a system or subsystem.

As in all projects, specifications are necessary to build an end product, and in keeping with our systems engineering approach, the Basalt Waste Isolation Project systems specifications were structured to and identify five end products which will be necessary to design, construct, and operate a repository in the basalt underlying the Hanford Site. These end products are identified as:

- Surface facility
- Subsurface facility
- Service system
- Waste handling system
- Waste package system.

They constitute the makeup of the total repository and complement the project work breakdown structure and the groupings categorized in the principal criteria and the Basalt Waste Isolation Project technical plan. The systems specifications redefine the criteria, regulations, and requirements into workable design, construction, and operation specifications through a specification tree (see Figure 2 in the section by Gurley and Alford) to the level of detail required.

The systems specifications support the principal criteria document concerning <u>what</u> has to be done to complete a nuclear waste repository in basalt. It also identifies <u>what</u> each element of work or tasks will ultimately have to support and is used as an aid in ensuring that all work performed is logically supportive of the end product.

Management visibility of the overall technical baseline is aided by a traceability and indexing system. Each element of work or task performed must be done for a specific purpose--to meet a criteria, requirement, regulation, or specification. Visibility is accomplished through a computerized numerical code, which identifies each item of work to each specific criteria or specification in the principal criteria document and systems specifications. It also allows the requirement to be traced to its original source, such as a government regulation or law. Traceability, such as this, gives management visibility for planning, cost, and schedular control.

Finally, management control (Figure 1) of the Technical Baseline utilizes and is achieved through a configuration management change control process and is integrated throughout the project via a forward planning document with the master project schedule and fiscal year budget. Baseline control supplies the guidance and visibility for long-term management, yet it allows for the flexibility which is necessary in the developmental stages of the program. It provides both the customer and the contractor the control mechanism for effective management.

REFERENCE REPOSITORY CONDITIONS FOR A REPOSITORY IN BASALT

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Reference repository conditions information is being compiled for a nuclear waste repository in basalt in conjunction with the National Waste Terminal Storage Program task to compile such information for all geologic media that are primary candidates for repository siting. The reference repository conditions information is being developed to serve as a guide for: scientists conducting material performance tests; engineers preparing repository designs; personnel defining technically conservative conditions to be used as bases for the U.S. Department of Energy repository license applications; and scientists and engineers developing waste forms. Present plans call for the completion of reference repository conditions reports for salt, basalt, tuff, granite, and shale by December 1981.

REFERENCE HIGH-LEVEL WASTE PACKAGES

The three types of high-level waste that are being considered for the National Waste Terminal Storage Program reference repository conditions task are as follows: spent fuel from light-water-cooled nuclear power reactors; commercial high-level waste that would result from reprocessing of light water reactor spent fuel; and defense high-level waste resulting from fuel reprocessing for nuclear weapons manufacturing. The choice of waste characteristics used as bases for specific calculations is based on a goal of conservatism; i.e., overprediction of expected impacts on the repository environment. For example, pressurized water reactor spent fuel is chosen over boiling water reactor spent fuel for thermal calculations because of its greater thermal power per canister.

The reference repository conditions task within the Basalt Waste Isolation Project has so far focused primarily upon spent fuel as a waste form for consistency with the nuclear waste repository in basalt conceptual design bases. Additional design studies specific to commercial high-level waste and Hanford defense high-level waste are currently in progress within the architect-engineering firm responsible for nuclear waste repository in basalt conceptual design. It is currently planned that the results of these studies will be included as appendices to the nuclear waste repository in basalt conceptual design report.

Descriptive information on waste package characteristics is presented in Table 1. The reference case shown for spent fuel, consistent with the conceptual design bases, utilizes a package containing disassembled fuel rods from three pressurized water reactor fuel assemblies or seven boiling water reactor fuel assemblies. The reference case package also

TABLE 1. Waste Package Characteristics.

Characteristics	Spent Fuel		Commercial High-Level Waste
	Reference Case	Alternate Case	
Waste Description			
Active length (meters)	3.7	3.7	2.4
Active volume (cubic meters)	NA	NA	0.18
Age of waste (years)[a]	10	10	10
Thermal loading (kilowatts per canister)[a]	1.65[b]	0.55[b]	1.0
Canister Dimensions			
Outer diameter (centimeters)	32.4[c]	35.6[d]	32.4[c]
Inner diameter (centimeters)	30.5	33.7	30.5
Length (meters)	4.6	4.7	3.0
Overpack Dimensions			
Outer diameter (centimeters)	53.3	40.6	40.6[e]
Inner diameter (centimeters)	52.8	38.1	38.1
Length (meters)	4.9	5.1	3.4
Backfill Dimensions			
Thickness (centimeters)	20.3	5.1	5.1
Length (meters)	5.4	5	5
Liner Dimensions			
Outer diameter (centimeters)	114.3	53.3	53.3
Inner diameter (centimeters)	94.0	50.8	50.8
Length (meters)	6.4	6.3	5.5
Materials			
Waste matrix	UO_2	UO_2	Glass
Filler in canister	Helium	Helium	Air
Canister	Carbon steel	Carbon steel	Stainless steel
Overpack	Titanium	Carbon steel	Carbon steel
Backfill	Clay and crushed basalt	Crushed basalt	None
Hole liner	None	Carbon steel	Carbon steel
Emplacement hole plug	Sand	Concrete	Concrete

[a] At emplacement (after discharge from reactor).
[b] Heat generation rates for spent fuel 10 years out of reactor.
[c] Nominal 12-inch Schedule 40 pipe.
[d] Nominal 14-inch Schedule 30 pipe.
[e] Nominal 16-inch Schedule 40 pipe.
NA = Not Applicable.

includes, in response to anticipated regulatory requirements, a system of engineered barriers for waste containment. The engineered barrier system is intended to provide reasonable assurance of overall package integrity for at least 1,000 years.

The Table 1 information on the alternate case spent fuel package is also included to allow compatibility comparisons between the nuclear waste repository in basalt design bases and the design assumptions being used to develop reference repository conditions for other geologic media. The alternate case package contains intact fuel assemblies (one pressurized water reactor or three boiling water reactor) and lacks many of the engineered barrier features of the reference case package. Table 1 also presents reference assumptions regarding the commercial high-level waste package that are consistent with those tentatively being used for other hard-rock geologic media. The engineered barriers assumptions indicated for the commercial high-level waste package are the same as those used for the alternate case spent fuel package, since engineered barrier conceptual design studies for these two package types have not yet been performed.

Relative thermal power decay projections for spent fuel and commercial high-level waste are presented in Table 2. The decay characteristics of these waste types were selected from the fuel cycles considered in the Draft Environmental Impact Statement for Management of Commercially Generated Radioactive Waste.(1)

REFERENCE REPOSITORY DESCRIPTION

The reference repository description for a potential nuclear waste repository in basalt is summarized in Table 3. These parameters are based upon ongoing conceptual design work being performed by an architect-engineering firm. This description is based upon the reference case spent fuel package, including its associated engineered barriers system. The chief impacts of the engineered barriers system are increased emplacement hole size (1.22-meter diameter x 6.4 meters deep) and potential physical limitation on local areal thermal loading.

The reference repository layout for the subsurface facilities is rectangular in shape (about 2,400 meters wide and 3,200 meters long). The reference repository in basalt for spent fuel is a single-row configuration. Based upon each canister containing fuel rods from three pressurized water reactor or seven boiling water reactor fuel assemblies, the pitch is 3.66 meters. For the alternate case of one pressurized water reactor or three boiling water reactor intact fuel assemblies per canister, and neglecting engineered barriers, the pitch could be about 1.22 meters for a nearly equivalent thermal density. The limiting parameter for a repository in basalt containing spent fuel is the fuel cladding temperature limit of 300°C. Current data show that basalt host rock has acceptable creep strength values up to at least 500°C, while joint property values of basalt are acceptable up to about 300°C.

TABLE 2. Relative Heat Generation Rates.[a]

Year after Emplacement[b]	Commercial High-Level Waste	Spent Fuel
0	1.0	1.0
1	0.950	0.956
2	0.907	0.919
3	0.871	0.889
4	0.851	0.861
5	0.810	0.838
6	0.783	0.819
7	0.769	0.799
8	0.734	0.782
9	0.714	0.763
10	0.692	0.750
15	0.600	0.681
20	0.529	0.622
30	0.402	0.525
40	0.313	0.449
50	0.246	0.387
70	0.157	0.301
100	0.0864	0.238
190	0.0296	0.137
290	0.0215	0.108
390	0.0163	0.0919
490	0.0145	0.0806
590	0.0127	0.0711
690	0.0113	0.0633
790	0.0100	0.0569
890	0.00897	0.0514
990	0.00810	0.0466
1,990	0.00404	0.0247
5,990	0.00230	0.0148
9,990	0.00175	0.0114

[a] The commercial high-level waste decay rates correspond to waste arising from fuel which is a 3:1 mix of UO_2 and mixed oxide fuels.

[b] Assumes waste is 10 years out of reactor.

TABLE 3. Reference Repository in Basalt Characteristics.

Characteristics	Spent Fuel
Repository Configuration (rounded values)	
Areal extent (meters)[a]	2,400 x 3,200
Thermally loaded area (hectares)[b]	475
Depth below surface (meters)	1,100
Thermal Loading (at emplacement)	
Local areal thermal loading (watts per square meter)	12.3
Average areal thermal loading (watts per square meter)	8.2
Room Description	
Room length (meters)	1,100
Room width (meters)	4.3
Room height (meters)	6.1
Adjacent pillar thickness (meters)	32.3
Canister Emplacement Holes	
Rows per room	1
Row separation	Single Row
Hole pitch (along row) (meters)[c]	--
Hole depth (meters)	6.4
Hole diameter (meters)[c]	--
Canisters per hole	1

[a] Near-field conditions near the center of a large repository are not significantly dependent on the size. These near-field conditions are described in this report. Conditions near the outer edges would not be as severe as near the center.

[b] Because of passive areas, this area is less than the overall repository area by approximately 33%.

[c] For a repository in basalt, two configurations have been calculated; a reference case of three pressurized water reactor or seven boiling water reactor elements per canister, and an alternate case of one pressurized water reactor or three boiling water reactor elements per canister. The hole pitch is 3.66 meters for the reference case and 1.22 meters for the alternate case. The hole diameter is 1.22 meters for the reference case and 0.54 meter for the alternate case.

The commercial high-level waste reference repository is tentatively assumed to be a single-row configuration with about the same areal thermal loading as for spent fuel, pending completion of ongoing design studies. Since the limiting spent fuel cladding temperature criterion is not applicable to commercial high-level waste, higher thermal loadings appear feasible.

BASALT PROPERTIES AND COMPOSITION

The reference repository in basalt is defined as being located about 1 kilometer beneath the ground surface within the Columbia River Basalt Group and also within the boundaries of the Hanford Site. The total basalt thickness for this reference location is about 3 kilometers thick.

Thermal and mechanical basalt properties, based upon data from the Pomona flow of the Saddle Mountains Formation, are presented in Table 4. These properties are currently used as reference information by virtue of the extensive test data available for Pomona basalt, which crops out within the Near-Surface Test Facility on the Hanford Site. Corresponding data for the successively deeper Wanapum and Grande Ronde Basalt Formations, including the Umtanum Flow (within the Grande Ronde Formation) currently being considered for repository siting, are being obtained and evaluated. The values used as bases for the thermal calculations are more conservative than the Table 4 data; therefore, differences in basalt properties between the Pomona flow and Umtanum flow should not invalidate the thermal calculations.

Typical average basalt chemical compositions for basalt flows within the Grande Ronde Basalt Formation are summarized as follows:(2)

Compound	Weight Percent
SiO_2	53.8 - 55.9
Al_2O_3	14.0 - 15.3
$FeO + Fe_2O_3$	9.5 - 11.8
MgO	3.4 - 5.9
CaO	6.9 - 9.8
Na_2O	2.8 - 3.1
K_2O	0.8 - 2.0
TiO_2	1.2 - 2.3
P_2O_5	0.3 - 0.4
MnO	0.2

TABLE 4. Reference Basalt Thermal and Mechanical Properties.

Item	Range	Mean ± Standard Deviation	Units	Comments
Density				
Bulk	2.80 - 2.88	2.85 ± 0.02	Grams per cubic centimeter	---
Grain	2.88 - 3.11	3.00 ± 0.05	Grams per cubic centimeter	---
Apparent Porosity	0.5 - 1.3	0.91 ± 0.28	Percent	---
Thermal Diffusivity	4.41 - 7.61	6.3 ± 0.68	10^{-3} square centimeters per second	Temperature (20-300°C)
Specific Heat	313.8 + 119.7 ln T		Joules per kilogram- K	Temperature (70-350°C)
Thermal Conductivity	$1.84 + 1.65 \times 10^{-3}$ T		Watts per meter- K	Temperature (20-300°C)
Coefficient of Thermal Expansion	$5.1 + 2.2 \times 10^{-3}$ T		10^{-6}/°C	Temperature (70-300°C)
Compressive Strength	26.6 - 41.4	35.6 ± 0.43	10^7 pascals	Temperature = 22°C Confining stress = 0 pascals
	40.4 - 44.1	42.3 ± 0.26	10^7 pascals	Temperature = 22°C Confining stress = 345x10^4 pascals
	34.2 - 47.8	40.9 ± 0.61	10^7 pascals	Temperature = 22°C Confining stress = 689x10^4 pascals
	47.0 - 50.3	48.5 ± 0.17	10^7 pascals	Temperature = 22°C Confining stress = 1378x10^4 pascals
	31.9 - 41.1	36.5 ± 0.65	10^7 pascals	Temperature = 150°C Confining stress = 68.9x10^4 pascals
	27.4 - 29.1	28.1 ± 0.09	10^7 pascals	Temperature = 300°C Confining stress = 68.9x10^4 pascals

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

THERMAL ENVIRONMENT

Thermal analyses have been performed in support of the repository in basalt conceptual design activity, based upon the reference case spent fuel package. Spacing of spent fuel packages was constrained by the spent fuel cladding maximum temperature criterion of 300°C. Therefore, the calculated peak fuel cladding temperature is slightly under 300°C, and the corresponding peak basalt temperature is less than 200°C. These calculations are based upon an ambient basalt temperature of 57°C.

Far-field temperature effects over long time periods have also been calculated using a plane-source computer model; the results of these calculations are presented in Figure 1. For these calculations, it has been assumed that the repository remains dry during the time periods involved; this assumption was made for conservatism, since basalt thermal conductivity increases with increasing moisture content. Actual temperatures would be lower than those calculated if post-closure repository flooding occurs.

Cursory thermal calculations were performed to compare the reference case spent fuel package with the alternate case. Results of these calculations confirmed that, for identical areal thermal loadings, basalt temperatures were nearly identical for the two cases at only a few meters from the emplaced packages. Furthermore, the maximum basalt temperatures at the emplacement hole wall were also nearly the same for the two cases, since the emplacement hole wall areal heat fluxes are coincidentally nearly equivalent. The engineered barriers associated with the higher thermal power reference case package necessitate a larger diameter emplacement hole than for the alternate case package. Calculated basalt and canister wall temperatures were actually slightly higher for the lower thermal power alternate case than for the reference case.

FLUID ENVIRONMENT

The range of physicochemical conditions expected to occur in a geologic repository are of special interest to engineers and scientists involved in the design of engineered barrier systems and waste packages. The parameters of interest include temperature, pressure, oxygen fugacity, Eh, pH, and dominant groundwater species. Over most of the repository life, these conditions will be controlled by repository depth, ambient geothermal gradients, and reactions between groundwater and basalt. Thus, the ambient conditions are directly relevant to long-term stability of the waste package.

In situ well measurements within the Grande Ronde Formation have shown the ambient temperature to be 45°C to 65°C and the groundwater pH to be 9.4 to 9.9. The reference groundwater chemical composition for the Grande Ronde aquifer is as follows:(3)

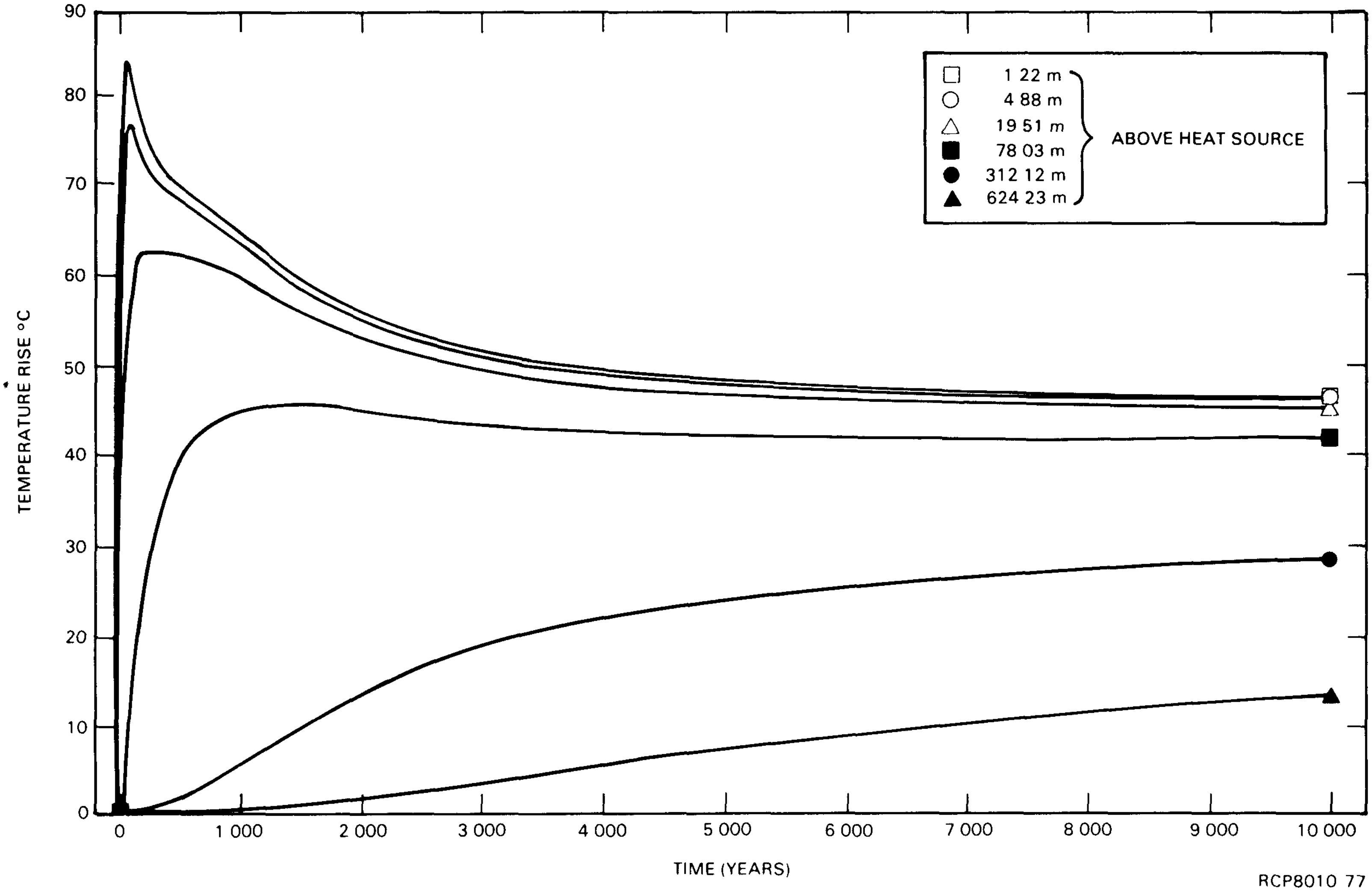

FIGURE 1. Far-Field Temperature Effects.

Ion Species	Concentration (milligrams per liter)
Na^+	250
K^+	1.9
Ca^{2+}	1.3
Mg^{2+}	0.04
$CO_3{}^{2-}$	21
$HCO_3{}^-$	25
OH^-	10
$H_3SiO_4{}^-$	145
Cl^-	148
F^-	37
$SO_4{}^{2-}$	108

The active oxygen content in the geologic environment directly affects barrier corrosion, waste solubility, and radionuclide migration. Available oxygen is controlled by oxygen exchange among mineral phases comprising the host geology. For basalt, oxygen fugacity (active oxygen concentration) is customarily taken to be in the range defined by the quartz-fayalite-magnetite buffer and the nickel-nickel oxide buffer. The calculated equilibrium oxygen fugacities for these reactions are shown as a function of temperature in Table 5.

TABLE 5. Repository Groundwater Equilibrium Conditions.(3)

Temperature (°C)	pH	Log Oxygen Fugacity (atmosphere)	Eh (volts)
65	9.4	-64.5 to -67.15	-0.05 to -0.54
100	8.7	-57.8 to -60.0	-0.49 to -0.53
150	7.9	-49.6 to -51.8	-0.48 to -0.53
200	7.2	-43.3 to -45.4	-0.47 to -0.52
250	6.7	-38.3 to -40.2	-0.48 to -0.52
300	6.2	-34.1 to -35.9	-0.45 to -0.51

Oxidation-reduction potential (Eh) is another parameter used to describe the corrosive properties of an aqueous solution. Eh is related to oxygen fugacity by the dissociation of water, which is dependent on hydrogen ion activity, or pH. Values of Eh may be calculated at any temperature, provided oxygen fugacity and pH are known. These values are also shown in Table 5.

Groundwater pH is dependent upon two processes which drive pH in opposite directions while proceeding at different rates. The two processes are precipitation and solid-liquid reaction, which both result in a clay product. For a relatively free-flowing groundwater, the absolute value for hydrothermal pH is difficult to predict; it might, however, be as low as pH = 4 within the repository. Under more normal, near-stagnant conditions, pH of groundwater near the reference repository horizon can be predicted from the following equation: $pH = 1.21 + 2.81 (1,000/T^{o}K)$. Values of pH are also listed in Table 5 as a function of temperature.

PRESSURE ENVIRONMENT

Two types of pressure, lithostatic and hydrostatic, are important to discussions of pressure within the repository. The difference between lithostatic and hydrostatic pressure is a result of the different densities of rock (∿3.0 grams per cubic centimeter for basalt) and water (∿1.0 gram per cubic centimeter). If a fluid phase (i.e., water) is present within the rock, the pressure within the fluid phase will be some value between the lithostatic and hydrostatic pressures. The lithostatic pressure at a repository depth of 1,100 meters would be approximately 3.3×10^7 pascals; the hydrostatic pressure at the same depth would be approximately 1.1×10^7 pascals.

The pressure within the repository prior to backfilling and closure will be 1 atmosphere plus the weight of the column of air between sea level and repository depth, a result insignificantly different from 1 atmosphere. After backfilling and sealing of the repository, two different pressure scenarios must be considered; one with non-expanding backfill and the second with expanding backfill. In the case of non-expanding backfill material, pressure buildup within the repository would be controlled principally by movement of water into the repository. The final pressure would probably be slightly above normal hydrostatic pressure because the deep aquifers beneath the Hanford Site tend to be confined. Pressures equivalent to 142 meters of water above mean sea level have been measured,(3) which is about 20 meters more than hydrostatic pressure at the measurement point.

For the case of expanding backfill in which an expanding clay (e.g., bentonite) is a major component, the pressure buildup within the repository would be influenced primarily by the expansion of the clays. Expanding clay within the backfill would be at least partly dehydrated prior to emplacement, and would react with any water entering the repository. The resultant expansion would cause a more rapid pressure increase within a sealed repository. If sufficient water and clay are available, the expansion would continue until the pressure on the clay is equal to the lithostatic pressure. Because of the low permeability of well-compacted clay, very little water migration between the backfill and the surrounding rock would occur.

At a temperature of 300°C, the vapor pressure of water is 8.6×10^6 pascals, which is considerably less than the hydrostatic pressure. Thus, steam should not be capable of displacing water from the surrounding rock and escaping from the repository.

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BASALT WASTE ISOLATION PROJECT PUBLIC AFFAIRS

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The Basalt Waste Isolation Project, as part of the National Waste Terminal Storage Program, is conducted under an open-information policy designed to establish and maintain credibility with the public and its elected officials. It is directed toward providing necessary information to the public and its elected officials to assist in their effective participation in the nuclear waste storage decision-making process.

The public information objectives are:

- To keep the public, interested individuals and groups, program participants, and other associated organizations informed about Basalt Waste Isolation Project activities.
- To interface with other National Waste Terminal Storage Program components to provide continuity in information provided to the scientific community, governmental agencies, local and state officials, the educational community, special interest groups, and labor organizations.
- To provide timely information to the news media, appropriate public officials, and concerned segments of the public to assure accurate news coverage of the Basalt Waste Isolation Project activities.
- To provide information to news media representatives upon request and to make reasonable and timely arrangements for visits to Basalt Waste Isolation Project work sites and facilities by interested groups and individuals.

To assure that the public, government, and technical communities are provided correct and factual information in a timely manner, the Basalt Waste Isolation Project provides updated scientific and technical information on all aspects of the project to the public in understandable terms through:

- Press releases, press briefings, and press seminars/conferences
- Brochures, booklets, pamphlets, fact sheets, briefing books, press kits, and information packets
- Testimonies, briefings, seminars, and a speakers' bureau
- Public information meetings, technical society meetings, technical overview/peer review committee meetings, and the annual Basalt Waste Isolation Project meeting
- Audio-visual media (slide, videotape, film presentations).

At the beginning of fiscal year 1980, a Visitor's Briefing Center was established at the Near-Surface Test Facility. This center has accommodated more than 135 media, government, special interest, and other group visits to the site (see Figure 1). Equipped with three-dimensional, computer, and graphic displays, the center has also accommodated more than 2,000 individuals during their participation in overview meetings, tours, and orientations.

The information services provided include literature and document searches. More than 800 requests for information have been processed during fiscal year 1980. In response to requests from the public, the media, and scientific and other groups and agencies about the project, an informational packet is issued, including:

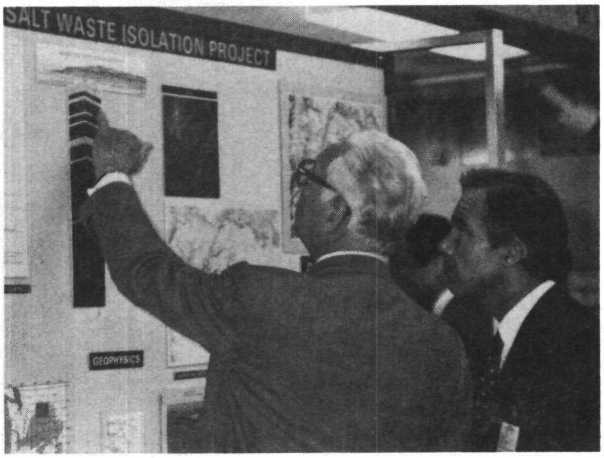
- A Basalt Waste Isolation Project brochure
- Current press releases on the Basalt Waste Isolation Project
- A Basalt Waste Isolation Project fact sheet
- Project photographs, graphs, and maps
- A Near-Surface Test Facility and project overview booklet
- A listing of all published Basalt Waste Isolation Project reports and documents
- Request for information cards
- Information regarding the National Waste Terminal Storage Program.

Consistent with the desire to develop a two-way communication relationship with the public at large, the second series of public information meetings will be expanded to include four or five major cities in the Pacific Northwest. These meetings and a technical society officers overview meeting will provide a forum where the Basalt Waste Isolation Project will present its findings to the public and technical community early in fiscal year 1981.

Also initiated during fiscal year 1980 was the Waste Management/Basalt Waste Isolation Project speakers' bureau that provides training for speakers, coordinates and schedules speaking engagements, and provides audio-visual services to the public. More than 35 presentations have been given in the states of Washington, Oregon, Idaho, and California.

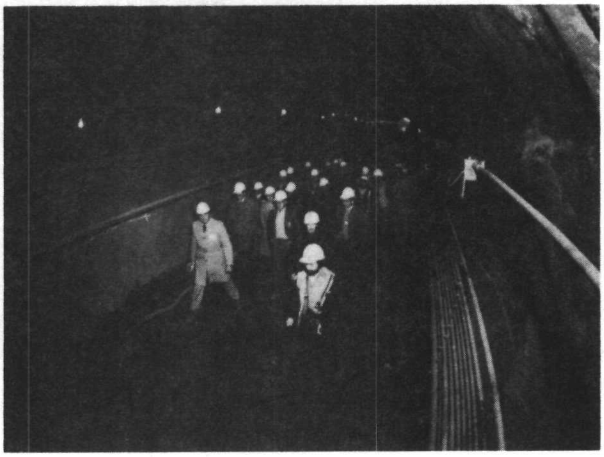
During fiscal year 1980, a visual documentation program was continued and expanded. On a regular basis, the various activities undertaken by the project have been video-taped and photographed to provide a permanent record of the work progress. This visual record was of particular importance in construction activities at the Near-Surface Test Facility to depict problem areas encountered and resolved. This visual documentation

COLIN HEATH, ACTING DIRECTOR, OFFICE OF WASTE ISOLATION, U.S. DEPARTMENT OF ENERGY, BEING INTERVIEWED AT THE BASALT WASTE ISOLATION PROJECT 1979 ANNUAL MEETING.

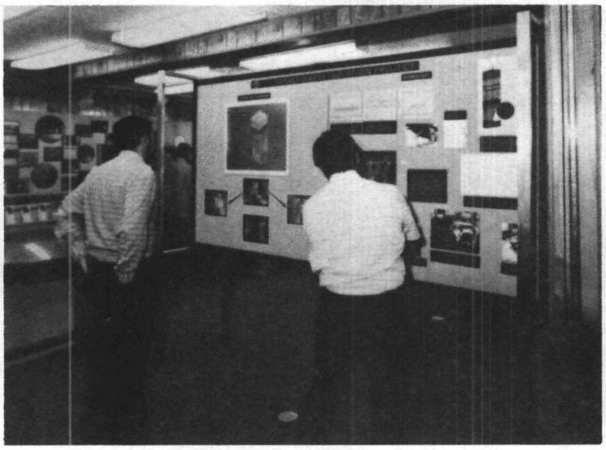


TWO VISITORS TO THE NEAR-SURFACE TEST FACILITY NOTE ITS STRATIGRAPHIC LOCATION.

H.B. DIETZ EXPLAINS THE LOCATION OF GABLE MOUNTAIN WITH RESPECT TO OTHER HANFORD LANDMARKS IN THE VISITOR'S BRIEFING CENTER AT THE NEAR-SURFACE TEST FACILITY.



M.R. KASPER CONDUCTS A TOUR THROUGH THE NEAR-SURFACE TEST FACILITY AFTER THE BASALT WASTE ISOLATION PROJECT 1979 ANNUAL MEETING.



THE VISITOR'S BRIEFING CENTER ADDRESSES ALL ASPECTS OF THE BASALT WASTE ISOLATION PROJECT, BESIDES INFORMATION DEALING WITH THE NEAR-SURFACE TEST FACILITY.

REGISTRATION FOR THE BASALT WASTE ISOLATION PROJECT 1979 ANNUAL MEETING, BACKED BY A NATIONAL WASTE TERMINAL STORAGE PROGRAM DISPLAY.

RCP8010-138

FIGURE 1. Public Affairs Activities at the Basalt Waste Isolation Project--Fiscal Year 1980.

is regularly incorporated into the 22-minute videotape feature, with narration, outlining the project. The videotape has been used by members of the staff to inform various groups and media representatives about the project. Video clips dealing with hydrology, engineered barriers, construction techniques, heater testing, and alternative shaft sinking methods have also been produced.

To assure overall public information continuity from National Waste Terminal Storage Program participants, the Office of Nuclear Waste Isolation coordinates input, data, and prepared materials on a regular basis for inclusion in the "Nuclear Waste Isolation" newsletter. The newsletter covers all elements of the National Waste Terminal Storage Program. On a regular basis, the Basalt Waste Isolation Project also supplies updated photograph and slide material for inclusion in National Waste Terminal Storage Program presentations and displays.

The Basalt Waste Isolation Project and the Office of Nuclear Waste Isolation have developed fact sheets, displays, exhibits, and audiovisual materials and have participated in technical conferences throughout the United States. In February 1980, the Office of Nuclear Waste Isolation and the Basalt Waste Isolation Project collectively presented a briefing on nuclear waste storage to both the Washington State House of Representatives and Senate.

CHAPTER II

SITE CHARACTERIZATION STUDIES - GEOSCIENCES

SUMMARY OF FISCAL YEAR 1980 GEOSCIENCES STUDIES

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The overall objective of the geologic studies is to provide technical information necessary to identify areas beneath the U.S. Department of Energy's Hanford Site that have a high probability of containing basaltic rock suitable for a nuclear waste repository. Geologic exploration activities thus far completed include detailed investigations in the vicinity of the Hanford Site and reconnaissance studies throughout much of the Columbia Plateau. These investigations were designed to emphasize those aspects of stratigraphy, lithology, structure, and tectonic stability that relate to geologic considerations pertinent to repository site identification and eventual site characterization.

To accomplish the required work, the geosciences work is divided into three activities: geology, geophysics, and seismic monitoring. The geology activity gathers data necessary to: (1) characterize the subsurface geology of candidate sites, (2) assess the tectonic stability of these sites, and (3) characterize the natural geologic events which have occurred or which could occur that could affect a repository. The geophysics activity provides the technology for evaluating the subsurface structural conditions in support of the geology activity. Seismic monitoring provides baseline data needed for the assessment of tectonic stability, as well as for the development of seismic design criteria.

All geosciences studies are directed toward gathering information on the specific geologic factors and considerations that relate to repository site qualification criteria. The main criteria addressed by geosciences studies are:

- Site geometry
- Tectonic environment
- Geologic characteristics
- Subsurface hydrology, as related to potential stratigraphic and structural flow patterns
- Human intrusion, as related to potentially exploitable resources.

The following tasks were completed during fiscal year 1980:

- The geology integration report (RHO-BWI-ST-4) was completed, printed, and distributed.
- A preliminary assessment of volcanic and geothermal resource potential was completed.

- A preliminary assessment of the effects of surficial geologic processes was completed.
- A precision geodetic survey was performed across several known faults.
- A preliminary assessment of the economic geology of the area was completed.
- Monitoring of the seismicity of the Columbia Plateau was continued.
- Intraflow structure relationships of the Umtanum flow were refined.
- Additional geophysical surveys were completed over the candidate site area.

Completion and distribution of the geology integration report marked a major milestone in the Basalt Waste Isolation Project effort. This major report provided extensive documentation of the geology, stratigraphy, tectonics, and seismicity of the Columbia Plateau. The document has been widely distributed to members of the scientific community.

A study to assess the potential for renewed volcanism which could affect the Pasco Basin and to assess the occurrence and development potential for geothermal resources in the Pasco Basin was completed. Results of this study indicate that:

- It is highly unlikely that renewed volcanism will pose a threat to a proposed nuclear waste repository at Hanford in the next one million years.
- No geothermal reservoirs with temperatures sufficiently high and depths sufficiently shallow to constitute an attractive energy exploration and development target are present within the Pasco Basin.

A study to assess the effects of surficial geologic processes on a proposed nuclear waste repository at Hanford was completed. This study leads to the conclusion that the surface elevation of the central Columbia Plateau, including the Pasco Basin, will remain relatively stable over the next one million years. Rates of uplift, subsidence, aggradation, and degradation have all been relatively slow and largely mutually canceling over the past several million years, and this pattern is likely to continue. The assessment has, therefore, been made that the effect of any foreseeable surface geologic processes on a nuclear waste repository at a depth of some 1,100 meters will be negligible.

Survey monuments were emplaced in a network of four triangular arrays across known faults. A laser interferometer survey of these arrays was performed to a precision of one part in ten million, thus establishing accurate baseline distance measurements between the points. These arrays will be periodically resurveyed. The preciseness of these laser interferometer surveys will allow detection of small movements along the faults monumented and thus reveal valuable information concerning their tectonic setting.

An assessment of potential mineral resources in the Pasco Basin was completed. The extensive data base collected as part of this study suggests that economic resource occurrence and development potential of the Pasco Basin is quite low. No mineral deposits of present economic value or with potential for future exploitation were identified or are predicted to occur in the basalts underlying the Pasco Basin. While the possibility of petroleum reserves in rocks beneath the basalts cannot be discounted, the thickness of the basalts beneath Hanford would make the area undesirable as a site for future exploration. The results from the exploration well currently being drilled by Shell Oil Company north of Yakima, Washington may yield valuable insight into the potential for petroleum reserves underlying the basalt.

Seismic monitoring of the Columbia Plateau was disrupted during March and April when earthquake activity associated with Mount St. Helens saturated the recording system. During the quiet period since April, the vast backlog of data from the Mount St. Helens' activity is being reduced for later analysis and interpretation. A three-component seismometer was temporarily installed in a deep borehole on the Hanford Site. Operation of this instrument has provided experience for future baseline seismic monitoring and data on ground accelerations at depth. In addition, a six-station portable seismic array is being deployed to gather site-specific seismic data. This portable array will be used to accurately monitor any future microseismic swarm activity and thus obtain data to help resolve the questions associated with this type of activity.

Continued progress was made in determining lateral variations within the intraflow structures in the Umtanum flow. Current data indicate that the interior of the Umtanum flow in the west-central Hanford Site is a relatively thick, uniform entablature, but the presence of inhomogeneities cannot as yet be dismissed.

During fiscal year 1980, 54 kilometers of high-resolution seismic reflection surveys were conducted on the Hanford Site across the central Cold Creek syncline. Interpretations of these data, coupled with data being gathered from geologic mapping, core hole studies, and other geophysical surveys are resulting in a fairly detailed understanding of the subsurface geology of the Hanford Site. Results of studies to date continue to indicate that the central and western portions of the Cold Creek syncline are underlain by largely undeformed, relatively flat-lying beds. Consequently, this area continues to look quite promising as a possible site for a nuclear waste repository.

A multilevel aeromagnetic survey of the entire Hanford Site was completed. Gridded flight lines at five separate levels have resulted in the collection of high-quality data. Preliminary interpretation of this data has been completed. Aeromagnetic lineaments have been plotted and some of these lineaments have been interpreted to represent real features in the subsurface geology. Other lineaments are as yet not interpreted and will be the focus of further studies. Recognition and interpretation of these lineaments are forming the basis for final screening of the central Hanford area for possible repository sites.

Other geophysical surveys have been completed in specific areas of interest. Features identified by field geologists during their mapping or by interpretation of previous geophysical surveys were investigated by Rockwell Hanford Operations' geophysicists, using the various techniques available to them. Results of these investigations are integrated into the overall interpretation of subsurface geology.

Details of this and other work conducted by geosciences personnel during fiscal year 1980 are continued in the following papers.

GEOLOGY OF THE COLUMBIA PLATEAU

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Geologic studies of the Columbia Plateau have been designed to augment more detailed studies conducted concurrently within the Pasco Basin, particularly to provide a preliminary assessment of the tectonic setting of the Hanford Site (Figure 1). Regional geologic studies conducted during fiscal year 1980 included:

- Update of Columbia Plateau bibliographies
- Compilation of surface geologic maps of the Columbia River Basalt Group, interbedded sediments, and suprabasalt sediments and volcanic rocks
- Analysis of satellite imagery and aerial photography.

These studies were concentrated primarily in the Columbia Plateau of Oregon and Idaho. The results of regional geologic work completed in the Washington portion of the plateau during fiscal years 1978(1) and 1979,(2) are summarized in a recently published report.(3)

UPDATE OF COLUMBIA PLATEAU BIBLIOGRAPHIES

An important objective of the regional geologic studies effort is the collection, centralization, and evaluation of all data currently available for the Columbia Plateau. Geologic work conducted during the initial fiscal year 1978 phase of the regional program included the compilation of Columbia Plateau bibliographies for their respective states by the Washington State Department of Natural Resources, Division of Geology and Earth Resources,(4,5) Oregon Department of Geology and Mineral Industries,(6) and Idaho Department of Lands, Bureau of Mines and Geology.(7) During fiscal year 1980, updates of all three bibliographies were completed.(8,9,10)

COMPILATION OF SURFACE GEOLOGIC MAPS

A second objective of the regional geologic studies effort is to prepare a reconnaissance geologic map (at a scale of 1:250,000) of the Columbia Plateau (using Army Map Service one- by two-degree quadrangles as base maps; Figure 1). Such a map is required to provide the stratigraphic and structural framework necessary to assess the tectonic history of the region. During fiscal year 1980, geologic mapping of approximately 70% of the Columbia River basalt of Oregon was completed by permanent and temporary personnel of the U.S. Geological Survey, Western Division. This work, combined with work carried out by the U.S. Geological Survey during fiscal years 1978 and 1979,(11) has produced basalt

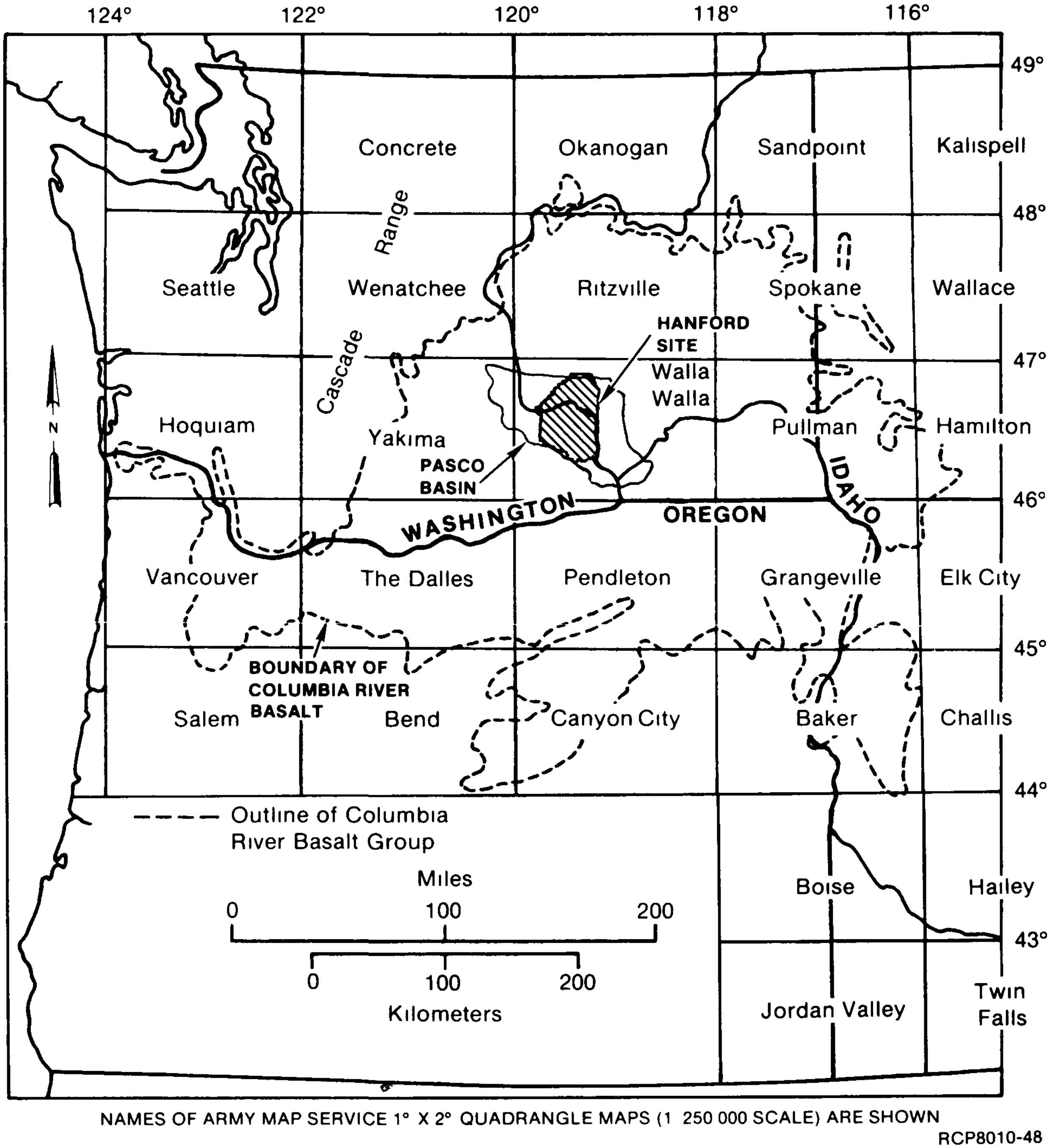


FIGURE 1. Army Map Service 1- by 2-Degree Quadrangles (scale 1:250,000).

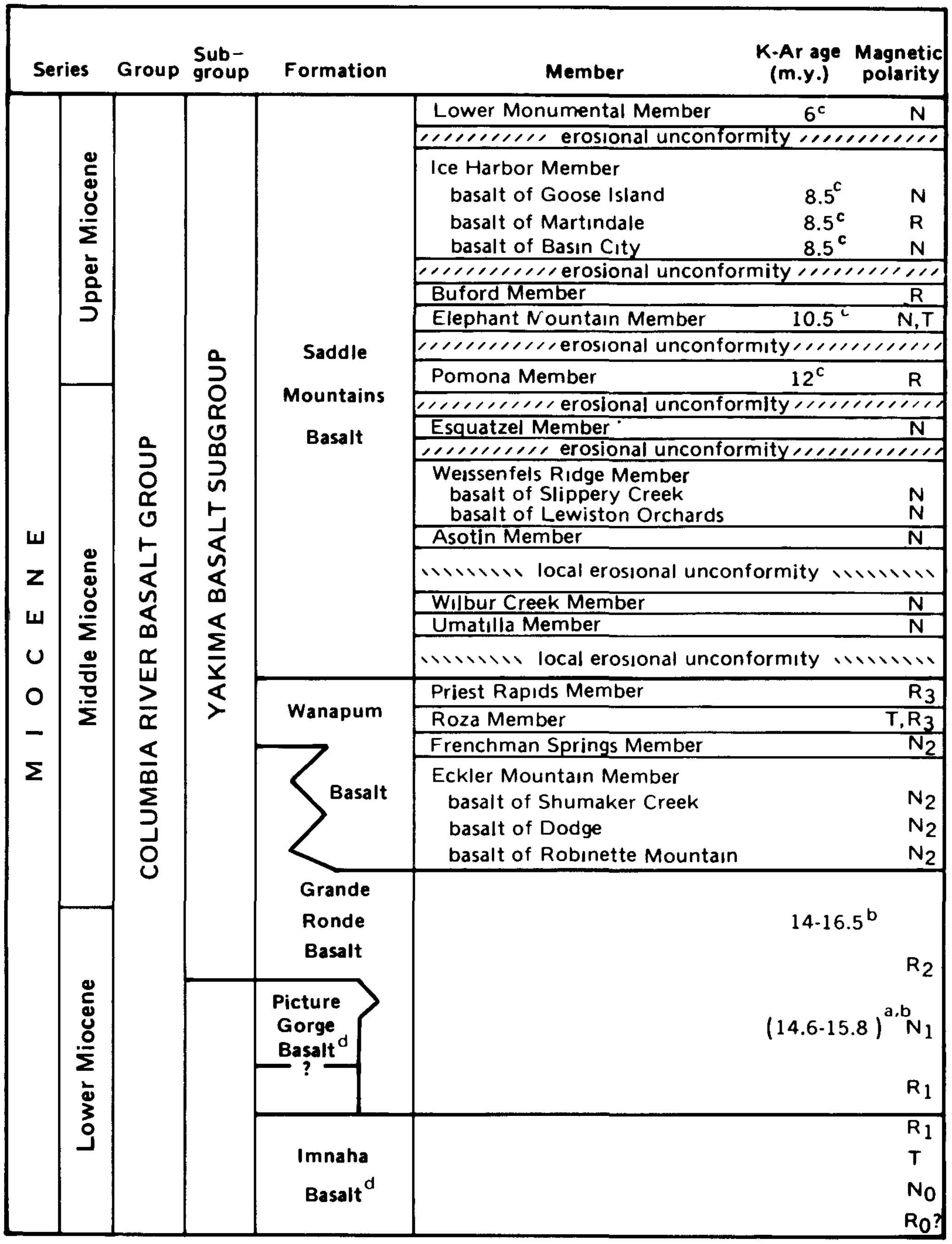
maps covering approximately 85% of the Columbia Plateau. In addition, reconnaissance geologic mapping of approximately 60% of the suprabasalt sediments and volcanic rocks of Oregon was completed by Oregon Department of Geology and Mineral Industries' personnel during fiscal year 1980. Work by the Oregon Department of Geology and Mineral Industries, combined with work completed by the Washington State Department of Natural Resources, Division of Geology and Earth Resources(12) and Idaho Department of Lands, Bureau of Mines and Geology(13-16) during fiscal years 1978 and 1979, has produced maps covering approximately 80% of the suprabasalt sedimentary and volcanic rocks of the Columbia Plateau. Significant stratigraphic and structural findings of fiscal year 1980 work are summarized below.

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

In the extreme southwest corner of the Pendleton Army Map Service quadrangle, two 20-kilometer-long, northwest-trending, linear vent systems occur. These systems probably fed two or more R_2 Grande Ronde Basalt flows. The western system, containing one dike and elongate cones or ramparts as much as 200 meters high, is the westernmost source yet found for the Yakima Basalt Subgroup (Figure 2).

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

Within The Dalles Army Map Service quadrangle, N_1 through N_2 Grande Ronde Basalt flows and possibly older R_1 Grande Ronde Basalt



Series		Group	Sub-group	Formation	Member	K-Ar age (m.y.)	Magnetic polarity
MIOCENE	Upper Miocene	COLUMBIA RIVER BASALT GROUP	YAKIMA BASALT SUBGROUP	Saddle Mountains Basalt	Lower Monumental Member	6[c]	N
					erosional unconformity		
					Ice Harbor Member		
					basalt of Goose Island	8.5[c]	N
					basalt of Martindale	8.5[c]	R
					basalt of Basin City	8.5[c]	N
					erosional unconformity		
					Buford Member		R
					Elephant Mountain Member	10.5[c]	N,T
					erosional unconformity		
					Pomona Member	12[c]	R
	Middle Miocene				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		
				Wanapum Basalt	Priest Rapids Member		R_3
					Roza Member		T,R_3
					Frenchman Springs Member		N_2
					Eckler Mountain Member		
					basalt of Shumaker Creek		N_2
					basalt of Dodge		N_2
					basalt of Robinette Mountain		N_2
	Lower Miocene			Grande Ronde Basalt		14-16.5[b]	
							R_2
				Picture Gorge Basalt[d] ?		(14.6-15.8)[a,b]	N_1
							R_1
				Imnaha Basalt[d]			R_1 T N_0 R_0?

RCP8001-127

[a] Information in parentheses refers to Picture Gorge Basalt.
[b] Data mostly from Reference 17.
[c] Data from Reference 18.
[d] 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.(19)

flows are exposed (Figure 2). Based on chemistry, N_2 Grande Ronde Basalt flows are divisible into an older low-MgO and a younger high-MgO sequence. Thinning of the high-MgO sequence to the south of the Columbia River is indicative of broad basining in Grande Ronde Basalt time; thinning of this sequence from east to west presumably reflects Cascadian uplift. A plagioclase-phyric unit, termed the "Winter Water flow," occurs at the top of the N_2 low-MgO sequence; one flow of this type has been observed in virtually every part of The Dalles Army Map Service quadrangle. Distribution of the "Winter Water flow," in relationship to underlying Grande Ronde Basalt flows, indicates that a pre-Grande Ronde Basalt topographic or structural high existed in the vicinity of The Dalles, Oregon.

Wanapum Basalt in The Dalles Army Map Service quadrangle is represented by the Frenchman Springs, Roza, and Priest Rapids Members (Figure 2). In the eastern half of the quadrangle, the rapid thinning of the Frenchman Springs Member to the south of the Columbia River appears to be tectonic, as is the distribution of the Roza and Priest Rapids Members which appear to be confined to synclinal areas. Along the west side of the Hood River Valley (located in the western third of The Dalles Army Map Service quadrangle; Figure 1), the Priest Rapids Member occupies a canyon cut into the Frenchman Springs Member. The Saddle Mountains Basalt-Pomona Member (Figure 2) is also present in the Hood River Valley as an intracanyon flow; exposures of this member extend out of the valley along the Columbia River for a distance of at least 10 kilometers to the west.

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

Regional studies to characterize and map suprabasalt sediments and volcanic rocks of Oregon were divided into two phases. The first phase of this effort involved a literature review and the production of a compilation geologic map set based on available publications. The distribution of 17 sedimentary and three volcanic units are shown on this map set, which includes The Dalles, Pendleton, Grangeville, Baker, Canyon City, and Bend Army Map Service quadrangles (Figure 1).(20) The compilation map set was used to identify areas where reconnaissance field mapping needed to be carried out to clarify stratigraphic relationships. The second phase of the project entailed an initiation of geologic mapping in these areas by Oregon Department of Geology and Mineral Industries' subcontractor personnel. Such mapping was concentrated in

The Dalles, Pendleton, and Grangeville Army Map Service quadrangles (Figure 1) with special attention given to discrete structural basins and the sediments filling them. Based on the work thus far conducted, the Oregon Department of Geology and Mineral Industries has proposed to raise the Dalles Formation (composed of sediments which immediately overlie the Columbia River basalt) to group level. This group would include sediments in four major Columbia River basalt basins in Oregon (Tygh, The Dalles, Arlington-Boardman, and Agency basins) as four formations in The Dalles group. In each basin, these formations overlie Columbia River basalt flows that range in age from 10 million years to 15 million years before present; that is, there exists a 5-million-year age difference between the basalt units that floor some adjacent basins.

A literature review and integration of geologic investigations of suprabasalt sedimentary and volcanic rocks overlying the Columbia River basalt of Idaho was completed by Idaho Department of Lands, Bureau of Mines and Geology personnel. A stratigraphic framework and tentative correlations for post-basalt units in northwest, west-central, and southwest Idaho (Figure 1) were developed as part of this work. The integration studies were keyed to previously published 1:250,000-scale maps.(13-16,21)

ANALYSIS OF SATELLITE IMAGERY AND AERIAL PHOTOGRAPHY

A third objective of the regional geologic studies effort is 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. Work to meet this objective was completed for the Washington State portion of the plateau during fiscal years 1978 and 1979 by personnel of Pacific Northwest Laboratory. This work, combined with work carried out by Pacific Northwest Laboratory personnel during fiscal year 1980, has produced photolineament maps covering approximately 90% of the Columbia Plateau. These maps are based on an analysis of LANDSAT, Skylab, and U-2 photography; photolineaments recorded on these maps are coded as to imagery association and as to interpreted origin (i.e., topographic, drainage alignments, tonal discontinuities, and cultural features). Initial draft copies of these maps were issued to regional field personnel to aid in their reconnaissance geologic mapping work. In turn, field personnel have conducted a review of these maps and have provided input which can be used to evaluate the relationship between structures observed in the field and mapped photolineaments. Digitizing has also been initiated which will enable a statistical analysis of photolineament types and trends to be carried out.

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TECTONICS AND SEISMIC STUDIES

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Geologic mapping to date in the Basalt Waste Isolation Project has emphasized the aerial distribution and stratigraphy of Miocene basalt and overlying Late Cenozoic sediments to facilitate an assessment of geologic structures in the region and the Pasco Basin. With this as background, studies to provide data on tectonic issues are accelerating with the intent of assessing the tectonic stability of the Columbia Plateau and Pasco Basin as required by the recent draft of Title 10, Code of Federal Regulations, Part 60.(1) In this draft, "stability means the rate of natural processes affecting the site during the recent geologic past are relatively low and will not significantly change during the next 10,000 years." Tectonic studies will build on current knowledge and interpretations which are summarized below.

The tectonic setting of the Pasco Basin and Columbia Plateau must be integrated and compatible with larger regional tectonic interpretations. Conceptual models of regional tectonics center about subduction of the Farallon Plate and its remnant, the Juan De Fuca Plate, during the Cenozoic.(2) Variations of this model include right lateral shear in a broad zone inland of the San Andreas transform fault,(2,3,4) clockwise rotation of the Oregon Coast Ranges,(5) back-arc spreading above a diapir rising from the mantle,(6,7) and migration of a hot spot (mantle plume) relative to continental crust.(8,9,10) These models are presented at small scale and explain some major features of the Cordillera, but none of the models satisfactorily explains all the geologic and geophysical data for the Cordillera, the Pacific Northwest, the Columbia Plateau, or the region of the Pasco Basin. Nonetheless, these hypotheses can be viewed as working models that guide research to provide essential data that may serve to assess the models. Each in turn can be evaluated in light of the existing data to ascertain what concepts are supported.

Field data are equivocal, but generally support north-south compression. This stress field is not compatible with eastward subduction of the Juan De Fuca Plate, but favors right lateral shear for development. Asymmetric, east-west- and northwest-trending anticlines and accompanying faults, along with the north to northwest trends of Columbia River basalt feeder dikes suggest compression from the north to northwest beginning sometime in the Miocene.(11) Focal mechanisms (mostly composites) of earthquakes in the Columbia Plateau similarly suggest that the maximum compressive stress (sigma one) is nearly horizontal and directed from the north-northwest.(12) Most focal mechanisms suggest that the minimum compressive stress (sigma three) is nearly vertical. Focal mechanism solutions for some small, shallow earthquakes west of the Cascade Range also suggest north-south compression.(13)

Direct measurements of in situ stress to date in the Columbia Plateau have been made only in the vicinity of the Near-Surface Test Facility on Gable Mountain by the hydrofracture and overcoring methods and are considered preliminary. The data obtained are inconclusive, but the measured west-northwest maximum compressive stress is apparently strongly perturbed by topography at Gable Mountain and is not indicative of tectonic stresses in the region.

Five surveys of a trilateration array at Hanford from 1972 to 1979 suggest minor, non-uniform, northeast-directed compression that is more compatible with subduction of the Juan De Fuca Plate.(14) However, the data obtained are barely beyond the limits of error of the technique.

Earthquakes in the Columbia Plateau located by an instrumental array operating during the last 11 years suggest that: (1) stress release is confined to a shallow (less than or equal to 28 kilometers) crust;(15,16) (2) stress does not build to high thresholds before release; and (3) slip occurs on different steeply dipping planes of generally east-west orientation. Hypocenters do not concentrate or align along planar zones or along mapped geologic structures. Stress release in the Columbia Plateau is characterized by shallow swarms (less than or equal to 3 kilometers) confined to limited volumes of rock (less than or equal to 50 cubic kilometers) with some deeper (greater than or equal to 6 kilometers) earthquakes diffused throughout the region.(15) The pattern of both instrumental and historical earthquakes generally indicates that compressive stress in the Columbia Plateau is relieved by small earthquakes (less than or equal to $M_L = 4$) in which slip occurs on different planes oriented generally east-west and dipping steeply north or south.(17,18)

Sediments overlying basalt have been found offset at several localities in the Columbia Plateau in recent years. The age of the sediments and the history of displacement are being studied. Investigations by Rockwell Hanford Operations and others are planned at these localities to determine whether the offset is tectonic, and if so, whether displacement occurred as a result of: (1) aseismic creep; (2) short ruptures that generate small earthquakes; or (3) infrequent large fault ruptures that generate large earthquakes.

Structural relief on radiometrically dated members of the Saddle Mountains and Wanapum Basalts allows calculation of rates of uplift (i.e., strain rates) in the upper Miocene.(19) The calculated rates are less than 1 millimeter per year, and the data fall on curves which, when projected, suggest that these rates have operated over the last 12 million years. Shortening of lines of a trilateration array similarly suggests strain of less than 1 millimeter per year in the area of the Pasco Basin.(14) Decreasing dip of sediments of progressively younger age overlying basalt also support a low rate of strain.(20)

Detailed geologic mapping, geodetic surveys, in situ measurements of stress, along with deployment of a dense network of surface and downhole, three-component seismometers may confirm that the Pasco Basin area of the Columbia Plateau is continuing a 12-million-year-old pattern of deformation at very low strain rates.

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LITHOLOGIC STUDIES OF GRANDE RONDE BASALT

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Lithologic studies of Grande Ronde Basalt have been aimed at determining the primary internal structures, including fracturing and brecciation, of individual flows in the Pasco Basin subsurface. Two approaches to this problem have been employed:

- Examination of intraflow structures in laterally extensive surface exposures of Grande Ronde Basalt to the north of the Pasco Basin
- Determination of intraflow structures of a candidate repository host rock (the Umtanum flow) at specific points (core holes) in the Pasco Basin subsurface.

The results of the first approach have provided information as to the kinds of lateral variation of intraflow structures that might be anticipated in the basin subsurface, whereas the results of the second approach have provided information specific to the Umtanum flow at point locations across the Pasco Basin.

SURFACE EXPOSURES

Studies of surface exposures of Grande Ronde Basalt indicate that typical intraflow structures which may be present from top to bottom of a flow are:

- A ropy to brecciated, vesicular flow top
- Upper colonnade with relatively large (0.7 to 2.2 meters in diameter), irregular columns, with or without vesicles
- Entablature consisting of relatively small (0.2 to 0.9 meter in diameter) columns
- Lower colonnade consisting of well-formed to wavy, large (0.5 to 1.5 meters in diameter) columns
- A glassy, basal zone that varies greatly in thickness and may be highly fractured, vesicular, or pillowed.

One or more of these features may be absent from any given flow or they may be present in multiple layers. Significant lateral changes in thickness have been observed for all of these intraflow structures, and such changes may be either abrupt or gradual and so constitute a lithologic property of the host rock that may be difficult to predict.

The possible development of pillowed zones, lateral changes in the thickness of the colonnade, and a marked increase in the thickness of flow top breccia at the expense of upper colonnade and entablature are of particular concern and interest. It is well known that pillowed zones form where basalt flows enter a significant depth of water. By studying the distribution of pillowed zones in a single flow overlying the Umtanum flow, it has been possible to infer the position of a major paleodrainage.(1) It was apparently located at least several kilometers to the west of the margin of the present day Pasco Basin during the time of deposition of this flow and probably occupied a similar position during emplacement of the Umtanum flow. This is consistent with the fact that boreholes in the Pasco Basin have not penetrated significant pillowed zones in Grande Ronde Basalt and suggests that extensive pillowed zones are unlikely to occur at the base of the Umtanum flow in the Pasco Basin.

BOREHOLES

Comparison of petrographic characteristics of the Umtanum flow in two surface sections with those in core samples allows the determination of the position of the entablature-colonnade contacts, the presence of tiering or alternating columnar and hackly jointed features within the entablature, and the presence of upper colonnade. (Flow top breccia is readily recognized in the core samples without petrographic examination.) An example of a petrographic characteristic that reflects intraflow structures is shown on Figure 1, where volume percent opaque phases (typically titanomagnetite or ilmenite) are plotted against position in a surface exposure where intraflow structures are known. Volume percent opaque phases are significantly higher in the colonnade than in the interior part of the entablature.

By using petrographic characteristics as indicators, the intraflow structures within the Umtanum flow have been delineated in several core holes across the Pasco Basin. A fence diagram (Figure 2) shows intraflow structures within the Umtanum flow at core holes (point locations) and diagrammatically depicts lateral variation of intraflow structures within the Umtanum flow between core holes. It is suggested in the diagram that there is a portion of the Umtanum flow beneath the west-central part of the Hanford Site that has a relatively thick, uniform entablature which probably possesses uniform hydrologic and mechanical properties. From the standpoint of intraflow structures, this part of the flow is probably the most suitable for a repository. This prediction must be tempered, however, by our knowledge that lateral changes in intraflow structure occur on a scale far too fine to be detected by the present spacing of vertical boreholes. Future field explorations now planned are designed to test our hypothesis of a thick, uniform entablature in the Umtanum flow beneath the west-central part of the Hanford Site, and check for lateral inhomogeneities in the Umtanum flow.

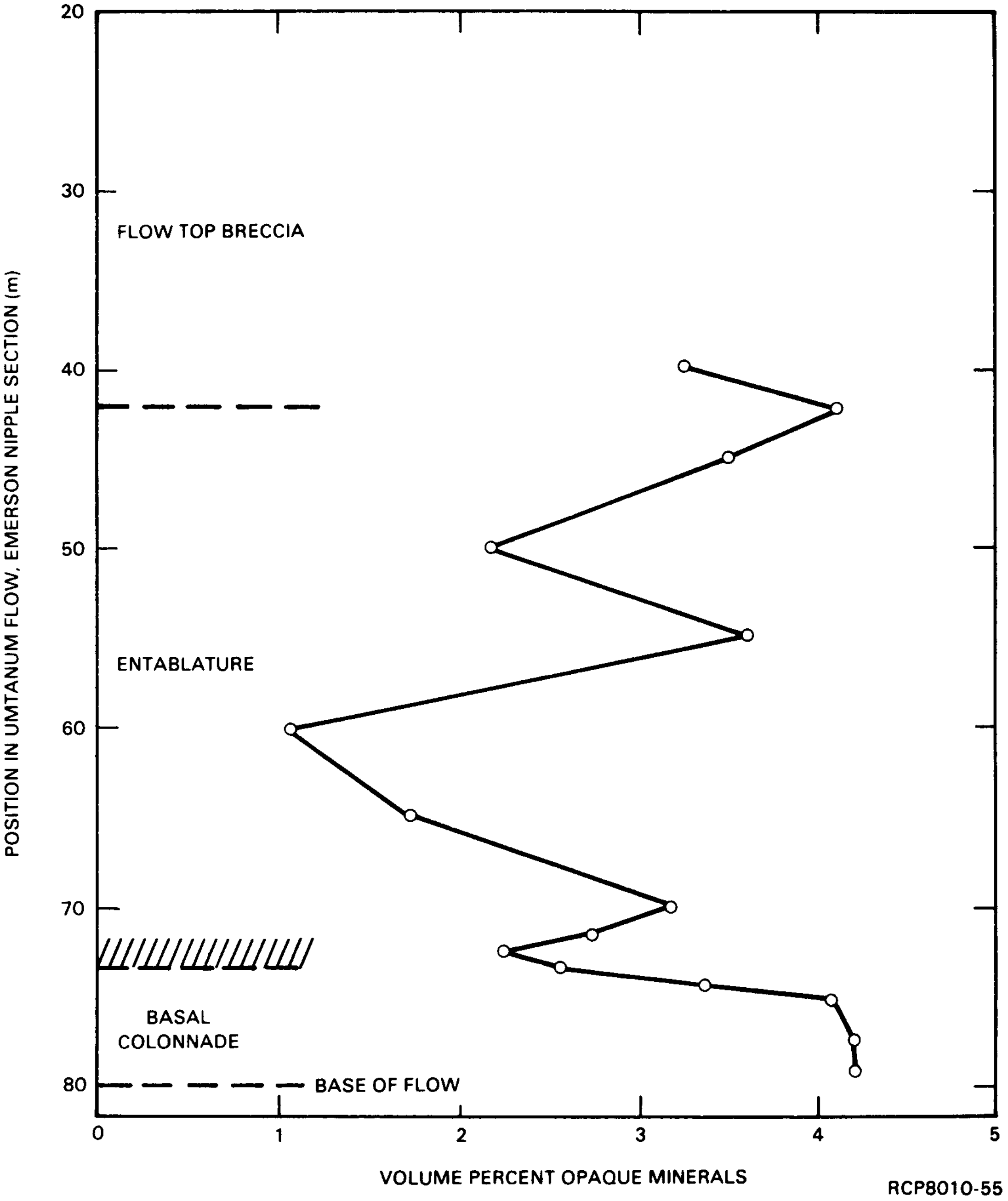

FIGURE 1. Volume Percent Opaques Versus Position in Flow. Note increase on volume percent opaques at entablature-basal colonnade contact.

