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Nuclear Waste Policy Act
(Section 113)

Consultation Draft

Site Characterization Plan

Reference Repository Location, Hanford Site, Washington

Volume 7

January 1988

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

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SITE CHARACTERIZATION PLAN

Chapter 8 - SITE CHARACTERIZATION PROGRAM

Section 8.3

Planned Investigations

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8.3 PLANNED INVESTIGATIONS

Section 8.3 describes the investigations to be conducted during site characterization. A table is included that relates these investigations to the information presented in Part A and to the issue resolution strategies presented in Section 8.2.2. The relationship between the site characterization program and system performance goals is also described. A brief summary of each major program is provided at the end of this introduction.

The U.S. Department of Energy (DOE) is currently in the process of establishing a systems engineering, development, and management contractor to manage and integrate efforts of the repository projects, including the Basalt Waste Isolation Project (BWIP). The systems engineering, development, and management contractor will control the characterization and engineering development efforts of each repository project, including work scope and schedule. Therefore, the plans described in this section of the Site Characterization Plan (SCP) must be considered preliminary and subject to revision by the systems engineering, development, and management contractor.

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RELATIONSHIP OF SECTION 8.3 TO PART A

Part A (Chapters 1 through 7) of this document presents information that has been compiled from previous investigations at the Hanford Site and describes current conceptual designs for the repository and the waste package. Chapters 1 through 5 include the data used to make the preliminary (i.e., lower-level) findings of site suitability that are reported in the Environmental Assessment (DOE, 1986). These chapters also include the data that were used in the decision-making process for identifying the three sites recommended for site characterization (DOE, 1987b). Chapters 6 and 7 present preliminary conceptual designs for the repository and the waste package; these designs are based on the existing knowledge of the site. For a more detailed overview, the reader is referred to the Introduction to Part A.

The site characterization plans presented in Section 8.3 are intended to augment this body of information sufficiently to accomplish the issue resolution process and to support the design of the repository and the waste package.

GOVERNING PRINCIPLES FOR THE SITE CHARACTERIZATION PROGRAM

The site characterization program will allow the DOE to determine whether the geologic disposal system at the BWIP site will meet the requirements of 10 CFR 60 (NRC, 1987a), 10 CFR 960 (DOE, 1987a), and 40 CFR 191 (EPA, 1986). Collectively, these regulations require the proposed site to establish the following:

- The site is suitable for constructing and operating a repository.

- The mined geologic disposal system will provide safe waste isolation in compliance with regulatory requirements.

The plans for site characterization are based on the issue resolution strategies and a series of subordinate performance and design issues. These key issues, performance issues, and design issues, taken together with the information needs identified to facilitate the resolution of these issues, make up an issues hierarchy around which the site characterization program is conceived.

THE ISSUES HIERARCHY

Issues are used to guide the development of plans for site characterization. These issues are defined as the questions relating to the performance of the mined geologic disposal system that must be resolved to demonstrate compliance with Federal regulations (including 10 CFR 60 (NRC, 1987a), 10 CFR 960 (DOE, 1987a), 40 CFR 191 (EPA, 1986), and 10 CFR 20 (NRC, 1987b)).

The issues hierarchy is a three-tiered framework that identifies what must be known before a site can be selected and licensed. In providing this information, each tier contains progressively more detail than the tier above it. The entire issues hierarchy for the Hanford Site is presented in Section 8.2.1.

On the first, or highest, tier are the three key issues. Stated as questions, they are derived from the system guidelines in the DOE siting guidelines; they therefore embody the principal regulations that govern repositories and are fundamental to the program described in Chapter 8.

The second tier consists of performance and design issues. Also stated as questions, these issues expand on the requirements stated in the key issue they support. When each group of issues was constructed, an attempt was made to include all the questions that must be answered to resolve the key issues.

The third tier consists of information needs. Information needs are necessary for resolving key issues and issues. The information needs are stated as requirements for technical information rather than as questions. The key issues and issues are common to site characterization plans for all proposed sites, but the information needs have been developed specifically for the BWIP site and take into account current knowledge about the site, the host rock, and the surrounding environment. Table 8.3-1 presents a complete list of the information needs to be addressed by the plans described in this section.

In principle, acquiring all the information required at the third tier of the issues hierarchy will allow all the issues to be resolved through analyses and evaluations that use the information. If the issues are resolved affirmatively, the key issues will be resolved.

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Table 8.3-1. Correspondence of information needs identified in Chapters 1 through 7 to planned investigations (sheet 1 of 3)

Information need	Relevant data chapter sections	Investigation where addressed	Section number of corresponding study
Stratigraphy	1.2, 2.1, 6.1	Stratigraphy and structure	8.3.1.2.3.3.1
Intraflow structure	1.2.1.2.2, 1.2.2.1.4, 2.1.1, 6.1.2.1	Stratigraphy and structure	8.3.1.2.3.3.2
Cooling joint characteristics	1.2.1.2.3, 1.2.2.1.5, 2.2.1, 2.2.2	Stratigraphy and structure	8.3.1.2.3.3.3
Structural geology	1.3	Stratigraphy and structure	8.3.1 2.3.3.4
Physical rock properties	1.2.1.2.4	Stratigraphy and structure	8.3.1.2 3.3.5
Stratigraphic and structural modeling	1.2.2, 1.3, 2.2.2, 2.2.3	Stratigraphy and structure	8.3 1.2.3.3.6
Deformation	1.2, 1.3.2.2, 1.3.2.3, 1.3.2.4	Tectonic events and processes	8.3 1.2.4.3.1
Seismology	1.3.2.3.3, 1.4, 6.1.2.1	Tectonic events and processes	9.3.1 2.4.3.2
Tectonic assessment	1.1.3.1, 1.3, 1.4, 1.5.2, 6.1.2.1	Tectonic events and processes	8.3.1.2.4.3.3
Mineralogic and petrologic characteristics	1.2.1.2.4, 1.7, 4.1	Mineralogic and petrologic characteristics	8.3.1.2.5.3
Surface water system	3 1, 3.3, 3 4, 6.1.2.3	Surface water	8.3.1.3.3.3.1
Site flooding	3 2	Surface water	8.3.1.3.3.3.2
Regional groundwater	3 6, 3.7, 3.8	Groundwater	8.3.1.3.4.3.1
Site groundwater	3.5, 3.9, 6.1.2.3	Groundwater	8.3.1.3.4.3.2
Groundwater flow system hydrochemistry	3 7, 3.9.1, 3.9.3, 3.9.5, 4 1 2 1, 4.2.2	Hydrochemical characterization	8.3.1.4.3.3.1
Groundwater redox characteristics	3.9.1.3, 4.1.3.4.1, 4.2.2, 7.4.1.1.1, 7.4.4.2.2.1, 7.4.5.3	Hydrochemical characterization	8.3.1.4.3.3.2
Radionuclide reactivity	4.1.3, 7.4.5, 7.4.6.3.6	Radionuclide retardation behavior	8.3.1.4.4.3
Past climatic change	5.2.1, 5.2.3, 5.3.3.1	Past climatic change	8.3.1.5.3.3
Future climatic change	5.2.2, 5.2.3, 5.3.3.2	Future climatic change	8.3.1.5.4.3
Site meteorology	5.1, 5.3.3.3	Meteorology	8.3.1.5.5.3
Mineral, hydrocarbon, and geothermal resource potential	1.7	Mineral, hydrocarbon, and geothermal resource potential	8.3.1.6.3.3
Water resource potential	1.7.3, 3.3, 3.8, 3.9.7, 5.1, 5.2.2	Water resource potential	8.3.1.6.4.3
In situ stress of host rock	2.6, 6.3.4	Verification or measurement of host rock environment	8.3.2.2.3.1
Thermal properties of host rock	2.4, 2.5, 2.8.3.1, 4.2.1, 6.3.4.2, 7.1.2.1	Verification or measurement of host rock environment	8.3.2.2.3.2
Mechanical properties of host rock	2.1, 2.2, 2.3, 2.8, 3.1, 6.3.4.1.1	Verification or measurement of host rock environment	8.3.2.2.3.3

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Table 8.3-1. Correspondence of information needs identified in Chapters 1 through 7 to planned investigations (sheet 2 of 3)

Information need	Relevant data chapter sections	Investigation where addressed	Section number of corresponding study
Opening performance of host rock	2.8	Verification or measurement of host rock environment	8.3.2.2.3.4
Constitutive model development	2.3	Repository geomechanics models	8.3.2.5.3.3.1
Repository constructibility	2.8, 5.1, 6.3.2.6, 6.3.6.2	Nonradiological health and safety of workers	8.3.2.8.3.5
Laboratory testing for selection of seals materials	6.3.5.4	Laboratory testing for seals materials properties and interactions	8.3.3.3.1.3.1
Effects of elevated temperatures on physical properties of reference seals materials	6.3.3.3	Laboratory testing for seals materials properties and interactions	8.3.3.3.1.3.2
Characteristics of reference seals materials	6.2.7.2, 6.2.8, 6.3.3, 6.3.5	Laboratory testing for seals materials properties and interactions	8.3.3.3.1.3.3
Long-term stability of reference seals materials	6.2.8.1.2, 6.3.3.1	Laboratory testing for seals materials properties and interactions	8.3.3.3.1.3.4
Exploratory shaft grout development	6.2.6	Laboratory testing for seals materials properties and interactions	8.3.3.3.1.3.5
Interface properties of reference seals material	6.2.8	Laboratory testing for seals materials properties and interactions	8.3.3.3.1.3.6
Development of subsurface borehole seals installation	6.1.5.3, 6.2.8.3, 6.2.8.4, 6.3.5	Field testing for seals materials properties and development of barriers emplacement methods	8.3.3.3.2.3.1
Development of drift seals installation methods	6.1.5.3, 6.2.7.3, 6.3.3	Field testing for seals materials properties and development of barriers emplacement methods	8.3.3.2.3.2
Basalt/groundwater interactions	4.1.2, 4.1.3.4.1, 4.2.2, 6.3.3, 7.1.2, 7.4.1.1	Post-emplacement waste package environment	8.3.4.2.3.3.1
Geochemical environment	4.2.1, 4.5.1.2, 4.5.1.3, 4.5.1.4, 4.5.1.6, 7.1.2.1	Post-emplacement waste package environment	8.3.4.2.3.3.2
Waste package natural analogs	7.4.1.1	Natural analogs and metallic artifacts	8.3.4.2.4.3.1
Waste package metallic artifacts	--	Natural analogs and metallic artifacts	8.3.4.2.4.3.2
Waste form materials	7.2.3.1, 7.3.1.2.1, 7.3.1.4, 7.4.2.2	Waste forms	8.3.4.3.3.3.2
Waste form/filler materials interactions	--	Waste forms	8.3.4.3.3.3.3
Waste acceptance specifications	7.4.2.3	Waste forms	8.3.4.3.3.3.4
General corrosion	7.4.3.2.1	Container materials	8.3.4.3.4.3.1
Pitting corrosion	7.4.3.2.2	Container materials	8.3.4.3.4.3.2
Environmentally assisted cracking	7.4.3.2.3	Container materials	8.3.4.3.4.3.3
Crevice corrosion	7.4.6.3.5.1	Container materials	8.3.4.3.4.3.4
Mechanical and physical properties of container materials	7.2.3.4, 7.3.1.2.4, 7.4.3.1	Container materials	8.3.4.3.4.3.5

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Table 8.3-1. Correspondence of information needs identified in Chapters 1 through 7 to planned investigations (sheet 3 of 3)

Information need	Relevant data chapter sections	Investigation where addressed	Section number of corresponding study
Chemical stability of packing materials	7.3.1.2.5, 7.4 1.3.3, 7.4.4.2	Packing materials	8.3.4.3.5.3.1
Physical properties and processes of packing materials	7.2.3.5, 7.3.1.2.5, 7.4.4.3	Packing materials	8.3.4.3.5.3.2
Radionuclide solubility/sorption and speciation behavior	4.1.3.4, 4.2.3.2, 7.4.1.1.2, 7.4.5.2, 7.4.5.3.1.7, 7.4.5.3.2.7	Waste package radionuclide behavior	8.3.4.3.6.3.1
Waste/barrier/rock interactions: spent fuel release	7.4.2.2, 7.4.5.3.1	Waste package radionuclide behavior	8.3.4.3.6.3.1
Waste/barrier/rock interactions: borosilicate glass release	7.4.2.2, 7.4.5.3.2	Waste package radionuclide behavior	8.3.4.3.6.3.3
Waste/barrier/rock interactions: other waste forms	7.4.2.2	Waste package radionuclide behavior	8.3.4.3.6.3.4
Pressure vessel container development	7.3.2.1.3	Container development	8.3.4.4.4.3.1
Monolith container development	7.3.2.1.3	Container development	8.3.4.4.4.3.2
Nonmetallic container development	7.3.2.1.3	Container development	8.3.4.4.4.3.4
Container handling and safety testing	--	Container development	8.3.4.4.4.3.3
Packing fabrication	7.4.4.1	Packing development	8.3.4.4.5.3.1
Packing nondestructive examination	--	Packing development	8.3.4.4.5.3.2
Packing handling and emplacement	7.2.3.6	Packing development	8.3.4.4.5.3.3
Container corrosion qualification testing	7.4.3.2.1	Qualification testing	8.3.4.4.6.3.1
Packing saturation qualification testing	7.4.4	Qualification testing	8.3.4.4.6.3.2
Container settlement testing	7.4.6.3.6	Qualification testing	8.3.4.4.6.3.3
Waste package in situ testing	--	Qualification testing	8.3.4.4.6.3 4

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IMPLEMENTATION OF THE ISSUE RESOLUTION PROCESS

Planned actions or groups of actions for resolving issues are categorized into the following hierarchy representing an increasing level of detail from top to bottom:

- Generic programs.
- Specific programs.
- Investigations.
- Specific programs.
- Investigations.
- Studies (or activities).
- Tests and analyses.

The plans outlined in Section 8.3 identify four generic programs: site program (Section 8.3.1), repository program (Section 8.3.2), seal subsystem program (Section 8.3.3), and waste package program (Section 8.3.4). Each generic program consists of four or more specific programs. The site program, for example, comprises five discipline-based specific programs: geology, hydrology, geochemistry, climatology, and resource potential. Each specific program is normally supported by one or more investigations. Most investigations are supported by either (1) one or more studies consisting of various tests and analyses or (2) a set of design, modeling, or data compilation activities.

The entire issue resolution strategy is intended to contain reiterations so that the licensing strategy and the performance goals, performance measures, and related parameters may change as new information becomes available. If any of the above items are changed, the steps that follow in the issue resolution strategy will also be reexamined and the products revised. Similarly, the analyses of the results of the investigations may produce new understandings that require rethinking earlier steps. Any of the steps may, in fact, lead to revisions of earlier steps.

The results of the investigations will be analyzed as soon as they are available, and analyses will continue throughout the site characterization period and beyond. Needed information will be collected until the information needs have been satisfied; whereupon, final analyses will be conducted to resolve the issues. All results and conclusions will be fully documented.

DATA COLLECTION PROCEDURES

The data collection process is designed to provide a logical, controlled method for identifying and compiling the data required for site and repository evaluation and for providing essential input for these models. To support this process, computer models and other analytical techniques are being developed specifically to evaluate the performance of the system before and after the closure of the repository. The process consists of the elements discussed below.

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To guide each study, a study plan is prepared that is based on the issues, the information needs, and the objectives for the investigation the study supports. Each study corresponds to a specific information need (see Table 8.3-1).

Test data collection specifications are generated to accomplish the technical program defined in the study plans. A test data collection specification defines the data requirements for activities implementing a study plan. It specifies technical and quality requirements in sufficient detail to fully support the preparation of all appropriate test plans and data collection procedures.

Test plans address the requirements identified in the test data collection specification, define the tests to be performed, and identify the technical procedures to be implemented. Test plans are developed to ensure that the data collection activities are carefully coordinated and prepared. All data collection activities in support of the BWIP site characterization must be defined and documented in a test plan. The number of test plans to be developed for each study depends on required information identified in the test data collection specifications.

All actions performed in support of the test plans are described in technical procedures. Technical procedures are approved, controlled procedures that provide consistent, detailed guidance for performing test activities, data collection, and operations in support of BWIP requirements.

Site characterization testing and repository design will be supported by an Exploratory Shaft Facility being constructed to provide access to the potential repository horizon at the reference repository location. The Exploratory Shaft Facility will consist of two shafts, the underground test facility, and associated surface facilities. Testing at this facility will start during its construction and continue until site characterization is complete. These tests will monitor various aspects of facility construction in addition to the geologic, hydrologic, and geomechanical characteristics of the site.

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APPLICATION OF RESULTS

The data collected during site characterization will establish a reference technical data base that will be used in the design of the repository and waste package, in the issue resolution process, and in various tests and analyses that will be required to receive U.S. Nuclear Regulatory Commission (NRC) approval for permanent closure.

The use of the data collected about the BWIP site will be an interactive process. These data will be used to determine various features of the repository (e.g., characteristics of the waste package and the spacing of the waste canisters in the underground disposal rooms). In turn, the design of the repository and waste package will help identify required information and thus define needed studies, tests, and analyses.

The issue resolution process will use the data collected during site characterization, the conceptual design of the repository and waste package, and various analytical models and techniques. The results of this process will be analyzed to make the higher-level findings required to demonstrate compliance with the siting guidelines as well as to demonstrate compliance with NRC and U.S. Environmental Protection Agency (EPA) regulations. In addition, these findings will be used (1) in a comparative evaluation of the characterized sites that will be reported in the environmental impact statement, (2) in selecting the site of the repository, and (3) in the safety analysis report to be submitted with the license application to the NRC if the Hanford Site is selected. After the repository has been constructed, these results will be used in obtaining a license from the NRC to operate the repository.

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ORGANIZATION OF SECTION 8.3

Section 8.3 is divided into separate discussions of generic programs for the site, the repository, the seal system, the waste package, and performance assessment. The purpose and objectives, rationale, supporting studies and activities, application of results, and schedule and major milestones are described for each investigation. Section 8.3 also describes plans for determining compliance with regulatory requirements, the strategy for preclosure and postclosure performance assessments, and performance assessment techniques.

Each generic program is organized according to the following heirarchy of terms for individual activities and groups of activities.

Generic program. Generic programs are third-level elements of the section outline and consist of the following: site program (Section 8.3.1), repository program (Section 8.3.2), seals subsystem program (Section 8.3.3), waste package program (Section 8.3.4), and performance assessment program (Section 8.3.5). Except for the performance assessment program, all generic programs are supported by four or more specific programs and a variety of investigations.

Specific program. Each generic program consists of four or more specific programs, which are carried at the four-digit level of the section outline. Each specific program normally includes two or more related investigations.

Investigation. An investigation is the first major subdivision of a specific program and is normally supported by two or more related studies or activities.

Study. A study is a combination of related tests and analyses in support of an investigation that is governed by a separate study plan. Each study normally corresponds to a specific information need identified in Part A and subsequently incorporated into the relevant issue resolution strategy (or strategies) in Section 8.2.2.

Activity. The term activity, as applied in Section 8.3, refers to a specific action or group of actions in support of an investigation. An activity occurs at the same hierarchical level as a study but is not governed by a separate study plan. It may consist of design, modeling, or data compilation actions.

Test or analysis. The term test refers to a combination of procedures used to identify, measure, or evaluate a quality, characteristic, or property of a material or system that produces data through one or more experiments. Written test plans are controlled by test data collection specifications. Analysis is used to refer to an assessment of test results through calculations, modeling, or technical judgment.

Procedure. This term describes the specific steps to be taken in implementing a test. Procedures are not normally presented in the Site Characterization Plan. Written technical procedures are required to guide each step of the testing process.

Experiment. An experiment is an operation carried out under controlled conditions as specified in the written procedures to establish characteristics or values of the quality, characteristic, or property of a material or system being examined.

The following descriptions provide a more detailed overview of each major section of Section 8.3.

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Site program (Section 8.3.1)

This section presents the five specific programs that will be used to characterize the geology, hydrology, geochemistry, climate, and resource potential of the candidate area and site. Section 8.3.1.2 describes the three geologic investigations planned to characterize the geomorphic, mineralogic and petrologic, and tectonic systems of the site. Section 8.3.1.3 describes two planned hydrologic investigations that will characterize the surface-water and groundwater systems. Section 8.3.1.4 describes the two planned geochemical investigations designed to characterize the hydrochemical system and to understand radionuclide retardation behavior better. Section 8.3.1.5 describes two climatological investigations that will increase knowledge of past climatic change and will provide accurate models for predicting future changes. Finally, Section 8.3.1.6 describes two investigations designed to assess the economic potential for the development of mineral and fossil fuels and groundwater resources in the area.

Repository program (Section 8.3.2)

This section summarizes the repository testing program and provides an overview of the engineering and design activities required to ensure that the

repository is capable of satisfying applicable performance objectives. This program will support site characterization by identifying the engineering technology needed for the detailed design and construction of the repository. The program comprises a series of seven specific programs and their supporting investigations designed to characterize the geomechanical host rock environment (Section 8.3.2.2) and related coupled interactions (Section 8.3.2.3), to optimize repository design (Section 8.3.2.4) and modeling (8.3.2.5) capabilities, and to provide for safe waste retrieval (Section 8.3.2.6) and worker radiological and nonradiological safety (Section 8.3.2.7 and 8.3.2.8) at the site.

Seal subsystem program (Section 8.3.3)

This section presents the four specific programs and eight supporting investigations that form the BWIP program for postclosure sealing of the repository. An effective seals subsystem design and development program is needed to provide reasonable assurance that the repository will effectively limit cumulative postclosure release of radionuclides to the accessible environment. Section 8.3.3.2 describes the two investigations that will characterize the environment in which the seals subsystem pathway barriers will be emplaced. Section 8.3.3.3 describes two investigations comprising laboratory and field testing required for materials selection, design optimization, installation, and performance assessment of the seals subsystem. Section 8.3.3.4 describes the two design optimization investigations for (1) selecting barrier materials, configurations, and locations and (2) developing barriers installation procedures. Finally, Section 8.3.3.5 describes the two modeling investigations necessary to document the performance sensitivity and postclosure performance of the seals subsystem as required for the repository licensing application.

Waste package program (Section 8.3.4)

This section provides an overview of the engineering and design activities being planned to ensure that the waste packages are capable of satisfying design and performance objectives. This program consists of four specific programs and fifteen supporting investigations. Section 8.3.4.2 describes the two investigations necessary to characterize the environment in which the waste package will be emplaced. Section 8.3.4.3 describes three investigations of waste package components (waste form, container materials, and packing materials) and a fourth investigation of radionuclide behavior in relation to interactions between these components and their environment. Section 8.3.4.4 describes five investigations related to waste package design development, including engineering design studies, container and packing development, and qualification testing. Finally, Section 8.3.4.5 describes four modeling investigations designed to assess waste package performance sensitivity, performance and reliability, preclosure safety, and the accuracy and reliability of the computer codes and models used in the analytical studies for this program.

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Performance assessment program (Section 8.3.5)

The performance assessment program described in this section is designed to assess the suitability of the site for disposing of high-level nuclear waste. It is thus a major segment of the issue resolution process governing project activities. Work associated with this program will evaluate the performance of the overall geologic repository system during both the preclosure period (exploratory shaft and facility design, construction, operation, safety measures, and decommissioning) and postclosure period (primarily the 10,000-yr interval following closure). Preclosure performance assessment is discussed in Section 8.3.5.1; postclosure performance assessment is discussed in Section 8.3.5.2.

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*A decision on July 17, 1987, by the U.S. Court of Appeals for the First Circuit has required the EPA to reconsider its postclosure standards (Subpart B) in 40 CFR 191. Consequently, the standards in 40 CFR 191 may be subject to revision in the future.

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SITE CHARACTERIZATION PLAN

Chapter 8 - SITE CHARACTERIZATION PROGRAM

Section 8.3.1

Site Program

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8.3.1 SITE PROGRAM

Section 8.3.1 describes the investigations that make up the site program. The purpose of this program is to characterize the geology, hydrology, geochemistry, climatology, and resource potential of the site and surrounding area to meet regulatory standards, guidelines, and requirements for licensing a geologic repository for the disposal of high-level radioactive wastes. The site program is oriented toward providing a description of the natural system; this system and the engineered system make up the two key barriers to radioactive waste migration. Regardless of the extent to which engineered barriers are used to contain or control the release of wastes, the natural system determines the environment in which these barriers must perform their intended function. Moreover, to the extent that the natural system is used to isolate the wastes or that it is relied on to mitigate the consequences of premature or unanticipated failure of the engineered barriers, it must be characterized and understood with respect to its ability to control the movement of radionuclides (NRC, 1983). As such, the site program provides basic information required for the resolution of essentially all design and performance issues relating to the selection and licensing of a repository (see Section 8.2).

REFERENCES

NRC, 1983. Staff Analysis of Public Comments on Proposed Rule 10 CRF 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," NUREG-0804, U.S. Nuclear Regulatory Commission, Washington D.C.

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SITE CHARACTERIZATION PLAN

Chapter 8 - SITE CHARACTERIZATION PROGRAM

Section 8.3.1.1

Overview

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8.3.1.1 Overview

This section summarizes the site program and provides an overview of the specific technical programs and investigations of which it is comprised. Included in this overview are discussions of the following:

- Regulations governing the site program (Section 8.3.1.1.1).
- Issues and issue resolution strategies guiding the site program (Section 8.3.1.1.2).
- Approach to site program investigations (Section 8.3.1.1.3).
- Organization of Section 8.3.1 (Section 8.3.1.1.4).

The purpose of site program investigations and associated data acquisition and analysis activities is to provide information on the geologic, hydrologic, geochemical, climatological, and resource potential characteristics of the site and surrounding area. The overall goal of all site program activities is to provide a basis for design determinations and for assessing the suitability of the Columbia River basalts as a natural barrier to the migration of nuclear waste. This basis must include an assessment of present-day conditions as well as an assessment of future conditions over the life of the repository. The organization of the site program into specific programs, investigations, and studies is shown in Figure 8.3.1.1-1.

Site program activities are oriented toward providing a conceptual understanding of the site and toward addressing performance parameters at the goals and confidence levels set forth in Section 8.2.2. Site program activities are designed to build on the results of previous work and to approach subsequent data acquisition and analysis in an iterative manner. As such, site program modeling results, design trade studies, and performance assessment sensitivity studies provide focus to the planning and execution of data acquisition and analysis activities as characterization progresses. Many of the site program activities are focused toward assessing the present and future hydrologic regime, since groundwater transport is viewed as the most likely means by which radionuclides could be released to the uncontrolled environment.

The currently planned data acquisition approach builds on previous work described in Chapters 1 through 5 and includes surface field activities, laboratory activities, and in situ activities in the exploratory shaft. Surface field and laboratory activities will be conducted prior to, and concurrent with, exploratory shaft activities. Site analysis activities, generally oriented toward the formulation and validation of conceptual and numerical models, will be conducted concurrently with all data acquisition activities. Details of currently planned site program activities are presented in study plans separate from the Site Characterization Plan (SCP). The program descriptions contained in the 8.3.1 SCP sections are drawn, for the most part, from these study plans.

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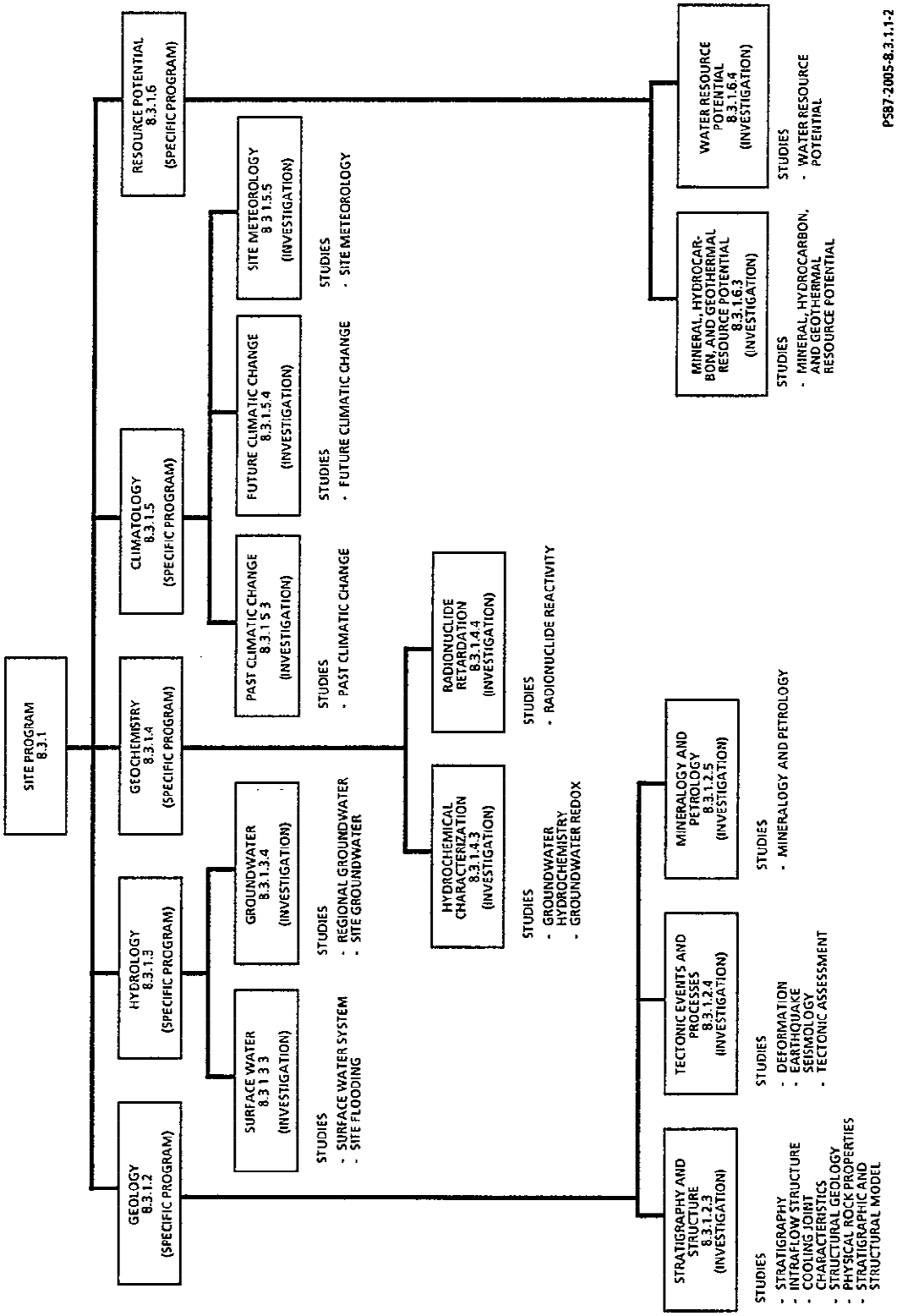

Figure 8.3.1.1-1. Organization of site program and Site Characterization Plan Section 8.3.1.

8.3.1.1.1 Regulations governing the program

The regulations for geologic disposal of high-level radioactive wastes are given in 10 CFR 60 (NRC, 1987a) and in 40 CFR 191 (EPA, 1986). The site subsystem performance requirements are related to the overall repository system performance objective stated in 10 CFR 60.112 (NRC, 1987a) as follows:

> The geologic setting shall be selected and the engineered barriers system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events.

The accessible environment is defined in 10 CFR 60 (NRC, 1987a) and 40 CFR 191 (EPA, 1986) as ". . .the atmosphere, the land surfaces, surface water, oceans, and the portion of the lithosphere that are outside the controlled area." The Basalt Waste Isolation Project (BWIP) defines the controlled area as ". . .a surface location, to be identified by passive institutional controls, that encompasses no more than 100 km^2 and extends no more than 5 km in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and the subsurface underlying such a surface location" (Reed, 1987).

Containment requirements are further defined by the U.S. Environmental Protection Agency (EPA) in 40 CFR 191.13 (EPA, 1986) as follows:

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative release of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:

1. Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and

2. Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).