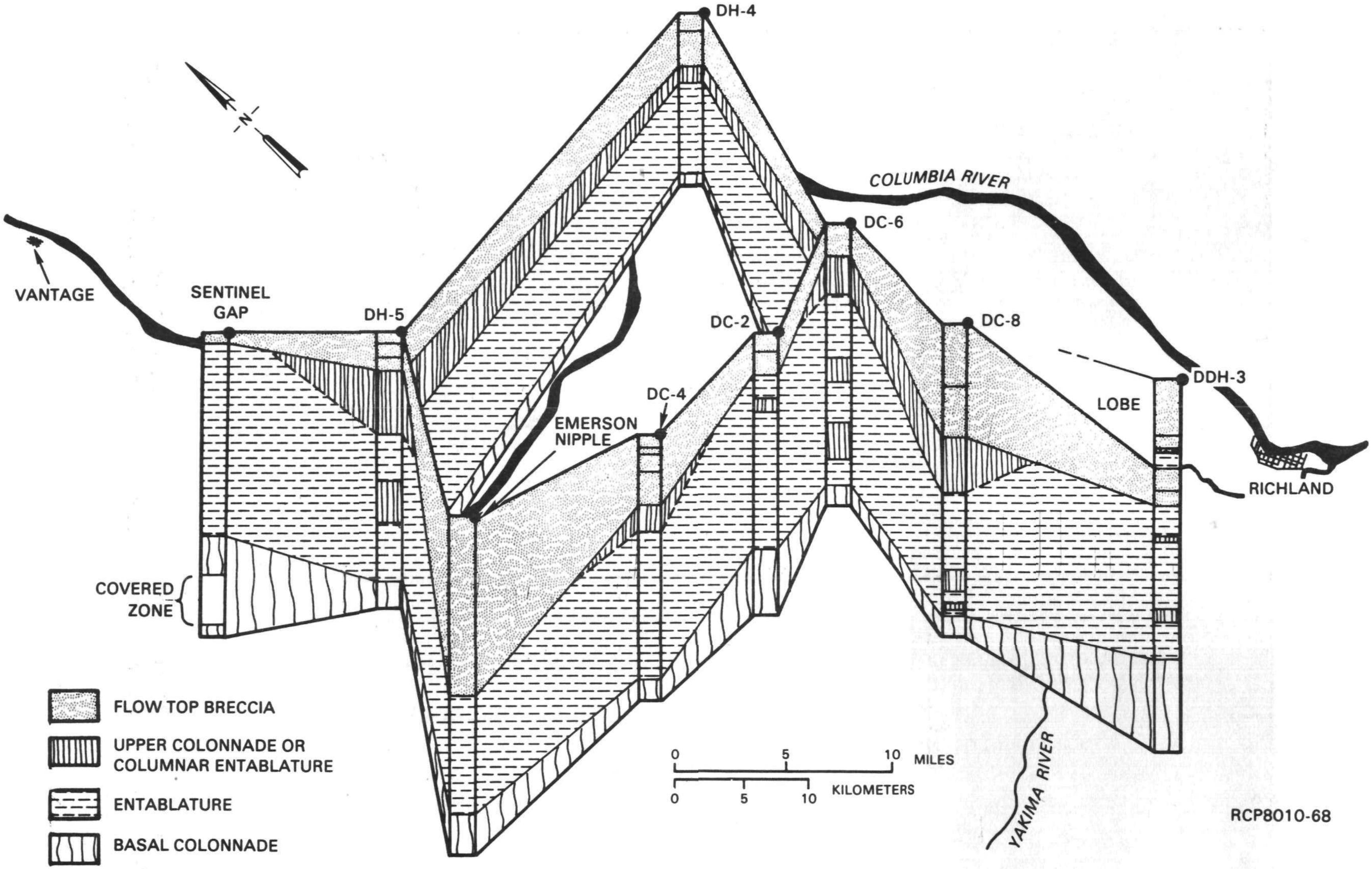

FIGURE 2. Fence Diagram of Intraflow Structures of the Umtanum Flow.

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GEOPHYSICAL SURVEYS IN THE PASCO BASIN

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Geophysical surveys in the Pasco Basin during fiscal year 1980 were designed to continue the following long-term Basalt Waste Isolation Project objectives:

- Assist in the general definition of subsurface structures in the central Pasco Basin using standard geophysical surveys performed through subcontractors
- Provide detailed geophysical profiles across specific structures in the Pasco Basin using high-resolution surveys performed by Rockwell Hanford Operations' geophysicists and equipment.

The location of geophysical surveys completed through the end of fiscal year 1979 are shown on Figure 1. Shown on Figure 2 are survey locations for the fiscal year 1980 investigations. All survey locations, as in the past, 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:

- 54 line-kilometers of VIBROSEIS seismic reflection surveying conducted along six individual survey routes
- 34 tensor magnetotelluric survey stations conducted on approximately a 10-square-kilometer gridded pattern and along a profile line
- Approximately 3,200 square kilometers of multi-level elevation (762, 990, 1,200, 1,444, 1,677 meters), high-resolution aeromagnetic surveying using 0.8-square-kilometer loop-tied flight lines.

High-resolution geophysical surveys conducted by Rockwell Hanford Operations are indicated by hexagons on Figures 1 and 2. These surveys are being used to investigate specific structures identified by the Rockwell Hanford Operations' staff or by the results of previous geophysical studies. The surveys have utilized the following methods:

- Gravity surveying with station spacing between 30 and 150 meters
- Land-born magnetic surveying using both total field and some vertical gradient techniques

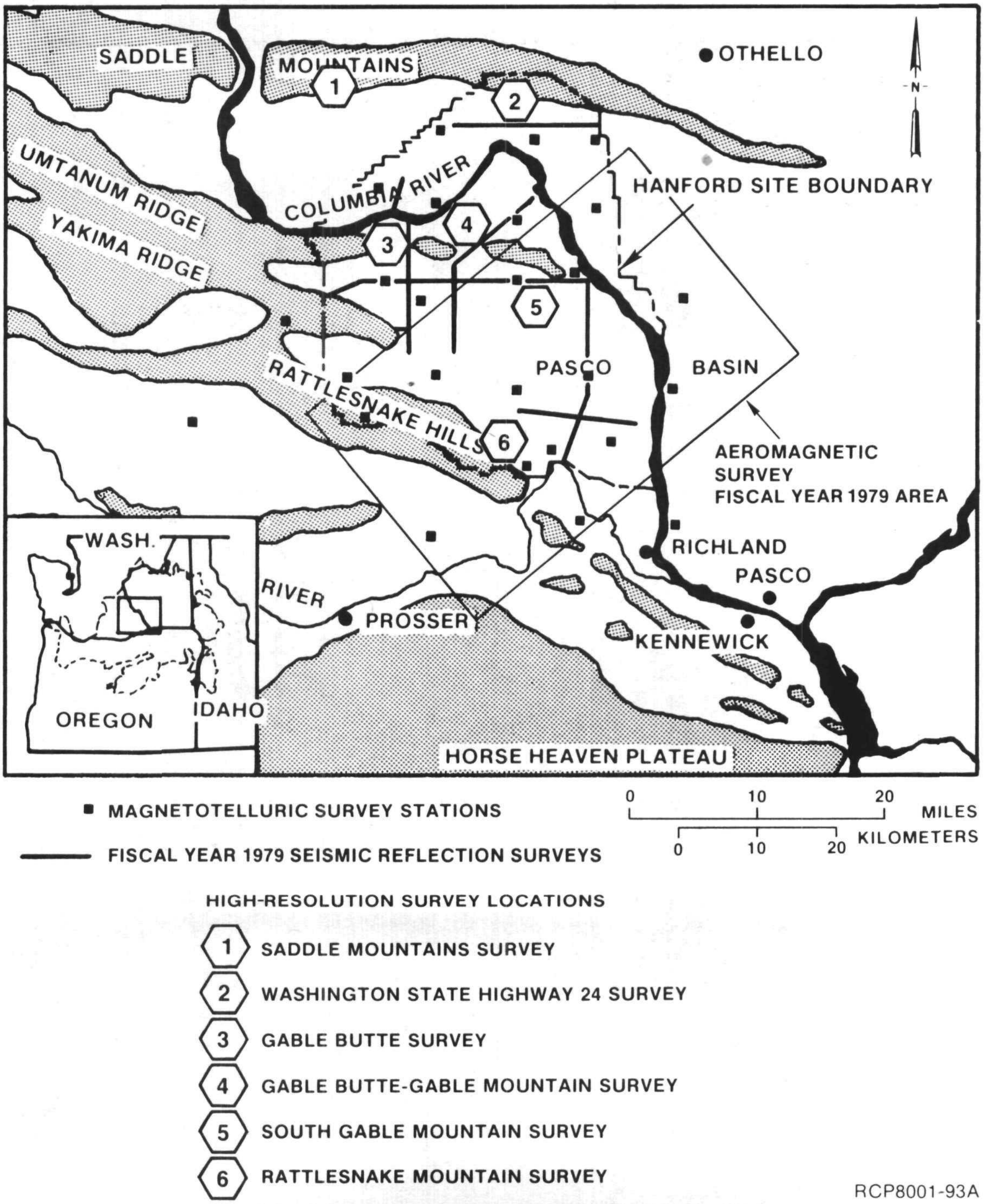

FIGURE 1. Summary of Geophysical Investigations Conducted during Fiscal Year 1979.

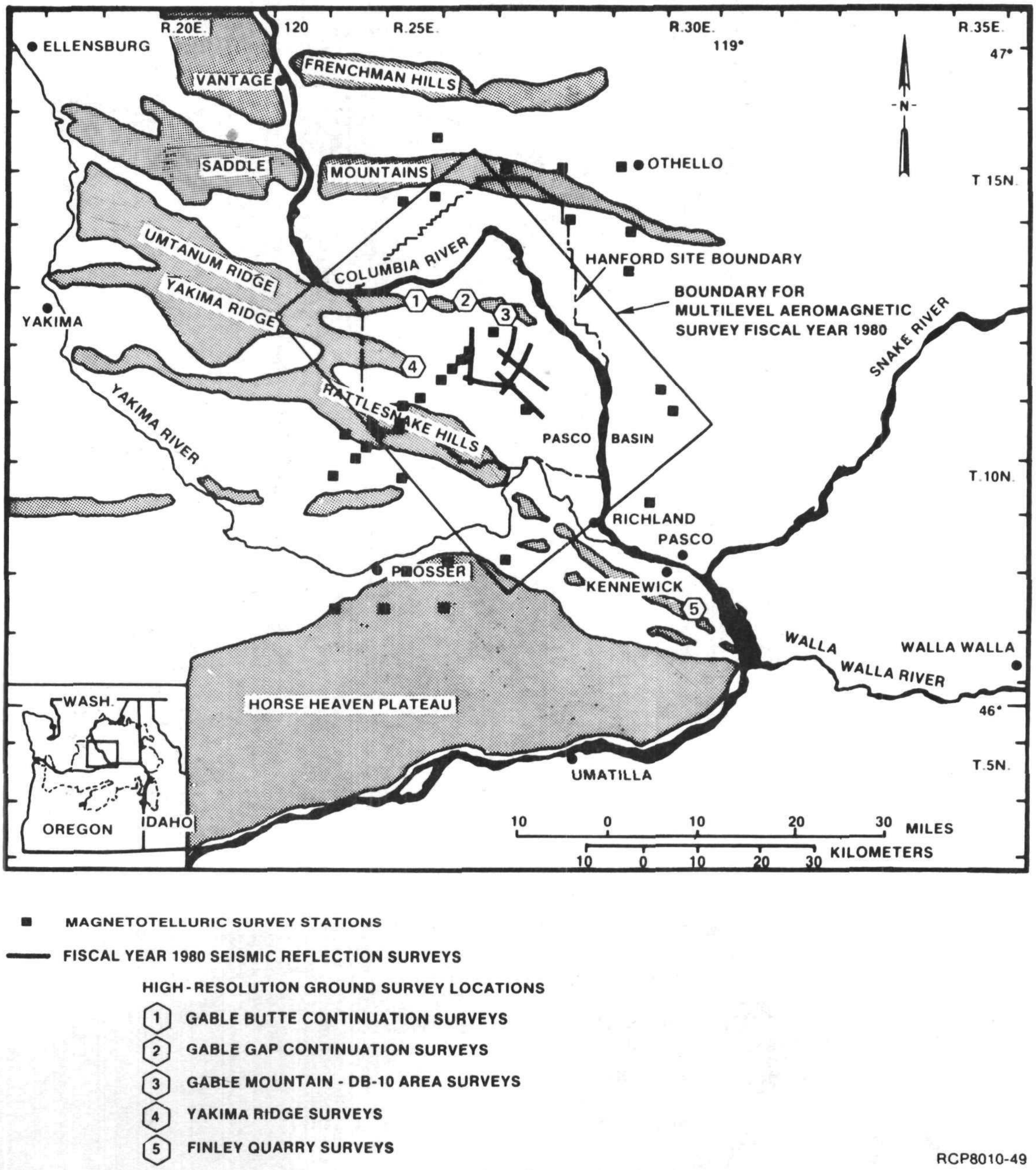

FIGURE 2. Summary of Geophysical Investigations Conducted or in Progress during Fiscal Year 1980.

- 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
- High-resolution seismic refraction surveying.

High-resolution surveys shown on Figure 1 and listed as "in progress" in last year's annual report (RHO-BWI-79-100) were completed during fiscal year 1980. Additional high-resolution ground surveys were conducted during fiscal year 1980 as indicated on Figure 2.

Briefly, geophysical surveys have provided these major findings:

- Reflection surveys have defined secondary features on the flanks of buried Yakima folds within the Pasco Basin. Some of these features are minor folding and faulting in the gentle flank of the Cold Creek syncline; others are probably features in the sediments overlying bedrock.
- Geophysical anomalies currently attributed to folding interpreted from aeromagnetic surveys indicate that the Pasco Basin can be interpreted as divided into structural blocks (see Myers and Bielefeld, this report). Some specific interpretations show that the Cold Creek syncline contains subbasins giving rise to an undulating character.
- Continued tensor magnetotelluric data gathering and interpretations indicate that interpretation of the deep subsurface as five separate geoelectric units and their associated structures is still valid.
- Specific in-house surveys conducted in many locations on and around the Hanford Site have provided greater insight into the understanding of the subsurface. For example, features interpreted as intercanyon flows have been identified north of the Columbia River and additional channeling and folding have been interpreted for the Gable Butte-Gable Mountain regions.

The results obtained during the fiscal year 1980 geophysical surveys will aid the intensified 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.

BEDROCK GEOLOGY AND REPOSITORY SITING STUDIES, COLD CREEK SYNCLINE AREA, PASCO BASIN, WASHINGTON

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Site A-H located in the western Cold Creek syncline area (Figure 1) is currently designated as the reference repository location based on work performed in fiscal year 1980. Site J, located in the central Cold Creek syncline area, is the alternate. The identification of the reference and alternate sites was made by ranking using a dominance analysis technique. The analysis was conducted by a committee consisting of Rockwell Hanford Operations and Woodward-Clyde Consultants' technical personnel under the guidance of Woodward-Clyde Consultants. The committee considered 10 sites in the Cold Creek syncline area (Figure 1). Seven of the 10 sites had been previously identified in fiscal year 1979;(1) three of the 10 sites were identified by Rockwell Hanford Operations' geologists and geophysicists in mid-fiscal year 1980--based on new data and interpretations--and submitted to the committee for consideration. The 10 sites were evaluated and ranked using available information on the geology, hydrology, tectonics, ecology, and socioeconomics of the Hanford Site and vicinity. A report documenting these siting studies is being prepared.

The Cold Creek syncline is a broad, open, asymmetric structure with a steep southern limb and a gentle northern limb. The trough of the syncline undulates and has two minor depressions, the Wye Barricade Depression and the Cold Creek Valley Depression, located along its strike. The location of the trough of the Cold Creek syncline is interpreted from seismic reflection surveys and aeromagnetic surveys (see Edwards, this report) and from borehole data. The Cold Creek syncline plunges east into the Wye Barricade Depression where the top of basalt is about 50 meters below mean sea level. In the Cold Creek Valley Depression, the top of basalt is at least as low as mean sea level.

Geophysical surveys are now under way in Site A-H (Figure 2). This work is necessary to refine interpretations of the bedrock structure within the central part of Site A-H and assist in locating the site for an exploratory core hole which is to be part of an exploratory shaft now being considered. Six locations for shallow boreholes have been staked in the A-H area. These boreholes will provide elevation of the basalt bedrock surface and the identification of the uppermost basalt unit. Gravity surveys have been started along three lines crossing Site A-H, and a 150- x 150-meter grid is being surveyed in the area to use as a base for future geophysical surveys.

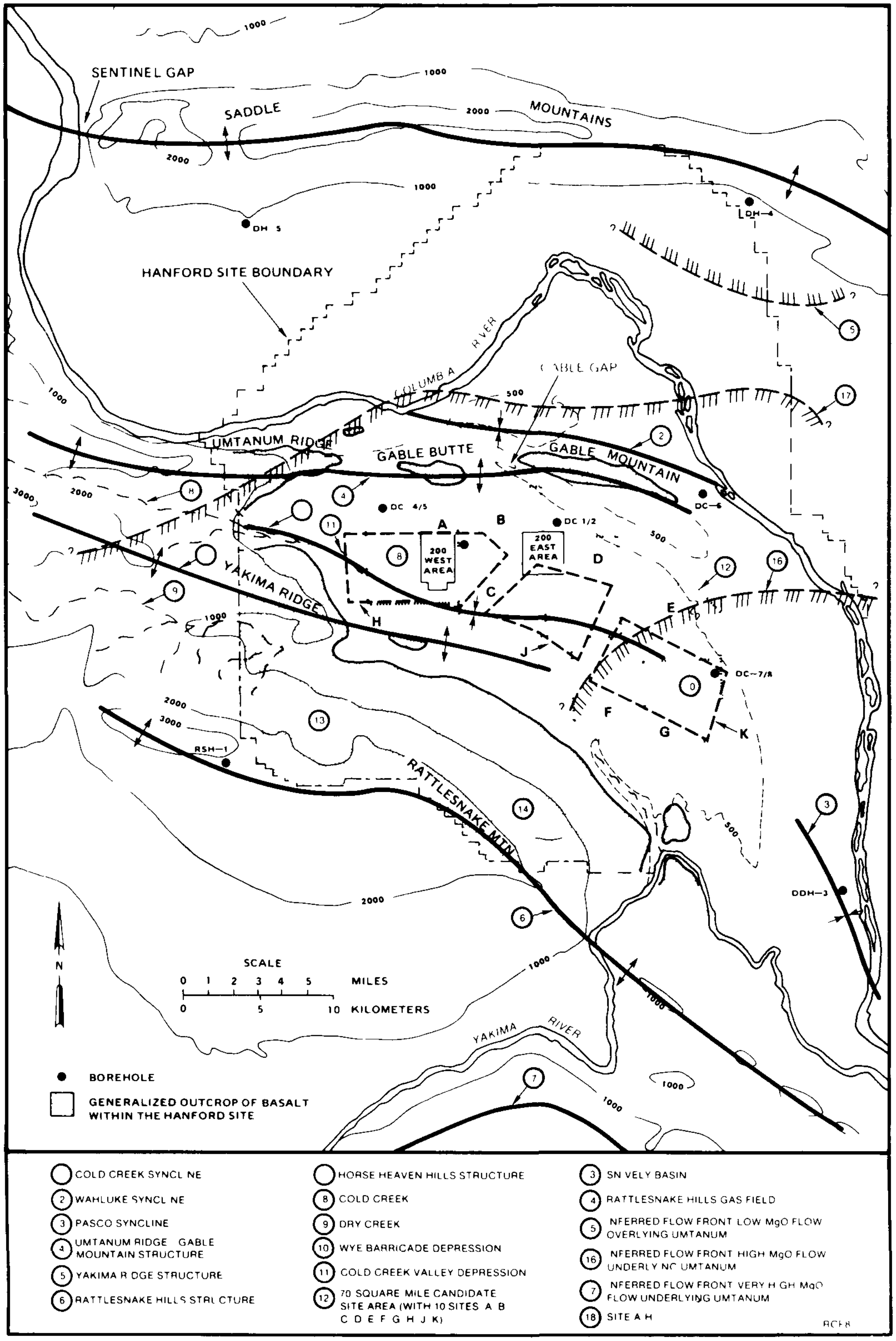

FIGURE 1. Index Map for the Cold Creek Syncline Area.

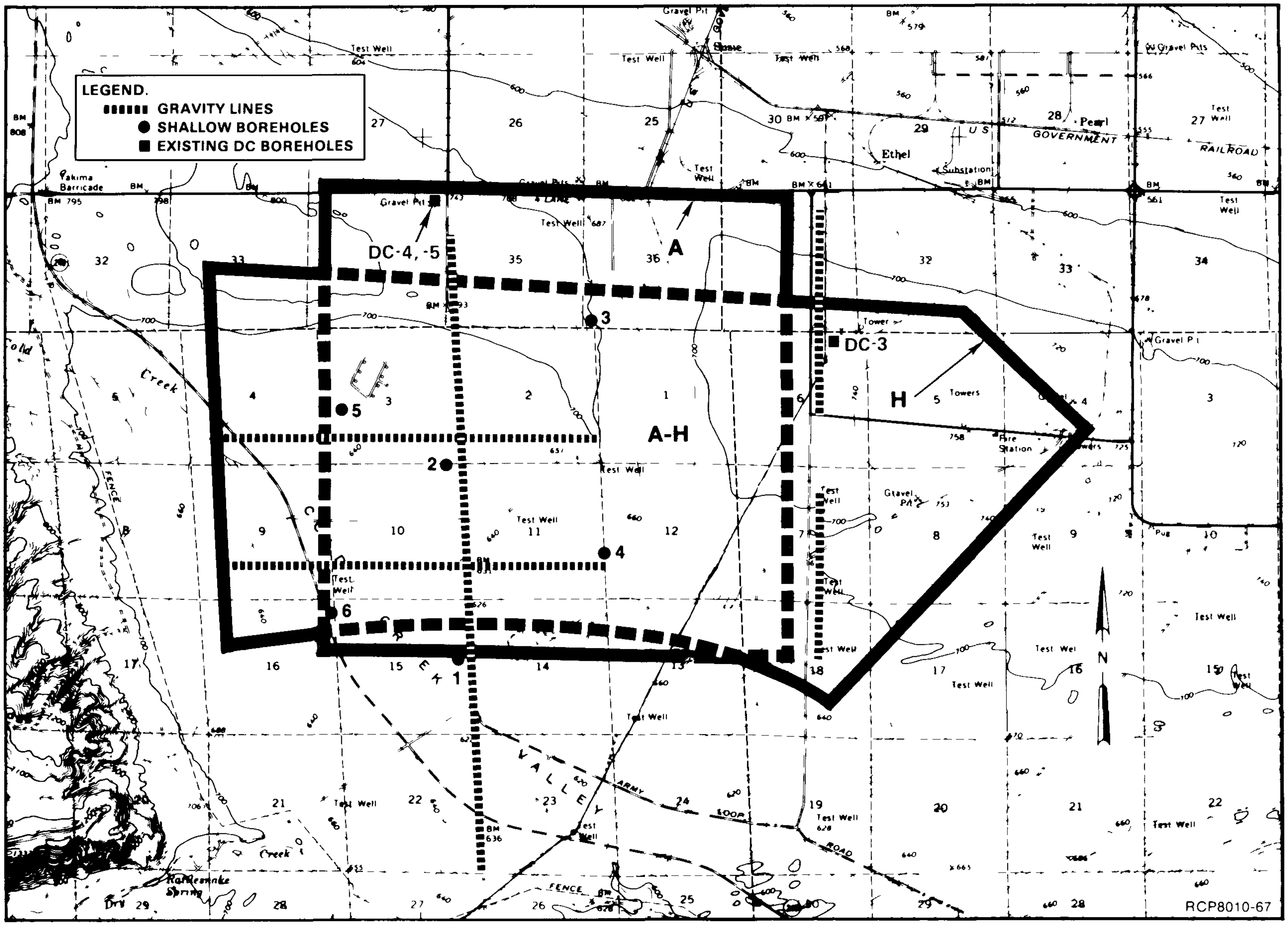

FIGURE 2. Reference Repository Location, Site A-H.

The concept of the structural block is currently being used to assist in repository site identification in the Cold Creek syncline. The use of the structural block concept appears valid based on geologic conditions in the Cold Creek syncline, as we understand them at this time. The term "structural block," as used here, refers to a generally intact volume of Saddle Mountains Basalt, Wanapum Basalt, and upper Grande Ronde Basalt in the Pasco Basin that is bounded by interpreted geologic structures (intraflow structures excluded) that are potential groundwater flowpaths--either now or in the future--or that might affect repository design and construction or the capability to retrieve waste once stored. Use of the term is restricted to the Pasco Basin, specifically the west-central Pasco Basin. The term is thus limited to geometric and site-specific considerations. (Other connotations that may accompany usage of the words "structural block," such as basin-and-range block faulting or extensive fragmentation, are not intended. Similarly, the term is probably not appropriate for use at other National Waste Terminal Storage sites because of the different geology of those sites.)

Currently recognized structures that could potentially form the boundaries of structural blocks in the Cold Creek syncline area are of three types: (1) hinge zones and steep limbs of Yakima folds; (2) northwest- and possibly northeast-trending structures that intersect and extend between the axes of Yakima folds; and (3) relatively minor structures that occur on the gently dipping to flat-lying limbs of Yakima folds. Locating the structures that separate masses of relatively intact rock (i.e., structural block boundaries) is a high priority during the site identification phase of the Basalt Waste Isolation Project, whereas evaluating the tectonic stability of these structures is of high priority during the site characterization phase of the Basalt Waste Isolation Project.

Refinement of stratigraphic interpretations for the section above and below the Umtanum flow, currently the prime candidate for a repository host rock, is continuing.(2) In the southern Pasco Basin, Cold Creek syncline area, the Umtanum flow is interpreted as being continuously overlain by the McCoy Canyon flow (Figure 3). In the northern Pasco Basin, however, a low-MgO flow is between the McCoy Canyon flow and the Umtanum flow. In the central and southern Pasco Basin, a high-MgO flow and very high-MgO flow are between the Umtanum flow and underlying Grande Ronde Basalt flows (Figure 1). Thus, in the Pasco Basin, at least one flow front overlies the Umtanum and at least two flow fronts underlie the Umtanum. Flow fronts are potential paths for groundwater to move to higher or lower stratigraphic levels.

A compilation geologic map of the Pasco Basin at a scale of 1:62,500 was prepared(3) and included in the geology integration report.(4) The Cold Creek syncline area of the Pasco Basin geologic map was field checked during fiscal year 1980, and selected areas were remapped at a scale of 1:12,000. Remapping of basalt outcrops on the eastern end of Yakima Ridge has shown the existence of two north-dipping thrust faults

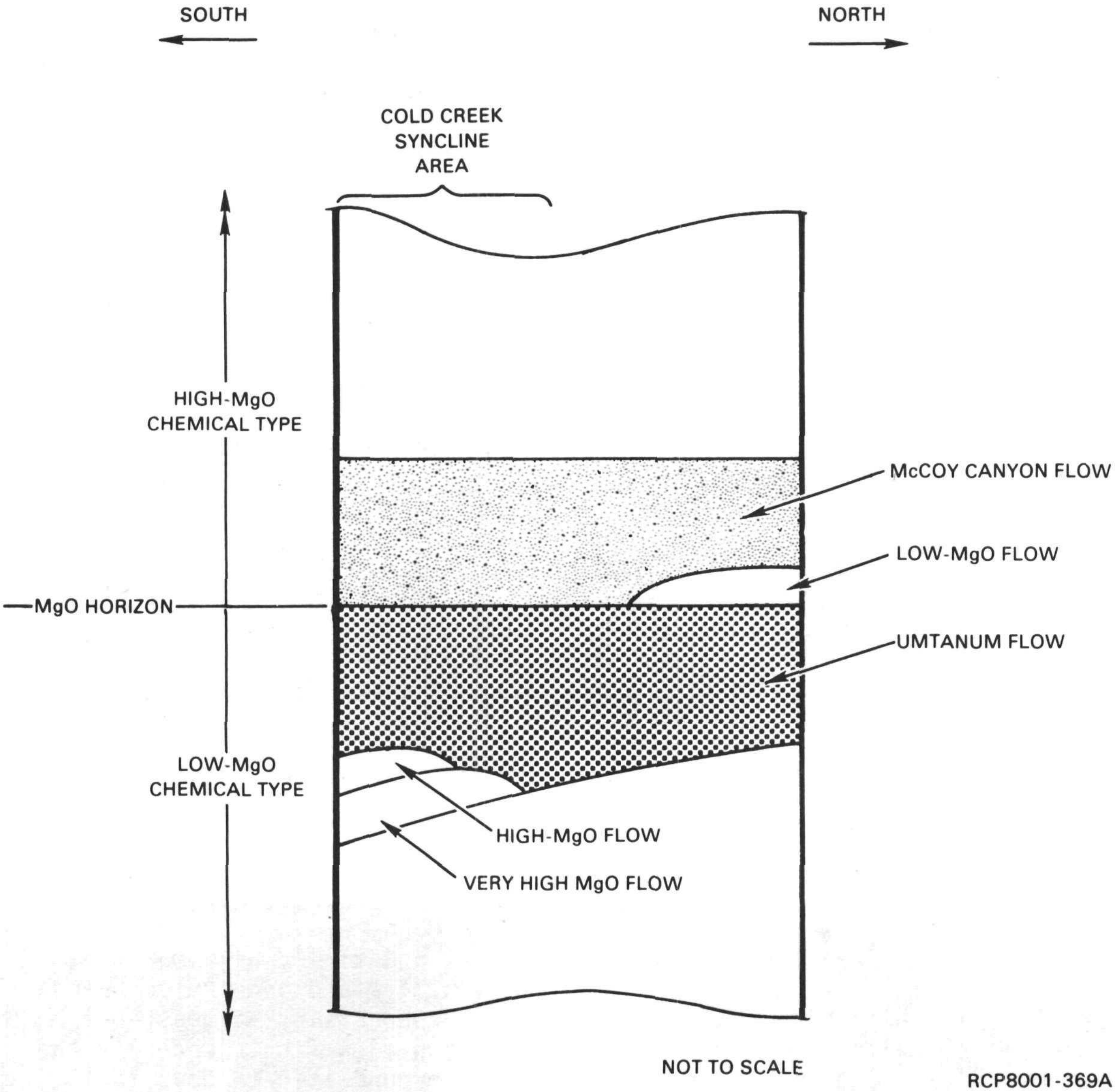

FIGURE 3. Chemical Stratigraphic Units in the Grande Ronde Basalt near the Umtanum Flow.(2)

that trend east-west along the south flank of the ridge. A fault offsets the ridge along a north-south trend. Offset is not more than 500 meters. Remapping of the Rattlesnake Mountain fault, located approximately 0.8 kilometer northeast of the crest of Rattlesnake Mountain, indicates that the Rattlesnake Mountain fault is a complex structure consisting of two parallel faults striking northwest-southeast with a complexly folded zone between the two faults. In addition, the surface geology in the most productive area of the old Rattlesnake Hills gas field is not that of a landslide as previously mapped, but is an anticline faulted on its northwest end. Remapping in the Snively Basin area indicates that much of the complex structure there represents true bedrock structure and is not the result of landsliding as was previously thought. In addition, the Rattlesnake Mountain fault has been relocated in the Snively Basin area.

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CHAPTER III

SITE CHARACTERIZATION STUDIES

HYDROLOGY

SUMMARY OF FISCAL YEAR 1980 HYDROLOGIC STUDIES

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Hydrologic studies are one of the principal research activities within the Basalt Waste Isolation Project. The objective is to provide an evaluation of the hydrologic systems present within the Columbia River basalt relative to the possible siting of a nuclear waste repository. This is accomplished through a field data-gathering effort coordinated with groundwater flow and solute transport modeling analyses of hydrologic scenarios.

The hydrology effort is centered within the Pasco Basin, located in south-central Washington State, particularly that portion of the basin within the Hanford Site. Regional hydrology studies for other portions of the Columbia Plateau are under way to assist in better understanding the surface-water and groundwater systems that exist within the Pasco Basin. The major thrust of these studies focuses upon the consideration of groundwater flowpaths, groundwater velocities, and solute concentrations and travel times. The following text gives a general overview of the field testing, borehole drilling, numerical modeling, and regional hydrology efforts. Specifics on work accomplished may be found in subsequent papers in this report.

FIELD TESTING

The primary objective of the field testing program is to provide input data for physical characterization and conceptual modeling. During fiscal year 1980, hydrologic testing was carried out in both existing and new boreholes. The hydrologic data obtained can be grouped into the categories of hydraulic head, hydraulic properties, and hydrochemistry.

When the desired rock interval is isolated in a borehole from other downhole conditions, head measurements are acquired using a variety of field test equipment, including calibrated steel tapes, electric sounders, and pressure transducers. Head measurements for zones of interest within the deep basalt formations are corrected for density and temperature variations.

Hydraulic property tests are conducted for selected horizons that have been isolated for testing through use of packer equipment. Tests utilized include air-lift and turbine pumping, slug and continuous injection or withdrawal, drill stem, and tracers. Hydraulic properties determined include hydraulic conductivity, storage coefficient, effective porosity, and dispersivity.

Borehole geophysical logs are utilized in the testing program for identifying the depths and thicknesses of specific stratigraphic zones to be hydrologically tested and for examining basic rock characteristics and downhole conditions. When these geophysical data are compared to the basalt core samples recovered from the same borehole, a highly reliable method is established for locating the rock zones to be straddled and tested.

Groundwater samples are collected from boreholes and spring sites for laboratory and field analysis. Samples are collected in specific horizons within boreholes which have been isolated through the use of packers and extensively developed prior to sampling. Hydrochemical analyses utilized in the field testing program are divided into four major categories: major inorganic, trace element, isotopic, and dissolved gases.

The basis for selecting a given basalt (columnar section or interflow) or sedimentary interbed horizon for the above tests depends upon a number of factors, including: geophysical log responses, examination of core samples, head conditions encountered during coring, and initial hydrologic test responses and test results extrapolated from similar stratigraphic horizons in other boreholes.

In each borehole presently being drilled, all major interflows and interbeds are tested as they are penetrated. The major testing in low-permeability zones (entablature/colonnade) is concentrated in the Grande Ronde Basalt. Selected testing of such zones has taken place in the Wanapum Basalt.

Principal accomplishments during fiscal year 1980 in the field studies were:

- Completion of physical testing and hydrochemical sampling of the Saddle Mountains Basalt in Boreholes DB-15, DC-14, and DC-15 (Figure 1)
- Completion of physical testing and hydrochemical sampling of the Wanapum Basalt in Boreholes DB-15, DC-12, DC-14, and DC-15
- Physical testing and/or hydrochemical sampling of the Grande Ronde Basalt in Boreholes DC-2, DC-6, DC-7, and DC-8; this also includes testing the portion of DC-7 that was deepened an additional 247 meters from its original depth of 1,249 meters.

Details on the field testing approach and interpretive techniques used and on the development of a better understanding of the hydrology of the Columbia River basalt from current data are addressed in the following sections.

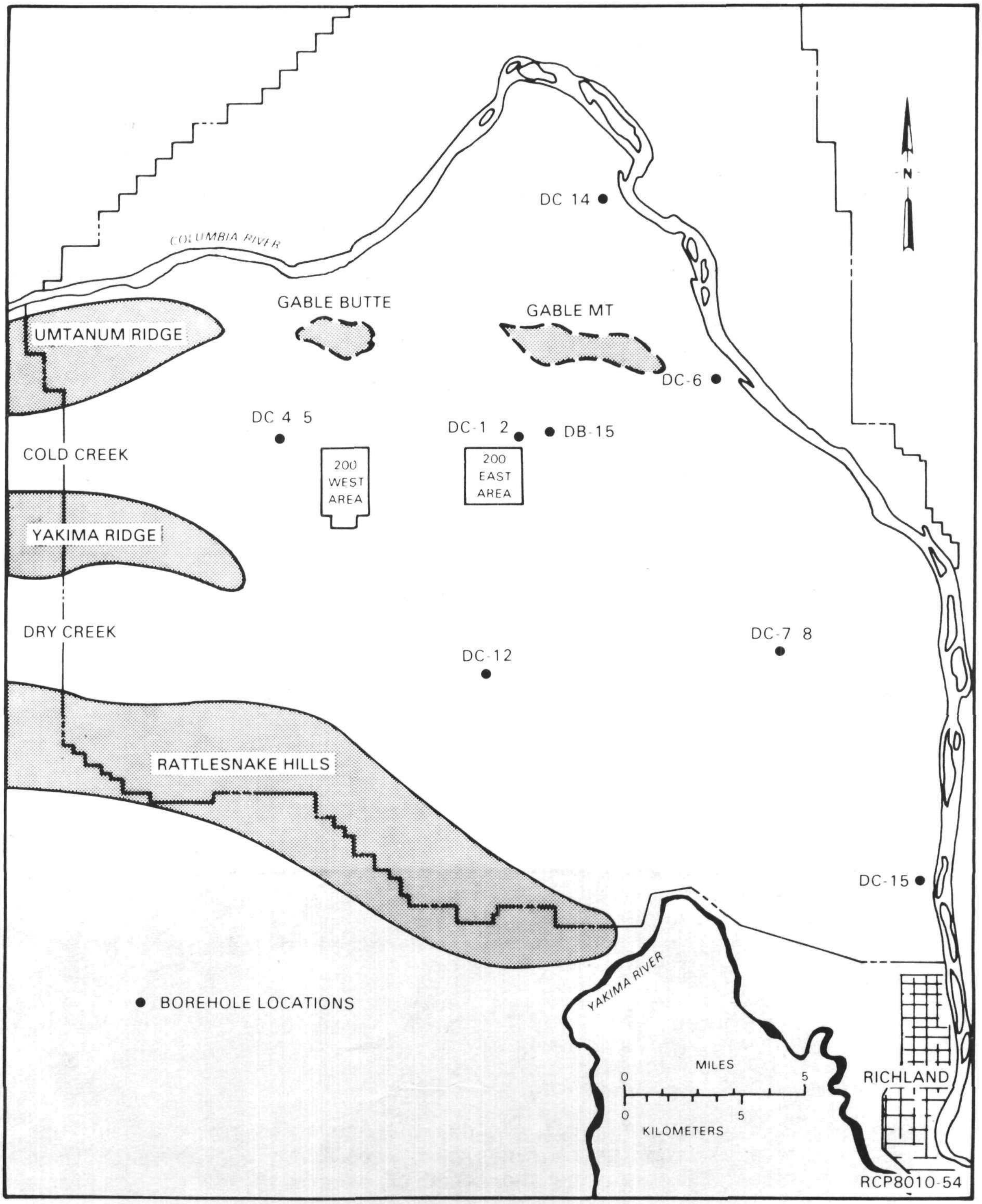

FIGURE 1. Location of Selected Borehole Sites.

BOREHOLE DRILLING

During fiscal year 1980, three new boreholes were begun and a fourth existing site was deepened.

Borehole DC-12, located just south of the axis of the Cold Creek Syncline, will assist in evaluating groundwater recharge from the direction of the Rattlesnake Hills south-west of the Hanford Site (Figure 1). Boreholes DC-14 and DC-15 are both within about 150 meters of the Columbia River. Information from them will assist in examining the potential hydraulic relationship between basalt groundwater systems and the river. Borehole DC-15 was specifically positioned in the southernmost section of the Hanford Site to address possible groundwater discharge to the Columbia River north of Richland, Washington. Each borehole will reach a total depth of approximately 1,300 meters below ground level during fiscal year 1981. They will be completed as NX (7.701-centimeter) diameter holes.

Existing Borehole DC-7 located near the axis of the Cold Creek syncline was, as noted earlier, deepened 274 meters. This was for coring and testing the same lower Grande Ronde Basalt stratigraphy examined in Borehole DC-6 located on the eastern edge of Gable Mountain.

When the data from Boreholes DC-12, DC-14, and DC-15 are combined with information from existing Boreholes DC-1/2, -4/5, -6, -7/8, and DB-15, they will facilitate construction of the first preliminary potentiometric maps for the Wanapum and Grande Ronde Basalts beneath portions of the Hanford Site. These data will provide the first evaluation of the areal and stratigraphic variations of basalt hydrologic properties within specific intraflow structures and interbeds.

NUMERICAL MODELING

The focus of the hydrologic modeling studies is on the assembly and use of predictive technology for assessments of the hydrologic regimes in the Columbia River basalt.

During fiscal year 1980, work was directed toward the following activities:

- Development and verification of a data base covering pertinent information related to groundwater flow and contaminant transport from repository candidate sites
- Development of a set of credible scenarios for radionuclide release from the confines of a repository whereby pathlines and travel times may be shortened or otherwise adversely affected
- Acquisition, testing, and documentation of groundwater flow and contaminant transport models

- Conducting a variety of near- and far-field groundwater flow and transport modeling runs and supporting activities, including runs to determine the sensitivity of the system response to various parameters and conditions.

Near-Field Modeling

In-house efforts in fiscal year 1980 have focused on the establishment of a modeling capability specifically applicable to basalt media. Various mathematical modeling approaches; e.g., continuum and noncontinuum, were reviewed and evaluated. Available numerical models for near-field simulations were acquired and tested. Principal accomplishments this fiscal year were:

- Derivation of the theoretical formulation for a coupled model of groundwater flow and heat transport in a fractured-porous (double porosity) media
- Development of a finite element numerical model, SEMTRA, for coupled groundwater flow and heat transport in two dimensions
- Development of a finite element numerical model, CHAINT, for nuclide transport of actinide elements; i.e. decay chains
- Performing extensive testing and verification of near-field computer codes
- Application of numerical models at candidate repository sites to estimate the waste isolation capability of basalt.

Far-Field Modeling

The three-dimensional groundwater model, RHAFE, was set up and applied to simulate the subsurface flow patterns in the Pasco Basin. Various multilayer representations of the basalts and interflow zones have been used in describing the geohydrologic system. A hydrologic data base was developed and computerized which contains the location of measurement points and associated field data. Major accomplishments in the far-field modeling included:

- Performing preliminary simulations of groundwater flow using a parametric sensitivity approach
- Computing initial streamlines and travel times from the candidate repository sites in the Cold Creek syncline
- Examining various hydrologic release scenarios for future analysis of disruptive events.

A discussion of numerical modeling is contained in subsequent papers in this report.

REGIONAL HYDROLOGY

Regional hydrologic studies involved the evaluation of the Pasco Basin hydrologic system as a component of the overall hydrologic system operating within the Columbia Plateau. The major activities of this investigation included: collection, organization, and evaluation of relevant existing hydrologic and geologic data; development of a conceptual description of the regional hydrologic system; and application of appropriate numerical models as needed to quantitatively evaluate flow system interrelationships.

The thrust of the work effort during fiscal year 1980 was related to the first two activities noted above. Data handling and conceptual model development are proceeding, leading to the eventual numerical modeling of the basic groundwater dynamics operative in other basins within the Columbia Plateau. This will contribute to the understanding of the hydrology of the Pasco Basin. The principal accomplishments included:

- A description of regional groundwater flow
- Refinement of the water budget for the Pasco Basin and vicinity
- Analysis of land-use trends using LANDSAT imagery.

Details of the regional hydrology program are addressed by Leonhart in a subsequent paper.

TESTING TECHNIQUES AND ANALYSIS PROCEDURES USED IN THE HYDROLOGY PROGRAM

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The objective of the hydrologic field testing program of the Basalt Waste Isolation Project is to provide data for characterization of groundwater hydrologic systems within the Columbia River Basalt Group beneath the Pasco Basin. Specifically, this effort is directed toward characterizing the areal head distribution, hydraulic properties, and hydrochemistry of groundwater within the basalt. Data obtained from these studies provide input for hydrologic modeling of groundwater flow and solute transport. The primary field testing techniques and analytical procedures applied by the Hydrology Group is to achieve these objectives are summarized below.

HYDROLOGIC TESTING EQUIPMENT

Both single- and straddle-packer systems are used to conduct hydrologic tests in vertical, single, and paired boreholes on the Hanford Site. These systems, including downhole and surface equipment, are described below.

Single-Packer System

The single-packer system has been used in boreholes where field testing was done on a progressive drill and test basis. This system was used to test each major interflow and interbed as a borehole was drilled. The packer arrangement consists of a pneumatic or tensional-compressional packer attached to steel tubing of sufficient diameter to conduct pump, swab, and displacement tests.

The surface equipment used to monitor water-level responses in the borehole interval as well as in the annulus includes:

- High-precision surface downhole pressure transducers
- Electric water-level indicator
- Chalked steel tape.

Discharge flow measurements are made with either a propeller-type instantaneous-totalizer flowmeter, calibrated container, and/or weir.

Straddle-Packer System

A Lynes Triple CWL straddle-packer system has been used to test anticipated high- and low-permeability zones across open intervals after completion of the borehole. This system consists of a downhole pressure probe capable of measuring temperatures and pressures above, in between, and below the straddled interval. These data are rapidly transmitted via a single conductor cable to surface electronic equipment for printing and recording. Major components of the downhole equipment are:

- Inflatable rubber packers
- Sensor carrier (containing three high-precision quartz transducers having an accuracy of 1.77 meters)
- J-slot tool
- Shut-in tool
- 4.76-millimeter single conductor cable.

Major components of the surface processing equipment are:

- Universal frequency counter
- Lynes signal converter
- Computer/calculator
- Printer/plotter.

HYDROLOGIC TESTING PROCEDURES

Outlined in Figure 1 are the field testing procedures which use a single- and straddle-packer system. The type of test performed depends largely on the permeability of the zone of interest. For permeable intervals, the field testing procedures in general consist of: selecting the test interval based on examination of core logs and borehole geophysical logs; seating and checking packer integrity; developing formation by washing and pumping; conducting long-term pumping tests for hydraulic properties and hydrochemical analysis; and conducting displacement tests. For less permeable zones, displacement tests and constant head injection tests are commonly employed. These suites of hydrologic tests normally take from 3 to 7 days in high-permeability zones and 2 to 4 weeks in lower-permeability zones.

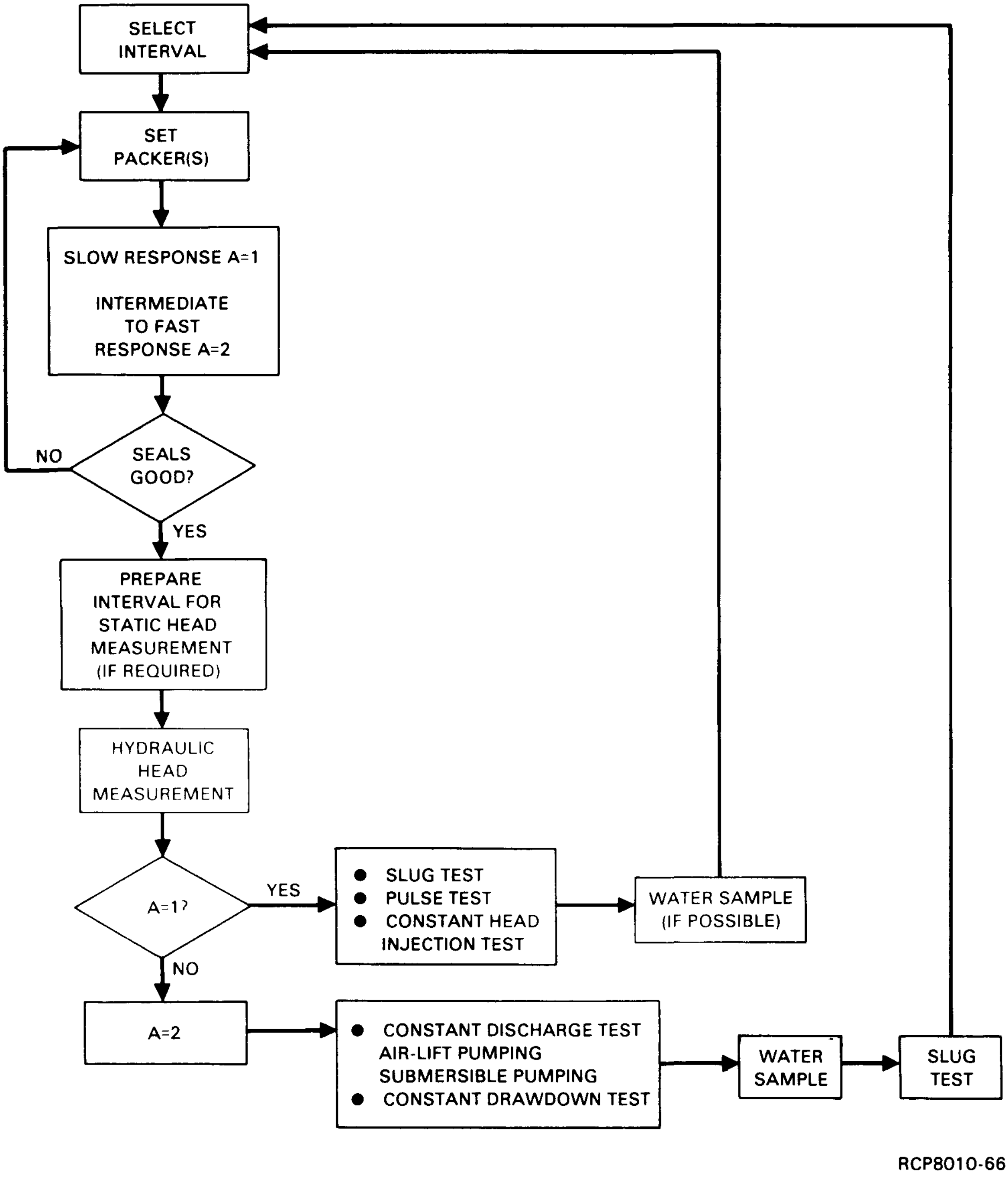

FIGURE 1. Hydrologic Field Testing Sequence.

DATA ANALYSIS METHODOLOGY

Hydraulic Head Measurement

When the desired rock interval is isolated by the single- or straddle-packer method, and the formation is sufficiently developed, head measurements are obtained until equilibrium is reached. Head measurements for units within deep basalt formations are corrected for viscosity and temperature variations.

Hydrologic Properties

Hydrologic properties which are determined from field tests include hydraulic conductivity,* transmissivity, storativity, effective porosity, and dispersivity. Some of the basic parameter analysis techniques being relied upon in the past 2 years of field testing efforts are identified in Table 1. As data are analyzed, some techniques will undoubtedly prove more useful than others. The strengths and weaknesses of several possible interpretive techniques are currently being examined. Some of these interpretive techniques used by the Basalt Waste Isolation Project are briefly described below.

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*An estimate of hydraulic conductivity is determined from field determination of transmissivity and effective thickness.

TABLE 1. Parameter Evaluation Techniques.

Parameter	Primary Data Acquisition Method	Selected Parameter Analysis Techniques (References)
Hydraulic head	Water potential	1, 2
Horizontal hydraulic conductivity (low-hydraulic conductivity zone)	Withdrawal and injection tests	3, 4, 5, 6, 7, 8
Horizontal hydraulic conductivity (high-hydraulic conductivity zone)	Pump, drill stem, and injection tests	3, 4, 6, 9, 10, 11, 12
Vertical hydraulic conductivity	Withdrawal, injection and pump tests	12, 13, 14, 15, 16, 17, 18, 19, 20, 21
Storativity (low-hydraulic conductivity zone	Withdrawal and injection tests	3, 4, 7, 11
Storativity (high-hydraulic conductivity zone	Withdrawal, injection, and pump	3, 9, 10, 11, 12
Effective porosity	Tracer test	22, 23
Dispersivity	Tracer test	22, 23, 24, 25

Constant Discharge Tests. The procedure for this type of test involves pumping at a constant discharge rate by means of air-lift or submersible pumping methods. Analysis of drawdown and recovery data permits determination of transmissivity and storativity. Analyses of these parameters are derived from standard nonequilibrium(9) and/or modified nonequilibrium(10) solutions. The range of transmissivity over which constant discharge tests can be realistically conducted is from about 10^{-3} to greater than 10^3 square meters per day.

Major advantages of pumping tests are:

- Radius of influence is large; i.e., larger volume of rock surrounding borehole is tested.
- Late-time recovery data are not affected by skin and borehole storage effects.

Major disadvantages of pumping tests are:

- Variations in pumping rate can affect drawdown data.
- They do not work well in low-transmissive intervals.
- Analysis does not account for phase separation (gas and water) in tubing.

Constant Drawdown Tests. This test has been employed for zones with flowing artesian conditions. The procedure involves allowing the water from a borehole to flow over a period of time while monitoring the declining flow rate. Solutions for determining transmissivity and storativity from a constant drawdown test are described in Reference 11. The estimated range of transmissivity over which constant drawdown tests can be conducted is about 10^{-4} to 10^2 square meters per day.

Major advantages of constant drawdown tests are:

- Easy to run (i.e., no pump)
- Analysis of corroborative flowing and recovery data is possible
- Provides an estimate of storativity.

Major disadvantages of constant drawdown tests are:

- Not very applicable in higher transmissive zones
- Discharge measuring equipment limitation.

Displacement Tests. The types of tests include instantaneous injection and withdrawal slug tests(3,5) and the pressurized pulse test.(7) The procedures involve the instantaneous adding or withdrawing of water in a borehole and monitoring the fluid response. For the pulse test, the interval is instantaneously pressurized at ground surface. Transmissivity and storativity can be determined by matching dimensionless pressure versus the log time plot to a family of type curves.(3,4,5,7) In more permeable formations, a method was described(6) of determining transmissivity by analyzing oscillating water levels following withdrawal/injection slug tests. The range of transmissivity over which these tests can be conducted is about 10^{-4} to 10^{3} square meters per day.

Major advantages of pulse tests and slug tests are:

- Short test time for pulse test
- Simple equipment setup.

Major disadvantages of pulse tests and slug tests are:

- Small radius of influence
- Skin-effect problem (i.e., borehole damage or simulation)
- Inertial effects.

Constant Head Injection Test. This test (also known as Lugeon test, packer test, and pressure test) has been commonly used to determine fractured rock permeability for engineering investigations. The test procedures are discussed in Reference 8. The procedures involve injecting water at a steady-state in the packed off interval at three to five pressures. The linear slope of the pressure points versus injection rate should be used to calculate permeability. These tests are used in the transmissivity range of about 10-8 to 10-4 square meters per day.

Major advantages of constant head injection tests are:

- Test can be run rapidly
- Can be used with any packer spacing
- Simple equipment setup.

Major disadvantages of constant head injection tests are:

- Problems with calibrating equipment; i.e., determining head loss
- Possibility of not achieving steady-state conditions
- Requires special pumps and flow meters for very low-permeable intervals
- Effects of near-field fracture characteristics.

Tracer Tests. An estimate of effective porosity and dispersivity can be determined from single or dual borehole sites.(22,23) Recently, Science Applications, Inc. performed a dual well tracer test at Boreholes DC-7 and -8 using iodine-131 as the tracer. Effective porosity and dispersivity were determined by other methods.(25) Studies are under way to assess types of tracers, analytical techniques, and methods of conducting tracer tests within fractured basaltic rock.

Hydrochemical Analysis

Groundwater samples are collected in horizons within boreholes which have been isolated through use of packers and extensively developed prior to sampling. Hydrochemical analyses used in the field testing program are divided into four major categories: major inorganic, trace elements, isotopic, and dissolved gases. The individual parameters analyzed within the four categories are shown in Table 2.

TABLE 2. Hydrochemical Data Analyzed from Groundwater Samples Acquired from the Field Testing Program.

Nonisotopic Analyses
Alkalinity, Cl^-, SO_4^{-2}, F^-, NO_3^-, PO_4^{-2}, Na^+, K^+, Ca^{++}, Mg^{++}, SiO_2, TOC, pH, Eh, electrical conductivity
Trace Elements
Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, Pb, Sr, Zn
Dissolved Gases
H_2, He, N_2, O_2, Ar, CO, CO_2, CH_4, C_2H_6
Isotopic Analyses
Stable Isotopes
$^2H/^1H$ $^{18}O/^{16}O$ $^{13}C/^{12}C$ $^{34}S/^{32}S$
Radioactive Isotopes
^3H $^{238}U/^{234}U$ ^{14}C ^{36}Cl

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GROUNDWATER HYDROLOGY OF THE COLUMBIA RIVER BASALTS BENEATH THE HANFORD SITE

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Hydrologic studies conducted during fiscal year 1980 have provided additional information to understanding the groundwater hydrology of the Columbia River basalts beneath the Hanford Site. Specifically, fiscal year 1980 studies focused on determining the areal and vertical distribution of hydraulic head, calculation of hydraulic properties, and hydrochemical characterization of basalt formations. The location of sites tested by the Basalt Waste Isolation Project is shown on Figure 1. Hydrologic data obtained for the various basalt formations beneath the Hanford Site during fiscal year 1980 are listed in Table 1.

HYDRAULIC HEAD MEASUREMENTS

Areal and vertical hydraulic head measurements were taken to provide information concerning groundwater flow patterns, recharge and discharge areas, etc. for specific geohydrologic units. As shown in Table 1, hydraulic head measurements were completed in 94 separate test intervals; most of which were taken in the Wanapum Basalt. Most hydraulic head data for an individual formation, however, are available for the Mabton interbed, which lies between the Saddle Mountains and Wanapum Basalts.

Areal hydraulic head data within the Mabton interbed are shown in Figure 2. The potentiometric map shows the general groundwater flow pattern within this formation. Salient features depicted include:

- The prominent recharge mound extending from Rattlesnake Hills
- The presence of a low-hydraulic head (potential discharge) region in the Gable Mountain structural area
- The lack of a dominant line sink (potential discharge) along the entire course of the Columbia River.

Vertical hydraulic head measurements were obtained at five borehole sites which were or are currently being progressively drilled and tested. As an example, the data depicted in Figure 3 show the distribution of hydraulic head with depth at Borehole DC-14, which is located in the northern part of the Hanford Site adjacent to the Columbia River. The hydraulic head distribution at Borehole DC-14 indicates:

- Pronounced increase in hydraulic head with depth within the Saddle Mountains Basalt, suggesting a potential discharge area for groundwater within this formation

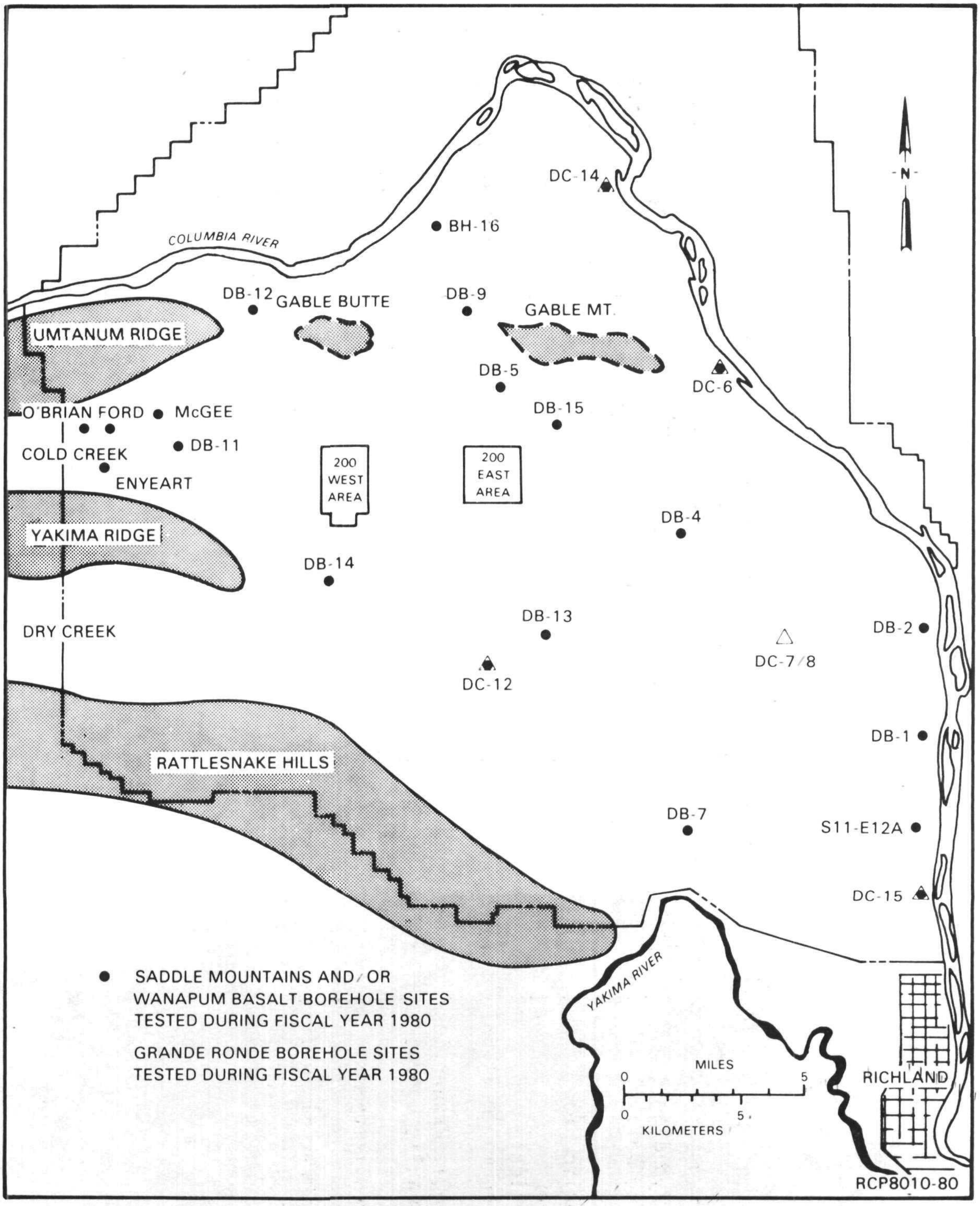

FIGURE 1. Location of Borehole Sites Tested during Fiscal Year 1980.

TABLE 1. Hydrologic Data Obtained for Basalt Formations at Hanford During Fiscal Year 1980.

Hydrologic Data	Saddle Mountains Basalt (test intervals)	Wanapum Basalt (test intervals)	Grande Ronde Basalt (test intervals)	Total (test intervals)
Hydraulic Head				
Areas	31	48	15	94
Vertical (borehole sites)	3	4	1	5 (borehole sites)
Hydraulic Properties				
Hydraulic Conductivity	31	48	15	94
Storativity	6	3	5	14
Hydrochemical Data	27	34	9	70

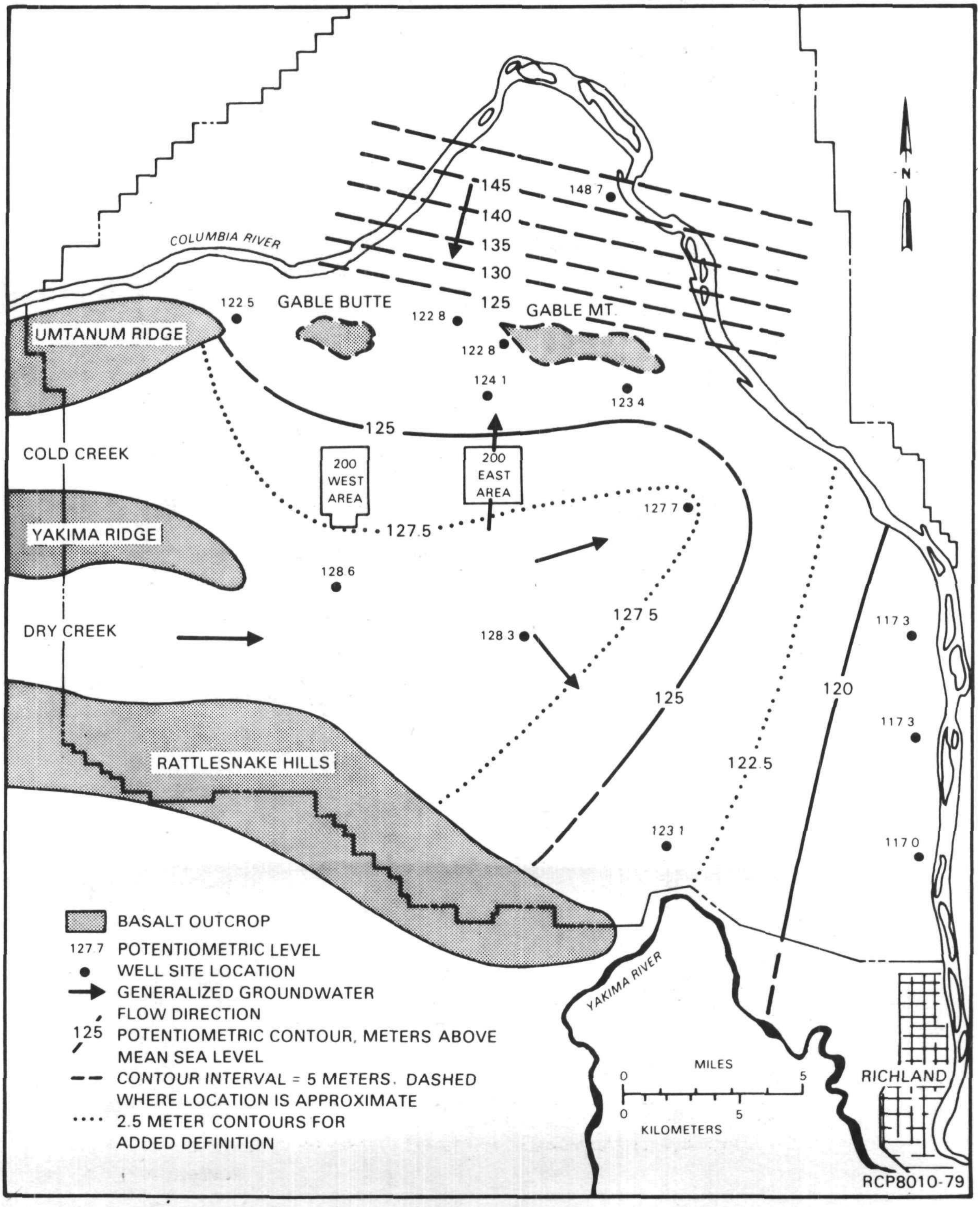

FIGURE 2. Potentiometric Map for and Inferred Flow Directions of Groundwater within the Mabton Interbed beneath the Hanford Site.

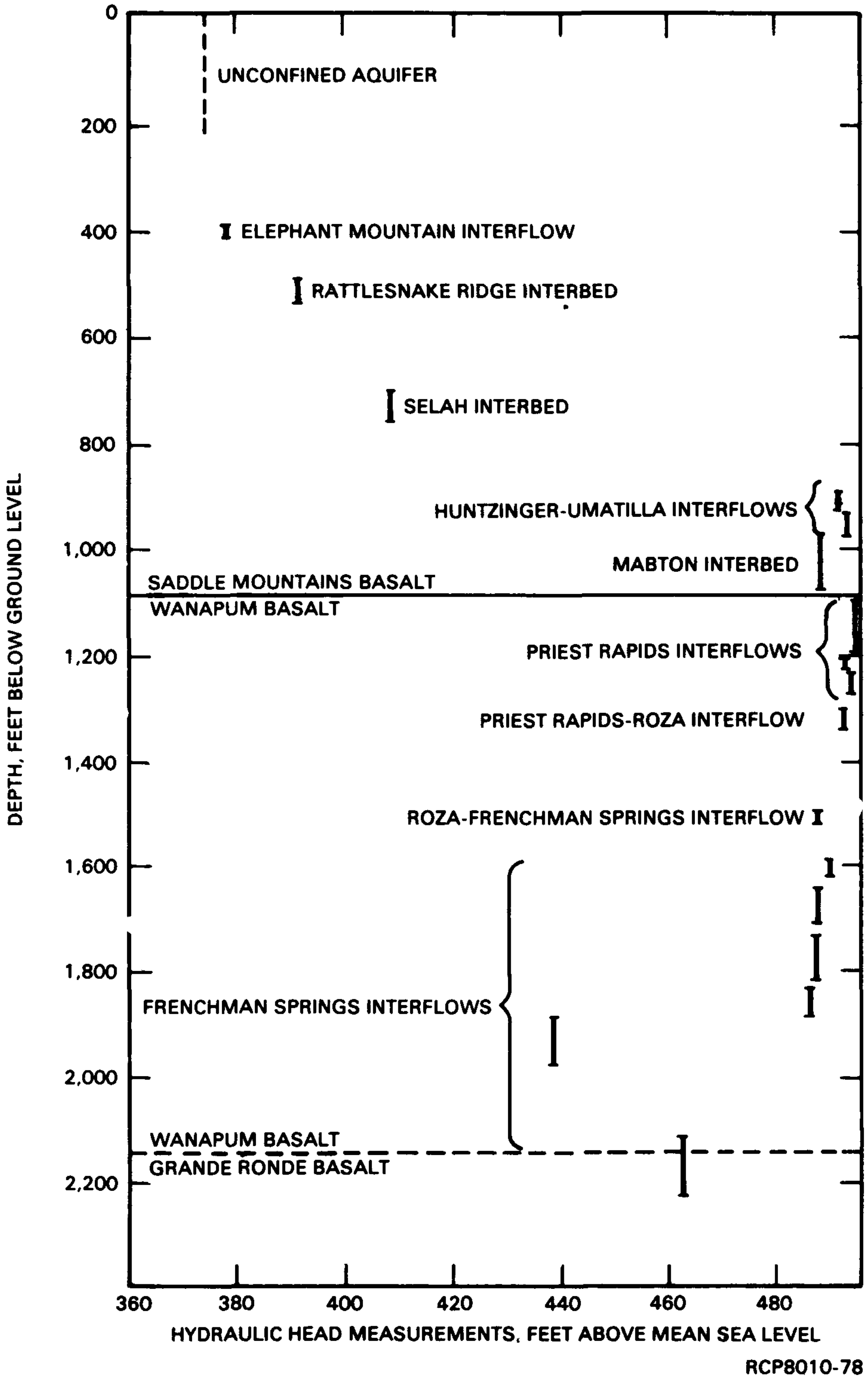

FIGURE 3. Hydraulic Head Measurements within the Saddle Mountains and Wanapum Basalts at Borehole DC-14.

- Uniform to slight decline in hydraulic head with depth from the lower Saddle Mountains to the lower Wanapum Basalts, suggesting lateral flow of groundwater within this section

- Significant decline in hydraulic head near the base of the Wanapum Basalt (i.e., lower Frenchman Springs Member).

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

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

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

HYDRAULIC PROPERTIES

Hydraulic properties for basalt formations were determined by a number of in situ field testing techniques. These hydraulic properties provide input for hydrologic modeling of groundwater flow at Hanford and afford information concerning the potential transport of radionuclides within basalt systems.

Ranges in hydraulic conductivity and storativity determined during fiscal year 1980 are listed in Table 3. Hydraulic conductivity values listed generally fall within the range previously reported(1) for interflow zones and sedimentary interbeds within the Columbia River Basalt Group.(2) Values shown for storativity were determined, for the most part, without benefit of observation well measurements, and, therefore, are qualitative in nature. The storativity values listed, however, fall within the range commonly reported for confined aquifers.(3)

TABLE 3. Ranges in Hydraulic Properties Determined during Fiscal Year 1980 for Columbia River Basalts and Associated Sedimentary Interbeds.

Geologic Formation	Hydraulic Conductivity (centimeters per second)	Storativity
Saddle Mountains Basalt		
Interbeds	10^{-2} - 10^{-5}	10^{-3} - 10^{-4}
Interflows	10^{-1} - 10^{-6}	
Wanapum Basalt		
Interbeds	10^{-6} - 10^{-8}	10^{-3}
Interflows	10^{-2} - 10^{-7}	10^{-4} - 10^{-5}
Grande Ronde Basalt		
Interflows	10^{-2} - 10^{-8}	10^{-3} - 10^{-6}

BASALT HYDROCHEMISTRY

Seventy intervals were sampled for hydrochemical characterization during the past fiscal year. As shown in Table 1, most intervals sampled were within the Wanapum Basalt. Available areal hydrochemical data indicate that groundwaters within the Saddle Mountains Basalt are of a relatively uniform chemical character. Slightly more heterogeneity is evident, however, for groundwaters within the Wanapum and Grande Ronde Basalts. Chemical type classification for formational waters sampled during fiscal year 1980 are summarized in Table 4.

Hydrochemical data collected with depth at five locations during fiscal year 1980 provided additional information concerning the hydrology of basalt formations underlying the Hanford Site. General descriptions of vertical hydrochemical patterns for the five sites are summarized in Table 4. Of hydrologic importance is the presence of a distinct hydrochemical break between the Saddle Mountains and Wanapum Basalts in the Cold Creek structural area (e.g., Borehole DB-15) as shown in Figure 4. The sharp distinction in chemical type suggests a lack of hydraulic

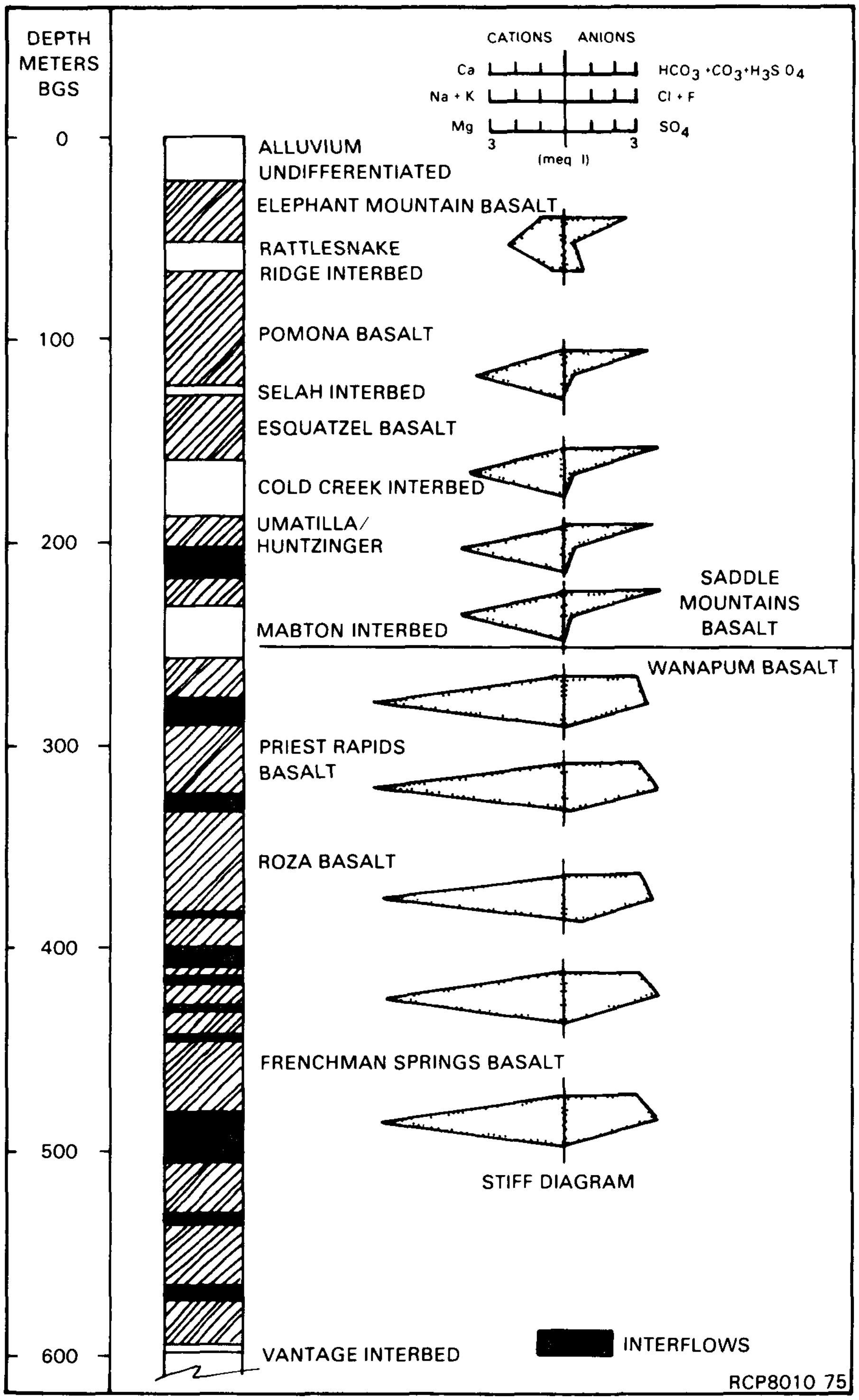

FIGURE 4. Preliminary Hydrogeologic and Hydrochemical Data within the Saddle Mountains and Wanapum Basalts at Borehole DB-15.

communication and mixing of groundwaters across this formational contact. For boreholes outside the Cold Creek structural element (e.g., DC-14 and -15), no major hydrochemical break was discerned at this boundary. A significant hydrochemical break was noted, however, between the Wanapum and Grande Ronde Basalts at Borehole DC-14.

TABLE 4. Chemical Type Classifications and Vertical Hydrochemical Patterns for Groundwater within Columbia River Basalt.

Borehole	Geologic Formation	Chemical Type
	Chemical Type Classifications	
DB-15, DC-14, and DC-15	Saddle Mountains Basalt	Sodium-Bicarbonate
DB-15, DC-12, DC-14, and DC-15	Wanapum Basalt	Sodium-Bicarbonate to Sodium-Chloride-Bicarbonate
DC-6	Grande Ronde Basalt	Sodium-Chloride
	Vertical Hydrochemical Patterns	
DB-15, DB-13, and DC-12	Significant hydrochemical breaks near the Saddle Mountains-Wanapum Basalt contact.	
DC-14	No hydrochemical break through Saddle Mountains and Wanapum Basalt; major break between Wanapum and Grande Ronde Basalt.	
DC-15	No significant hydrochemical break; slight increase in chloride and fluoride content below Saddle Mountains-Wanapum Basalt contact.	
DC-6	Variation in concentration, but no change in hydrochemical type for Grande Ronde Basalt groundwaters.	

SUMMARY

Hydrologic studies completed in fiscal year 1980 contributed additional data to understanding the complexities of the groundwater hydrology of basalt formations underlying Hanford. Some of the salient findings are outlined below:

- Hydraulic property determinations for basalt interflow zones and associated sedimentary interbeds tested in fiscal year 1980 generally fall within the range of previously reported values.

- Areal and vertical hydraulic head measurements indicate that the Columbia River does not act as a line sink (i.e., potential discharge area) along its entire course for basalt formations underlying the Hanford Site.
- Areal potential data depict the presence of a low-hydraulic head (potential discharge) region in the Gable Mountain structural area.
- Available data indicate the presence of significant hydrochemical breaks with depth between several basalt formations at various locations beneath the Hanford Site. The hydrochemical breaks, together with corroborating hydraulic head measurements, suggest the lack of hydraulic communication and mixing of groundwaters across these boundaries.

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RECONNAISSANCE STUDIES OF THE HYDROLOGY WITHIN THE WASHINGTON STATE PORTION OF THE COLUMBIA PLATEAU

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The regional hydrology study of the Basalt Waste Isolation Project involves an evaluation of the total hydrologic system operating within the Columbia Plateau with emphasis on that portion within Washington State which has essentially a direct hydrologic interface with the Pasco Basin (Figure 1). The study involves the assemblage, organization, characterization, and reduction of available hydrologic data. These data, in turn, are intended for use in:

- Developing a data base for conceptual and numerical modeling and risk assessment needs
- Determining the nature of data inadequacies and needs for acquiring additional data.

The ultimate goal of this effort is to establish the nature of the relationship between the groundwater flow system operating within the Pasco Basin and within the surrounding region. Because the level of knowledge being developed represents a rather general assessment intended to provide a framework for more advanced studies as required, the regional study is regarded as reconnaissance in nature, after the definition by Peek.(1)

Within the regional program, data acquisition has remained passive in the sense that hydrologic interpretations have been made solely on the basis of existing data. No formal field reconnaissance has been made outside of the Pasco Basin. The future need to actively acquire hydrologic data outside of the basin in order to achieve the above-stated goal remains subject to justification. Analysis of data thus far has focused on:

- Identification and description of principal hydrologic units
- Location of areas of recharge and discharge for those units
- Description of the chemical character of groundwater
- Quantification of hydraulic characteristics of aquifers
- Dynamic behavior of groundwater systems
- Surface water characteristics
- Evaluation of the hydrologic effects of anthropogenic activities.

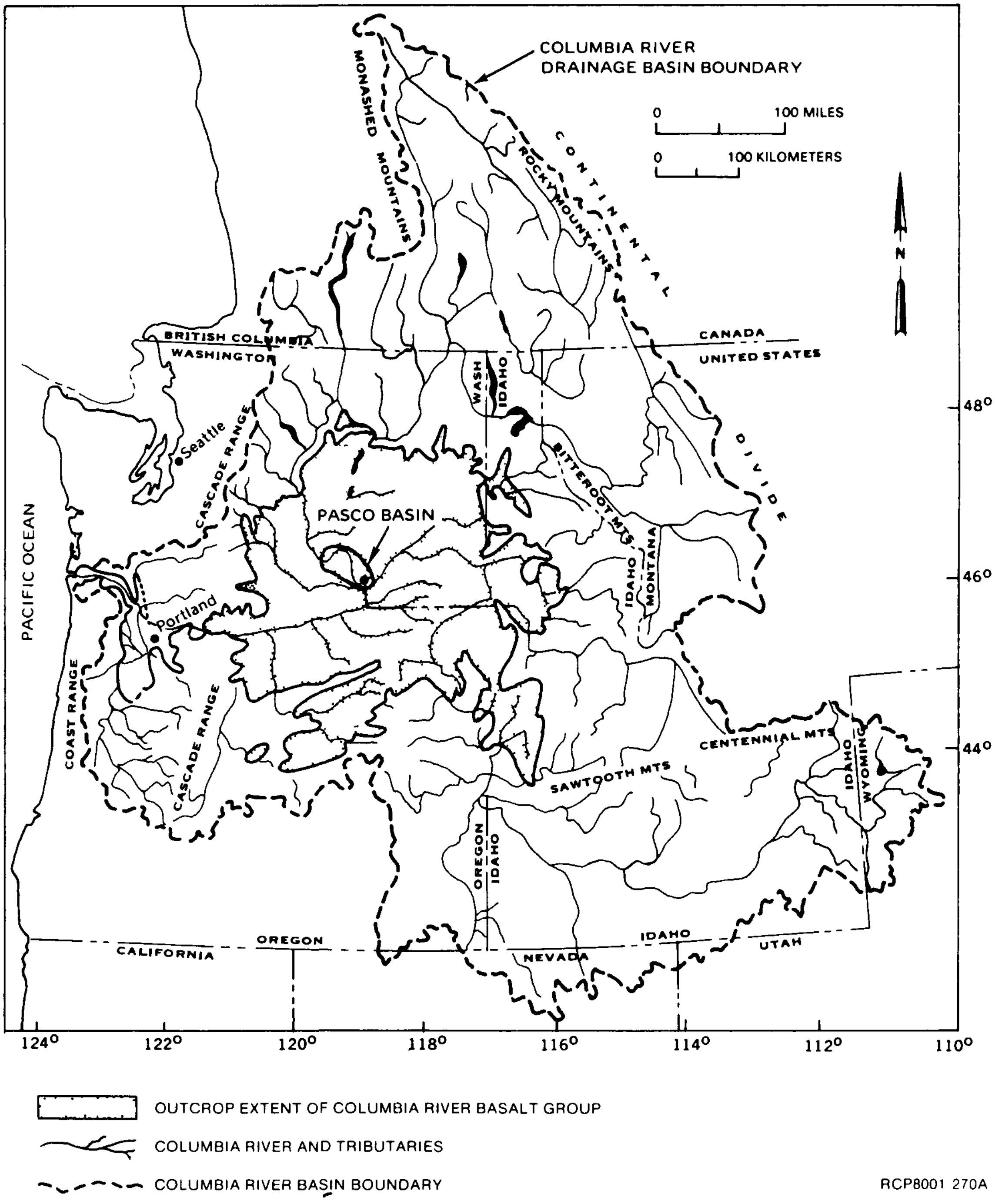

FIGURE 1. Location of the Pasco Basin within the Columbia Plateau.

During the past year, data acquisition activities continued. Some 250 new water well records containing various hydrologic and stratigraphic data, as received from the Washington State Department of Ecology, were added to the existing data set. Additional detail with regard to hydrometeorological data (precipitation, evapotranspiration, etc.) within and adjacent to the Pasco Basin was obtained, and LANDSAT multispectral imagery recorded over the region in 1979 was acquired.

Using the U.S. Geological Survey's Groundwater Site Inventory Data Base, it was possible to generate hydrographs for 43 wells at various locations within the region showing basalt aquifer potentiometric surface trends over a period of 20 years or more. Similarly, using available water-level contour maps, different maps were produced for aquifers at various parts of the region. An effort to correlate the trends shown to past anthropogenic activities is currently in progress.

Remote-sensing data are also being utilized to assist in the evaluation of anthropogenic groundwater dynamics. During fiscal year 1979, LANDSAT data recorded over the region in 1975 were classified and digitally encoded. With the corresponding classification of fiscal year 1979 LANDSAT data, it has become possible to perform a direct digital comparison of land-use changes over the 4-year period. The comparison of changes in the distribution of irrigated agriculture over this period was of particular interest because of the potential for altering the groundwater flow regime. Recognizing that the type of irrigation practice (i.e., surface-water importation versus groundwater pumpage) is important with respect to the hydrologic impact, efforts are under way to provide this type of discernment on the basis of digital imagery.

Another important parameter with respect to the quantitative evaluation of a hydrologic system is that of recharge. Past efforts in this regard produced preliminary water budget estimates for six sub-basins within the Columbia Plateau.(2) Fiscal year 1980 studies have focused on providing a more detailed study of the hydrometeorology, soil moisture balance, and recharge within the Pasco Basin and areas immediately adjacent to it. This detail will be useful in the far-field modeling study being performed within the Pasco Basin.

Another study conducted during fiscal year 1980, as part of the regional hydrologic investigation, assessed the possible effects of existing major dams upon the proposed repository.(3) In general, on the basis of available information, it was possible to conclude that:

- Failure of Grand Coulee Dam on the Columbia River would result in a much greater flood magnitude than probable maximum flooding under natural conditions. In any case, the period of maximum concern is prior to permanent closure of the repository, and the possibility of hazard avoidance through proper site selection and design remains high.

- Impoundments behind major dams might result in transient adjustments of the groundwater flow regime; however, available data show no reason to expect that these adjustments would be significant.

- The potential for reservoir-induced seismicity and attendant hazards remains low at the Hanford Site.

A separate assessment was made with respect to the potential effects of the repository upon adjacent water resources. This study focused on the occurrence of known surface-water and groundwater resources within and adjacent to the Pasco Basin, discussed current and projected use, examined institutional involvements with administration of the water resources, and speculated upon the possible interfaces of these resources with the proposed facility at Hanford.

A final assessment involved a review of current regional information in an effort to identify factors needed to establish a relationship between the regional and Pasco Basin hydrologic systems.

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NEAR-FIELD MODELING: AN OVERVIEW OF CURRENT STUDIES

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One of the major aspects of the Basalt Waste Isolation Project hydrology modeling studies deals with the analysis of potential waste migration from a nuclear waste repository in basalt. Ongoing numerical modeling studies are being performed to assess the waste isolation effectiveness of basaltic rock in retarding waste migration for long-term periods taking into account various hypothetical release conditions. In this paper, an overview is presented that surveys the recent near-field modeling work on hydrologic processes in a basalt rock environment.

INTRODUCTION

A detailed predictive analysis of waste isolation in a hard rock medium, such as basalt, requires the consideration of four major types of phenomena; rock stress/strain, heat transfer, groundwater flow, and nuclide transport. The extent of coupling and interdependence between these processes is important and depends on the physical scale and location of the analysis region. For example, within a relatively small region around a deep geologic repository, the rock medium will exhibit a behavior distinct from the overall geohydrologic system by virtue of the physical and thermal pertubations created by repository conditions. Such a region is typically referred to as the "near-field" zone. Thus, in the near-field zone, the hydrologic and thermomechanical processes are strongly interdependent. These unique features are sharply contrasted by the phenomenological characteristics of the "far-field" region, where the physical scale of the system is much larger and the groundwater flow regime is virtually independent of the repository perturbations.

Within the near-field zone, the performance of the natural barrier; i.e. basalt rock strata, will depend on the relative changes in the hydrologic regime and properties of the water-rock system. The important phenomena which predominate in the near-field zone are shown in Figure 1. As indicated by the arrows in this illustration, the couplings are generally in both directions, except in the case of waste migration. From a systems analysis of these near-field processes, it is known that the radiogenic heat produced by the decay of radionuclides in the repository will have a significant impact on the in situ stress-strain state of the rock mass; moreover, this thermal perturbation may be significant over such periods as 5,000 years after repository closure. During this thermal period, the induced rock stresses can produce changes in the permeability and porosity of the media as well as in the bulk thermal conductivity of the water-rock system. Simultaneous heat transfer through the groundwater and the rock mass is affected by these changes and buoyancy-induced circulation which, in turn, alter the temperature field around the repository. These combined effects create a significant modification of the natural hydrologic regime and are ultimately reflected in the patterns of groundwater flow and nuclide movement.

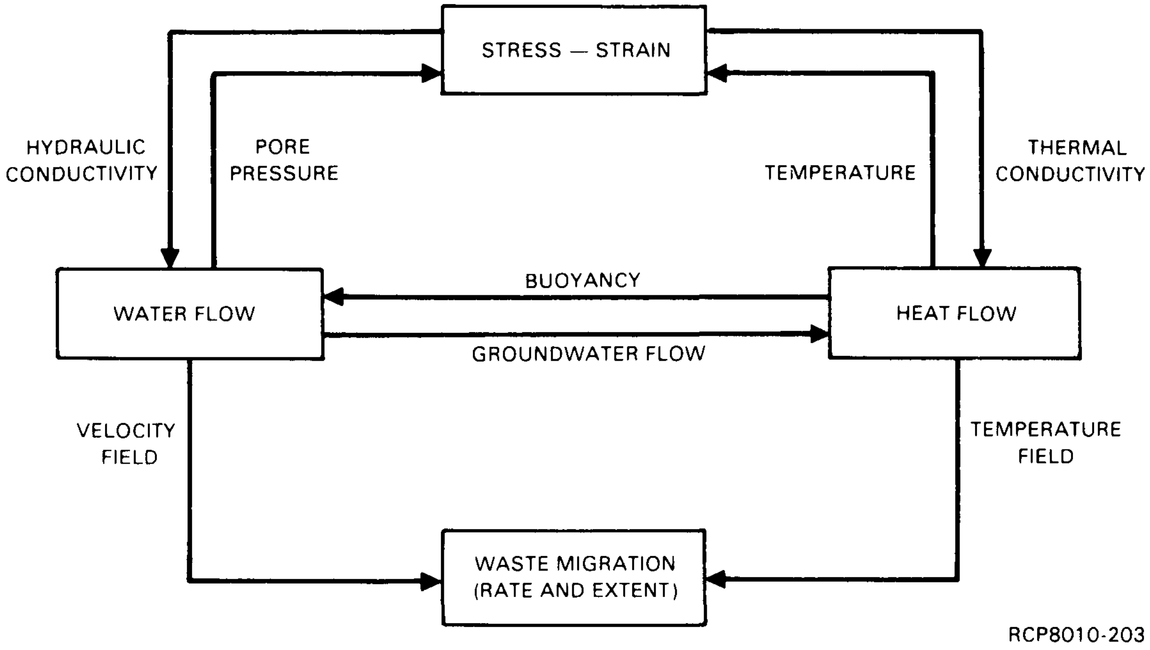

FIGURE 1. Interrelationships of Near-Field Processes.

To describe these phenomena in a a quantitative manner requires the formulation of relatively complex mathematical model consisting of a set of governing equations. Numerical solutions of these governing equations yield a relatively complete "system" description of the rock mass and the hydrologic system in terms of four basic "state variables"; stress, temperature, hydraulic head, and nuclide concentrations.

REVIEW OF MODELING STUDIES

The principal objectives of the Basalt Waste Isolation Project near-field modeling studies are two-fold: to develop a quantitative understanding of the fundamental interrelationships between the hydrological and thermomechanical processes, and to assess the waste isolation capability of candidate repository sites at Hanford. To achieve these objectives, the Basalt Waste Isolation Project staff and its subcontractors have assembled and interfaced a suite of sophisticated numerical models that are capable of realistically portraying the near-field processes. In fiscal year 1980, the major accomplishments of the hydrologic modeling efforts included:

- Development of a theoretical basis for modeling nonisothermal flow in "fractured-porous" media
- Completion of a detailed parametric and sensitivity analysis to assess waste isolation in a basaltic rock environment
- Completion of a preliminary hydrologic analysis of postulated release events for a hypothetical repository in the Columbia River basalts.

The important findings and results from these near-field modeling studies are summarized below.

MODELING FRACTURED-POROUS MEDIA

The problem of modeling hydrologic phenomena in fractured and porous media, such as the Columbia River basalts, is relatively complex. This inherent complexity arises from the problem that the media exhibit hydraulic characteristics of both a continuum and noncontinuum nature. This aspect is perhaps better understood by recognizing that a basaltic rock system is typically composed of a sequence of basalt flows separated by interflow zones and occasionally by sedimentary interbeds. The basalt flows are low-conductivity, fractured rock layers, whereas the porous interflows and interbeds are moderate- to high-permeability zones. In addition, through-running joints and faults represent discrete zones of channelized flow.

To provide a mathematical model specifically applicable to a basaltic rock environment, the Basalt Waste Isolation Project staff has employed the so-called dual-porosity approach. The theoretical framework was originally developed by researchers in the petroleum industry and has been successfully used to simulate flow in fractured oil reservoirs.(1,2) For applications to waste isolation problems in a hard rock geology, this approach has been extended to include nonisothermal effects and discrete fractures (of tectonic origin). The general governing equations(3) derived for coupled groundwater flow, heat transfer, and nuclide transport are expressed by:

Heat Transport

$$S_t \frac{\partial T}{\partial t} = \rho C_{vf} \{\bar{\bar{K}} \cdot (\nabla h + \delta_b \nabla z) \cdot \nabla T + \nabla \cdot (\bar{\bar{K}} \cdot (\nabla h + \delta_b \nabla z) T)\}$$

$$+ \nabla \cdot (\bar{\bar{D}} \cdot \nabla T) + Q \qquad (1)$$

Groundwater Flow

$$S_p \frac{\partial h}{\partial t} = \nabla\cdot(\bar{\bar{K}}\cdot(\nabla h + \delta_b \nabla z)) + \beta_i(h_s - h) + \gamma \frac{\partial T}{\partial t} \qquad (2)$$

$$\tilde{S}_p \frac{\partial h}{\partial t}s = \beta_i(h - h_s) + \tilde{\gamma}\frac{\partial T}{\partial t} \qquad (3)$$

Nuclide Transport

$$\frac{\partial}{\partial t}(\theta k_i C_i) + \bar{V}\cdot\nabla C_i = \nabla\cdot(D_{ij}\cdot\nabla C_i) + M_i$$

$$+ \sum_{i=1}^{n} \ell_{ij}\ \lambda_j k_j \theta C_j - \lambda_i k_i \theta C_i \qquad i = 1,2,.....N \qquad (4)$$

S_t	is a heat transfer coefficient	$\bar{V}$	is the velocity vector
C_{vf}	is a specific heat capacity of fluid	$\bar{\bar{D}}$	is the heat dispersion tensor
$\bar{\bar{K}}$	is the hydraulic conductivity tensor	D_{ij}	is the mass dispersion tensor
δ_b	is the density disparity factor	ℓ_{ij}	is the nuclide splitting fraction
Q	is the heat source term	λ_i, λ_j	are the decay constant
$S_p, \tilde{S}_p$	are the specific storage coefficient	θ	is the porosity
h	is the hydraulic head	M_i	is the mass source term
h_s	is the hydraulic head in secondary pores	n	is the number of radionuclide components
β_i	is a coupling coefficient between primary and secondary pores	T	is the fluid temperature
$\gamma, \tilde{\gamma}$	are thermal coupling coefficients	t	is the time
ρ	is the fluid density	C_i	is the nuclide concentration
k_i	is the retardation factor	z	is the vertical direction

The two numerical models currently being used to solve the above governing equations are: SEMTRA, for simultaneous energy and moisture transport in fractured-porous media, and CHAINT, for multicomponent radionuclide transport with chain decay. Sample results from recent hydrothermal calculations for a hypothetical repository are shown in Figures 2 and 3. These simulation results clearly show the impact of the heat transport on the natural groundwater flow patterns; in particular, the buoyancy effects created by the temperature field superimpose on the regional flow system to produce an upward flow during the peak thermal period.

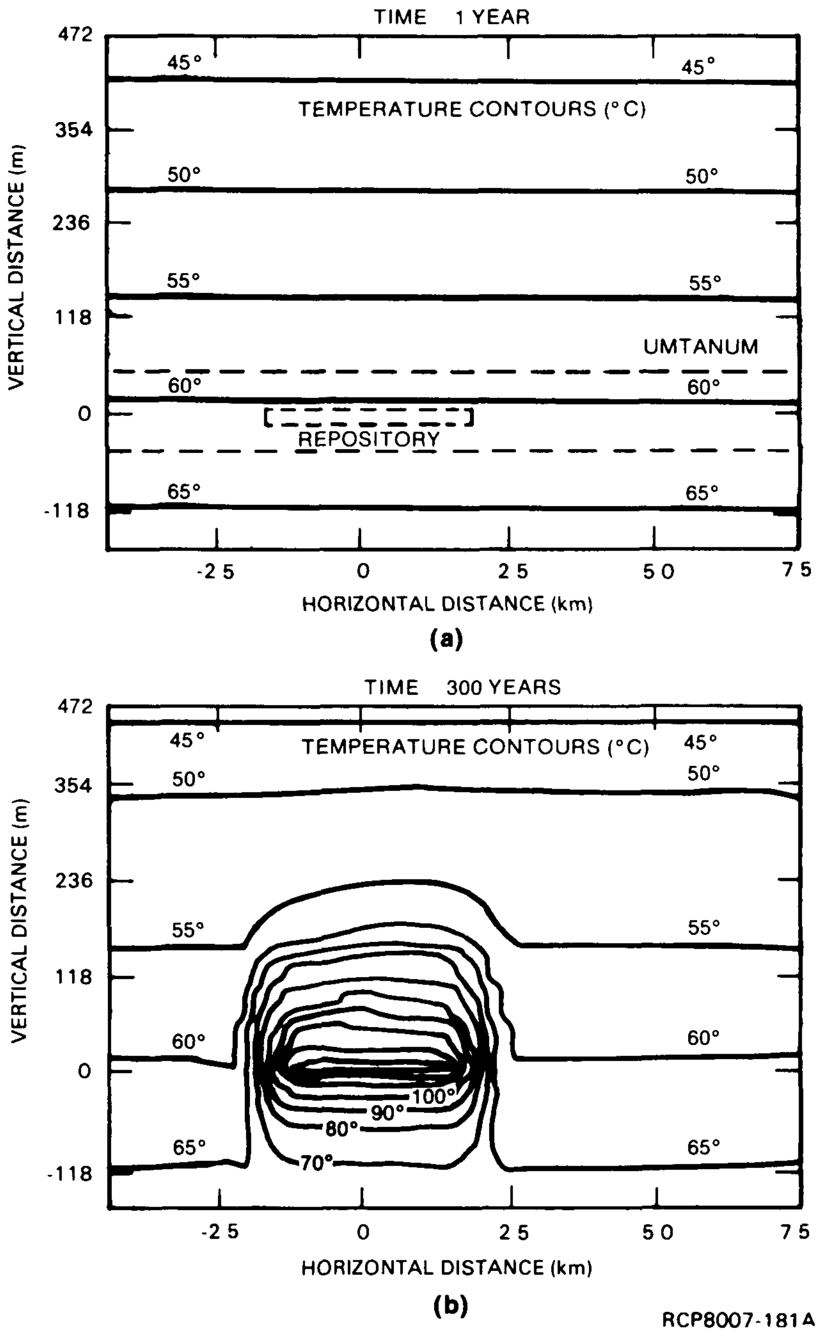

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FIGURE 2. Hydrothermal Calculations for a Hypothetical Repository (temperature contours).

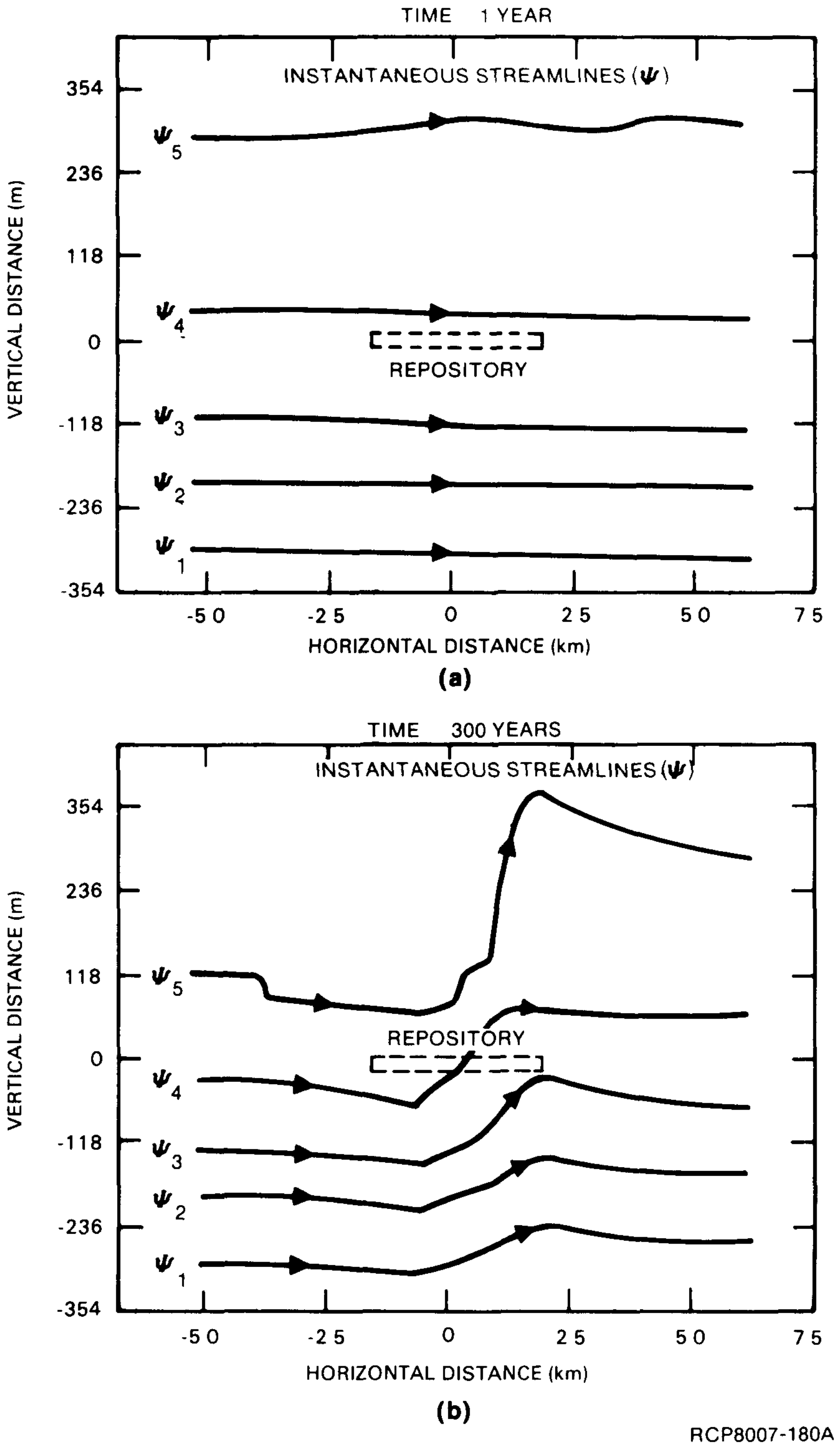

FIGURE 3. Hydrothermal Calculations for a Hypothetical Repository (streamline plots).

PARAMETRIC AND SENSITIVITY ANALYSIS

The numerical models developed for near-field analysis have been applied in a comprehensive parametric and sensitivity analysis. Resource Management Associates, under subcontract to Rockwell Hanford Operations, recently conducted a computer modeling study designed to examine the waste isolation characteristics of the Columbia River basalts. Applications of the SEMTRA and CHAINT models provided estimates of the spatial and temporal changes in the thermal field, groundwater flow patterns, and contaminant plumes as a function of hydrologic and transport parameters. A decision-tree strategy was used in the analysis to provide a logical and systematic approach which would lead to conservative estimates of waste migration. The primary decision tree consisted of four major stages; rock mass thermal properties, hydrologic properties, radionuclide properties, and container longevity.

Two-dimensional computer simulations for a vertical cross section were made using geologic and hydrologic data for the Columbia River basalts.(4,5) A waste inventory equivalent to one-half the projection for the U.S commercial nuclear power industry by the year 2000(6) was assumed. Simulations for various radionuclides; e.g., the carbon, technetium, iodine, and neptunium series, actinium series, and uranium series, were performed for time periods up to 250,000 years after closure. A set of conservative assumptions was made in specifying the simulations, such as:

- Groundwater completely fills the repository immediately after closure (instantaneous resaturation phase).
- The loss of integrity of the repository barriers is assumed to initiate immediately after closure.
- The waste inventory is released at an exponential rate to the groundwater over a 10,000-year or smaller period.
- The principal flow direction is predominantly vertical across the Grande Ronde Formation.
- The permeability ratio is 100:1 vertical to horizontal in the basalt flows.

Sample results from this parametric and sensitivity study are presented in Figures 4 and 5; Figure 4 presents the pathline and travel time calculations for the base case; whereas Figure 5 shows the iodine plume for various time planes.

The major findings and results from the parametric and sensitivity analysis are summarized below:

- With regard to heat transport, the simulations indicate that conduction through the rock mass dominates over dispersion and convection in the fluid phase.

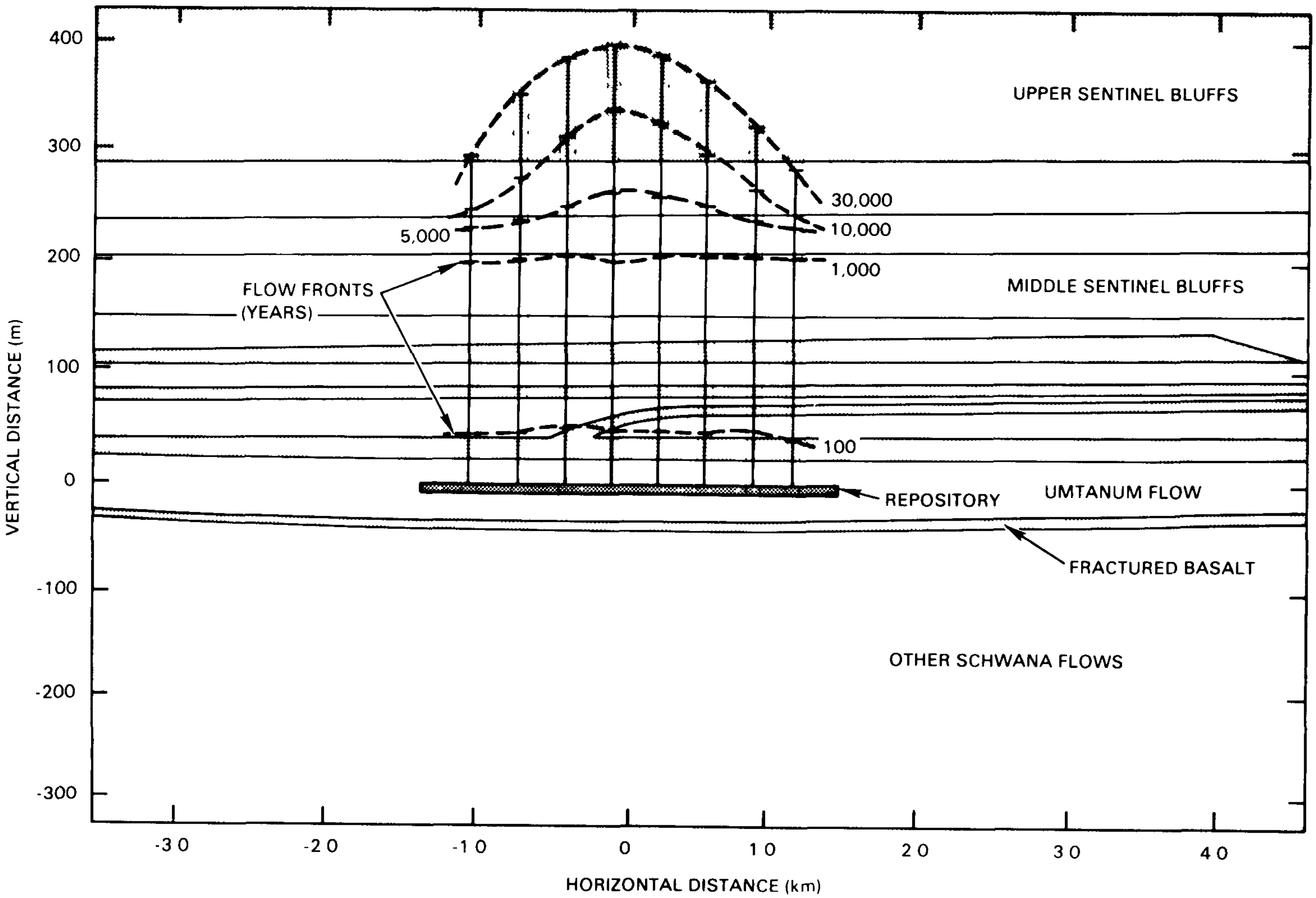

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FIGURE 4. Pathline and Travel Time Calculations for Baseline Conditions.

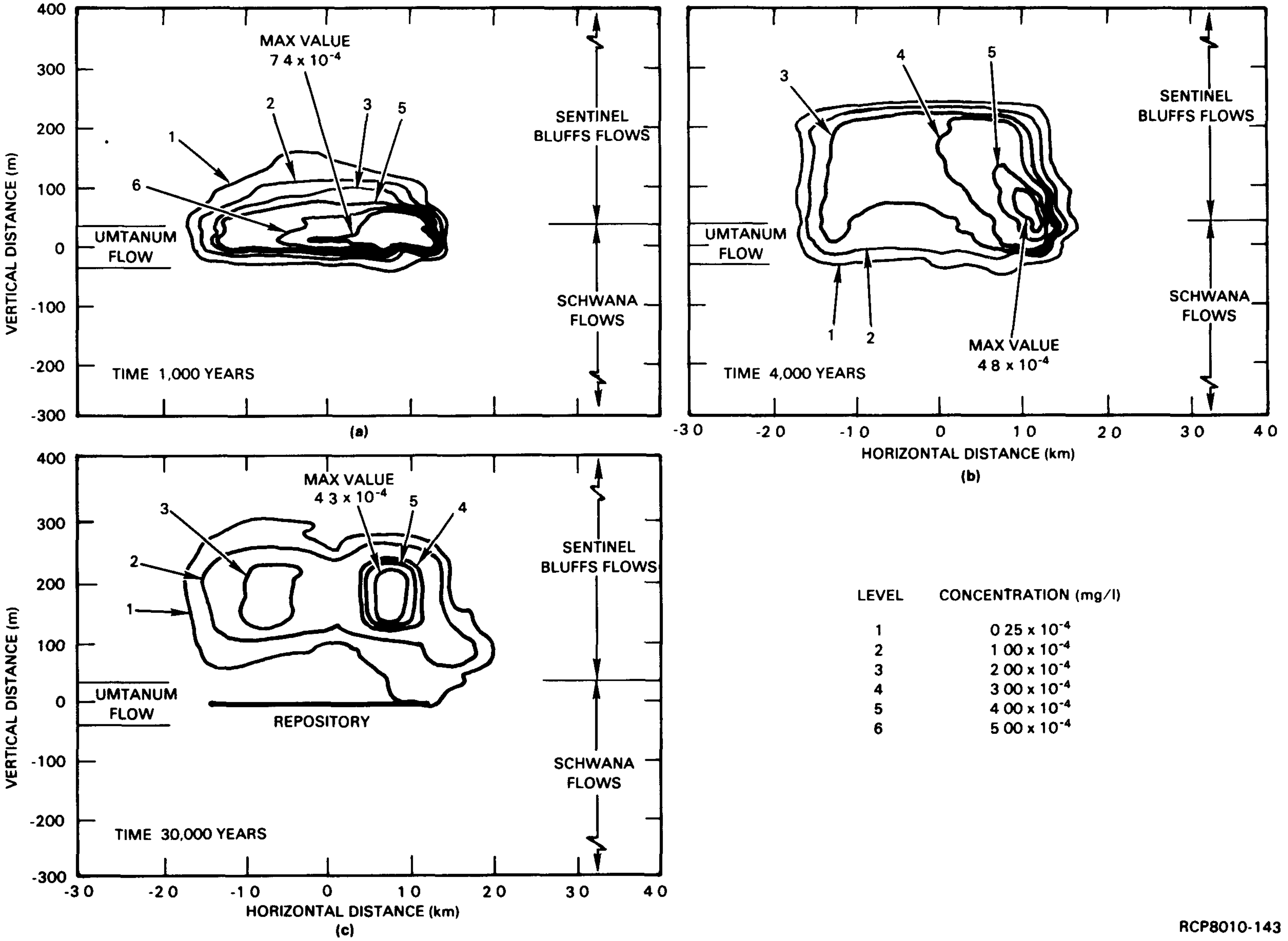

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FIGURE 5. Iodine-129 Contours for Baseline Conditions.

- Concerning groundwater flow, buoyancy velocities generated by the high temperature in the vicinity of the repository are much greater (two to four orders of magnitude) than those produced by the hydraulic gradients.

- Simulation results for nuclide transport indicate that the rate and extent of waste migration (during the peak thermal period) would be greatly affected by buoyancy-induced convection.

- Simulations for a 70,000-year period after closure indicate that all radionuclides considered would be contained in a small region around the repository and within the bounds of the Grande Ronde Formation.

Overall, the fundamental conclusion from this study is that a basaltic rock environment can provide a high degree of waste isolation over long-term periods, under the condition that no initiating events occur that create a direct pathway from the repository to the upper aquifers in the Saddle Mountains and Wanapum Formations. In addition, only the migration of iodine is significant by virtue of its relatively large initial inventory, long half-life, and low sorption properties in basalt. One of the recommendations made in the study is that future parametric and sensitivity studies should address release conditions associated with disruptive events and should account for potential undetected features such as faults, anomalous high-permeability zones, and other situations which relate to the "descriptive uncertainty" of the conceptual model. Future work on these topics is planned for fiscal year 1981.

HYDROLOGIC ANALYSIS OF RELEASE SCENARIOS

Numerous generic scenarios have been developed and described in the literature(7,8,9) related to potential initiating events which could cause releases of radionuclides from a deep geologic repository. The selection and analysis of specific hydrologic release scenarios germane to the Columbia River basalts are part of other ongoing Basalt Waste Isolation Project studies. For this study, the release scenarios consisted of a fault zone, microearthquake swarm, and magma movement in the deep basalts.

In the first scenario, it is assumed that a vertically extensive fault zone develops adjacent to the repository, creating a hydraulic pathway which connects the repository with the aquifers in the upper formations. The fault zone, having higher permeability than the adjacent media, channels the groundwater in an upward direction. The microearthquake scenario is based on the concept that a series of low-magnitude earthquakes occur after closure that are clustered in time and space. It is further assumed that the swarm zone, located in the host rock, has higher permeability and porosity associated with induced fracturing. This increases the groundwater flow through the repository and enhances the waste movement. For the third scenario, it is assumed that magma movement in the deep basalts creates a significant perturbation of the natural geothermal gradient; this condition results in the convective circulation of groundwater in the vicinity of the repository, thus enhancing the upward transport of the radionuclides.

Numerical models originally developed for thermomechanical/hydrologic analysis(10) were used to evaluate the release scenarios. This particular study was performed by Dames & Moore under subcontract to Rockwell Hanford Operations. In this limited effort, the study focused on evaluating the significance of postulated release events for a hypothetical repository in the Umtanum flow. In specifying the baseline conditions, the geologic and hydrologic data base assembled for the parametric and sensitivity analysis was also used in this study, and similar conservative assumptions were also made.

The computer simulations were performed using the nonisothermal flow and transport model GWTHERM,(11) which is interfaced with the stress analysis model DAMSWEL. The theoretical framework of GWTHERM is based on the assumption that the rock mass is characterized by a single porosity system and that it behaves as an "equivalent porous medium." Simulations of the near-field processes were performed for a 50,000-year time period. Sample results from this initial scenario analysis are presented in Figures 6 and 7. Illustrated in Figure 6 are the temperature patterns around the repository at 1,000 and 50,000 years after closure; the technetium plumes for the base case assuming very low sorption and the fault scenario, but using nominal values for the sorption coefficient are shown in Figure 7. In both cases, the extent of the waste migration is relatively small.

CONCLUDING REMARKS

In fiscal year 1980, the Basalt Waste Isolation Project hydrologic modeling studies made significant progress in assembling and integrating near-field models for repository analysis. Moreover, applications of the numerical models with available field data have provided the first quantitative indication of the waste isolation capabilities of the Columbia River basalts. To develop confidence in these theoretical analyses, additional parametric and sensitivity studies will be performed with more detailed geologic and hydrologic data to evaluate the significance of descriptive and model uncertainty.

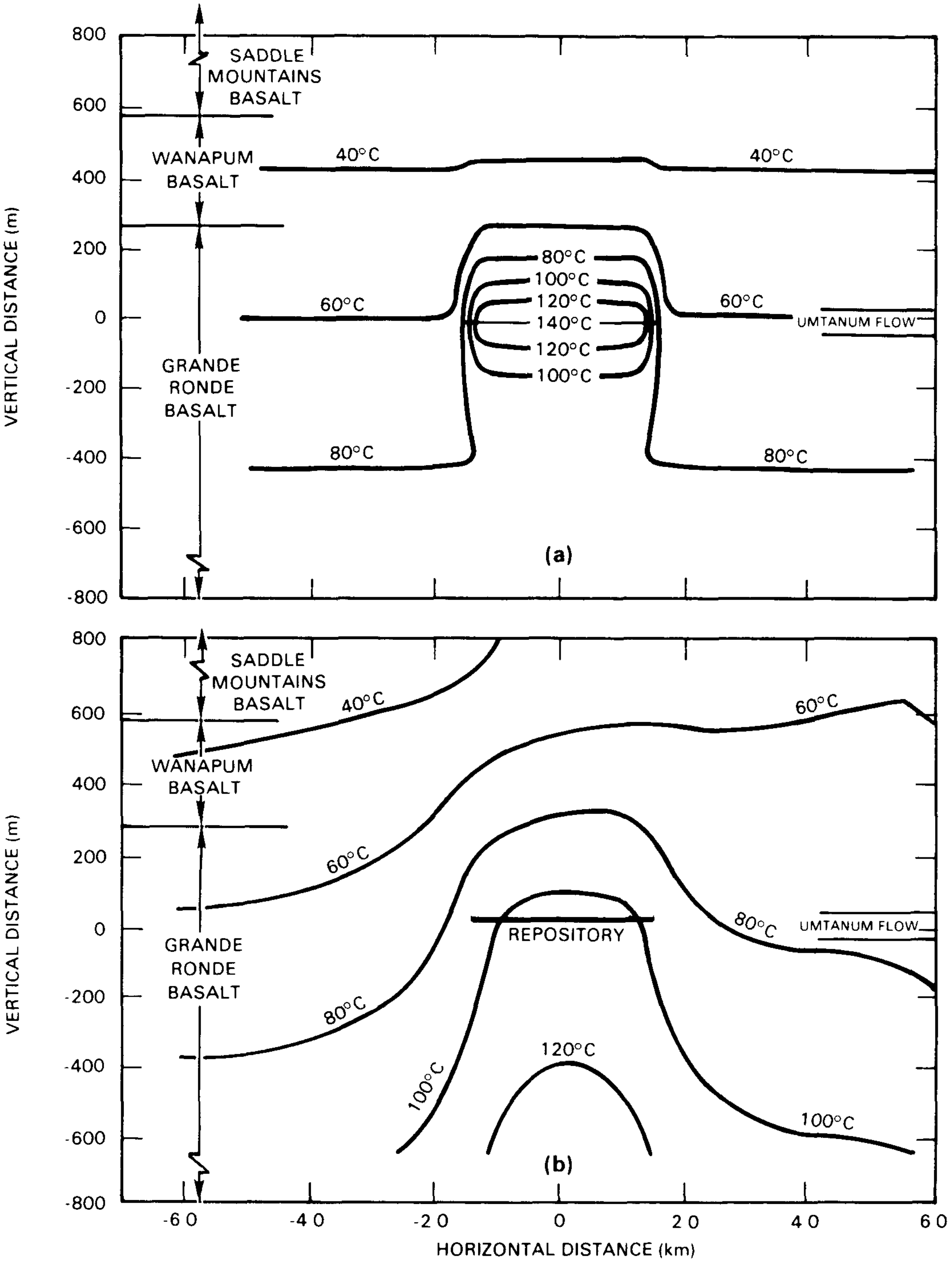

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FIGURE 6. Simulations of Temperature Patterns at (a) 1,000 Years and (b) 50,000 Years in the Near Field.

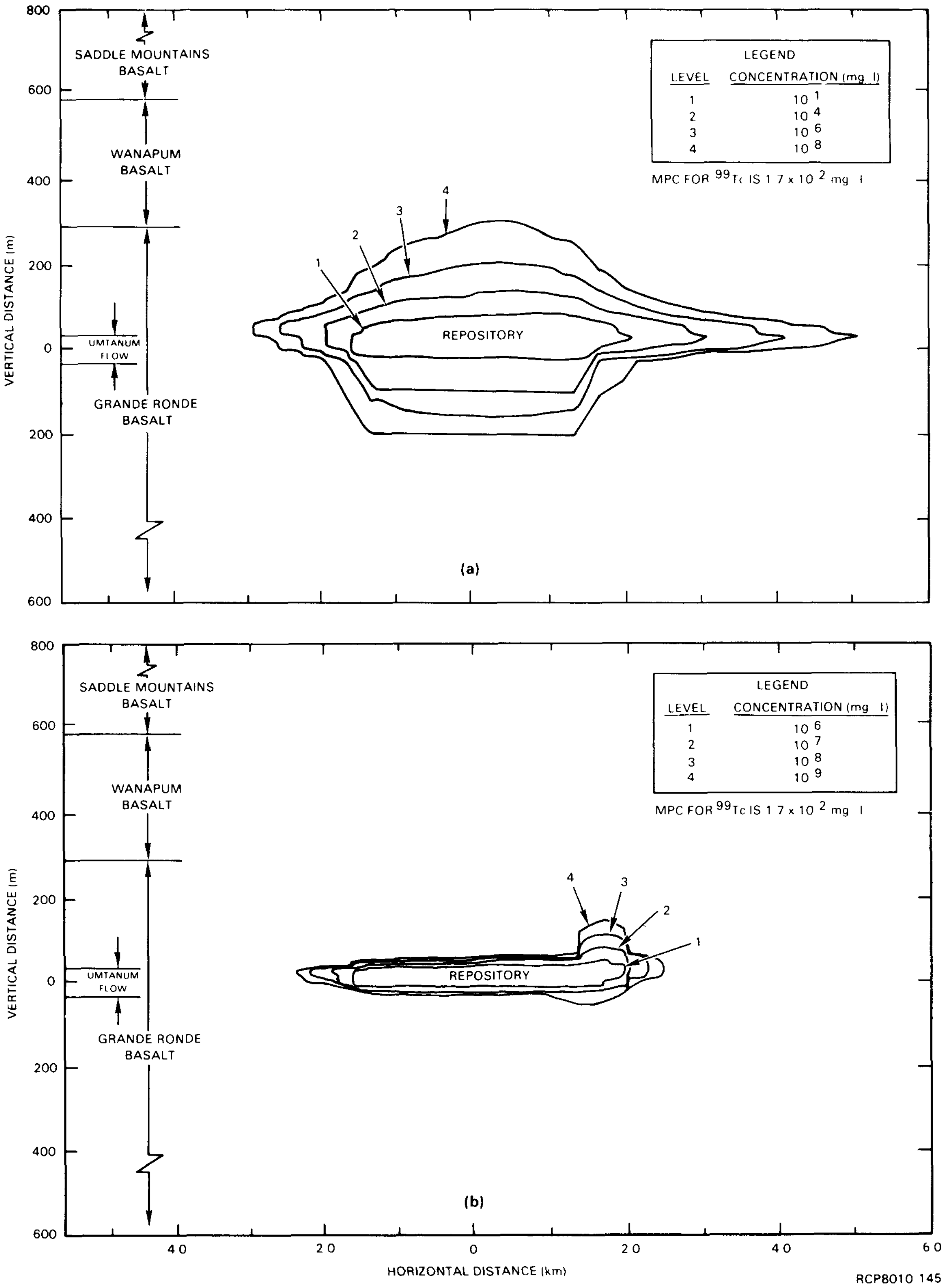

FIGURE 7. Near-Field Simulation Results for Technetium Plumes at (a) 50,000 Years, Base Case Simulation with Low Sorption and (b) 50,000 Years, Fault Zone Scenario with Nominal Sorption.

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FAR-FIELD MODELING: SIMULATION OF THE NATURAL GROUNDWATER SYSTEM IN THE PASCO BASIN

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An adequate assessment of the hydrologic regime for a subsurface radioactive waste repository requires knowledge of groundwater flow dynamics along all potential flowpaths leading to the biosphere. Basically, the subsurface hydrologic data gathering and analyses 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)
- 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.

As mentioned in the discussion of near-field flow modeling,(1) several coupled physical phenomena must be simulated in the near-repository zone. For the purposes of this discussion, the far field is defined as the zone where thermal and rock stress/strain phenomena can be neglected and the groundwater flow and transport can be simulated in a decoupled fashion. Illustrated in Figure 1 are the steps in the far-field modeling process.

BACKGROUND

Currently, two groundwater flow models are being used in far-field modeling; the RHAFE three-dimensional flow model and a version of the near-field SEMTRA model from which the thermal and stress/strain calculations have been removed. The RHAFE model has been used for the three-dimensional analysis, whereas SEMTRA has been applied to the two-dimensional cross-sectional analysis. A three-dimensional version of SEMTRA is being completed to take advantage of some the superior features and code structures of SEMTRA, as well as to minimize the machine dependence of the far-field models (the RHAFE is highly machine-dependent). The important characteristics of these models were presented earlier(2) and

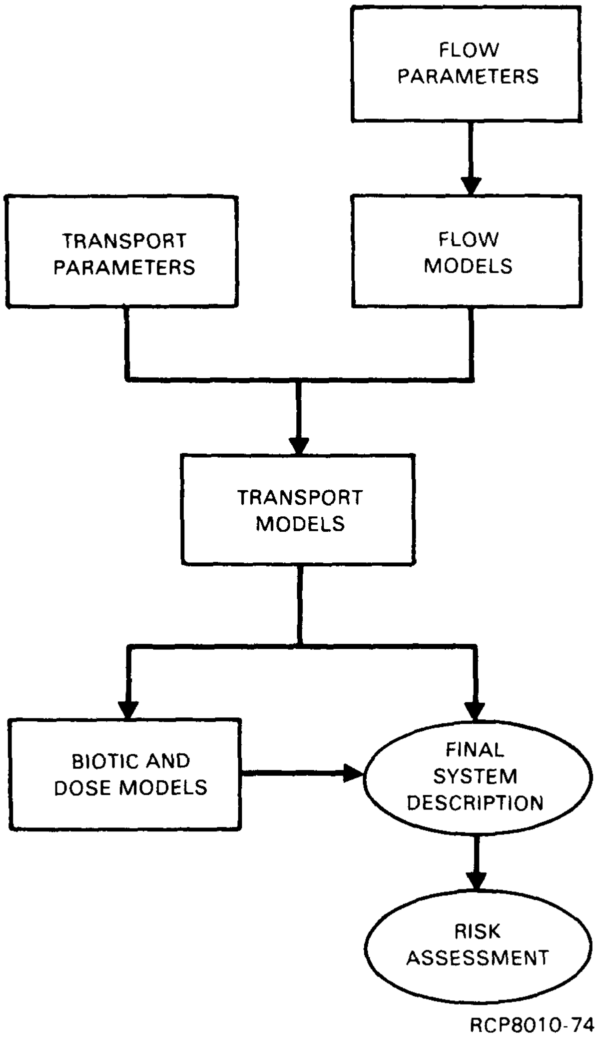

FIGURE 1. Far-Field Modeling Process.

in the preceding section by Baca (this report). In addition, a set of auxiliary codes is being used which calculate the groundwater velocities from head distributions provided by the RHAFE and SEMTRA models.

Modeling during fiscal year 1980 has focused upon:

- Using available data and the evolving conceptual model to simulate the natural groundwater flow system within the Pasco Basin
- Providing feedback to the development of the conceptual model.

In order to accurately predict the actual groundwater movement within the Pasco Basin, it is necessary for the numerical model input to incorporate the important elements of the conceptual model, which in turn are developed from field and laboratory measurements.

The numerical model requires as independent input a value of the head or flow at each of the model boundary nodes and a value of the hydraulic conductivity at every model node. Calculation of groundwater velocities requires definition of the effective porosity at each model node. This input is usually obtained in one or more of the following ways:

- Interpolation from field maps
- Adaptation of other related field data
- Application of professional judgment based upon the principles of geohydrology and the specific conditions of the site
- Output from a parameter-estimation routine.

EXAMPLE RESULTS

The Pasco Basin/Hanford Site basalt hydrology conceptual model has been presented(3) and updated by Spane (this report). Figure 2 is a map of the Pasco Basin with the boundaries of the Hanford Site and key topographic and hydrologic features marked. The outlines of the Pasco Basin serve as the boundaries of the three-dimensional model; note that the Saddle Mountains to the north, the Rattlesnake Hills to the southwest, and the Horse Heaven Hills to the south form natural drainage boundaries. The western boundary of the Pasco Basin intersects several east-west-trending ridges, so that topographically it is a series of highs and lows. The eastern boundary does not closely follow any marked topographic feature, but does roughly correspond to a dip in the deep basalt structure. A plan view of the present finite element network for the Pasco Basin three-dimensional flow model is shown in Figure 3. This network represents an improvement over the previous network,(2) in that it is smoother and is better oriented with the expected directions of groundwater flow. At the same time, more detail is provided in the central portion of the Hanford Site.

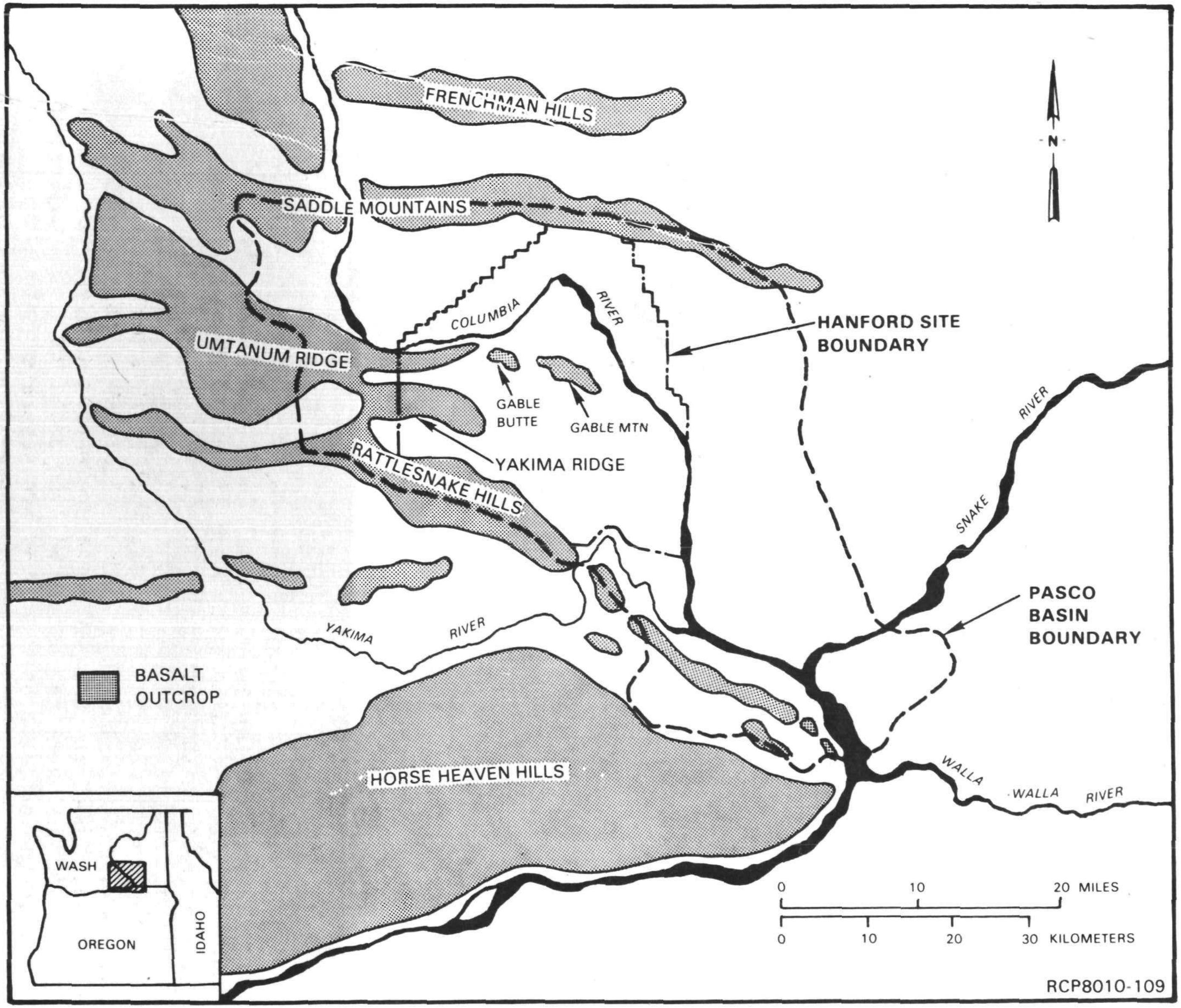

FIGURE 2. Pasco Basin and Hanford Site.