As stated in Section 8.2.2, a reasonable interpretation of the preceeding excerpts is that the EPA "significant events and processes" are equivalent to the summation of the U.S. Nuclear Regulatory Commission (NRC) "anticipated" and "unanticipated" events and processes. Accordingly, scenarios having a probability less than 10^{-4} in 10,000 yr are not sufficiently credible to warrant consideration.

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With regard to the above overall performance objective, the site program activities provide information on the present geologic setting and on projected changes to that setting that could be due to natural or man-induced events and processes. Thus, information generated by the site program provides the basis for all evaluations of overall system performance, including scenario development.

The site subsystem performance requirements are also related to performance of particular barriers after permanent closure as stated in 10 CFR 60.113(2) (NRC, 1987a) as follows:

> (2) *Geologic setting*. The geologic repository shall be located so that pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission.

The site program, particularly activities under the geologic, hydrologic, and geochemical investigations, provides information required to address this requirement.

In addition to the above performance objectives, the site program must address "siting criteria" set forth in 10 CFR 60.122 (NRC, 1987a). This section defines favorable and potentially adverse conditions in paragraph (b) and paragraph (c), respectively, that must be considered as follows:

> (a)(1) A geologic setting shall exhibit an appropriate combination of the conditions specified in paragraph (b) of this section so that, together with the engineered barriers system, the favorable conditions present are sufficient to provide reasonable assurance that the performance objectives relating to isolation of the waste will be met.
>
> (2) If any of the potentially adverse conditions specified in paragraph (c) of this section is present, it may compromise the ability of the geologic repository to meet the performance objectives relating to isolation of the waste. In order to show that a potentially adverse condition does not so compromise the performance of the geologic repository the following must be demonstrated:
>
> (i) The potentially adverse human activity or natural condition has been adequately investigated, including the extent to which the condition may be present and still be undetected taking into account the degree of resolution achieved by the investigations; and
>
> (ii) The effect of the potentially adverse human activity or natural condition on the site has been adequately evaluated using analyses which are sensitive to the potentially adverse human activity or natural condition and assumptions which are not likely to underestimate its effect; and

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(iii)(A) The potentially adverse human activity or natural condition is shown by analysis pursuant to paragraph (a)(2)(ii) of this section not to affect significantly the ability of the geologic repository to meet the performance objectives relating to the isolation of waste, or

(B) The effect of the potentially adverse human activity or natural condition is compensated by the presence of a combination of the favorable characteristics so that the performance objectives relating to isolation of the waste are met, or

(C) The potentially adverse human activity or natural condition can be remedied.

The applicable favorable conditions and potentially adverse conditions contained in paragraphs (b) and (c) of 10 CFR 60.122 (NRC, 1987a) are listed in Table 8.3.1.1-1.

In accordance with requirements of the Nuclear Waste Policy Act of 1982 (NWPA, 1983), the U.S. Department of Energy (DOE) has developed guidelines to be used in evaluating the suitability of sites for the development of repositories. These guidelines, documented in 10 CFR 960 (DOE, 1987a), are intended to complement the requirements set forth in the Nuclear Waste Policy Act of 1982, 10 CFR 60 (NRC, 1987a), and 40 CFR 191 (EPA, 1986). The preclosure and postclosure system and technical guidelines used in 10 CFR 960 provide "a statement of policy or procedure that may include, when appropriate, qualifying, disqualifying, favorable, or potentially adverse conditions" (DOE, 1987a). The site subsystem performance requirements are related to the postclosure system guideline stated in 10 CFR 960.4-1 (DOE, 1987a) as follows:

(a) *Qualifying Condition.* The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subpart B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60.

In addition to the above system guideline, the site program must address the eight postclosure and five preclosure technical guidelines noted in Table 8.3.1.1-2. The conditions specified under these guidelines are similar to those contained in 10 CFR 60 (NRC, 1987a) and listed in Table 8.3.1.1-1. A key distinction between 10 CFR 60 (NRC, 1987a) and 10 CFR 960 (DOE, 1987a) is that the latter may involve comparative evaluations of site conditions over a 100,000-yr time period rather than a 10,000-yr time period.

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Table 8.3.1.1-1. Favorable and potentially adverse conditions (sheet 1 of 2)

	Favorable conditions
1)	The nature and rates of tectonic, hydrogeologic, geochemical, and geomorphic processes (or any of such processes) operating within the geologic setting during the quaternary period, when projected, would not affect or would favorable affect the ability of the geologic repository to isolate the waste.
2)	For disposal in the saturated zone, hydrogeologic conditions that provide i) A host rock with low horizontal and vertical permeability ii) Downward and dominantly horizontal hydraulic gradient in the host rock and the immediately surrounding hydrogeologic units iii) Low vertical permeability and low hydraulic gradient between the host rock and the surrounding hydrogeologic units.
3)	Geochemical conditions that i) Promote precipitation or sorption of radionuclides ii) Inhibit the formation of particulates, colloids, and inorganic and organic complexes iii) Inhibit the transport of radionuclides by particulates, colloids, and complexes.
4)	Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having equal or increased capacity to inhibit radionuclide migration.
5)	Conditions that permit the emplacement of waste at a minimum depth of 300 m (984 ft) from the ground surface. (The ground surface shall be deemed to be the elevation of the lowest point on the surface above the disturbed zone.)
7)	Pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 yr.
	Potentially adverse conditions
1)	Potential for flooding of the underground facility, whether from the occupancy and modification of flood plains or from the failure of existing or planned manmade surface water impoundments
2)	Potential for foreseeable human activity to adversely affect the groundwater flow system, such as groundwater withdrawal, extensive integration, subsurface injection of fluids, underground pumped storage, military activity, or construction of large-scale surface water impoundments.
3)	Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitude that large-scale surface water impoundments could change the regional groundwater flow system and thereby adversely affect the performance of the geologic repository.
4)	Structural deformation, such as uplift, subsidence, folding, or faulting that may adversely affect the regional groundwater flow system.
5)	Potential for changes in hydraulic conditions that would affect the migration of radionuclides to the accessible environment, such as changes in hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.
6)	Potential for changes in hydrologic conditions resulting from reasonably foreseeable climatic changes.
7)	Groundwater conditions in the host rock, including chemical composition, high ionic strength of ranges of Eh-ph, that could increase the solubility of chemical reactivity of the engineered barrier system.
8)	Geochemical processes that would reduce sorption of radionuclides, result in degradation of the rock strength, or adversely affect the performance of the engineered barrier system.

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Table 8.3.1.1-1. Favorable and potentially adverse conditions (sheet 2 of 2)

Potentially adverse conditions
9) Groundwater conditions in the host rock that are not reducing.
10) Evidence of dissolutioning such as breccia pipes, dissolution cavities, or brine pockets.
11) Structural deformation such as uplift, subsidence, folding, and faulting during the quaternary period.
12) Earthquakes that have occurred historically and that if they were to be repeated, could affect the site significantly.
13) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase.
14) More frequent occurrences of earthquakes or earthquakes of a higher magnitude than is typical of the area in which the geologic setting is located.
15) Evidence of igneous activity since the start of the quaternary period.
16) Evidence of extreme erosion during the quaternary period.
17) The presence of naturally occurring materials, whether identified or undiscovered, within the site, in such form that i) Economic extraction is currently feasible or potentially feasible during the foreseeable future ii) Such materials have greater gross value or net value than the average for other areas of similar size that are representative of and are located within the geologic setting.
18) Evidence of subsurface mining for resources within the site.
19) Evidence of drilling for any purpose within the site.
20) Rock or groundwater conditions that would require complex engineering measures in the design and construction of the underground facility or in the sealing of boreholes and shafts.
21) Geomechanical properties that do not permit design of underground openings that will remain stable through permanent closure.

Source: 10 CFR 60.122 (NRC, 1987a).

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Table 8.3.1.1-2. Technical guidelines from 10 CFR 960 (DOE, 1987a) addressed by the site program

Section 960	Guideline	Table 8.3.1.1-3 designator
Postclosure		
4-2-1	Geohydrology	A
4-2-2	Geochemistry	B
4-2-3	Rock characteristics	C
4-2-4	Climatic change	D
4-2-5	Erosion	E
4-2-6	Dissolution	F
4-2-7	Tectonics	G
4-2-8	Natural resources	H
Preclosure		
5-2-3	Meteorology	I
5-2-8	Surface characteristics	J
5-2-9	Rock characteristics	K
5-2-10	Hydrology	L
5-2-11	Tectonics	M

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8.3.1.1.2 Issues and issue resolution strategies guiding the program

The Issues Hierarchy for a Mined Geologic Disposal System (DOE, 1987b) is introduced in Section 8.1 of this document. As explained in this section, the issues hierarchy consists of key issues plus associated performance and design issues. The key issues embody the principal requirements established by the regulations governing geologic disposal. The associated issues expand on the requirements of the key issues. Key Issue 1 contains postclosure performance requirements. Key Issue 2 contains preclosure radiological safety requirements. Key Issue 3 is concerned with environmental, socioeconomic, and transportation issues that will be identified in a future amendment of the issues hierarchy document (DOE, 1987b); as such they will not be discussed further in the SCP. Key Issue 4 is concerned with ease and cost of repository siting, construction, operation, and closure. Identification of issues associated with Key Issues 1, 2, and 4 is shown in Figure 8.3.1.1-2. Those issues requiring site program input are highlighted in this figure.

Strategies for the resolution of issues are presented in Section 8.2.2 of this document. This section includes a top-level strategy for BWIP site characterization as well as a strategy for each performance and design issue associated with Key Issue 1, 2, and 4. The strategy for each performance and design issue identifies performance measures, performance parameters, and information needs required for issue resolution. Performance measures are statements of a measurable or derived quantity defined for a given system component that serves as part of the basis for evaluating the performance of the system component (Reed, 1987). Performance parameters are quantities identified in the issue resolution strategies that will be used directly in the resolution of issues; these parameters are those to be used directly in the evaluation of performance measures developed in the issue resolution strategies (Reed, 1987). Information needs are basically "technical groupings" of parameters and are generally equivalent to studies supporting the site, repository, seals, and waste package programs. A listing of site program studies, and their relationship to investigations and specific technical programs, is shown in Figure 8.3.1.1-1. Table 8.3.1.1-3 correlates these studies, or information needs, with the issues they address. The remainder of this section contains a general discussion of issues and issue strategies relevant to the specific programs and investigations of the site program. In this discussion emphasis is placed on the top-level strategy for BWIP site characterization and Issues 1.1, 1.6, and 1.8. These three issues and their strategies specifically address the regulations governing the site program discussed in the previous section, 8.3.1.1.1. In this discussion, "studies" and "information needs" will be used as essentially synonymous.

The top-level strategy for BWIP site characterization is discussed in Section 8.2.1 of this document. This strategy specifies that while short-term containment should emphasize waste package performance, long-term isolation should emphasize natural system performance. With regard to the natural system, compliance with NRC limits (NRC, 1987a) defined by the overall repository system performance objective (i.e., EPA, 1986) addressed by Issue 1.1 (see Fig. 8.3.1.1-2) is considered to be critical. Compliance with

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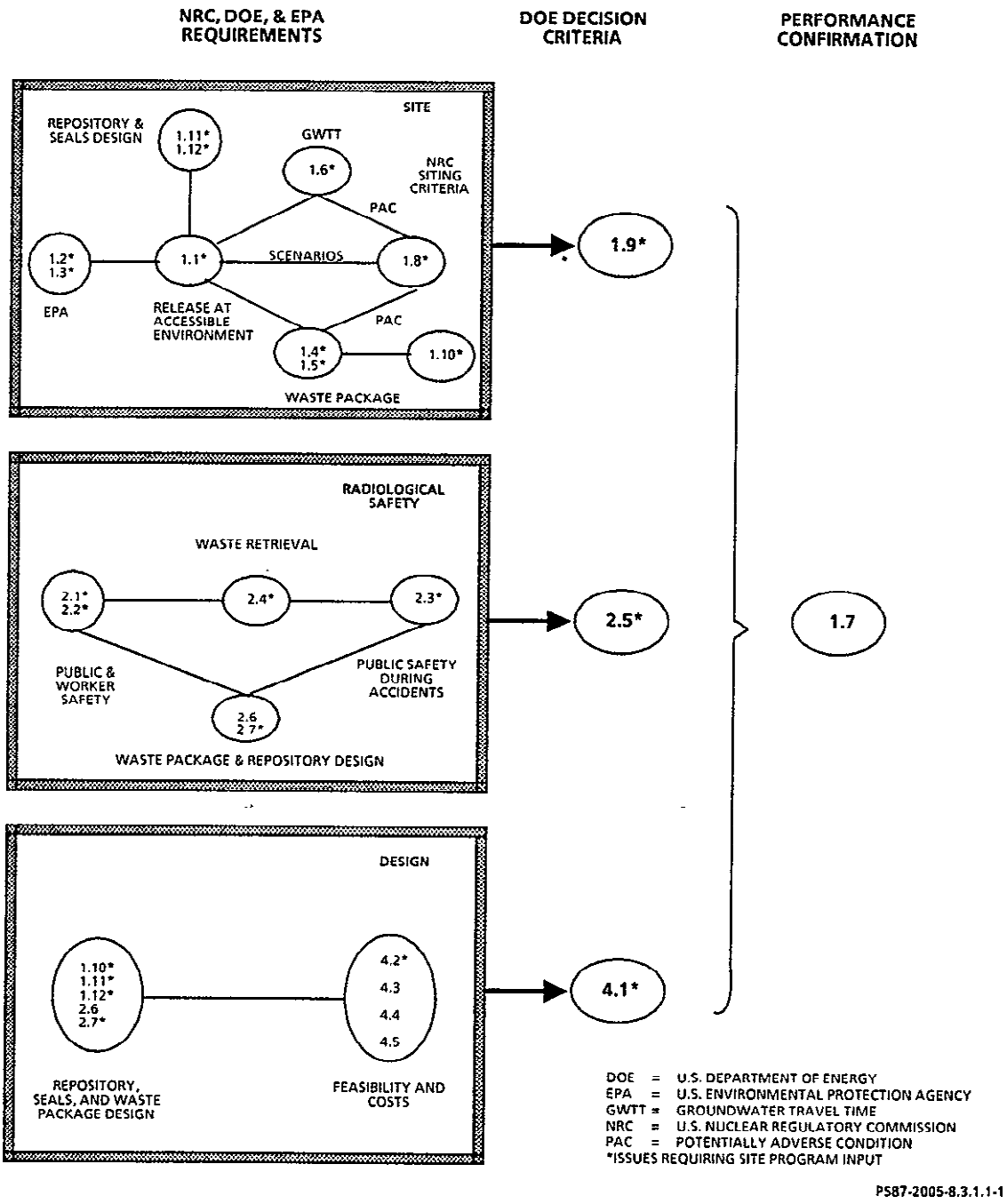

Figure 8.3.1.1-2. Interrelationships of issues.

the individual site subsystem performance objective addressed by Issue 1.6 (see Fig. 8.3.1.1-2), groundwater travel time, will receive less emphasis. The top-level strategy further recognizes that resolution of Issue 1.8 (see Fig. 8.3.1.1-2) is most critical to resolution of Issue 1.1. Issue 1.8 essentially addresses the siting criteria set forth in 10 CFR 60.122 (NRC, 1987a) as discussed in the previous section on "Regulations governing the program" (see Table 8.3.1.1-1). The activities conducted for resolution of Issue 1.8 provide essential information for the disruptive scenario analysis that is a key element of the strategy for resolution of Issue 1.1.

8.3.1.1.2.1 Issue 1.1

Issue 1.1 addresses whether the disposal system meets the system performance objective for radionuclide release to the accessible environment as required by 10 CFR 60.112 (NRC, 1987a). The BWIP expects to assess compliance with this system performance objective by conducting performance assessments (see Section 8.2.2 and 8.3.5). It is expected that these assessments will (1) identify anticipated and unanticipated processes and events that could affect the repository; (2) evaluate the likelihood of each process and event, aggregate events and processes into appropriate scenarios, and estimate the release of radionuclides to the accessible environment for each scenario; and (3) to the extent practicable, combine these estimates into an overall probability distribution displaying the likelihood of the amount of radionuclide material released to the accessible environment exceeding specified values. These assessments will take into account all those scenarios that are sufficiently credible to warrant consideration and will consider uncertainties. Generally, scenarios that can be shown to have a probability less than one chance in 10,000 over 10,000 yr, along with scenarios that otherwise can be shown not to change the remaining probability distribution of cumulative release significantly, would not be included in the detailed assessments.

The performance assessments that have been conducted thus far indicate that the following factors dominate the constraint of radionuclide release to the accessible environment.

- Site geohydrologic characteristics that lead to slow convective transport.
- Site geochemical characteristics that lead to adsorption of most radionuclides except ^{14}C and ^{129}I.
- Cohassett flow interior hydrologic properties that, in combination with the waste form, restrict the rate of ^{14}C release from the engineered barrier subsystem.

As natural barriers relating to groundwater travel time and geochemical retardation are viewed as dominant factors constraining radionuclide release, geohydrologic and geochemical information developed by the geology, hydrology, and geochemistry specific programs are of particular relevance.

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The technical strategies of these programs, as well as those of the climatology and resource potential programs, are oriented toward defining the current hydrologic regime and future processes and events that could impact that regime. A brief review of site program input to the Issue 1.1 licensing strategy follows; a review of the technical strategy or approach for providing that input is addressed in Section 8.3.1.1.3.

The strategy for resolution of Issue 1.1, outlined in Figure 8.3.1.1-3, entails an iterative process involving information acquisition and performance assessment activities. The principal steps in this strategy leading to the information needed for performance assessments include (1) developing a system description, (2) setting a licensing strategy, (3) specifying performance measures and goals, and (4) identifying information needs (e.g., site parameters) associated with the evaluation of the performance measures.

The strategy outlined in Figure 8.3.1.1-3 (Blocks 1 through 15) requires information from the site program in several areas. Information on the natural system (see Block 3) is essential for defining the site description and identifying anticipated and unanticipated natural processes and events (see Block 1). This information is also used to establish the licensing strategy depicted in Block 4. The principal elements in this licensing strategy encompass the following: (1) establish nominal cases, (2) analyze nominal cases, (3) develop disruptive scenario classes, (4) analyze disruptive scenario classes, (5) construct complementary distribution function, and (6) develop and analyze human intrusion scenarios. Block 5 represents the identification of performance measures and goals for the purpose of initial planning for site characterization. As part of this step, a performance measure goal for the site subsystem was established as less than 99% of the EPA release limit (EPA, 1986) with a probability of 90%. Block 6 depicts the identification of site information needed to evaluate this performance measure. This step includes the identification of site parameters and the establishment of goals for these parameters that are considered to be consistent with meeting the performance measure goal. Block 7 depicts the program of site characterization planned and conducted to address parameters identified in Block 6.

As data are obtained by the site program, they will be used to develop and validate the analytical techniques to be used in the performance assessments (see Blocks 8 and 9). As part of this process, site information obtained to address Issue 1.1 parameters, along with that obtained to address Issue 1.8, will be used to establish "nominal" case models--models that depict expected conditions for the overall repository system. As part of the analysis of the "nominal" case (see Block 9) site information, as well as design information, will be used to determine parameter values and these values will be used to calculate cumulative release of radionuclides for the nominal case conceptual model(s). Site program input will also be required to develop conceptual models for release of radionuclides that take into account disruptive conditions. Disruptive conditions, addressed as a part of Issue 1.8, include those that are due to credible, unanticipated processes and events that could lead to conceptual models for release qualitatively different from those already identified. These are considered in the development of disruptive scenarios and classes of scenarios spanning a

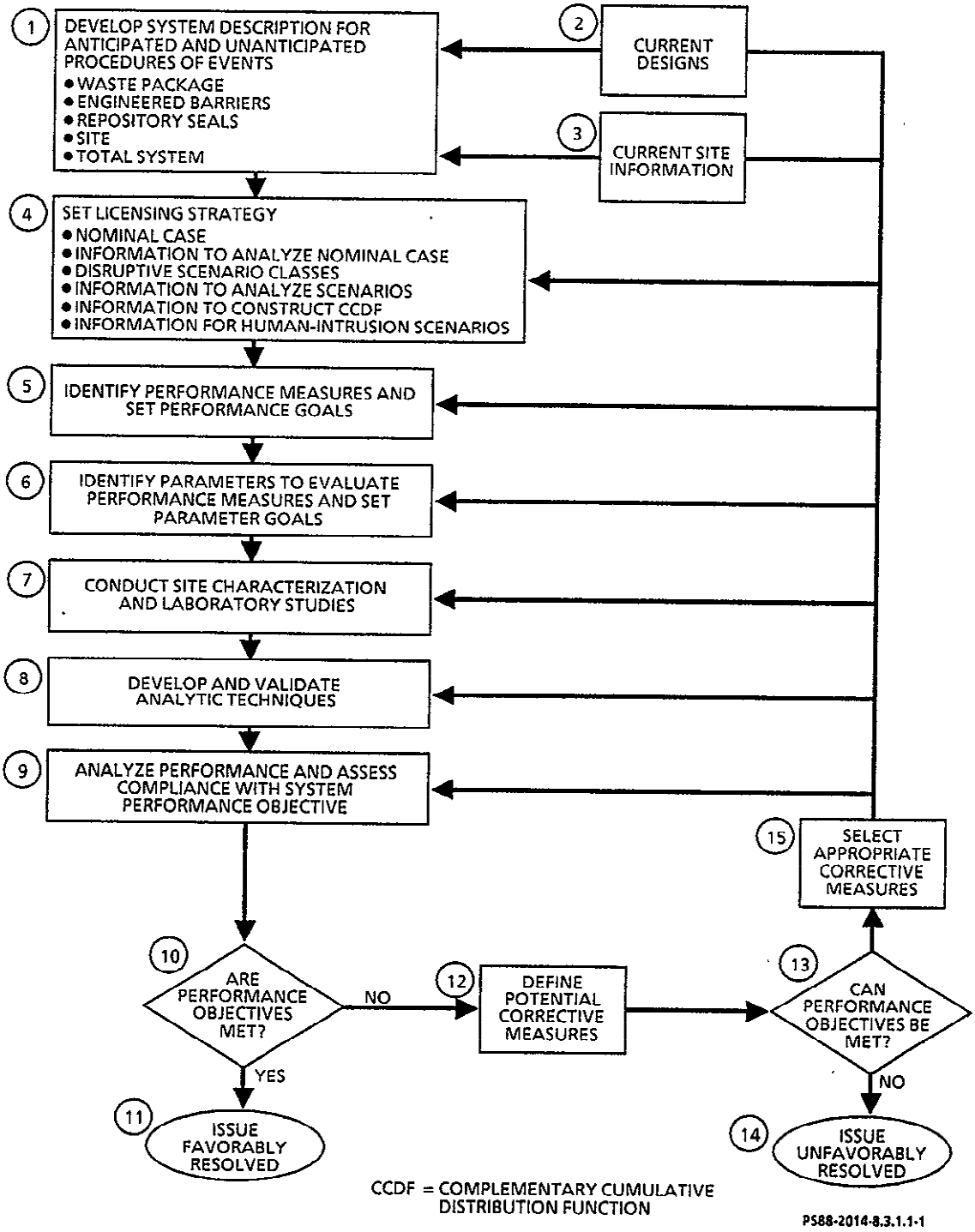

Figure 8.3.1.1-3. Strategy for resolution of Issue 1.1.

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spectrum of closely related scenarios. As part of Block 9 these scenarios will be analyzed to determine bounding conditions that can be used to evaluate cumulative release of radionuclides to the accessible environment, assuming the scenario occurs. Site program information will also be used to define the probability of occurrence of scenario classes as well as the range of parameter values used in these analyses. The results of the analyses of the disruptive scenario classes will be integrated with those for the nominal case, taking into account the probability of occurrence of each of the scenarios, to develop the appropriate cumulative distribution function. The site program will also provide information regarding uncertainties in parameter values and in the conceptual models themselves that must be taken into account in developing this complementary cumulative distribution function. Once the complementary cumulative distribution function is obtained, it can be used to compare with the overall system performance objective (see Block 9).

As stated earlier, the strategy outlined in Figure 8.3.1.1-3 is an iterative process, with data collected under the site program playing a key role in refining and validating conceptual models and in developing numerical models. If, after a pass through the steps in this strategy, the system performance objective has been demonstrated to have been met, Issue 1.1 can be potentially resolved (see Block 11). If not, corrective actions can be considered as outlined in Block 12. For example, it may be determined that some of the uncertainties may be reduced by explicitly addressing them through development of additional disruptive scenarios. In the site program area, corrective action may include the collection of additional site data to reduce uncertainties, resulting in another pass through of the previously discussed steps (see Block 15). As shown in Block 14, it is also possible to reach a finding that performance objectives cannot be met.

8.3.1.1.2.2 Issue 1.6

Issue 1.6 addresses pre-waste-emplacement groundwater travel time as required by 10 CFR 60.113 (NRC, 1987a). Groundwater travel time is an indirect measure of the ability of the site subsystem to isolate radionuclides and, in this sense, is related to the measure of isolation provided by the total system performance criterion described in Issue 1.1. Hence, as noted in Table 8.3.1.1-3, some of the same information needs and associated parameters used to determine groundwater travel time are also used in calculations of total system performance.

For this issue, groundwater travel time is defined as the time of travel for an infinitesimal particle of groundwater that is advected along a pathline from the disturbed zone to the accessible environment. The "pre-waste-emplacement" modifier in this issue means that travel time is to be determined in the prevailing, undisturbed groundwater flow regime prior to any significant perturbation of the flow regime due to testing, repository

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construction, or repository operation (NRC, 1987a). The steps to be followed in the licensing strategy for Issue 1.6 are illustrated in Figure 8.3.1.1-4 and are summarized as follows:

1. Determine the extent of the disturbed zone around the repository and locate the groundwater particle starting points for determining travel time.

2. Locate the boundary of the accessible environment and, hence, determine the extent of the controlled area.

3. Define the stratigraphic and structural framework of the basalt sequence in the controlled area.

4. Identify the components within the stratigraphic and structural framework of the site subsystem that must be studied in order to estimate groundwater travel times.

5. Characterize the hydrologic, geochemical, and hydrochemical properties of the site subsystem components identified in Step 4 that will allow groundwater flow paths to be understood and travel times to be estimated.

6. Determine the fastest path(s) of likely radionuclide travel between the edge of the disturbed zone and the accessible environment.

7. Calculate the pre-waste-emplacement groundwater travel time between the edge of the disturbed zone and the accessible environment.

The above steps will involve an iterative approach of data acquisition, conceptual model refinement, travel time calculation, and comparison with acceptance criteria.

With regard to the Issue 1.6 strategy outlined above, Steps 3 through 7 require key information from the site program. Step 3 requires a knowledge of the stratigraphic and structural framework of the basalt sequence within the site to define geologic features that might be groundwater pathways to the accessible environment. Information needs for this purpose will be addressed by the stratigraphy and structure investigation of the geology program (see Table 8.3.1.1-3). The results of Step 3 will serve as the basis for Step 4, the identification of the components of the site subsystem that require further investigation to support issue resolution. Step 5 requires determination of (1) the spatial distribution of hydraulic properties of the basalt sequence within the site and (2) the boundary conditions controlling the flow regime within the site. This information, to be provided by regional and site groundwater studies of the hydrology program (see Table 8.3.1.1-3), will allow the rates and directions of groundwater flow in the site to be predicted. The geochemistry program (see Table 8.3.1.1-3) will further support a definition of groundwater flowpaths by conducting geochemical and hydrochemical investigations of groundwater composition and equilibrium. The emphasis of the hydrologic and geochemical programs, as well as the

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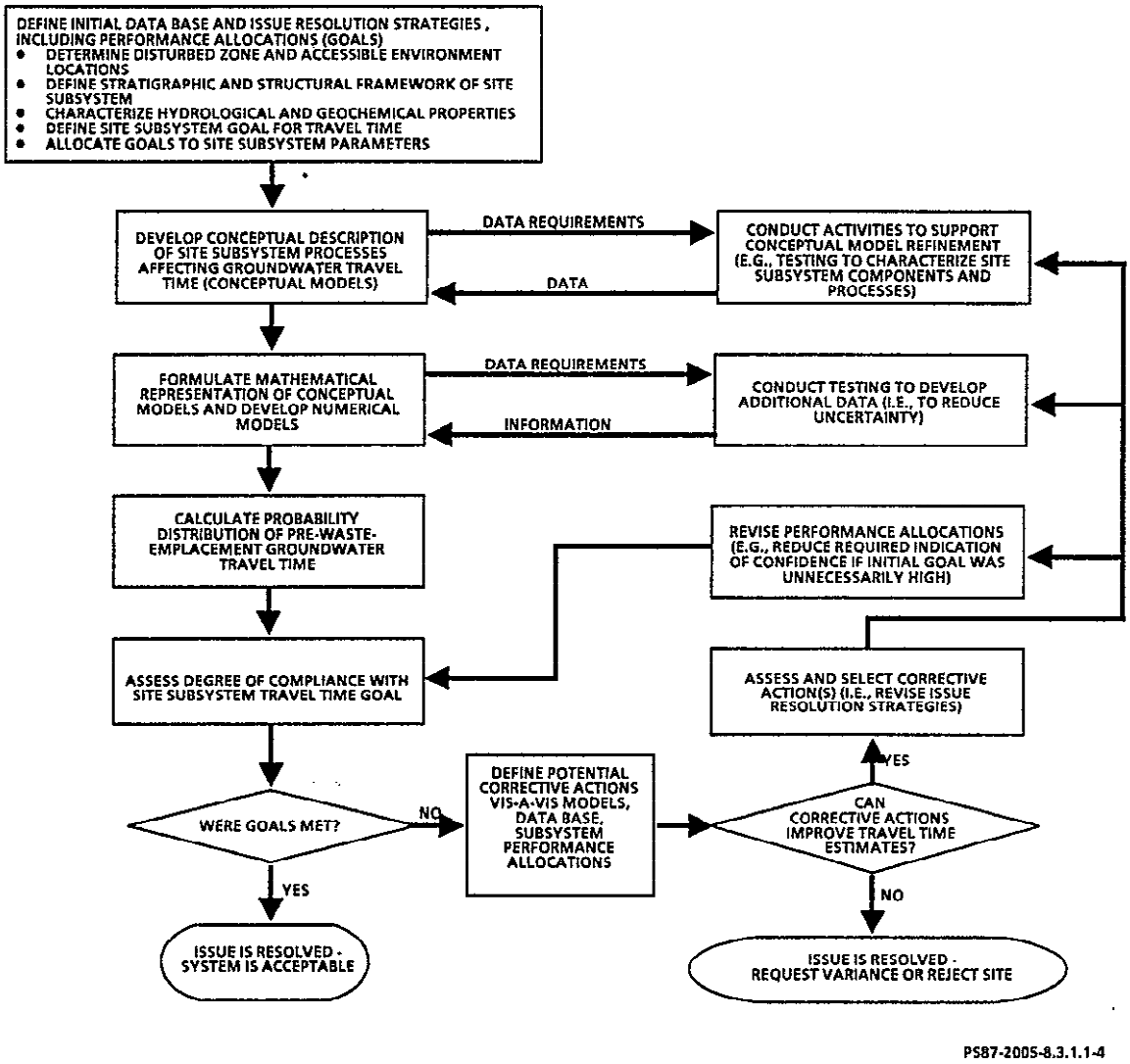

Figure 8.3.1.1-4. Flow diagram for resolution of Issue 1.6.

geology program, will be to develop and evaluate alternative hypotheses or conceptual models describing the groundwater flow system. As site characterization progresses, the direction of the field program for collecting the required geologic, hydrologic, and geochemical data will be guided by the need to evaluate these alternative hypotheses. Step 6, selecting the fastest path for groundwater particles to travel between the edge of the disturbed zone and the accessible environment, will follow after the flow regime is characterized and the rates and directions of groundwater flow are predicted. The final calculation of groundwater travel time, Step 7, will be made by means of a physically based mathematical model that will be numerically implemented in a computer code. A stochastic modeling approach will be followed to determine the cumulative probability distribution of travel time that is required by the NRC (1986). Estimates of the input parameters and boundary conditions for the model will be derived from the geologic, hydrologic, and geochemical data collected as part of the site program.

The Issue 1.6 resolution process outlined in Figure 8.3.1.1-4 will involve an iterative approach of data acquisition, conceptual model refinement, travel time calculation, and comparison with acceptance criteria. One performance measure defined for Issue 1.6 is groundwater travel time to the accessible environment. The goal for this performance measure is groundwater travel time of greater than 1,000 yr with an exceedance probability of 95%.

Hydrologic models developed in Issue 1.6 will be used to perform site (geohydrologic) subsystem sensitivity studies to determine the effect of variation in site conditions on the performance parameters in the total subsystem performance models. The results of these sensitivity studies will determine the magnitude of processes and the initiating events required to affect total subsystem performance, develop characterization needs, and identify potential disruptive scenarios. Thus, Issue 1.6 has a key interrelationship with Issue 1.1 and Issue 1.8.

8.3.1.1.2.3 Issue 1.8

Issue 1.8 addresses the NRC siting criteria set forth in 10 CFR 60.122 (NRC, 1987a). Each of these siting criteria (see Table 8.3.1.1-1) represents a favorable or potentially adverse process, event, or condition whose probability of occurrence and effect on performance must be considered. Thus, the activities conducted for resolution of this issue provide essential information for the nominal case analysis and disruptive scenario analysis that is a key element of the strategy for resolution of Issue 1.1 (see Fig. 8.3.1.1-3). The results of these analyses, in turn, determine priorities for site characterization. The iterative interrelationship between strategies for Issues 1.1 and 1.8 is discussed under Issue 1.1 and will not be repeated here. As noted in Table 8.3.1.1-3, information needs required to support resolution of Issue 1.8 are related to virtually every site program investigation; thus, this issue is considered to be a primary driver for characterization of the site subsystem.

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8.3.1.1.2.4 Issues 1.11, 2.7, and 4.2

Issues 1.11, 2.7, and 4.2 address repository design criteria set forth in 10 CFR 60 (NRC, 1987a). Issue 2.7 and 4.2 are concerned with preclosure safety considerations; Issue 1.11 is concerned with postclosure design considerations. Repository design is an iterative and developmental process with specific phased outputs established for a nuclear waste repository. The overall repository program strategy is guided by these predetermined outputs defined in the Mission Plan for Civilian Radioactive Waste Management Program (DOE, 1985) as follows:

- Site Characterization Plan conceptual design.
- Advanced conceptual design.
- License application design.
- Final procurement and construction design.

The first of these four major outputs, SCP conceptual design, is summarized in Chapter 6.

Advanced conceptual design will develop alternative design concepts for elements of the repository as a part of planned engineering trade-off studies. The alternative design concept that best handles the 10 CFR 60 performance and design requirements is brought forward to the license application design where it is detailed.

The license application design output fulfills the 10 CFR 60 (NRC, 1987a) requirements. Those items necessary to demonstrate compliance with the design requirements and performance objectives of 10 CFR 60 and the license application requirements of 10 CFR 60.21 will be developed. If the site is found acceptable and the license application is approved, the final procurement and construction design will proceed.

The repository design issues require a wide assortment of site program information needs as shown in Table 8.3.1.1-3. Parameter goals for these information needs will generally show increasing degrees of confidence as the characterization program advances through the design phases described above. Design sensitivity and trade-off studies will be used to establish these goals and to focus the efforts of the site program.

Issue 4.2 addresses 10 CFR 60 (NRC, 1987a) repository design criteria for preclosure nonradiological safety. In the strategy for resolution of this issue, consideration is given to subsystem elements that will be relied on to ensure there will be no undue hazard to workers (i.e., mine construction, ventilation, and surface facilities). The sequence of activities that takes place during construction of the repository has been examined to produce a list of initiating events that highlight the potential for accidents involving nonradiological health and safety of workers. In the site area, these events generally relate to potentially adverse conditions listed in Table 8.3.1.1-1. Site program information needs and associated parameters relating to these

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events will be measured and checked against mitigating design measures. Sensitivity analyses will be used to set or evaluate initial parameter goals and to assess whether these goals have been met as characterization progresses through the established design phases. The same general strategy is used to address Issue 2.7, preclosure radiological safety.

Site program information needs defined by Issues 4.2 and 2.7 are shown in Table 8.3.1.1-3. Geology program information needs generally relate to an evaluation of the stratigraphic and structural framework of the repository host rock. These include conditions that could affect repository layout (e.g., distribution of intraflow structures, displacement of the host flow due to faulting) or opening stability considerations (e.g., joint characteristics). They also include processes and events that could cause facility damage and jeopardize worker safety (e.g., seismicity). The site flooding and site groundwater information needs of the hydrology program relate, respectively, to site flooding considerations that could affect repository surface facilities and to water inflow considerations that could impact subsurface facilities and worker safety. The groundwater hydrochemistry information need of the geochemistry program contributes to an evaluation of gassy mine considerations that could result from methane gas intrusion.

Issue 1.11 addresses postclosure design criteria requiring that the repository facility contribute to the containment and isolation of the waste (10 CFR 60.133, NRC, 1987a). The overall strategy for resolution of this issue is outlined in Figure 8.3.1.1-5. Closure of this issue is complete when it has been demonstrated that performance goals for each of the five functions shown in this figure have been met. To address issue closure, design sensitivity analyses are performed to initially set performance measure goals and performance parameter goals; sensitivity analyses are subsequently used to assess whether these goals have or have not been met as characterization progresses through the design phases. Site program information needs and associated parameters are primarily required to address Functions 1.11.1, 1.11.2, and 1.11.3 shown in Figure 8.3.1.1-5. These include geology program information needs (see Table 8.3.1.1-3) that relate to maximizing use of the interior of the repository host flow for repository placement. These information needs also relate to defining unfavorable geologic conditions that should be avoided by the repository layout.

8.3.1.1.2.5 <u>Issues 1.4, 1.5, and 1.10</u>

Issues 1.4, 1.5, and 1.10 address waste package design criteria set forth in 10 CFR 60 (NRC, 1987a). Like repository design, waste package design is an iterative and developmental process with essentially the same four design phases defined in the Mission Plan for Civilian Radioactive Waste Management Program (DOE, 1985). Site program information needs support waste package

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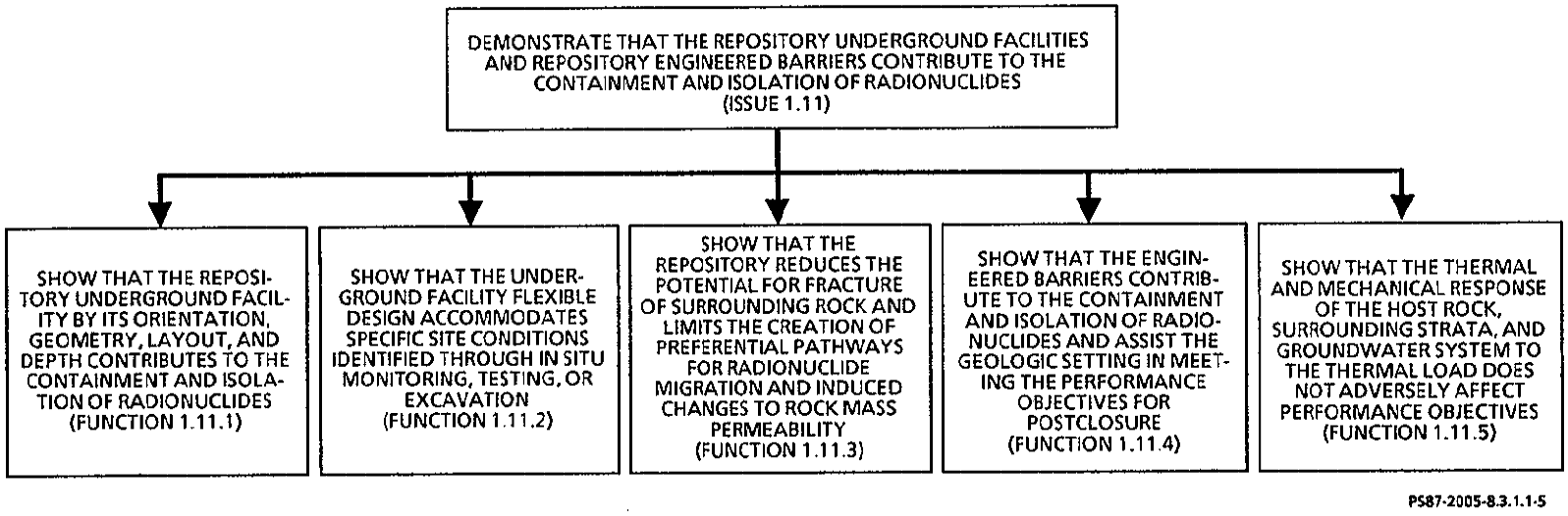

Figure 8.3.1.1-5. Overall strategy for closure of Issue 1.11.

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design strategies requiring that both preclosure and postclosure scenarios be identified and evaluated for the waste package environment. These information needs are primarily in the geochemistry program (i.e., groundwater composition and redox environment) and in the geology program, (i.e., mineralogy and petrology) (see Table 8.3.1.1-3). These information needs enable an analysis to be made of the effect of the geochemical environment on waste package performance.

8.3.1.1.2.6 Issue 1.12

Issue 1.12 addresses shaft and borehole seal criteria set forth in 10 CFR 60 (NRC, 1987a) and in 40 CFR 191 (EPA, 1986). Issue resolution will be guided by a strategy of allocating goals for performance to barriers installed in pathways that could transport radionuclides. This strategy uses an iterative process of data collection and analysis to evaluate which alternatives to implement for design and installation of repository seals. Site program information needs supporting Issue 1.12 are primarily those addressing potential geohydrologic pathways. In the geology program these include stratigraphy, intraflow structure, and joint characteristics information needs, and information needs addressing disruptive scenarios such as seismicity. Hydrology and geochemistry program information needs include site groundwater and hydrochemistry information needs addressing groundwater transport concerns.

8.3.1.1.2.7 Issue 2.4

Issue 2.4 addresses the NRC requirement for waste retrievability set forth in 10 CFR 60.111(b) (NRC, 1987a). The retrievability option must be maintained up to 50 yr after waste emplacement operations are initiated. In the strategy for Issue 2.4, three general design functions have been identified to provide a basis for issue resolution. These are to (1) maintain access to and from emplaced waste, (2) retrieve the waste container from the emplacement borehole, and (3) transport the waste container to the surface. Site program information needs will be used to develop and evaluate design options relating to these three functions. These information needs include those in the geology program relating to stratigraphy, joint characteristics, and seismicity and those in the hydrology program relating to site groundwater and groundwater composition (see Table 8.3.1.1-3). These information needs address conditions that could reduce opening stability of the emplacement boreholes and repository drifts and shafts.

8.3.1.1.2.8 Issues 2.1, 2.2, and 2.3

Issues 2.1, 2.2, and 2.3 address radiological exposure of workers and the general public as result of operation, closure, and decommissioning of a repository. The strategies for these issues use a preclosure risk assessment methodology. This methodology entails a hierarchy of analytical steps that can be used to assess compliance with applicable regulatory limits set in 10 CFR 60 (NRC, 1987a), 40 CFR 191 (EPA, 1986), and 10 CFR 20 (NRC, 1987b). The atmosphere system is viewed as the most likely means of transport of radionuclides from the repository to the general public. Hence, the primary

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site program information need is site meteorology (see Table 8.3.1.1-3). Other site program information needs are included in the geology and hydrology programs (see Table 8.3.1.1-3). These information needs primarily address water inflow concerns.

8.3.1.1.2.9 Issues 1.9, 2.5, and 4.1

Issues 1.9, 2.5, and 4.1 deal with higher level findings with respect to preclosure and postclosure guidelines identified in 10 CFR 960 (DOE, 1987a). These guidelines have been developed by the DOE to be used in evaluating and comparing the characterized sites to support selection and recommendation of a site for repository development. The site program information needs required to make the higher level findings have already been identified in other issues (see Fig. 8.3.1.1-2). These information needs will be used as follows:

- Issue 1.9: Closed using information needs from Issues 1.1, 1.3, 1.4, 1.5, 1.6, 1.8, 1.10, 1.11, and 1.12.
- Issue 2.5: Closed using information needs from Issues 2.1, 2.2, 2.3, 2.4, and 2.7.
- Issue 4.1: Closed using information needs from Issues 1.10, 1.11, 1.12, 2.7, 4.2, and 4.3.

In the case of Issue 1.9, additional site program work may have to be conducted to address the future climatic change information need (see Table 8.3.1.1-3). Cycles of climatic change are generally greater than 10,000 yr. As such, the 100,000-yr assessment period that may be used in the implementation of 10 CFR 960 (DOE, 1987a), is a significant program planning consideration.

8.3.1.1.2.10 Issue resolution strategy parameters

For issue resolution strategies discussed above, two classes of parameters are addressed by the site program: "performance" parameters and "supporting" parameters. Performance parameters are those quantities identified in the issue resolution strategies that will be used directly in the evaluation of performance measures. Performance parameters, therefore, include any of the input parameters for performance assessment calculations or any of those input to design basis analyses of the engineered systems. Performance parameter tables and their rationale appear in Section 8.2.2.

In many cases, performance parameters listed under the issues relate to the results of analyses; i.e., they are not measured directly. The additional information required to derive these performance parameter values is identified through the development of supporting parameters. Supporting parameter tables for each study/information need and their rationale appear in the 8.3 sections.

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Supporting parameters are generally hierarchical in nature as illustrated by the example shown in Figure 8.3.1.1-6. In this example, "dispersivity field" is considered to be a performance parameter; those parameters listed below are considered to be supporting parameters. However, the "boundary" between performance parameters and supporting parameters in such a hierarchy often varies, as determined by the needs and licensing strategies for each issue. This accounts for the overlap or duplication between performance parameters and supporting parameters often present in the Section 8.3.1 supporting parameter tables. The lowest level for supporting parameter development is that level in the hierarchy at which parameters become methodology-dependent. If supporting parameter hierarchies have multiple levels, only the uppermost levels may be shown in the Section 8.3.1 supporting parameter tables to preclude undue repetition.

An example of the general supporting parameter table format for the 8.3.1 sections is shown in Table 8.3.1.1-4. Columns 1 through 3 of this example are derived from performance parameter tables included in Section 8.2.2. Adjacent to each performance parameter listed in Column 1 is a consolidated listing of the Section 8.2.2 source issue (Column 2). Column 3 designates the scale and (or) location for which this performance parameter must be defined (see bottom of Table 8.3.1.1-4 for scale definitions). Column 4 contains a listing of supporting parameters derived for each performance parameter. The remaining columns in Table 8.3.1.1-4 relate to the test basis for a given supporting parameter and summarize the rationale for the activities associated with that parameter. This basis is frequently dependent on the scale/location needs designated in Column 2. The test basis may be given in one of the following formats.

- Format described for performance parameter tables; table lists the tentative parameter goal, needed confidence, expected values, and current confidence.

- Format specifying "needed accuracy" where this term specifies the degree of accuracy needed for the parameter.

- Format in terms of the current estimate for the range of the parameter, the current confidence in the estimate, and the needed confidence in the estimate. Where estimates or confidences cannot be given quantitatively, qualitative terms are used.

Where possible, the entries into the test basis columns are quantitative. In many cases in the site area, however, quantification is not appropriate and the entry into the test basis columns is descriptive, or qualitative, in nature. For example, several studies such as intraflow structure (see Table 8.3.1.1-4) contain parameters with goals resembling "define spatial distribution" (see Column 5). In these cases, the goal is to define some aspect of the natural system as it exists. As such, an arbitrary quantitative goal would be meaningless. Comparison of the test basis "current" and "needed confidence" column (see Column 6) gives a general indication as to whether the existing data base is adequate or whether additional site characterization work will be required. As such, entries into the "confidence" columns should primarily be viewed as "targets" to guide the emphasis of site program planning rather than as "absolutes."

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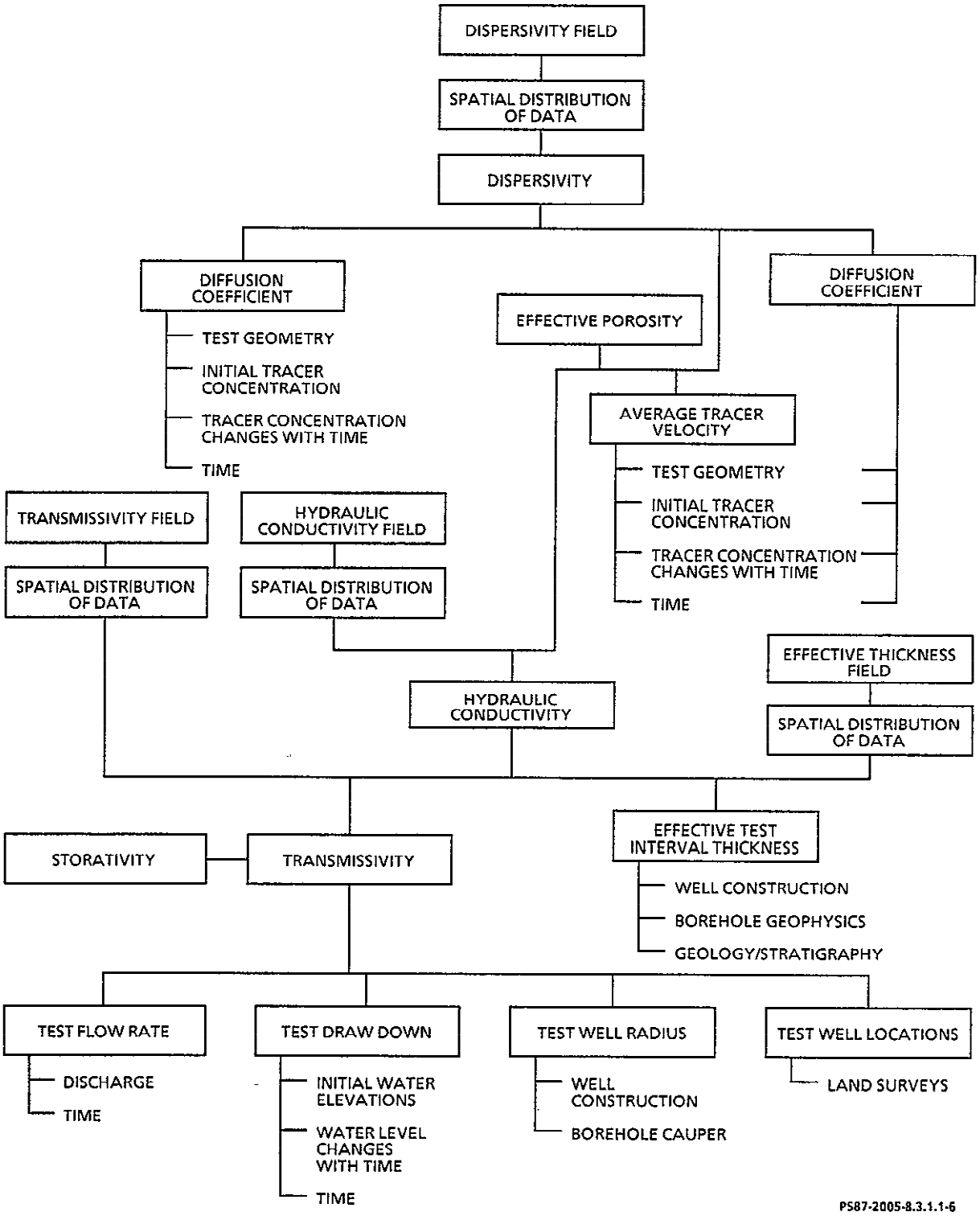

Figure 8.3.1.1-6. Example of supporting parameter hierarchy.

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Table 8.3.1.1-4. Example of Section 8.3.1 supporting parameter table

Performance parameter 1	Issue 2	Scale/location 3	Supporting parameter 4	Tentative parameter goal/needed accuracy 5	Confidence 6		Current estimate of goal/accuracy 7
					Needed	Current	
Intraflow structure geometry	1.11.1a and b 1.11.2c 1.11.3a 1.11.5 1.6, 1.8	Host Rock/RS PIZ/CASZ	Position of intraflow structures	Determine to ±5 m	High	Medium	±7-10 m
			Thickness of intraflow structures	Determine to ±5 m	High	Medium	±7-10 m
			Lateral continuity of intraflow structures	Define spatial distribution	Medium to High	Low to Medium	Limited ability to define spatial distribution
Intraflow structure lithology	1.11.1b, 1.6, 1.8 1.6, 1.8	Host Rock/RS PIZ/CASZ RIZ/CCS all flows/PB	Lithologic characteristics of intraflow structures	Describe qualitatively/ quantitatively as applicable	High	Medium to High	Description based on current data
Detected anomalous intraflow structures	1.11.1c 1.11.2a (implicit in 1.6)	Host Rock/RS	Occurrence of anomalous intraflow structures	Identify location to within ±5m	Medium to High	Low	Only known as detected in boreholes and outcrop
Intraflow structure geometry	1.6, 1.8	RIZ/CASZ all flows/PB	Position	Determine to ±7 m	Medium	Medium	±10 m
			Thickness	Determine to ±7 m	Medium	Medium	±10-15 m
			Lateral continuity	Define spatial continuity	Medium	Low to Medium	Limited ability to define
		RIZ/CASZ RIZ/CCS all flows/PB	Occurrence of anomalous intraflow structures	Estimate frequency of occurrence	Medium	Low	Can estimate some features via probability encoding

NOTE: To convert m to ft, multiply by 3.28.

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Intraflow structure = Related to internal characteristics of basalt flows; flow-top breccias, vesicular zones, pillow zones, and cooling joint patterns such as the entablature, columnar-entablature, and colonnade (Reed, 1987).

CASZ = Controlled area study zone, here used as the sum of all likely controlled areas, approximately a lateral area that extends no more than 5 km in any direction from the outer boundary of the proposed repository site.

CCS = Cold Creek syncline.

ES = Exploratory Shaft(s).

ESF = Exploratory Shaft Facility.

PAC = Potentially adverse condition.

PB = Pasco Basin.

PIZ = Primary isolation zone, here used as the stratigraphic section of basalt flows in the Pasco Basin extending from the top of the Vantage Horizon to the base of the umtanum flow (upper Grande Ronde Basalt).

RIZ = Repository isolation zone, here used as the stratigraphic section of basalt flows in the Pasco Basin extending from the top of the Priest Rapids member to the N_2 - R_2 paleomagnetic contact. (Wanapum Basalt, PIZ, and several Grande Ronde Basalt flows below the PIZ)

RS = Repository site, here used as the lateral area in the subsurface that would be occupied by the repository including surrounding buffers.

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8.3.1.1.3 Approach to investigations

This section contains an overview of the site program approach to investigations. This overview emphasizes common programmatic elements of this approach. The subsequent section, 8.3.1.1.4, more specifically addresses the technical objectives of each site investigation and summarizes the approach, or technical strategy, to be used to meet these objectives.

The generalized approach used to implement the site program is depicted by the strategy process diagram in Figure 8.3.1.1-7 (Blocks 1 through 19). Blocks 1 through 3 of this diagram relate to aspects of the issue resolution strategy process discussed in the previous section. As noted in this section, this process has identified a diversity of performance measures and performance parameters to be addressed by the site program. Consideration of these performance parameters has further resulted in the identification of supporting parameters--parameters that provide information useful in determining performance parameter values. In summary, these three blocks represent the "program driver" portion of the site program strategy process.

Block 4 relates to the development of Part A of the SCP (i.e., data chapter input). Formulation of this input has served as a vehicle to identify programmatic areas where the data base is sufficient or insufficient in relation to conceptual models and parameters identified in the issue resolution strategies; it has also served to identify technical considerations that help organize and focus the technical approach that must be implemented to address these additional data needs. Hence, the results of Block 4 have served as the basis for addressing the Block 5 question regarding data adequacy and for proceeding to either Block 6 or 7.

Block 7 is the focus of Part B of the SCP, Section 8.3.1. This block also embodies production of the initial site program study plans on which the 8.3.1 sections are based. The overall objective of these plans is to provide a description in conceptual and mathematical terms of the site, the natural barrier that will be relied upon to prevent the release of high-level nuclear waste from the repository to the accessible environment. This description includes a prediction of future changes to the site that may affect repository performance; these changes may be the result of either natural or man-induced events. The site description will be presented in sufficient detail and with sufficient confidence such that present and future site conditions can be predicted with reasonable assurance. "Proof" of the present and future conditions of the site is not achievable in the ordinary sense of the word (NRC, 1983). There will be no opportunity to carry out test programs that simulate the full range of relevant conditions or that can be used to duplicate long periods of geologic time (NRC, 1983). Therefore, the general strategy and approach for characterizing the site must involve a variety of methodologies in an effort to reduce or define uncertainties. Considering the above rationale, the planned site program approach has generally been predicated on the basis of the following considerations and assumptions.

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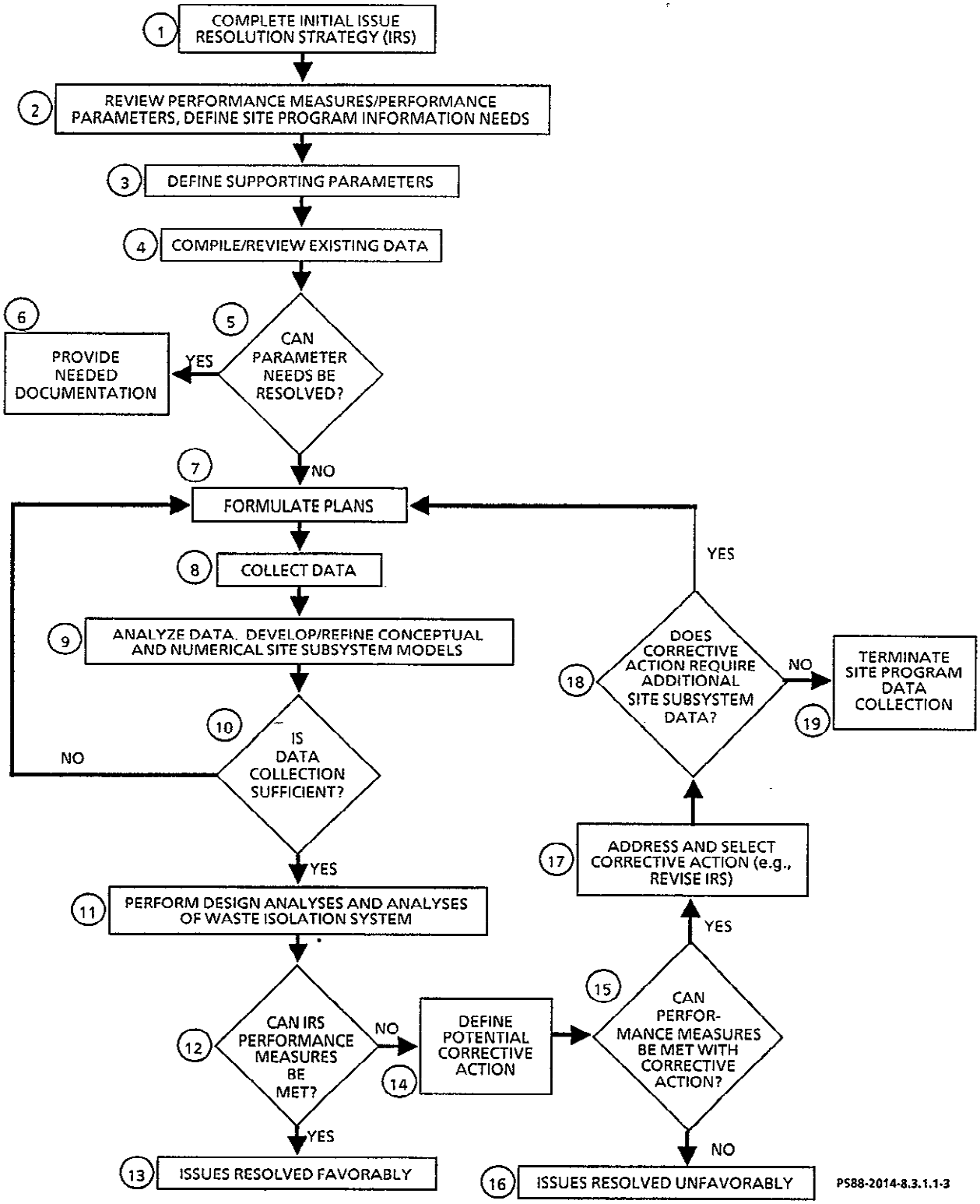

Figure 8.3.1.1-7. Site program strategy process diagram.

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- Program orientation--The controlled area study zone is defined as the "sum of all likely controlled areas for a repository in the reference repository location to be used until sufficient information is available to establish a controlled area within the constraints of 40 CFR 191 (EPA, 1986)"* (Reed, 1987). For purposes of program orientation, it is assumed that the repository area under consideration will be located within the controlled area study zone and within the Cohassett flow (WCC, 1981; Long and WCC, 1984) as shown in Figure 8.3.1.1-8. In addition to the repository host flow, other basalt flows of interest include those located within the primary isolation zone and the repository isolation zone (see Fig. 8.3.1.1-8). On the basis of previous work, key factors relating to constructibility and preclosure safety considerations are deemed to be stratigraphic and structural discontinuities, water inflow, seismicity, and in situ stress. In addition, groundwater transport has been assumed to be the most likely way, under postclosure conditions, by which radionuclides could be released from a repository within the controlled area study zone to the accessible environment. Characterization work will be oriented toward assessing the "stability" of the controlled area study zone generally defined in terms of conditions and rates of processes and events that either (1) leave the relevant, ambient characteristics of the controlled area study zone relatively unchanged (i.e., relatively low rates of change) or (2) change them in a way that allows confident predictions of no adverse consequences to the isolation of the waste (NRC, 1983). Due consideration will be given to 10 CFR 60.122 (NRC, 1987a) that implies that the appropriate way to address the degree of required "stability" is to assess the controlled area study zone in the context of favorable and potentially unfavorable conditions (see Table 8.3.1.1-1) as they affect the proposed repository's achievement of the overall system performance objectives. Of particular concern will be the bounding of the nature and extent of conditions, processes, and events (i.e., scenarios).

- Temporal considerations--Emphasis will be placed on predicting the future through an analysis and projection of the recent geologic past and present. The recent geologic past has generally been defined in terms of the Quaternary geologic record (NRC, 1983). However, in the CASZ and surrounding area, only a limited Quaternary rock record is present. Consequently, studies of the "recent" geologic past will also involve evaluations of late Grande Ronde Basalt time through the present in an effort to reduce uncertainty (see Fig. 8.3.1.1-8). Predictions of future conditions, processes, and events will be presented for two time periods: (1) the

*The reference repository location is the highest ranked site on the Hanford Site for repository construction as determined by a screening and ranking process documented by Woodward-Clyde Consultants (WCC, 1981) (Reed, 1987) (see Fig. 8.3.1.1-8). (See p. 8.3.1.1-3 for definition of controlled area.)