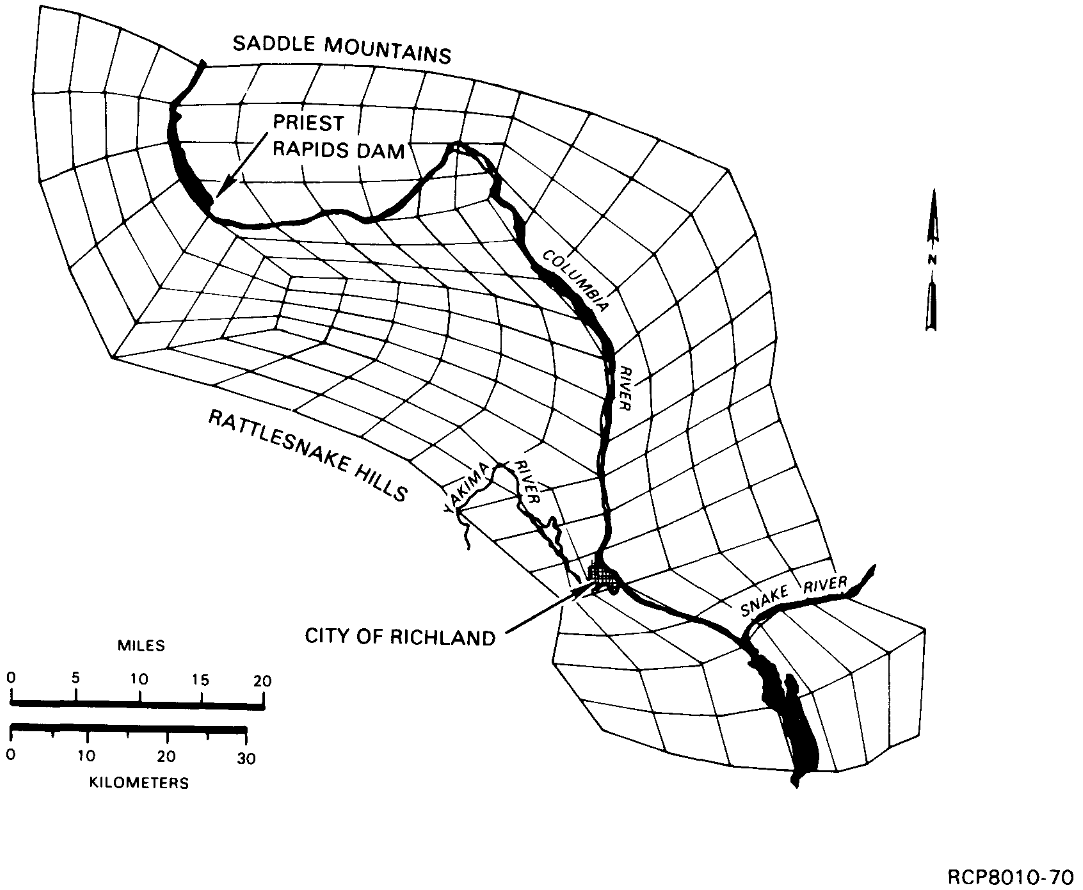

FIGURE 3. Plan View of Three-Dimensional Finite Element Network for Pasco Basin.

Illustrated in Figure 4 is an example of the vertical layering at Well DC-15 of the three-dimensional RHAFE model analysis. Note that the layers of the three-dimensional model combine several physical layers (see Figure 4 in the section by Spane, this report). This was done to limit the computer resource requirements while examining the relative significance of the various model inputs. This particular layering breakdown reflects the major hydrogeologic groupings as determined by groundwater head and chemistry measurements. However, it is anticipated that additional vertical detail will be added until the major interbeds, interflows, and basalt flows are separated into distinct model layers. This more complex description will be compared to those of the earlier, less complex descriptions to determine the optimum level of detail. The effort to date has focused upon evaluating the sensitivity of the calculated head distributions to the range of hydraulic conductivities and boundary conditions. Considerable judgment is necessary to

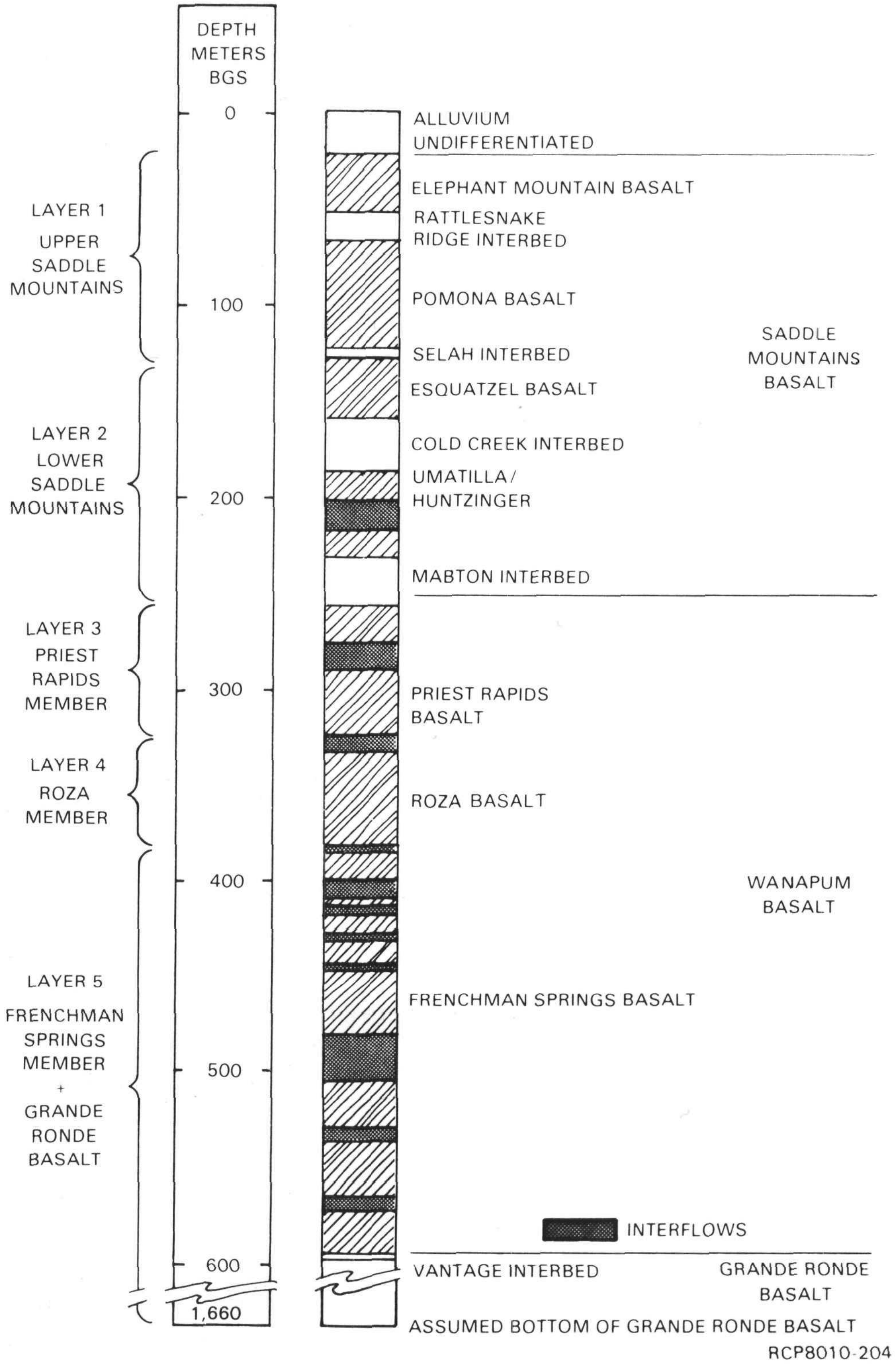

FIGURE 4. Vertical Layering for Pasco Basin Three-Dimensional Model at Well DC-15.

supplement the field observations and the models have been used to examine the significance and consistency of such judgments. In this way, the modeling provides a positive feedback to the continuing conceptual model development.

A key model input parameter is the hydraulic conductivity, K. In steady-state model analysis, only the relative values of hydraulic conductivities are important. In order to estimate the relative importance of the vertical versus horizontal conductivities, composite vertical hydraulic conductivities for the major basalt formations where initially calculated by:

$$K_z = \frac{D}{\sum_{i=1}^{n} d_i K_i} \qquad (1)$$

where K_z is the composite conductivity, K_i is the conductivity of each layer, d_i is the thickness of each layer, n is the total number of layers, and D is the total distance across all layers.

The composite horizontal conductivities were calculated by:

$$K_x = \sum_{i=1}^{n} \frac{K_i d_i}{D} \qquad (2)$$

The relative fractions of interbed, interflow, and competent basalt materials in each formation were used to estimate the d_i values in Equations 1 and 2. Typical conductivities were assigned to each of the three principal material types. The initial values used to calculate conductivity ratios by Equations 1 and 2 are shown in Table 1.

Using the values of Table 1 and Equations 1 and 2, the K_z/K_x ratio was calculated as 4×10^{-7} for the Saddle Mountains and Wanapum Basalts and 1.7×10^{-6} for the Grande Ronde Basalt.

TABLE 1. Baseline Material Hydraulic Conductivities Used in Calculating Basalt Composite Conductivities.

Basalt	Material	Percent of Total Basalt Thickness	K (feet per day)
Saddle Mountains	Basalt	60	10^{-6}
	Interflow	20	10
	Interbed	20	10
Wanapum	Basalt	60	10^{-6}
	Interflow	35	10
	Interbed	5	10
Grande Ronde	Basalt	60	10^{-6}
	Interflow	39	10^{-2}
	Interbed	1	10

These conductivity ratios were used as the starting point for a series of numerical model runs designed to evaluate the range of conductivities in light of field observed head measurements. Examples of model-calculated groundwater head distributions for different ratios of vertical-to-horizontal hydraulic conductivity are shown in Figures 5 and 6. These results are the product of steady-state model runs, so that time-dependent variables are not considered.

Ratios of vertical-to-horizontal conductivities were varied over several orders of magnitude and the results compared to the field-observed patterns. The conductivity ratios used in the model run which produced the results of Figure 5 were 2×10^{-3} for the Saddle Mountains Basalt, 8×10^{-3} for the Wanapum Basalt, and 3×10^{-2} for the Grande Ronde Basalt. The corresponding ratios used to produce Figure 6 were 2×10^{-5}, 8×10^{-5}, and 3×10^{-4}.

A comparison of Figures 5 and 6 shows a notable difference in the head patterns. Whereas the head contours of Figure 5 indicate discharge to the Columbia River along its entire length, the contours of Figure 6 indicates that significant discharge to the Columbia River primarily occurs immediately downstream of Priest Rapids Dam and also south of the city of Richland. Although the heads of both Figures 5 and 6 are substantially higher than seen in the field (see Figure 2 in the section by Spane, this report), the relative pattern of Figure 6 more closely corresponds to the pattern observed in the field than that of Figure 5. This suggests that the composite hydraulic conductivity ratios are closer to 10^{-4} or 10^{-5} than 10^{-2} and that the vertical pathway from a potential candidate site is a significant portion of the total path in terms of overall travel time from a repository to the biosphere. Modeling analysis is continuing, and a set of reasonable properties and conditions is being sought which provide a quantitative match of the field-measured heads as well as a relative match. It is believed that the higher-than-measured heads of Figures 5 and 6 may be from the lack of a groundwater barrier in the model to correspond to the one in the field trending north-south at the mouth of Cold Creek Valley (see Figure 1). Heads measured at the same stratigraphic horizon as Figures 5 and 6 show values of 800 to 900 feet to the west of this line and 400+ feet a short distance to the east. The boundary conditions may also need some additional adjustment, but are believed to be in the proper range as based upon the limited head measurements near the boundaries.

SUMMARY OF RESULTS

Progress in the far-field modeling during fiscal year 1980 can be summarized by the following:

- The three-dimensional network was improved and extended to four layers and more recently to six layers to provide increasing detail.
- A range of model boundary conditions was examined and a set of boundary conditions selected which is consistent with available data and hydrologic judgment.

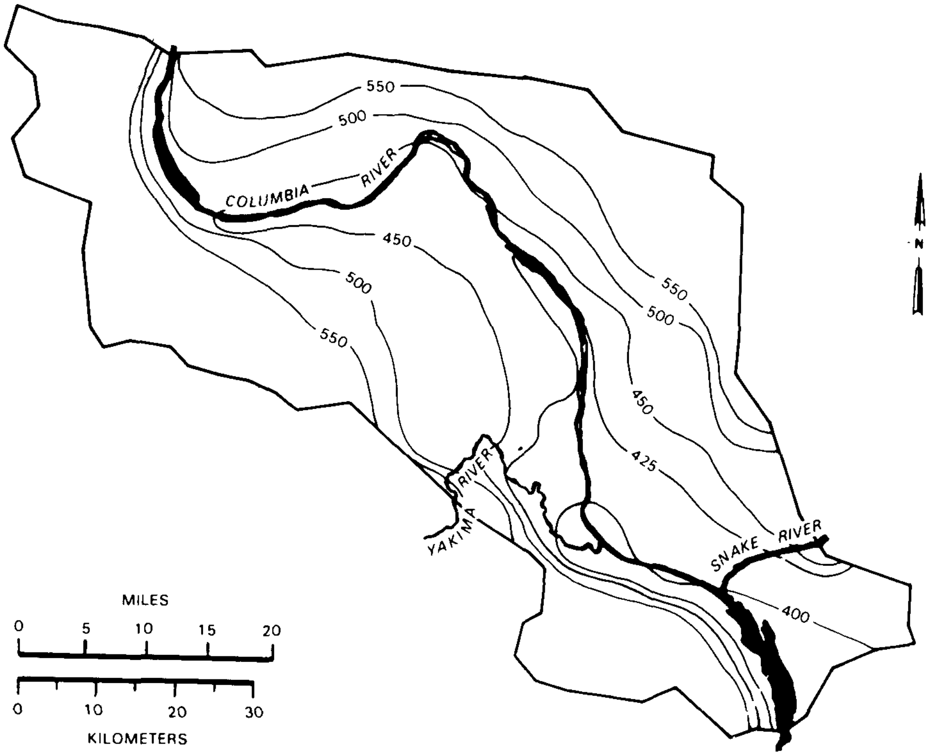

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FIGURE 5. Model-Calculated Heads, Top of Wanapum Basalt K_z/K_x from 10^{-2} to 10^{-3}.

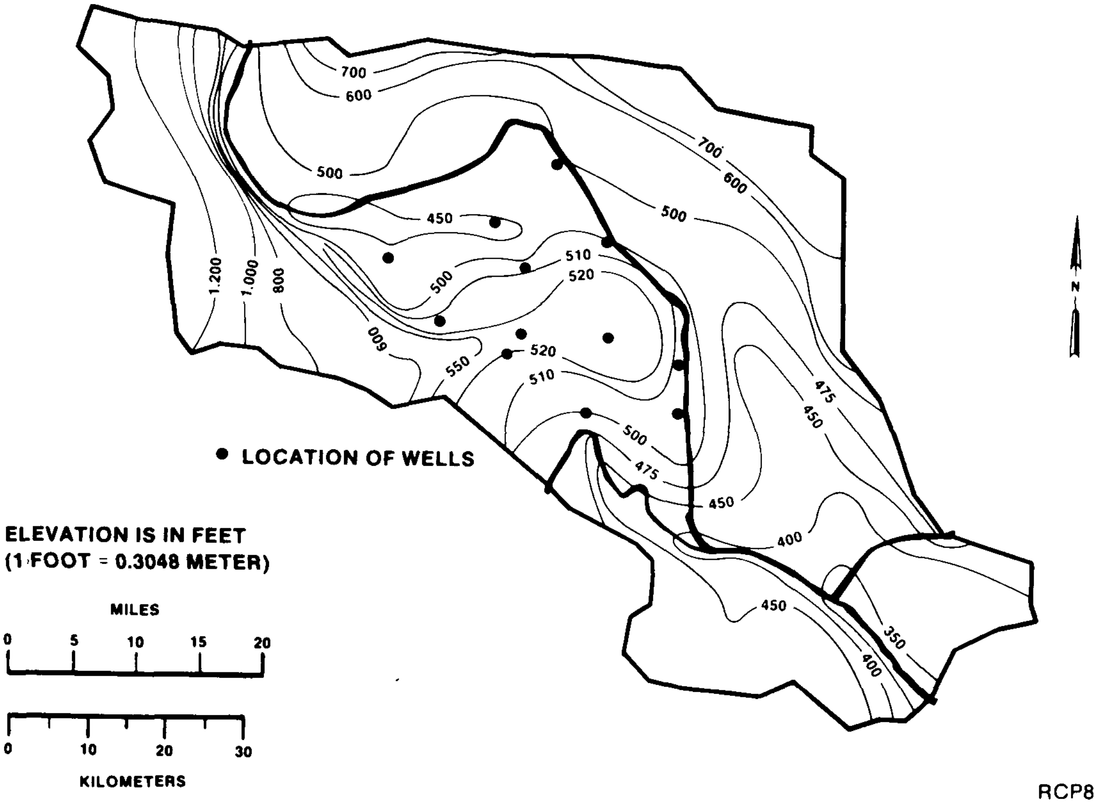

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FIGURE 6. Model-Calculated Heads, Top of Wanapum Basalt K_z/K_x from 10^{-4} to 10^{-5}.

- A range of vertical to horizontal composite hydraulic conductivities for the three major basalt formations was examined. The ratios which gave the best relative match of observed heads were in the range of 10^{-4} to 10^{-5}.
- Some structural features of the Pasco Basin might have a significant impact on the basalt groundwater flow.

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CHAPTER IV

WASTE PACKAGE

SUMMARY OF FISCAL YEAR 1980 WASTE PACKAGE STUDIES

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The waste package program of the Basalt Waste Isolation Project has been developed as an integral part of the National Waste Terminal Storage Program to provide a practical approach to the selection of materials and designs for site-specific, multiple-barrier assemblages to be used in a commercial nuclear waste repository located in basalt. While the concept of a multiple-barrier waste package system designed to provide redundancy in waste isolation has received firm support, the design and functions of such a system have been described only in general terms.

During fiscal year 1980, the Basalt Waste Isolation Project began the development of an acceptable barrier system by conceptualizing a site-specific waste package for spent fuel.(1) The design approach that employs redundant chemical and physical subsystems, each with mutually supportive components, is shown on Figure 1. The design appears to be compatible with U.S. Nuclear Regulatory Commission draft requirements. A concise statement of the function of each barrier in the conceptual package has been developed to support the proposed design. These functional requirements are described in terms of repository history, which can be divided into two fundamental periods based upon prevailing repository conditions. The early repository history (e.g., 1,000 years) is defined as the thermal period. It is that interval of time during which the ambient geothermal gradient is perturbed by the heat produced by radionuclide decay and includes the portion of time before repository closure when the repository is under institutional control. Late repository history is the period of geologic control. It is defined as the interval of time after the thermal period when geologic conditions have returned to a static, natural condition. The differing environmental conditions existing during the two time periods give rise to separate problems, different engineered barrier functions, and different materials requirements.

The conceptual waste package design and associated functional descriptions have formed the basis for material selection and testing, compatibility requirements, and advanced engineering design. During fiscal year 1980, a detailed report(2) was completed to support the selection of materials capable of meeting the waste package functional requirements outlined in Reference 1. The logic needed in selecting materials for further testing is detailed in that report.

An assessment has been made to identify the potentially most hazardous radionuclides expected within an operating repository located in basalt.(3) This assessment was based on the total inventories of the different radionuclides as a function of time and their relative toxicities. Account was also taken of the possibility of transporting each

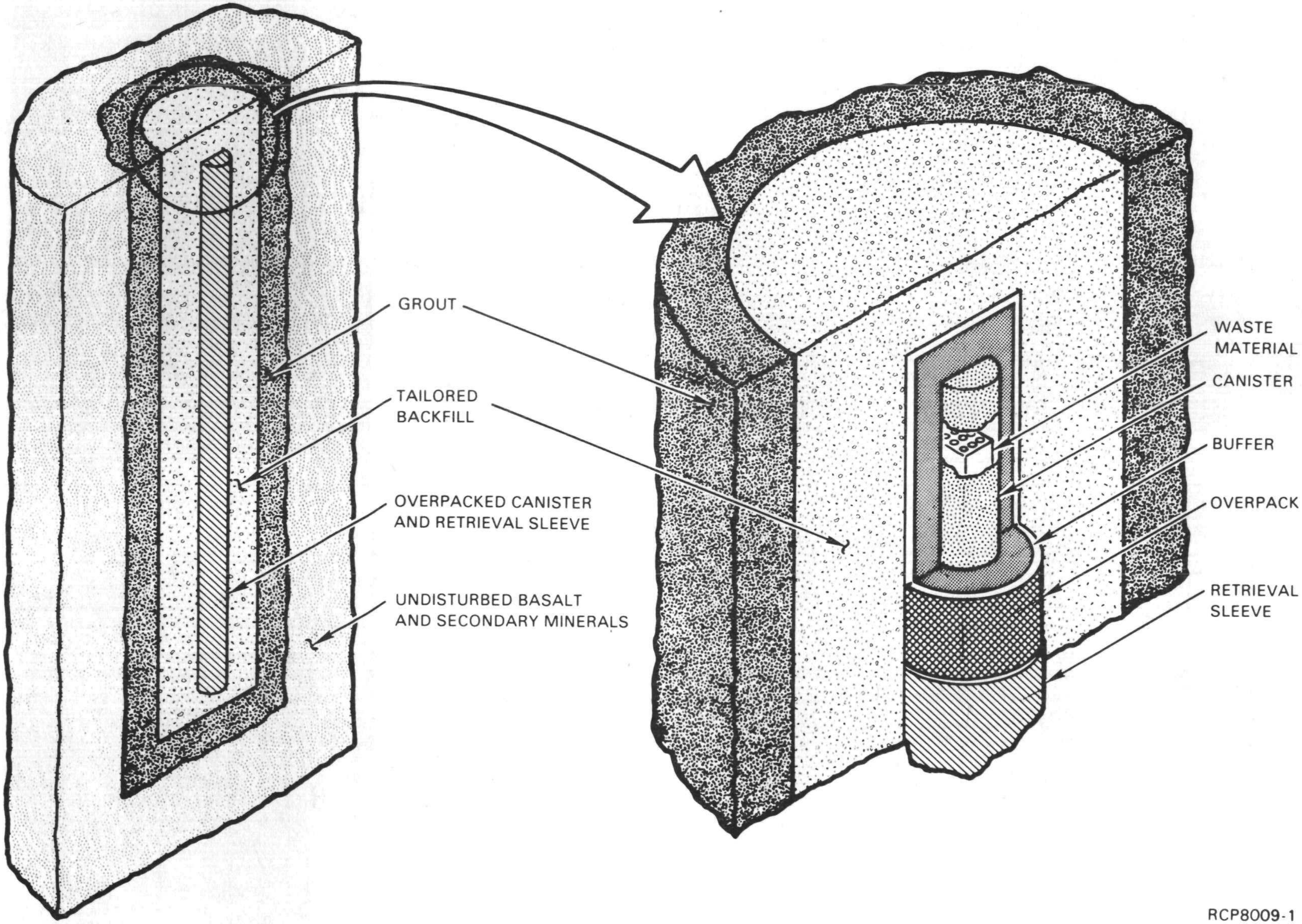

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FIGURE 1. Engineered Barriers Emplacement Concept.

radionuclide to the accessible environment. This was done using a far-field transport model along with available sorption parameters measured between basalt and Hanford groundwater. The 10 most important (based on hazard and transport potential) nuclides in descending order were found to be ^{99}Tc, ^{129}I, ^{237}Np, ^{226}Ra, ^{107}Pd, ^{230}Th, ^{210}Pb, ^{126}Sn, ^{79}Se, and ^{242}Pu.

Transport of ^{226}Ra, ^{210}Pb, and ^{230}Th is controlled by their long-lived parents, ^{234}U and ^{238}U. Under the low Eh conditions likely to occur in a repository located in basalt, it was calculated that the uranium isotopes are extremely insoluble--a few parts per billion of uranium in solution. If this estimate proves to be correct, all members of the uranium decay series will be below the recommended concentration guide(4) in solutions within the repository.

Sorption experiments completed during fiscal year 1980 determined the distribution coefficients (K_d's) of key radionuclides between basalt, secondary minerals, interbed materials, and groundwater to assess their potential as barriers to radionuclide transport. Experiments have been designed to determine the effects of ion concentration, temperature, pressure, oxygen content, and time on the sorption of radionuclides on basalt, secondary minerals, and interbed materials. These experiments have demonstrated: strong sorption of cesium, strontium, plutonium, and americium on basalt and secondary minerals; sorption dependence on temperature and solute concentration; and ineffective sorption of iodine (and, at elevated oxygen pressure, technetium) on geologic materials from potential repository horizons to date.

Hydrothermal geochemistry activities were used to investigate reactions occurring above about 150°C, while the sorption experiments described above were carried out below 150°C. Preliminary hydrothermal tests conducted in fiscal year 1980 demonstrated that waste solubility is dependent on the presence or absence of basalt. Experiments in leaching simulated spent fuel resulted in removal of 90% to 100% of the cesium, rubidium, and molybdenum present in the waste form. In contrast, experiments in leaching simulated spent fuel in the presence of basalt produced residual solutions containing less than 10% of the soluble cations mentioned above. Thus, basalt quite favorably affects spent fuel performance in the repository environment.

In fiscal year 1980, alternative waste-package design concepts for spent fuel and backup waste forms were developed for the specific geologic environment expected in basalt in order to assure an integrated repository system capable of retaining hazardous waste materials in a satisfactory manner. Experimental work will be continued in fiscal year 1981 and will consist of hydrothermal testing of candidate barrier materials selected in fiscal year 1980 to quantify their performance under conditions expected in a repository constructed in basalt. Waste/basalt/water interaction studies will determine the thermal stability and hydrothermal solubility of spent fuel and alternate waste forms as inputs to the identification of waste-package performance requirements. The performance of candidate single and multicomponent backfill materials will be determined and the corrosion resistance of candidate canister and overpack materials will be measured to permit the selection of reference materials for further in-depth testing. Continued near-field modeling of waste migration will also help establish the long-term performance of waste package components.

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A CONCEPTUAL WASTE PACKAGE AND ITS TIME-DEPENDENT FUNCTIONS FOR A NUCLEAR WASTE REPOSITORY IN BASALT

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Until a year ago, the United States' philosophy for geologic storage of high-level nuclear wastes placed great emphasis on the host rock acting as the primary barrier for the containment of radionuclides. In recognition of the complexity and uncertainty in predicting the long-term reliability of geologic formations as barriers to radionuclide migration, the United States has adopted a multiple barriers approach to high-level nuclear waste storage and disposal. Described here are the functions of the components of a multiple barrier waste package for a repository in basalt.

For purposes of illustration, a five-component barrier system is depicted on Figure 1 in the preceding section by Smith. These components encompass the several types of barriers that may be required for an effective barrier system. The operation of this engineered barrier system can best be described in terms of repository history, which can be divided into two periods with distinctly different repository environments. The early period or thermal period, lasting roughly 1,000 years, is characterized by high temperatures and oxidizing conditions. The later period is characterized by low temperature and an anoxic environment controlled by the host rock. The different environmental conditions existing during these two periods give rise to different barrier degradation and radionuclide containment problems. The engineered barrier functions anticipated during the two periods of repository history are listed in Table 1. The functions of the basalt host rock are included to show the relationship between the engineered barriers and the natural barriers.

As noted in Table 1, the canister protects the waste form during handling and transportation. The waste form limits dissolution and dispersion of radionuclides for the life of the repository. During the thermal period, the canister, overpack, and backfill act to retard or prevent groundwater from contacting the waste form. In the event of a premature failure of the overpack, the buffer or "getter" modifies the groundwater chemistry to decrease corrosion of the canister. Should the canister also become breached, the tailored backfill along with the basalt retard radionuclide migration. The overpack materials will be primarily selected to resist corrosion in the environment prevailing during the early thermal period, while the canister material should be selected to resist corrosion during the conditions existing after the thermal period.

TABLE 1. Barrier Function Versus Time.

Item	Barrier	Operating Period	Function
1	Geology (Basalt)	(1) Thermal Period[a]	Supplementary chemical barrier to radionuclide migration
		(2) Geologic Control[b]	Primary chemical barrier to radionuclide migration
		(3) Repository Life[c]	Physical isolation of waste material from man
2	Backfill	(1) Thermal Period	Primary chemical barrier to radionuclide migration Inhibit groundwater intrusion
		(2) Geologic Control	Secondary chemical barrier
3	Overpack	Thermal Period	Primary physical barrier to groundwater intrusion Aids in retrievability
4	Buffer	Thermal Period	Chemically inhibit canister corrosion in event of failed overpack
5	Canister	(1) Pre-Emplacement[d]	Provide physical support and protection for waste form
		(2) Thermal Period	Supplement to overpack preventing groundwater intrusion Permit retrievability
		(3) Geologic Control	Primary physical barrier to groundwater intrusion
6	Waste Form	Pre-Emplacement and Repository Life	Retard release of radionuclides in the event of containment failure

[a] Thermal Period = Time before 1,000 years of operation
[b] Geologic Control = Time after 1,000 years of operation
[c] Repository Life = Thermal period + geologic control
[d] Pre-Emplacement = Time from canister filling to emplacement in the repository

The tailored backfill will consist of materials which will sorb or chemically react with radionuclides and act as a diffusion barrier both to radionuclides and groundwater. The buffer or "getter" materials will be selected to sorb water, raise groundwater pH, and depress oxygen fugacity.

The engineered barrier system must be designed to meet certain criteria to provide adequate health, safety, and environmental protection. Criteria controlling the design of multiple-barrier systems are contained in regulations issued in final or draft form by the U.S. Environmental Protection Agency,(1) the U.S. Nuclear Regulatory Commission,(2-4) and the U.S. Department of Energy.(5-9)

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CANISTER AND OVERPACK MATERIAL STUDIES UNDER CONTROLLED Eh AND pH IN A REPOSITORY LOCATED IN BASALT

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The development of canister and overpack materials for the radioactive waste engineered barrier system is being conducted to provide timely input to the Basalt Waste Isolation Project and the Nuclear Waste Terminal Storage Program. The initial phase of development, in progress during fiscal year 1980, comprises data compilation and evaluation to identify candidate materials and experimental work to provide information for screening materials. Materials selected during the screening process will undergo extensive testing to establish their design properties.

In national and international programs supporting the storage and disposal of nuclear waste, principal reliance for radionuclide containment has been placed on the canister. The canister has been regarded as a container of high integrity that must withstand the abuse of handling and transportation, must survive a period of interim storage, and then, once in the repository, must be quantitatively resistant to environmental degradation for a defined period of time. The longevity life requirement for the canister as a component of the engineered barrier system for emplacement in a repository in basalt has not been fully defined. This must await the development and formal approval of barrier system performance criteria. For the present, however, it is sufficient to follow the U.S. Nuclear Regulatory Commission general guidelines(1) and consider an engineered barrier system design life of 1,000 years and allow the canister design life to vary with barrier system concept.

Presumably there are several engineered barrier system concept options available for achieving the design life requirements of 1,000 years. Extremes in barrier system complexity are shown on Figure 1. The relatively simple concept of Figure 1 consists of a waste canister located in an emplacement hole in the repository surrounded by a backfill, tailored to both retard the intrusion of groundwater and to modify the chemistry of the groundwater to provide a less corrosive environment for the canister. (The use of the retrieval sleeve shown is to aid in the retrieval of the canister, if required, during the operational period of the repository and would not constitute a long-lived barrier.) For this simple concept, the canister must bear the principal burden for radionuclide containment through the thermal period; hence, its design life must be equivalent to that of the barrier system. A canister material highly resistant to groundwater attack would, therefore, be necessary. Swedish investigators claim that their thick-walled copper spent fuel

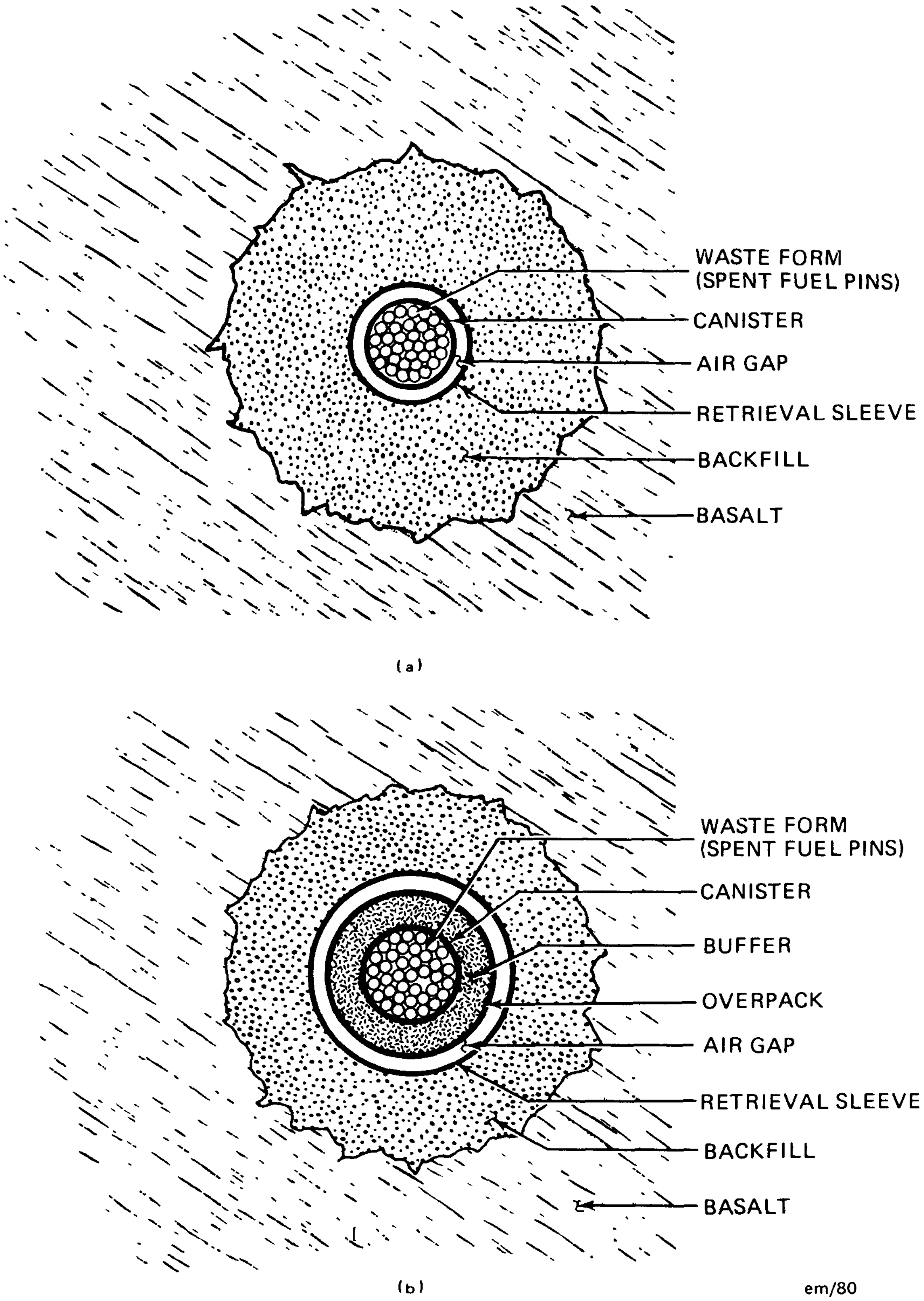

FIGURE 1. Engineered Barrier System Incorporating (a) Minimum Barrier Components and (b) Maximum Barrier Components.

canister should last at least 5,000 years because of the inertness of copper in oxygen-free water in a repository located in granite.(2) Titanium exhibits very low corrosion rates when exposed to dilute brines and seawater.(3,4) When exposed to basalt groundwater of lower ionic strength, corrosion rates are expected to be lower. Both copper and titanium, therefore, would have potential application as canisters for emplacement in basalt.

The more complex barrier system depicted on Figure 1 would allow the use of a less corrosion-resistant, less expensive material such as low carbon steel or a cast iron for the canister. For this concept, the overpack would provide protection for the canister through most or all of the barrier system design life of 1,000 years. In the event of a premature failure of the overpack, the local environment of the canister would be modified by the presence of a buffer material to adjust groundwater pH and oxygen fugacity and a tailored backfill to retard groundwater intrusion. For this more complex barrier system, a much shorter design life for the canister of perhaps 600 years can be considered. All components of this barrier system then would function in a mutually supportive manner to achieve the barrier system design life requirement of 1,000 years.

A list of potentially useful materials for canister fabrication may include both metallic and nonmetallic materials. Metals are more susceptible to chemical attack than nonmetallics, but some materials in the latter group, such as graphite and ceramics, are far more susceptible to shock-induced fracture. Thus, the use of these materials for canisters appears to be unacceptable because of the canister-handling requirements. The only exception to this may be the use of a hot-isotatic-pressing process to form heavy-walled ceramic spent fuel canisters, which Sweden has proposed.(5) For the present, however, only metallic materials are being considered for canister fabrication by the Basalt Waste Isolation Project staff.

The wall thicknesses tabulated in Table 1 were used for the first of the two screenings. A wall thickness of 1.27 cm was selected as that which would provide reasonable strength for a canister to meet design requirements. Those alloys requiring a corrosion allowance less than 1.27 cm to meet the 1,000-year design life criterion were classified as prime candidates and the remainder were classified as backup candidates.

The candidate alloys surviving the first screening were next screened on the basis of weldability. For this screening, five welding processes were selected for their adaptability to remote processing. They were gas tungsten arc, gas metal arc, submerged arc, plasma arc, and laser beam. The weldability of each alloy was judged to lie on a scale ranging from readily weldable to very difficult to weld. The results are shown in Table 2. The judgment considered such parameters as sluggishness of weld puddle, cleanliness requirements, general tooling requirements, and extent of need for internal, external, and trailing cover gas. Cast iron was included in the weldability evaluation because of its potential as a low-cost canister material.

TABLE 1. Corrosion Rates at 250°C for Candidate Canister Alloys in Simulated Brines and Seawater.

Alloy	Corrosion Rate (millimeters per year)			
	Deoxygenated 1% NaCl Solutions with 10 Milligrams Per Liter H_2S	Deoxygenated 1% NaCl Solution	Deoxygenated Seawater	Wall Thickness Required for 1,000-Year Life (millimeters)
Titanium	0.005	--	--	5.1
Zircaloy 2	0.0025	--	--	2.5
Inconel 625	0.005	0.008	0.013	5.1
Inconel 600	0.234	0.015	0.0025	234
Incoloy 825	0.005	0.010	0.005	5.1
Hastelloy C-276	0.038	0.023	0.015	38.1
Ebrite 26-1	0.015	0.05	0.005	15.2
SS-20Cb3	--	--	0.005	5.1
90-10 Cupronickel	--	--	0.071	71.1
Low Carbon Steel	0.178	0.279	0.304	178

TABLE 2. Weldability of Candidate Canister Alloys for a Repository Located in Basalt.

Alloy	Welding Process Available for Remote Application*	Weldability
TiCode-12	1, 4, 5	Weldable with care
Zircaloy 2	1, 4, 5	" " "
Inconel 625	1, 2, 3, 4, 5	Weldable
Inconel 600	1, 2, 3, 4, 5	"
Incoloy 825	1, 2, 3, 4, 5	"
Hastelloy C-276	1, 2, 3, 4, 5	Weldable with care
90-10 Cupronickel	1, 2, 4, 5	Difficult
Low Carbon Steel	1, 2, 3, 4, 5	Readily weldable
Cast Irons	1, 2	Very difficult
SS 20Cb3	1, 2, 3, 4, 5	Weldable
Ebrite 26-1	1, 2, 3, 4, 5	Weldable

*1 = Gas tungsten arc welding, 2 = gas metal arc welding, 3 = submerged arc welding, 4 = plasma arc welding, 5 = laser beam welding.

The results of the two screenings are shown in Table 3. The copper alloy, 90-10 Cupronickel, was placed in the list of backup alloys because of its poorer weldability. Further welding development using a process such as electron-beam welding may overcome its weldability problems. However, the electron-beam process may be a difficult process to operate and maintain remotely.

Low carbon steel and cast iron are being considered by the Basalt Waste Isolation Project for engineered barrier system designs where the canister is protected by outer barrier components such as a buffer and overpack. These two materials are inexpensive, strong, and do not involve the commitment of scarce natural resources. The weldability of cast iron may be improved by using the resistance welding technique presently being developed by the Savannah River Laboratory for the remote closing of waste canisters.

The alloys listed as prime candidates in Table 3 are those that appear to have the greatest potential for qualifying as components of an engineered barrier system for emplacement in a repository located in basalt. As materials testing techniques advance and the performance of these alloys under geothermal conditions and radiation become better understood, further screening may change the position of some candidates between the two lists or eliminate some altogether.

TABLE 3. Preliminary List of Candidate Canister Alloys for a Repository Located in Basalt.

Prime Candidates	Backup Candidates
TiCode-12	SS 20Cb3
Inconcel 625	Ebrite 26-1
Incoloy 825	Inconel 600
Zircaloy 2	Hastelloy C-276
	90-10 Cupronickel
	Low Carbon Steel*
	Cast Iron*

*These iron-base alloys are considered as prime candidates, since they offer many advantages to a repository system. They are inexpensive, strong, and do not involve the commitment of scarce natural resources; therefore, are promising alloys for canisters when protected by a buffer, overpack, and backfill.

The property of canister and overpack materials of paramount importance, with respect to meeting design criteria and assuring performance reliability, is the corrosion rate. Since the corrosion rate is dependent upon the surrounding environment, it is imperative that laboratory testing simulates the appropriate repository conditions. One important feature of the repository environment is the composition of the groundwater. The reference groundwater composition used to simulate the Grande Ronde Basalt groundwater is shown in Table 4. In the screening tests, two additional compositions will be used in which the only variation of significance to corrosion is in the hydrogen ion activity (pH), also shown in Table 4. One of these represents a relatively small difference from the reference composition (pH 9.9 to 9.6) and is intended to account for any inherent variability in the repository groundwater. The second represents an appreciable change (pH 9.9 to 7.5) which is expected to occur in the first few thousand hours of overpack service. Another feature of the repository environment is the extremely low oxygen content of the groundwater. Control of the oxygen content must be maintained before and during testing and is provided by using appropriate test techniques and equipment.

The test method being used for material screening tests is to subject specimens to the simulated groundwater composition at high temperature and pressure under controlled oxygen conditions. Corrosion information is obtained from post-test examination. The highest expected service temperature is used, in order to subject the materials to the most severe service corrosion conditions. Specimen variables include stressed material and welded material.

TABLE 4. Simulated Grande Ronde Basalt Groundwater Compositions.

Compound	Reference Composition (milligrams per liter)	Additional Solution Compositions (milligrams per liter)	
		#1	#2
Na_2CO_3	170	256	340
SiO_2 x H_2O	157	157	157
NaCl	235	205	143
HCl	--	1.47×10^{-5}	4.51×10^{-5}
NaF	82	82	82
Na_2SO_4	160	160	160
CaCl	3,600	3,600	3,600
MgCl	1,570	1,570	1,570
KCl	3,650	3,650	3,650

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WASTE FORM/BASALT/BARRIER INTERACTIONS UNDER HYDROTHERMAL CONDITIONS

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The basalts beneath the Hanford Site are being considered as a potential medium for a repository to contain commercial high-level nuclear waste. In order for basalt to be an acceptable medium for the emplacement of nuclear waste, the basalt, together with the waste package, must be proven capable of retarding the transport of key radionuclides between a repository located at depth and the biosphere. An assessment of the degree of retardation possible in a repository located in basalt is being accomplished by performing a series of hydrothermal experiments designed to simulate repository conditions and include as components Hanford basalts, waste forms, and potential barrier materials.

During fiscal year 1980, hydrothermal experiments were completed over a range of temperatures up to and exceeding the maximum temperature expected to occur in the near-field repository environment. The experimental components included water, Hanford basalts, and simulated waste forms (spent fuel, borosilicate glass, and supercalcine). The results of these experiments were then compared to parallel experiments completed in fiscal year 1979 in which water and the same simulated waste forms were reacted under identical conditions without basalt. The implications of the total data set are discussed below. The basalt/waste/water experiments are useful because basalt is not only the host environment, but also a potential backfill material in the waste package.

SIMULATED SPENT FUEL

Solution compositions resulting from simulated spent fuel/water reactions and simulated spent fuel/water/basalt reactions are listed in Table 1. Distilled water, a spent fuel composition,(1) and Umtanum basalt were used in the experiments. The solids were crushed to a fine powder to enhance reactivity. The experiments were run for 8 weeks at 200°C to 300°C, respectively. The purpose of the simulated waste/water experiments was to determine which elements are most likely to remain in solution under repository conditions.

In the spent fuel case, 100% of the cesium and rubidium and over half of the molybdenum were dissolved into the solution when spent fuel was reacted with water alone at 200°C. However, when these experiments were repeated in the presence of basalt, the spent fuel, basalt, and water react to form the stable phases pollucite ($CsAlSi_2O_6 \cdot nH_2O$) and powellite ($CaMoO_4$). Although the rubidium concentration was too small to be detected, it was probably incorporated into the pollucite or the

TABLE 1. Compositions of Residual Solutions from Experiments[a] Reacting Simulated Spent Fuel in Distilled Water.(2)

	Spent Fuel (alone)		Spent Fuel + Basalt	
	Micrograms per Milliliter	Relative Percent	Micrograms per Milliliter	Relative Percent
	Temperature = 300°C			
Rubidium	33	100	ND[b]	--
Cesium	281	100	ND	--
Strontium	ND	--	ND	--
Molybdenum	190	54	ND	--
Uranium	3	0.004	ND	--
Others[c]	ND	--	ND	--
	Temperature = 200°C			
Rubidium	44	100	ND	--
Cesium	363	100	3	1
Strontium	1	1	ND	--
Molybdenum	308	87	ND	--
Uranium	1	0.003	ND	--
Others	ND	--	ND	--

[a] 8 weeks duration; 10:1 water-to-solid ratio.

[b] ND = none detected by atomic absorption, atomic emission, or fluorometry.

[c] Barium, lanthenum, neodymium, and zirconium were not detected in solution.

basalt phase, plagioclase. The significance of these results is that, in the presence of basalt, many of the potentially hazardous materials dissolved from spent fuel under hydrothermal conditions are removed from solution and permanently immobilized as stable precipitates.

Fission products comprise less than 5 weight percent of the spent fuel. The major component of the waste form is uranium. At the completion of the spent fuel/basalt/water experiments, only a small fraction of the total uranium was found in solution. As with the fission products, uranium solubility is depressed in the presence of basalt. It is suggested that the absence of uranium in solution results from the precipitation of uranium dioxide which is stable under the reducing conditions imposed by basalt. The estimated solubility of uranium dioxide under repository conditions is in the range of tenths to hundredths of a part per billion.(3,4) Thus, maximum concentrations of uranium expected in heated basalt groundwater are several orders of magnitude below the maximum permissible concentrations set forth by the U.S. Environmental Protection Agency. Since uranium is relatively immobile in a basalt environment, neither uranium nor members of its decay chain are likely to reach the biosphere in hazardous concentrations from a repository located in basalt.

SIMULATED BOROSILICATE GLASS

Solution compositions resulting from borosilicate glass/water and borosilicate glass/water/basalt reactions are listed in Table 2. Results from parallel experiments done by The Pennsylvania State University and Pacific Northwest Laboratory are shown. Distilled water, a glass composition,(5) and Umtanum basalt were used in the experiments. All experiments were of 1-month duration at similar temperatures (300°C at The Pennsylvania State University and 325°C at Pacific Northwest Laboratory) and a pressure of 300 bars. All solids were ground to a fine powder to promote reactivity. The one difference in the experimental conditions between the two laboratories was the water-to-solid ratio. The studies at The Pennsylvania State University used a water-to-solid ratio of 20:1 and Pacific Northwest Laboratory used a water-to-solid ratio of 1:1.

Both laboratories produced similar results in the glass/water experiments. However, opposite effects were demonstrated in the glass/water/basalt experiments. The Pennsylvania State University data show an increase in the solubility of cesium, rubidium, and strontium in the presence of basalt, but the Pacific Northwest Laboratory data show the familiar decrease in the solubility of these elements in the presence of basalt. These apparently conflicting experimental results may be explained by the different water-to-rock ratios used. A temporary pH depression below the expected steady-state pH has been observed experimentally in basalt/water experiments(6) and is favored by high water-to-solid ratios. The short duration of these experiments and the higher water-to-solid ratios in The Pennsylvania State University experiments may have resulted in a lower pH during the experiments. Glass leaching rates are known to increase as the solution to which the solids is

TABLE 2. Leachability[a] of Simulated Pacific Northwest Laboratory 76-68 Glass Using Distilled Water in the Presence of Basalt (near 300°C).(2)

	Glass	Glass and Basalt	Net Change
	The Pennsylvania State University[b]		
Rubidium	12	17	+5%
Cesium	14	20	+6%
Strontium	ND[d]	0.4	+4%
Boron	80	88	+8%
Molybdenum	68	59	-9%
Uranium	--	--	--
Silicon	2.3	1.3	-1%
	Pacific Northwest Laboratory[c]		
Rubidium	16	0.06	-15.4%
Cesium	6	0.04	-5.96%
Strontium	0.2	0.05	-0.15%
Boron	100	5.9	-94.1%
Molybdenum	49	0.05	-48.95%
Uranium	0.1	0.002	-0.998%
Silicon	2.2	0.07	-2.13%

[a] Experiments 1 month in duration; concentrations reported as relative percent oxide (grams in liquid/grams in original solid).

[b] Water:rock = 20:1, T = 300°C.

[c] Water:rock = 1:1, T = 325°C.

[d] Not determined.

exposed becomes more acidic. Since greater amounts of glass as well as cesium, rubidium, and strontium did dissolve, the basalt phases may have had insufficient time to remove these elements from solution. Another alternative is that an insufficient amount of reactive basalt phases was present to remove the larger concentration of these elements from solution.

Both data sets are useful to waste package design. The data obtained by The Pennsylvania State University demonstrate that glass leachability may be high if rapidly moving water intersects the repository. (The effective water-to-rock ratio would be high, consequently the pH could be low.) Therefore, an effective water-retardant barrier is important to any waste package system supporting a glass waste form. A pH-moderating agent (i.e., buffer) is also desirable.

SIMULATED SUPERCALCINE

Solution compositions resulting from supercalcine/water and supercalcine/water/basalt reactions are shown in Table 3. Distilled water, a supercalcine,(7) and Umtanum basalt were the experimental components. Experiments were run for 4 months at 200°C and 300°C and a pressure of 300 bars. At 300°C, rubidium, cesium, strontium, and molybdenum solubilities are suppressed when basalt is added to the supercalcine/water system. At 200°C, apparently little reaction took place because the solid and liquid phases remain relatively unchanged.

Analysis of residual solids from the 300°C basalt/waste/water experiments reveals the presence of pollucite, powellite, weeksite ($K_2(UO_2)_2(Si_2O_5)_3 \cdot 4H_2O$), haiweeite ($Ca(UO_2)_2(Si_2O_5)_3 \cdot nH_2O$), apatite ($Ca_5(PO_4)_3OH$), and zeolites. Weeksite and powellite contain uranium which is ordinarily mobile in aqueous environments. The presence of these phases may indicate a tendency for a basalt backfill to stabilize uranium even under oxidizing conditions.

Analysis of the solid phases in the ceramic indicates that some of the phases change chemistry in response to the increase in thermal environment. These changes are minor (e.g., an increase in the calcium/sodium ratios in powellite) and not destructive to the waste form.

SUMMARY

Basalt appears to be an effective agent for use as a backfill component in a nuclear waste repository located in basalt. The basalt rock reacts to form stable hosts for cesium, strontium, rubidium, and molybdenum that might be released from a breached canister. In addition, the anoxic conditions imposed by basalt immobilize uranium and its associated daughter products. Quantitative estimates on the amount of backfill required for waste package systems supporting each waste form will be made after well-controlled experiments (Eh, pH) are completed. Development of procedures for these tests is scheduled for fiscal year 1981.

TABLE 3. Compositions of Residual Solutions from Experiments[a] Reacting Supercalcine[b] and Basalt.(2)

	Supercalcine		Supercalcine and Basalt		Comparison with Maximum Permissible Concentration SPC-4 and Basalt (Micrograms per Milliliter)
	Micrograms per Milliliter	Relative Percent	Micrograms per Milliliter	Relative Percent	
			Temperature = 300°C		
Rubidium	25	4.6	ND[c]	--	--
Cesium	25	0.6	9	0.4	100 ^{135}Cs; 2.3 x 10^6 ^{137}Cs
Strontium	2.3	0.06	--	--	--
Molybdenum	370	6.8	13	0.5	650
Uranium	--	--	--	--	--
Lanthanum	ND	--	ND	--	--
Neodymium	ND	--	ND	--	--
			Temperature = 200°C		
Rubidium	30	0.5	30	0.6	0.3 ^{87}Rb
Cesium	10	0.2	10	0.2	125 ^{135}Cs; 2.3 x 10^6 ^{137}Cs
Strontium	0.5	0.01	0.1	0.1	3.3 x 10^7
Molybdenum	83	1.5	100	1.8	5,000 ^{99}Tc
Uranium	--	--	--	--	--
Lanthanum	ND	--	ND	--	--
Neodymium	ND	--	ND	--	--

[a] 300 bars pressure; 4 months duration.

[b] Formulation SPC-4.

[c] ND = not detected by atomic absorption, atomic emission, or fluorometry.

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ESTIMATION OF WASTE PACKAGE PERFORMANCE REQUIREMENTS FOR A NUCLEAR WASTE REPOSITORY IN BASALT

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One of the most important steps in the development of a waste package is the determination of how well the package has to perform. Thus, it is not efficient to design a system of engineered barriers without knowing the maximum permissible release rate of each nuclide and hence, the "key" radionuclides for which the waste package must perform most effectively. This study is aimed at determining the most hazardous nuclides in spent fuel located in a repository in basalt and at estimating the maximum permissible release rates of these nuclides from the waste package. The method of estimating required performance of the waste package was based on:

- Baseline and potential "worst case" release scenarios
- Federal regulations(1) concerning permissible concentrations in solution at the point of discharge to the accessible environment
- A one-dimensional transport model.

The one-dimensional approach to transport is inherently conservative in that it neglects dilution due to dispersion in the plane at right angles to the direction of flow. The transport equation in one dimension, corrected for radioactive decay, is:

$$aV \frac{\partial^2 C}{\partial^2 x^2} - V \frac{\partial C}{\partial x} - R \frac{\partial C}{\partial t} - R\lambda C = 0 \qquad (1)$$

where a is the dispersive length, V is the water velocity, R is the retardation factor, C is concentration, x is distance, t is time, and is the radionuclide decay constant.

Equation 1 can be solved for certain boundary conditions and applied to nuclides that decay, but are not formed during transport. Given constant release rate and total release period, T (year), the <u>peak</u> discharge rate, D, may be approximated by one or other of the two expressions:

$$D \approx \frac{I}{2T} \exp\ (-\lambda t_c) \text{ curies per year} \qquad (2)$$

$$D \approx \frac{I}{4t_c} \sqrt{\frac{x}{a}} \exp\ (-\lambda t_c) \text{ curies per year} \qquad (3)$$

where I is the initial inventory and t_c is the characteristic travel time from the repository to the biosphere for the nuclide of interest. Equation 2 applies if the leach period is of the same order as t_c, whereas Equation 3 applies if the travel time is very much longer than the leach time. The characteristic travel time is simply the distance between repository and biosphere, x, divided by nuclide velocity, V/R.

The latter two equations can readily be modified to yield reasonable approximations for members of actinide chains which form as well as decay during travel. They also provide a very simple means of performing sensitivity analyses for different values of x, R, dispersivity, etc. In the region where Equation 2 applies, the important parameters are leach time and initial inventory; travel time, t_c, only affects peak discharge rate through the decay term. In contrast, if Equation 3 applies, leach time does not affect peak discharge rate, and t_c, x, and dispersivity become the controlling parameters.

The equations have been used to determine maximum permissible release rates in the repository which would keep solution concentrations at the biosphere below the recommended concentration guide at all times. The three release scenarios and most stringent performance requirements were as follows.

CASE 1

Transport through 25 kilometers of massive basalt to discharge point (Table 1).

V = 0.1 meter per year; porosity = 0.01; dispersive length, a = 2.5 meters.

CASE 2

Instantaneous leakage into an interflow zone and transport 25 kilometers to discharge (Table 2).

V = 20 meters per year; porosity = 0.05; dispersive length, a = 2.5 meters.

CASE 3

Instantaneous leakage into the unconfined aquifer and discharge at a well 1,750 meters from the repository center (Table 3).

V = 1,000 meters per year; porosity = 0.1; dispersive length, a = 2.5 meters.

TABLE 1. Nuclides Requiring Release Rates $<10^{-3}$ per Year to Keep Concentrations below Recommended Concentration Guide for Case 1.

Nuclide	Time of Peak Discharge (in years)	Release Rate Required to Keep below Recommended Concentration Guide (per year)
^{129}I	2.5×10^5	2×10^{-9}
^{79}Se	2.5×10^5	1×10^{-7}
^{99}Tc	2.5×10^5	4×10^{-8}
^{234}U*	2.5×10^5	1×10^{-7}*
^{235}U	2.5×10^5	2×10^{-6}
^{236}U	2.5×10^5	1×10^{-7}
^{238}U	2.5×10^5	2×10^{-7}

*Includes daughters ^{239}Th, ^{226}Ra, and ^{210}Pb.

TABLE 2. Nuclides Requiring Release Rates $<10^{-3}$ per Year to Keep Concentrations below Recommended Concentration Guide for Case 2.

Nuclide	Time of Peak Discharge (in years)	Release Rate Required to Keep below Recommended Concentration Guide (per year)
^{79}Se	1,250	1×10^{-5}
^{99}Tc	1,250	2×10^{-5}
^{107}Pd	6.3×10^5	4×10^{-5}
^{129}I	1,250	2×10^{-6}
^{234}U	1.9×10^5	4×10^{-5}
^{236}U	1,250	1×10^{-4}
^{237}Np	1.9×10^5	2×10^{-7}*
^{238}U	1,250	2×10^{-4}

*Includes daughter ^{233}U.

TABLE 3. Nuclides Requiring Release Rates $<10^{-3}$ per Year to Keep Concentrations below Recommended Concentration Guide for Case 3.

Nuclide	Time of Peak Discharge (in years)	Release Rate Required to Keep below Recommended Concentration Guide (per year)
^{129}I	2.5	2×10^{-4}
^{239}Pu	2,500	2×10^{-5}
^{240}Pu	2,500	4×10^{-6}
^{242}Pu	2,500	8×10^{-4}
^{241}Am	1,000	10^{-6}
^{243}Am	1,000	10^{-4}

Required release rates are less stringent in the rapidly conducting Cases 2 and 3 than in the baseline Case 1. This is because the nuclides are more readily diluted due to the relatively high volume flow of 3×10^7 liters per year in Case 2, and 3×10^9 liters in Case 3, compared with 3×10^4 liters per year in Case 1. It should be noted, however, that the volume flow in Case 1 is so low that it could not constitute a significant water resource, whereas the volumes involved in the aquifer release scenarios might have resource potential. In practice, therefore, the required release rates for Cases 2 and 3 are of the most significance.

The calculated waste package performance requirements are anticipated to be conservative by one to two orders of magnitude because of the effects of radial dispersion. Future work will extend the model to two and three dimensions in order to quantify the influence of these dispersion effects. Additional input to the modeling effort will be made from consideration of the maximum solubilities of key nuclides within the repository. The isotopes of uranium and their daughters have been found to comprise many of the most hazardous nuclides (Tables 1 through 3). It appears, however, that UO_2 (spent fuel) would be sufficiently insoluble (3×10^{-8} moles per liter) in a repository in basalt, so that the performance requirements could readily be met without engineered barriers. Such simple solubility constraints may conceivably apply for plutonium, neptunium, americium, and technetium, as well as for uranium (Table 4).

TABLE 4. Calculated Rates of Uranium Release Based on UO_2 Solubility of 3×10^{-8} Moles per Liter.

Case	Maximum Permissible Rate of Release (per year)	Maximum Possible Rate of Release (per year)
1	1×10^{-7}	5×10^{-12}
2	4×10^{-5}	5×10^{-9}
3	$>10^{-3}$	5×10^{-7}

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AN OVERVIEW OF SORPTION STUDIES

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A knowledge of the sorptive properties of radionuclides associated with nuclear waste is necessary to evaluate the ability of the geohydrologic system surrounding a repository located in basalt and candidate engineered barrier materials to prevent the transport of radionuclides to the biosphere. Groundwater is considered to be the most probable transport medium for radionuclide migration in or near a repository mined in basalt. The migration of radionuclides may be retarded by sorption of the radionuclides onto basalt, secondary minerals, interbed materials, sediments, and engineered backfill materials. The sorption of radionuclides is measured in terms of a distribution ratio (K_d), which is defined as the ratio of the activity sorbed onto the solid phase to the activity in the aqueous phase. These distribution ratios, along with other relevant chemical and physical data, will be used to model radionuclide behavior under the environmental conditions expected in a repository situated in basalt and as a source term for radionuclide transport modeling of the repository. These models and the K_d data will then be used to determine the needs and priorities for the development of waste package systems for those radionuclides found to be mobile in the geohydrologic environment surrounding a repository mined in basalt.

The objective of the sorption studies is to obtain K_d values of key radionuclides(1) under conditions which exist in the groundwater flowpath. The distribution ratio is an empirical value and is dependent on many system parameters, including: solution composition, solid composition, radionuclide species and concentration; and system Eh, pH, temperature, and pressure. Radionuclide distribution ratios for key radionuclides have been determined between representative geologic materials from the Hanford Site and synthetic groundwaters which simulate actual Hanford groundwaters using an equilibrium batch technique. The geologic materials include Umtanum, Flow E, and Pomona basalts, secondary mineralization found associated with the Pomona basalt, and an interbed tuff from the Ellensburg Formation. The characteristics of the geologic materials are summarized in Table 1. The groundwater formulations(2) used in the K_d determinations are presented in Table 2, and the results of the static K_d experiments at 25°C and 60°C are given in Table 3. Several conclusions may be drawn from these data:

- The radionuclide distribution ratio usually is greater for those geologic materials which have the greater surface area, such as the secondary mineralization materials.

TABLE 1. Characteristics of the Geologic Materials Used in the Sorption Experiments.

Characteristic	Umtanum Basalt	Flow E Basalt	Pomona Basalt	Secondary Mineralization	Tuff
Surface Area					
by ethylene glycol	17.7 ± 3.8 m^2/g	10.3 ± 1.0 m^2/g	31.2 ± 1.4 m^2/g	646 ± 19.3 m^2/g	--
by B.E.T.	--	--	--	--	18.9 ± 0.2 m^2/g
Cation Exchange Capacity	1.7 ± 0.1 meq/ 100 grams	4.7 ± 0.2 meq/ 100 grams	2-3 meq/100 grams	100-150 meq/ 100 grams	11.4 ± 0.1 meq/ 100 grams
Major Minerals	Plagioclase Augite	Plagioclase Augite	Plagioclase Augite	Smectites	Smectites Feldspar
Weight Percent Groundmass	37.5%	13%	26%	--	--

TABLE 2. Synthetic Groundwater* Formulations Used in Sorption Measurements.

Component	Concentration (milligrams per liter)	
	Groundwater #1	Groundwater #2
Na^+	30.7	225
K^+	9.0	2.5
Ca^{2+}	6.5	1.06
Mg^{2+}	1.0	0.07
Cl^-	14.4	131
CO_3^{2-}	0	59
HCO_3	81.5	75
F^-	0	29
SO_4^{2-}	11.1	72
SiO_2	25	108
	pH = 8.0	pH = 10.0

*Groundwater #1 is representative of groundwaters in the upper Wanapum and lower Saddle Mountains Basalts. Groundwater #2 is representative of groundwaters in the Umtanum basalt at the proposed repository depth.

TABLE 3. Radionuclide Distribution Ratios (K_d) between Synthetic Groundwater and Representative Geologic Materials.

Radio- nuclides	Umtanum Basalt*	Flow E Basalt*	Pomona Basalt*	Secondary Mineralization*	Tuff**
23°C K_d', milliliters per gram					
^{75}Se	5.4 ± 1.3	1.2 ± 0.3	2.4 ± 0.7	7.6 ± 0.3	--
^{85}Sr	105 ± 4	91 ± 5	121 ± 9	274 ± 16	541 ± 127
^{99}Tc	26.8 ± 21.9	0	0	0	0
^{125}I	6.8 ± 1.3	1.0 ± 0.4	2.0 ± 1.0	14.0 ± 1.8	2.6 ± 0.5
^{137}Cs	705 ± 18	278 ± 6	1,685 ± 245	11,000	3,052 ± 184
^{226}Ra	187 ± 24	127 ± 21	158 ± 5	339 ± 94	--
^{237}Np	30.0 ± 13.0	4.1 ± 0.9	9.8 ± 05	36.9 ± 7.5	25 ± 3
^{241}Am	277 ± 103	622 ± 180	696 ± 93	1,355 ± 152	335 ± 183
^{241}Pu	102 ± 97	165 ± 16	267 ± 18	2,572 ± 341	--
60°C K_d', milliliters per gram					
^{75}Se	0	1.0 ± 0.1	0	0	--
^{85}Sr	122 ± 3	104 ± 1	130 ± 4	339 ± 5	224 ± 70
^{99}Tc	25.5 ± 5.2	0	0	0	0
^{125}I	0	0	0	0	2.4 ± 0.6
^{137}Cs	463 ± 5	187 ± 6	747 ± 37	1,432 ± 695	554 ± 40
^{226}Ra	360 ± 69	313 ± 50	399 ± 80	351 ± 55	--
^{237}Np	31.2 ± 4.7	8.3 ± 0.5	12.1 ± 3.2	53.5 ± 18.8	25 ± 22
^{241}Am	236 ± 98	400 ± 245	717 ± 3	1,489 ± 350	189 ± 55
^{241}Pu	353 ± 224	300 ± 26	700 ± 108	3,328 ± 609	--

* Contact time 50 days, synthetic groundwater #1.
**Contact time 30 days, synthetic groundwater #2.
K_d values reported are the mean of triplicate experiments ± one standard deviation.

- The temperature effects on K_d between 25°C and 60°C are relatively minor.
- Radionuclides which normally occur in an anionic or neutral form, such as technetium, neptunium, or iodine, are relatively poorly removed from solution under oxic conditions.