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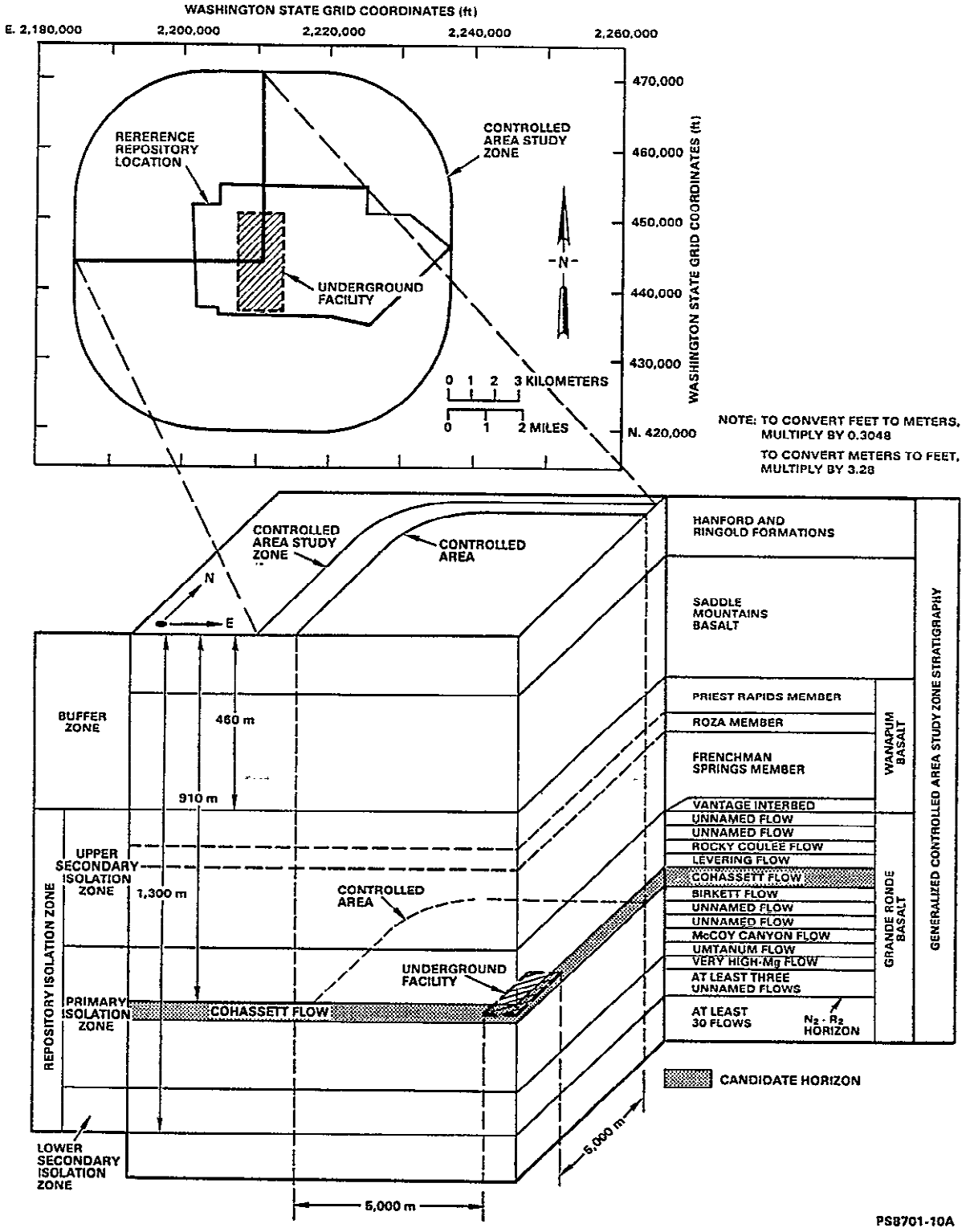

Figure 8.3.1.1-8. Schematic: Stratigraphic position of repository and its relationship to the controlled area study zone and the reference repository location. (See page 8.3.1.1-3 for definition of controlled area.)

relatively short, 100-yr long construction and operation (preclosure) period of the repository and (2) the relatively long, 10,000-yr (postclosure) performance period. Where possible, natural analog studies will be used to simulate the effects of geologic time.

A defensible site program will require development of a predisturbance groundwater-level baseline for the controlled area study zone. Hence, the initial phase of the program will be oriented toward obtaining all data that will henceforth be unobtainable due to permanent alteration of hydraulic properties and hydraulic heads of the groundwater flow system by exploratory shaft construction.

- Spatial/sampling considerations--An assessment of past and present conditions within the controlled area study zone will be based primarily on interpolation, using a combination of data points derived from outcrop studies, geophysical surveys, borehole sampling and testing, surveillance networks, and sample analyses. An assessment of ambient conditions within the controlled area study zone will be constrained by sample size and availability. During site characterization, direct observation of repository conditions will only be possible on a limited scale (e.g., a finite number of boreholes and exploratory shaft excavations). Hence, emphasis will be placed not just on immediate site conditions but on a much larger area to provide data that can contribute to an assessment of past, present, and future conditions in the controlled area study zone.

  Conditions and processes will generally be considered in five hierarchical areas: (1) Pacific Northwest/Columbia Plateau, (2) Pasco Basin, (3) Cold Creek syncline, (4) controlled area study zone, and (5) repository site (Fig. 8.3.1.1-9). The search for information will, in general, be most intense closest to the site, where data may be most representative. However, detailed work will be carried out in selected distal areas when such work will help clarify present and predicted site conditions. In addition, studies of selected analogue areas outside the five hierarchical areas will also be considered. In general, the geology, climatology, and resource potential programs require that more consideration be given to the Pacific Northwest/Columbia Plateau area than do the hydrology and geochemistry programs.

  Central to almost all planned site program sampling considerations within the Cold Creek syncline, controlled area study zone, and repository site is the need for and use of surface-based boreholes. A location map of the currently planned site program deep boreholes (penetrating the repository isolation zone) is shown in Figure 8.3.1.1-10. As noted in this figure, each of these boreholes is based on the needs of a primary specific program. However, boreholes will be multipurpose where possible and will be the subject of a variety of data acquisition activities. Further

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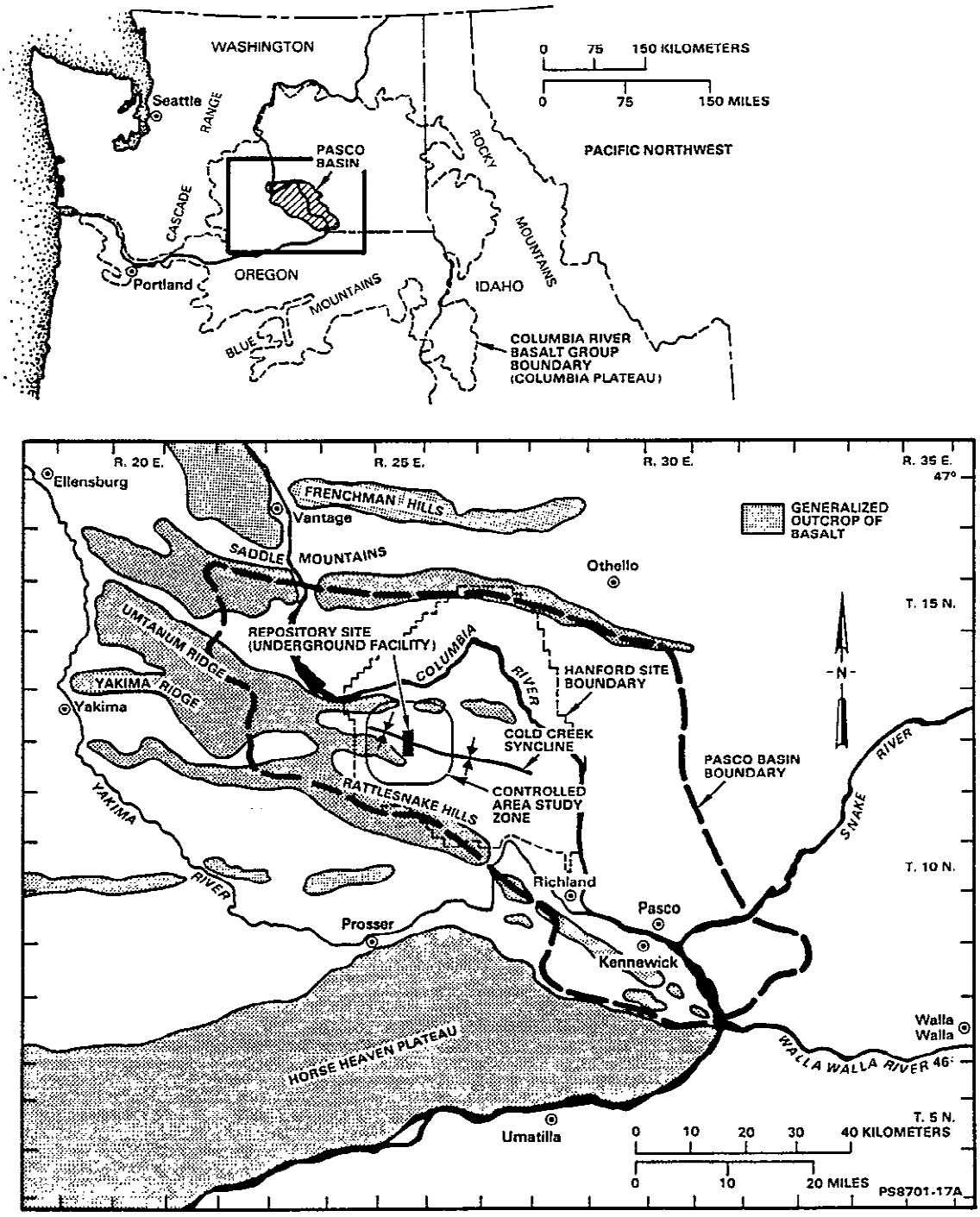

Figure 8.3.1.1-9. Hierarchy of areas/scales (see Figure 8.3.1.1-8 for relationship of repository site area/scale to the controlled area study zone).

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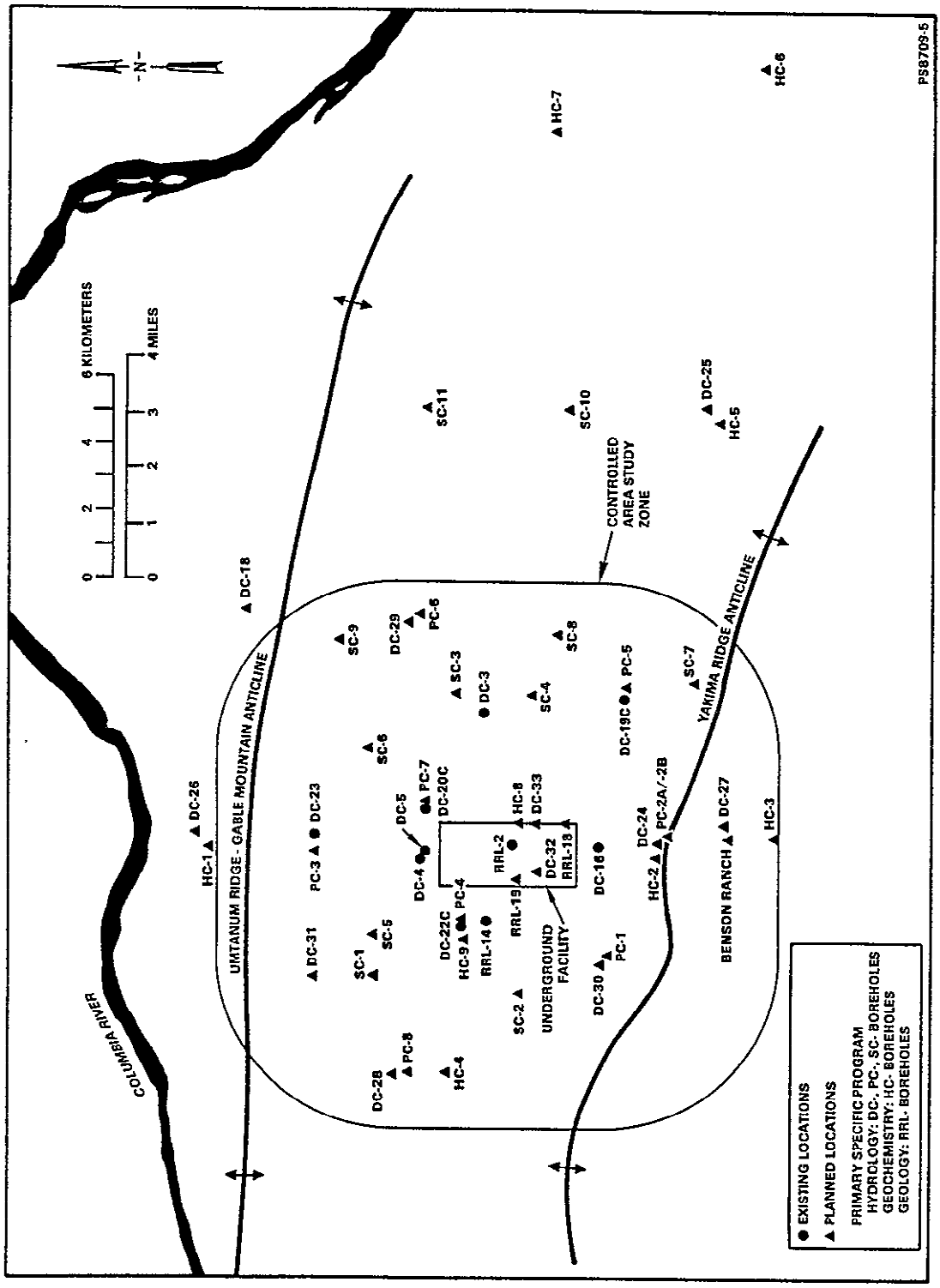

Figure 8.3.1.1-10. Existing and planned boreholes penetrating the repository isolation zone within and in the vicinity of the controlled area study zone (see Figure 8.3.1.1-8 for explanation of repository isolation zone and controlled area study zone).

planning activities will be conducted as site characterization progresses to maximize multipurpose utilization of boreholes. As part of this planning, the need for a deep borehole through the basalt will be assessed and outlined in a position paper. Such a borehole would support stratigraphic, hydrologic, geochemical, rock deformation, mineralogy and petrology, structure, and resource potential studies.

The initial boreholes to be drilled (DC-24, DC-25, DC-32, DC-33; see Fig. 8.3.1.1-10) support the establishment of a hydrologic baseline. As mentioned above, the establishment of this baseline is on the critical path to the startup of exploratory shaft drilling and to the drilling of other deep boreholes that could impact the acquisition of "perishable" groundwater data. Hence, the need to establish this baseline is a key consideration factored into the approach used by all site program investigations involving drilling within the controlled area study zone. After establishment of this baseline, large-scale hydrologic stress testing of boreholes will be conducted to address scale effects associated with some hydrologic parameters.

- Role of model development--Data collection efforts and interpretations will be guided by the "multiple-working-hypothesis" approach (Chamberlain, 1890). Multiple interpretations or hypotheses that explain a given data set will be tested by defining and carrying out studies that address the concerns. The primary tool to implement this approach will be conceptual and mathematical model development. Modeling is considered to be an iterative process of gathering data to address specific questions or hypotheses identified during the interpretation of a given data set. Hence, model development will be used as a tool to accomplish the following (DOE/NRC, 1984):

  - Integration and reconciliation of existing data.
  - Guidance of data collection efforts, including data priorities.
  - Provision of a mechanism for handling new data.
  - Facilitation and synthesis of data and concepts.
  - Provision of input to performance assessment and design analyses.
  - Provision of a basis for sensitivity analyses.

Given the uncertainties in studies of the natural setting, it is clear that a single, all encompassing model will not be developed. Instead, separate models will be developed to address specific goals or objectives. Where more than one model can be developed to address specific goals or objectives, the appropriate model will be the credible conservative case model, and compatible with models developed for other specific goals. For a given objective, the appropriate model(s) may be conceptual, stochastic, or analytical. Whether the actual form of the model(s) is one or more of these will depend upon the information available. In general, models evolve from conceptual to stochastic to analytical. Currently, only small

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subproblems are amenable to analytical analysis; given the uncertain nature of studies of the natural setting, conceptual modeling will play a primary role (NRC, 1984).

Validation of models of the natural setting will be a continual process of refinement and testing, involving data collection and analysis. Part of this validation process will involve a recognition of the hierarchical nature and dependence of models (e.g., models need to be consistent in a hierarchical sense with other models as well as with the data specific to those models) (NRC, 1984). The principal goal of model validation is to provide the site data required to formulate, apply, and interpret defensible performance analysis models at a variety of scales in support of licensing assessments. Implicit in this approach is the realization that reasonable assurance regarding the final results of performance assessment modeling will be attainable only when a sufficiently comprehensive site data base is available.

- Role of peer review--As previously stated, interpretations regarding the past, present, and future natural setting cannot be tested in the traditional sense. Peer review will be heavily relied on to make decisions regarding the sufficiency of the data base and the sufficiency of models (i.e., validation) based on that data base. Peer review will be implemented throughout the site program and will involve the BWIP staff and technical consultants and technical representatives from Federal and State agencies, affected Indian Tribes, the academic community, and the concerned public. Such review will also include publication in the referred literature. The approach to peer review will consider aspects outlined by the NRC (NRC, 1987c, 1987d).

- Quality assurance requirements--Site program data acquisition and analysis will be conducted in accordance with quality assurance requirements set forth in the Basalt Quality Assurance Requirements Document (DOE/RL, 1987). A general description of these requirements, and the graded quality assurance methodology through which they are implemented, is contained in Section 8.6. In the case of the site program, study plans will serve as the basis for outlining data collection/analysis needs; work initiation packages, test data collection specifications, technical operating procedures, and training plans will further document quality controls required to meet these needs. Such documents will also address controls on work conducted in the controlled area study zone that might affect performance of the natural barrier or interfere with its characterization.

An overview of the technical approach used by each specific site program, based on the above programmatic considerations and assumptions, is provided in Section 8.3.1.1.4.

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Blocks 8 and 9 of Figure 8.3.1.1-7 represent the implementation of the planned data acquisition and analysis tasks currently discussed in the 8.3.1 sections. The overall sequencing and scheduling of these tasks is depicted in the generalized schedule for the site program shown in Figure 8.3.1.1-11. Of the planned data acquisition tasks, surface field and laboratory activities will be conducted prior to, and concurrent with, exploratory shaft activities (Fig. 8.3.1.1-11). Data analysis activities, generally oriented toward the formulation and validation of conceptual and numerical models, will be conducted concurrently with all data acquisition activities (see Fig. 8.3.1.1-11).

In Figure 8.3.1.1-7, the results of Block 9 will serve as the basis for addressing the Block 10 question. This question entails an assessment as to whether the planned data collection approach was sufficient to address pre-established performance and supporting parameter goals and site subsystem conceptual and numerical model development needs. If the answer is no, and additional data collection appears warranted, site program plans will be re-evaluated and reformulated in Block 7 and the associated data acquisition and analysis tasks implemented. If the answer to Block 10 is yes, the results from Block 9 will be input to design and performance assessment analyses depicted in Block 11. In reality, Blocks 7 through 10 involve an iterative process of planning, data collection, and data analysis that will be ongoing throughout site characterization.

Blocks 11 through 17 represent an iterative process of modeling, sensitivity, and trade studies carried out to assess engineered barriers and repository design options and total system performance. Primary outputs of Box 11 will coincide with key repository design phases, advanced conceptual design and license application design, and with the draft environmental impact statement used to evaluate the BWIP site in the context of the 10 CFR 960 guidelines (DOE, 1987a). Hence, site program data collection and analysis efforts (see Fig. 8.3.1.1-11) are focused toward providing input required to support these design and performance assessment outputs produced by the BWIP programs discussed in Sections 8.3.2 through 8.3.5.

The models developed and applied in Block 11 determine if the performance objectives prescribed in the issues can be met and define the sensitivity of total system performance to subsystem parameters and alternate conceptual models. Concurrently, the analyses identify deficiencies in system design, the data base, or the performance assessment models. The results of Block 11 will serve as the basis for addressing the Block 12 question regarding whether performance and design objectives have been met. If the answer is yes, performance and design issues can be resolved favorably as designated in Block 13. If the answer is no, corrective action will be considered as outlined in Block 14. Such corrective action, if viable (Block 15), may include the collection of additional site data (Block 18), resulting in another pass through Blocks 7 through 10. It may also require reevaluating design options and performance allocation decisions set in the original issue resolution strategies for the site, waste package, engineered barriers, and repository seals subsystems (Block 17). If corrective action is not viable, issues cannot be resolved favorably as noted in Block 16.

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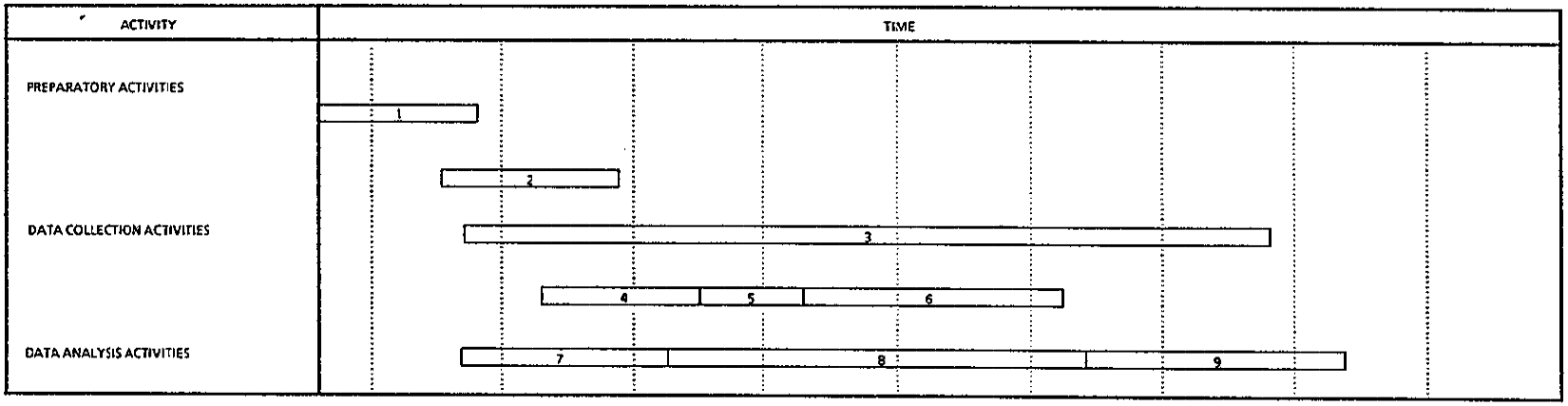

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1 SITE CHARACTERIZATION PLAN AND STUDY PLAN PREPARATION, WORK INITIATION PACKAGE PREPARATION.

2 STUDY PLAN APPROVAL; TEST DATA COLLECTION SPECIFICATION, TEST PLAN AND PROCEDURE PREPARATION; TRAINING.

3 SURFACE-BASED DATA COLLECTION (OUTCROPS, BOREHOLES, GEOPHYSICAL SURVEYS, TRENCHES, LABORATORY ANALYSIS, AND MONITORING).

4 HYDROLOGIC BASELINE ESTABLISHMENT.

5 EXPLORATORY SHAFT 1 CONSTRUCTION.

6 EXPLORATORY SHAFT PORTHOLE AND DRIFT DATA COLLECTION

7 ANALYZE/DOCUMENT DATA FOR REPOSITORY/WASTE PACKAGE ACD AND ACD-PERFORMANCE ASSESSMENT.

8 ANALYZE/DOCUMENT DATA FOR REPOSITORY/WASTE PACKAGE LAD AND LAD-PERFORMANCE ASSESSMENT.

9 ANALYZE/DOCUMENT DATA FOR THE DRAFT ENVIRONMENTAL IMPACT STATEMENT.

ACD = ADVANCED CONCEPTUAL DESIGN
LAD = LICENSE APPLICATION DESIGN

Figure 8.3.1.1-11. Generalized site program schedule.

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8.3.1.1.4 Organization of Section 8.3.1

This section contains a preview of the five specific site programs and associated investigations supporting these programs (see Fig. 8.3.1.1-1). This preview includes a summary of the technical objectives of each investigation and the approach, or technical strategy, to be used to meet these objectives.

8.3.1.1.4.1 Geology Program

Section 8.3.1.2 contains a discussion of the geology program and its three investigations. The primary objectives of these investigations and their 10 associated studies (see Fig. 8.3.1.1-1) are to develop and provide key information on the following:

- Three-dimensional geometry of the site and surrounding area, that is, the present day rock configuration of the site (stratigraphy and structure investigation, Section 8.3.1.2.3).
- Tectonic, volcanic, and geomorphic stability of the site and surrounding area, including the past and potential future deformation and seismicity (tectonic events and processes investigation, Section 8.3.1.2.4).
- Distribution and composition of mineralogic phases in basalts and sediments and the chemical stability of the individual phases as well as the total geochemical environment as reflected by the mineral assemblages, that is, the site mineralogic makeup (mineralogy and petrology investigation, Section 8.3.1.2.5).

To accomplish the above objectives, a variety of methodologies will be used to examine both the surface and subsurface environment at all five "scales" discussed in the previous section. The stratigraphy and structure investigation will obtain data using geologic mapping, geophysical surveys, trenching, and borehole drilling and testing. Because of sediment cover, boreholes will be relied on to provide "point sources" of information within the Cold Creek syncline, the controlled area study zone and the repository site; geophysical surveys will be used to extrapolate between these boreholes. This information will be supplemented by geologic and geophysical data from the Pasco Basin and region and by in situ geologic and geophysical data obtained from the exploratory shaft. These data will be used to construct models of the present configuration of the site. Such models will serve as the basis for repository design and for defining potential groundwater pathways from the repository to the accessible environment.

The tectonic events and processes investigation will build on data obtained by the stratigraphy and structure investigation. These data will be supplemented with information obtained from seismic monitoring and geodetic surveys. Information on geologic structure, deformation rates, and seismicity will be used to assess tectonic processes and events that could alter the present configuration of the site and affect preclosure and postclosure repository performance.

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The mineralogy and petrology investigation will use samples obtained from geologic mapping, from surface-based boreholes, and from the exploratory shaft. Laboratory analysis techniques will be used to provide data on the mineralogic makeup of the site.

The results of the geologic investigations will provide key input to both design and performance assessment programs. These results will also provide key support to other specific site programs; all hydrologic, geochemical, climatological, and resource potential interpretations must be made in the context of the geologic framework.

8.3.1.1.4.2 Hydrology Program

Section 8.3.1.3 contains a discussion of the Hydrology Program and its two investigations. The primary objectives of these investigations and their four associated studies (see Fig. 8.3.1.1-1) are as follows:

- Determine the flooding potential of the proposed site (surface water investigation, Section 8.3.1.3.3).
- Provide groundwater recharge parameter information (surface water investigation, Section 8.3.1.3.3).
- Construct a groundwater flow model for the Pasco Basin and Cold Creek syncline (groundwater investigation, Section 8.3.1.3.4).
- Construct a model of the groundwater flow system within the controlled area study zone (groundwater investigation, Section 8.3.1.3.4).

To accomplish the above objectives, the surface water investigation will obtain data for calculating flooding potential and recharge parameters. The approach used to calculate flooding potential is centered on the use of accepted U.S. Army Corps of Engineers' computer models (COE, 1981a, 1981b, 1982). Determination of this potential will be supported primarily by data from existing sources addressing (1) physical characteristics of the drainage, (2) meteorological data, (3) relief and ground cover, and (4) hydrologic characteristics of the drainage. The surface water investigation will also provide data that will be used to conduct a groundwater recharge analysis under the groundwater investigation. Most of the required data will come from existing sources addressing (1) potential evapotranspiration, (2) soils and ground cover, and (3) basin characteristics.

The groundwater investigation will obtain data needed to construct groundwater flow models for the Pasco Basin and Cold Creek syncline. The regional groundwater flow model is necessary for defining hydraulic boundaries of the hydrologic system in the controlled area study zone. To develop the regional model, the groundwater investigation will (1) collect data on groundwater flow, recharge, and discharge; (2) integrate the collected data with existing data using a geographic information system type of data base; (3) use the integrated data to develop a conceptual model of the regional groundwater flow system; and (4) use the conceptual model as the basis for a

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numerical model of the regional groundflow system. The numerical model will then be used to predict the effects of man-induced, climatic, and tectonic stress to the regional groundwater system.

The groundwater investigation will also obtain data needed to produce a conceptual model of the groundwater flow system within the controlled area study zone. To collect technically accurate data and to predict the effect of repository construction, data acquisition will be divided into three parts. Surface-based borehole tests conducted prior to the construction of the exploratory shaft will focus on baseline measurements of hydraulic parameters in and near the controlled area study zone. Surface-base borehole tests conducted after the construction of the exploratory shaft will provide additional information on the hydraulic characteristics of the site. Subsurface-based tests conducted after the construction of the exploratory shaft will provide information required to predict the effects of construction on the hydrologic system and will provide smaller scale measures of hydraulic parameters within the controlled area study zone. Information from the groundwater investigation will be used in numerical models employed to determine groundwater travel time and radionuclide release rates. This information will also be used to calculate water inflow to a repository and to design the engineered system (waste package and engineered barriers).

8.3.1.1.4.3 Geochemistry Program

Section 8.3.1.4 contains a discussion of the geochemistry program. This section addresses only the natural or undisturbed case portion of the program; Section 8.3.4 deals with the disturbed case involving the hydrothermal effects within the waste package/engineered barrier and surrounding rock zone ("thermal pulse") and radiation effects as well as geochemical interactions within the engineered barrier system. The primary objectives of the two Section 8.3.1.4 investigations and their three associated studies (see Fig. 8.3.1.1-1) are as follows:

- Characterize surface and groundwaters within the controlled area study zone, the Hanford Site, and the subregional basin (hydrochemical characterization investigation, Section 8.3.1.4.3)

- Characterize geochemical processes that retard or promote the transport of key radionuclides through flow tops, fractured zones, and flow interiors (radionuclide retardation investigation, Section 8.3.1.4.4).

To accomplish the above objectives, the hydrochemical characterization investigation will involve characterization of groundwater samples, secondary mineral phases, bulk rock, and mesostasis; laboratory tests of basalt/groundwater interactions; and geochemical modeling. Samples of water and rock will be obtained from surface and surface-based boreholes and from the exploratory shaft. The results of sample characterization will be used to design appropriate laboratory tests of basalt/groundwater interactions. The results of the characterization and interaction tests will then be used in geochemical models to predict flow paths and travel times in the natural system. The hydrochemical characterization investigation will also involve

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measurement of the ratios of certain redox pairs and the concentration of certain isotopes in the natural system. These measurements will be used to assess the groundwater redox environment and the redox status of the host rock.

The radionuclide retardation investigation will involve laboratory tests of the sorption properties of core samples, tests on naturally occurring radionuclides, and tracer tests. The laboratory tests will be used to quantify the steady-state distribution of key radionuclides between the basalt and groundwater. By determining the concentrations of radioactive daughters in the uranium and thorium decay chains, the test of naturally occurring radionuclides will support estimates of the in situ retardation capability of the host rock and flow top solids. The tracer tests will be used to help transfer the results of the laboratory tests to the scale of the repository setting. The radionuclide retardation investigation will be conducted simultaneously with the hydrochemical characterization investigation and depends on input from that investigation. The results of the radionuclide retardation investigation will be used to determine radionuclide retention characteristics of flow tops and flow interiors and will provide bounding estimates for radionuclide retardation and distribution. Thus, this investigation provides key input to an evaluation of the waste isolation capability of the site subsystem.

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8.3.1.1.4.4 Climatology Program

Section 8.3.1.5 contains a discussion of the climatology program and its three investigations. The primary objectives of these investigations and associated studies (see Fig. 8.3.1.1-1) are as follows:

- Develop past and modern climate baseline and augment paleohydrologic groundwater characterization (past climatic change investigation, Section 8.3.1.5.3).
- Develop climatic model and project climatic variability that would affect groundwater recharge into the future based on calibration and validation with past and modern climates (future climatic change investigation, Section 8.3.1.5.4).
- Define site meteorology and atmospheric dispersion characteristics (site meteorology investigation, Section 8.3.1.5.5).

To accomplish these objectives, the past climatic changes investigation will conduct analyses to produce direct evidence about the paleoclimatic characteristics of the geologic setting at various times during the Quaternary. Existing paleoclimatic information will be summarized and new data collected in several independent tasks conducted to define the standard climate; calculate pollen/climate transfer functions; acquire fossil pollen, lacustrine biotic, and lake-level fluctuation data; and determine paleowindflow patterns. All of this information will be synthesized into a consistent description of paleoclimatic changes. Because the most extreme changes are believed to be those accompanying major glaciation events, tasks will also be oriented toward reconstructing the Cordilleran ice sheet in the

late Quaternary, defining the dynamic behavior of that ice sheet during its growth and decay, including its effects on the tectonic regime, determining the direct and indirect disruptions of the surface-water system as a result of glaciation, and obtaining field evidence concerning the dynamics of glaciofluvial flooding. In addition, tasks will characterize the history of the northeast Pacific Ocean during the Quaternary and the variability of sea surface temperatures throughout the area at each of several time periods. The climatic reconstructions formulated using the above information will provide bases for validation of models of future climate.

The future climatic change investigation will use a regression approach to construct a local climate model. This model will describe the climate over the Columbia Plateau geohydrologic system. Boundary conditions for the local model will be provided by models of global ocean-atmosphere circulation and ice volume. Forecast values to be obtained will consist of the temperature, precipitation, evapotranspiration, and runoff. Such information will be used to specify bounding conditions on recharge to the regional groundwater system for use in sensitivity analyses; it will also be used to provide best estimates, if warranted, by the results of the sensitivity studies. In addition, a numerical computer model of glacier dynamics will be produced to represent the characteristics of glaciation in the region. The glaciation model will be used to directly forecast glacially related phenomena and provide input to another model that will consider the indirect effects of glaciofluvial flooding. Analyses will also be conducted to evaluate regional climatic changes in the context of global climatic changes over the next 100,000 yr. Such analyses will include the use of general circulation models of the atmosphere and fully coupled ocean-atmosphere general circulation models.

The results of the past and future climatic change investigations will be used to characterize the long-term variability of climate at the site and forecast the nature and impact of changes within the next 100,000 yr. As such, these investigations provide key input to an assessment of the effects of long-term climatic variability on the performance of a repository.

The meteorology investigation will obtain data on wind velocity, temperature, precipitation, solar radiation, atmospheric moisture, atmospheric pressure, atmospheric mixing, and severe weather. The investigation will use information from meteorological monitoring and analysis activities that have been conducted at the Hanford Site for over 40 yr. Additional tasks will be conducted to acquire and compare data specific to the controlled area study zone with the existing Hanford Site data base. Atmospheric transport and dispersion data will be collected in the vicinity of the controlled area study zone by deploying additional wind monitoring equipment and by conducting tracer tests. An expansion of the existing instrumentation network will be conducted to characterize the spatial variation of precipitation and atmospheric moisture in the Pasco Basin. An extreme meteorological event analysis will be conducted to determine the frequency of occurrence and intensity of some severe weather events.

The above data will be analyzed and modeled to provide information on meteorological averages and extremes for the design of facilities and the

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scheduling of operations. Such work will also be used to estimate the probability that a particular area would be impacted if there were a significant emission from the repository. In addition, information for this investigation will be used in site characterization studies that require meteorological data, in particular for hydrological investigations evaluating the potential for flash flooding and estimating groundwater recharge rates.

8.3.1.1.4.5 Resource Potential Program

Section 8.3.1.6 contains a discussion of the resource potential program and its two investigations. The primary objectives of these investigations and their associated studies (Fig. 8.3.1.1-1) are as follows:

- Identify the mineral, hydrocarbon, and geothermal resource potential of the Hanford Site (investigation of mineral, hydrocarbon, and geothermal resource potential, Section 8.3.1.6.3).
- Assess the impacts of potential water resource development on groundwater flow patterns (investigation of water resource potential, Section 8.3.1.6.4).

To accomplish the above objectives, the mineral, hydrocarbon, and geothermal resource potential investigation will obtain the following information: (1) available data and analyses concerning known occurrences and past and present production of each resource in the Columbia Plateau, (2) published economic evaluations of resources within the Columbia Plateau, and (3) available and newly acquired data to be used to define and measure geological conditions of each resource. The information for each resource will be used to evaluate the probability of the particular resource occurring within the controlled area study zone. Concentrations will be estimated for each resource and these estimates will be used to assess the present value of each resource within the controlled area study zone. The resource evaluation of the controlled area study zone will include a comparison of the resource occurrences to other analog areas within or beyond the Columbia Plateau that share a similar size and geological setting with the controlled area study zone. The results of these analyses will provide a basis for estimating the likelihood for postclosure human intrusion of the repository subsystem during possible future resource exploration and exploitation in the controlled area study zone that could result in an inadvertent loss of waste isolation.

The water resource potential investigation will include the following tasks: (1) identification of past, present, and potential water resource activities; (2) analysis of the sensitivity of the groundwater system to change in water resource activities; (3) analysis of sensitivity of the groundwater system to changes in water resource development scenarios (i.e., combined water resource activities); and (4) identification of any special sources of groundwater within 10 km (6.2 mi) of the proposed repository location. The results of these tasks will be used to assess how future activities involving water resources will alter regional groundwater flow and hydrologic boundary conditions of the controlled area study zone. Such changes could adversely impact the ability of the site subsystem to isolate waste.

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8.3.1.1.5 References

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*A decision on July 17, 1987, by the U.S. Court of Appeals for the First Circuit has required the EPA to reconsider its postclosure standards (Subpart B) in 40 CFR 191. Consequently, the standards in 40 CFR 191 may be subject to revision in the future.

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SITE CHARACTERIZATION PLAN

Chapter 8 - SITE CHARACTERIZATION PROGRAM

Section 8.3.1.2
Geology

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8.3.1.2 Geology

The geology program for the Basalt Waste Isolation Project (BWIP) entails the collection and analysis of data concerning geologic factors influencing radionuclide containment. Geologic factors can influence radionuclide containment by:

- Serving as potential geohydrologic pathways from the repository to the accessible environment.
- Establishing conditions that must be addressed by the design of the repository and engineered barriers.
- Producing changes in the geologic setting that could affect the ability of the repository to isolate the waste.

Section 8.3.1.2 of the Site Characterization Plan (SCP) describes the role of the geologic program for site characterization and plans for future geologic investigations and supporting studies.

Background

Geologic activities in support of the BWIP have been under way since the initiation of the BWIP in 1977. These activities have included the collection, analysis, and interpretation of geologic, geophysical, structural, and tectonic data for the Pacific Northwest, Columbia Plateau, and the Pasco Basin in which the Hanford Site and the controlled area study zone are located. In general, the regional activities have been reconnaissance in nature while studies within and nearby the Pasco Basin have focused on the collection and analysis of detailed data.

Initially, the geologic activities for the BWIP were oriented toward providing information that could be used to support a repository site identification study (Myers/Price et al., 1979; Myers and Price, 1981). The site identification study resulted in the selection, in 1981, of a preferred potential site or reference repository location from among 10 candidate sites on the Hanford Site (WCC, 1981). Subsequent BWIP geologic work provided information that was used to support a horizon identification study completed in 1984. This study resulted in the selection of a preferred candidate repository horizon, the Cohassett flow, in the Grande Ronde Basalt within the reference repository location (Long and WCC, 1984). Geologic activities since the selection of the Cohassett flow have focused on (1) the compilation and evaluation of existing data to support the Environmental Assessment (DOE, 1986) that formally recommended the reference repository location on the Hanford Site as one of three sites for characterization and (2) development of the Site Characterization Plan (SCP) of which this section is a part.

In addition to the geologic activities conducted directly by the BWIP, a considerable body of geologic, structural, geophysical, and tectonic data was collected and evaluated in support of commercial nuclear powerplant siting and licensing at the Hanford Site (WPPSS, 1977, 1981; NESCO, 1981; NRC, 1982a).

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More recently, hydrocarbon exploration in the western Columbia Plateau has resulted in the development of a geological and geophysical data base of the deeper geologic and structural environment.

A summary of the broad base of existing geologic data that describe the current knowledge of the sub-basalt, basalt, and suprabasalt sediment stratigraphy, structure, geophysics, seismology, and tectonic evolution of the Pasco Basin area and region is given in Chapter 1. The previous geologic activities of the BWIP and other organizations are not of sufficient scope for the specific needs of geologic characterization for a repository (as input to repository design or for the evaluation of repository performance). In addition, the current geologic data base contains a number of uncertainties with respect to the ability and confidence of predicting geologic conditions in the subsurface and predicting the future geologic and tectonic environment of the repository and region.

These inadequacies and areas of uncertainty have been noted where appropriate in Chapter 1. The areas of data uncertainties and the geologic informational needs identified by the performance and design issue resolution strategies (Section 8.2.2) have been used to develop the geologic program outlined in this SCP. This program will be conducted to reduce uncertainties so that characterization can provide a more complete picture of the present and anticipated future geologic conditions at the site and so that the required quantitative and qualitative data may be used in repository design and performance evaluations.

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Summary of program

The geology program includes the 3 investigations and 10 associated studies listed below. These investigations and studies were developed to address the geologic parameters identified by the design and performance issues listed in Table 8.3.1.2-1 and discussed in Section 8.2.2. The approach, rationale, and brief descriptions of the investigations and studies are the subjects of this section of the SCP. Detailed study plans for each study have been or will be issued separately.

- Stratigraphy and structure investigation.
  1. Stratigraphy study.
  2. Intraflow structure study.
  3. Cooling joint characteristics study.
  4. Structural geology study.
  5. Physical rock properties study.
  6. Stratigraphic and structural model study.
- Tectonic events and processes investigation.
  1. Deformation study.
  2. Earthquake seismology study.
  3. Tectonic assessment study.
- Mineralogy and petrology investigation.
  1. Mineralogy and petrology study.

Table 8.3.1.2-1. Correlation between issues and geology program

Specific site program (SCP Section)				Geology (8.3.1.2)									S
Investigation (s = same title as study)				Stratigraphy and structure						Tectonic events and processes			s
Issue		Study/information need		Strati-graphy	Intraflow structure	Cooling Joint Charac-teristics	Structural geology	Physical rock proper-ties	Strati-graphic and structural model	Defor-mation	Seis-mology	Tectonic assess-ment	Mineralogy and petrol-ogy charac-terization
Key issue	Post-closure Perfor-mance	1.1 Release to accessible environment		●	●	●	●	●	●	●	●	●	●
		1.2 Individual protection		●	●	●	●		●			●	●
		1.3 Groundwater protection		●	●	●	●	●	●			●	●
		1.4 Waste package containment											●
		1.5 Radionuclide release rates											●
		1.6 Groundwater travel time		●	●	●	●		●				
		1.7 Performance confirmation			●		●						
		1.8 NRC siting criteria[a]	FC	5, 7	7	7	7	2, 5, 7		1		1	4, 7
			PAC	2, 4, 17, 19, 18	20, 21	10, 20	20	20	21	11, 13, 16	4, 11, 12, 13, 14	3, 4, 13, 15	9
		1.9 DOE guideline findings[b]		A	A, C, K	A, C, K	A, C, G, K, M	C, K	A	C, E, G, K, M	G, M	E, G, J, M	A, B, F
		1.10 Waste package design											
		1.11 Repository design		●	●	●	●	●	●				
		1.12 Shaft and borehole seals		●	●	●			●		●		
	Preclo-sure radiol-ogical safety	2.1 Public safety during normal operation											
		2.2 Radiological safety of workers											
		2.3 Public safety during accidents			●	●	●				●		
		2.4 Waste retrieval		●	●	●					●		●
		2.5 DOE guideline findings[c]		●	●	●	●	●			●		●
		2.6 Waste package design											
		2.7 Repository design		●	●	●	●	●			●		
	Design	4.1 DOE guideline findings[d]		●	●	●	●	●	●		●		●
		4.2 Nonradiological worker safety		●	●	●	●	●			●		●
		4.3 Waste package production											
		4.4 Adequacy of technology for repository											
		4.5 Costs											

● Issue identifies geology program parameter(s).
[a]Number refers to favorable condition (FC) and potentially adverse condition (PAC) listed in Table 8.3.1.1-1.
[b]Letter refers to technical guideline listed in Table 8.3.1.1-2.
[c]Uses parameters from Issues 2.1, 2.2, 2.3, 2.4, and 2.7.
[d]Uses parameters from Issues 1.10, 1.11, 1.12, 2.7, 4.2, and 4.3.
DOE = U. S. Department of Energy.
NRC = U. S. Nuclear Regulatory Commission.
SCP = Site Characterization Plan.

PST87-2005-8.3.1.1-3

The stratigraphy and structure investigation entails six studies addressing design and performance issue parameters relating to the three-dimensional geometry of the site and surrounding area. It is this geometry that controls groundwater flow and establishes the rock configuration that must be considered by performance assessment and design. The six studies of the stratigraphy and structure investigation address one or more of the following five scales: (1) repository site, (2) controlled area study zone, (3) Cold Creek syncline, (4) Pasco Basin, and (5) the region.

The stratigrahy study of this investigation establishes a stratigraphic framework for the above five scales.

The stratigraphy study, the intraflow structure study, and the cooling joint characteristics study use subsurface data from boreholes, shafts, and geophysics and surface data from outcrops. These data are used in the stratigraphy study to determine the stratigraphic sequences and their extent. They are used in the intraflow structure study to establish the three-dimensional geometry of the internal characteristics of basalt flows at the site that results from the emplacement and cooling history of the flows. The focus of the intraflow structure study is on the arrangement and characteristics of the intraflow structures within the Cohassett flow and the flows of the repository isolation zone as they occur in the repository site and the controlled area study zone. The surface and subsurface data are used in the cooling joint characteristics study to address ubiquitous joints formed by the stress induced as lava cools.

The structural geology study locates and characterizes tectonic structures within the controlled area study zone, Pasco Basin, and the Columbia Plateau region. This study is designed to address secondary features (i.e., fractures, faults, folds). Because of sediment cover, boreholes will be relied on to provide "point sources" of information within the Cold Creek syncline, the controlled area study zone, and the repository site; geophysical surveys will be used to extrapolate between these boreholes. This information will be supplemented by geologic, geophysical, and remote sensing data from the Pasco Basin and region and by in situ geologic and geophysical data obtained from the exploratory shaft.

The physical rock properties study provides geophysical data from which physical properties of rocks within selected stratigraphic units will be derived. Measurements will be accomplished by borehole logging, cross-hole seismic surveys, and electromagnetic and acoustic surveys on the surfaces of excavated openings in the Exploratory Shaft Facility. These measurements will provide a basis for studies of a number of other parameters such as boundary locations, flow thicknesses, the extent and characteristics of the disturbed rock zone, and the presence and extent of permeable zones.

The stratigraphic and structural model study integrates information from the previous five studies to develop the geometric depictions and descriptions of the present geologic conditions of the repository site, controlled area study zone, Cold Creek syncline, Pasco Basin, and the region. These

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depictions and descriptions serve as the basis for repository design and for defining potential groundwater pathways from the repository to the accessible environment.

The tectonic events and processes investigation entails three studies addressing design and performance issue parameters relating to the tectonic, volcanic, and geomorphic stability of the site and surrounding area. This investigation includes work involving a projection of the nature and rates of future processes and events, their effect on repository design, and preclosure and postclosure performance. The tectonic events and processes investigation uses and builds on structural and stratigraphic data obtained from the stratigraphy and structure investigation. The deformation study determines the evolution of exiting geologic structures in south-central Washington and evaluates the potential for future deformation under the present stress field. This study uses data from geologic mapping of outcrops and trenches, boreholes, age determinations, geomorphic analyses, geodetic surveys, and in situ stress evaluations. The earthquake seismology study provides site-specific data on the magnitudes, spatial distribution, and rate of earthquake occurrences. This study also provides estimates of ground-motion attenuation and seismic source parameters. The study uses data from site and regional seismic monitoring networks. The data developed from this study are used in combination with data from other geologic, geophysical, and tectonic studies, to estimate the probability of future occurrence and the potential effects of earthquakes on the repository system. The tectonic assessment study develops tectonic models that satisfactorily explain the structural evolution of the crust in the Columbia Plateau and surrounding terrain over the last 15 m.y. The tectonic models serve as basis to estimate future tetonic processes and events over the preclosure and especially, postclosure periods and to develop disruptive event or process scenarios. Data to be evaluated will be gathered in other studies and will include geologic maps and cross sections at various scales, borehole geologic and geophysical data, exploratory shaft mapping and test data, ground and aerial remote-sensing data (data from exploration geophysical surveys and aerial photographic, radar, and other imagery), and seismological, trenching, and geodetic data.

The mineralogy and petrology investigation entails one study of the same name. This study addresses design and performance issue parameters relating to (1) characterization of rocks, minerals and mineral assemblages in the repository layout area, controlled area study zone, and Cold Creek syncline; (2) provision of illustrations of the inferred distribution of the rocks, minerals, and mineral assemblages; and (3) assessment of the chemical stability of individual phases and the geochemical environment under natural and repository conditions. The data to be obtained in the study are mineral abundances, petrographic features, compositions, ages, formation conditions (e.g., temperature, pressure, and composition), and spatial distributions of primary and secondary minerals in basalt, tectonic joints, faults, cooling joints, and interbeds. These data will be acquired from laboratory analyses of samples from outcrops, boreholes, and the Exploratory Shaft Facility. Information obtained from the mineralogy and petrology study will be used in hydrochemistry, near-field geochemistry, geologic characterization, and performance assessment. Waste package design must account for mineralogic

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properties in the near-field that are subject to change under repository operating conditions. In support of performance assessment, spatial distributions of mineralogic and petrologic properties are used as a basis for estimating coefficients along flowpaths.

8.3.1.2.1 Purpose and objectives

The primary purpose of the geologic program of investigations and associated studies that are presented in Section 8.3.1.2 is to develop and provide key information on the following:

- The three-dimensional geometry (structure) of the site and surrounding area (i.e., the present day rock configuration of the site).
- The tectonic, volcanic, and geomorphic stability of the site and surrounding area, including the past and potential future deformation and seismicity.
- The distribution and composition of mineralogic phases in basalts and sediments and the chemical stability of the individual phases and the total geochemical environment as reflected by the mineral assemblages (i.e., the site mineralogic makeup).

The hierarchy of the geologic program is illustrated in Figure 8.3.1.2-1. The geologic data obtained as a result of the geologic program will be collected and analyzed through the 10 studies previously identified under the three geologic investigations. The studies will use a number of investigative approaches and methodologies to examine both the Earth's surface and the subsurface geologic environment of the repository and nearby areas. Such approaches and methodologies may include surface geologic mapping, trench excavation and logging, remote sensing interpretation, geophysics (gravity, ground-level magnetics and aeromagnetics, seismology, electromagnetics, radar), exploratory boreholes, and laboratory analyses. The degree to which a particular approach or methodology is used in a given study will depend on the specific needs and objectives of the study and the anticipated success of the method. The approaches and methodologies for each of the ten planned studies are discussed below and in more detail in the study plans.

Because the repository will be placed at depth in a geologic environment, it is necessary to be able to adequately identify and understand the geologic and tectonic processes that are likely to affect the site over both the short-term preclosure period and the long-term postclosure period. The 3 investigations and the 10 studies of the geologic program have been developed to provide information that adequately describes the past and present geologic environment and allows for prediction of future events and processes with reasonable certainty. The framework of the investigations and the details of the studies are designed to address issues discussed in Section 8.2.2 that encompass (1) specific performance goals or parameters such as repository layout requirements and (2) the requirements of specific regulations such as

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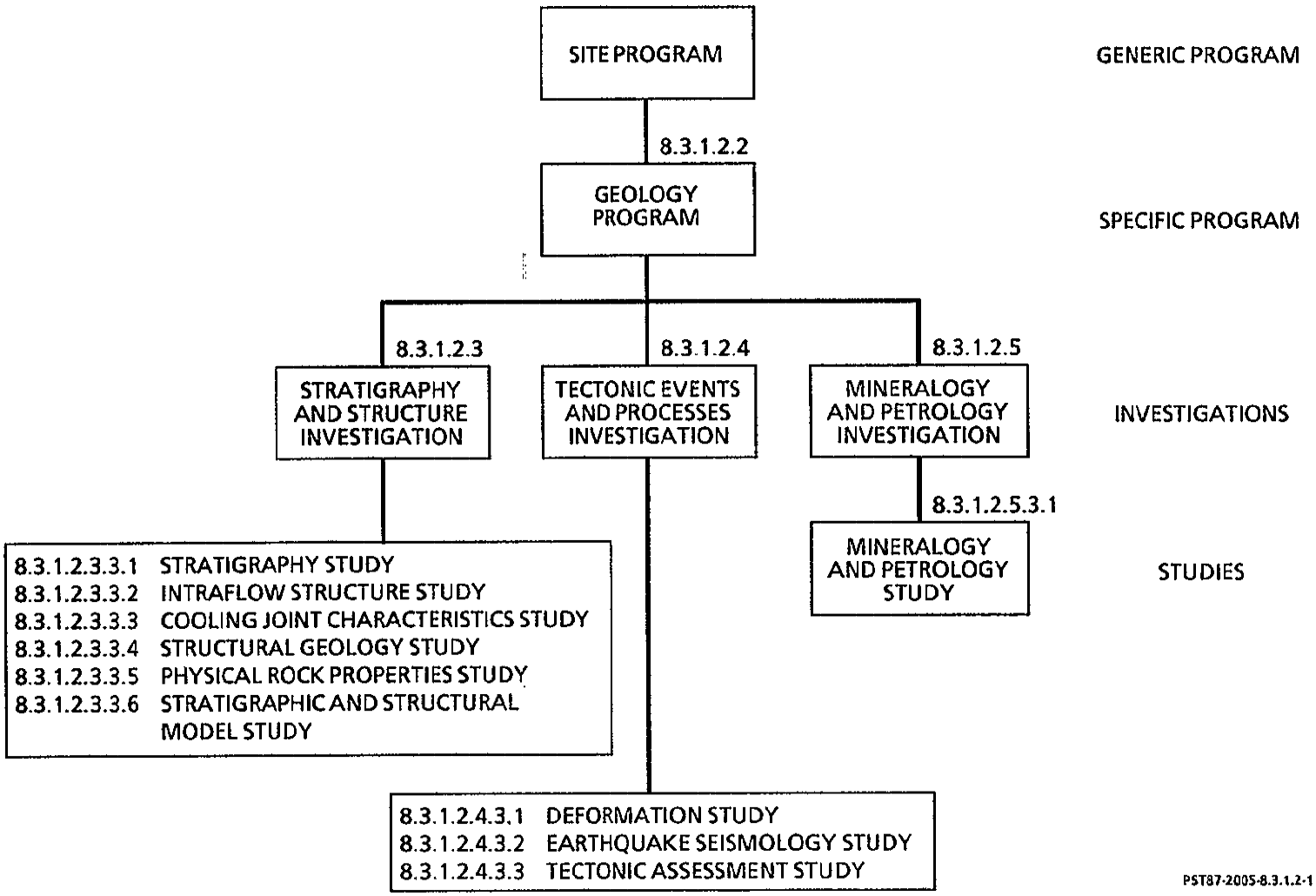

Figure 8.3.1.2-1. Hierarchy of the geology program.

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the siting guidelines of 10 CFR 960 (DOE, 1987), the site licensing requirements of 10 CFR 60 (NRC, 1987), and the release requirements of 40 CFR 191 (EPA, 1986). The relationship between the studies of the geologic program and the issues addressed by the studies is illustrated in Figure 8.3.1.2-2.

8.3.1.2.2 Rationale

As a means to address performance and design issue parameters defining the geology program, technical considerations have been used. These considerations evolved from the need to consider the specific geologic environment of the Hanford Site . As such, they were used to help define and organize the technical approach to be implemented by each of the geologic studies. The focus provided by the technical considerations aids in fulfilling the design and performance parameters and the resolution of the issues. The pertinent issues that were used to develop the geology program are discussed under the appropriate investigations while the specific technical considerations are discussed under the study descriptions.

8.3.1.2.3 Stratigraphy and structure investigation

The stratigraphy and structure investigation consists of six studies that provide the data needed to characterize the specific geologic environment of the Hanford Site. Issues addressed by the studies of this investigation are noted in Table 8.3.1.2-1.

8.3.1.2.3.1 Purpose and objectives

The purpose of the stratigraphy and structure investigation is to develop the three-dimensional geometry of the strata, faults, and folds within the site and surrounding area. Such information is required for resolution of issues relating to pathways for radionuclide migration. Therefore, adequate evaluation of the site performance depends on the adequacy and completeness of resulting three-dimensional stratigraphic and structural models. The models are also an input to design efforts (e.g., the design of repository shaft seals and the repository site). Such models provide the configuration of competent rock for repository construction and will be developed as engineering geology input to repository design. This investigation also provides fundamental data on structural geology to the tectonic events and processes investigation.

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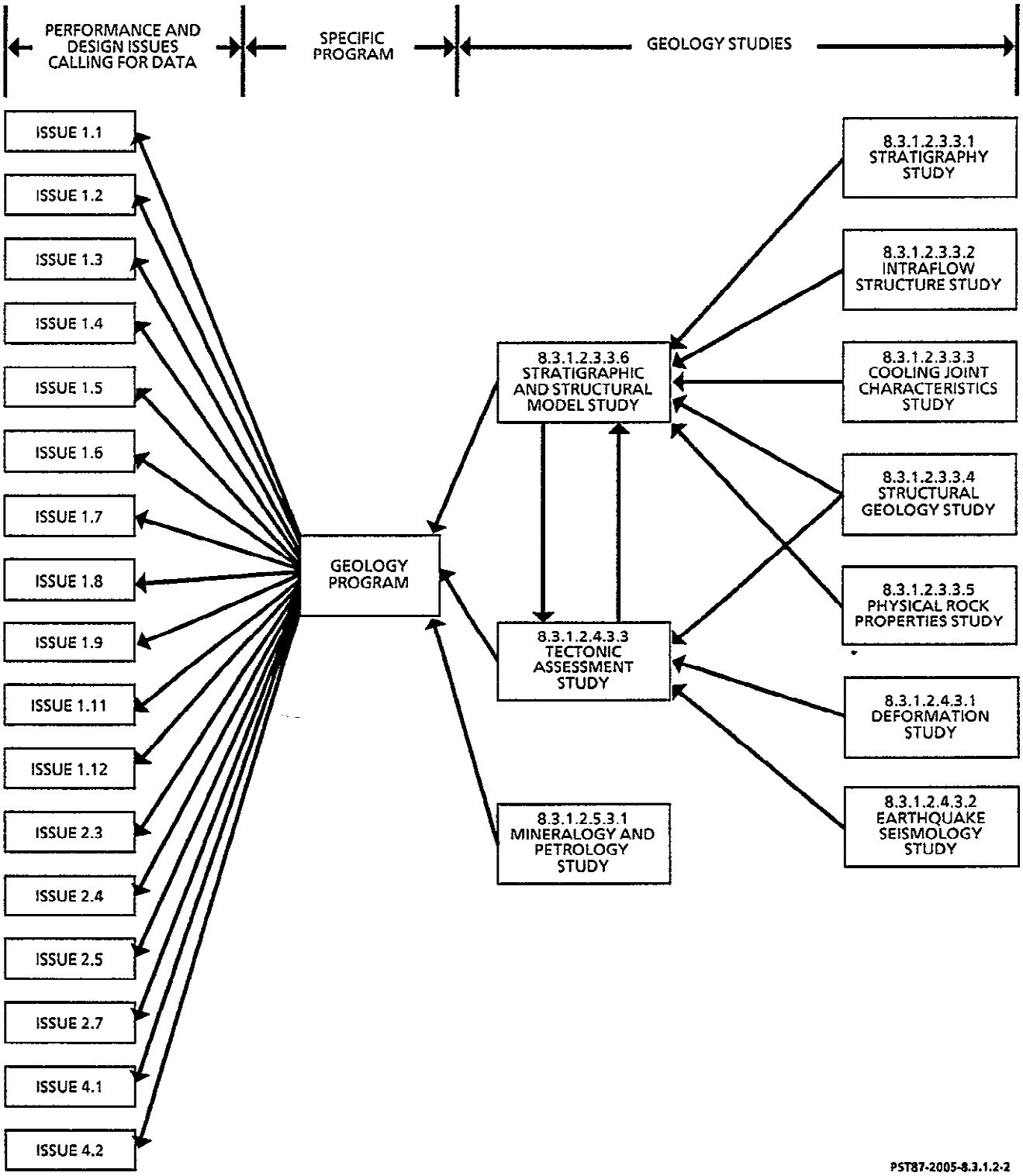

Figure 8.3.1.2-2. Framework of the geologic investigations.

Stratigraphic and structural models developed by this investigation will depict the following:

- Configuration, thickness, lateral variation, and internal characteristics of basalt and sedimentary layers.

- Location and dimensions of faults, tectonic joints, and folds at several scales ranging in size from the repository site to the Columbia Plateau. Graphic representations will include cross sections, block diagrams, structure contour maps, and isopach maps.

The information from this investigation will receive broad application throughout the BWIP in performance assessment, design, and other site characterization activities. The stratigraphic and structural models resulting from this investigation represent the specific arrangement of rocks at the site and, thus, must be considered for virtually all efforts relating to design and performance. Groundwater flow models will be developed by using the stratigraphic and structural models to define the geometry of nodes in the groundwater flow models.

Justification for obtaining the information required by this investigation is based on issues, performance measures, and parameters derived to address regulations. Tables 8.3.1.2-2 through 8.3.1.2-7 present the issue-identified parameters organized by the six studies within the stratigraphy and structure investigation.

The parameters developed in this investigation are both performance and supporting parameters. Performance parameters have evolved from the informational needs of the issues and address the general stratigraphic, geometric, lithologic, and structural characteristics of the geology of the site and region. Supporting parameters provide further specific geologic data that help in fulfilling the performance parameters that in turn are used in resolution of the issues. The relationship between the performance and supporting parameters is given in Tables 8.3.1.2-2 through 8.3.1.2-7 along with the associated issues. These tables also list the goals and accuracies required for the various parameters.

The characterization of potential pathways for groundwater or radionuclides is a primary output of this investigation. Travel paths are identified in regulations in the context of travel-time criteria for groundwater or radionuclides between the disturbed zone and the accessible environment. The basis for such calculations is a geohydrologic model that relies on structural and stratigraphic models to define the geometries of stratigraphic layers, intraflow structures, faults, and tectonic joints. Stratigraphic and structural models provide characterization of the internal structure of flows and the attributes of faults used in assessing the hydrologic properties of these features.

The stratigraphy and structure investigation provides key input to address performance measures and parameters associated mainly with the following issues.

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Issue		Specific site program (SCP Section)	Geology (8.3.1.2)										Hydrology (8.3.1.3)				Geochemistry (8.3.1.4)			Climatology (8.3.1.5)			Resource Potential (8.3.1.6)	
		Investigation (s = same title as study)	Stratigraphy and structure						Tectonic events and processes			s	Surface water		Groundwater		Hydrochemical characterization		Radionuclide retardation	s	s	s	s	s
		Study/information need	Stratigraphy	Intrafloow structure	Cooling joint characteristics	Structural geology	Physical rock properties	Stratigraphic and structural model	Deformation	Earthquake seismology	Tectonic assessment	Mineralogy and petrology	Surface water	Site flooding	Regional groundwater	Site groundwater	Groundwater hydrochemistry	Groundwater redox	Radionuclide reactivity	Past climatic change	Future climatic change	Site meteorology	Mineral, hydrocarbon, geothermal	Water resource
Key issue	Post-closure Performance	1.1 Release to accessible environment	●	●	●	●	●	●	●	●	●	●				●	●	●	●				●	●
		1.2 Individual protection	●	●	●	●		●			●	●				●								
		1.3 Groundwater protection	●	●	●	●	●	●			●	●				●								
		1.4 Waste package containment										●					●	●						●
		1.5 Radionuclide release rates										●				●	●	●						
		1.6 Groundwater travel time	●	●	●	●		●							●	●	●							
		1.7 Performance confirmation																						
		1.8 NRC siting criteria* FC	5, 7	7	7	7	2, 5, 7		1		1	4, 7			1, 7	2, 7	3, 7	3	3	1	1			
		1.8 NRC siting criteria* PAC	2, 4, 10, 17, 18, 20	20, 21	10, 20	20	20	21	11, 13, 16	4, 11, 12, 13, 14	3, 4, 13, 15	9	3	1	4, 5	5	7, 20, 24	7, 9	7, 8		6		2, 17, 18	2
		1.9 DOE guideline findings**	A	A, C, K	A, C, K	A, C, G, K, M	C, K	A	C, E, G, K, M	G, M	E, G, I, M	A, B, I	I, L	L	A, L	A, L	A, B	A, B	A, B	D, E	D, E	I	15	11
		1.10 Waste package design																						
		1.11 Repository design	●	●	●	●	●	●								●	●	●	●					
		1.12 Shaft and borehole seals	●	●	●			●		●									●					
	Pre-closure radiological safety	2.1 Public safety during normal operation														●	●	●	●					
		2.2 Radiological safety of workers																				●		
		2.3 Public safety during accidents		●	●	●				●				●		●						●		
		2.4 Waste retrieval	●	●	●					●		●				●	●					●		
		2.5 DOE guideline findings[a]	●	●	●	●	●			●		●		●		●	●							
		2.6 Waste package design																				●		
		2.7 Repository design	●	●	●	●	●			●				●		●	●							
	Design	4.1 DOE guideline findings[b]	●	●	●	●	●	●		●		●	●	●		●	●	●						
		4.2 Nonradiological worker safety	●	●	●	●	●			●		●	●	●		●	●	●						
		4.3 Waste package production																						
		4.4 Adequacy of technology for repository																						
		4.5 Costs																						

● Issue identifies site program parameter(s).
* Number refers to favorable condition (FC) and potentially adverse condition (PAC) listed in Table 8.3.1.1-1
** Letter refers to technical guideline listed in Table 8.3.1.1-2
DOE = U.S. Department of Energy
NRC = U.S. Nuclear Regulatory Commission
SCP = Site Characterization Plan.
[a] Uses parameters from issues 2.1, 2.2, 2.3, 2.4, and 2.7
[b] Uses parameters from issues 1.10, 1.11, 1.12, 2.7, 4.2, and 4.3.