Distribution ratios for uranium, cesium, strontium, technetium, and neptunium have been determined between the basalts and fracture mineralization and the two groundwater formulations given in Table 2. Only uranium showed a significant difference in K_d values due to the differing groundwater compositions. The sorption of uranium from groundwater #2 is approximately an order of magnitude less than the sorption of uranium from groundwater #1. This feature is probably due to the fact that groundwater #2 contains greater amounts of carbonate and is higher in pH than groundwater #1, leading to higher uranium anionic complexing levels, probably as uranyl carbonate.

The concentration levels of the radionuclides can be expected to vary considerably due to changes in the thermal and physicochemical conditions within the repository with time. Distribution ratios are sensitive to radionuclide concentration changes. Because of this fact, sorption isotherm experiments have been conducted to determine K_d values for cesium, strontium, neptunium, and technetium over a radionuclide concentration range expected in a repository in basalt. These concentration ranges were selected by considering factors such as radionuclide solubility, specific activity, and the analytical detection limits. Cesium sorption has been found to be independent of radionuclide concentration below approximately 10^{-9} moles per liter for the basalts and secondary mineralization. Strontium sorption has been found to be independent of radionuclide concentration below approximately 10^{-7} moles per liter for the basalts. Both strontium and cesium K_d values decrease with increasing radionuclide concentration above these values. Strontium sorption onto the secondary mineralization shows no dependence on radionuclide concentration over the concentration range investigated (10^{-4} to 10^{-10} moles per liter). Neptunium K_d values for all geologic materials exhibited a slight increase with decreasing radionuclide concentration over the concentration range investigated (10^{-5} to 10^{-8} moles per liter). Technetium was sorbed only by Umtanum basalt in any measurable amount. These results indicate that the technetium concentration has little effect on the K_d value under oxic conditions. Sorption isotherm experiments to determine the radionuclide concentration effects on K_d are presently under way for other key (potentially mobile) radionuclides.

Radionuclide distribution ratios also can be greatly affected by Eh and pH conditions in the environment. Repository conditions are expected to vary in pH from approximately 6 to 10 and in Eh from -0.5 to +0.5 volts (10^{-68} atmospheres O_2 to $10^{-0.7}$ atmospheres O_2).(3) Radionuclide distribution ratios have been determined under slightly anoxic conditions for those radionuclides which have more than one stable oxidation state. An oxygen concentration of 7.87 x $10^{-0.7}$ atmospheres O_2 was attained during the sorption experiments. This concentration corresponds to repository conditions expected shortly after repository closure. A comparison of the K_d values obtained under oxic and slightly anoxic conditions is presented in Table 4. Little or no enhancement of sorption for these isotopes onto the basalt and secondary mineralization was observed under the slightly anoxic conditions imposed. However, there would almost certainly be observable effects on these radionuclide K_d values if the oxygen partial pressure approached the 10^{-68} atmospheres predicted for a closed repository in basalt.

TABLE 4. Effect of Oxygen Fugacity On Radionuclide Distrubution Ratios between Synthetic Groundwater and Basalt and Associated Secondary Minerals at 23°C.

	23°C, K_d milliliters per gram			
Radionuclide	Umtanum Basalt	Flow E Basalt	Pomona Basalt	Secondary Mineralization
^{75}Se	0* 5.4 ± 1.3	1.2 ± 0.3	2.4 ± 0.7	7.6 ± 0.3
	A**16.8 ± 4.0	1.0 ± 0.6	0	3.3 ± 0.3
^{99}Te	0 26.8 ± 21.9	0	0	0
	A 4,489 ± 3,165	2.5 ± 1.7	0	0
^{237}Np	0 30 ± 13	4.1 ± 0.9	9.8 ± 0.5	36.9 ± 7.5
	A 148 ± 27	11.2 ± 10.9	11.9 ± 2.5	79 ± 10
^{241}Pu	0 102 ± 97	165 ± 16	267 ± 18	2,572 ± 341
	A 5,190 ± 3,250	51.6 ± 14.4	70.8 ± 51.1	415 ± 178
^{233}U	0 2.8 ± 0.9	1.0 ± 0.2	0.9 ± 0.2	72 ± 2
	A 9.3 ± 1.0	1.6 ± 0.7	1.6 ± 0.7	108 ± 23

*0 = 0.2 atmospheres O_2.

**A = 7.9×10^{-7} atmospheres O_2.

K_d values reported are the mean of triplicate experiments ± one standard deviation.

The need for radionuclide distribution measurements under controlled Eh and pH conditions has prompted the investigation of several control methods. System pH buffers of definite ionic strength can be used to ascertain the effects of ionic strength as well as pH on resultant K_d values. Quinhydrone has been found to be a potentially useful Eh-poising agent for systems with pH values less than 7.5. The quinhydrone would poise the system at an oxygen fugacity of approximately 10^{-36} atmospheres at 25°C. Ferrion also has been tested as a potential Eh-poising agent, but was found to interfere with the sorption of radionuclides. Sodium sulfite and hydrazine are presently being investigated as potential Eh-poising agents for the basalt groundwater system at elevated pH values.

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CHAPTER V

TEST FACILITIES

SUMMARY OF FISCAL YEAR 1980 NEAR-SURFACE TEST FACILITY ACTIVITIES

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The objectives of the Near-Surface Test Facility are to:

- Develop a multipurpose facility for in situ testing of basalt
- Provide thermomechanical qualification of basalt as a repository medium
- Provide a design basis for key repository elements
- Demonstrate the placement, storage, and retrievability of nuclear waste canisters in an underground basalt environment.

Specific objectives of the Near-Surface Test Facility test program include the following:

- Establish data base for numerical models for the very near field and the near field.
- Determine thermomechanical rock mass properties including deformation, thermal expansion, and thermal conductivity, and their variations as a function of temperature and stress.
- Determine rock mass response to: thermomechanical loading with respect to scale for the very near field and the near field; operating, accelerated, and overload levels; and spent fuel and vitrified waste forms.

The overall layout of the Near-Surface Test Facility is shown on Figure 1. Planned testing is divided into two phases. Phase I consists of implementing several heater tests which will characterize the thermomechanical response of basalt at and near simulated nuclear waste canister boreholes. Phase II will consist of placing three nuclear waste canisters in boreholes; one will contain a 2-year out-of-reactor pressurized water reactor fuel assembly, the second will contain a 5-year out-of-reactor pressurized water reactor fuel assembly, and the third will contain a vitrified waste form "log." Data collected from Phase II will be compared to Phase I. The tentative locations for the Near-Surface Test Facility tests are shown on Figure 2.

Full-Scale Heater Tests #1 and #2 started on July 1, 1980. The first test simulates the placement of a 5-year out-of-reactor spent fuel assembly (1 kilowatt) and the effects of heat generation from surrounding canisters. The second test will heat the basalt, starting with an input power of 1 kilowatt and increasing the power, in steps, to 5 kilowatts.

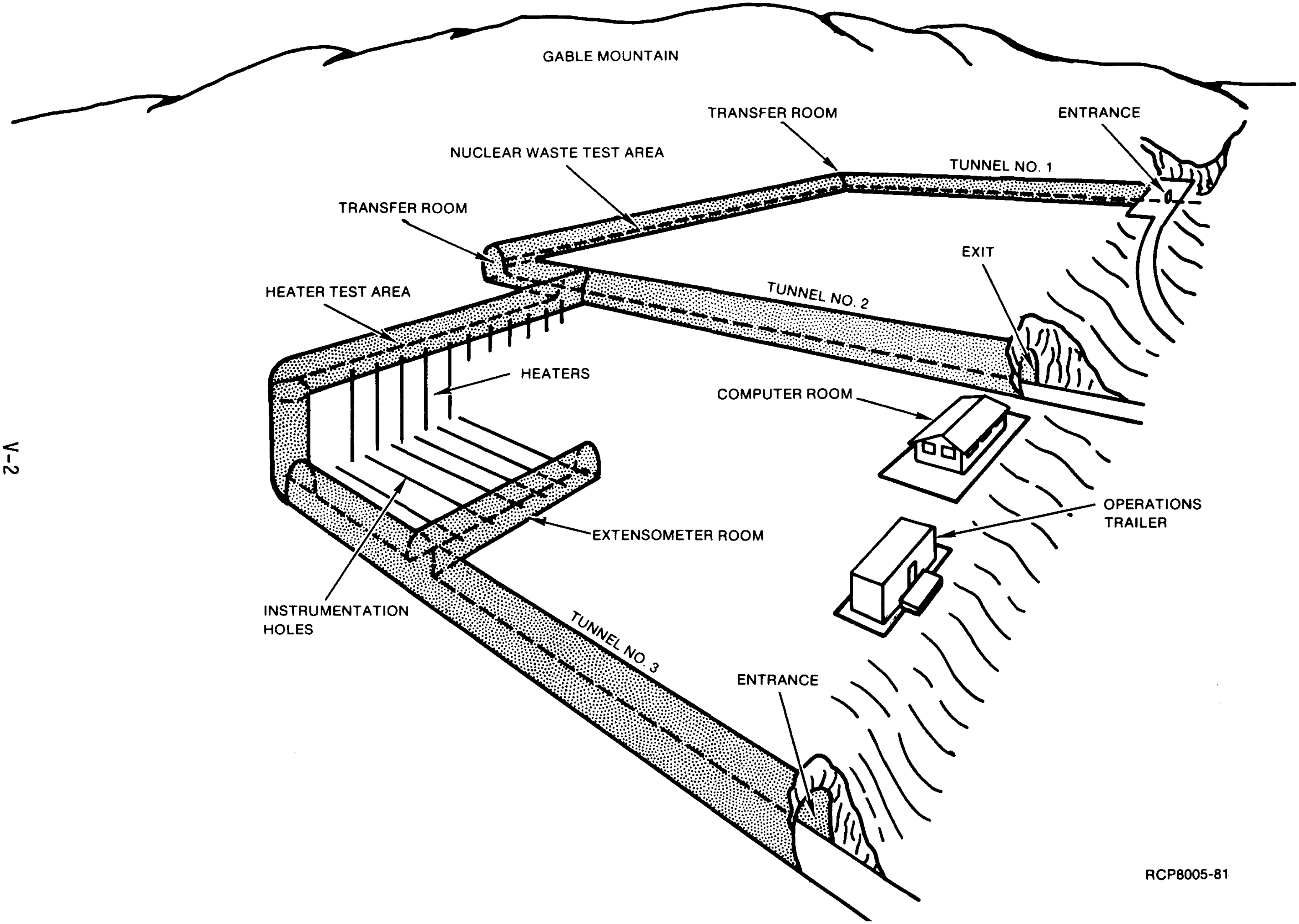

FIGURE 1. Near-Surface Test Facility Layout.

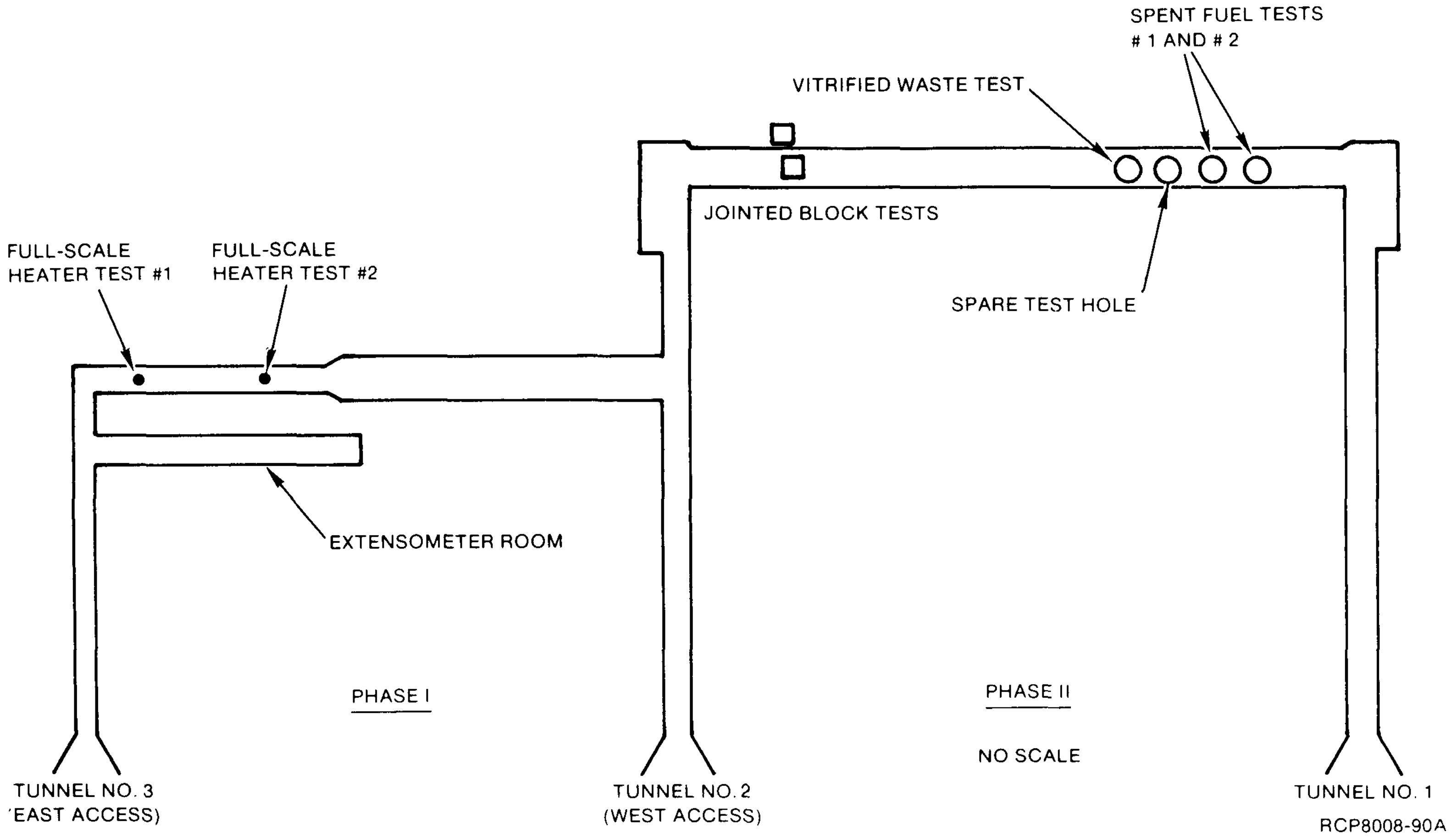

FIGURE 2. Tentative Layout of Near-Surface Test Facility Tests.

This test will provide basalt response at high thermal loadings which will assist in establishing upper limits for canister loading. Further discussions of these tests are provided in the following reports.

The thermomechanical response of the full-scale heater tests is measured by rock instrumentation, processed by a data acquisition system, and evaluated by the rock mechanics staff. Further discussions of these activities are the subjects of the following reports.

Other tests tentatively planned for Phase I are:

- Jointed block tests which will determine in situ rock mass properties as a function of confining pressure and temperature
- Room-scale tests which will simulate room-scale effects of placing nuclear wastes in a repository.

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

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Rockwell Hanford Operations, in conducting their in situ test program at the Near-Surface Test Facility, is monitoring the thermomechanical 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 types of rock instruments are being used; e.g., extensometers, borehole deformation gauges, stressmeters, and thermocouples.

The design, fabrication, testing, and assembly of the rock instrumentation assemblies was accomplished by Foundation Sciences Inc., Portland, Oregon, to the requirements specified by Rockwell Hanford Operations.

Initial Phase I testing at the Near-Surface Test Facility is comprised of two electric heater tests--Full-Scale Heater Test #1 and Full-Scale Heater Test #2.

Full-Scale Heater Test #1 is designed to simulate the temperatures and thermally induced stresses expected in an actual repository. The test is located in the east end of the Phase I test room, as shown in Figure 2 of the preceding paper. One full-size heater unit will be peripherally heated by eight smaller heaters to simulate the heating effects of nearby canisters in an actual repository. Rock instrumentation is installed in an array around the full-size heater, as shown on Figures 1 and 2. Instrument assemblies that make up the Full-Scale Heater Test #1 array are:

- 9 Extensometer (4 anchor)--includes 5 thermocouples/extensometer (vertical)
- 13 Extensometer (3 anchor)--includes 5 thermocouples/extensometer (horizontal)
- 3 U.S. Bureau of Mines (USBM)/Irad Manufacturing Company (IRAD) (1 USBM, 2 IRAD)--includes 3 thermocouples/assembly (vertical)
- 3 USBM--includes 1 thermocouple (vertical)
- 1 IRAD (2 gauges)--includes 1 thermocouple/gauge (vertical)
- 1 USBM--includes 1 thermocouple (horizontal)
- 5 USBM/IRAD (1 USBM, 2 IRAD)-- includes 3 thermocouples/assembly (horizontal)
- 6 Thermocouples--includes 5 thermocouples/assembly (vertical).

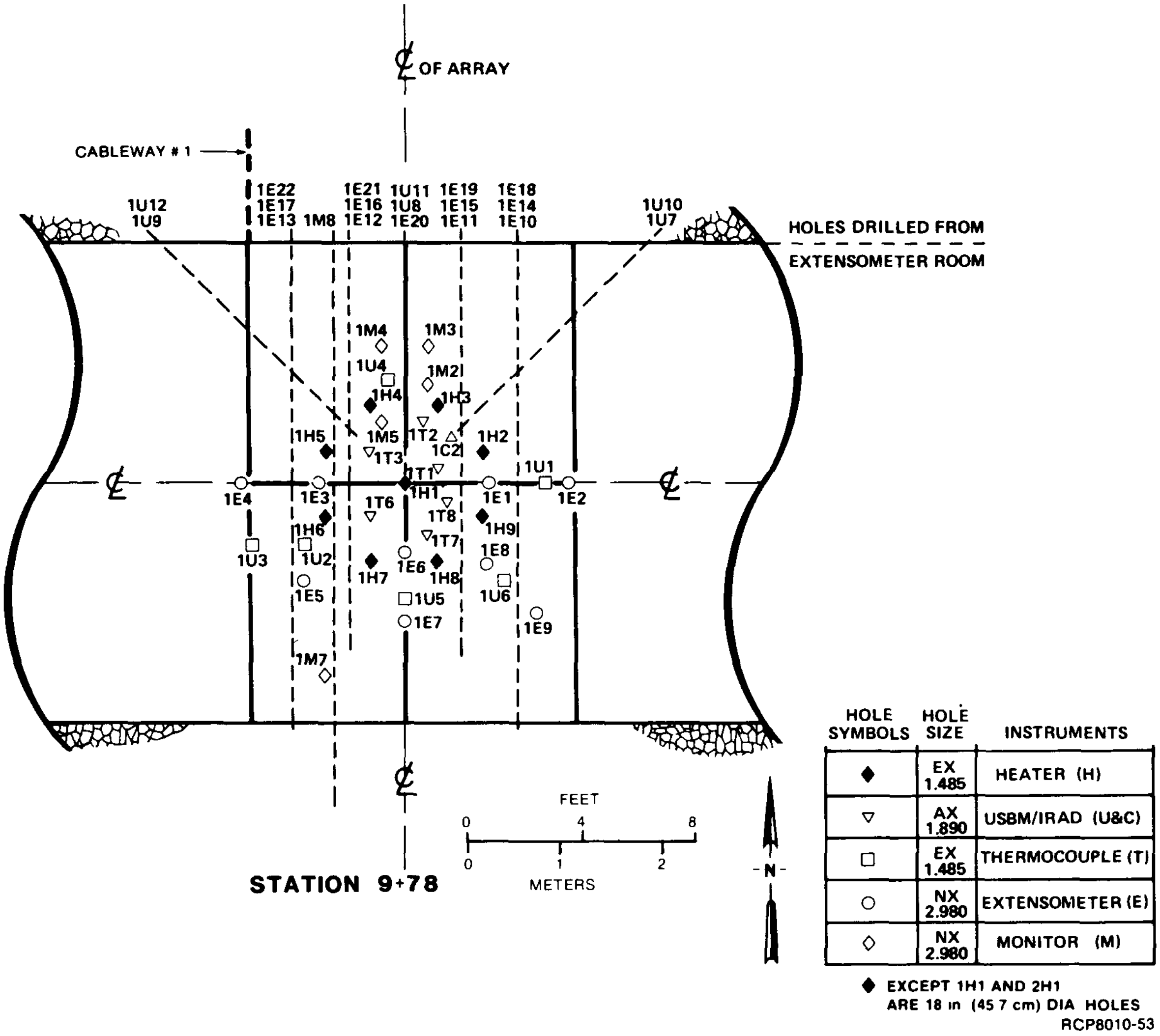

FIGURE 1. Plan View of Boreholes Drilled for Full-Scale Heater Test #1.

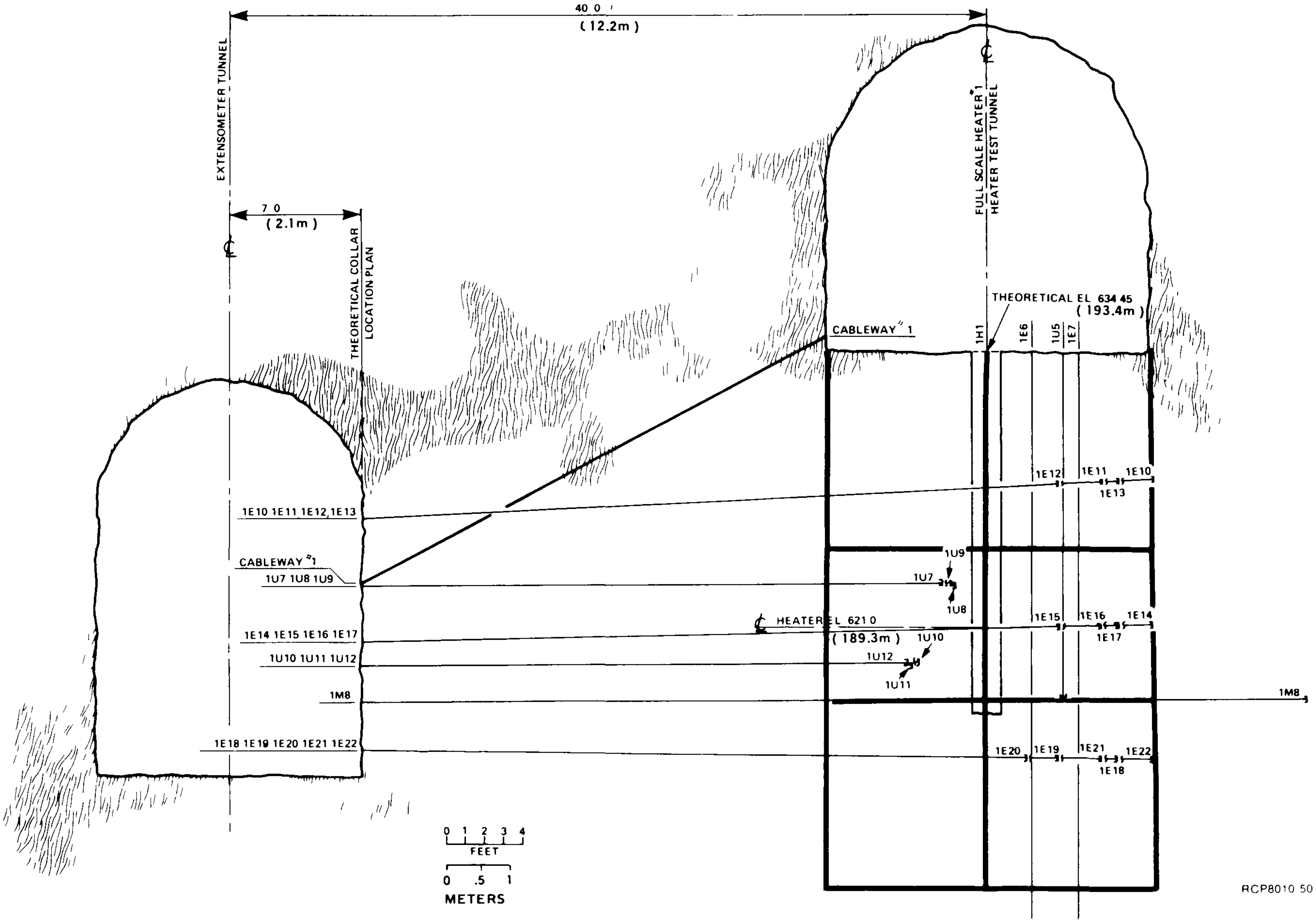

FIGURE 2. Elevation View of Boreholes for Full-Scale Heater Test #1 (looking east).

The extensometers are Terrametrics, Inc. (Golden, Colorado) Model CSLT(R) with Terrametrics Model HG hydraulic anchors. They are used to measure axial displacement of the basalt. Each extensometer assembly was modified to incorporate the addition of a pipe branch Y to the anchor string to allow the five thermocouple leads and any water that might invade the anchor conduit to exit prior to reaching the extensometer head assembly.

The IRAD gauges (vibrating wire stress meter Model VBS-1HT) are used to measure radial stress in the borehole. Each IRAD gauge was modified to provide more stable output and better reliability. These modifications include an improved swedging procedure for attaching the vibrating wire to the stress meter body and heat treatment of the epoxy end plug to minimize possible water leakage into the stress meter.

The USBM borehole deformation gauge, manufactured by Rogers Arms and Machine Company, Grand Junction, Colorado, is used to measure changes in borehole diameter along three axes spaced 60 degrees apart. Each gauge is modified to incorporate silicone rubber-impregnated cable, tapered Teflon packing bushing, and room-temperature vulcanizing rubber seal for each individual conductor in the cable for water-proofing. Thermocycling during and after gauge assembly is done to improve gauge stability and minimize long-term drift. Longer pistons and shoulders were added to the gauge body to enable the gauge to be installed in a larger hole, thereby providing more clearance for the equipment and cabling to be placed in the borehole.

Thermocouples are Type E (chromel/constantan), as per National Bureau of Standards special limits of error, and are used to measure basalt temperatures and temperatures at the locations of sensors such that the appropriate thermal calibration factors can be applied. Each thermocouple assembly consists of five thermocouples (each encased in its own Teflon tube), staggered at predetermined spacing, and securely fastened to a flexible tube. This design also incorporates a spare Teflon tube that provides the means to produce temperature profiles of each thermocouple borehole.

Full-Scale Heater Test #2 is similar to Full-Scale Heater Test #1 without the eight peripheral heaters. It is located adjacent to Full-Scale Heater Test #1, as shown on Figure 2 in the preceding paper. This test is designed to determine the maximum acceptable power input to the basalt by steadily increasing the power level of the main heater. Rock instrumentation is installed in an array around the main heater as shown on Figures 3, 4, and 5. Instrument assemblies that make up the Full-Scale Heater Test #2 array are:

- 13 Extensometer (4 anchor)--includes 5 thermocouples/extensometer (vertical)
- 16 Extensometer (3 anchor)--includes 5 thermocouples/extensometer (horizontal)
- 5 USBM/IRAD (1 USBM, 2 IRAD)--includes 3 thermocouples/assembly (vertical)

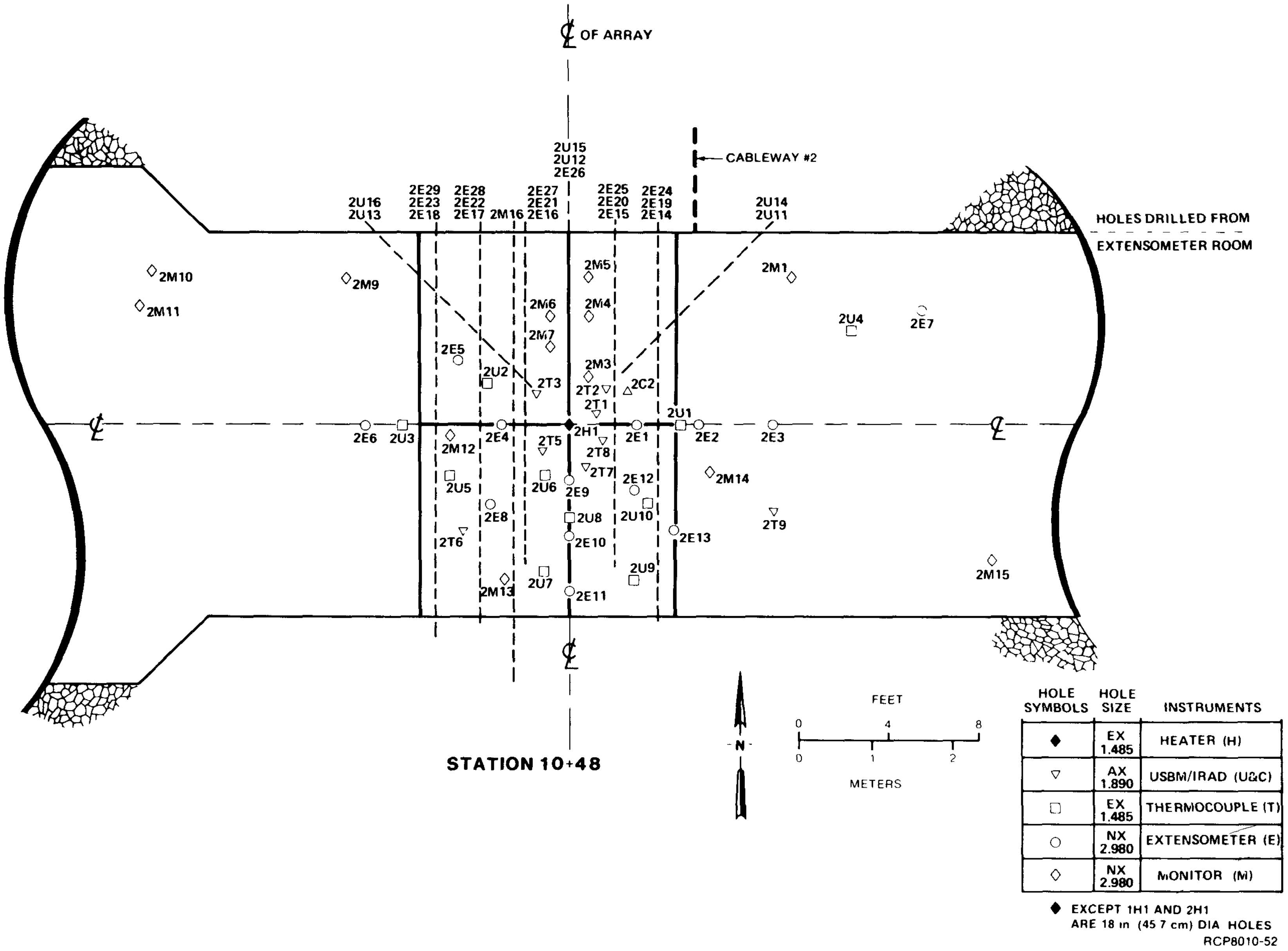

FIGURE 3. Plan View of Boreholes Drilled for Full-Scale Heater Test #2.

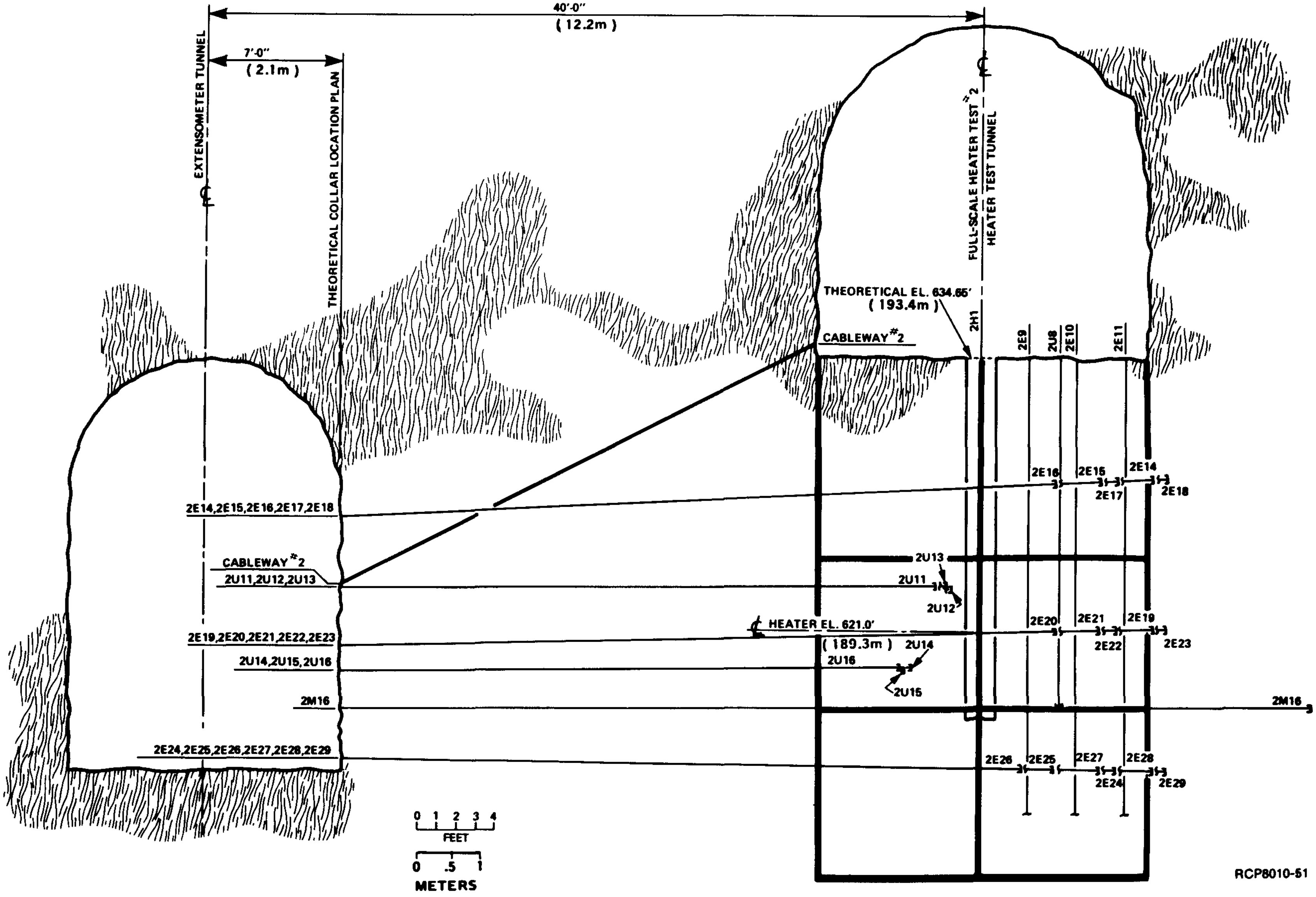

FIGURE 4. Elevation View of Boreholes for Full-Scale Heater Test #2 (looking east).

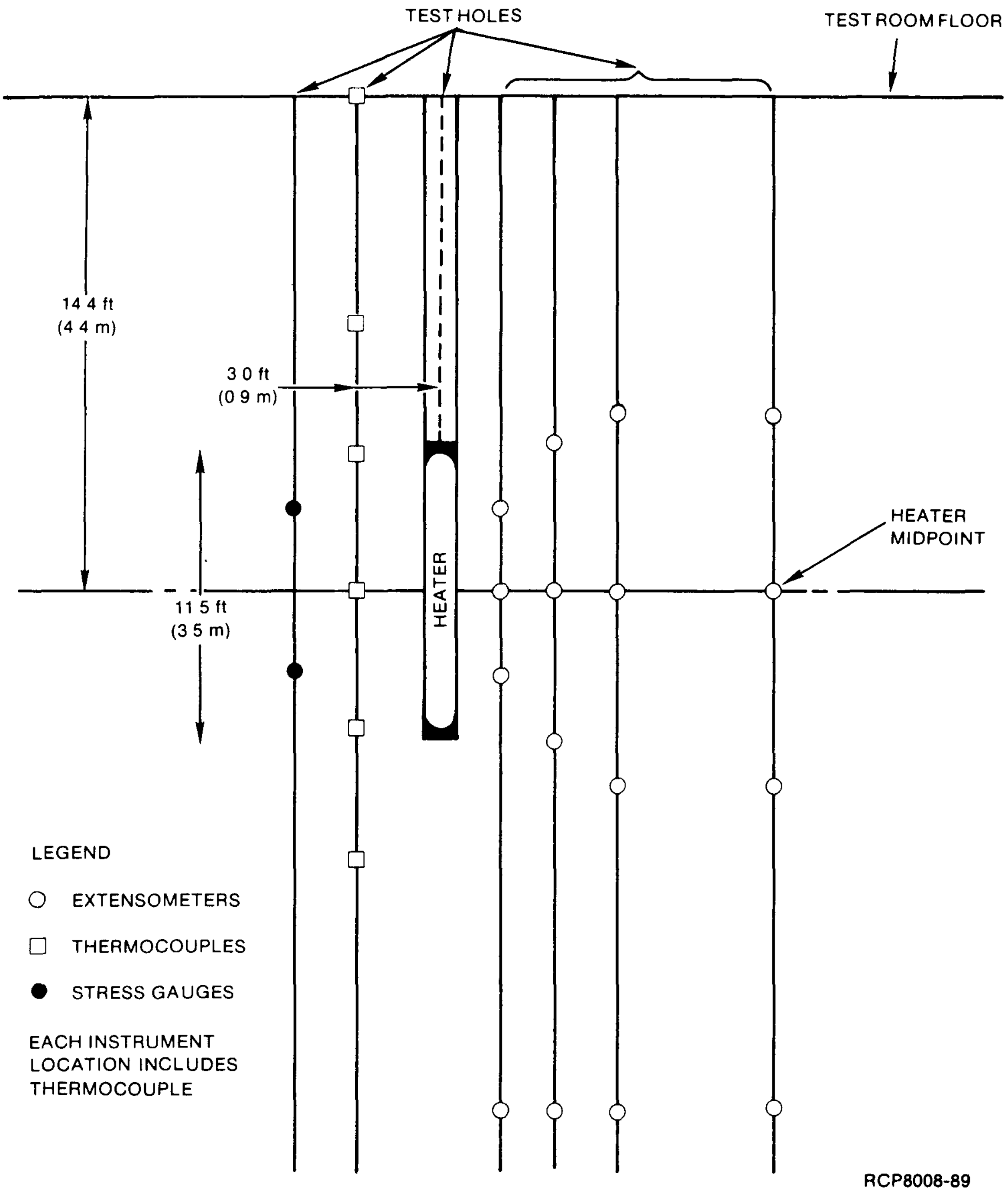

FIGURE 5. Schematic View of Typical Instrumentation Location in Full-Scale Heater Test #2.

- 5 USBM (1 gauge)--includes 1 thermocouple (vertical)
- 5 USBM/IRAD (1 USBM, 2 IRAD)-- includes 3 thermocouples/assembly (horizontal)
- 1 IRAD (2 gauges)--includes 1 thermocouple (vertical)
- 1 USBM (1 gauge)--includes 1 thermocouple (horizontal)
- 8 Thermocouple--includes 5 thermocouples/assembly (vertical).

INSTALLATION

The installation of the rock instrumentation systems required trained craft personnel. A 2-week class was conducted by Foundation Sciences, Inc. personnel to train the electricians and pipefitters. The course covered installation procedures for each instrument assembly type; i.e., extensometers, thermocouples, USBM gauges, and IRAD gauges. Two installation teams were selected; one to install the extensometers and thermocouple assemblies, and the other team to install the USBM and IRAD gauge assemblies (Figure 6).

Surveillance of the installation was performed and daily logs were used to record progress. Notations representing as-built instrument sensor placements were entered onto a set of master control prints to update the drawings upon completion of installation (Figure 7).

Installation of the rock instrumentation systems for Full-Scale Heater Tests #1 and #2 was completed in April 1980.

Full-Scale Heater Tests #1 and #2 were started July 1, 1980.

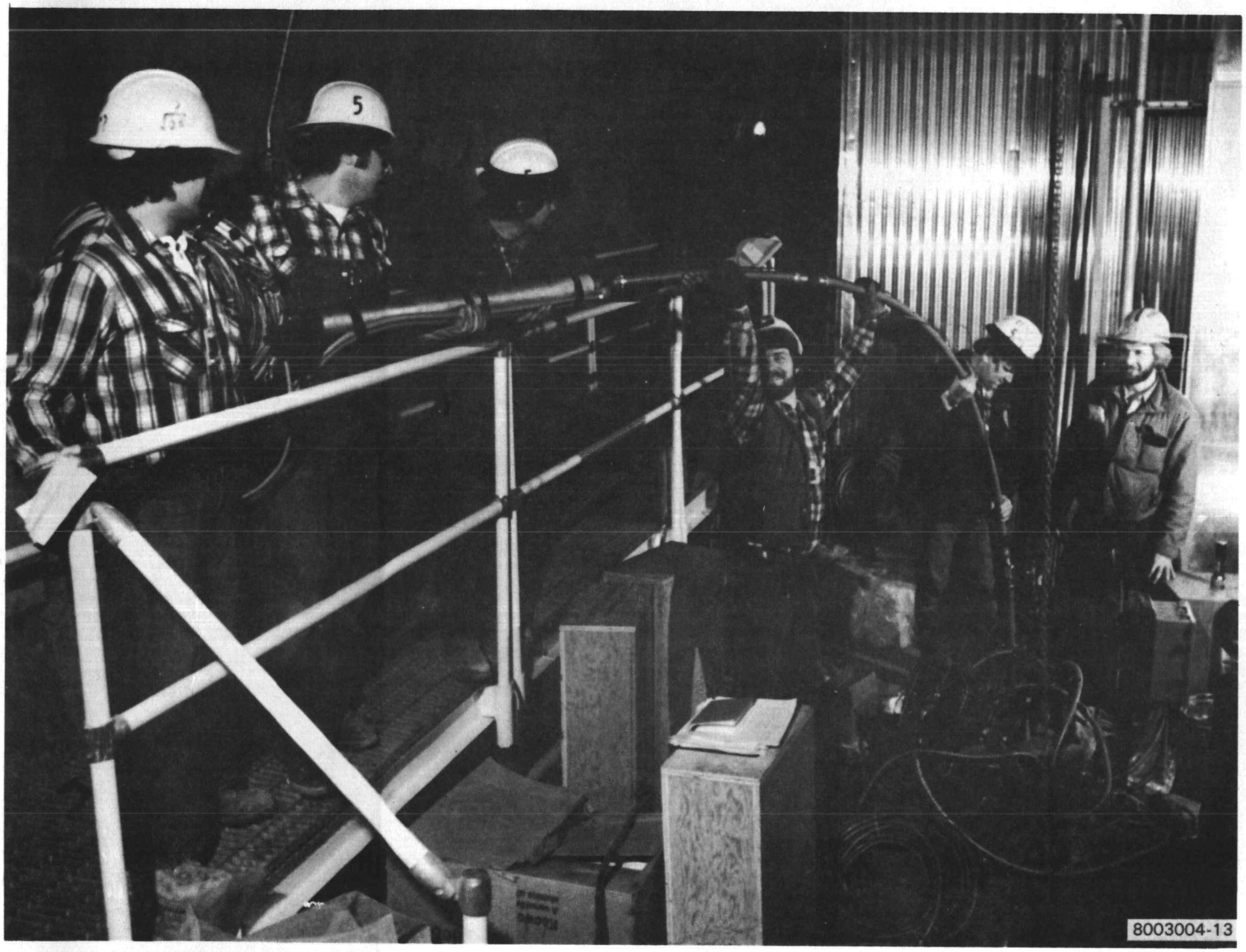

FIGURE 6. Installation of Extensometer.

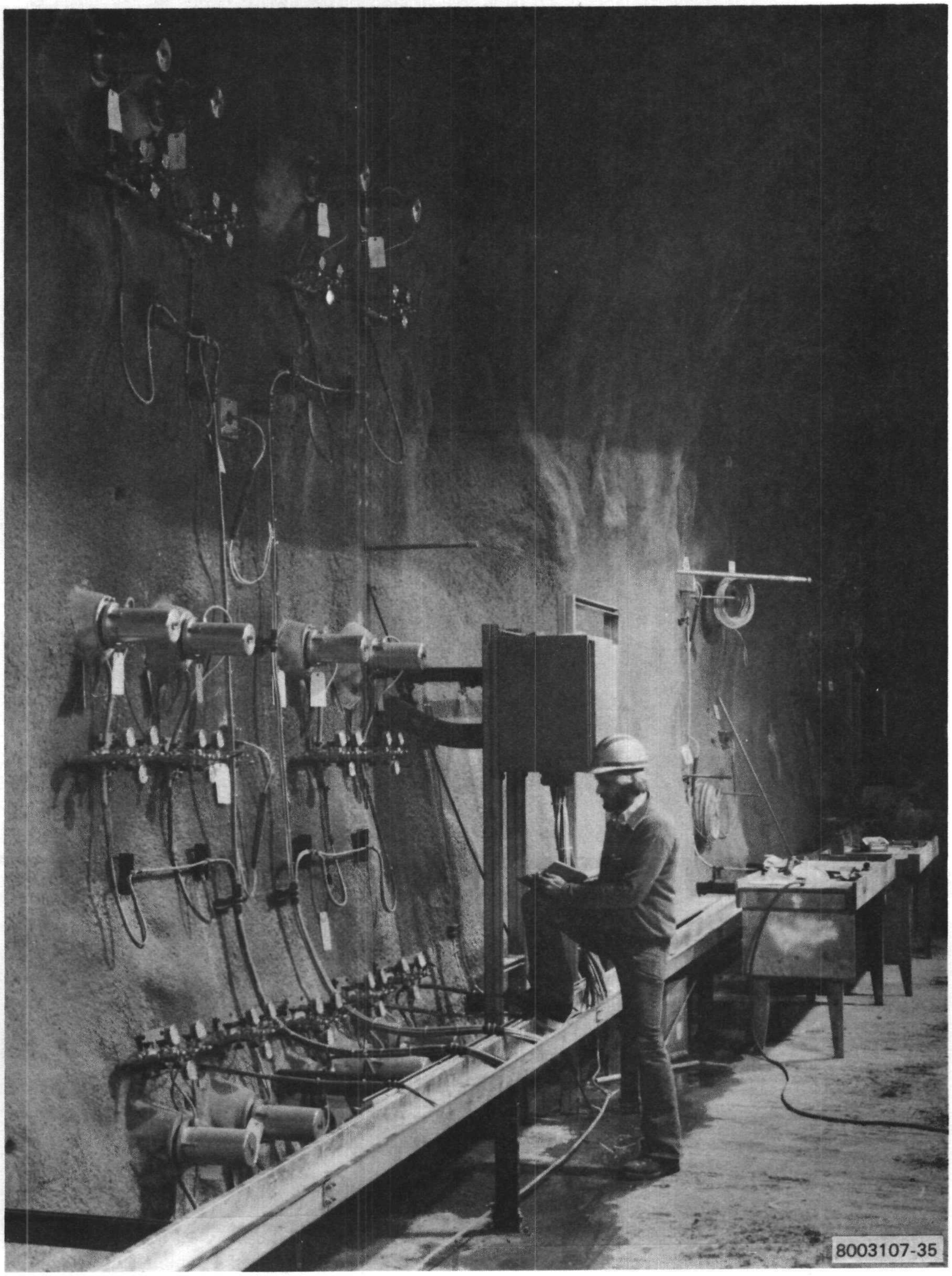

FIGURE 7. Taking Anchor Pressure Readings in the Extensometer Room.

DATA ACQUISITION SYSTEMS FOR THE NEAR-SURFACE TEST FACILITY

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The data acquisition system became fully operational on June 30, 1980. It is composed of both computer hardware and original software and is designed to capture, record, and process Near-Surface Test Facility instrument responses and theoretical data. Simply described, it is a surveillance and information system consisting of sensors, data loggers, and computers that produces a wide variety of on-line informational and analytical reports.

HARDWARE

The hardware component of the data acquisition system is depicted on Figure 1. Data loggers (block 1) receive analog signals from USBM gauges, extensometers, and thermocouples and digital signals from IRAD gauges via a scanner (block 2). The sensor responses are read at 1/2-hour intervals and these data are written on magnetic tapes (block 3), and input through data transmission channels (block 4) to the computer (block 5). The computer processes the data to provide plots on the graphics terminals (block 6), data on magnetic tapes (block 7), and produces other hard-copy and video outputs (block 8). The system is capable of monitoring a maximum of 1,018 sensors. Currently, approximately 900 sensors are active. Four data loggers, four tape drives, four graphics terminals, various other output devices, and two Data General M600 computers complete the system. These items are redundantly configured to provide a highly reliable data acquisition system.

SOFTWARE

The software component is described on Figure 2. The total software (block 1) is composed of two categories; those that execute automatically or by someone other than the systems analyst or programmer (block 2) and that executed by the programmer (block 8). The out-of-limits instrument status report provides the capability to retain a historical record of instrument performance, reliability, and out-of-tolerance information (block 3). The in situ model (block 4) supports real-time data acquisition. The graphics software (block 5) provides a variety of tables and graphs. These are discussed in more detail below. Likewise, the archive software (block 6) is discussed below. The field installation and verification module (block 7) is used for instrument calibration, rock instrumentation, and acceptance tests. Similarly, a programmer-executed code consists of recovery software, predicted data, and file/software support utilities (blocks 9, 10, and 11, respectively).

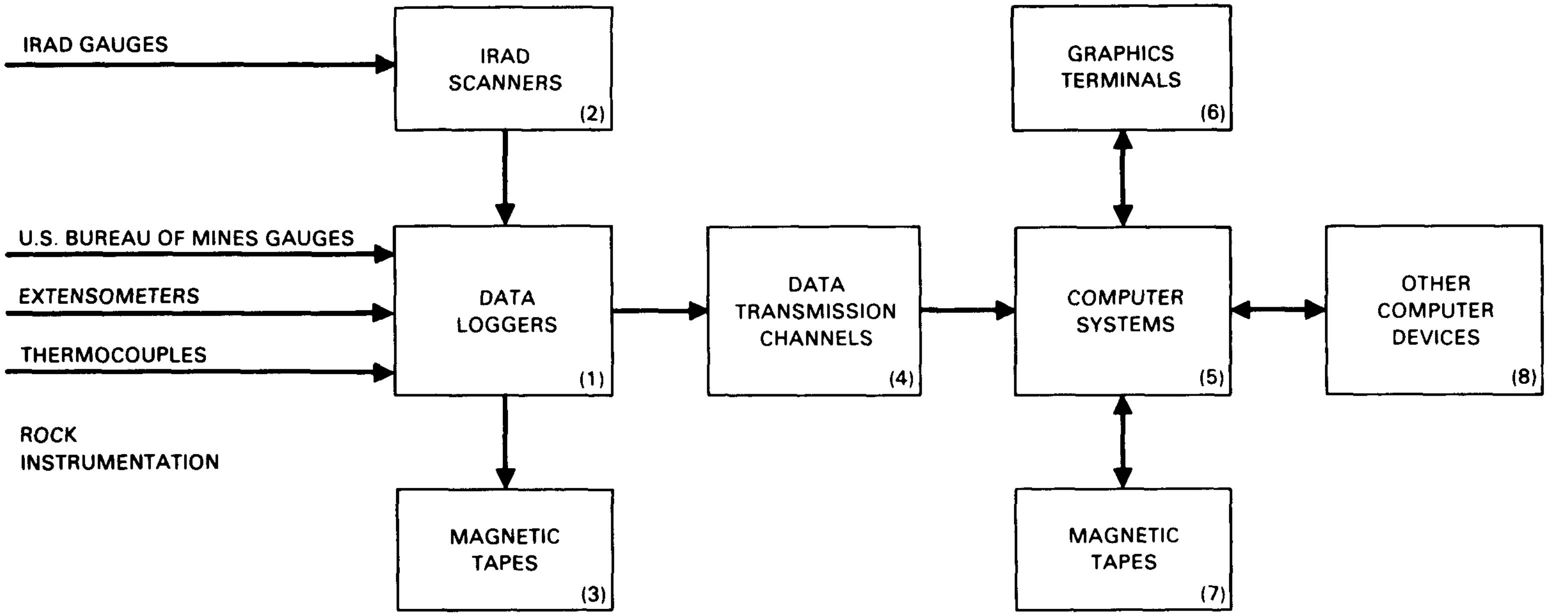

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FIGURE 1. Simplified Diagram of the Data Acquisition System.

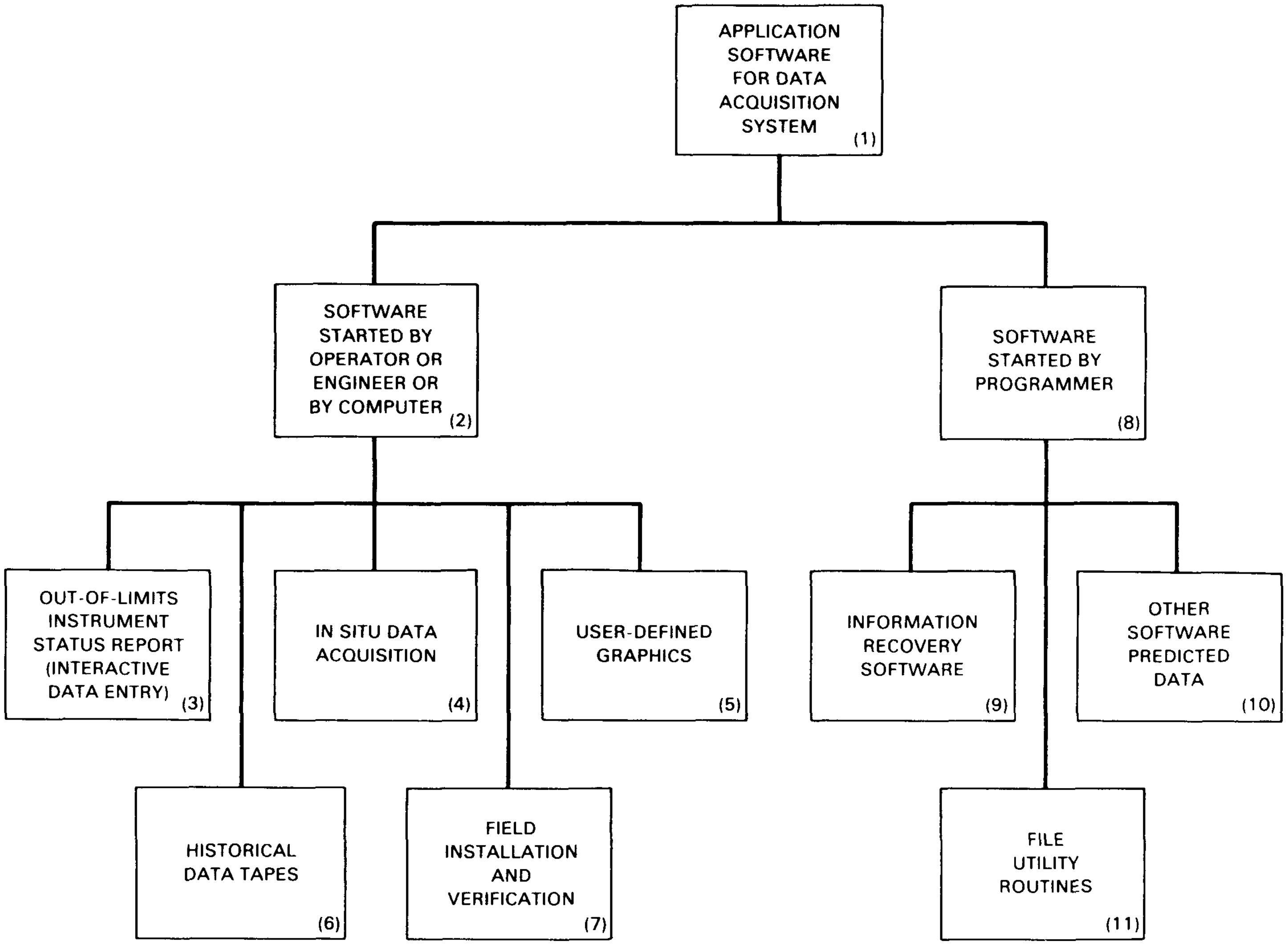

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FIGURE 2. Simplified Diagram of Software for the Data Acquisition System.

IN SITU DATA ACQUISITION

The system has been designed with such redundancy that the probability of data loss is very small. If both computer systems fail, in situ data are not lost. Raw data from each sensor are simultaneously recorded on two independent magnetic tapes. When one of the computers is operational again, information recovery software (block 9, Figure 2) is started by a programmer to insert the data into on-line files. On-line files allow the data to be readily examined by engineers, scientists, and technicians. This information recovery software provides the capability to restore the files to a complete state in the event of a total or intermittent failure of the data acquisition system components.

Each data logger (Fluke Model 2240-B) is equipped with a magnetic tape cartridge recorder (Columbia Model 300-C) to record all scan data independent of the data acquisition system computer availability. The tape cartridges are collected on a daily basis and retained indefinitely. Critical alarm functions such as power supply and instrument rack temperatures are also monitored by the data loggers.

USER-DEFINED GRAPHICS

Engineers and scientists may select from a wide variety of graphic output (block 5). These options are:

- Isotherm plots
- Heater power/heater temperatures
- Temperatures
- Displacement (vertical)
- Displacement (horizontal)
- Stress table
- Stress scatter (USBM)
- Stress (USBM) (vertical)
- Stress (USBM) (horizontal)
- Stress scatter (IRAD)
- Stress (IRAD) (vertical)
- Stress (IRAD) (horizontal)
- Stress ellipses
- Temperatures for other boreholes.

These routines allow the users to select from a "menu" of parameters to minimize keyboard (user) inputs.

ARCHIVES

Historical data tapes are produced for permanent storage in the Engineering Data Management-secured storage facility (block 6, Figure 2). Two types of data will be archived; processed data and configuration data. Processed data have been manipulated by the software. Configuration data describe the data acquisition system software. These data consist of: instrument descriptions (such as instrument identification and data logger channel number), graphics, program software modules, and system software. Processed data are categorized as raw converted data, smooth data, test analysis data, and out-of-limits data.

Raw converted data are raw data and reduced raw data converted to engineering units by programmed instrument algorithms. Smooth data are calculated values of the converted data that represent the statistical median of all individual readings (48) over a 24-hour period for each sensor. Test analysis data are a selected subset of the smooth data that are used for offsite analysis. Out-of-limits data are those raw converted readings that have gone outside predefined limits on each interval.

SYSTEM ACCEPTANCE AND DOCUMENTATION

The system has been formally accepted as an operational system. This was done by conducting carefully controlled acceptance test procedures on essential system functions. Data acquisition system user's manuals and operator manuals have been published. Software maintenance manuals are close to publication.

FUTURE DEVELOPMENTS

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

INSTRUMENT ALGORITHM DEVELOPMENT

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The objective of the instrument algorithm development effort is to provide the best instrument conversion algorithms for the needs of the Basalt Waste Isolation Project.

Included in this objective is the identification of further testing for the different instrument types which will be used to improve the understanding of the instrument's response to variations in its environment and, therefore, be used to improve the accuracy of the instrument conversion algorithms.

The instruments involved are: the USBM borehole deformation gauge shown in Figure 1, the vibrating wire stress meter (IRAD gauge) shown in Figure 2 and installed in a basalt cylinder in Figure 3, and the multiple position borehole extensometer shown in Figure 4. These instruments are now in use in Full-Scale Heater Tests #1 and #2 at the Near-Surface Test Facility located just below the surface of Gable Mountain.

The scope of this fiscal year's activities was limited to the results of the testing performed on the instruments prior to September 1980. The data were obtained from tests performed under subcontract to Foundation Sciences, Inc., Portland, Oregon. The testing centered on the USBM gauge thermal response and on the multiple position borehole extensometer Super-INVAR rod thermal expansion testing. Other tests were performed on selected gauges of all three types for the purpose of calibration and calibration verification prior to installation. The instrument conversion algorithm efforts required evaluation and integration of these various test results into a baseline set of conversion equations.

This development effort supports the Basalt Waste Isolation Project by providing the instrument conversion algorithms that are used to convert the electrical signals of the instruments into a measure of the changes in the rock parameters being measured by the gauge. This conversion is necessary to provide an input to the data verification efforts at the Near-Surface Test Facility and to provide meaningful data for evaluation of the test results. Additionally, the development effort identifies further testing which will result in a better understanding of these gauges. This understanding can then be used in the application of these instruments in follow-on Near-Surface Test Facility tests based upon a follow-on test's expected rock response. This understanding will also identify the minimum instrument sensitivity required for replacement of a gauge by a different gauge or different design of the same gauge.

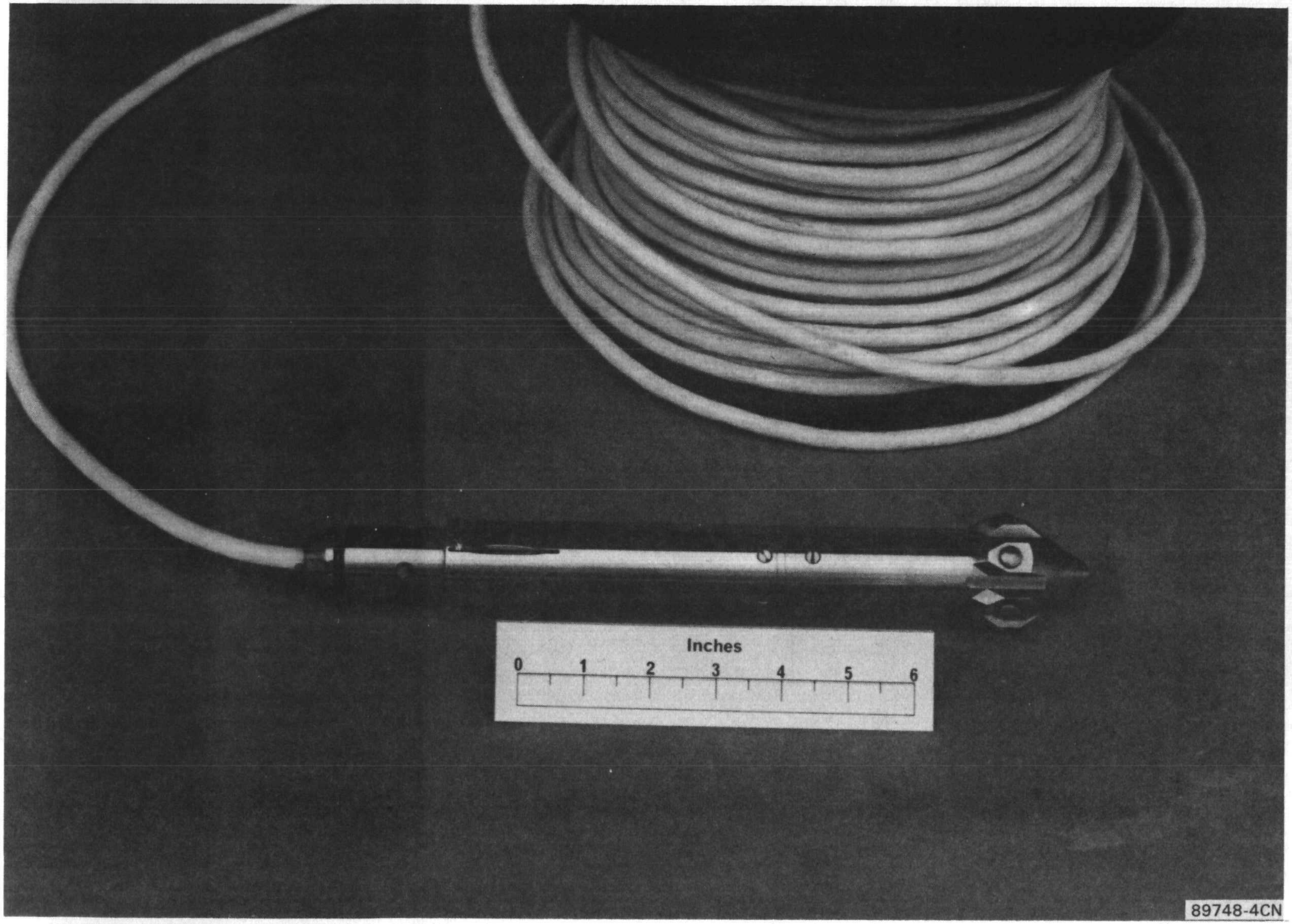

FIGURE 1. U.S. Bureau of Mines Borehole Deformation Gauge.

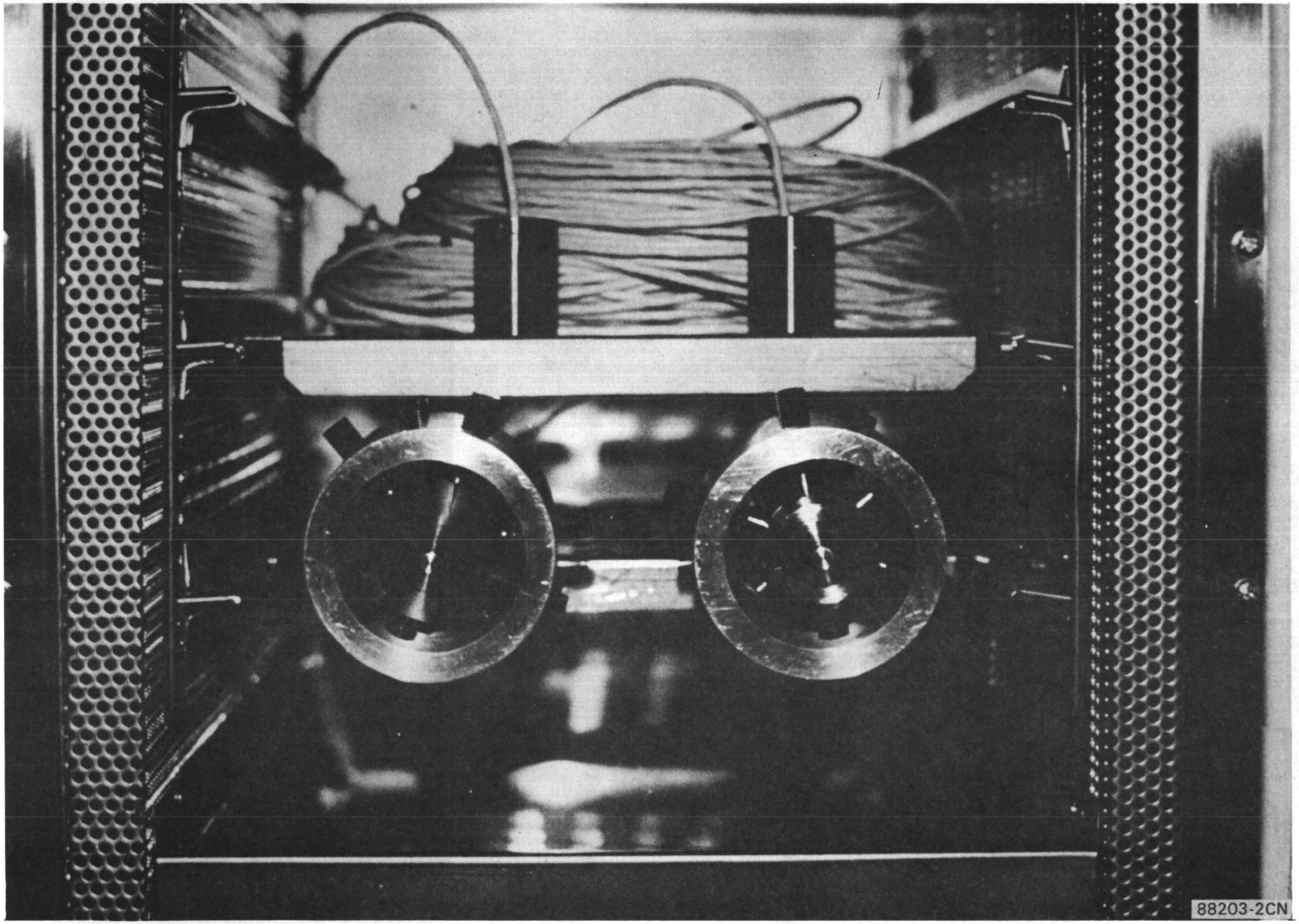

FIGURE 2. Vibrating Wire Stress Meter in the IRAD Gauge.