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Table 8.3.1.1-3. Correlation between issues and specific site programs

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Table 8.3.1.2-2. Parameters addressed by the stratigraphy study (sheet 1 of 3)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Three-dimensional subsurface geometry (Umtanum flow to upper Wanapum basalt)	1.1, 1.2, 1.3, 1.12	RIZ/CASZ	From stratigraphic and structural model study				
	1.1, 1.2, 1.3, 1.6, 1.8 (PAC 2,4, 17, 18), 1.11, 1.12	CASZ/Cold Creek syncline/ Pasco Basin/Region	Stratigraphic correlations	Positive identification of all units	High	Positive identification of stratigraphic unit	Medium to high
	1.1, 1.2, 1.3, 1.6, 1.8 (PAC 4, 17, 18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin/Region	Basalt chemical composition	Chemical composition	High	NA	High
	1.1, 1.2, 1.3, 1.6, 1.8 (PAC 4,1 7 ,18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin/Region	Paleomagnetic signature	Paleomagnetic pole position	High	NA	High
	1.1, 1.2, 1.3, 1.6, 1.8 (PAC 4, 17, 18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin/Region	Borehole geophysical logs	Log signature	High	NA	High
	1.1, 1.2, 1.3, 1.6, 1.8 (PAC 4,1 7, 18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin/Region	Borehole descriptive logs	Physical description of units and contacts	High	NA	High
	1.1, 1.6, 1.8 (PAC 4, 17, 18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin	Sediment petrography	Establish sediment mineralogy	High	NA	High
	1.1, 1.6, 1.8 (PAC 4,17, 18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin	Sediment porosity	TBD	TBD	TBD	Low
	1.1, 1.6, 1.8 (PAC 4,17, 18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin	Sediment permeability	TBD	TBD	TBD	Low
	1.1, 1.6, 1.8 (PAC 4,17, 18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin	Ash characteristics	Physical characteristics	Medium	NA	Medium
	1.1, 1.6, 1.8 (PAC 4, 17, 18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin	Paleosol characteristics	Physical characteristics	Medium	NA	Medium

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Table 8.3.1.2-2. Parameters addressed by the stratigraphy study (sheet 2 of 3)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Three-dimensional subsurface geometry (Umtanum flow to upper Wanapum basalt) (cont.)	1.1, 1.2, 1.3, 1.6, 1.8 (PAC 4, 17, 18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin	Lithologic age dating	Age of unit	Medium	NA	Medium
	1.1, 1.2, 1.3 1.6, 1.8 (PAC 17, 18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin/ Region	Thickness of stratigraphic units	Define thickness variations to ±5 m	High	±7 m in (23 ft) central CASZ	Medium to high
	1.1, 1.2, 1.3, 1.6, 1.8 (PAC 2,17, 18), 1.11, 1.12	CASZ/Cold Creek syncline/Pasco Basin/ Region	Distribution of stratigraphic units	Define spatial distribution	High	Well known in the central CASZ	Medium to high
	1.1, 1.2, 1.3, 1.6, 1.8 (FC 5), 2.7, 4.2, 1.12, 1.11	CASZ/Cold Creek syncline/Pasco Basin/ Region	Position of stratigraphic units	Define depth of stratigraphic units	High	Depths known well in central CASZ	Medium to high
Stratigraphic sequence	1.6, 2.4	RIZ/CASZ/Cold Creek syncline/Pasco Basin	Stratigraphic sequence in boreholes and shafts	Positive identification of all units	High	Positive identification of all stratigraphic units	Medium to high
Data base of boreholes that could act as conduits for accelerated groundwater flow	1.8 (PAC 19), 1.12	CASZ	Borehole location	Coordinates ±1 m (3.2 ft)	High	Coordinates ±1 m (3.2 ft)	High
	1.8 (PAC 19), 1.12	CASZ	Borehole identifier	Name	High	All boreholes within CASZ are identified	High
	1.8 (PAC 19), 1.12	CASZ	Borehole diameter	±3 cm (1.18 in)	High	±3 cm (1.18 in)	High
	1.8 (PAC 19), 1.12	CASZ	Borehole total depth	±1 m (3.2 ft)	High	± m (3.2 ft)	High
	1.8 (PAC 19), 1.12	CASZ	Borehole orientation	±1 degree in central CASZ	Medium to high	To be determined	Medium
	1.1, 1.8 (PAC 4, 17, 18, 19), 1.12, 4.2	RS/CASZ/Cold Creek syncline/Pasco Basin	Stratigraphic sequence in boreholes and shafts	Positive identification of all units	High	Positive identification of stratigraphic units	Medium to high

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Table 8.3.1.2-2. Parameters addressed by the stratigraphy study (sheet 3 of 3)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Vantage interbed thickness	1.12	CASZ	Contained in thickness of stratigraphic units (above)				

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Definitions:

CASZ = Controlled area study zone, the sum of all likely controlled areas, approximately a lateral area that extends no more than 5 km in any direction from the outer boundary of the proposed repository site.
FC = Favorable condition.
NA = Not applicable.
PIZ = Primary isolation zone, the stratigraphic section of basalt flows in the Pasco Basin extending from the top of the Vantage interbed to the base of the Umtanum flow (upper Grande Ronde basalt).
RIZ = Repository isolation zone, the stratigraphic section of basalt flows in the Pasco Basin extending from the top of the Priest Rapids member to the N_2-R_2 paleomagnetic contact (Wanapum Basalt, PIZ, and several Grande Ronde flows below the PIZ).
RS = Repository site, the lateral area in the subsurface that would be occupied by the repository including surrounding buffers.
TBD = To be determined.

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Table 8.3.1.2-3. Parameters addressed by the intraflow structure study (sheet 1 of 4)

Performance parameter	Issue*	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Cohassett flow interior depth	1.1, 1.2, 1.3	Host rock/CASZ	Position of intraflow structures in boreholes	>800 m (2,625 ft) from ground surface	High	>800 m (2,6245ft)	Medium to high
Cohassett flow interior thickness	1.1, 1.2, 1.3	Host rock/CASZ	Thickness of intraflow structures in boreholes	Determine if >50 m (164 ft) or actual value	High	≥43 m (141 ft)	Medium to high
Flow interior thickness	1.1, 1.2, 1.3	Umtanum flow to top of the Wanapum Basalt/CASZ	Thickness of intraflow structures	Determine to ± 10 m (33 ft)	Medium	± 7-10 m (23 - 33 ft)	Medium
Flow top thickness	1.1, 1.2, 1.3	Umtanum flow to top of the Wanapum Basalt/CASZ	Thickness of intraflow structures	Determine to ± 10 m (33 ft)	Medium	± 7-10 m (23-33 ft)	Medium
Distribution of intraflow structures	1.1, 1.2, 1.3	Umtanum flow to top of the Wanapum Basalt/CASZ	Position of intraflow structures	Determine to ± 7 m (23 ft)	High	± 7-10 m (23 - 33 ft)	Medium
			Thickness of intraflow structures	Determine to ± 7 m (23 ft)	High	± 7-10 m (23 - 33 ft)	Medium
			Lateral continuity of intraflow structures	Define spatial distribution	High	Limited ability to define	Low to medium
			Occurrence of anomalous intraflow structures	Estimate frequency of occurrence	High	Can estimate some features via probability encoding	Low
Intraflow structure geometry	1.11.1a&b 1.11.2c 1.11.3a 1.11.5 1.6,1.8	Host rock/repository site	Position of intraflow structures	Determine to ± 5 m (16 ft)	High	± 7-10 m (23 - 33 ft)	Medium
		PIZ/CASZ	Thickness of intraflow structures	Determine to ± 5 m (16 ft)	High	± 7-10 m (23 - 33 ft)	Medium
			Lateral continuity of intraflow structures	Define spatial distribution	Medium to high	Limited ability to define spatial distribution	Low to medium

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Table 8.3.1.2-3. Parameters addressed by the intraflow structure study (sheet 2 of 4)

Performance parameter	Issue*	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Intraflow structure lithology	1.11.1b,1.6,1.8 1.6,1.8	Host rock/repository site PIZ/CASZ, RIZ/Cold Creek syncline, all flows/Pasco Basin	Lithologic characteristics of intraflow structures	Describe qualitatively/ quantitatively as applicable	High	Description based on current data	Medium to high
Detected anomalous intraflow structures	1.11.1c 1.11.2a (implicit in 1.6)	Host rock/repository site	Occurrence of anomalous intraflow structures	Identify location to within ± 5 m (16 ft)	Medium to high	Only known as detected in bore-holes and outcrop	Low
Intraflow structure geometry	1.6,1.8	RIZ/CASZ, all flows/ Pasco Basin	Position of intraflow structures	Determine to ± 7 m (23 ft)	Medium	± 10 m	Medium
			Thickness of intraflow structures	Determine to ± 7 m (23 ft)	Medium	± 10-15 m	Medium
			Lateral continuity of intraflow structures	Define spatial continuity	Medium	Limited ability to define	Low to medium
		RIZ/CASZ, RIZ/Cold Creek syncline all flows/Pasco Basin	Occurrence of anomalous intraflow structures	Estimate frequency of occurrence	Medium	Can estimate some features via prob-ability encoding	Low
Cohassett flow interior thickness	1.12	Host rock/CASZ	Thickness of intraflow structures in boreholes	Determine to within ± 10% precision ± 0.5 m (1.6 ft)	High	Known to ± 1-2 m precision ± 1 m	High
Cohassett flow top thickness	1.12	Host rock/CASZ	Thickness of intraflow structures in boreholes	Determine to within ± 10% precision ± 0.5 m (1.6 ft)	High	Known to ± 1-2 m (3.2-6.5 ft) precision ± 1 m (3.2 ft)	High
Cohassett flow bottom thickness	1.12	Host rock/CASZ	Thickness of intraflow structures in boreholes	Determine to within ± 10% precision ± 0.5 m (1.6 ft)	High	Known to ± 1-2 m (3.2-6.5 ft) precision ± 1 m (3.2 ft)	High
Flow interior thickness	1.12	PIZ/CASZ	Thickness of intraflow structures in boreholes	Determine to within ± 10% precision ± 0.5 m (1.6 ft)	High	Known to ± 1-2 m (3.2-6.5 ft) precision ± 1 m (3.2 ft)	High

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Table 8.3.1.2-3. Parameters addressed by the intraflow structure study (sheet 3 of 4)

Performance parameter	Issue*	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Flow top thickness	1.12	PIZ/CASZ	Thickness of intraflow structures in boreholes	Determine to within ± 10% precision ± 0.5 m (1.6 ft)	High	Known to ± 1-2 m (3.2-6.5 ft) precision ± 1 m (3.2 ft)	High
Flow bottom thickness	1.2	PIZ/CASZ	Thickness of intraflow structures in boreholes	Determine to within ± 10% precision ± 0.5 m (1.6 ft)	High	Known to ± 1-2 m (3.2-6.5 ft) precision ± 1 m (3.2 ft)	High
(Not identified)	1.12	PIZ/CASZ	Position of intraflow structures in boreholes	Determine to ± 10%	High	Known to 1-2 m (3.2-6.5 ft)	High
(Not identified)	1.12	PIZ/CASZ	Detected occurrence of anomalous intraflow structures in boreholes	Determine to ± 10%	High	Known to ± 1-3 m (3.2-9.8 ft)	Medium to high
(Not identified)	1.12	PIZ/CASZ	Lithologic characteristics of intraflow structures in boreholes	Describe qualitatively/ quantitatively as applicable	High	Description based on current data	Medium to high
Intraflow structure characteristics	2.3	RIZ/Exploratory Shaft Facility	Position of intraflow structures	Determine to ± 5 m (16 ft)	High	± 7 m (22.9 ft)	Medium
			Thickness of intraflow structures	Determine to ± 5 m (16 ft)	High	± 7 m (22.9 ft)	Medium
			Occurrence of anomalous intraflow structures	Identify location to ± 5 m (16 ft)	High	Only known as detected in borehole and outcrop	Medium
			Lithologic characteristics of intraflow structures	Describe sufficiently to estimate water/ methane inflows	High	Descriptions based on current data are mostly adequate	Medium to high

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Table 8.3.1.2-3. Parameters addressed by the intraflow structure study (sheet 4 of 4)

Performance parameter	Issue*	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Primary geologic features (control of water and gas)	1.7, 2.7, 4.2	Host rock/repository site, RIZ/exploratory shaft	Position of intraflow structures	Locatable to within ± 10% of interval between drift and feature	High	TBD	TBD
Intraflow structure characteristics	2.4		Thickness of intraflow structures	± 5 m (16 ft)	High	± 7 m (22.9 ft)	Medium
			Lateral continuity of intraflow structures	Define spatial distribution	High	Limited ability to define	Low to medium
			Occurrence of anomalous intraflow structures	Locatable to within ± 10% of interval between drift and feature	High	TBD	TBD
			Lithologic characteristics of intraflow structures	Determine characteristics that would contribute to water and gas storage and conductivity and affect stability	High	Characteristics of typical features known with moderate confidence	Medium

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Definitions:

CASZ = Controlled area study zone, the sum of all likely controlled areas, approximately a lateral area that extends no more than 5 km in any direction from the outer boundary of the proposed repository site.

PIZ = Primary isolation zone, the stratigraphic section of basalt flows in the Pasco Basin extending from the top of the Vantage interbed to the base of the Umtanum flow (upper Grande Ronde Basalt).

RIZ = Repository isolation zone, the stratigraphic section of basalt flows in the Pasco Basin extending from the top of the Priest Rapids member to the N_2-R_2 paleomagnetic contact (Wanapum Basalt, PIZ, and several Grande Ronde Basalt flows below the PIZ).

RS = Repository site, the lateral area in the subsurface that would be occupied by the repository including surrounding buffers.

TBD = To be determined.

*For all 1.8 issues on this table, the potentially adverse conditions (PAC) supported are 2, 3, 4, 5, 6, 11, 14, 16, 17, 18, 19, 20, and 21. Most of these are indirectly supported by intraflow structure input to develop a hydrologic model to in turn support the PAC.

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Table 8.3.1.2-4. Parameters addressed by the cooling joint characteristics study (sheet 1 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Cooling joint characteristics	1.1, 1.11, 1.12	RIZ/Pasco Basin Cohassett flow/ repository site	Cooling joint persistence	Estimate/determine range and average	High	0.03 through 10's of meters (little quantitative data available)	Low
		RIZ/Pasco Basin RIZ/CASZ Cohassett flow/ repository site	Cooling joint frequency	Determine range and average frequency of cooling joints	High	Range of sample averages: 14-38 fractures per meter	Medium
		RIZ/Pasco Basin RIZ/CASZ Cohassett flow/ repository site	Cooling joint orientation (strike and dip)	Determine range distribution of cooling joint orientation	High	Limited ability to define spatial distribution	Low to medium
		RIZ/Pasco Basin Cohassett flow/ repository site	Cooling joint width	Determine range and average width of cooling joints	High	0.23 ±0.489 mm	Medium
		RIZ/Pasco Basin RIZ/CASZ Cohassett flow/ repository site	Cooling joint roughness	Estimate roughness of colonnade and entablature cooling joints	High	Smooth-planar to rough undulating	Low to medium
		RIZ/Pasco Basin	Cooling joint termination type	Determine termination type	TBD	Majority of cooling joints terminate on other joints	Low
		RIZ/CASZ Cohassett flow/ repository site	Volume percent infilling of cooling joints	Estimate volume percent of joint possible for ground-water flow	High	~99.4% completely filled ~0.6% partially open	Medium
		RIZ/CASZ Cohassett flow/ repository site	Cooling joint infilling composition	Determine secondary mineral types	High	Clay, zeolite, silica	Medium
	1.1, 1.2, 1.3, 1.11, 1.12	RIZ/CASZ Cohassett flow/ repository site	Cooling joint wall rock alteration	Estimate range and average width of cooling joint alteration	High	Majority of joints show little or no alteration	Low to medium

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Table 8.3.1.2-4. Parameters addressed by the cooling joint characteristics study (sheet 2 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Cooling joint characteristics (cont.)	1.1, 1.2, 1.3, 1.11, 1.12 (cont.)	RIZ/Pasco Basin RIZ/CASZ Cohassett flow/ repository site	Cooling joint void geometry and interconnection	Determine shape and degree of inter-connection of voids	TBD	No data collected	Low
		Cohassett flow/ repository site	Ratio of intact cooling joints to total number of cooling joints (needed for damaged rock zone calculation)	Determine ratio of cooling joints to total number of cooling joints	TBD	Range of sample averages: 0.18-0.50	Low
Cooling joint geometry	1.6, 1.8	RIZ/Pasco Basin Cohassett flow/ repository site	Cooling joint persistence	Estimate/determine range and average	High	0.03 through 10's of meters (little quantitative data available)	Low
		RIZ/Pasco Basin RIZ/CASZ Cohassett flow/ repository site	Cooling joint frequency	Determine range and average frequency of cooling joints for design	High	Range of sample averages: 14-38 fractures per meter	Medium
		RIZ/Pasco Basin RIZ/CASZ Cohassett flow/ repository site	Cooling joint orienta-tion (strike and dip)	Determine range distribution of cooling joint orientation	High	Limited ability to define spatial distribution	Low to medium
		RIZ/Pasco Basin Cohassett flow/ repository site	Cooling joint width	Determine range and average width of cooling joints	High	0.23 ± 0.489 mm	Medium
		RIZ/Pasco Basin RIZ/CASZ Cohassett flow/ repository site	Cooling joint roughness	Estimate roughness of colonnade and entablature cooling joints	High	Smooth-planar to rough-undulating	Low to medium
		RIZ/Pasco Basin	Cooling joint termination type	Determine termination type	TBD	Majority of cooling joints terminate on other joints	Low

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Table 8.3.1.2-4. Parameters addressed by the cooling joint characteristics study (sheet 3 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Cooling joint persistence	2.4, 2.7, 4.2	RIZ/Pasco Basin Cohassett flow/ repository site		Estimate/determine range and average	High	0.03 through 10's of meters (little quantitative data available)	Low
Cooling joint frequency	2.4, 2.7, 4.2	RIZ/Pasco Basin RIZ/CASZ Cohassett flow/ repository site		Determine range and average frequency of cooling joints	High	Range of sample averages: 14-38 fractures per meter	Medium
Cooling joint orientation (strike and dip)	2.4, 2.7, 4.2	RIZ/Pasco Basin RIZ/CASZ Cohassett flow/ repository flow		Determine range and distribution of cooling joint orientation	High	Limited ability to define spatial distribution	Low to medium
Cooling joint width	2.4, 2.7	RIZ/Pasco Basin Cohassett flow/ repository site		Determine range and average width of cooling joints	High	0.23 ±0.489 mm	Medium
Cooling joint roughness	4.2	RIZ/Pasco Basin RIZ/CASZ Cohassett flow/ repository site		Estimate roughness of colonnade and entablature cooling joints	High	Smooth-planar to rough-undulating	Low to medium
Cooling joint void geometry and interconnection	2.3	RIZ/Pasco Basin RIZ/CASZ Cohassett flow/ repository site	Cooling joint void geometry and interconnection	Determine range of void shapes and their degree of interconnection	TBD	No data collected	Low
Volume percent infilling of cooling joints	1.8, 2.3, 2.4, 2.7, 4.2	RIZ/CASZ Cohassett flow/ repository site		Estimate volume percent of joint possible for groundwater flow	High	~99.4% completely filled ~0.6% partially open	Medium
Cooling joint infilling composition	1.8, 2.3, 2.4, 2.7, 4.2	RIZ/CASZ Cohassett flow/ repository site		Determine secondary mineral types	High	Clay, zeolite, silica	Medium

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Table 8.3.1.2-4. Parameters addressed by the cooling joint characteristics study (sheet 4 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Cooling joint wall rock alteration	1.8, 2.7, 4.2	RIZ/CASZ Cohassett flow/ repository site		Estimate range and average width of cooling joint alteration	High	Majority of joints show little or no alteration	Low to medium
Ratio of intact cooling joints to total number of cooling joints counted (needed for damaged rock zone calculation)	1.11, 2.4, 2.7, 4.2	Cohassett flow/ repository site		Determine ratio of cooling joints to total number of cooling joints in core	TBD	Range of sample averages: 0.18-0.50	Low

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Definitions:

CASZ = Controlled area study zone, the sum of all likely controlled areas, approximately a lateral area that extends no more than 5 km in any direction from the outer boundary of the proposed repository site.

RIZ = Repository isolation zone, the stratigraphic section of basalt flows in the Pasco Basin extending from the top of the Priest Rapids member to the N_2-R_2 paleomagnetic contact (Wanapum Basalt, primary isolation zone, and several Grande Ronde Basalt flows below the primary isolation zone).

TBD = To be determined.

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Table 8.3.1.2-5. Parameters addressed by the structural geology study (sheet 1 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Hydraulic gradient across the controlled area study zone	1.1, 1.2, 1.3, 1.6, 1.8	CASZ, Pasco Basin		$\leq 1 \times 10^{-3}$	High	1×10^{-5} to 1×10^{-3}	Low
	1.1, 1.2, 1.3, 1.6, 1.8, 1.11.1		Distribution of stratigraphic units within controlled area study zone (Umtanum flow to upper Wanapum Basalt)	Characterize each unit	High	NA	Medium
	1.1, 1 2, 1.3, 1.6, 1.8, 1.11.1	CASZ, Pasco Basin	Structural contours of hydrologic boundaries	± 200 m	High	NA	Low
	1 1, 1.2, 1 3, 1.6, 1.8, 1.11.1, 2.3	CASZ	Fault zone geometry	± 100 m	Medium	NA	Low
	1.1, 1.2, 1.3, 1.6, 1.8	CASZ	Fault zone thickness	± 1 m	Medium	NA	Low
	1.1, 1.2, 1.3, 1.6, 1.8	CASZ	Tectonic fracture geometry	Description of geometry	Medium	NA	Low
	1.1, 1.2, 1.3, 1.6, 1.8	CASZ	Spacial variability and continuity of structures	Structural geometry of each limit	Medium	NA	Low
	1.1, 1.2, 1.3, 1.6, 1.8	CASZ	Three-dimensional subsurface geometry (Umtanum flow to upper Wanapum Basalt)	Spatial relationships of units and structural features	Medium	NA	Low
	1.8	CASZ	Fault zone physical properties	Description of physical properties	Medium to high	NA	Low
Fault zone physical properties	1.7	ESF		Description of physical properties	High	NA	Low
Curvature of Cohassett flow	1.7	ESF		± 2°	High	± 2°	Low
Dip of Cohassett flow	1.7	ESF		± 2°	High	± 2°	Low
	1.6, 1.8	Pasco Basin	Structural configuration	± 200 m	Medium	NA	Low

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Table 8.3.1.2-5. Parameters addressed by the structural geology study (sheet 2 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Probability of occurrence of faulting within underground facility	1.1, 1.2, 1.3, 1.8	Underground facility		<1%	High	NA	Low
Probability of occurrence of faulting within a controlled area	1.1, 1.2, 1.3, 1.8	CASZ		<1%	High	0 to 1%	Low
Probability of occurrence of faulting within region	1.1, 1.2, 1.3, 1.8	Region		<1%	High	0 to 1%	Low
Probability of occurrence of faulting within region			Fault location[a]				
	1.8	Region		1:62,500	Medium	NA	Low
	1.6, 1.8	Pasco Basin		1:24,000	High	NA	Medium
	1.1, 1.2, 1.3, 1.6, 1.8	CASZ			High	NA	Low
	1.1, 1.2, 1.3, 1.6, 1.8, 2.3	Layout area			High	NA	Low
	1.7, 1.11, 2.7, 4.2	ESF			High	NA	Low
Probability of occurrence of faulting within region			Fault orientation				
	1.8	Region		Strike and dip	Medium	NA	Low
	1.6, 1.8	Pasco Basin		Strike and dip	Medium to high	NA	Low
	1.1, 1.2, 1.3, 1.6, 1.8	CASZ		Strike and dip	High	NA	Low
	1.1, 1.2, 1.3, 1.6, 1.7, 1.8, 2.7.17, 4.2	Layout area		Strike and dip	High	NA	Low
	1.7	ESF		Strike and dip	High	NA	Low

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Table 8.3.1.2-5. Parameters addressed by the structural geology study (sheet 3 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Probability of occurrence of faulting within region			Quarternary offset[b]				
		Region		7 ≈ 1 m	Medium		Low
		Pasco Basin		7 ≈ 50 cm	High		Low
		CASZ		7 ≈ 10 cm	High		Low
	1.8, 4.2	Layout area		7 ≈ 10 cm	High		Low
Probability of occurrence of faulting within region			Prequarternary offset[b]				
		Region		TBD	Medium		Medium to low
		Pasco Basin		TBD	High		Medium
		CASZ		TBD	High		Low
	1.8, 4.2	Layout area		TBD			
Probability of occurrence of faulting within region			Fault strike-slip				
	1.8, 2.7, 4.2	All types of dip-slip			High	NA	Medium
Probability of occurrence of faulting within region			Fault width				
	1.7	ESF		± 10 cm	High		Low

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Table 8.3.1.2-5. Parameters addressed by the structural geology study (sheet 4 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Topography surface characteristics	2.3	Pasco Basin CASZ		NA NA	Medium		Low
Anticlines, synclines, grabens	4.2	Layout area		± 10% distance between feature and drift	High	Depends on distance from drift	Low
Surface geomorphology	2.2	Layout area		No goal given	High	NA	Medium
Landslide characteristics	2.3	CASZ		No goal given	High	NA	High

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[a]Goals are generally related to identification and mapping faults large enough to map at the scale indicated. Larger scale mapping will be performed at potential seismogenic faults.

[b]Quarternary offset required accuracy is dependent on age of strata and related to the demonstration of late Pleistocene and recent offset.

NA = Not available.
CASZ = Controlled area study zone
ESF = Exploratory Shaft Facility.

CONSULTATION DRAFT

Table 8.3.1.2-6. Parameters addressed by the physical rock properties study (sheet 1 of 2)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Porosity in host rock	1.1, 1.3, 1.8, 2.7	Exploratory Shaft Facility	Resistivity in host rock study	Establish host rock porosity at numerous sample points	High	TBD	TBD
Effective porosity in host rock	1.1, 1.2, 1.3	Exploratory Shaft Facility	Temperature, resistivity	Collect data to support determina-tion of effective porosity at numerous sample points	High	TBD	TBD
Porosity in damaged rock zone	1.1, 1.3	Exploratory Shaft Facility	Resistivity in damaged rock zone	Evaluate damaged rock zone porosity at numerous sample points	Low	TBD	TBD
Porosity in disturbed rock zone	1.1, 1.3, 1.11	Exploratory Shaft Facility	Resistivity in disturbed rock zone	Establish porosity at numerous sample points in disturbed rock zone	High	TBD	TBD
Density in disturbed rock zone	1.1, 1.3, 1.11	Exploratory Shaft Facility	TBD	Determine bulk density at numerous sample points in disturbed rock zone	High	TBD	TBD
Radial extent of disturbed rock zone	1.1, 1.3, 1.11, 4.2	Exploratory Shaft Facility	Porosity, density, acoustic parameters, electromagnetic parameters	Measure radial extent of disturbed rock zone	High	TBD	TBD
Density of host rock	1.1, 1.3, 2.7, 4.2	Exploratory Shaft Facility	TBD	Determine density at numerous sample points in host rock	High	TBD	TBD
Flow interior thickness, Cohassett flow	1.11, 1.8	Exploratory Shaft Facility	Porosity, density, acoustic parameters, electromagnetic parameters	Establish porosities of flow boundaries	High	TBD	TBD
Flow top thickness, Cohassett flow	1.11, 1.8	Exploratory Shaft Facility	Porosity, density, acoustic parameters, electromagnetic parameters	Determine thickness of flow top	High	TBD	TBD

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Table 8.3.1.2-6. Parameters addressed by the physical rock properties study (sheet 2 of 2)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Rock temperature	2.7	Exploratory Shaft Facility	TBD	Determine temperature profiles within Cohassett flow	Medium	TBD	TBD
Resistivity, electromagnetic, and acoustic parameters	1.11, 4.2	Exploratory Shaft Facility	TBD	Quantify parameters at numerous sample	Medium	TBD	TBD

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Definitions:
CASZ = Controlled area study zone, the sum of all likely controlled areas, approximately a lateral area that extends no more than 5 km in any direction from the outer boundary of the proposed repository site.
TBD = To be determined.

CONSULTATION DRAFT

Table 8.3.1.2-7. Parameters addressed by the stratigraphic and structural model study

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal or needed accuracy	Needed confidence	Current estimate of goal or accuracy	Current confidence
Three-dimensional subsurface geometry	1.1, 1.2, 1.3, 1.6, 1.8, 1.11, 1.12	Layout/CASZ	(a)	NA	NA	NA	NA
	1.1, 1.2, 1.3, 1.6, 1.8	Pasco Basin	(a)	NA	NA	NA	NA
	1.6, 1.8	Region	(a)	NA	NA	NA	NA
Cohassett flow interior depth	1.1, 1.2, 1.3, 1.12	CASZ	(a)	NA	NA	NA	NA

[a]This study does not collect any new data, but rather uses supporting parameters from other studies in the Stratigraphy and Structure Investigation to produce the three-dimensional geometry.

CASZ = Controlled area study zone.
NA = Not applicable.

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8.3.1.2.3.1.1 Issue 1.1.

The stratigraphy and structure investigation will address performance assessment requirements by determining the three-dimensional lateral and vertical sequence and areal extent of strata (i.e., sediments, basalt flows, interbeds, their physical characteristics, and geologic boundaries for groundwater flow and system performance models). Properties of fractures and fractured rock and the accessible environment will also be obtained. The information required for site subsystem performance assessment does not have specific numerical goals for the stratigraphic and structural investigation, because the investigation is a process of discovery of the characteristics of the natural system. Lack of such goals reflects the absence of sensitivity studies to establish clear relationships between the stratigraphic and structural characteristics of the site and their relationship to groundwater flow and system performance goals. Such relationships may evolve as characterization and performance assessment of the site advances.

8.3.1.2.3.1.2 Issues 1.6, 1.8, 1.9, 1.11, and 1.12.

The stratigraphy and structure investigation will provide data and information on the three-dimensional lateral and vertical extent of strata as needed for the resolution of Issues 1.6, 1.8, 1.9, 1.11, and 1.12. Stratigraphic and structural information is needed to qualify the site (Issues 1.8 and 1.9) and to provide data for preclosure and postclosure analyses of the site subsystem and repository performance. The lateral and vertical extent of strata (flow tops, dense interiors, and interbeds) will be input as geometry to conceptual and numeric hydrogeologic flow models (Issue 1.6), recharge/discharge systems and paleohydraulic conditions as well as determining effective thickness and characteristics for repository construction (Issue 1.11) and for design of repository seals (Issue 1.12). No stratigraphic and structural data will be gathered specifically to address Issue 1.9, because the required data are essentially identical to those required for resolution of Issue 1.8.