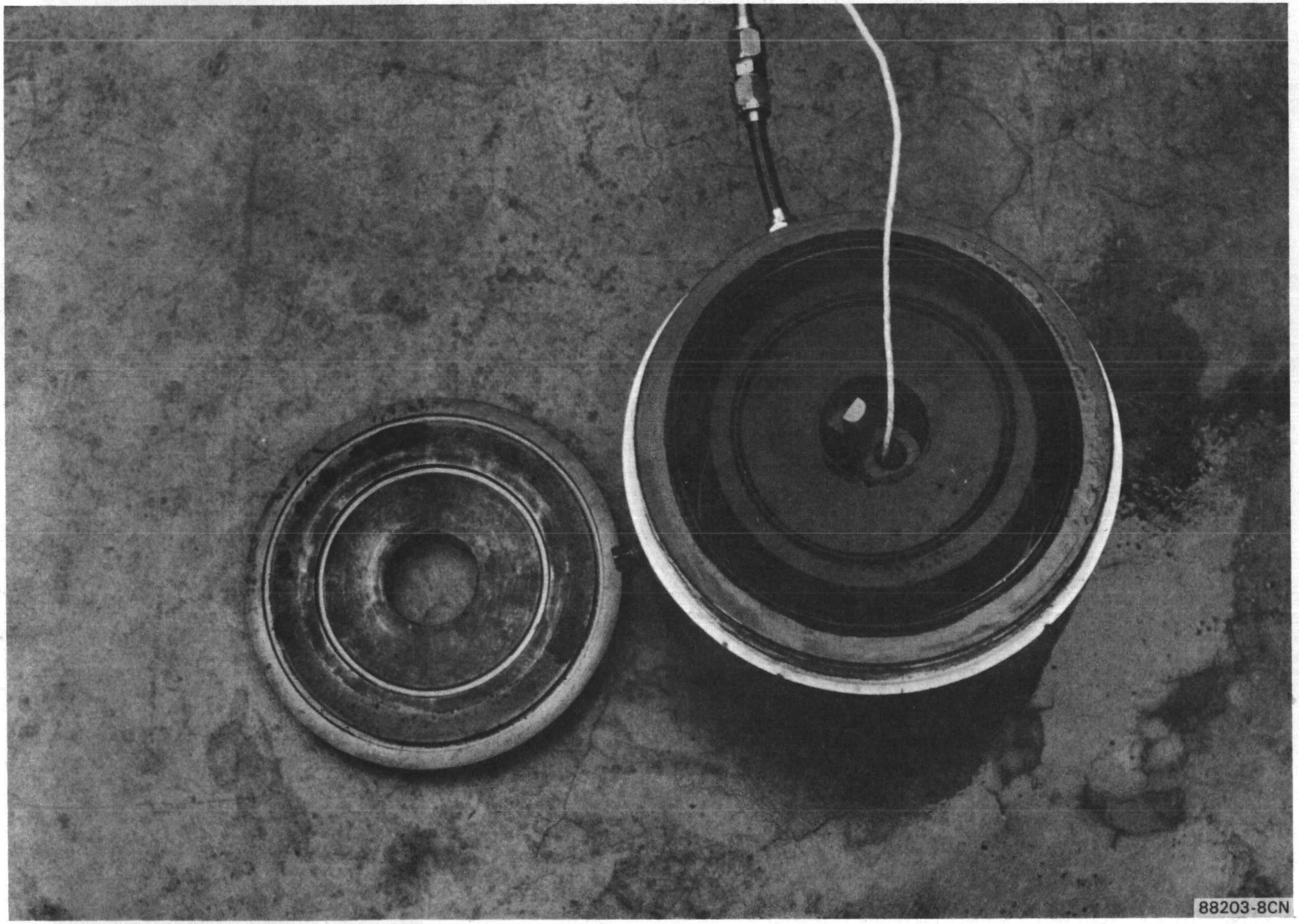

FIGURE 3. Vibrating Wire Stress Meter Installed in Basalt Cylinder.

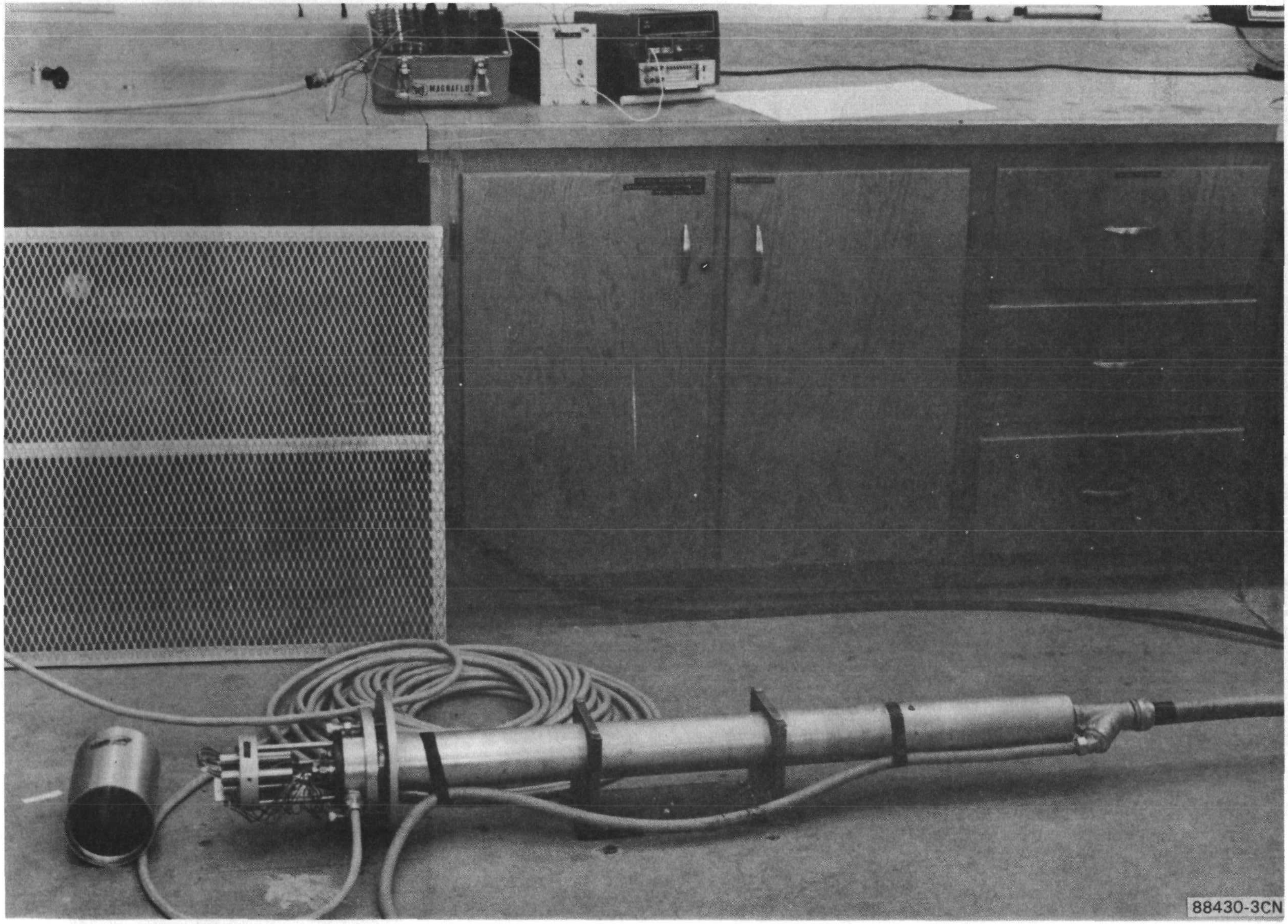

FIGURE 4. Multiple Position Borehole Extensometer.

The baseline instrument algorithm documents have been prepared for the three instrument types. Included in these documents, in addition to the instrument conversion algorithm, are a preliminary error analysis of the instrument conversion algorithm and the recommended additional testing.

Since the testing program produced a limited amount of data on the IRAD gauge thermal response, a preliminary measure of the error of that instrument's conversion algorithm response versus the actual instrument response was not obtainable. The preliminary error analysis for the USBM gauge and the multiple position borehole extensometer resulted in the approximate average or probable error values of 8% and 14%, respectively. These preliminary values are based on a small sample size and are expected to be refined by further testing and evaluation.

The relatively low values of error percentages give some support to the belief that the instruments will adequately record the rock responses for Full-Scale Heater Tests #1 and #2. The recommended additional testing is necessary to improve and refine the results so far obtained and to provide a basis for further instrument algorithm development actions (e.g., equation modifications, additional testing).

The instrument algorithm development effort is vital to the proper evaluation of the test results. Because the instrument conversion algorithm takes the electrical signal and converts it into engineering units, the accuracy of the results reported by the computer is directly related to the accuracy of the algorithm. The baseline algorithm documents provide the best instrument conversion algorithms attainable using the current data base, and they recommend the appropriate testing to further our knowledge of each instrument type.

ROCK MECHANICS FIELD TEST RESULTS TO DATE

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Various types of rock mechanics field tests have been conducted by the Basalt Waste Isolation Project at the Near-Surface Test Facility to enhance the capability of predicting the response of Columbia River basalt to thermomechanical loading resulting from decay of radioactive waste. The major tests that commenced in fiscal year 1980 were Full-Scale Heater Tests #1 and #2. These tests were designed to study basalt behavior in canister scale under simulated thermal loading conditions expected from waste canister emplacement in the underground rock.

Prior to the startup of the heater tests, a site characterization test program was undertaken. The program consists of in situ stress measurements by two different techniques before and after excavation of the Near-Surface Test Facility and in situ deformation property measurement by a borehole jacking method. The primary objective of these tests was to obtain the basic input parameters required for predictive modeling. The analysis of the test results has been completed, and areas for further investigation have been identified.

The test results that have been verified and analyzed are described here. A brief statement is included regarding the site characterization work to be conducted in the near future.

FIELD TEST SITE CHARACTERIZATION

In Situ Stress Measurements

As part of the site characterization effort, in situ tests were carried out to measure the state of stress and deformation properties of rock masses at the Near-Surface Test Facility. Two types of stress measurements were conducted, namely the hydraulic fracturing method and overcoring stress relief method using USBM gauges. The former test was performed before the excavation of the Near-Surface Test Facility and the latter after completion of the facility.(1)

Although the high fracture frequency (12 to 18 fractures per meter) inherent in columnar basalt caused serious difficulties in conducting tests and interpreting the results for both tests, a reasonable agreement was found in the results obtained by these two contrasting test methods. The results are summarized in Tables 1 and 2 for comparison.

TABLE 1. Results of Pre-Excavation In Situ Stress Measurements by Hydraulic Fracturing Method.

Test No.	Depth (meters)	σ_v (megapascals)	σHmin (megapascals)	σHmax (megapascals)	σHmax (direction*)
1	16.8	0.4	0.8	14.6	N70°W
6	43.9	1.2	1.6	15.1	N80°W
2	52.6	1.4	1.0	13.6	N70°W
3	59.7	1.7	1.2	18.7	N40°W
5	61.0	1.7	1.4	22.6	-
4	69.2	1.9	1.9	24.3	N50°W

*Rounded to the nearest 5 degrees.

TABLE 2. Comparison of Principal Stresses Measured by Overcoring and Hydrofracturing Methods at Near-Surface Test Facility Level.

Overcoring Method USBM		Hydrofracturing Method	
Magnitudes (megapascals)	Orientations	Magnitudes (megapascals)	Orientations
6.9	N81°W (11 degrees up)	13.6	N70°W
2.1	N8°E (5 degrees up)	1.0	N20°E
2.1	S65°W (77 degrees up)	1.4	Vertical

Two points can be made by examining the above results. One is that the orientations of the principal stresses are within about 10 degrees of each other, which is in excellent agreement considering the difficulties encountered in the tests. Furthermore, the maximum stress orientation is parallel to the long axis of Gable Mountain. The other point is the contrasting difference in the magnitudes of the maximum principal stresses. Although this difference can be explained, more tests by other methods would be a better approach to resolve this discrepancy in stress magnitudes.

In Situ Rock Mass Deformation Property Measurement

The rock mass deformation properties were measured by a borehole jacking test. The Goodman jack was selected because of the simple operation and relatively large amount of published data obtained by this method. Most pressure displacement curves obtained from six holes exhibited an upwardly concave trend at low pressure and fairly linear behavior at high pressure above 20 megapascals. This behavior supports the use of the bilinear model in numerical prediction. Some curves showed very pronounced hysteresis loops which are attributed to the joint displacement. Two typical pressure displacement curves are given on Figure 1. The tangent moduli calculated at the linear portion of the curves and corrected by Heuze and Salem's method(2) are tabulated in Table 3.

TABLE 3. Average Tangent Moduli Obtained by Goodman Jack Test above 20 Megapascals.

Holes	Depth of test (meters)	Avg. Tan. Moduli (gigapascals)	
Horizontal	1.5 to 13.7	18.76	1.86
Vertical	6.1, 7.6	13.10	1.93
	1.5, 3.0	6.90	0.69

In general, the basalt in the test area (Full-Scale Heater Tests #1 and #2) exhibits moderately anisotropic deformation behavior. The joint property is considered a predominant factor governing the behavior. The in situ modulus, 13.1 to 18.8 gigapascals, obtained by this method is, as expected, substantially lower than the intact modulus, 89.0 gigapascals, but is close to the estimated value of 30 gigapascals obtained from Bieniawski's(3) empirical equation, E_m = 2 x RMR-100 gigapascals, where E_m = rock mass modulus, RMR = rock mass rating (65 for Pomona basalt). This result compares favorably with other published results (Figure 2).

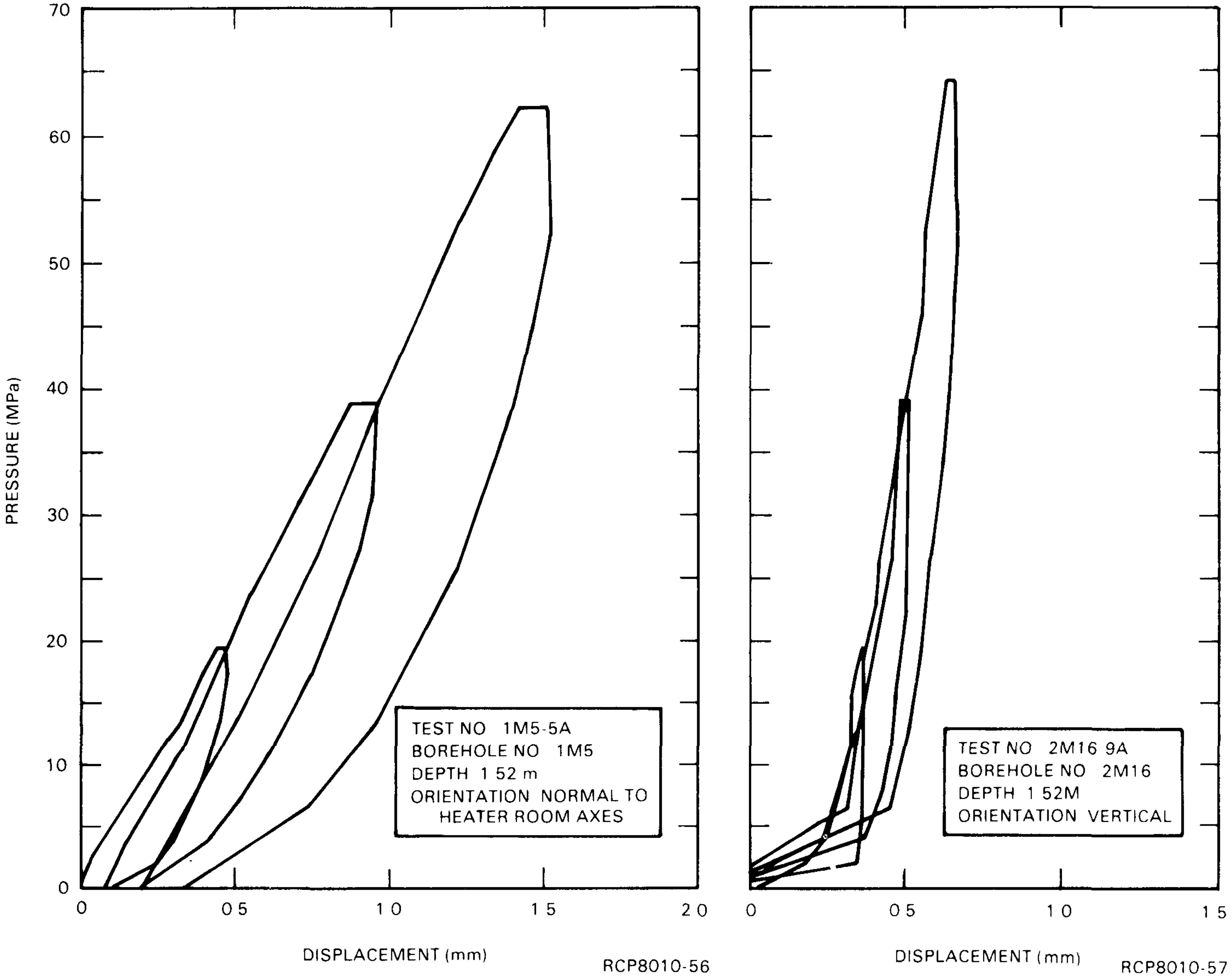

FIGURE 1. Pressure-Displacement Curve Obtained from (left) a Vertical Borehole and (right) a Horizonal Borehole.

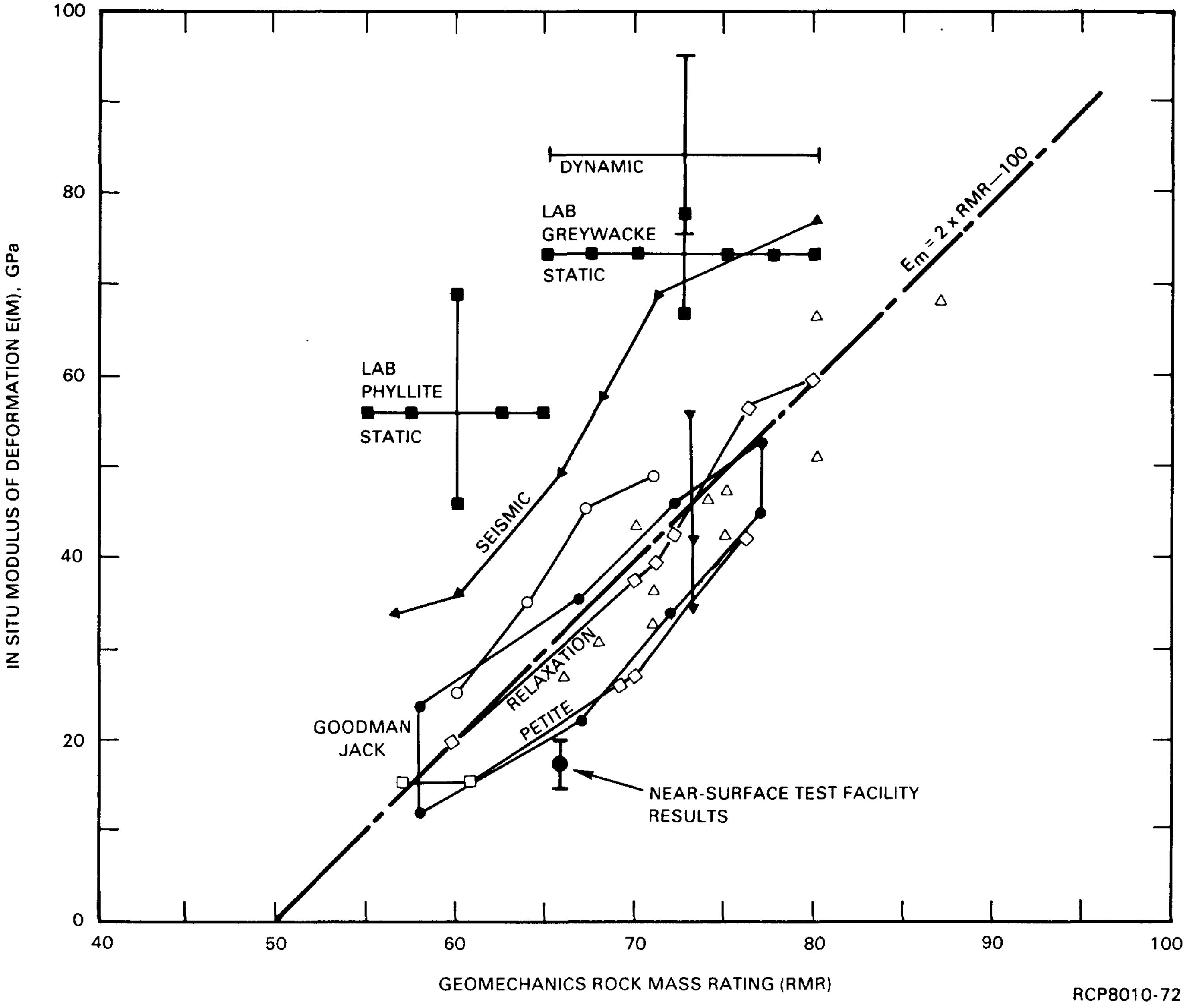

FIGURE 2. Rock Mass Rating Versus In Situ Modulus of Deformation.(3)

Further tests, such as the Jointed Block Test, should be able to verify the validity of each method attempted to estimate the representative rock mass moduli.

Full-Scale Heater Tests

Full-Scale Heater Tests #1 and #2 were initiated on July 1, 1980. Full-Scale Heater Test #1 was designed to simulate the expected repository conditions on the canister scale and Full-Scale Heater Test #2 was to determine the thermal condition at which the onset of borehole instability occurs.

The data generated from 740 channels of four instrument types are collected every 30 minutes around the clock. This massive amount of data is being validated. The predictive data(4) are used as a guideline for data verification. At present, temperature data appear to be reasonably close to prediction. The deformation and stress data require further work to be validated; i.e., the algorithm needs to be substantially refined. A vigorous effort is being made to improve the algorithm through calibration of more instruments at operating conditions.

Isotherm plots for Full-Scale Heater Tests #1 and #2 are given on Figure 3. Both plots exhibit slight nonsymmetry, probably caused by anisotropic material properties of the basalt. A typical predicted versus actual (measured) data plot is given on Figure 4. These data are from thermocouples grouted in a vertical borehole 0.4 meter away from the main heater in Full-Scale Heater Test #1. In this particular plot, the measured values were only slightly lower than predicted values.

CONCLUSIONS

The heater tests are progressing smoothly, producing information regarding basalt behavior under thermal loading. The current effort on data verification and refinement of a conversion algorithm and subsequent analysis is directed toward the validation of a predictive model which will be eventually used for repository design. The forthcoming Jointed Block Test and other planned tests will greatly enhance the present level of understanding of basalt behavior under thermal loading.

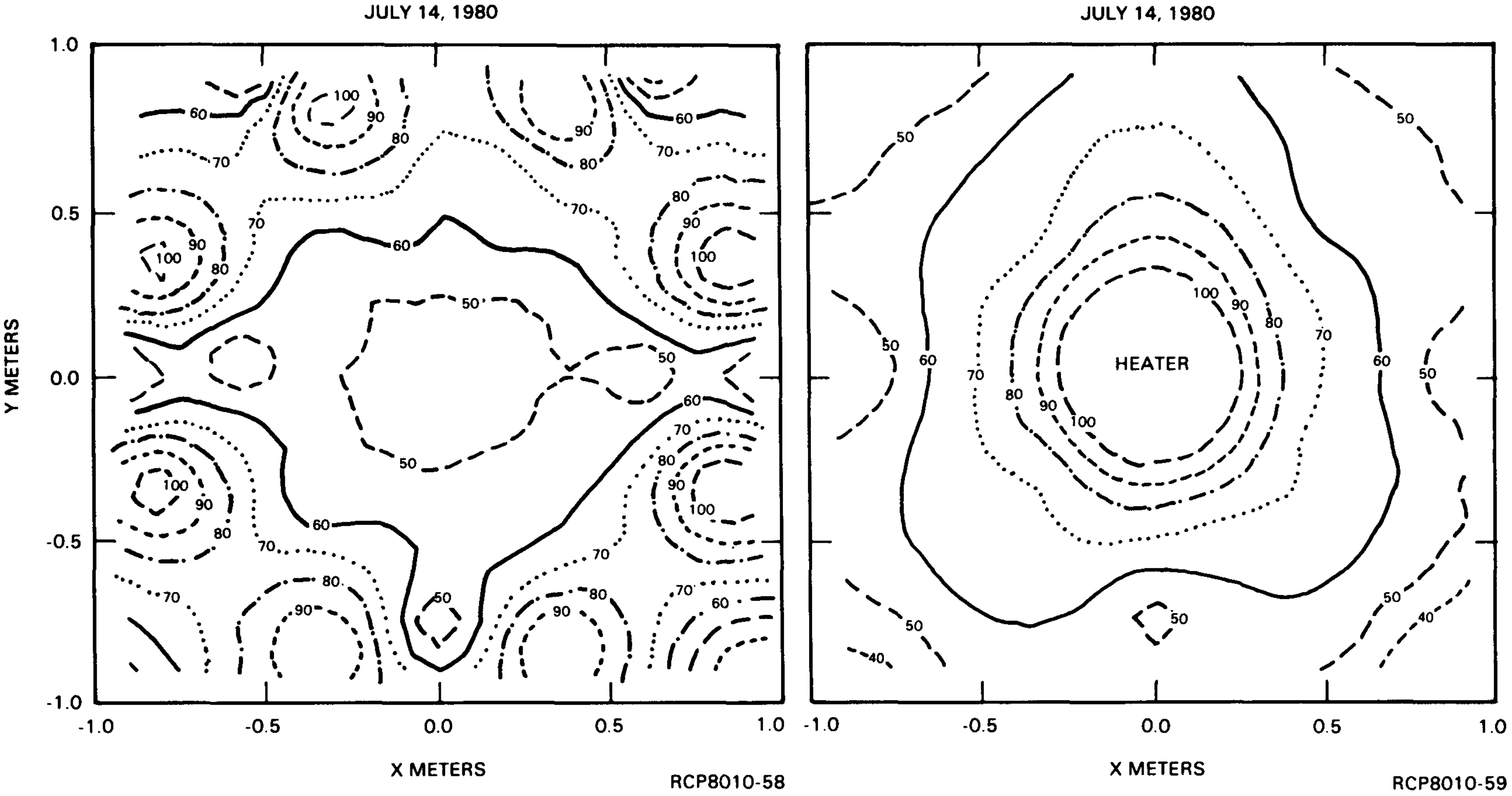

FIGURE 3. Isotherm Plot of Actual Temperature (^{0}C), Midplane of (left) Full-Scale Heater Test #1 and (right) Full-Scale Heater Test #2 Main Heater.

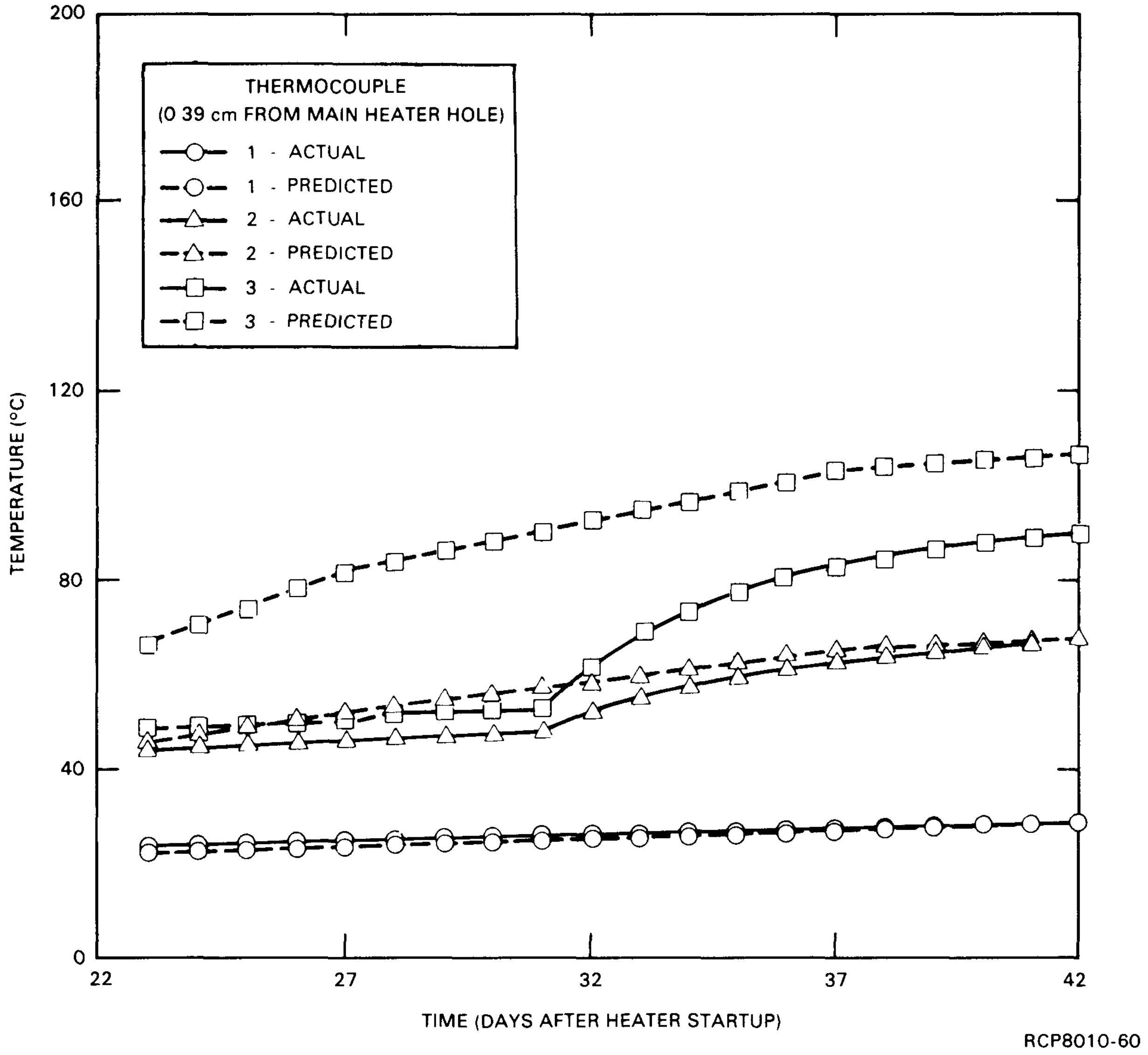

FIGURE 4. Temperature (°C) Versus Time (Days)--Actual and Predictive Data for Thermocouples Grouted into Vertical Borehole IT01 (Full-Scale Heater Test #1).

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FUTURE TESTS AT THE NEAR-SURFACE TEST FACILITY

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JOINTED BLOCK TESTS

Jointed Block Tests are planned and Room-Scale Tests have been scoped as possible parts of the Phase I testing program. The Jointed Block Tests are in preparation and will start early in 1981.

The Jointed Block Tests are designed to measure the following rock mass characteristics:

- Deformability as a function of temperature, stress, rock mass quality, and direction
- Thermal expansion as a function of temperature, stress, rock mass quality, and direction
- Thermal conductivity as a function of temperature, stress, rock mass quality, and direction.

A conceptual design of a Jointed Block Test is shown in Figure 1. The size of the Jointed Block Test was selected from knowledge of scale effects in various rock types. Since the fracture spacing of minor joints in many basalt flows is similar to the Pomona flow, a block size of 2 meters square was chosen to adequately represent the rock mass.

SCOPING ANALYSIS AND TEST DESIGN FOR THE JOINTED BLOCK TESTS

Three-dimensional thermomechanical scoping analyses were computed to evaluate instrument and heater locations and electric heater power levels. Calculations were based on the assumption that the rock mass is homogeneous and the thermomechanical properties are linear.

Placement of heaters within the block will be limited to approximately five 1-kilowatt heaters with the balance (majority) of the heaters located peripherally outside of the slot. This approach will minimize violating the test specimen while allowing the block to be heated to a planned 200°C.

Thermal gradients may induce compressive and tensile stresses in the block. Due to the significance of tensile stresses on rock mass disturbance, the selection of temperature gradients and flatjack pressures must be chosen to minimize induced tensions in the block. Further analyses must be undertaken to predict the optimum temperature gradients for this test. With the aid of peripheral heaters, thermal gradients across the block can be controlled, ensuring minimal disturbance to the rock. The induced thermal strains and displacements will be monitored by deformation gauges and extensometers.

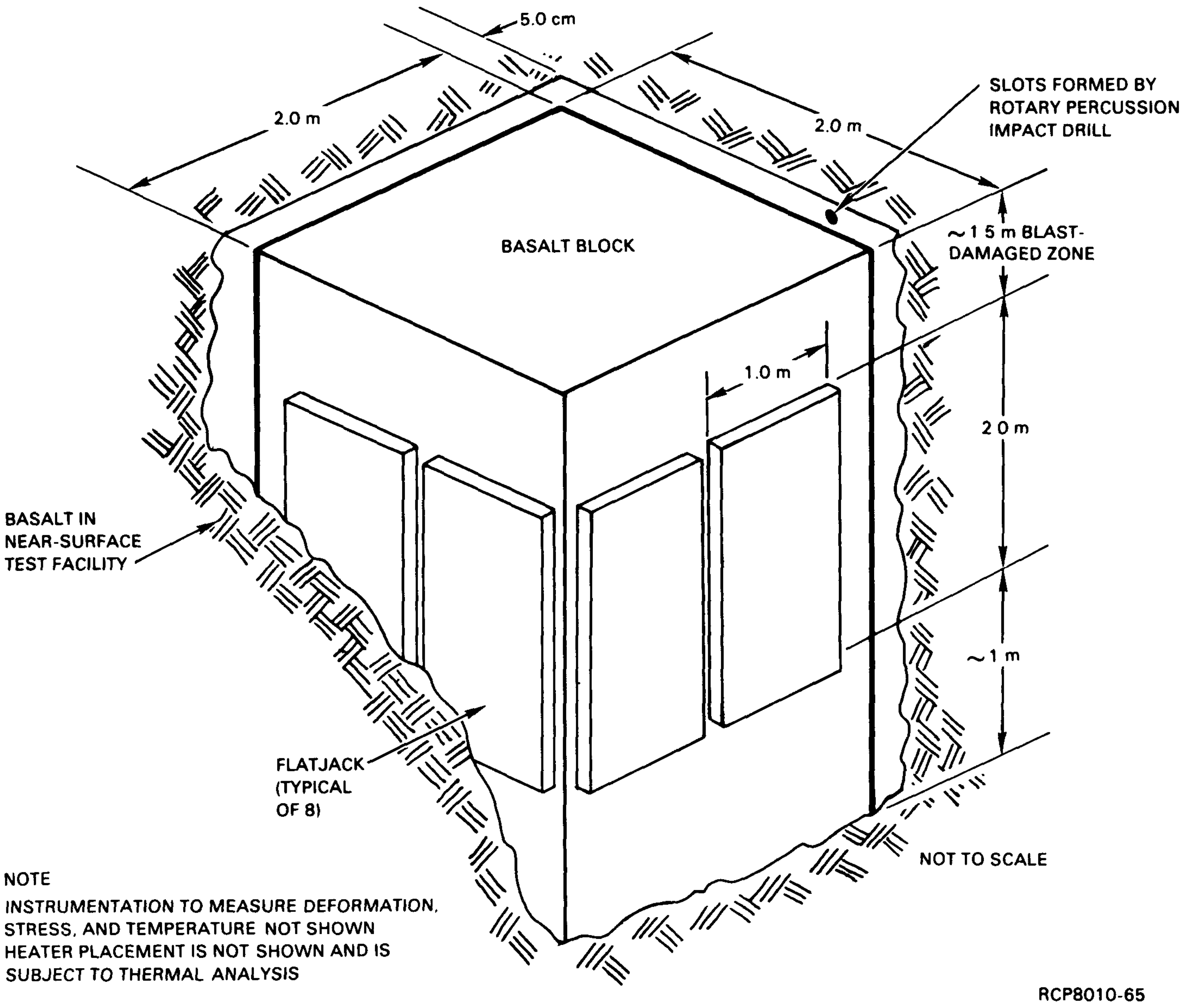

FIGURE 1. Conceptual Jointed Block Test Design.

The basic test program will increase the confining pressure in approximately five steps to a maximum of 20 megapascals. (The actual maximum will be a function of flatjack performance and the ability of the surrounding rock mass to support these stress levels.) At each step, the temperature of the block will be cycled from ambient to approximately 200°C and back to ambient.

Rock mass thermomechanical response will be sensed by borehole deformation gauges, extensometers, and thermocouples. Output signals will be digitized by data loggers and recorded on magnetic tape. The tapes will then be processed by a mini computer to provide various formatted data outputs.

ROOM-SCALE TESTS

The Room-Scale Tests are being considered to evaluate the thermomechanical response of basalt on a room scale when thermally loaded. By heating the basalt surrounding a room, a stress condition of 5 megapascals (the thermal loadings expected above the Near-Surface Test Facility in situ condition) will be achieved. This generic testing technique will provide a technical bridge between the Near-Surface Test Facility and any room-scale testing at depth.

A generic room-scale test has been scoped and is undergoing review. If conducted at the Near-Surface Test Facility, the test shall:

- Demonstrate the feasibility of test concept
- Stress a large volume of basalt to provide data on the impact of local variations in rock mass quality on thermomechanical response
- Provide data for validation of thermomechanical predictive analyses on a room scale under controlled test conditions.

The Room-Scale Test will help to determine thermomechanical response, on a room scale, of the roof support system when subjected to uniform thermal loading. This is needed to analyze nonlinear behavior and the effect of pillar confining condition when using a large-scale test in a highly jointed crystalline rock. Exact placement of the heaters will require analytical methods to ensure the overhead rock will remain in compression during the test period.

Rock instrumentation (borehole deformation gauges, extensometers, and thermocouples) will measure the thermomechanical response of the basalt, data loggers will digitize these signals, and a mini-computer will process the data and provide permanent records.

NUCLEAR WASTE TESTING AT THE NEAR-SURFACE TEST FACILITY

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

These tests will employ two spent fuel assemblies and one vitrified waste form. Each unit will be inserted into a spent fuel canister designed by Westinghouse-Advanced Energy Systems Division, Pittsburgh, Pennsylvania. The loaded canisters will be shipped to the Near-Surface Test Facility in a shipping cask, where they will be transferred into a bottom loading transporter for emplacement into the floor of the test room. The rock instrumentation, data acquisition, site characterization, and operations will be similar to those of Full-Scale Heater Tests #1 and #2.

SPENT FUEL/VITRIFIED WASTE ASSEMBLIES

The present plan is to obtain the spent fuel assemblies from the Turkey Point reactor operated by Florida Power and Light Company or from the climax test at the Nevada Test Site. These assemblies are from a pressurized water reactor built by Westinghouse. One spent fuel assembly will be 5 continuous years out of the reactor at the time of delivery to the Near-Surface Test Facility, with a total burnup between 26,000 and 33,000 megawatt days per metric ton. This fuel assembly will produce a nominal heat generation rate of $\sim$1 kilowatt at the beginning of Phase II testing. The second fuel assembly will be 2 years out of the reactor at the time of delivery to the Near-Surface Test Facility with the same burnup rate as specified above. This assembly will produce a heat generation rate of 2.45 kilowatts at the beginning of Phase II testing. The source of the vitrified waste form will be the Pacific Northwest Laboratory, Richland, Washington and the thermal output will be approximately 1 kilowatt, similar to 5-year-old spent fuel.

CANISTER DESIGN

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

- The canister is divided into four main pieces; the body, the lower end cap, the fuel assembly support ring, and the closure lid. The lower end cap and closure lid are fabricated from a standard ellipsoidal end cap having a 2:1 ratio between major and minor diameters.
- The weld for the canister lid/body was made using the plasma arc welding process. This method was selected following testing and evaluation of several alternatives.
- The evacuation and backfill collar encircles the lid/body joint (unwelded) and connects to a vacuum/helium backfill system. The top and bottom rings form an atmospheric seal, while the center ring fittings connect to the vacuum/helium system.
- The drop tests from a height of 9.1 meters in the vertical orientation resulted in the following design changes: (1) to have the lower support rung rest in a machined taper in the end cap vice fusing the plate to the body, (2) increase end cap thickness from 0.635 to 0.953 centimeters, and (3) eliminate the reversed-dished end cap to the present ellipsoidal shape.
- The seismic loading was a 0.7 g maximum horizontal earth motion event with no detectable effect on the canister, hence no reduction in its integrity.
- The shipping cask/canister thermal interference study indicated that both casks being considered for shipping have tight diameter and length clearances.
- The initial development of the ultrasonic system indicated it was a viable method. Due to fund restraints, the design and proof testing was not completed, but it is believed this system can be made operational without changes to the canister or Engine-Maintenance and Disassembly Facility equipment design.
- The pintle required for the canister is to be compatible with the Near-Surface Test Facility grapple design for the bottom loading transporter.

The vitrified waste form (in a Pacific Northwest Laboratory canister) is physically smaller than a pressurized water reactor spent fuel assembly and, therefore, will require a "cage" such that the currently designed canister can be used for both waste forms. Also, modifications to the Pacific Northwest Laboratory canister are required.

SHIPPING CASKS

During the past year, several shipping casks have been investigated for use in transporting the spent fuel and vitrifed waste to the Near-Surface Test Facility. The two candidate casks are the Nuclear Assurance Corporation cask and the NL Industries cask. Initially, the Nuclear Assurance Corporation cask was viewed as the most available and adaptable for canister transport; however, a major effort may be required for license renewal at the end of this year. The NL Industries cask will require some licensing modification, but added costs will be incurred to retrofit the Pacific Northwest Laboratory facility for handling this cask and performing dry runs. The Office of Nuclear Waste Isolation is assessing both casks to determine the preferred cask for shipment of both spent fuel and vitrifed waste.

CHAPTER VI

REPOSITORY STUDIES

SUMMARY OF FISCAL YEAR 1980 REPOSITORY DESIGN ACTIVITIES

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Repository conceptual design work was initiated in October 1979 as part of the Basalt Waste Isolation Project's mission to establish the feasibility and to provide the technology needed to design and construct a nuclear waste repository in the Columbia River basalts which underlie the Hanford Site. The U.S. Department of Energy selected the joint venture of Kaiser Engineers, Inc. and Parsons Brinckerhoff Quade and Douglas, Inc. to perform the conceptual design.

This paper highlights the criteria which represent the technical baseline for conceptual design of a nuclear waste repository in basalt.

The function of the repository is to isolate nuclear waste from the biosphere so it poses no significant threat to public health and safety. Nuclear waste forms requiring isolation are:

- Spent fuel from commercial light water reactors
- Commercial low-level transuranic waste
- Commercial high-level waste from the reprocessing of spent light water reactor fuels
- Defense high-level waste
- Defense low-level transuranic waste.

The nuclear waste repository in basalt conceptual design is based on the receipt and storage of commercial spent fuel and low-level waste. Supporting engineering studies are being conducted to evaluate the impact on the nuclear waste repository in basalt conceptual design of the receipt and storage of both commercial and defense high-level wastes.

The purpose of the conceptual design is to assist in the determination of the feasibility of constructing a repository in basalt. The design philosophy for the conceptual design effort, in order of importance, is:

- Maximize the safety of the public and the worker
- Minimize the impact to the environment
- Minimize the total cost of construction, operation, and decommissioning.

The purpose of the nuclear waste repository in basalt is to provide permanent, environmentally safe, and secure underground storage of nuclear waste. The facility design will fulfill federal requirements for responsible custody and permanent isolation of commercial radioactive waste in the United States. The nuclear waste repository in basalt will be owned by the Federal Government under the control of the U.S. Department of Energy and will be licensed by the U.S. Nuclear Regulatory Commission.

The storage medium will be the Columbia River basalts. Waste will be stored 1,128 meters below the surface, with access shafts to the mine level the only penetrations of the natural confinement barrier which isolates the waste from the biosphere.

Waste will be shipped to the repository from a federal packaging facility. Upon receipt it will be processed and overpacked. The resulting waste packages will be transported to the subsurface for storage. The waste flow is illustrated in Figure 1.

The repository will receive and store waste for a period of 20 years. It will remain operable until retrievability of the waste is no longer required. 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 ensure safety. Occasional retrieval of stored waste may be required and would be conducted concurrently with disposal operations.

The repository will receive waste at a constant rate and will have the ultimate capacity to store a total of 35,000 waste packages, each containing a canister with fuel rods from seven boiling water reactor or three pressurized water reactor spent fuel assemblies. A total of 103,250 boiling water reactor and 60,500 pressurized water reactor assemblies will be accommodated by the repository. Canisters will be received and will be overpacked at the repository to form the waste ackages. Storage capacity also will be provided for 32,000 drums of low-level waste received from offsite, in addition to in-plant generated waste.

The design will allow for incremental development of the subsurface facilities over the period of use and include provisions for expansion of capacity and of operating periods. If the repository is expanded after its currently planned capacity is reached, the expansion will be at the rate of 1,750 canisters of 10-year-old fuel per year

The repository will eventually be backfilled and sealed during decommissioning.

The major physical components of the repository are indicated in the work breakdown structure of Figure 2.

The functions of the major systems which comprise the repository are illustrated in Figure 3 and described in summary below.

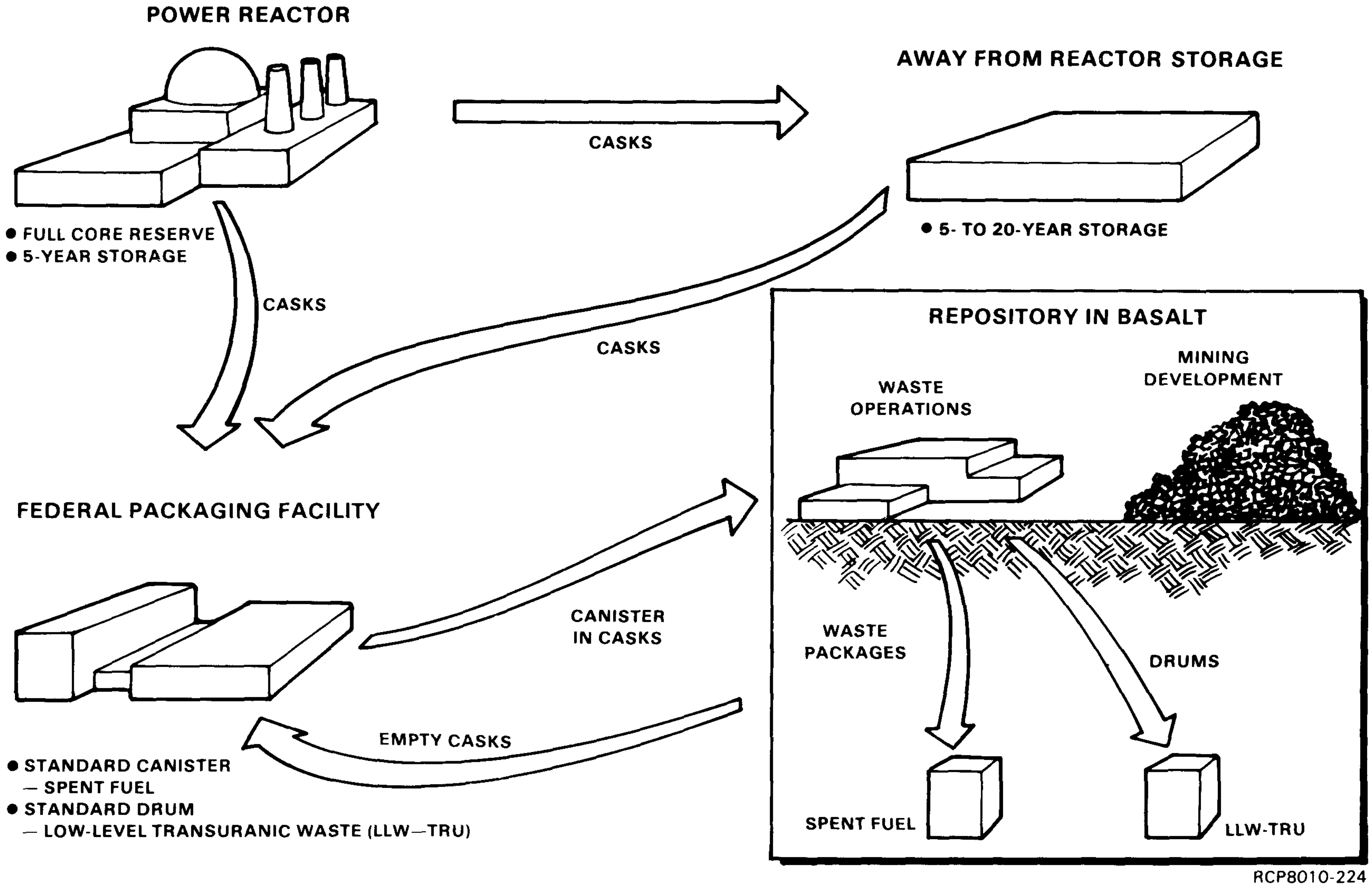

FIGURE 1. Waste Flow.

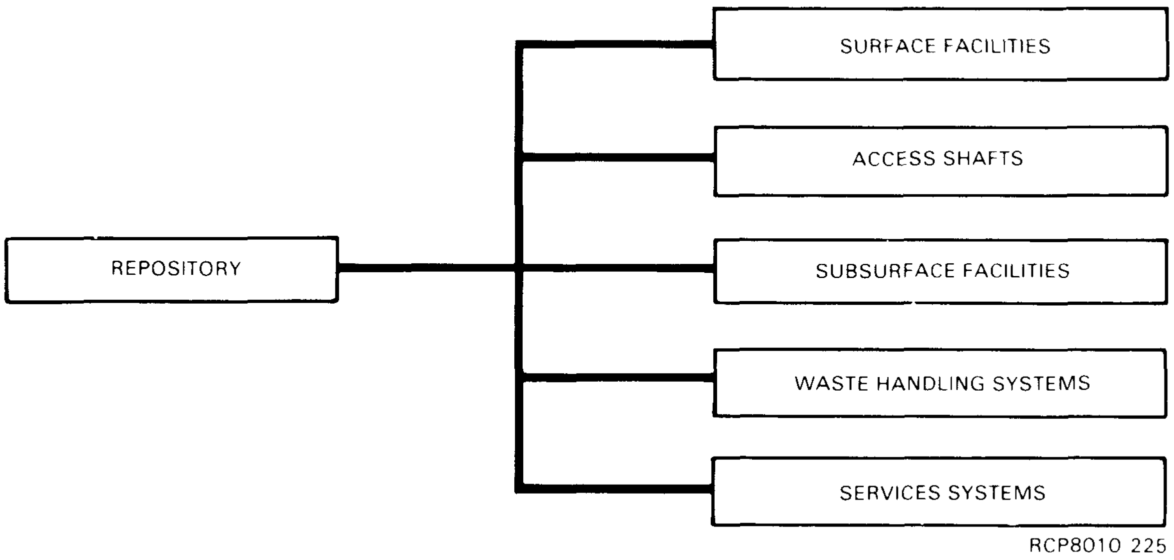

FIGURE 2. Work Breakdown Structure.

SURFACE FACILITIES

Surface facilities are required to operate the repository, receive incoming waste, and house operations and support functions for the repository. The key components of the surface facilities are:

- Offsite development
- Land improvements
- Waste operations facilities
- Service facilities
- Storage facilities.

ACCESS SHAFTS

Shafts provide controlled penetration of the isolation barrier (basalt formation) for transport of waste, personnel, equipment, support services, and materials to the subsurface facilities during repository operations. The shaft services and functions are shown in Figure 4.

SUBSURFACE FACILITIES

The subsurface facilities provide for the placement and storage of radioactive waste. The subsurface facility functions are shown in Figure 5.

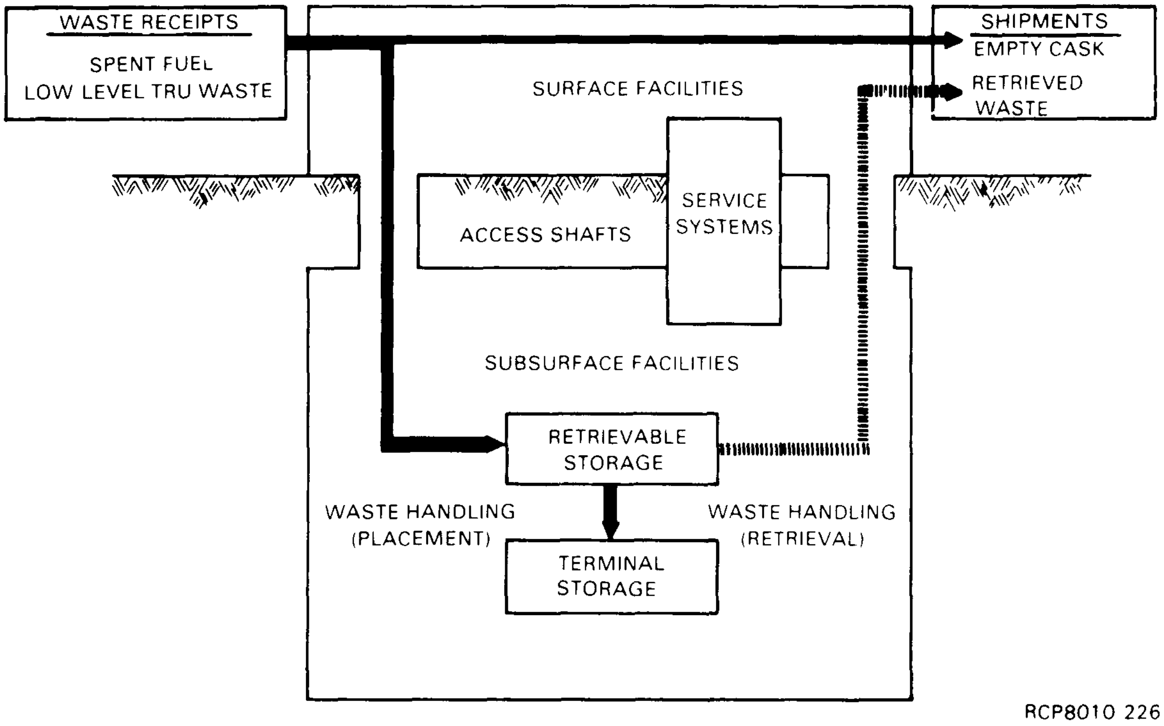

FIGURE 3. Functions-Repository.

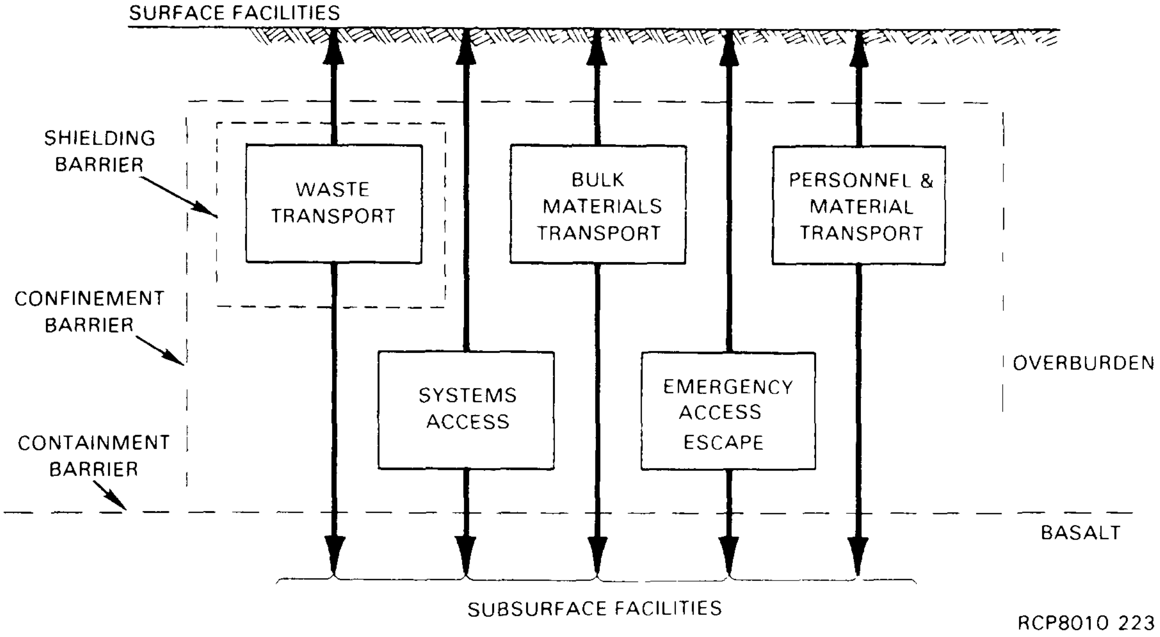

FIGURE 4. Functions-Access Shafts.

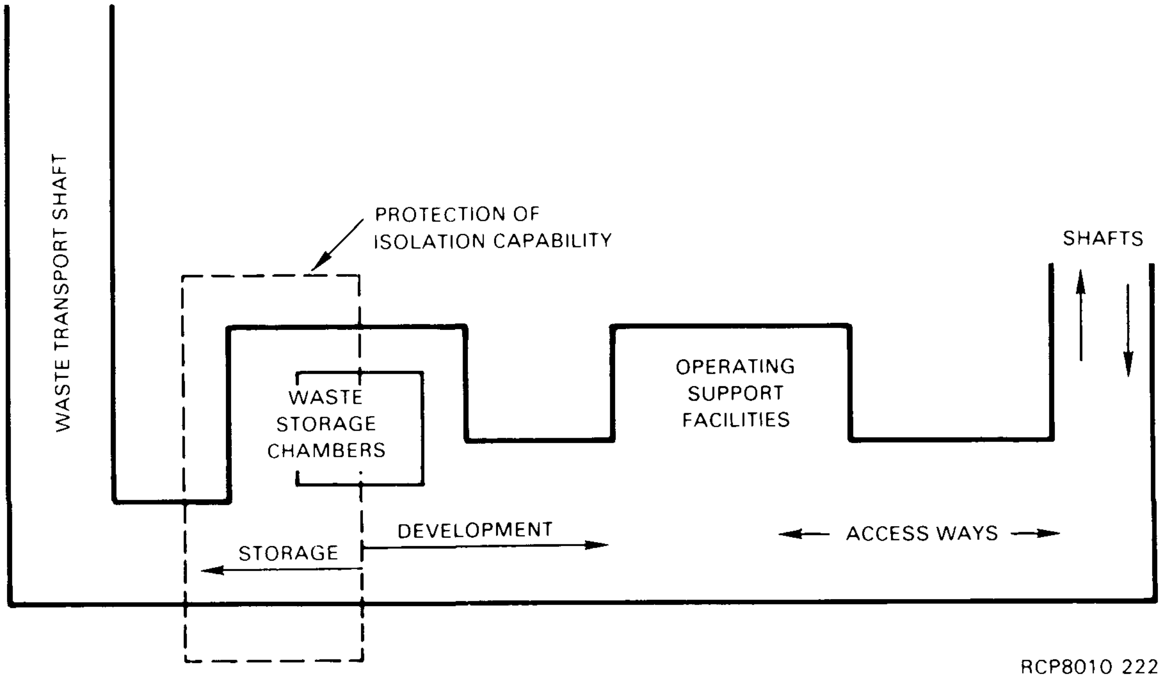

FIGURE 5. Functions-Subsurface Facilities.

WASTE HANDLING SYSTEMS

The waste handling system will transport waste from the point of receipt on the surface to the subsurface storage positions. The waste handling systems functions are shown in Figure 6.

SERVICE SYSTEMS

The service systems provide the utilities and services necessary for repository operations. Service system functions are as follows:

- Bulk handling
- Personnel and material transport
- Subsurface ventilation
- Electric power
- Communication network
- Water supply
- Radiological waste management
- Material disposal
- Physical security
- Miscellaneous systems.

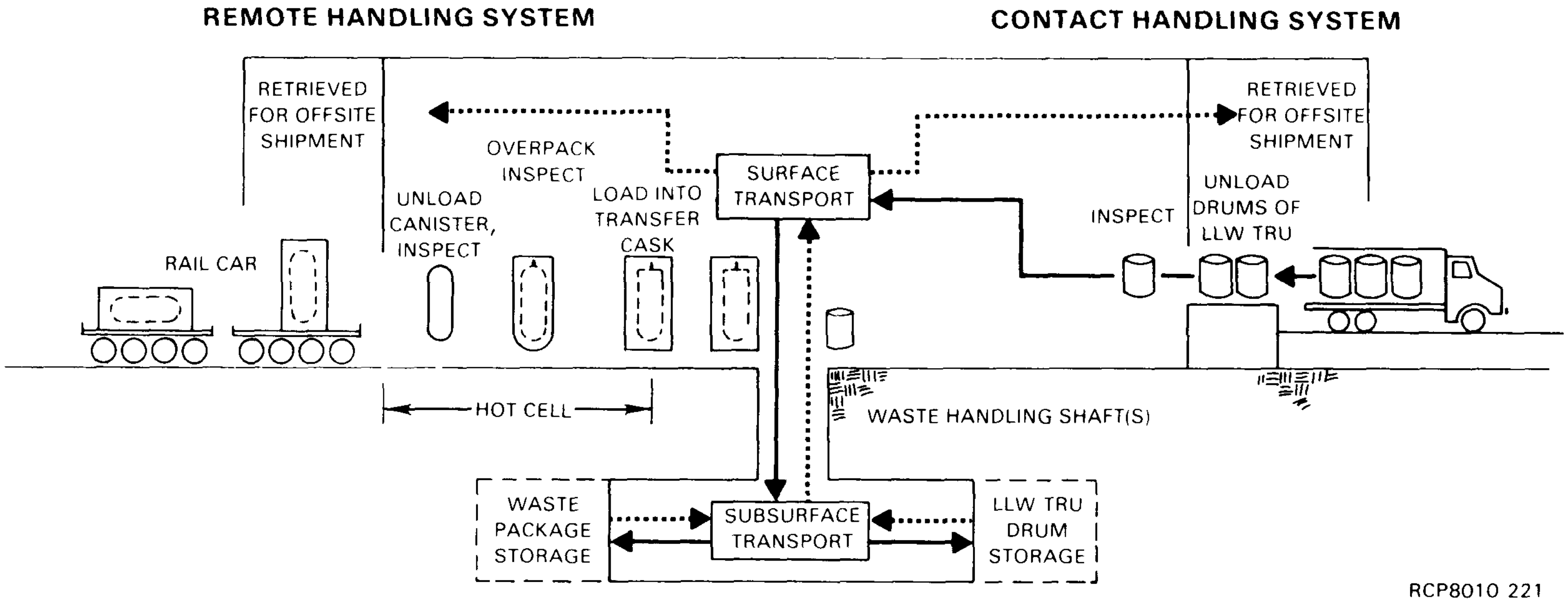

FIGURE 6. Functions-Waste Handling System.

DESCRIPTION OF A NUCLEAR WASTE REPOSITORY IN BASALT

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Kaiser Engineers, Inc.
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Oakland, California 94623

The conceptual design of a nuclear waste repository in basalt was started by Kaiser Engineers, Inc./Parsons Brinckerhoff Quade & Douglas, Inc. in October 1979 under contract to the U.S. Department of Energy-Richland Operations Office and under the technical direction of Rockwell Hanford Operations' Office of Repository Studies. The conceptual design is based on receiving canistered, disassembled, spent-fuel assemblies and drummed low-level waste and overpacking and storing the spent fuel in an engineered barrier configuration. Storage is to be at a depth of 1,128 meters in the Umtanum basalt entablature at the Hanford Site. Waste is to be stored so that it is retrievable for 25 years. The nuclear waste repository in basalt is to be licensed by the U.S. Nuclear Regulatory Commission.

For design purposes, spent fuel is 10 years old at time of storage. The design rate for canister receipts is 1,750 canisters per year for 20 years. Each canister contains the disassembled rods from either three pressurized water reactor fuel assemblies or seven boiling water reactor fuel assemblies. Spent fuel is in the ratio of 37% pressurized water reactor to 63% boiling water reactor fuel assemblies. The total repository capacity is 47,000 metric tons of heavy metal; however, expansion capability is provided. The design rate for low-level waste is 1,600 drums per year for 20 years.

Figure 1 is an artist's concept of the repository, which shows the extent of the underground facilities and five shafts connecting the subsurface facilities with the surface facilities. The shaft pillar is near the center of the subsurface facilities.

Cross sections of the five shafts are illustrated in Figures 2 through 6. Independent ventilation systems are provided for confinement and development activities. Shaft No. 1 exhausts air from the confinement ventilation system; i.e., from the waste storage areas. Shaft No. 2 is used for transporting nuclear waste to and from the underground facilities. This shaft also exhausts a small portion of the confinement ventilation air. Shaft No. 3 supplies air to the confinement ventilation system. Shaft No. 4 is used for moving personnel and materials to and from the subsurface facilities and supplying air to the mine development ventilation system. Shaft No. 5 is used for transporting mined basalt to and from the underground facilities and exhausting the mine development ventilation air. The shaft's inner diameters range from 3.05 to 4.88 meters and were minimized by using electric equipment instead of diesel equipment, except for the waste transporter.

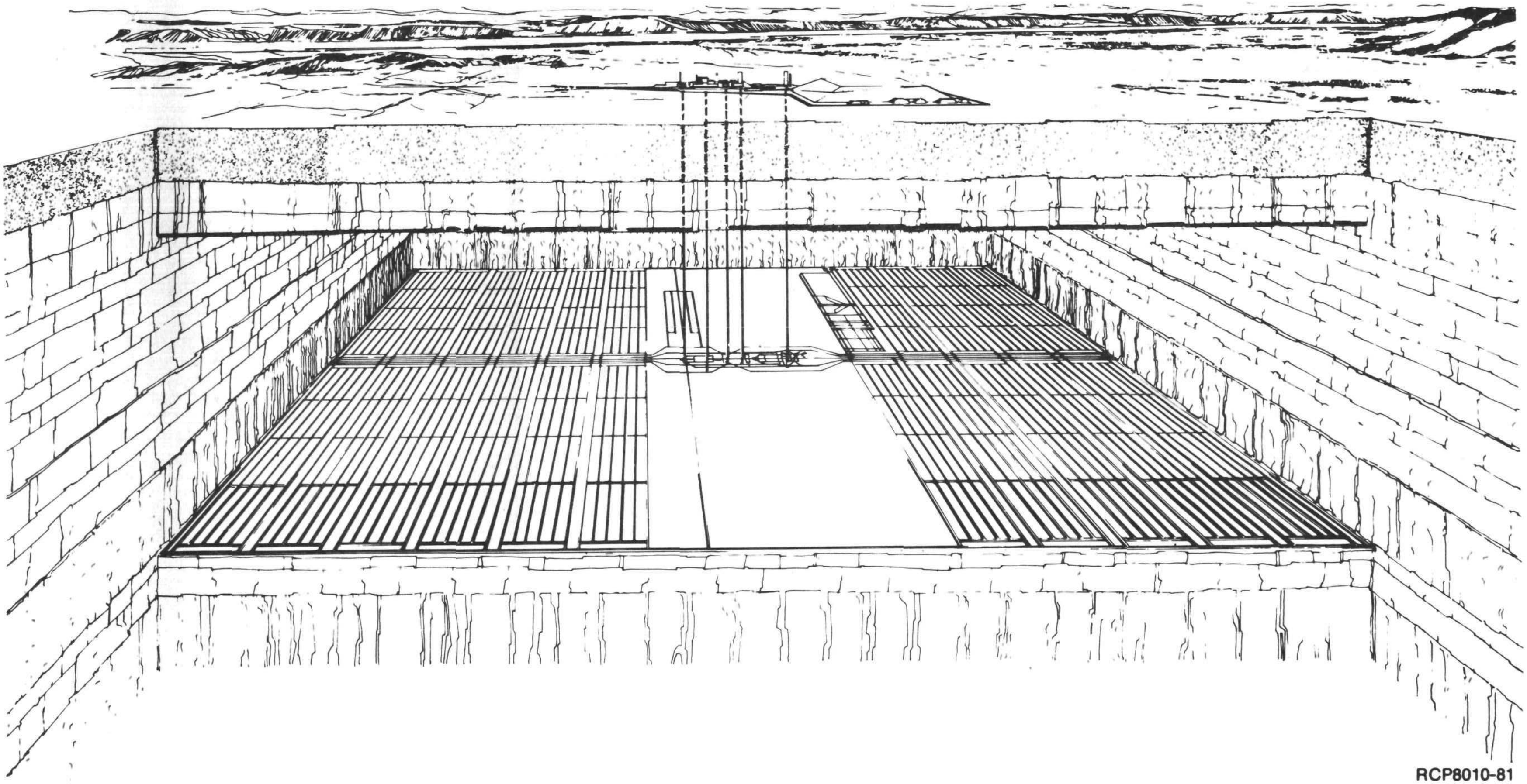

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FIGURE 1. Mine Cutaway and Surface (perspective).

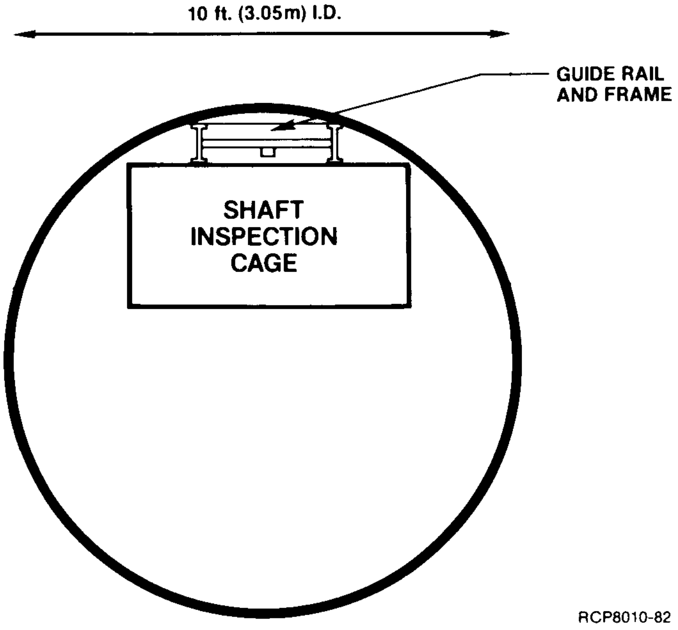

FIGURE 2. Shaft No. 1 Confinement Exhaust Air Shaft.

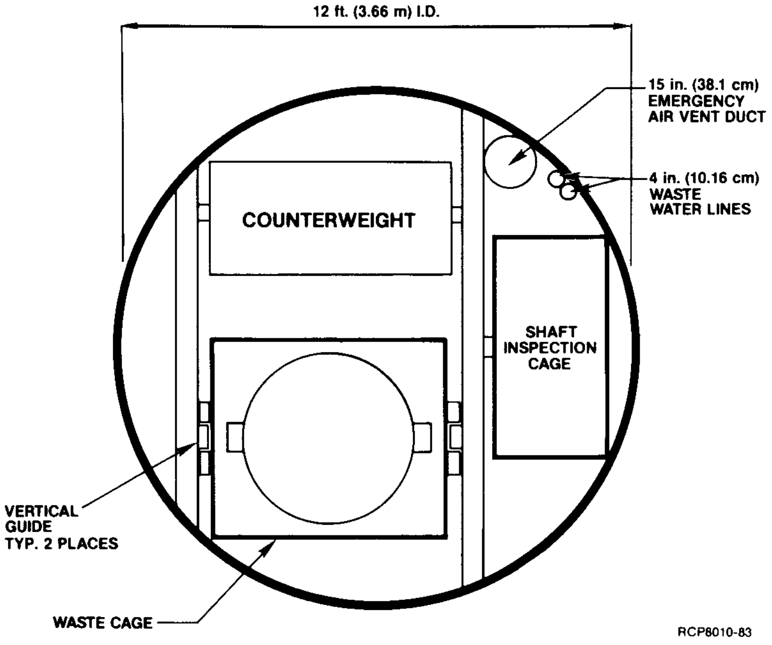

FIGURE 3. Shaft No. 2 Waste Transport Shaft.

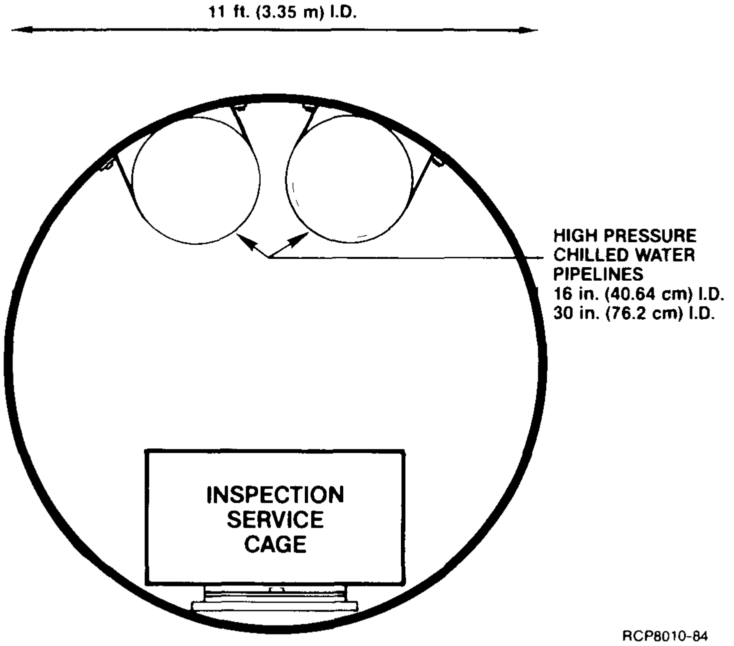

FIGURE 4. Shaft No. 3 Confinement Intake Shaft.

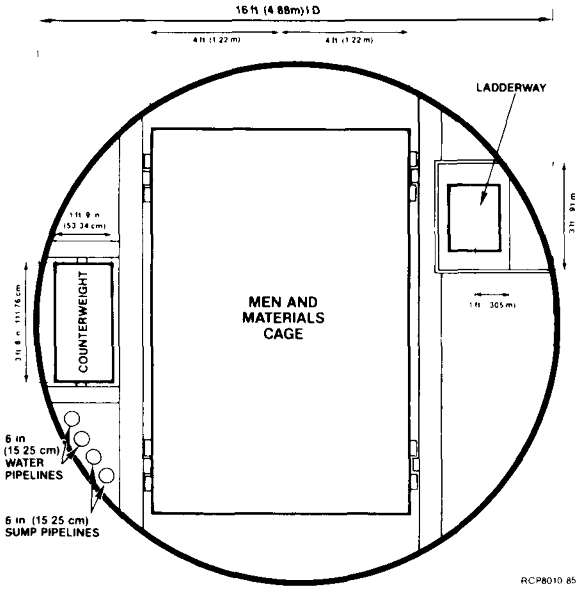

FIGURE 5. Shaft No. 4, Service Shaft (mine intake).

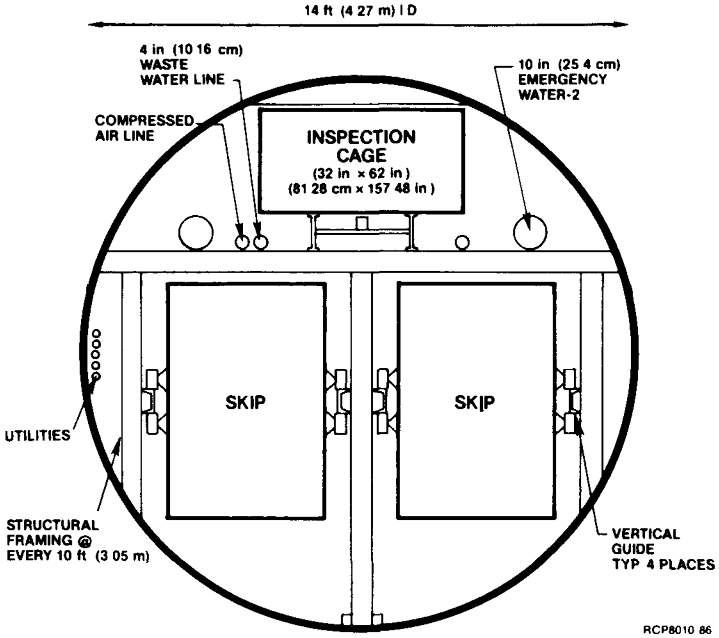

FIGURE 6. Shaft No. 5 Basalt Hoisting Shaft (mine exhaust).

An isometric view of the shaft pillar area is shown in Figure 7. In Figure 8, the shafts and the many operational functions that are provided in the shaft pillar development are identified. Air flowpaths (through the shaft pillar) for confinement intake, confinement exhaust, mine development intake, and mine development exhaust ventilation are shown in Figure 9. A plan view of the subsurface facilities layout is shown in Figure 10; the shaft pillar is near the center, the contact waste storage panel is to the north, and an experimental panel is to the northeast. The remainder of the subsurface facilities is divided into 21 spent fuel storage panels, of which one is a spare. The repository is 3,207 meters long and 2,377 meters wide. Five main entries parallel the long access of the repository near the centerline and provide confinement intake, development intake, and return airways. The confinement-return airway is along the perimeter of the repository.

A typical spent-fuel storage panel is shown in Figure 11. Each panel is 187 meters wide and 1,089 meters long and will store 1 year's receipts of spent fuel. There are six storage rooms running the full length of each panel with cross cuts for escape and ventilation purposes at three intermediate locations.

The cross-sectional room size and the storage configuration within a room are illustrated in Figure 12. An artist's view of a portion of the storage room (Figure 13) shows holes that have been drilled in the floor along the room's centerline and the typical vertical emplacement of a canister. A cross section of a typical spent-fuel storage position is

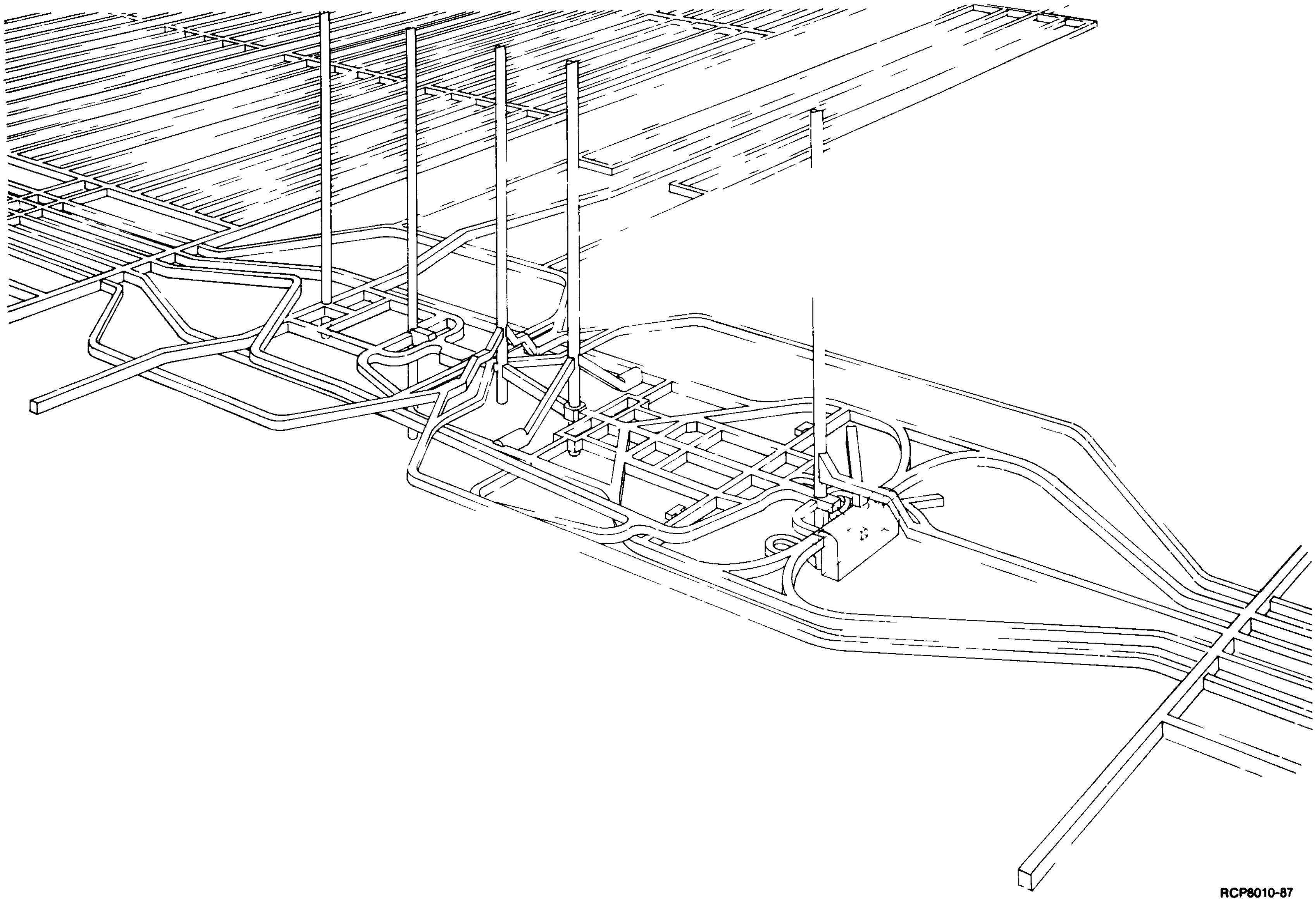

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FIGURE 7. Shaft Pillar.

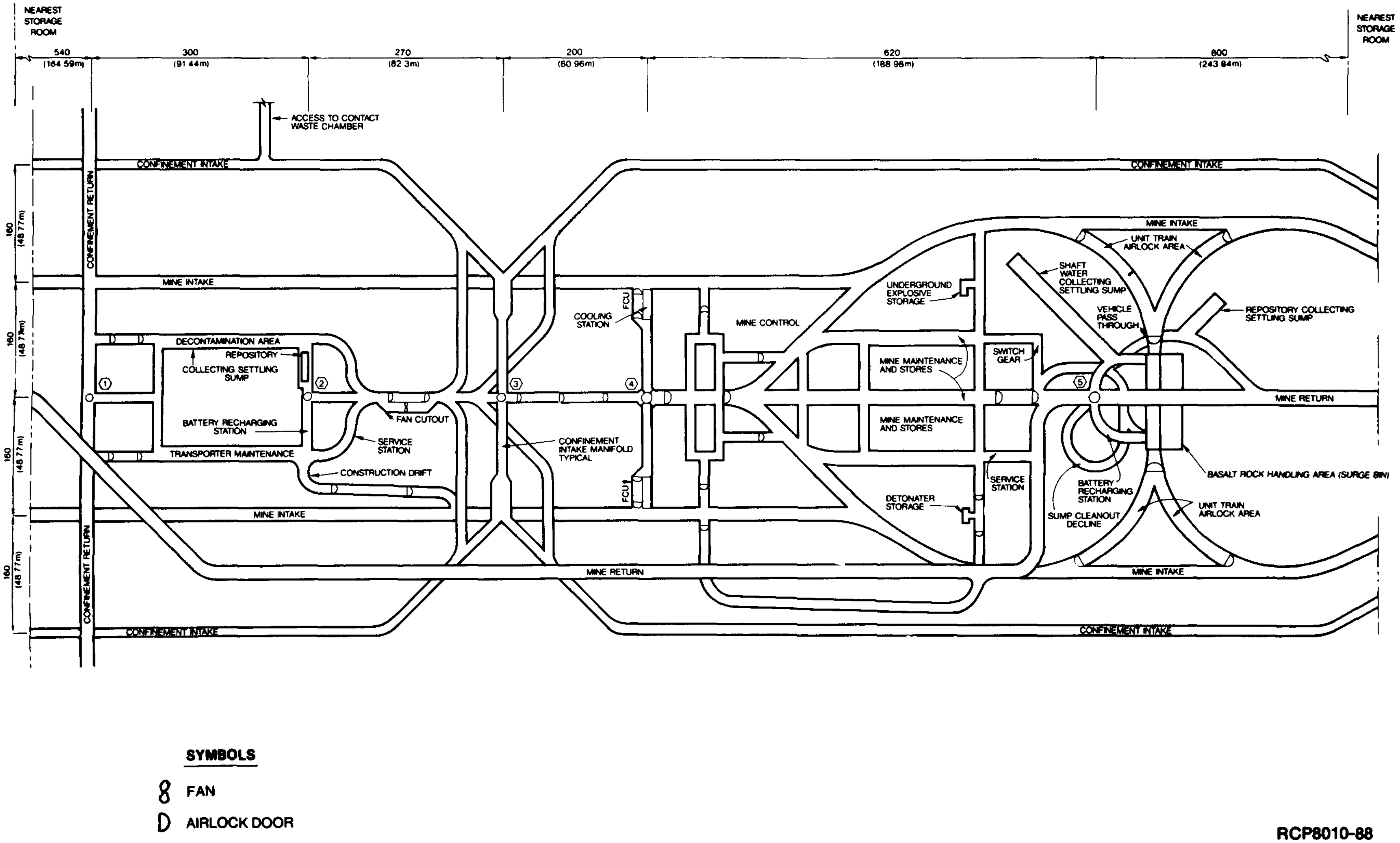

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FIGURE 8. Shaft Pillar Layout.

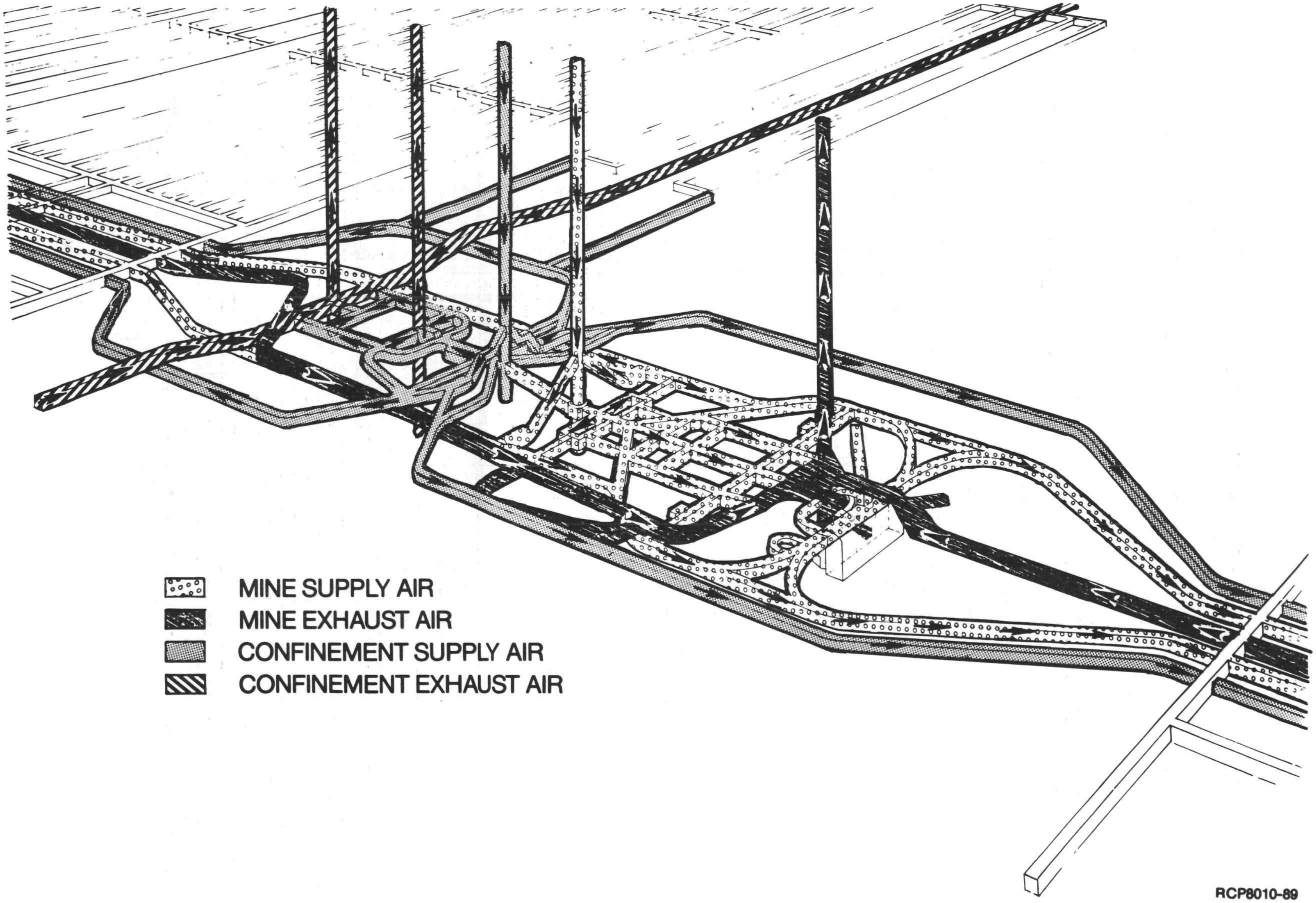

FIGURE 9. Shaft Pillar Flowpaths.

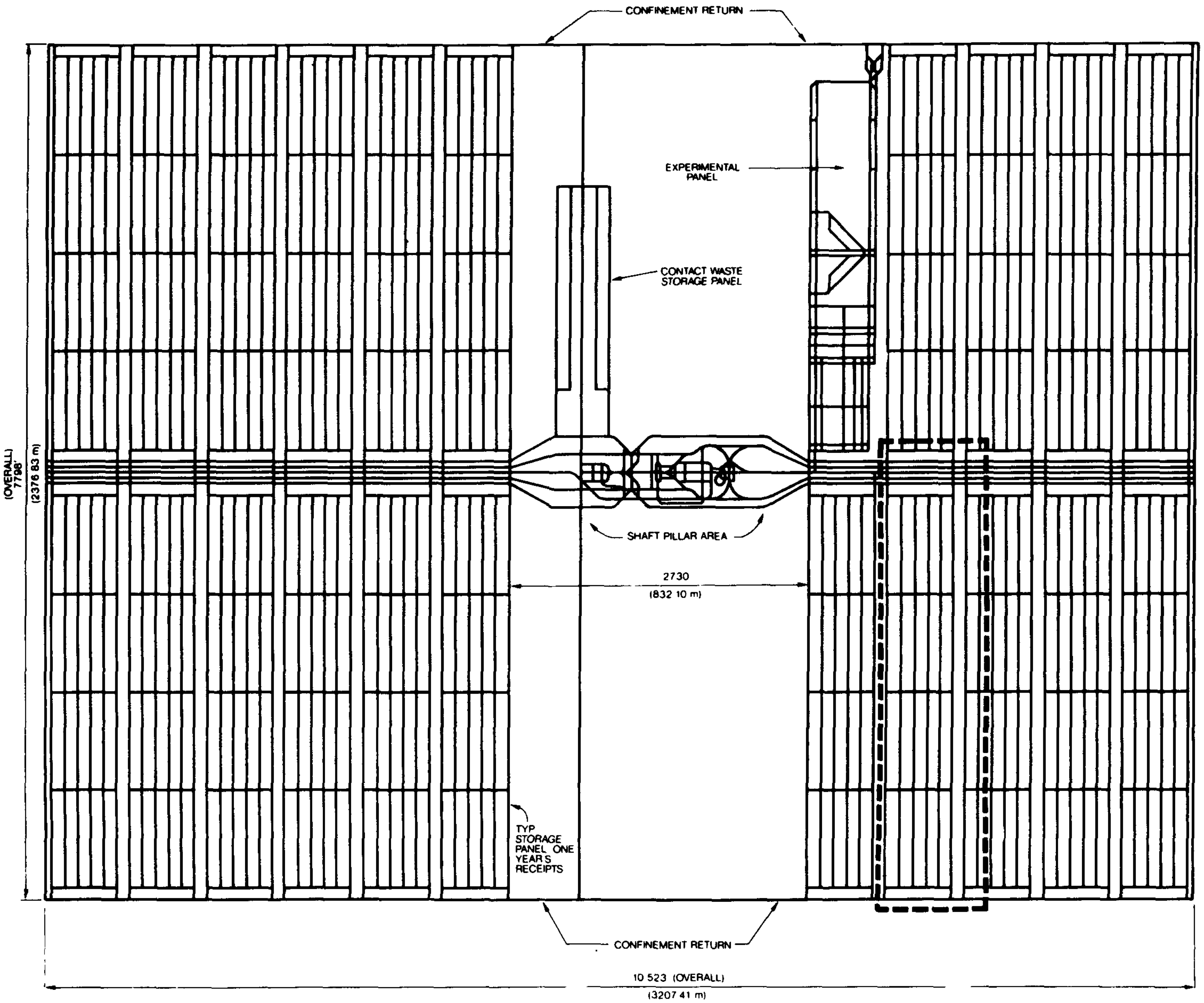

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FIGURE 10. Underground Facilities Layout.

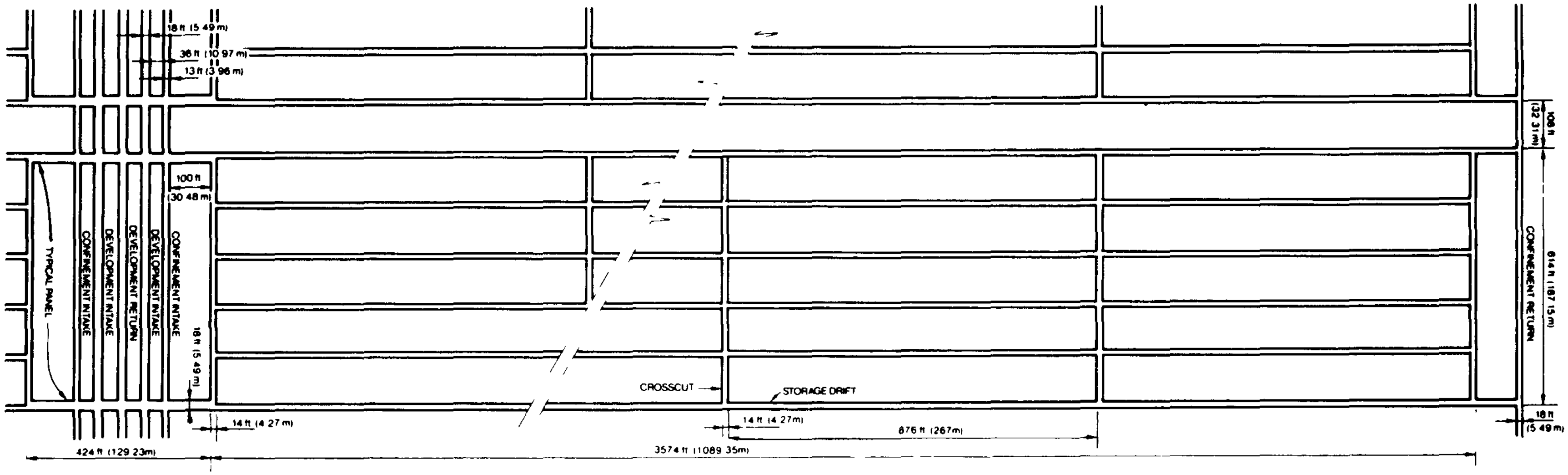

FIGURE 11. Typical Storage Panel.

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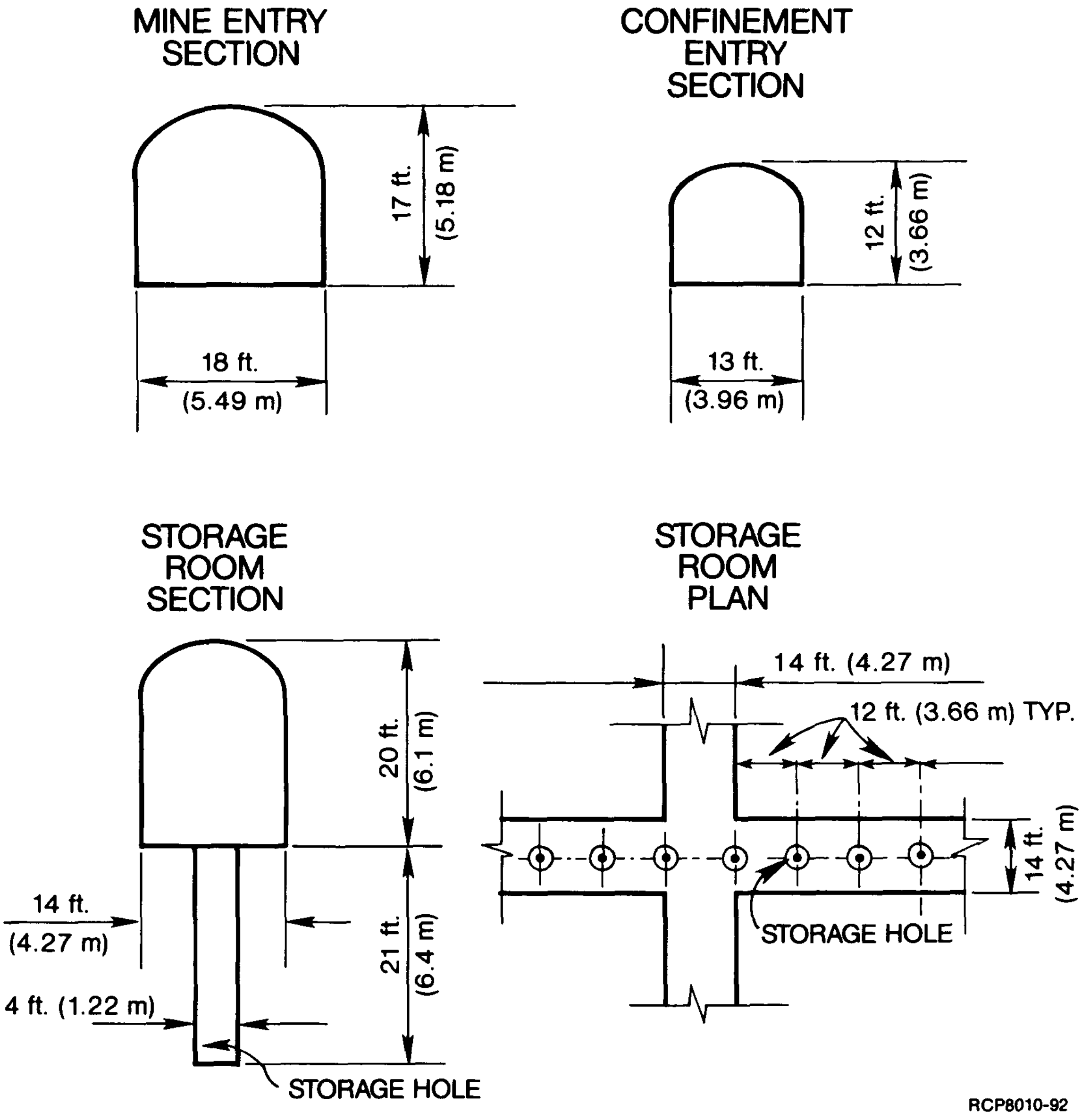

FIGURE 12. Room Cross Sections and Plan.

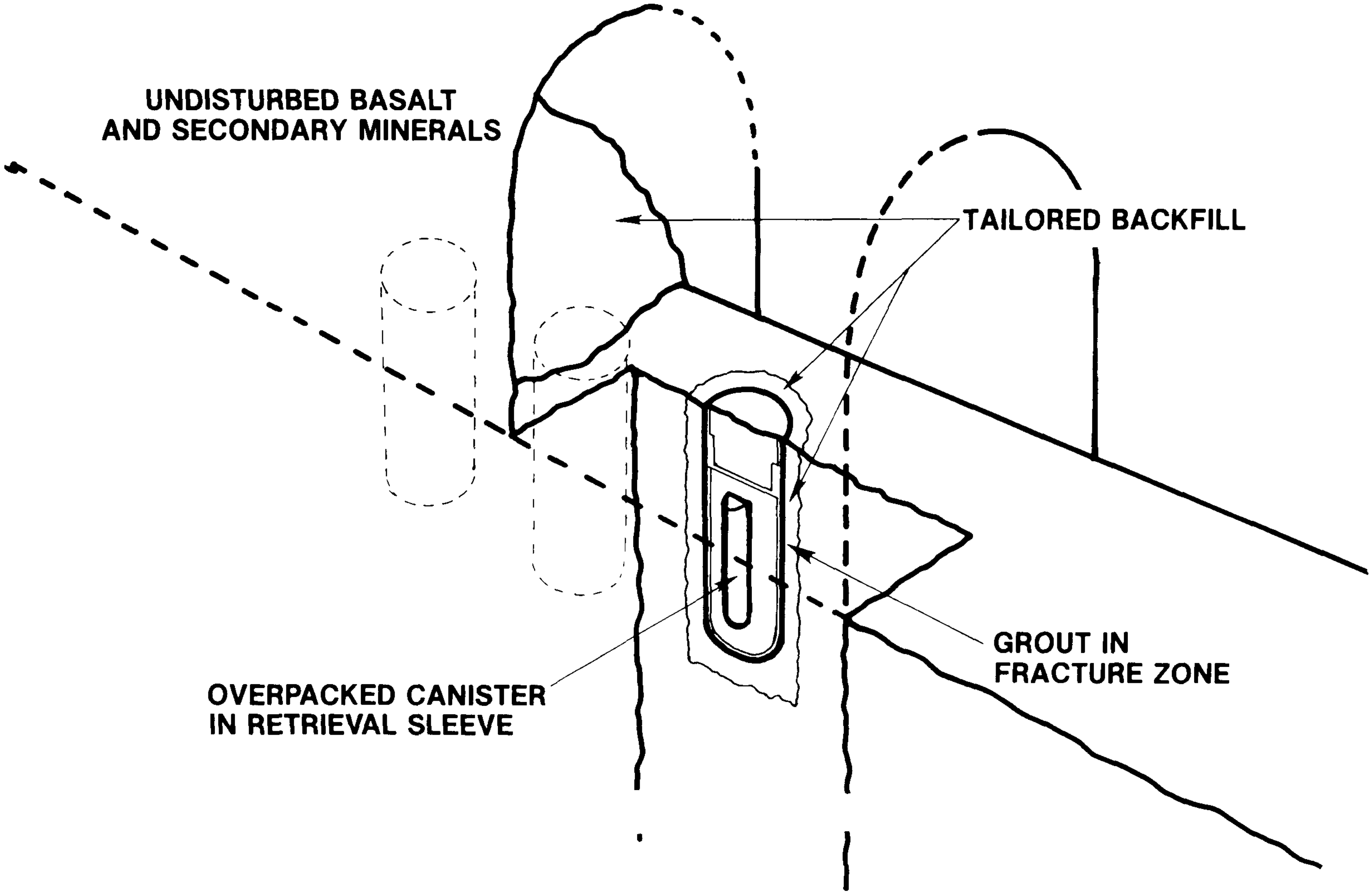

FIGURE 13. Storage Room.

shown in Figure 14; the waste package is located within a ceramic sleeve which is surrounded by tailored backfill and enclosed in an aluminum container. A shield plug above the waste package decreases radiation levels to 2.5 millirems per hour.

The thermal basis for the spent-fuel spacing is shown in Figure 15. The initial basalt temperature is 57°C and the maximum basalt temperature criterion is 500°C. The maximum permissible fuel-cladding temperature criterion is 300°C. The temperature drop from the fuel rod nearest the canister centerline to the basalt at the identification of the storage hole is 100°C. Thus, the cladding temperature criterion governs, and the basalt temperature must not exceed 200°C. This sets the pitch and row separation. Optimized for minimum basalt excavation, the pitch is 3.66 meters, and the row separation is 36.6 meters.

Because of the relatively high initial basalt temperature and the heat added by the spent fuel, cooling of the repository is required for habitability both in the development and confinement areas. Figure 16 is a simplified flow diagram of the cooling water system. Chilled-water supply and return lines in the confinement intake shaft (Figure 4) circulate water through heat exchangers at the storage level. The heat exchangers isolate the secondary chilled-water system in the repository from the 6.23-megapascal hydrostatic pressure at the bottom of the primary systems. The total repository cooling load is 3,084 metric tons; however, 181 metric tons of heat removal are provided by service water to drilling and mucking operations, thus the refrigeration plant capacity is 2,903 metric tons.

A typical spent-fuel waste package is depicted in Figure 17. The canister, which is received at the repository containing the disassembled spent fuel rods, is shown in the center of the waste package. The canister is surrounded by a graphite buffer, part of the engineered barrier, which protects the carbon steel of the canister in case of water intrusion. The waste package has an outer shell of titanium into which the canister is sealed at the repository by laser welding. The canister and waste package dimensions are given in Figure 17.

Waste packages are handled in the repository in transfer casks that reduce radiation levels to 10 millirems per hour at 0.91 meter from the surface. A transfer cask is shown in Figure 18.

Waste packages are emplaced by a diesel-powered, rubber-tired transporter (Figure 19). This transporter receives a transfer cask at the base of the waste transport shaft, carries it to the storage location in a horizontal position to minimize excavation requirements, and then raises it to a vertical position at the storage location. After a floor shield has been set in place over the storage hole by the transporter, a shield door is opened at the bottom of the transfer cask and the waste package is lowered into storage.

Waste is received at the repository on the surface. A plan view of the surface facilities (Figure 20) shows the extent of the basalt storage pile, which will be 472 meters long, 472 meters wide, 46 meters high, and will weigh approximately 13.6 million metric tons before the start of

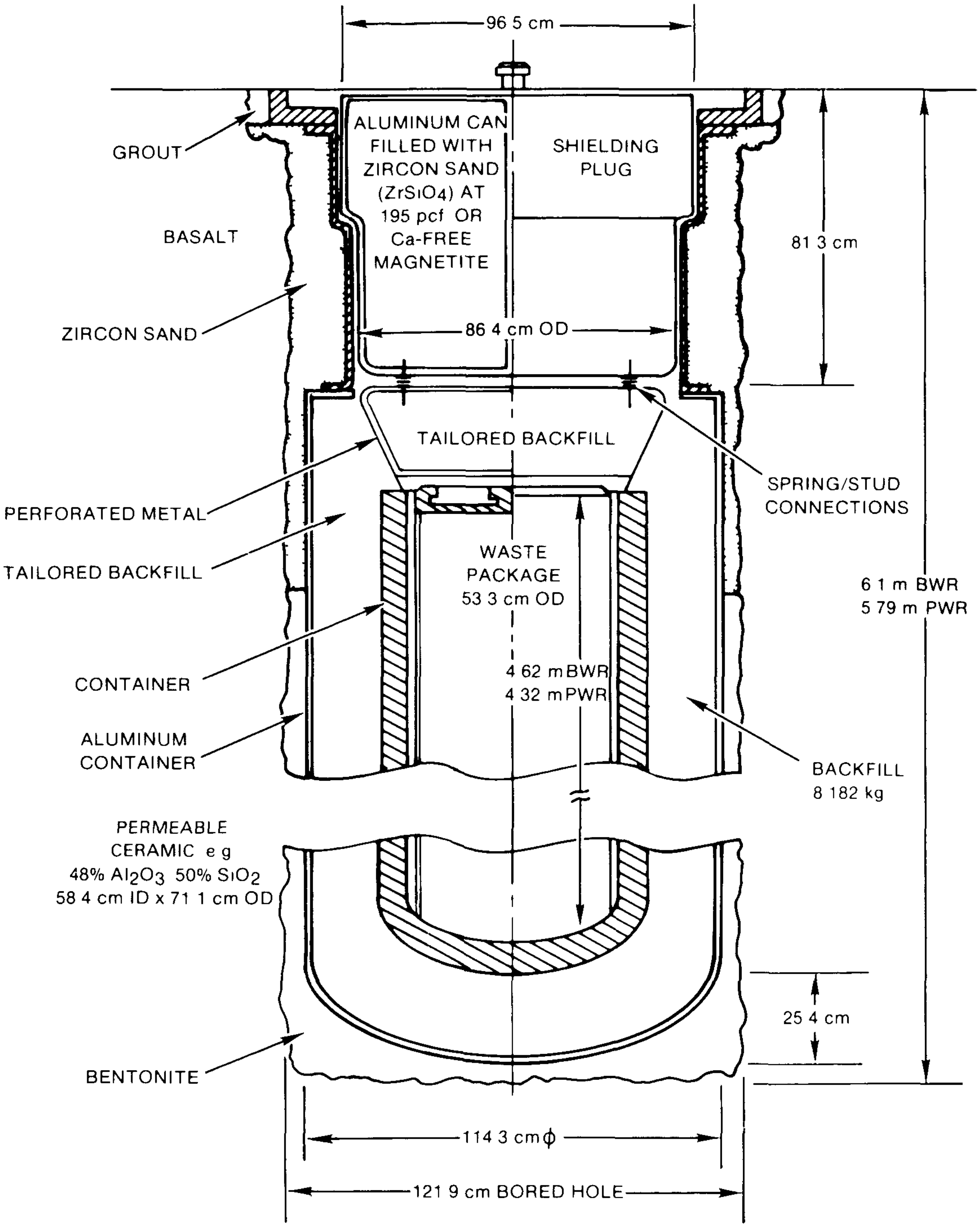

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FIGURE 14. Storage Position.

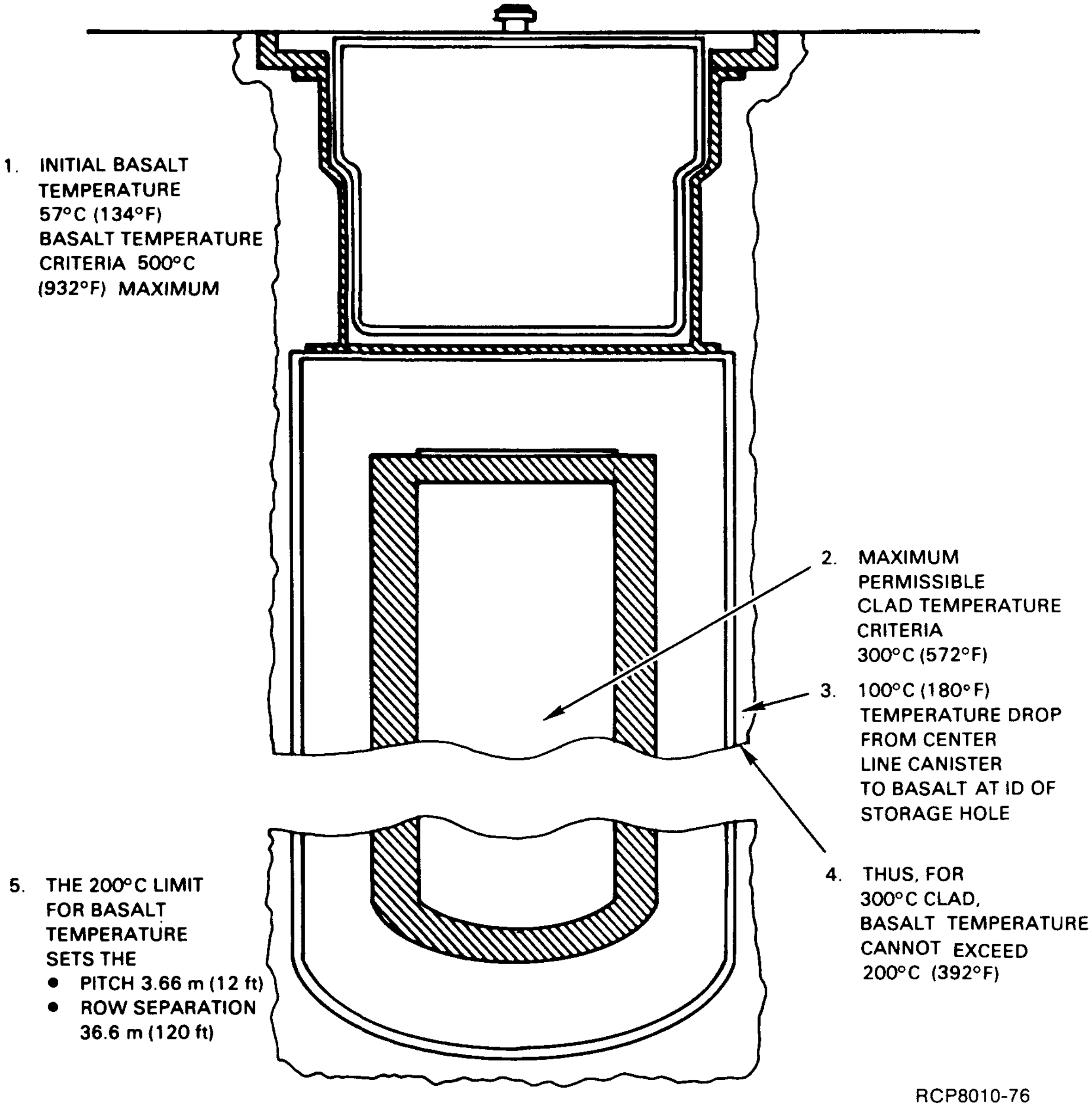

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FIGURE 15. Heat Transfer.

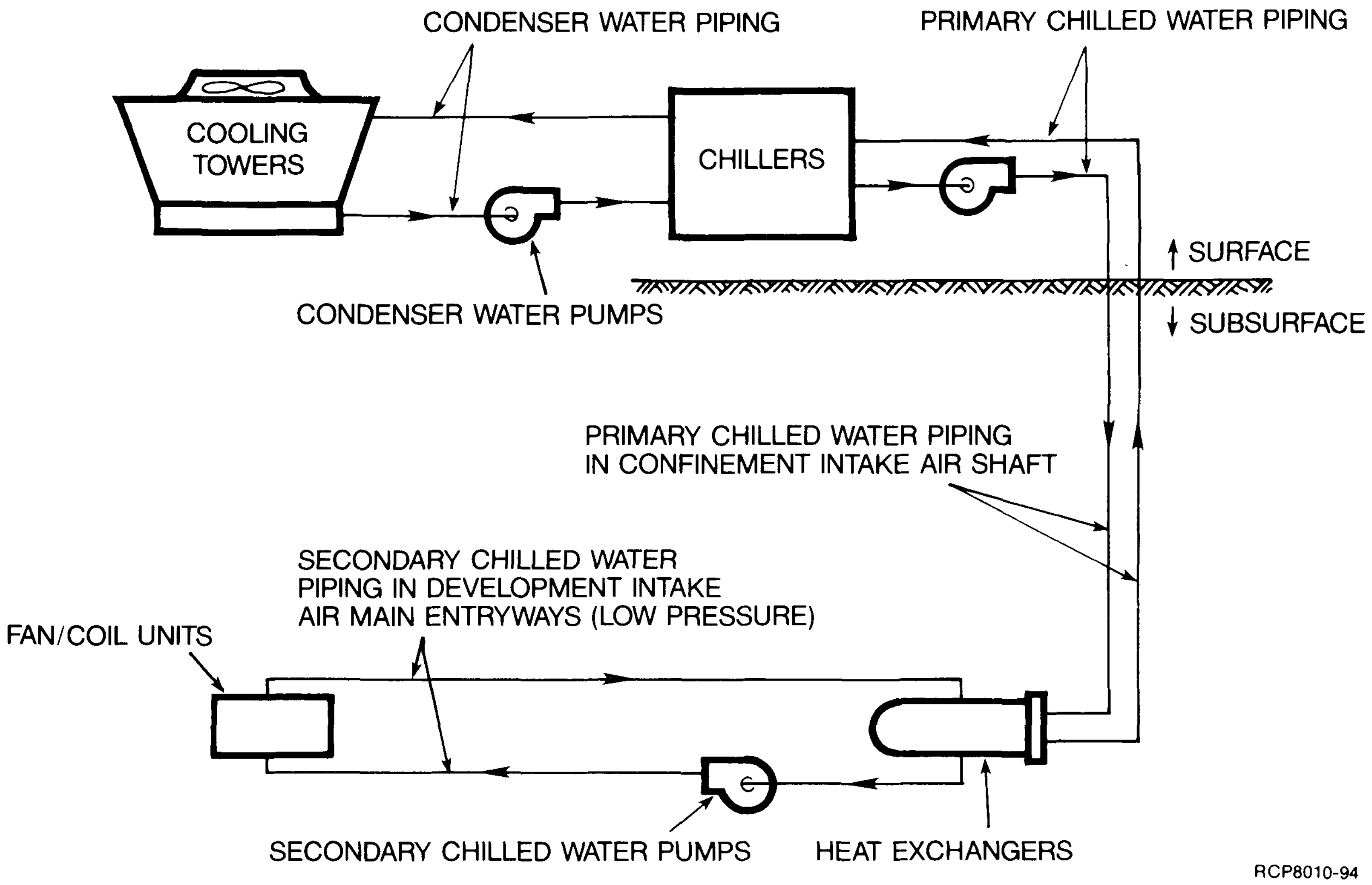

FIGURE 16. Cooling Water System.

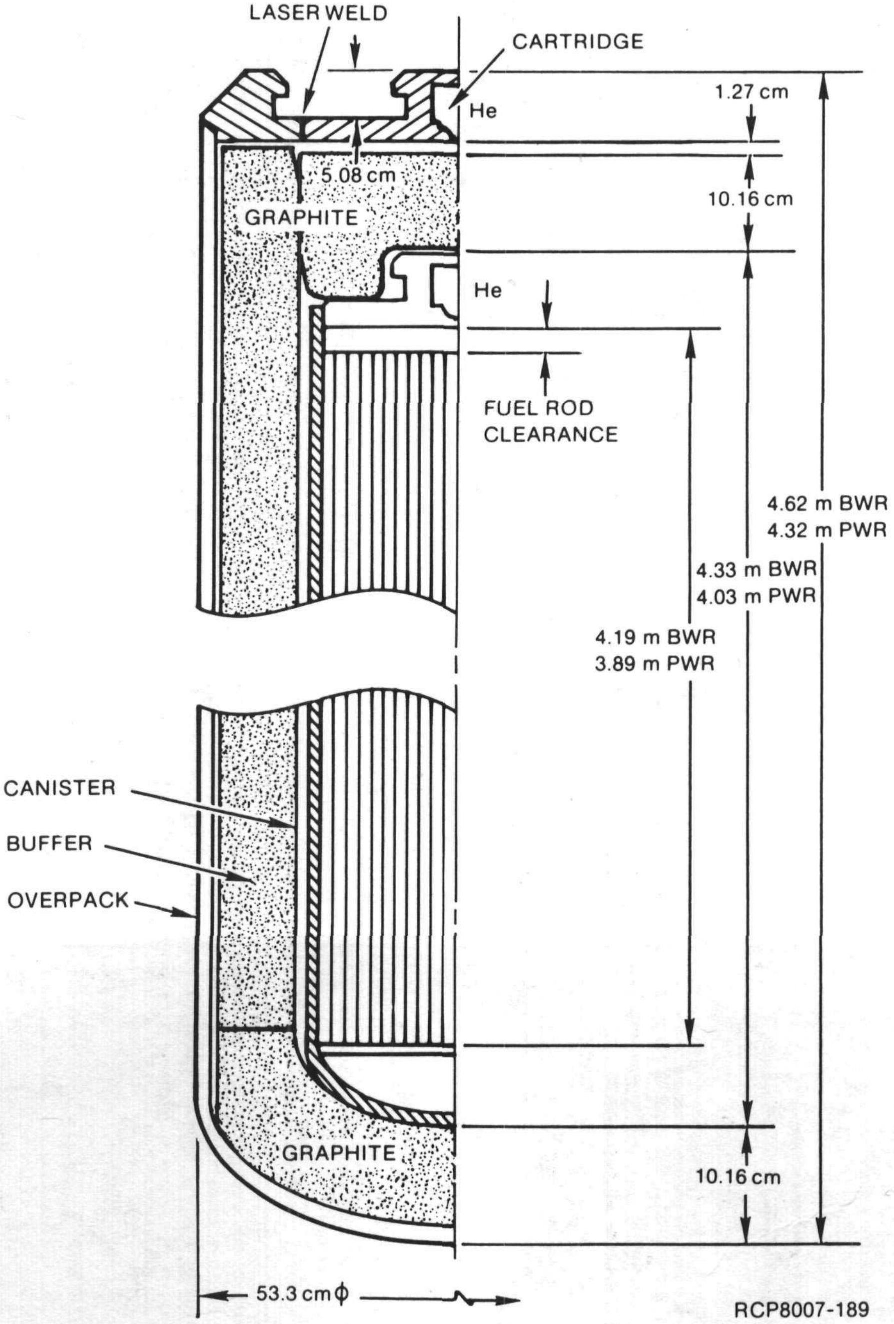

FIGURE 17. Waste Package.

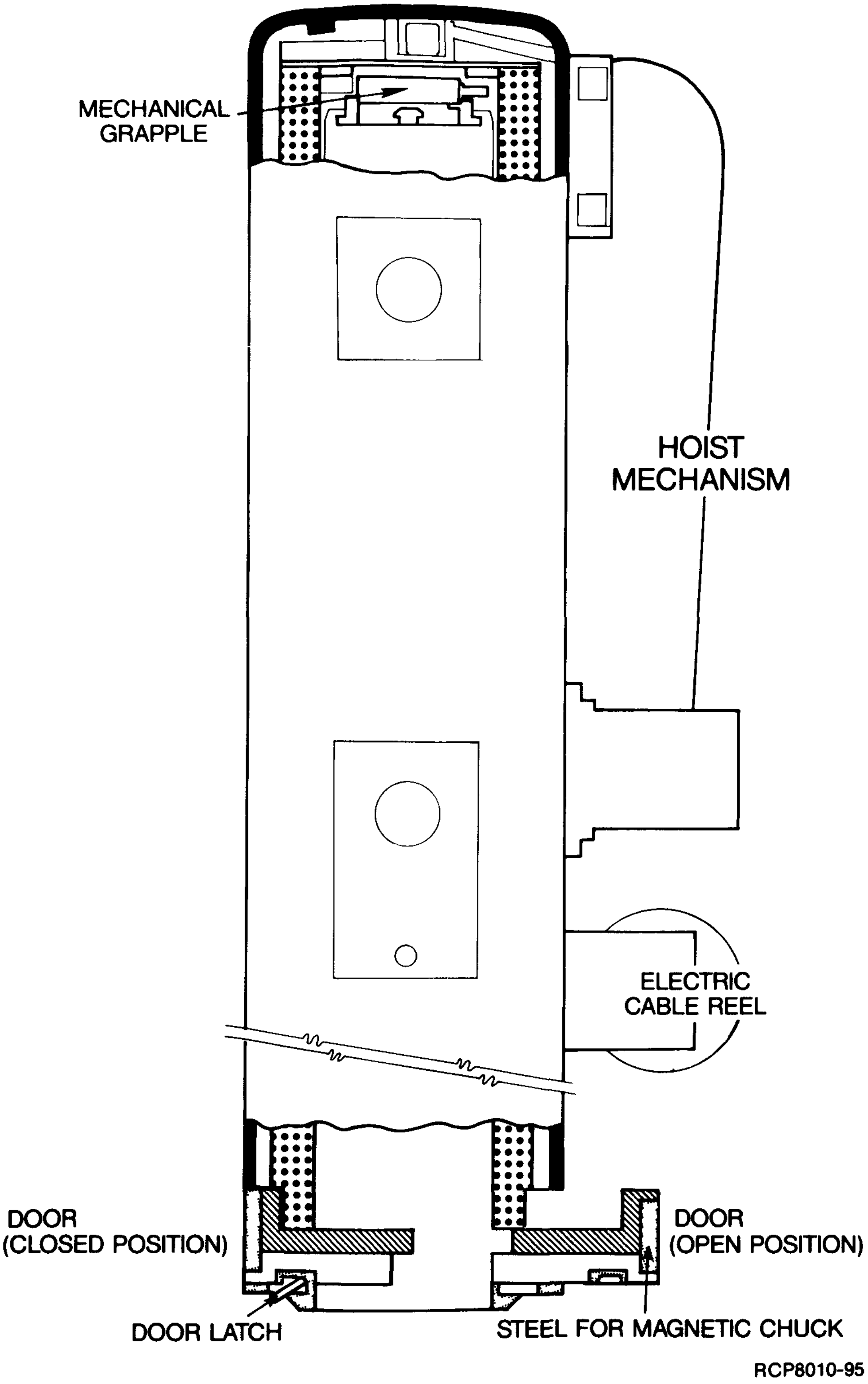

FIGURE 18. Transfer Cask.

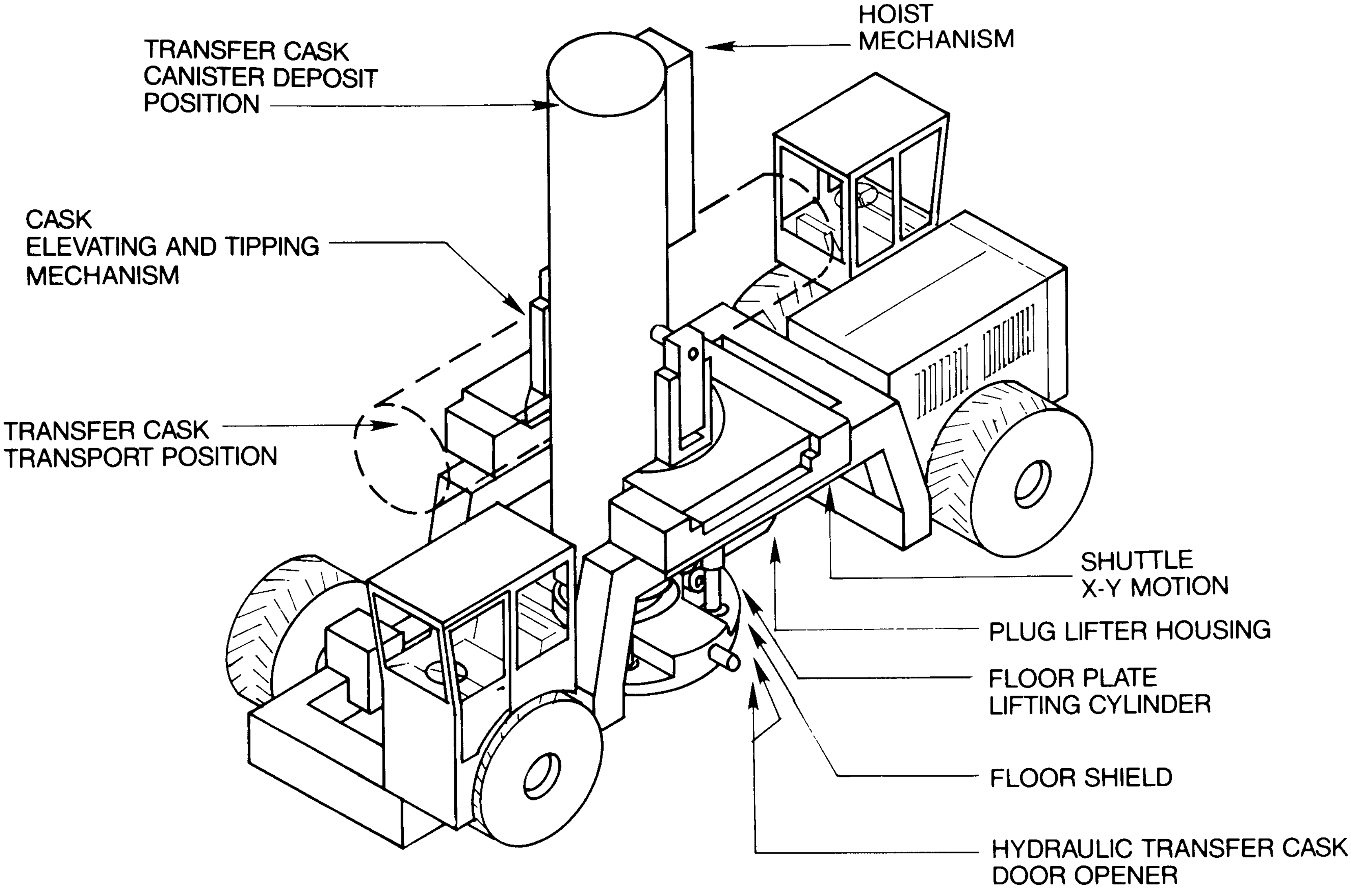

FIGURE 19. Transporter.

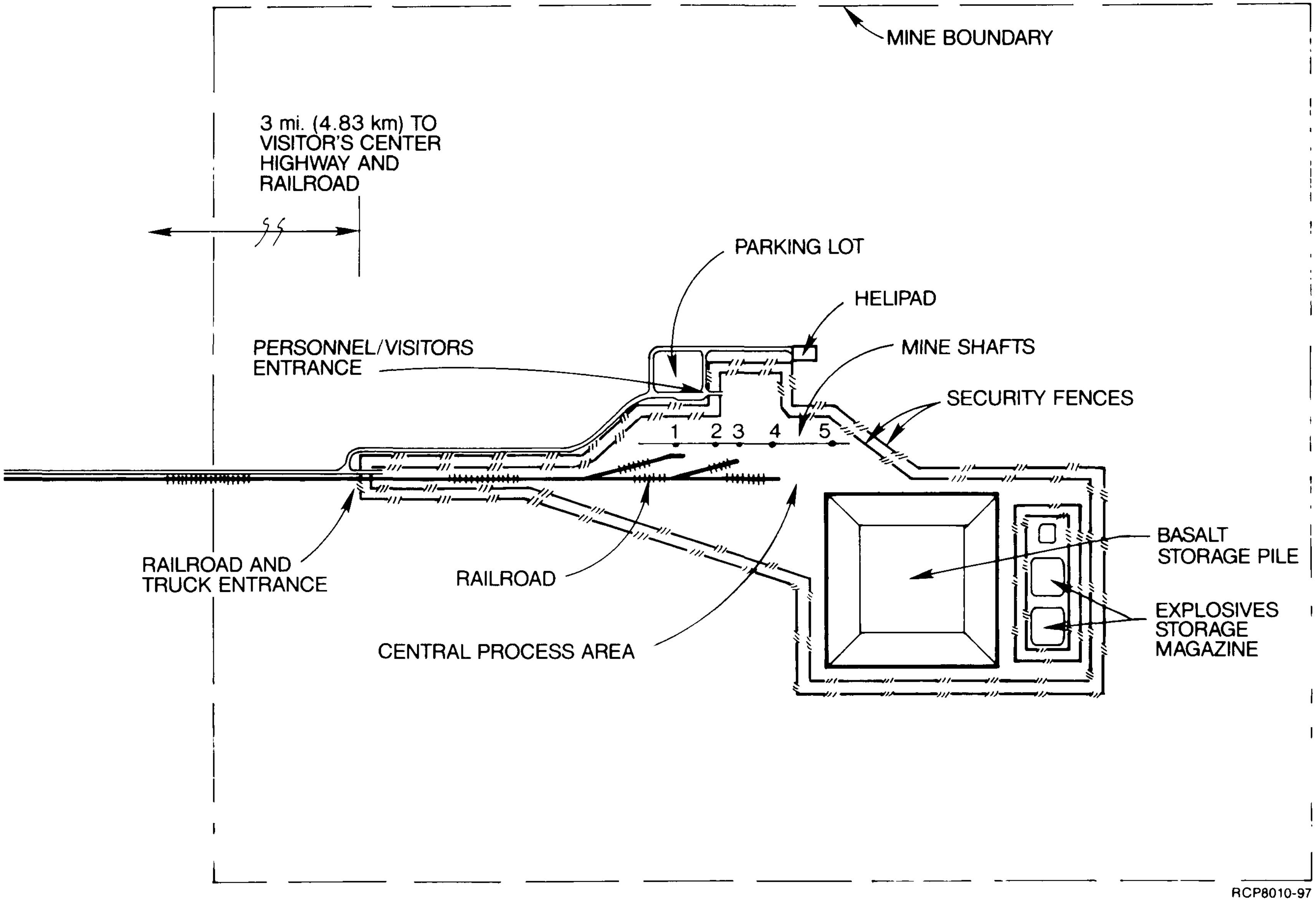

FIGURE 20. Surface Facilities Plan (overall).

room backfilling. A closer view of the buildings in the central process area and identity of their functions are shown in Figure 21. The most prominent building is the waste-handling building; a cutaway view is shown in Figure 22.

Figure 23 is an enlarged drawing of the canister-receiving and handling areas in the waste-handling building. In this figure, a canister is being unloaded from a shipping cask on a rail car. The shipping cask was horizontal during transit and has been raised to a vertical position for unloading and then mated with a shielding collar lowered from the hot cell. A canister mover in the hot cell is shown removing the canister from the shipping cask. Twenty surge storage positions for canisters or waste packages are located in the floor to the left of the canister mover. Slightly farther to the left in the floor is a process tank wherein the canister is welded into the overpack to form a waste package. Completed waste packages are positioned below a port at the left end of the hot cell; a transfer cask on a mover above the hot cell then picks up the waste package and moves it farther left for placement in the cage in the waste transport shaft.

The conceptual design represents the results of analyses, tradeoffs, and optimizations. An extensive description of the nuclear waste repository in basalt conceptual design will be given in a conceptual design report, currently in preparation.