8.3.1.2.3.1.3 Issue 4.2.

Design requirements derived from Issue 4.2 will be addressed by the stratigraphy and structure investigation (primarily by the intraflow structure and structural geology studies with assessment of flow tops and bottoms and geologic features such as faults, tectonic joints and spiracles). Estimates of horizon thickness variability is a specific design goal related to the favorable and potentially adverse conditions for rock characteristics discussed previously. The overall objective is assurance that the repository does not encounter flow top or flow bottom while maintaining a sufficient safety margin. Meeting this objective (1) avoids potentially adverse conditions associated with relatively high permeability and low rock strength of the flow tops and (2) helps define whether or not the favorable conditions are met. Preliminary geostatistical evaluation of the SCP design indicates that additional borehole data will be needed to meet the required level of confidence for the advanced conceptual design (Taylor, 1987). Alternatively, it may be possible to alter the elevations of repository layout design to meet

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uncertainty objectives. Additional seismic reflection data in the geologic repository operations area also may reduce uncertainty. Boreholes and seismic reflection surveys aimed at reducing uncertainty are appropriately discussed under this investigation.

8.3.1.2.3.2 Rationale

The stratigraphy and structure investigation was developed primarily to meet a widespread need in the BWIP for representation of the three-dimensional geometry of the site and surrounding area at several scales ranging generally from large scale (approximately 1:5,000) for the repository site to small scale (1:500,000) for the region.

The principal technical problem addressed by this investigation is defining site three-dimensional geometry at depth in a geologic setting where the basalt layers are covered by up to 250 m (825 ft) of overlying sediments. Included in this problem are identification and location of tectonic features (faults, folds, and joints; determination of the attitude, length, and displacement of faults) and determination of the configuration and characteristics of basalt and sedimentary layers. Data that result from this investigation come from the use of a combination of data collection methodologies, such as boreholes, geophysical surveys, and geologic observations of exposures away from the controlled area. These data are then interpreted in a manner permitting inferences to be drawn regarding geologic conditions at depth.

The component studies of the investigation have been developed in response to the nature of the geologic system. The studies comprising the investigation are in the following sections.

- Stratigraphy study (Section 8.3.1.2.3.3.1).
- Intraflow structure study (Section 8.3.1.2.3.3.2).
- Cooling joint characteristics study (Section 8.3.1.2.3.3.3).
- Structural geology study (Section 8.3.1.2.3.3.4).
- Physical rock properties study (Section 8.3.1.2.3.3.5).
- Stratigraphic and structural model study (Section 8.3.1.2.3.3.6).

The stratigraphy study was developed because of the layered character of the site (basalt flows and suprabasalt and interbedded sediments). Because of contrasting permeability and rock strength of flow tops and flow interiors of basalt flows, the site stratigraphy influences feasible depths for a repository. For example, a repository must be located in the interior of a basalt flow of sufficient thickness and depth to meet regulatory requirements. Thus, a repository would be located at specific depths defined by the location of a suitable host flow. In an unlayered medium the location of a repository is unconstrained except that it must be at least 200 m (660 ft) below the surface. The permeability contrasts associated with each layer also exert strong influence on groundwater flow and, thus, on long-term performance of a repository. Therefore, stratigraphy is an important consideration in modeling the geohydrology of the site and is fundamental to the stratigraphic and structural model. Moreover, stratigraphy is the basis for dating geologic

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events, such as faulting at the site, which, in turn, is useful information in developing potentially disruptive scenarios for performance assessment modeling.

The intraflow structure study is based on the need to characterize the internal characteristics of individual basalt flows. Individual flows exhibit flow top, flow interior, and flow bottom. The flow interior is subdivided into colonnade, entablature, and columnar entablature. Because of the permeability and strength contrasts between flow interior and flow top or flow bottom, optimization of both long-term performance and construction feasibility in this setting requires that the repository be located within the interior of a single basalt flow. Thus, understanding and depicting the lateral variability of intraflow structures, especially in the Cohassett flow, are the objectives of the intraflow structure study. The intraflow structure study will be a contribution in determining if sufficient competent rock is available for repository construction in the Cohassett flow (see 10 CFR 60.130 and 10 CFR 60.133; NRC, 1986).

The cooling joint characteristics study reflects the ubiquitous occurrence of cooling joints in the basalt flows of the site. Cooling joints are the most abundant potential pathways for groundwater flow in basalt flow interiors, and they play a key role in determining the stability of mined openings. Because of their abundance and variability among intraflow structures, a statistical approach will be used to characterize cooling joints. Tectonic joints will be investigated as part of the structural geology study.

The structural geology study is pertinent because of the deformation of the layers at the site. Both folding and faulting have occurred in the controlled area study zone and surrounding terrain. Folding has warped the layers and is responsible for the dip of the layers within the repository site. Faulting has the potential to decrease rock strength locally and to provide avenues for increased vertical groundwater flow. Faulting, if present in the repository site, is critical to design of the repository layout and drainage and will influence a determination of whether or not sufficient undisturbed rock is present in the repository site for repository construction. Thus, the three-dimensional distribution of faults and folds is of fundamental importance to the stratigraphic and structural model study. The structural geology study is also a major input to the tectonic events and processes investigation.

The stratigraphic and structural model study will combine and integrate the results of the above studies where appropriate for a particular scale. The scales and stratigraphic units associated with each scale are given in Table 8.3.1.2-8. A preliminary stratigraphic and structural model of the controlled area study zone scale has been completed (Landon and Bjornstad, 1986). This version covers only the reference repository location portion of the controlled area study zone because it was produced before the definition of the controlled area study zone.

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Table 8.3.1.2-8. Level of detail for the stratigraphy study (sheet 1 of 2)

Study area scales[a]	Units included	Level of detail
Repository site[b] (1:1,000, 1:12,000)	Suprabasalt sediments	Beds
	Interbedded sediments	Beds
	Saddle Mountains Basalt	Flow
	Wanapum Basalt	Flow
	Top of Grande Ronde Basalt to base of Grande Ronde N2 Basalt	Flow
Controlled area study zone (1:12,000 to 1: 24,000)	Suprabasalt sediments	Beds
	Interbedded sediments	Beds
	Saddle Mountains Basalt	Flow
	Wanapum Basalt	Flow
	Grande Ronde N2 Basalt	Flow
	Remainder of Grande Ronde Basalt to base of basalt (as needed)	Magnetostratigraphic units
Cold Creek syncline (1:12,000 to 1:62,500)	Suprabasalt sediments	Member
	Interbedded sediments	Bed
	Saddle Mountains Basalt	Flow
	Wanapum Basalt	Member
	Grande Ronde N2 Basalt	Flow
	Remainder of Grande Ronde Basalt to base of basalt (as needed)	Magnetostratigraphic units
Pasco Basin[b] (1:24,000 to 1:100,000)	Suprabasalt sediments	Member
	Interbedded sediments	Bed
	Saddle Mountains Basalt	Member
	Wanapum Basalt	Member
	Grande Ronde N2 Basalt	Sequence to flow
	Remainder of Grande Ronde Basalt to base of basalt (as needed)	Magnetostratigraphic units

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Table 8.3.1.2-8. Level of detail for the stratigraphy study (sheet 2 of 2)

Study area scales[a]	Units included	Level of detail
Region[b] (1:100,000 to 1:500,000)	Suprabasalt sediments	Formation
	Interbeds	Formation to member
	Saddle Mountains Basalt	Formation to member
	Wanapum Basalt	Formation to member
	Grande Ronde Basalt	Formation
	Picture Gorge Basalt	Formation
	Imnaha Basalt	Formation

[a] Typical range of working scales given in parentheses. Other scales to be developed as needed for engineering design or publication of results. PST88-2014-8.3.1.2-4

[b] Additional detail may be necessary in portions of the Pasco Basin and region to satisfy special requirements of a particular study.

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In general, the stratigraphic and structural model study will use five different scales. These scales and the areas in which they will be used are listed as follows:

- Repository site.
- Controlled area study zone.
- Cold Creek syncline.
- Pasco Basin.
- Region.

The approximate extent of each of the areas to be mapped at the different scales is illustrated in Figures 8.3.1.2-3 and 8.3.1.2-4. The stratigraphy study, intraflow structure study, and structural geology study will use matching scales for their products in order to facilitate integration of data into the stratigraphic and structural models.

The stratigraphic and structural model study will also produce engineering geology input from the results of detailed studies on cooling joints, faults, and tectonic joints and intraflow structures into a form useful to rock mechanics and design applications.

The principal constraint on the investigation is that the rocks within the controlled area study zone cannot be observed directly except in the Exploratory Shaft Facility. Sedimentary cover of the uppermost basalt layer increases this constraint. It is also both impractical from a cost point of view and undesirable from a waste isolation point of view to drill an arbitrarily large number of boreholes. Hence, the identified studies were selected because they provide a means of effectively using borehole, geophysical, and outcrop data to interpret subsurface conditions.

The measurement of the hydrologic baseline and the conduct of the large-scale hydrologic stress tests will preclude drilling boreholes deeper than Wanapum Basalt for an unspecified period of time before large-scale hydrologic stress tests are completed. Drilling deeper than the Wanapum Basalt during this time period would inject or extract fluid in the horizons being monitored and, thus, impact hydrologic data being obtained. The sequence will be to drill deep boreholes before and after large-scale hydrologic tests.

8.3.1.2.3.3 Description of studies

The six studies that make up the stratigraphy and structure investigation are described in the following sections.

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9 2 1 2 5 5 4 1 7 9 9

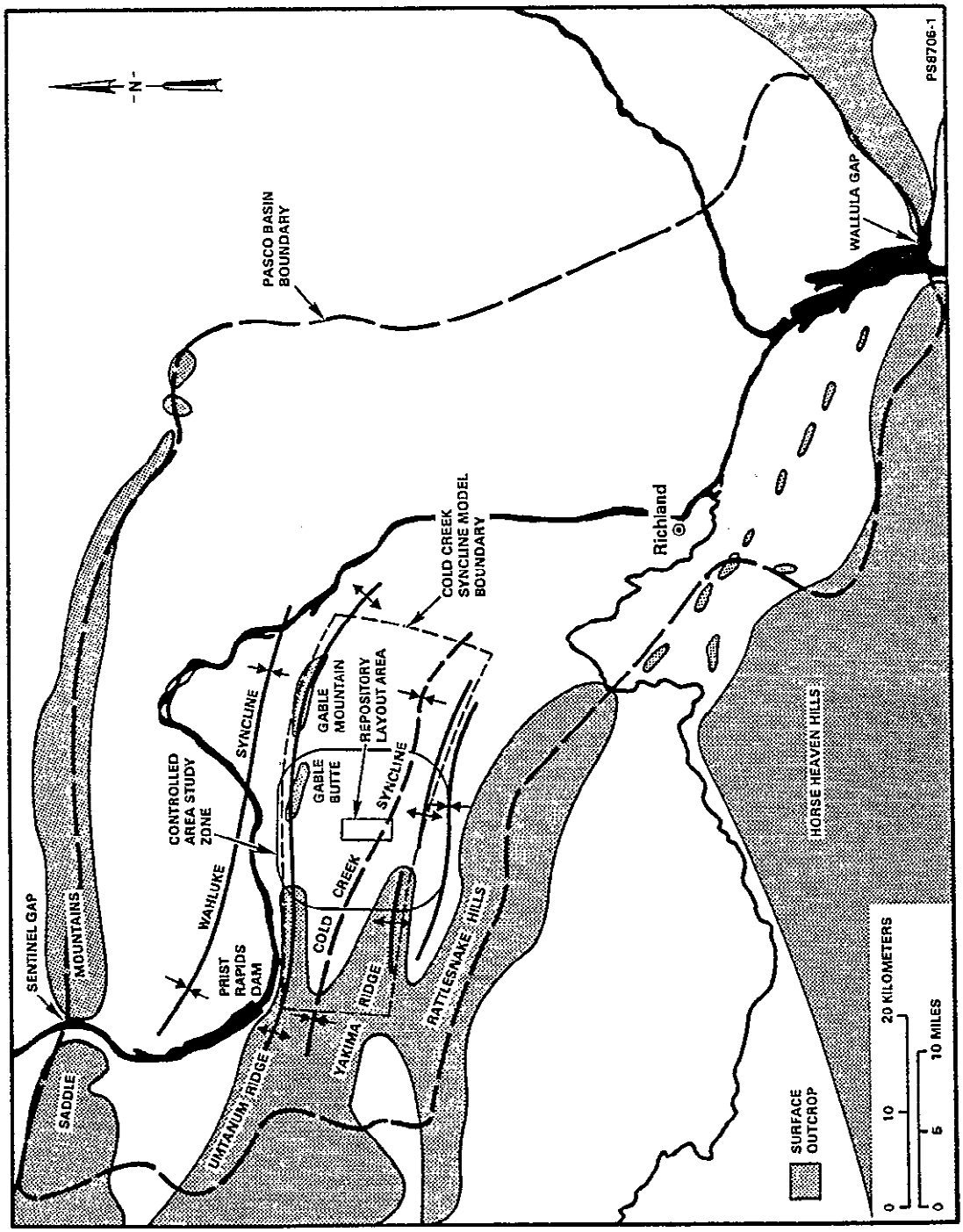

Figure 8.3.1.2-3. Location map showing scales for the repository site, the controlled area study zone, and the Cold Creek syncline.

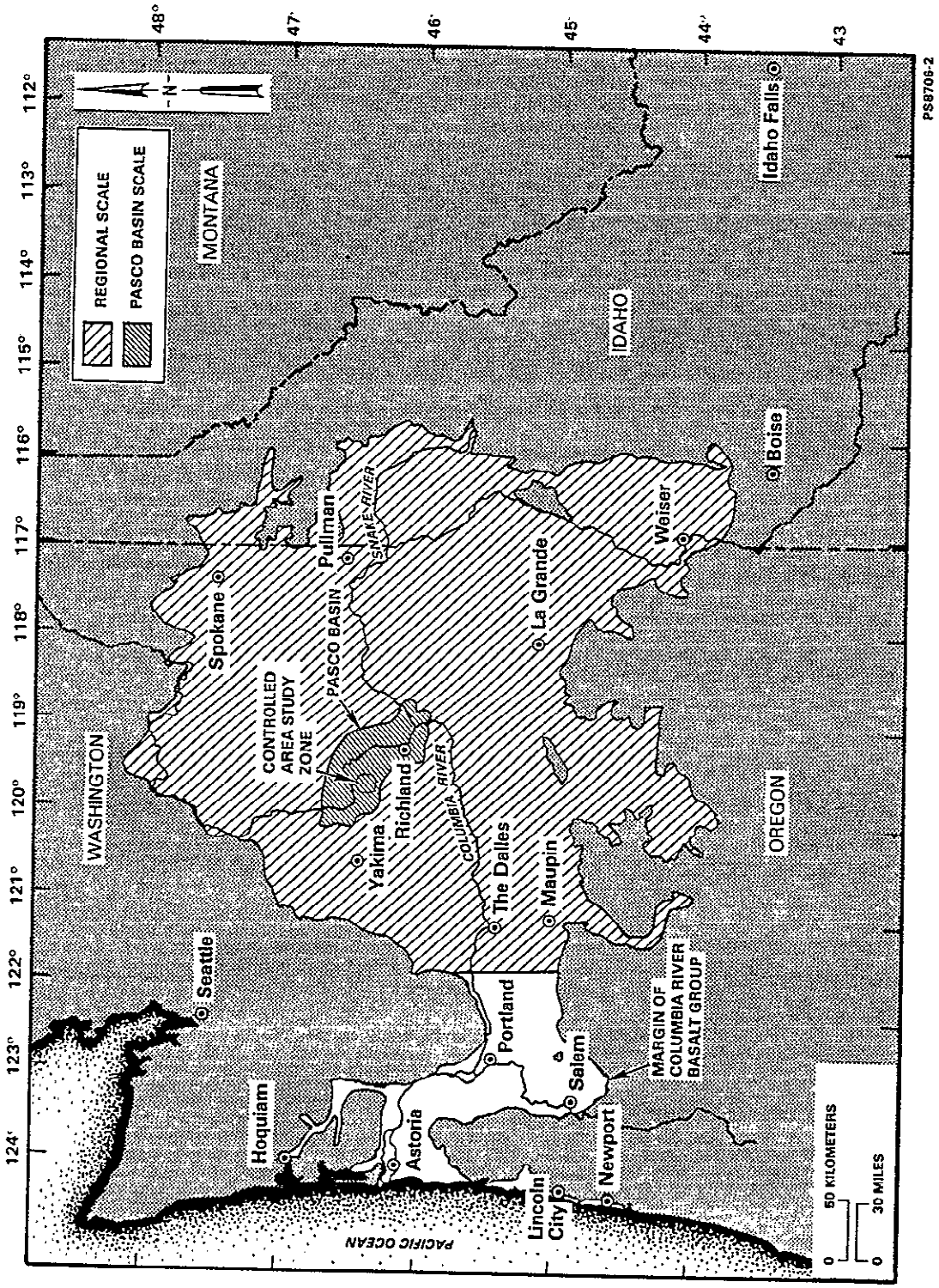

Figure 8.3.1.2-4. Location map showing approximate extent of study scales for the region and Pasco Basin.

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8.3.1.2.3.3.1 Stratigraphy study.

The stratigraphic study addresses performance and design issue parameters relating to the geometry, thickness, and distribution of stratigraphic units. As such, the primary objective of the stratigraphy study is to establish a stratigraphic framework for the repository site, controlled area study zone, Cold Creek syncline, Pasco Basin, and region (see Fig. 8.3.1.2-3 and 8.3.1.2-4). The stratigraphy study uses subsurface data from boreholes, shafts and geophysics and surface data from outcrops to determine the stratigraphic sequences and their extent.

Figure 8.3.1.2-5 gives the stratigraphic units within the controlled area study zone and current stratigraphic nomenclature. The study provides the stratigraphic foundation for hydrologic and design studies and for other geologic studies such as intraflow structure and cooling joint characteristics. This study does not cover stratigraphic work done to support field mapping studies for structural geology and deformation studies or subsurface mapping for deep structural interpretation work. In addition, studies of the deep sub-basalt stratigraphy are addressed by the mineral, hydrocarbon, and geothermal potential investigation (Section 8.3.1.6.3).

The stratigraphy study has as its basis three sub-objectives: (1) to characterize and correlate stratigraphic units (2) to determine the thickness and distribution of the strata, and (3) to determine the drilling history of the site. To satisfy the objectives, four components have been established for this study, which are divided into tasks and analyses. These components and the tasks and analyses are listed below.

1. Characterization and correlation of strata.

   a. Basalt units.
   b. Interbedded sedimentary units.
   c. Suprabasalt sedimentary units.

2. Stratigraphic analyses of seismic reflection and refraction data in the repository site and controlled area study zone.

   a. Seismic reflection development testing in the controlled area study zone.
   b. Acquisition of three-dimensional test data near the exploratory shaft.
   c. Processing and interpretation of three-dimensional data.
   d. Acquisition of three-dimensional data in the repository site.
   e. Acquisition of two-dimensional data in the controlled area study zone.
   f. Processing and interpretation of two-dimensional and three-dimensional data.

CONSULTATION DRAFT

PERIOD	EPOCH	GROUP	SUBGROUP	FORMATION	MEMBER OR SEQUENCE	SEDIMENT STRATIGRAPHY OR BASALT FLOWS	UNIT THICKNESS RANGES (m)		
QUATERNARY	Holocene				SURFICIAL UNITS	LOESS; SAND DUNES; ALLUVIUM ALLUVIAL FANS; LANDSLIDE; TALUS; COLLUVIUM	<3[a]		
	Pleistocene			Hanford	TOUCHET BEDS / PASCO GRAVELS		≤5[a] / ≤64[a]		
TERTIARY	Pliocene					PLIO-PLEISTOCENE UNIT	0-26[a]	BUFFER ZONE	DEFENSE WASTE PROGRAM OPERATIONS SYSTEM
				Ringold		UPPER RINGOLD	0-33[a]		
						MIDDLE RINGOLD	55-100[a]		
						LOWER RINGOLD	0-17[a]		
						BASAL RINGOLD	6-60[a]		
	Miocene	Columbia River Basalt Group	Yakima Basalt Subgroup	Saddle Mountains Basalt	ELEPHANT MOUNTAIN MEMBER	ELEPHANT MOUNTAIN FLOW	0-39.0		
						RATTLESNAKE RIDGE INTERBED	0-34.4		
					POMONA MEMBER	POMONA FLOW	0-69.0		
						SELAH INTERBED	0-30.8		
					ESQUATZEL MEMBER	GABLE MOUNTAIN FLOW	0-36.3		
						COLD CREEK INTERBED	0-36.6		
					UMATILLA MEMBER	SILLUSI FLOW (DISCONTINUOUS)	20.7-73.2		
						UMATILLA FLOW			
						MABTON INTERBED	25.6-51.8		
				Wanapum Basalt	PRIEST RAPIDS MEMBER	LOLO FLOW	39.3-65.2	UPPER SECONDARY ISOLATION ZONE	COMMERCIAL WASTE PROGRAM REPOSITORY ISOLATION ZONE
						ROSALIA FLOW	16.5-33.5		
						QUINCY INTERBED (DISCONTINUOUS)	0-0.5		
					ROZA MEMBER	ROZA FLOW (2 COOLING UNITS)	42.1-59.4		
						SQUAW CREEK INTERBED (DISCONTINUOUS)	0-0.9		
					FRENCHMAN SPRINGS MEMBER	SENTINEL GAP FLOW	50.9-64.6		
						SAND HOLLOW FLOWS (2 FLOWS)	32.6-54.4		
						SILVER FALLS FLOWS (1 TO 3 FLOWS)	19.8-47.9		
						GINKGO FLOWS (2-3 FLOWS)	68.0-100.9		
						UNNAMED INTERBED (DISCONTINUOUS)	0-3.7		
						PALOUSE FALLS FLOW	9.1-25.0		
						VANTAGE INTERBED	0-9.1	PRIMARY ISOLATION ZONE	
				Grande Ronde Basalt	SENTINEL BLUFFS SEQUENCE	FLOW 1	5.3-25.6		
						FLOW 2	16.9-34.9		
						ROCKY COULEE FLOW	40.2-57.0		
						LEVERING FLOW (DISCONTINUOUS)	0-28.0		
						COHASSETT FLOW	65.8-81.4		
						BIRKETT FLOW	34.7-43.3		
						FLOW 7	9.0-18.2		
						FLOW 8	11.6-24.4		
						McCOY CANYON FLOW	32.3-45.0		
					SCHWANA SEQUENCE	UMTANUM FLOW	60.5-75.0		
						VERY HIGH-Mg FLOW	0-22.6	LOWER SECONDARY ISOLATION ZONE	
						AT LEAST 3 FLOWS[b]	93.5[a]		
						N_2-R_2 PALEOMAGNETIC CONTACT GREATER THAN 10 FLOWS	>1,750 TO BASE OF BASALT		

ELLENSBURG FORMATION

NOTE: TO CONVERT METERS TO FEET, MULTIPLY BY 3.28
[a]THICKNESS RANGE FOR THE REFERENCE REPOSITORY LOCATION ONLY.
[b]VALUE IS A MINIMUM ONLY (ONLY ONE BOREHOLE PENETRATED TO BASE OF LOWER BUFFER ZONE).

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Figure 8.3.1.2-5. Stratigraphic units found within the controlled area study zone and associated rock package nomenclature.

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3. Analysis of thickness and distribution of strata.

   The data from the first two components are analyzed in this component for the characterization of thickness and distribution of stratigraphic units.

4. Controlled area borehole inventory.

   This component has been established to create and maintain a data base for documenting the locations, the completion details, and the stratigraphic characteristics of all boreholes that have been drilled within the controlled area study zone.

The first and second components of this study will answer the first sub-objective of this study, i.e., to characterize and correlate stratigraphic units. The second and third components will answer the second objective, i.e., to determine the thickness and distribution of the strata. The fourth component will answer the third sub-objective, i.e., to determine what is the drilling history of the site.

Parameters to be collected by the stratigraphy study are listed in Table 8.3.1.2-2. Locations of stratigraphic data collection activities are determined by the locations of boreholes and stratigraphic sections drilled or measured for other geologic, hydrologic, and design studies. These data collection localities are deemed sufficient to fulfill the stratigraphic parameter needs.

Technical considerations that have been used to help organize and focus the stratigraphy study are listed below.

- Identification, characterization, and extent of interbeds in the controlled area study zone and Pasco Basin.
- Origin, identification, characterization, distribution, extent and age of suprabasalt sediments and marker beds in the controlled area study zone and Pasco Basin (e.g., Ringold Formation and markers, Quaternary sediments and volcanic ash markers).
- Characteristics of basalt, interbed and suprabasalt stratigraphy with respect to hydrologic properties.

For example, the sedimentary interbeds of the Columbia River Basalt Group have different and unique characteristics relative to the basalt flows. These different characteristics ultimately result in different groundwater flow characteristics of the interbeds relative to the basalt flows. Therefore, it is an important technical consideration to identify and characterize the sedimentary interbeds and to know how far they extend within the controlled area study zone and surrounding areas.

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8.3.1.2.3.3.1.1 Characterization and correlation of strata. This study component will provide the unit characteristics that are important to the stratigraphic identification of rock units. These characteristics are such properties as macroscopic texture and mineralogy, rock chemistry, and paleomagnetic inclination and declination for basalt units. They include mineralogy, grain size, bedding features, age dating, and paleomagnetic properties for sedimentary units. Other characteristics common to both basalt and sedimentary units are relative stratigraphic position and thickness.

Unit characteristics will be used to correlate the units from sample locality to locality and to determine the variability of the individual unit characteristics around the site. The tests and analyses to be used in this study are listed in Table 8.3.1.2-9. Included in this table are study locations, number of tests, and methods. Table 8.3.1.2-9 also lists the level of detail required at the five study area scales (repository site, controlled area study zone, Cold Creek syncline, Pasco Basin, and region). Correlations will be completed at varying detail according to the proximity to the repository site and the detail necessary to satisfy the needs of other studies (such as intraflow structure studies). An example of this detail is that within the repository site the Grande Ronde Basalt must be correlated on a flow-by-flow basis, while at the Pasco Basin scale these units need only be correlated at the sequence level. However, intraflow structure studies at Sentinel Gap in the north part of the Pasco Basin require a flow-by-flow correlation of flows.

Interpretations will be performed for all boreholes and shafts drilled by the BWIP as well as selected boreholes drilled for other purposes. Figures 8.3.1.2-6 through 8.3.1.2-9 show the proposed locations for new boreholes below the top of basalt to be drilled at the site in support of the stratigraphy study and other site characterization activities at the BWIP. Three of the deep boreholes will be drilled to the N2/R2 paleomagnetic horizon to provide stratigraphic data on the basalts in the lower portion of the Grande Ronde N2 magnetostratigraphic unit. This is required to characterize the lower secondary isolation zone of the repository isolation zone. Data from sources outside the BWIP will also be used in this study. However, the data from the non-BWIP sources may not necessarily meet all of the BWIP quality assurance requirements. These data, however, will be considered for development of the stratigraphy, although limits to the use of the data may be necessary.

The characterization and correlation of strata study component is divided into three tasks based upon the rock type or the occurrence of the rock type. The three tasks are (1) basalt units, (2) interbedded sedimentary units, and (3) suprabasalt sedimentary units.

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Table 8.3.1.2-9. Tasks/tests/analyses for the stratigraphy study (sheet 1 of 2)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Correlation of strata	Chemical composition (major and trace elements, used predominantly for Basalt Flows)	Boreholes and outcrops as appropriate	Analyses as required typically two to three samples per flow for major oxides	Major and trace elemental abundance	Discriminator chemical composition
	Paleomagnetic orientation (sediments and basalt units)	Boreholes and outcrops as appropriate	Typically seven samples per flow	Remanent magnetic vectors, polarity	Normal-reverse polarity, inclination and declination of primary magnetic vector
	Lithologic description, petrographic observation, core logging (all rock units)	Boreholes and outcrops as appropriate	All cored boreholes, chip samples/ outcrops (see figures 8.3.1.2.2-6, 8.3.1.2-7, 8.3.1.2-8, 8.3.1.2-9)	Lithology, mineralogy, textural relations, modal abundances of minerals	Discriminators: lithology, mineral, modal and textural
	Geophysical log response (all rock units)	All boreholes	Logs: spontaneous potential, resistivity, caliper, natural gamma, neutron-epithermal-neutron, gamma-gamma density, full-wave acoustic, neutron density, magnetometer, borehole television, and dip meter	Porosity, density, mechanical properties, and chemical properties (some)	Stratigraphic sequence of geophysical log data
	Discriminate analysis statistical techniques	NA	NA	Uncertainty estimates for correlations of flows based on data from test of strata on correlation	Uncertainty estimates for correlations of flows based on data from tests of strata on correlation
Stratigraphic analysis of seismic reflection/ refraction data	Interpretation of seismic records (sediments and basalts)	Controlled area study zone	Three-dimensional seismic reflection survey in layout area	Reflection/refraction profiles	Areal flow/interbed discriminators
	Seismic reflection (sediments and basalts)	Geologic repository operations area and controlled area study zone	Two-dimensional seismic reflection and profiles to extended three-dimensional survey into controlled area study zone	Seismic profiles	Stratigraphic disposition of reflector layer
	Seismic refraction (all units)	Geologic repository operations area and controlled area study zone	Two-dimensional seismic reflection and profiles to extended three-dimensional survey into controlled area study zone	Three-dimensional seiscrop	

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CONSULTATION DRAFT

Table 8.3.1.2-9. Tasks/tests/analyses for the stratigraphy study (sheet 2 of 2)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Stratigraphic analysis of seismic reflection/ refraction data (cont.)	Vertical seismic profiling (sediments and basalts)	Saddle Mountains well to controlled area study zone profile	Seismic reflection and refraction profile to extend Saddle Mountains borehole data to controlled area study zone	Vertical seismic profiling	
Analysis of thickness and distribution of strata	Geostatistics	NA	NA	Geostatistical analysis will provide uncertainty estimates for thickness maps and for depth of horizons	Geostatistical analysis will provide uncertainty estimates for thickness maps and for depth of horizons
	Isopach maps	At scales specified in Table 8.3.1.2-2	NA	Thickness and distribution maps of units	Thickness

NA = Not applicable.