1 PERSONNEL/VISITORS ROAD
2 TRUCK ROAD
3 SECURITY FENCES
4 PARKING LOT
5 GATE HOUSE NO 1
6 HELIPAD
7 ADMINISTRATION BLDG
8 CAFETERIA
9 SUBSTATION
10 INDUSTRIAL SAFETY
11 TRAINING CENTER
12 SECURITY HEADQUARTERS
13 FIRE STATION
14 CONFINEMENT EXHAUST BLDG
15 STACK
16 SHAFT NO 1
17 COOLING TOWERS
18 STACK
19 SHAFT NO 2
20 WASTE HANDLING BLDG
21 CASK CAR STORAGE YARD
22 REFRIGERATION BLDG
23 SHAFT NO 3
24 CONFINEMENT AIR INTAKE BLDG
25 PERSONNEL & MATERIAL ACCESS FACILITY
26 SHAFT NO 4
27 MINE AIR INTAKE
28 MAINTENANCE
29 SHAFT NO 5
30 STACK
31 MINE EXHAUST BLDG
32 BASALT & MATERIALS HANDLING BLDG
33 PATROL ROAD
34 BASALT CRUSHER BLDG
35 CORE STORAGE & LAB BLDG
36 SLEEVE & PLUG STORAGE YARD
37 SUSPECT RAIL CAR & TRUCK STORAGE AREA
38 STANDBY GENERATOR BLDG
39 MINE WATER RETENTION PONDS
40 RECEIVING SUBSTATION
41 WAREHOUSE
42 SANITARY SEWAGE TREATMENT PLANT
43 PROCESS WASTE EVAPORATION PONDS
44 OVERHEAD POWER LINES
45 MINE WATER PERCOLATION POND
46 BASALT HAUL POND
47 BASALT STORAGE PILE

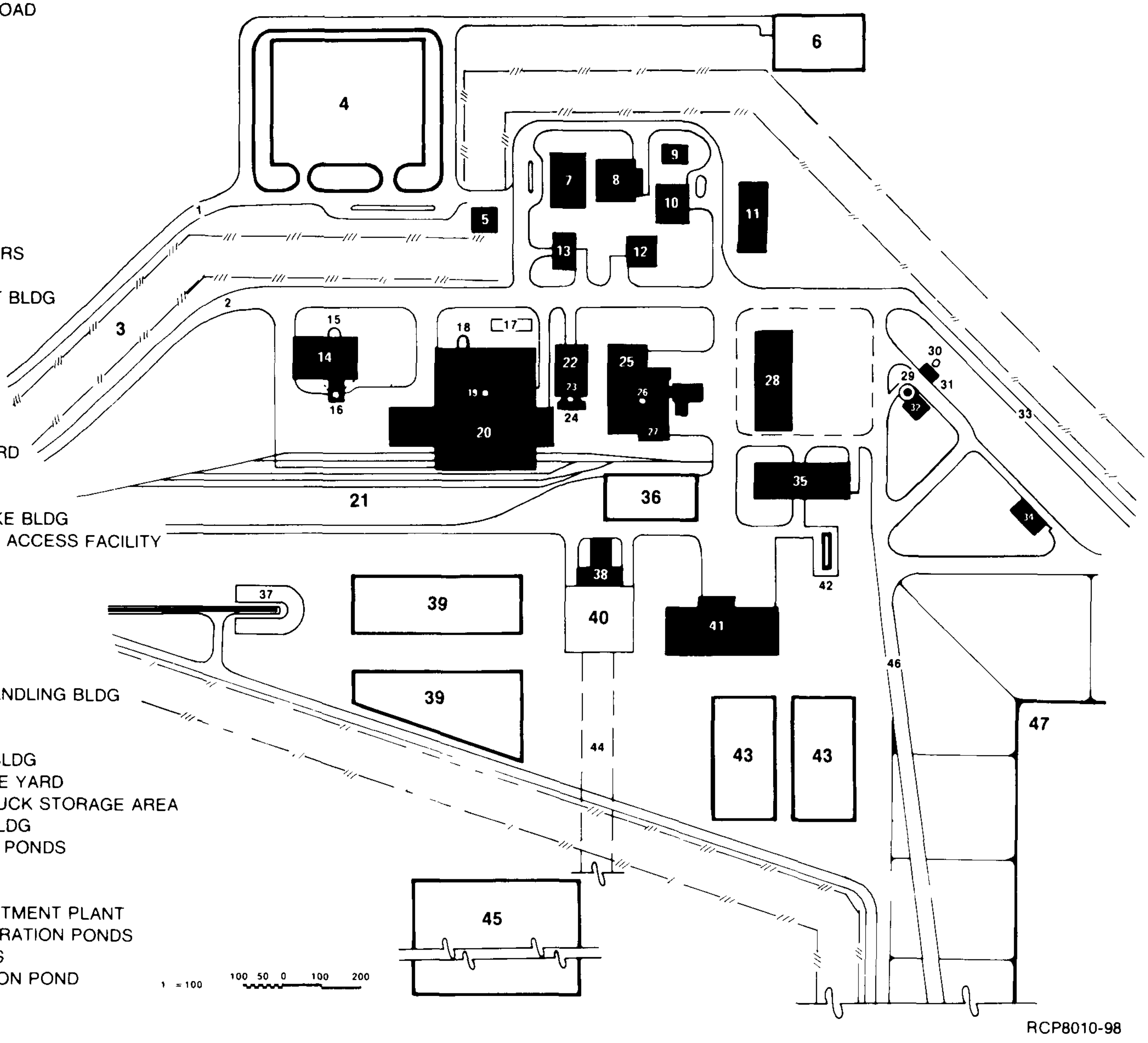

FIGURE 21. Surface Facilities Plan (central process area).

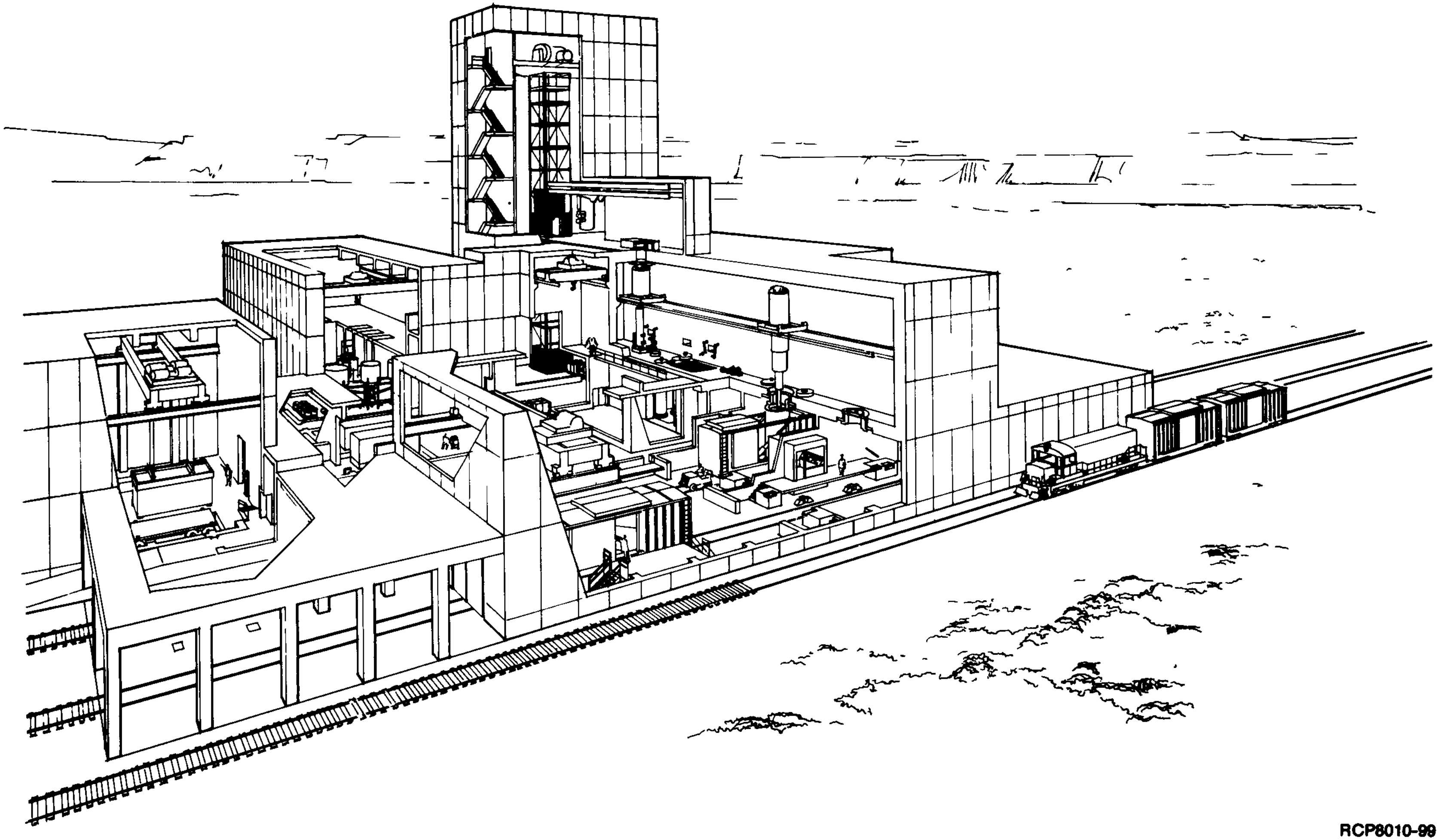

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FIGURE 22. Waste Handling Building (cutaway).

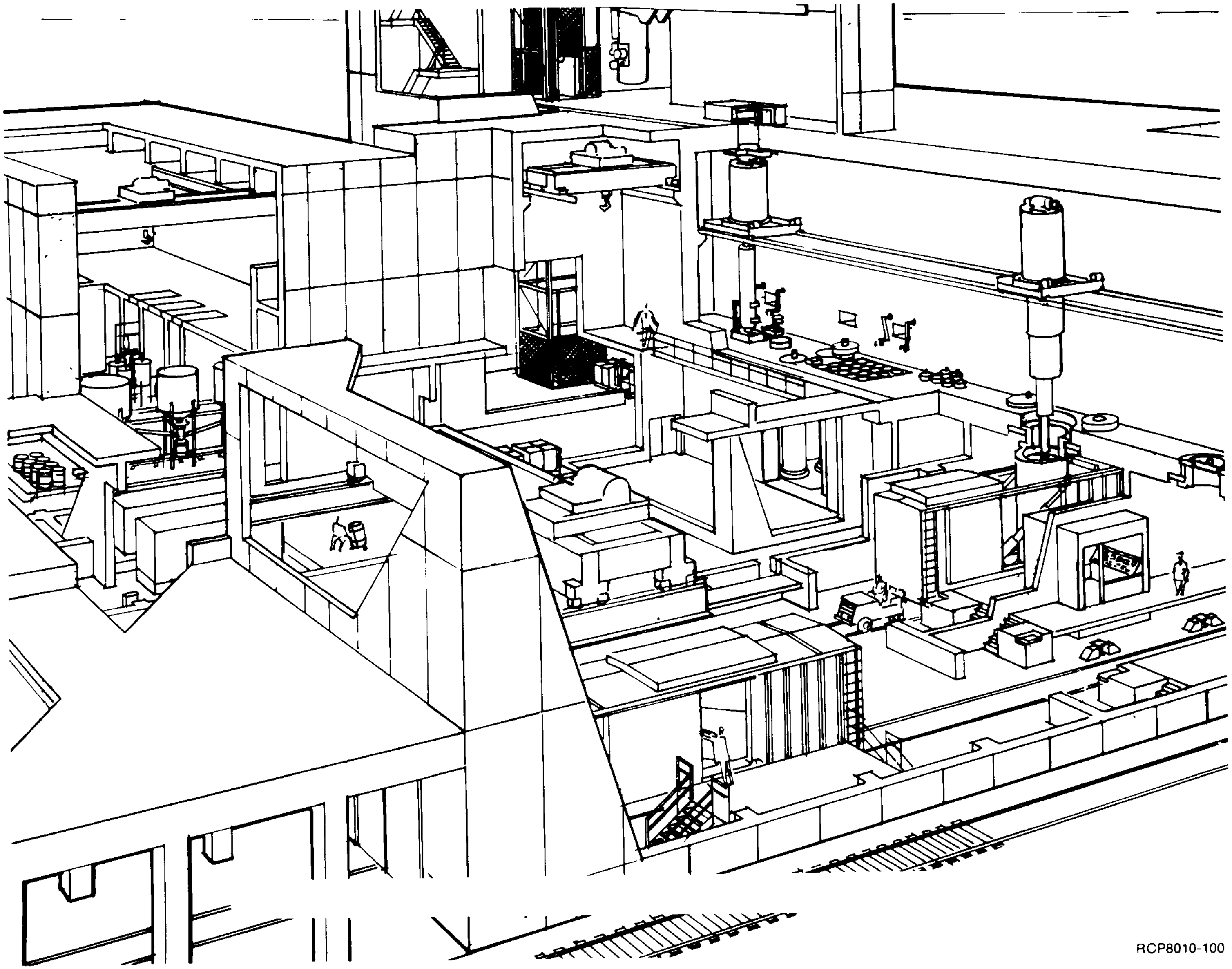
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FIGURE 23. Canister Receiving and Handling.

EXPLORATORY SHAFT TEST FACILITY PRECONCEPTUAL DESIGN

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Richland, Washington 99352

During fiscal year 1980, the need for an exploratory shaft test facility was recognized,(1) a test plan was prepared, and a preconceptual design was completed. The test plan is currently being reviewed within the National Waste Terminal Storage Program. A preconceptual design arrangement and design data sheet for a proposed exploratory shaft test facility are shown in Figure 1 and Table 1, respectively.

The functions of the exploratory shaft test facility project are to provide an access shaft and underground test chambers and to perform in situ testing in Columbia River basalt at a reference site for a nuclear waste repository. The objective of the primary test program and the reason for construction of the exploratory shaft test facility at this time is to provide a detailed characterization of a reference repository site. The exploratory shaft test facility, when constructed, will also contain space for certain identified ancillary tests. After the currently identified test objectives are achieved, follow-on in situ testing is expected to be conducted in an expanded exploratory shaft test facility. The shaft and underground chambers will be constructed so that they are licensable and could be later incorporated into the repository.

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

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

At the base of the shaft, underground chambers will be constructed to the minimum requirements necessary to support the in situ testing program. The underground chambers will consist of a shaft access station or "bell," access tunnels penetrating the shaft pillar area, and test chambers or rooms. The "H" layout selected for preconceptual design

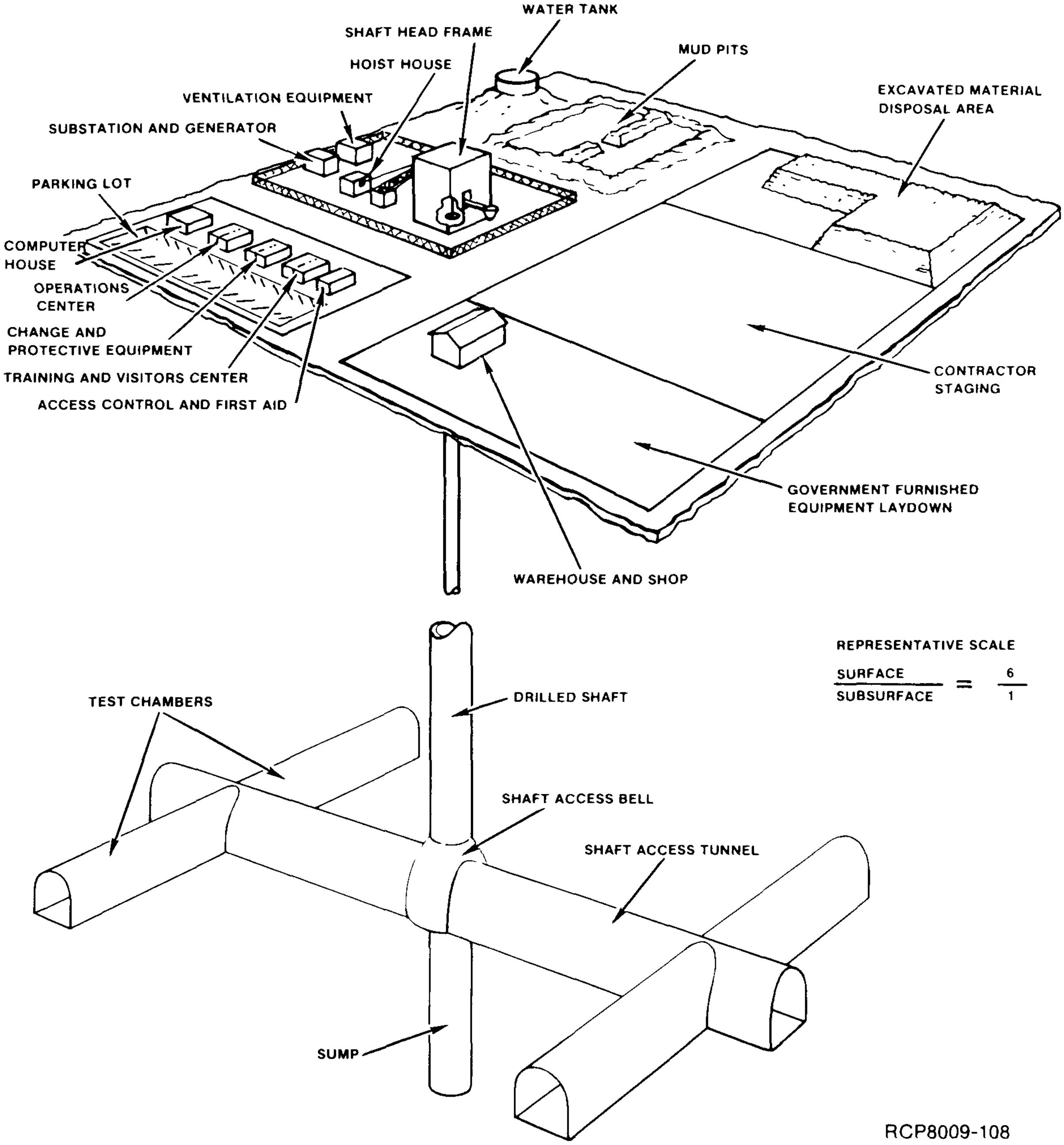

FIGURE 1. Exploratory Shaft Test Facility Conceptual Arrangement.

TABLE 1. Exploratory Shaft Test Facility Preconceptual Design Data Sheet.

Functions	
Initial tests	Primary: Site characterization Ancillary: Rock mechanics
Additional tests	Requires facility expansion
U.S. Nuclear Regulatory Commission Licensing	Licensable
Ultimate disposition	Incorporate into repository
Surface Facilities	
Site location	Hanford, Washington
Land improvements	8 hectares
Temporary buildings	1,100 square meters
Utility interfaces	1 to 10 kilometers
Drilled Shaft	
Depth	1,130 meters
Cross section	1.83 meters
Ground support	Grouted steel liner
Excavation	8,000 cubic meters
Steel liner	2,000 metric tons
Construction method	Big hole drilling
Underground Chambers	
Tunnel length	140 meters
Cross section	4.6 x 4.6 meters
Ground support	Rock bolt and mesh
Excavation	2,750 cubic meters
Construction method	Drill and blast
Design basis occupancy	20 persons
Major Systems	
Hoist rating	81 metric tons
Underground ventilation	7 cubic meters per second
Water consumption	91,000 liters per day
Dewatering time	10 minutes
Normal power	5 megavolt-ampere
Facility supervisory data acquisition system	1,000 channels

provides the shortest escape paths to the shaft station bell. The test chambers will allow observation of exposed rock surfaces, drilling of horizontal test holes for near- and far-field characterization of the candidate horizon, and space for ancillary rock mechanics tests.

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

The exploratory shaft test facility preconceptual design was part of a limited effort to develop a feasible reference facility concept utilizing existing technology, provide the technical basis for functional design criteria (to be written later), assemble schedule and cost data for project planning, and recommend alternatives that should be considered in subsequent design. All phases of design effort were accomplished concurrently. Because of this, conclusions developed in one area could not always be integrated into the design. The conceptual design phase will allow iteration and resolution of the following considerations:

- Possible use of a repository-size drilled shaft--recent improvements in the technology and availability of big hole drilling equipment indicate a larger drilled shaft may be feasible. A 3-meter ventilation shaft is the smallest shaft currently being considered in the nuclear waste repository conceptual design.

- Possible use of a "loop" underground chamber layout--in case of emergency, the "loop" provides two escape paths to both the shaft "bell" and to a refuge chamber.

- Wherever practical, use of prototypical repository tunnel cross sections, mining methods, and rock support systems.

- A more detailed design description of the operational, safety, and maintenance features of the underground chambers.

- Definition of the exploratory shaft test facility time-phased expansion and ultimate disposition.

- Optimization of exploratory shaft test facility systems.

During fiscal year 1981, the project schedule calls for the drilling of vertical test or pilot holes (to confirm the siting assumptions and provide site-specific design data), preparation of functional design criteria, and completion of a conceptual design. Drilling of the shaft could start as early as fiscal year 1983.

REFERENCE

1. Disposal of High-Level Radioactive Waste in Geologic Repositories, Title 10, Code of Federal Regulations, Chapter 60, U.S. Nuclear Regulatory Commission, Washington, D.C., 1979.

ESSENTIAL CHARACTERIZATION DATA FROM AN EXPLORATORY SHAFT TEST FACILITY IN BASALT

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The Basalt Waste Isolation Project is aimed at assessing the feasibility of disposing high-level nuclear waste in basalt beneath the Hanford Site and providing technology needed to design and construct such a repository should feasibility be proven. One of the fundamental objectives of this project is to select a site through a screening process and primary characterization of surface and subsurface environments until a preferred site is identified. This process of screening and characterization of the Hanford Site leads to the "banking" of a preferred site for basalt as a host rock type. A site is banked when the participants in the siting process reach a consensus on the technical, environmental, and institutional adequacy of the site relative to established criteria, and an interest in the land has been obtained by the U.S. Department of Energy to maintain the integrity of the site through the remainder of the selection process. The Hanford Site has already been dedicated to be used as a U.S. Department of Energy nuclear energy reservation.

The initial characterization work and screening process of the Hanford Site have shown that disposal of nuclear materials within basalt flows beneath the Hanford Site appears to be feasible and has narrowed the site location to an area of 180 square kilometers within the southeastern portion of the Cold Creek syncline (Figure 1). A site characterization plan has been submitted to the U.S. Department of Energy outlining the source of action to further reduce this potential location to the preferred site for banking. It is expected that a draft environmental impact statement and a detailed site characterization plan will be submitted to the U.S. Department of Energy for review in fiscal year 1982, describing the method for collecting all additional data necessary if a license application were submitted for the preferred site in basalt at Hanford.

Most of the data required for adequate detailed site characterization would be obtained from surface exploration and from drilled boreholes. However, some essential data needed for site characterization would be obtained by sinking a shaft and exploring at the repository depth. These essential characterization data include:

- Determination of the geometry of the repository horizon to assure adequate host rock exists for repository placement
- Assessment of the subsurface hydrologic characteristics to assure that the rocks are sufficiently impermeable to permit construction of large underground chambers
- Assessment of the stability of an underground opening in basalt at the repository depth.

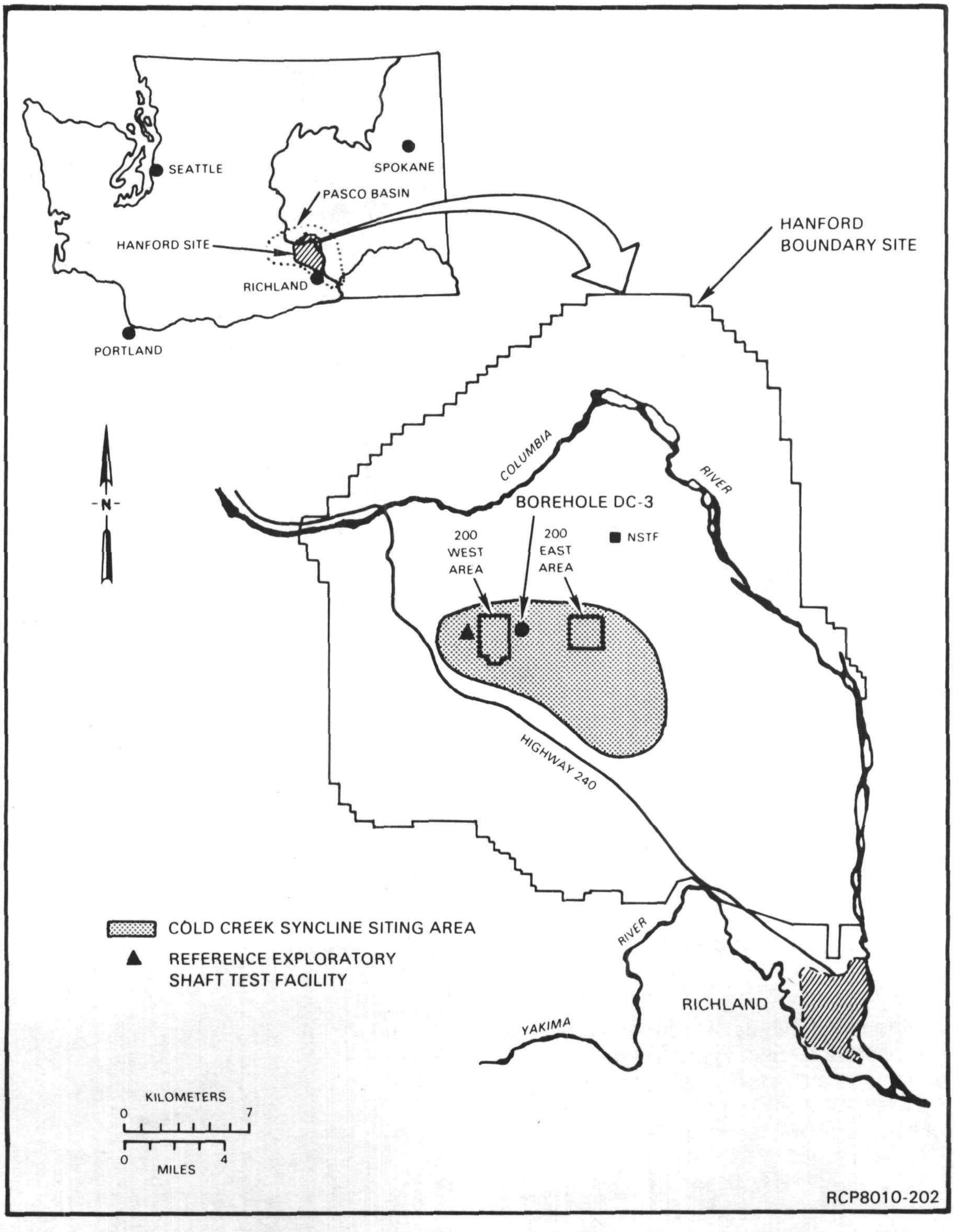

FIGURE 1. Location Map--Hanford Site.

The results of these in situ measurements will be summarized in a detailed site characterization report prior to submitting an application for construction authorization.

GEOMETRY OF REPOSITORY HORIZON

The stratigraphy of the flows within the Pasco Basin has been developed from surface exploration and from analyses of basalt core samples. The stratigraphic column for the Pasco Basin is shown in Figure 2. The method of flow identification developed under this project is now widely accepted by universities, private industry, and federal and state agencies. Within the stratigraphic framework, the structure of a basalt flow within the Pasco Basin can also be predicted with reasonable assurance. Furthermore, it is possible to extrapolate the thickness and attitude of a flow like the Umtanum from one borehole location to another.

The current interpretation of data from core holes drilled on the Hanford Site is that the interior of the primary candidate flow, the Umtanum flow, located within the eastern portion of the Cold Creek syncline, contains 8 to 15 meters of flow top, 30 to 46 meters of entablature, and 3 to 18 meters of colonnade. These data also indicate that there is a high probability of a thicker flow-top breccia in selected areas and/or multiple entablature-colonnade tiers. It is doubtful, however, that these structures related to cooling of the lava can be extrapolated over any great distance.

There is a close relationship between the structure and thickness of a flow and the cooling history of an eruption. As noted above, the information obtained to date suggests the Umtanum flow is about 60 meters thick and that the intraflow structures are nearly the same over the area of the Cold Creek syncline. Although not a common occurrence, large pillow palagonite zones do occur within the Columbia River basalt. Many of these weathered and altered zones of a flow are well exposed in road cuts and along the cliffs of deep river gorges in the region. These pillow palagonite complexes were formed as a result of the molten lava entering a body of water, like a pond, lake, or stream, and were, in most instances, localized. In order to have reasonable assurance that a pillow palagonite complex is not present within the preferred site, either the drilling of a larger number of boreholes within the preferred site or an exploratory shaft and test facility at depth are required. There is a reasonable limit to the number of boreholes that can be drilled in the preferred site without compromising the integrity of the site. An exploratory shaft test facility, on the other hand, would have less impact on compromising site integrity, while still obtaining the required data. A diagrammatic sketch of such a facility is discussed in the preceding section. It is envisioned that horizontal boreholes up to 300 meters in length would be drilled out from underground test chambers, which are part of the exploratory shaft test facility.

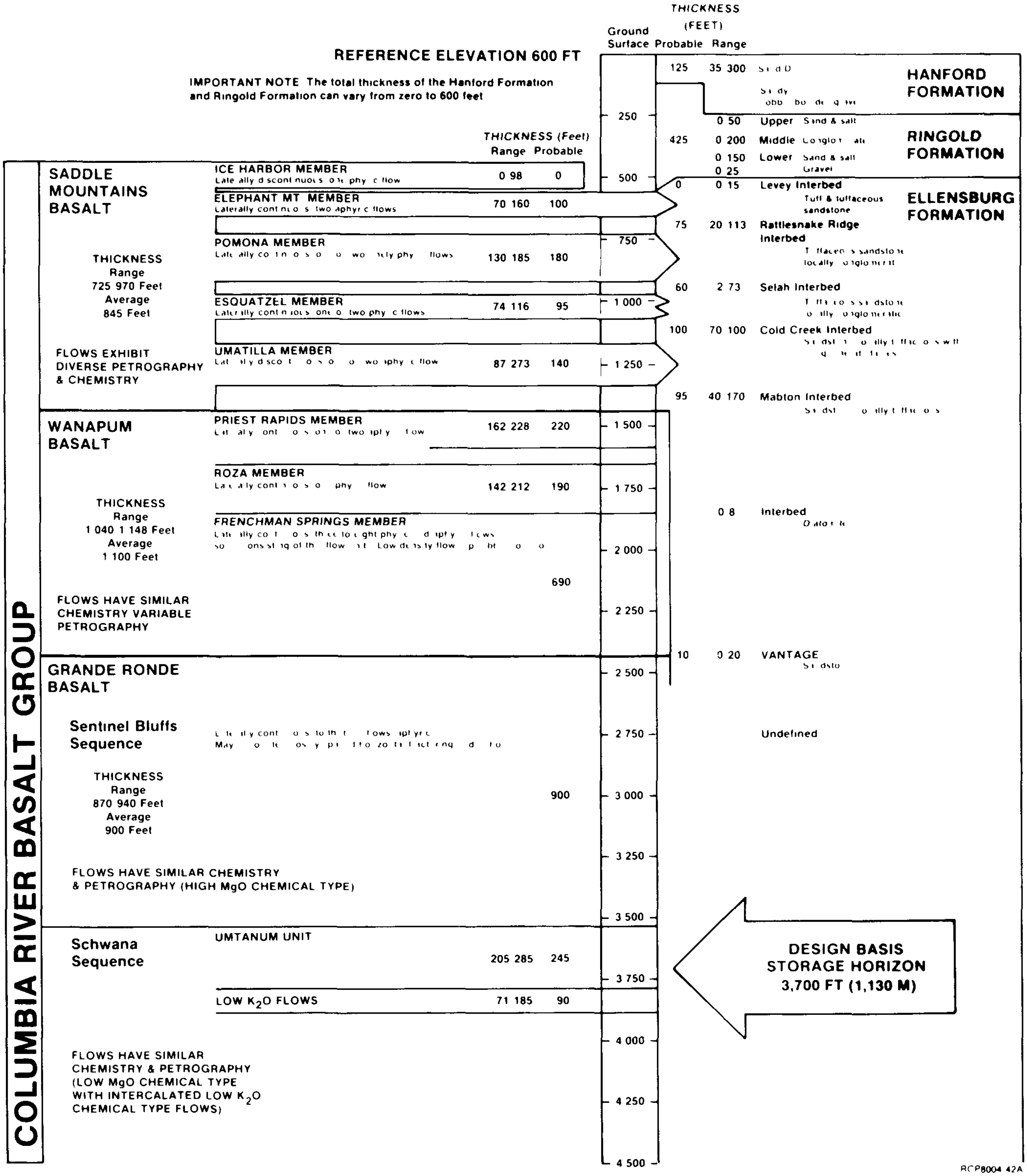

FIGURE 2. Hypothetical Reference Site Stratigraphic Column.

HYDROLOGIC CONDITIONS FAVORABLE TO MINING

Since groundwater is the primary mode by which radionuclide and toxic materials are transported to the accessible environment (biosphere), the hydrologic system and related host rock characteristics must be well understood. Primary emphasis is placed on this aspect of the hydrologic characterization work. Results from field studies have led to a sound interpretation of the regional flow systems, which has been supported by subsequent measures of hydrologic parameters in small boreholes. Figure 3 is a map showing the conceptualized groundwater flow system for the upper basalt flows within the Pasco Basin. Areas of potential recharge and discharge are indicated by the pattern of arrows. The hydrochemistry of groundwater samples tends to confirm this hypothesized flow system. Within the basalts at depth (directly above and below the Umtanum flow), groundwater flow is predominantly in the same plane as the interflow contacts. Discharge from these lower aquifers is believed to be into the Columbia River near Wallula Gap. Hydraulic conductivity values measured within the Umtanum flow are extremely low (10^{-5} to 10^{-7} meters per day). Further, direct observation of the Umtanum flow in Borehole DC-3 (see Figure 1) tends to confirm these measurements. Since Borehole DC-3 was completed, there has been no measurable water inflow. Photographs (Figure 4) show the sidewalls of the borehole to be dry. The water present in the bottom of this borehole was what remained at the time the borehole was completed.

The extremely low hydraulic conductivity of the basalt at first glance appears to be anomalous because of the highly fractured nature of basalt. Normally, one would consider basalts to have a high permeability. Through analyses of core samples, however, it has been established that the fractures within flows are healed as a result of either weathering and secondary mineralization or by hydrothermal alteration. This is confirmed by the many hydrologic tests conducted within these boreholes. There are some fracture zones within flows that are not completely healed and do permit groundwater to move more freely. Such movement into an underground opening could restrict mining if the volume were large enough. It is this aspect of the subsurface hydrologic system that can only be evaluated with reasonable assurance in an underground chamber.

The problem involved with obtaining these data from small-diameter boreholes drilled from the surface is illustrated in Figure 5. Several basalt flows are shown, each with a generalized fracture pattern. A graph is included in the figure to show the relationship between the area of the opening where the measurement is made and the value of the physical parameter measured. Small-diameter boreholes are best represented by the microscopic example. From the graph, it is seen that a wide range of values could be measured in a small-diameter borehole, depending on the interconnections of the fractures and the position of the borehole within a flow. It would be difficult to determine if the fluctuations in the range of values measured are the results of the size of the borehole or changes in the character of the rock; for example, from small-diameter columns to columns of large diameter. In the case of a macroscopic opening, consideration is given to the size of the opening within the basalt flow into which groundwater can move. With a larger opening, more

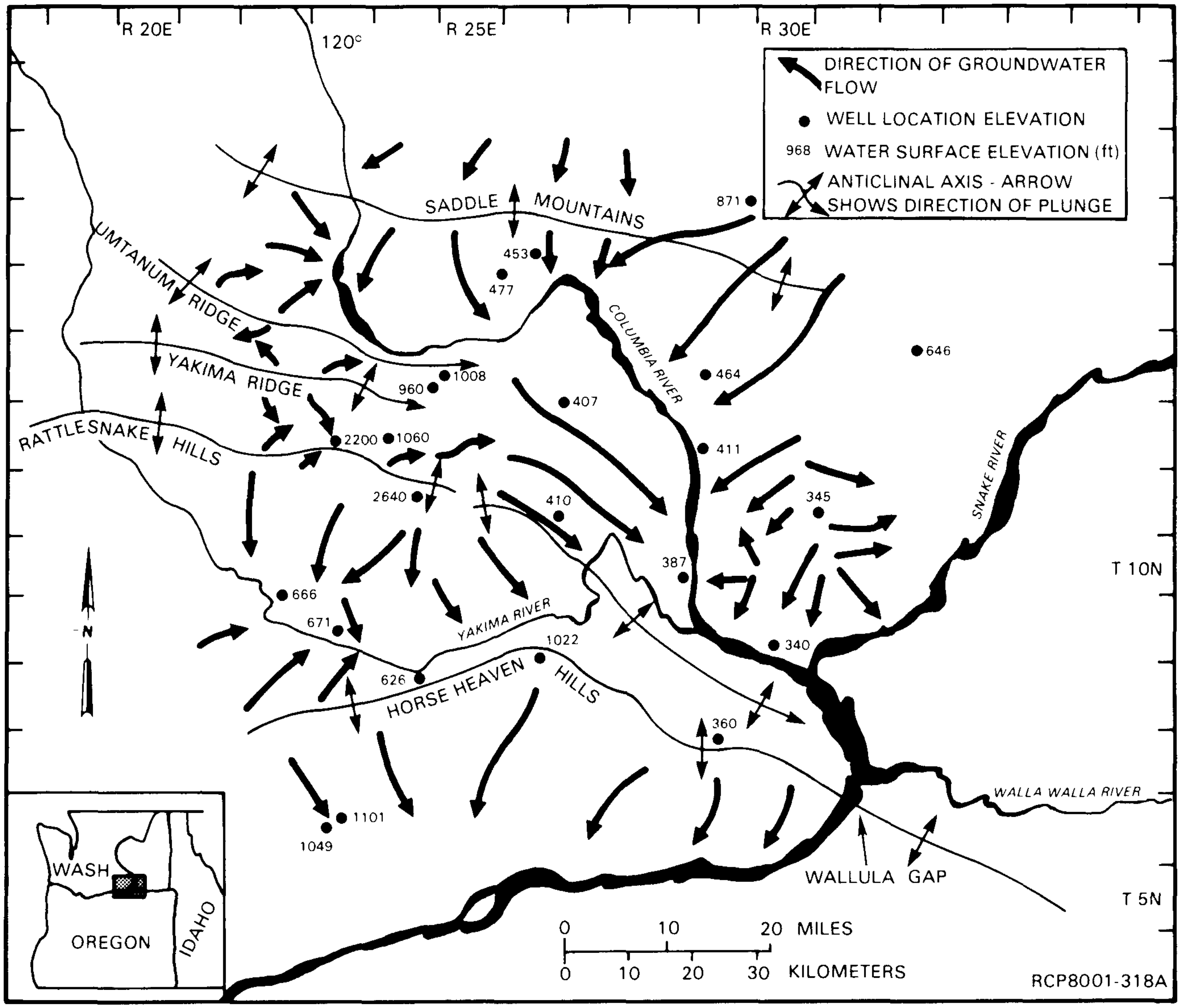

FIGURE 3. Generalized Groundwater Flow Pattern in the Pasco Basin.

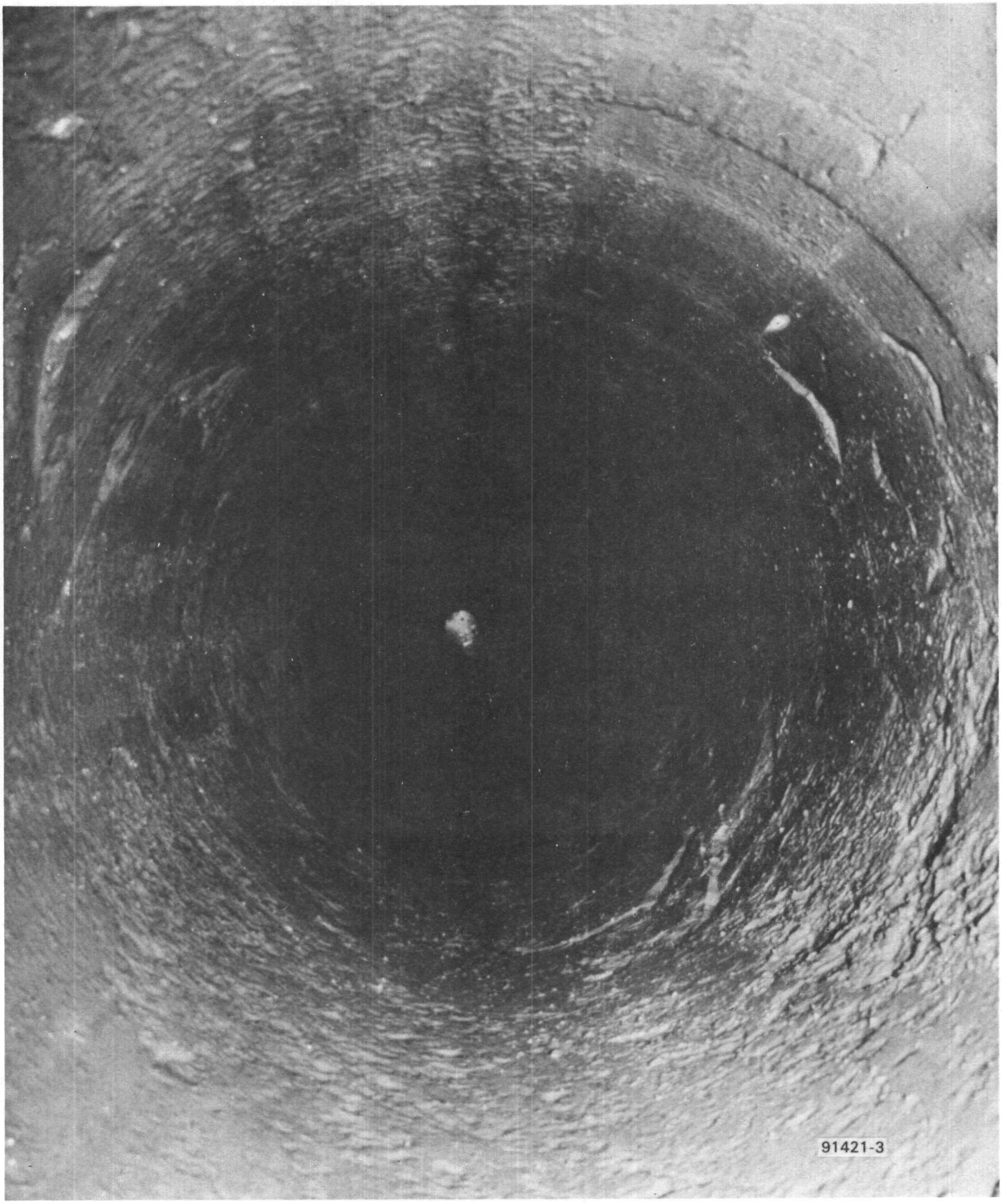

FIGURE 4. Photograph of Umtanum Borehole at Well DC-3 (see Figure 1 for location) at a Depth of 1,070 Meters below Ground Surface.

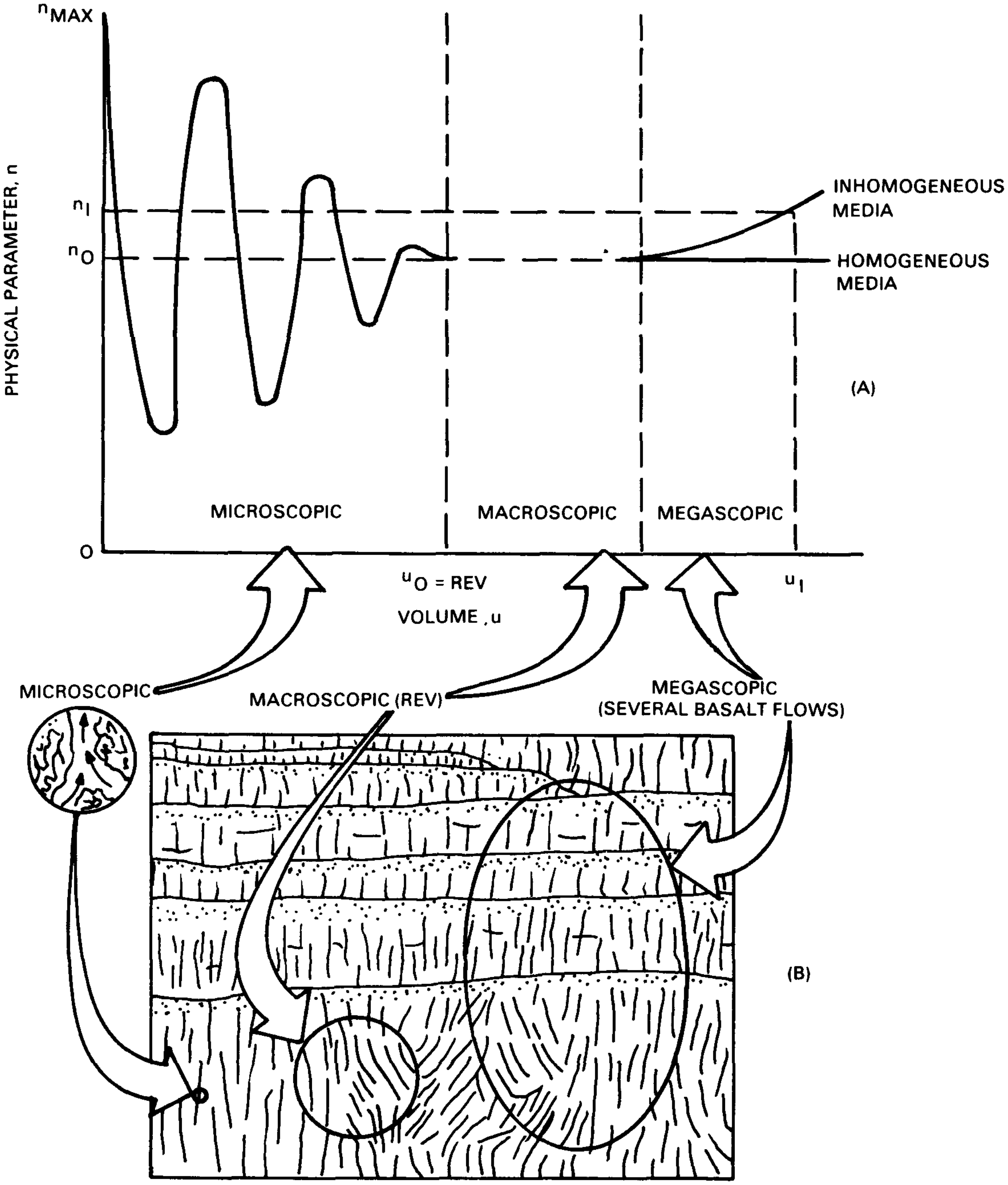

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FIGURE 5. Relationship between Physical Properties Determined in Basalt and the Size of the Opening.

fractures are intercepted per unit surface area until a constant number of fractures per unit area is reached. The expression used to convey this concept is a representative elementary volume. When an underground opening is equivalent to a representative elementary volume, the most representative value of the parameter being measured is obtained. When the underground opening is so large that more than one flow is exposed, the measured value of the parameter can either be greater or less than a representative elementary volume, depending on the character of the rock involved.

The only method available for attaining an underground opening that approaches a representative elementary volume for basalt is through mining; sinking a shaft to repository depth and mining test chambers out from the shaft.

REGIONAL STRESS AND DEFORMATION

Basalts underlying the Hanford Site, as mentioned above, are highly fractured with most of the fractures either filled or healed through the natural processes of secondary mineralization and/or hydrothermal alteration. In most instances, deformation of basalt flows due to regional stress occurs along these fractures. It is not uncommon to observe slickensides (shiny or polished grooved surfaces) on all surfaces of a block of basalt removed from an outcrop. As mentioned above, permeability measurements in boreholes attest to the extent of this natural healing or filling of fractures within a flow.

When regional stresses are placed on these rocks, the tendency is for them to deform by gradually sliding along the fracture planes much like a deck of playing cards set on a table and tilted to one side, each adjacent card face moving in an equal and opposite direction. Samples of blocky basalt removed from excavated flows sustain this hypothesis. It is quite common to find slickensides on all surfaces of the block removed from the flow.

The in situ natural fracture conditions are the result of the regional stress field and the weight of the overburden. The resultant stress pattern around the opening affects the overall stability of the opening in three ways. First, it can cause closure of the opening if the stresses are great and the rock has little resistance to deformation. Second, an induced fracture pattern develops around the opening which tends to weaken the rock. Third, there is a potential for sudden collapse of the opening if the rock is not sufficiently rigid and strong.

Techniques have been developed for measuring the magnitude and direction of regional stress in boreholes; however, data obtained in this manner are always subject to question. The measurements required to adequately determine the stability of an underground opening can only be determined where people have physical access to the rock of interest. The degree of assurance required that the rock is stable and will support underground mining is vital when compared to the importance of the project being undertaken.

PRECONCEPTUAL DESIGN OF A BOREHOLE PLUGGING SYSTEM IN A REPOSITORY IN BASALT

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Preliminary work in the borehole plugging studies is being conducted by Woodward-Clyde Consultants for the Basalt Waste Isolation Project. Initial studies involved characterization of geologic, hydrologic, and geochemical features of the Columbia Plateau basalt flows relevant to borehole plugging performance. Approximately 10 candidate plug materials judged suitable to the environment were selected for laboratory testing and preconceptual design studies. These materials included coarse- to fine-grained basalt; Oregon and Wyoming bentonites; processed bentonites; Ringold clay; Oregon zeolite; glaciofluvial sands; and Type II, Type V, calcio-aluminate, and Type K portland cements. The preliminary laboratory tests of the geochemical and geotechnical properties of these candidate materials were conducted and concluded this year.

The geochemical properties were tested at temperatures up to 250°C and pressures up to 34.5 megapascals. These tests indicate that the candidate plug materials are compatible with each other and with the geochemical environment expected near a repository in Columbia River basalts. However, much longer experiments may be required to detect low rates of reaction that might prove detrimental to plug performance over a long containment period.

Preliminary runs in a stirred autoclave (250°C, 3.9 megapascals) indicate that crushed Columbia River basalt, in the presence of simulated groundwater, undergoes a self-cementing reaction. In runs of 2-weeks' duration, approximately one-half of the basalt in the autoclave was cemented into a hard, durable mass. The self-cementation may be a result of dissolution of the glassy phase within the basalt and precipitation of silica. This result suggests the interesting possibility of producing natural cements from repository materials of known long-term stability. Efforts will be made in the continuing program to determine the exact nature and kinetics of the cementing reaction and to produce pieces of self-cemented basalt sufficiently large enough for physical testing.

The physical testing program is designed to aid in the selection of individual materials and mixtures from the list of preferred candidate materials and to describe the physical properties of these materials for use in design studies. Preliminary results indicate that, of the cements tested, portland cement Type V is the most preferred for use in plugs because of its high-sulfate resistance and good mechanical performance. The addition of finely ground, high-silica pozzolan to portland cement reduced shrinkage, increased workability, improved impermeability, and increased stability of cement mixtures exposed to moderate temperatures (less than 100°C). The addition of finely ground silica flour to portland cements reduced shrinkage and substantially improved thermal stability and structural strengths of cement mixtures exposed to temperatures greater than 100°C.

Preliminary results for cohesive materials indicate that bentonite clay is a preferred material for use in clay/sand or skip-graded clay/sand/aggregate mixtures. Its high plasticity, excellent swelling properties, and very low permeability, coupled with high ion exchange potential and sorption capacity, should substantially decrease both fluid and radionuclide migration through plugs. Wyoming bentonite is superior to Oregon bentonite in terms of plasticity and impermeability, and both are far superior to Ringold clays from the Hanford Site. Both crushed basalt and glaciofluvial sand and gravel from the Hanford Site are strong, competent, granular materials and are suitable for use as aggregate in concrete, compacted earth materials, and premixed clay slurries. At the present time, crushed zeolite appears useful only as a component in compacted backfill.

Preliminary tests using plug models emplaced in holes drilled into blocks of basalt indicate that it is possible to design mixtures of candidate plug materials that have permeability of less than 10^{-8} centimeters per second and will form good bond strengths with the host rock. Mud contamination of simulated borehole walls during model testing was found to substantially decrease the bond strength between miniature cement and soil plugs and the basalt. However, high bond strengths for compacted bentonite/sand mixtures cured at 100°C indicate the possibility of cementation between plug and basalt at high temperatures.

PLUG DESIGN

Preconceptual plug design studies concentrated on plugging schemes that appear to be available on a near-term basis (5 to 10 years). Numerous other plugging schemes were also identified that could be feasible with varying degrees of development. Schemes considered most feasible were subjected to a technical analysis of their design performance under expected conditions. At this state of the study, only thermomechanical and hydraulic performances were considered to be potentially useful for prediction. Numerical analysis of hydraulic performance indicates that an expected zone of construction disturbance around tunnels and shafts can have a profound influence upon plug design. This zone, which results from energy input during construction and subsequent stress relaxation, can have a higher permeability and a cross-sectional area considerably larger than that of the tunnel. Grouting of the disturbed zone is contemplated; however, because of the uncertainties inherent in grouting, the proposed designs utilize cutoff collars through the disturbed zone. This technique involves either excavating the disturbed rock zone over a length of tunnel sufficiently short (1 to 2 meters) to promote overburden load transfer (arching) to adjacent rock or use of adjacent, temporary tunnel supports to avoid relaxation above the fresh cutoff collar excavation. The excavated collar would then be filled with low-permeability plug material to intercept fluid flow through the disturbed zone.

Following technical evaluation, the plugging schemes were rated on their ability to fulfill five design functions: core barrier performance, plug/wall rock interface performance, support performance, disturbed rock zone performance, and long-term integrity. The ratings were carried out for each plug environment (boreholes, shafts, tunnels) and, in each case, no single scheme best performed all design functions. Thus, multiple-zone plugs are proposed for each plug environment.

A preconceptual design for a tunnel plug, which consists of alternating zones of concrete, clay/sand/silt slurry mixtures, and basalt blocks, is presented on Figure 1. Concrete is considered appropriate on the basis of core barrier performance, plug/wall rock interface performance, and support performance. Clay/sand/silt slurry mixtures are considered appropriate for disturbed rock zone treatment. In order to satisfy criteria for long-term stability of the multiple-zone plugs, basalt blocks, mortared with cement or bentonite, are a backup feature to the concrete zone.

A preconceptual design for a shaft plug, which consists of alternating zones of compacted earth material and concrete, is also presented on Figure 1. Compacted earth plugs are considered appropriate for core barrier performance, plug/wall rock interface performance, and long-term integrity. Concrete is considered appropriate for support performance and is preferred for disturbed rock zone treatment because it has low permeability, it can provide support during the construction of cutoff collars, and it will limit axial movement of the plug.

A preconceptual design for a borehole plug, which consists of gravel and clay slurry with bentonite pellets and cement grout, is presented on Figure 1. Gravel and clay slurries containing pellets of compressed bentonite are preferred for core barrier performance and long-term integrity, while cement grout is preferred for plug/wall rock interface performance.

In future geochemical and geotechnical laboratory testing, materials specifications for construction performance needs will be evaluated, and material stability and strength factors will be assessed at ambient and elevated temperatures. Future design and analysis work will investigate impaired performance modes, excavation techniques, and the possible influence that access excavation techniques might have on the future plug performance. Several field demonstrations of shallow and deep borehole and shaft plug installation and performance are also being planned.

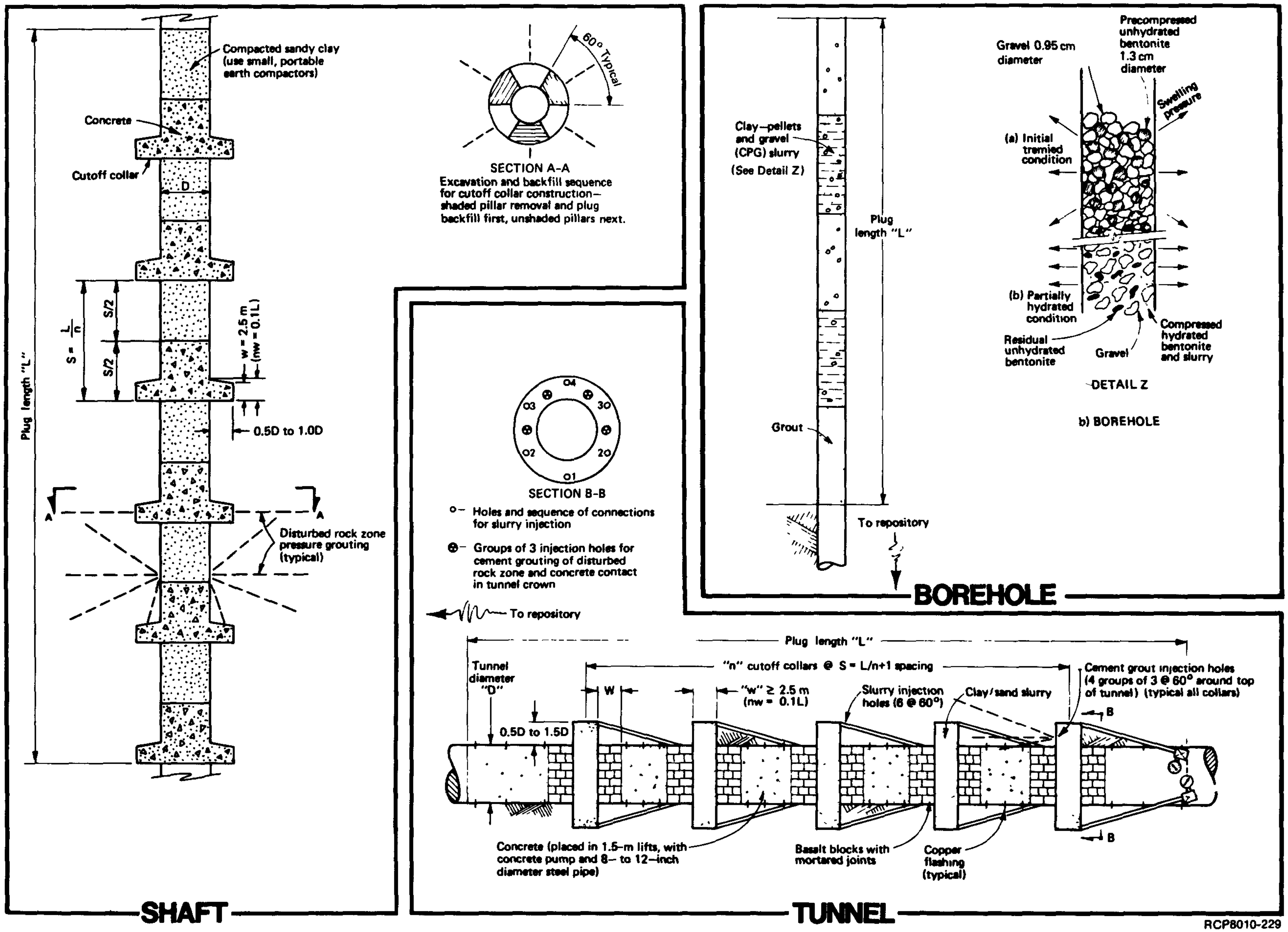

FIGURE 1. Preconceptual Design for Tunnel Plug.

THE SHALLOW BOREHOLE PLUGGING TEST

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The success of deep geologic disposal for commercial high-level nuclear waste in a repository in basalt is strongly dependent upon the ability to seal the many man-made openings (i.e., shafts, tunnels, and boreholes) that will exist in and around the repository. The most favorable geology will be nullified if the excavations necessary for emplacement of the waste provide rapid access to the biosphere. The time over which the plugs must remain effective (10^4 to 10^6 years) and the degree of assurance that the plugs will function as designed are unique in normal engineering design experience. These requirements may necessitate the use of unconventional plug materials (i.e., clays) and either the modification of existing plug placement machinery or the development of new types of machinery.

Field tests, including in situ tests of repository seals are necessary to provide the degree of assurance of repository sealability required for licensing of a geologic repository for high-level nuclear waste. The Basalt Waste Isolation Project borehole plugging program includes a graduated series of field tests, integrated with site-specific laboratory and modeling studies. The proposed field test series starts with tests of borehole, shaft, and tunnel seals at relatively shallow depths either within or near the Near-Surface Test Facility on Gable Mountain and ends with in situ tests in either an exploratory shaft test facility or within a repository test area. The early field tests, carried out near the surface, are necessary to test plugging techniques, plug designs, and plug materials prior to large-scale, in situ plugging demonstrations.

The first proposed field test in basalt, the Shallow Borehole Plugging Test, will plug a series of shallow, small-diameter boreholes to test material properties, emplacement techniques, and instrumentation. The initial field tests, carried out at shallow depths, are necessary to provide data for the design and interpretation of later, full-scale, in situ tests under repository conditions. This is particularly important in the plugging of deep boreholes. These holes, 10 to 20 centimeters in diameter, must be plugged at depths on the order of 1,000 meters. Plugging must be done remotely and it is unlikely that undisturbed plug material will be recovered or observed subsequent to plug emplacement. Therefore, it is important that preliminary field testing be carried out where techniques can be more readily evaluated and where plugs and instrumentation can be accessed and recovered for evaluation at the end of testing.

The site selected for the Shallow Borehole Plugging Test should meet the following criteria:

- The site should be located above a thick, competent basalt flow(s) with well-understood physical properties and geology.

- The flow(s) to be used for the test should be near the surface and above the water table.
- The site should be readily accessible by existing, all-weather roads.
- The site should be near an existing water supply and source of electricity.
- The surface of the site should require a minimum of preparation.

Several sites on Gable Mountain and Gable Butte have been evaluated and a candidate site has been chosen on Gable Mountain near the Near-Surface Test Facility (Figure 1). The candidate site is well away from the major fold axes on Gable Mountain and is above gently dipping, relatively undisturbed portions of the Elephant Mountain and Pomona basalt flows. The candidate site is easily accessible from existing Near-Surface Test Facility roads and is near water, electricity, and engineering services at the Near-Surface Test Facility. The site is on a relatively flat bench and will require little or no site preparation.

Five characterization core holes have been drilled at the candidate site. The holes were cored to a depth 46 meters and the NX core has undergone preliminary characterization. In addition, standard geophysical techniques, including acoustic, resistivity, and natural gamma logs and borehole photography, have been used to characterize the site. Preliminary evaluation of the characterization data collected indicates that there are several intervals within the 46-meter section that are suitable for testing.

The proposed Shallow Borehole Plugging Test will test the strength, stress- strain, and fluid flow characteristics of plugged boreholes in basalt, as well as emplacement techniques and quality assurance procedures for emplacement of plugs in small-diameter boreholes. Plug materials to be tested will consist of portland cement grouts and bentonite slurries containing crushed basalt and compressed bentonite pellets. The proposed tests are:

- Test 1--source sink plug permeability test
- Test 2--point source/flow net plug permeability test
- Test 3--thermomechanical plug/wall rock bond strength test.

The source sink plug permeability test (Test 1) uses injection and withdrawal points to assess plug and plug/wall rock permeabilities. The point source flow net plug permeability test (Test 2) uses an injection point and sensitive electric piezometers to assess plug and plug/wall rock permeabilities. Swelling pressures developed by expanding clays (bentonites) will be measured in both Tests 1 and 2, and a fluorescent dye will be injected during the later portion of the tests so that fluid

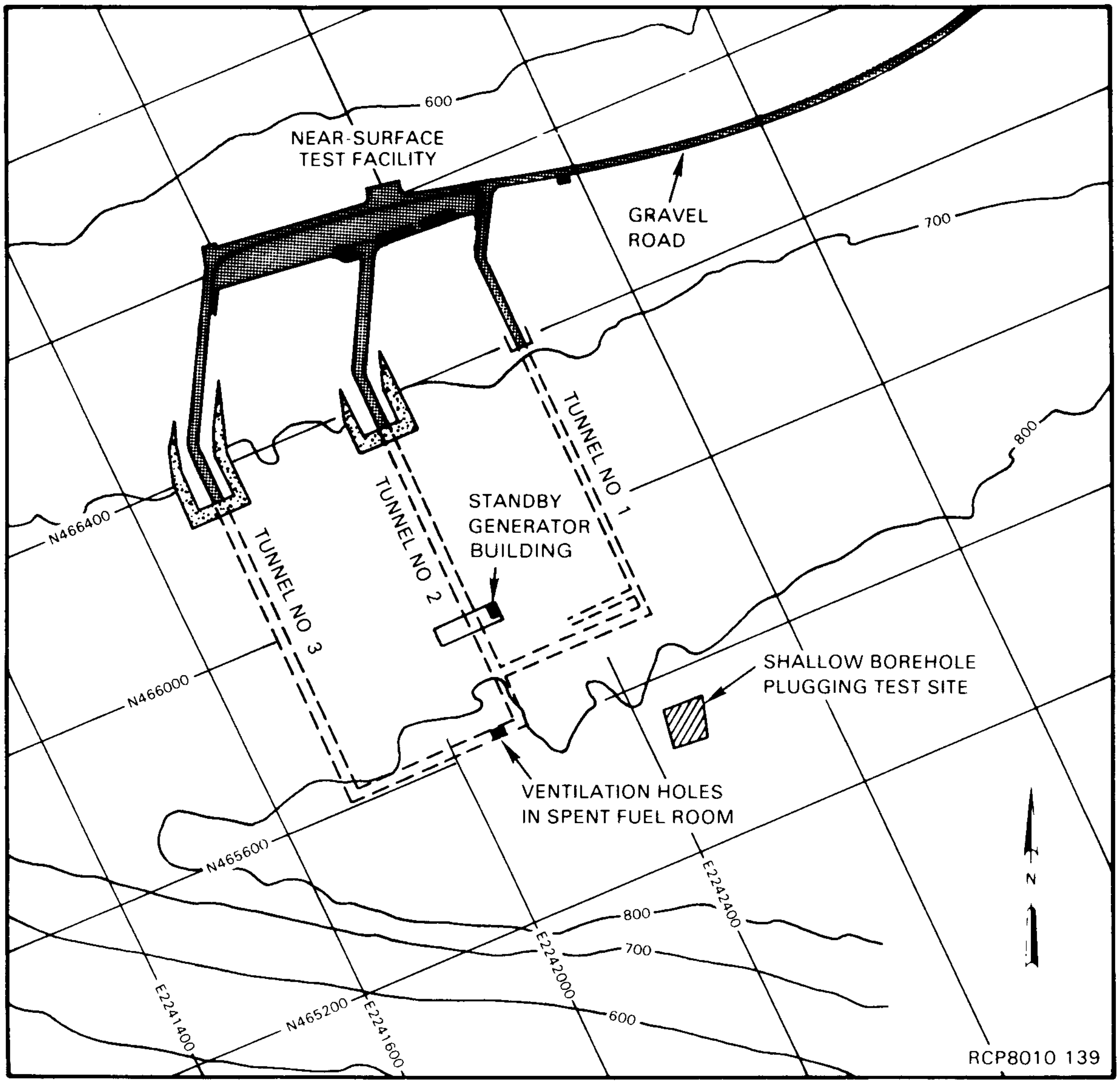

FIGURE 1. Shallow Borehole Plugging Test Site Location.

flowpaths can be determined in plug and host rock material recovered through overcoring. The thermomechanical plug/wall rock bond strength test (Test 3) will examine the strength and stress-strain properties of the plug/wall rock bond under heat-induced stresses. Test 3 will be carried out only with concrete grout plugs. Subsequent to field testing, all plugs will be overcored for further laboratory evaluation of plugs and instrumentation.

Modeling of plug performance will be required prior to testing. Preliminary modeling will aid in test design, permit predictions of plug performance, and support the determination of test data requirements. Refined models will provide a predictive base for evaluation of test results. A series of carefully planned laboratory tests and small-scale field tests designed to evaluate potential problem areas will help ensure the success of the Shallow Borehole Plugging Test prior to its startup.

APPENDIX

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