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CONSULTATION DRAFT

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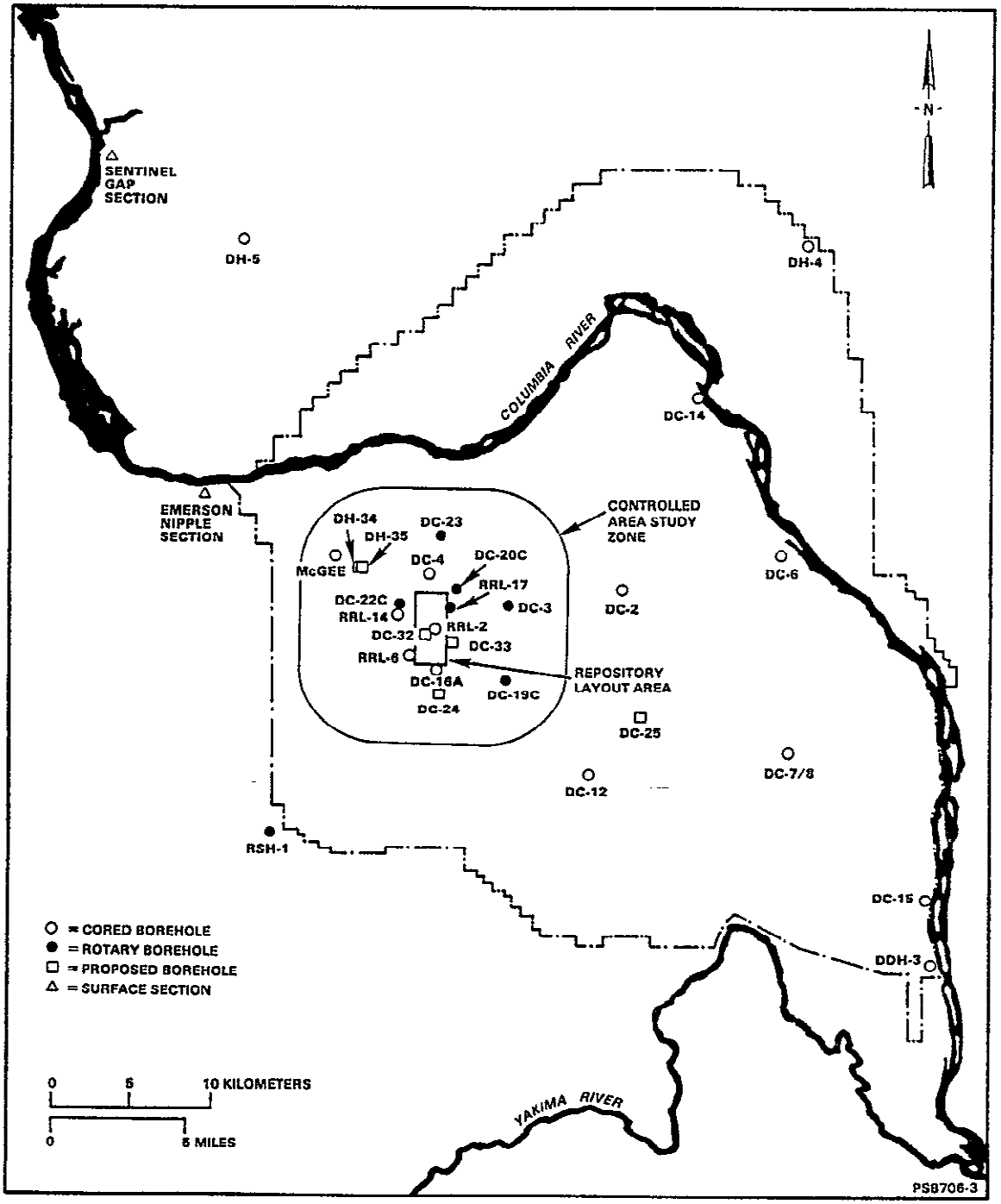
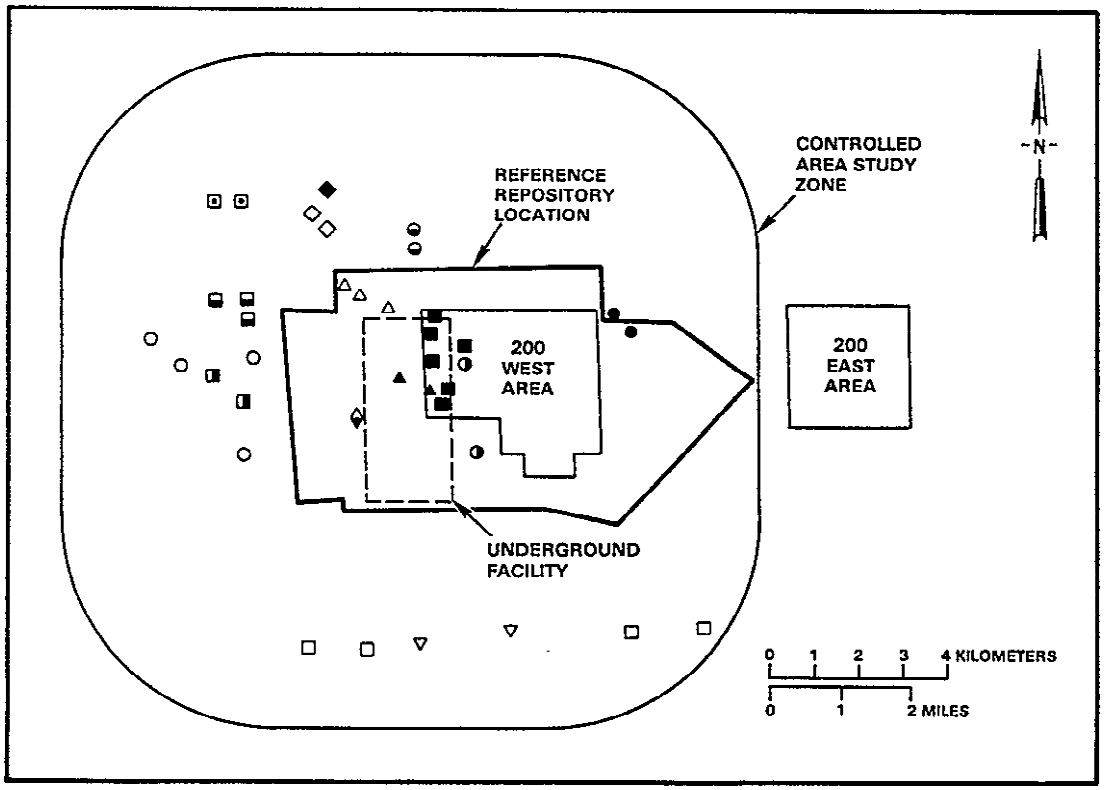


Figure 8.3.1.2-6. Map showing existing and proposed borehole locations and surface sections.



ITEM

- ⊡ TWO ROTARY HOLES TO THE BOTTOM OF THE POMONA FLOW TO INVESTIGATE THE NORTH TERMINUS OF THE GEOPHYSICAL ANOMALY PARALLELING THE HYDROLOGIC BARRIER.
- ⊟ THREE ROTARY HOLES TO THE BOTTOM OF THE POMONA FLOW TO INVESTIGATE THE SOUTH TERMINUS OF THE GEOPHYSICAL ANOMALY PARALLELING THE HYDROLOGIC BARRIER.
- ◨ TWO CORED HOLES TO THE BOTTOM OF THE POMONA FLOW TO INVESTIGATE GEOPHYSICAL ANOMALY FROM WERNER SOLUTIONS.
- ▽ TWO CORED HOLES TO THE BOTTOM OF THE FIRST BASALT FLOW TO INVESTIGATE STRUCTURE SOUTH OF THE YAKIMA RIDGE EXTENSION. THE LOCATIONS WILL BE ADJUSTED ACCORDING TO ANY PERTINENT INFORMATION GAINED FROM THE ANALYSIS OF GEOPHYSICAL DATA PREVIOUSLY ACQUIRED.
- ▲ TWO ROTARY HOLES FOR GEOPHYSICAL ANOMALY/TOP OF BASALT INVESTIGATIONS.
- ◆ ONE ROTARY HOLE TO THE BOTTOM OF THE POMONA FLOW TO INVESTIGATE AEROMAGNETIC ANOMALY (NANCY).
- △ THREE CLOSELY MONITORED ROTARY HOLES, OR CORED HOLES TO THE TOP OF THE POMONA FLOW TO INVESTIGATE DC-4/5 GEOPHYSICAL ANOMALY. POSSIBLY COULD INCORPORATE WITH HOST ROCK STUDIES UNIT'S HOLES.
- ● TWO CLOSELY MONITORED ROTARY HOLES OR CORED HOLES TO INVESTIGATE THE DC-3 GRAVITY ANOMALY.

ITEM

- ⊖ TWO ROTARY HOLES TO INVESTIGATE A SEISMIC ANOMALY.
- ◑ INTRAFLOW STRUCTURE BOREHOLE RRL-17 COMPLETED.
- ■ PLANNED SHALLOW BOREHOLES (TOP-OF-BASALT) TO REDUCE UNCERTAINTIES IN STRUCTURE CONTOURS OF TOP-OF-BASALT IN A PORTION OF THE GEOLOGIC REPOSITORY OPERATIONS AREA FOR INTRAFLOW STRUCTURE STUDIES.
- ○ FOUR ROTARY AND CORED HOLES TO EXPAND INVESTIGATION OF COLD CREEK SYNCLINAL AXIS, YAKIMA RIDGE TERMINUS, AND STRUCTURAL RELATIONSHIP OF WERNER SOLUTIONS.
- □ TWO TO FOUR ROTARY AND/OR CORED HOLES AS DEFINED BY POTENTIAL-FIELDS DATA.
- ◇ TWO ROTARY HOLES TO FURTHER DEFINE WERNER SOLUTIONS IN AREA OF NANCY LINEAR.
- ◊ CURRENTLY PLANNED DEEP BOREHOLES FOR INTRAFLOW STRUCTURE INVESTIGATIONS OF BOREHOLES RRL-18 AND RRL-19.

DEPENDING ON WHAT IS FOUND FROM THE ABOVE DRILLING, CORED, INCLINED HOLES MAY BE REQUIRED FOR DEFINITIVE, FEATURE IDENTIFICATION.

AS MORE DEFINITIVE SEISMIC DATA IS ACQUIRED A NUMBER OF ANOMALY-VERIFICATION HOLES WILL BE REQUIRED. WERNER ANOMALIES MAY LEAD TO ADDITIONAL VERIFICATION BOREHOLES

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Figure 8.3.1.2-7. Boreholes proposed for characterization of geophysical anomalies, top-of-basalt structure, and Cohassett intraflow structures in the controlled area study zone and surrounding areas.

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9 2 1 2 5 5 4 1 8 0 9

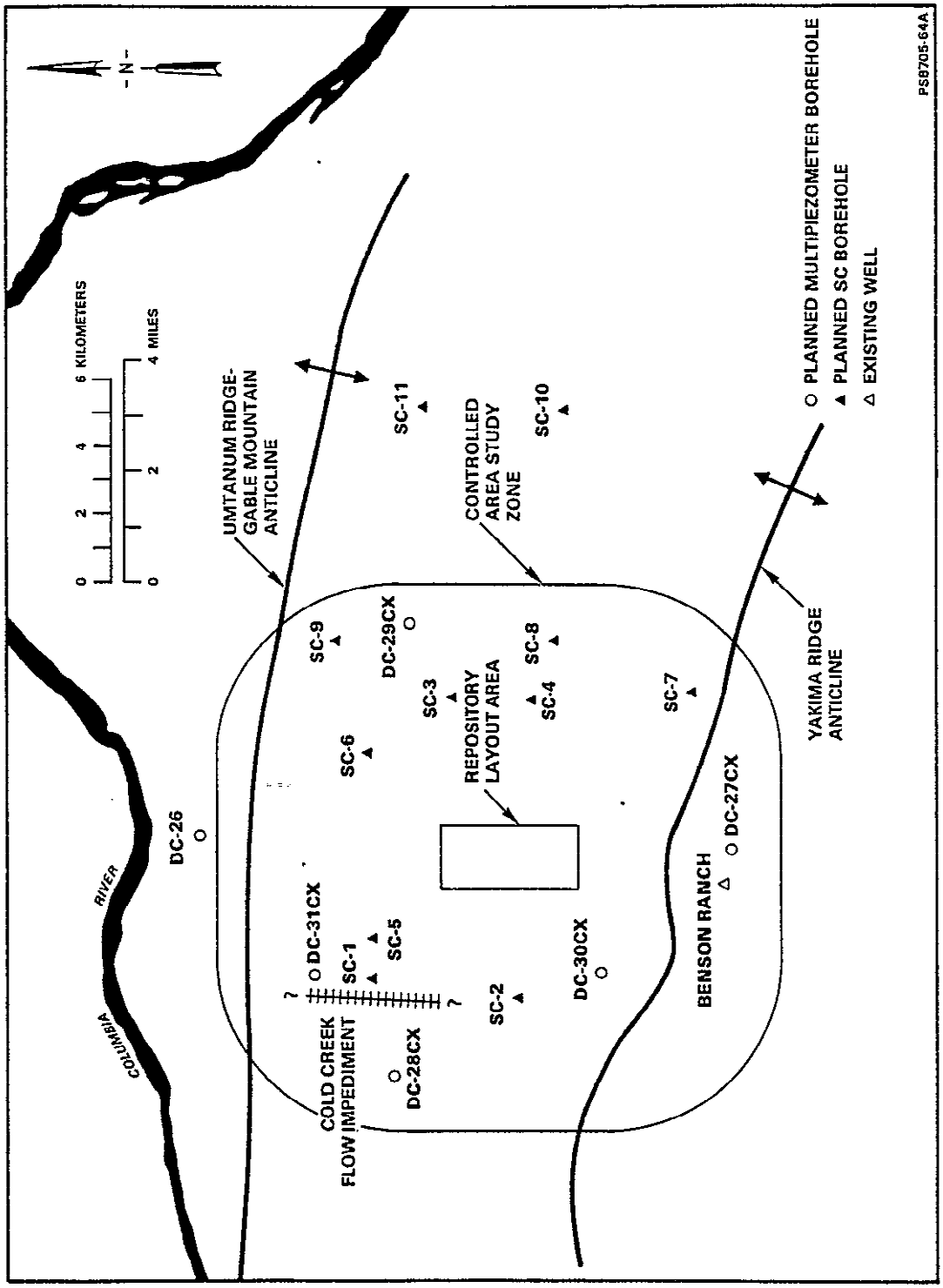

Figure 8.3.1.2-8. Location of the facilities planned for installation of the post-exploratory shaft hydrology program.

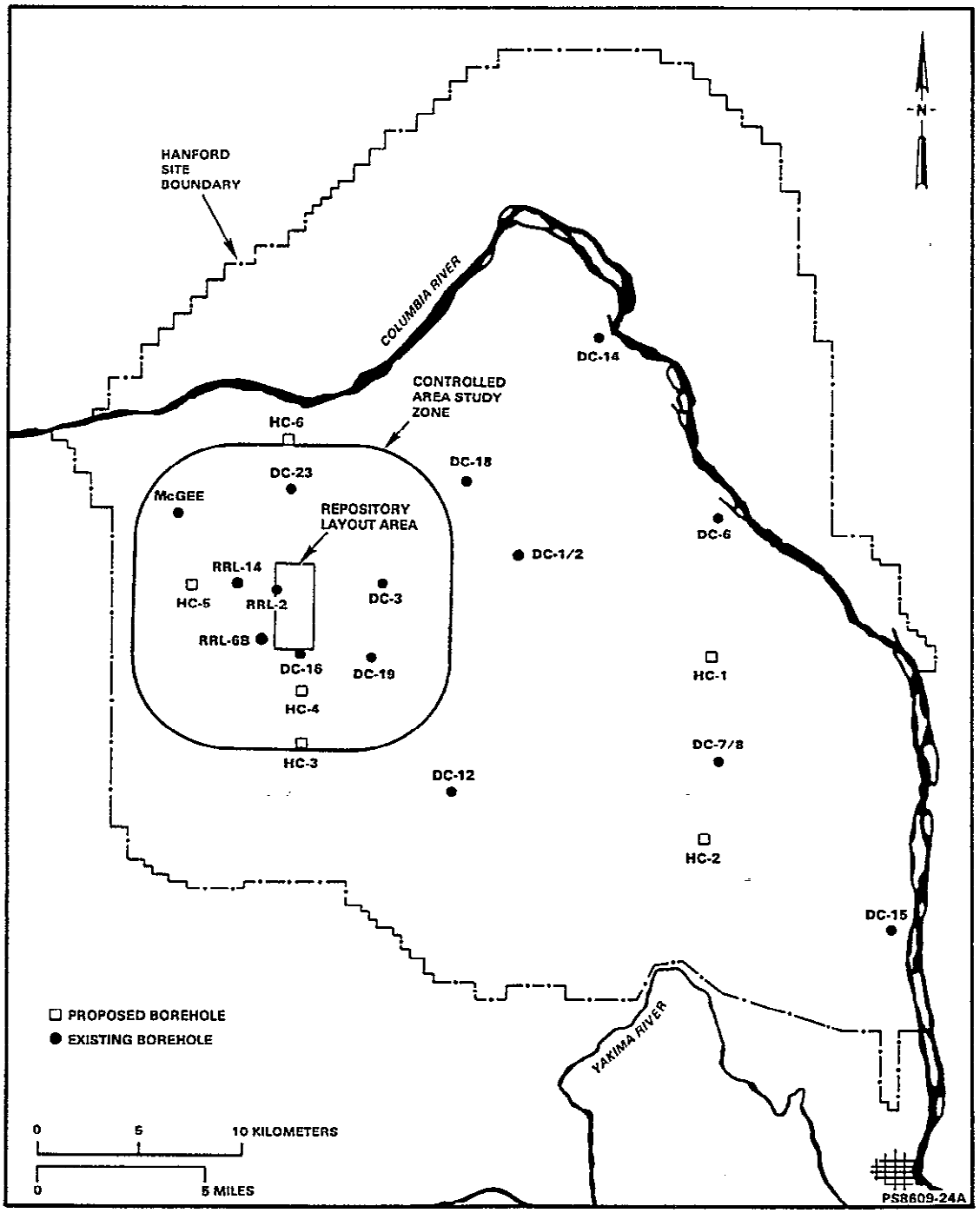

Figure 8.3.1.2-9. Locations of hydrochemistry boreholes.

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8.3.1.2.3.3.1.1.1 Basalt units

The approach for characterization of basalt units will be to use multiple properties that are important to the stratigraphic identification of the basalt units. These properties are rock chemistry, paleomagnetic signature, distinguishing physical characteristics (texture, mineralogy), geophysical log signature, stratigraphic position, and unit thickness. Information on these properties will be collected for all boreholes and shafts drilled by the BWIP. Other boreholes, which are not drilled by the BWIP, may also be used in this study. However, their usefulness may be limited due to data availability and quality assurance requirements. Basalt characterization and correlation studies will be completed on previously drilled boreholes RRL-17, DC-18, DC-23W, and DC-23GR (see Fig. 8.3.1.2-6) and on planned boreholes shown on Figures 8.3.1.2-6 through 8.3.1.2-9.

Outcrop studies are planned to be completed at Sentinel Gap (see Fig. 8.3.1.2-6) in support of the intraflow structure study. Stratigraphic data will be obtained from eight regional hydrology boreholes. Locations of these boreholes have not been determined. Stratigraphic characterization and correlation of basalt work in the Pasco Basin and region will be conducted at a low level of effort during the first two years of this study. Work to be completed will entails collection of stratigraphic data from boreholes drilled for groundwater studies or for resource investigations by non-BWIP entities. Stratigraphic work to support field mapping will be conducted under the structural geology or deformation studies as this is an integral part of field mapping. Special detailed studies such as surface section measurement or trench logging will be supported by this study; however, details as to the location or extent of studies have not been described as yet. Correlations of basalt units will be completed at the level of detail listed in Table 8.3.1.2-8.

8.3.1.2.3.3.1.1.1.1 Summary of Task Methods. Rock chemical analysis will require two samples per flow for major element chemistry. These samples will be collected for all basalt units penetrated in boreholes and shafts. Sampling will be only as necessary at outcrop (one sample per flow) to verify identification. Major and minor oxide and some minor element chemistry will be determined by x-ray fluorescence technique. Two samples per flow for trace element chemistry for flows within the repository isolation system will be required. Trace element chemistry will be determined by either x-ray fluorescence or the instrumental neutron activation analysis technique.

Paleomagnetic analysis will require seven samples per flow for flows within the repository isolation system in cored boreholes. Paleomagnetic sampling is not possible from rotary drilled boreholes due to absence of core. Cored boreholes will have a gyroscopic deviation survey. Paleomagnetic sampling and analysis at outcrop will be done only as necessary to verify identification (seven samples per flow). Fluxgate magnetometer measurements will determine the paleomagnetic polarity of outcrops, which is useful for stratigraphic correlations.

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Physical characteristics of the basalt will be obtained from geologic logging of the core or chip samples from boreholes and shaft and from field mapping observations and notes from surface outcrop studies. Physical properties that may be useful for stratigraphic identification are the texture and mineralogy of the unit. These properties may only represent local correlative features, or in some instances the texture and mineralogy may be a regional correlation tool. During the drilling of rotary boreholes, chip samples will be taken at approximately 1.5-m (5-ft) intervals to provide samples for preparation of geologic logs and for chemical sampling. During the drilling of ES-1, samples will be collected at approximately 0.3-m (1-ft) intervals to ensure that a detailed geologic log is completed for the first shaft. Sampling requirements for the second shaft will be determined later, following review of the ES-1 geologic log. Surface outcrop mapping will be completed.

Geophysical log signature, although used primarily for identification of contact positions in boreholes, can be useful for determining flow identification. The following borehole geophysical logs will be run for stratigraphic purposes:

- Spontaneous potential.
- Resistivity.
- Caliper.
- Natural gamma.
- Neutron-epithermal-neutron.
- Gamma-gamma density.
- Full wave acoustic.
- Neutron density.
- Magnetometer.
- Borehole television.
- Dip meter.

The natural gamma and borehole magnetometers are useful tools for unit identification in basalt flows. The natural gamma geophysical tool is sensitive to certain naturally occurring radioactive isotopes of potassium, thorium, and uranium. By observing the natural gamma signature and comparing the known isotope concentrations of basalt units, preliminary stratigraphic identification can be made. The borehole magnetometer is sensitive to the paleomagnetic polarity of the unit. The log records a shift in signature when the tool crosses a polarity change from normal to reverse or reverse to normal.

Stratigraphic position is determined by the unit's relative position to another unit using drill core, borehole geologic logs, or borehole geophysical logs. At outcrops this is done by using standard geologic mapping practices or stratigraphic section measurement.

Unit thickness is determined by the difference between the drilled depth or elevation of the upper and lower contacts of the unit, or its measured thickness. Unit contacts shall be located to within ±1 m (3 ft) in boreholes and ±2 m (6 ft) at outcrop. Unit thickness will be corrected for structural attitudes if structural dips of contacts exceed 3 degrees.

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The rock chemical compositions, paleomagnetic data, physical characteristics, geophysical logs, and unit position will be interpreted together to determine a stratigraphic sequencing of the units for individual boreholes or outcrop. Thickness data will be combined with the above data and correlations will be made from sampling locality to locality.

8.3.1.2.3.3.1.1.2 Interbedded sedimentary units

Interbeds will be characterized through a combination of borehole and surface outcrop studies. Detailed studies will be limited to the Pasco Basin except where interbed studies outside the basin are necessary to understand the three-dimensional facies distribution within the basin. Outside of the Pasco Basin interbeds will be correlated only at the member level. The primary method of identifying interbeds is by the bounding basalt flows. Studies are designed to characterize interbeds for differentiation and correlation of internal features as well as to provide a basis for the three-dimensional model of lithofacies needed to model groundwater flow. The studies in this task address the technical consideration relating to the characteristics and extent of interbeds because the hydrologic properties of interbeds are distinct from those of the basalt flows.

8.3.1.2.3.3.1.1.2.1 Summary of task methods. Methods used to characterize and correlate the interbedded sediments are listed as follows.

- Descriptive borehole logging.
- Geophysical logging.
- Stratigraphic section measurement.
- Age dating.
- Granulometric analysis.
- Gravel lithologic counts.
- Petrography.
- Porosity and permeability measurements.
- Paleomagnetic measurement.
- Ash characterization.
- Paleosol characterization.
- Density measurement.
- Chemical analysis.

Descriptive borehole logging provides the basic information on the interbeds and forms the basis for most other tests. Descriptive analysis will be obtained on sedimentologic features such as color, sorting, roundness, and sedimentary structure, as well as secondary alteration due to groundwater or pedogenesis. Quantitative analyses will be obtained on texture, provenance, paleomagnetic signature, chemistry of included tephra or alteration products, and hydrologic parameters such as porosity and permeability.

Stratigraphic information on interbeds will be analyzed and interpreted to determine which criteria are significant to a three-dimensional facies analysis. If distinguishing features within interbeds are found to correlate internally, then these contacts will be contoured using computer contouring process. Sedimentary units may vary significantly, both vertically and

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laterally, from one borehole or outcrop to another. Therefore, considerable interpretation (hand contouring and drawing of sedimentary facies) may be required to produce a realistic, usable product.

8.3.1.2.3.3.1.1.3 Suprabasalt sedimentary units

Sediments overlying basalt are to be characterized through a combination of borehole and surface outcrop studies. Studies will be limited to the Pasco Basin except where sediment studies must extend outside the basin in order to correlate units within the basin. Correlations of suprabasalt sedimentary units outside of the Pasco Basin will be done at the formation level, and thus detailed descriptions will not be necessary for stratigraphic studies. However, detailed descriptions may be produced under other studies such as deformation or structural geology studies. Studies are designed to characterize suprabasalt sediments for differentiation and correlation of internal features, to assess evidence for erosion and other potentially adverse geomorphic processes, and to provide a three-dimensional model of lithofacies for input into the structural geology and deformation studies. The studies in this task address the technical considerations relating to the establishment of marker units within the supra-basalt sequences that may be used to constrain the location, amount, and age of post-basalt deformation.

8.3.1.2.3.3.1.1.3.1 Summary of task methods. Methods used to characterize and correlate the suprabasalt sediments are listed in Table 8.3.1.2-9. Among these, borehole logging (both descriptive and geophysical) is performed on a routine basis for all boreholes drilled on the Hanford Site. An important test is age dating, which is required to determine timing and rates of post-basalt sedimentation and tectonic deformation. Other tests are performed on an as-needed basis. These types of tests include granulometric analysis, gravel lithologic counts, petrographic analysis, and density measurements. Other tests, such as paleomagnetics and paleosol characterization, will focus on specific intervals to refine stratigraphic correlations.

Stratigraphic information on the suprabasalt sediments will be analyzed and interpreted to determine which criteria are significant to a three-dimensional facies analysis. Units within the suprabasalt section will be contoured and correlated through cross sections and fence diagrams. Unlike basalt, however, sedimentary units may vary significantly, both laterally and vertically, from one borehole or outcrop to another. Therefore, considerable interpretation (hand contouring and drawing of sedimentary facies) may be required to produce a realistic, usable product. This information may then be used to assess geomorphic history and provenance as well as location, timing, and rates of tectonic deformation as discussed in the deformation study plan. Evaluation of detailed logs, from existing and planned boreholes, together with geophysical studies, will guide the need and design of additional borehole arrays through the suprabasalt sediments.

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8.3.1.2.3.3.1.2 Stratigraphic analysis of seismic reflection and refraction data. This study component will provide data to be used in defining the distribution of rock layers and the thickness variability of the layers. This definition process is accomplished by seismically mapping the subsurface units in the repository site and controlled area study zone. The data from this process will aid in extending stratigraphic mapping away from boreholes and has the potential to produce maps of thickness for both sediment and basalt units. These data are needed to improve correlation certainty between boreholes, to demonstrate unit continuity, and to identify areas of stratigraphic discontinuity which could affect vertical groundwater movement. This study component includes a series of tasks that will aid in resolving the stratigraphy of the controlled area study zone. Each task usually consists of a seismic reflection and (or) refraction survey for acquisition of the data. These data will be processed and the resulting seismic sections will be interpreted in conjunction with other geological, geophysical, and borehole data. These data are also being collected to support the structural geology study discussed in Section 8.3.1.2.3.3.4. Location maps of seismic surveys are included in this section.

Investigations of the stratigraphy using geophysical methods will rely principally upon seismic exploration methods. This is because other methods generally do not provide the resolution that is required to investigate the strata within the controlled area study zone. Other geophysical methods will be utilized in other studies to investigate the structure of the site. If any of these other methods are able to provide detailed stratigraphic information, they will be incorporated into this study.

The purpose of this study component is to provide a detailed, three-dimensional stratigraphic description of the rock, sediments, and disrupting structures in the controlled area study zone and the repository site. This description will be in terms of seismic parameters such as velocity and density, and the location and extent of interfaces and disturbing structures. Stratigraphic interpretation of these seismic parameters will depend upon the successful acquisition and processing of the seismic data in a basalt terrain. Previous seismic investigations at BWIP indicate that seismic data quality and resolution deteriorate rapidly within the basalt. High-resolution cross borehole geophysical techniques employing high frequency seismic and electromagnetic energy may be employed in strategic horizons within the basalt and sedimentary units as borehole and seismic data quality and resolution dictate.

8.3.1.2.3.3.1.2.1 Task descriptions

8.3.1.2.3.3.1.2.1.1 Seismic reflection development testing in the controlled area study zone. The purpose of this task is to acquire test data within the controlled area study zone and repository site, to develop acquisition methods necessary for future studies, to map the stratigraphy in the northwest area of the controlled area study zone, and to determine the origin of some potential geologic features that have been identified using other geophysical techniques. These techniques include magnetic, gravity, and reflection seismology.

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8.3.1.2.3.3.1.2.1.2 Acquisition and processing of three-dimensional test data near the exploratory shaft. The BWIP plans to conduct a full-scale test of high-resolution seismic reflection methods in the immediate vicinity of the exploratory shaft. It is expected that this test will use three-dimensional data acquisition methods although two-dimensional methods with a high grid density have not been ruled out. The surveys will be planned in stages with about one survey per year.

The first survey, a three-dimensional seismic test acquisition, must be completed before the beginning of the exploratory shaft. This is because exploratory shaft and Exploratory Shaft Facility construction will produce seismic noise that will preclude three-dimensional seismic survey data acquisition during construction. The preliminary three-dimensional test to be conducted is required to determine the acquisition parameters for the three-dimensional test. The three-dimensional test acquisition will be a major test of the three-dimensional seismic method within the repository site. This test will determine whether or not this method is usable within the BWIP site. If it is successful, then the repository site will be completely surveyed using this method. Otherwise these surveys will not be conducted. This decision will be made after extensive processing and interpretation of the test data.

8.3.1.2.3.3.1.2.1.3 Processing and interpretation of the three-dimensional test data. Because the fold of the data in a three-dimensional survey can be considerably higher than in a standard two-dimensional survey, considerable processing is required. In addition, considerable work is required to determine statics corrections and the velocity field for stacking. Processing of the small test survey will be carried out both by the contractor and the BWIP. The BWIP will concentrate on solving selected problems in the processing sequence that require significant effort and are specific to the area. To solve these problems, specific processing modules will probably have to be developed that are generally unavailable from suppliers.

8.3.1.2.3.3.1.2.1.4 Acquisition of three-dimensional data in the repository site. Assuming that the three-dimensional testing is successful, a three-dimensional seismic survey will be acquired in the repository site. The parameters to be used in the acquisition will be determined during the processing of the preliminary three-dimensional test data. Because of the large number of uncertainties, estimates of these parameters must be given at a later date.

8.3.1.2.3.3.1.2.1.5 Acquisition of two-dimensional data in the controlled area study zone. These data will be acquired to characterize the subsurface stratigraphy of the controlled area study zone. Based on a 225-km^2 (90-mi^2) controlled area study zone and a line spacing of 0.5 km (0.3 mi), 62 seismic reflection lines will be acquired for characterization of the controlled area study zone. This is about 900 km (560 mi) of seismic acquisition. This data will be acquired using the techniques that will be developed as a result of the tasks described above. If structures are found within the controlled area study zone which need better definition, additional two-dimensional or three-dimensional lines will be run in these selected areas.

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8.3.1.2.3.3.1.2.1.6 Processing and interpretation of two-dimensional and three-dimensional data. This task will involve processing and interpretation of the two-dimensional data acquired in the controlled area study zone and the three-dimensional data in the repository site. The processing will take place in parallel with data acquisition and will be assisted by the creation of synthetic seismograms for all applicable acoustic borehole logs within the area of the survey.

8.3.1.2.3.3.1.3 Analysis of thickness and distribution of strata. This study component will provide the analysis to determine the distribution and thickness variability of stratigraphic units. It will also contribute to the development of the geologic history of the site. The distribution of all units listed in Table 8.3.1.2-8 will be analyzed. This component will provide the stratigraphic models for the various areas of study listed on Table 8.3.1.2-8. These models will feed directly into the stratigraphic and structural model study.

The methods used in the analysis are standard geologic methods. These methods are construction of isopach maps, fence diagrams, facies maps, and geostatistical analysis. These will be constructed using both hand and computer mapping techniques. The data for the analysis will originate from the two previous components of this study (characterization and correlation of strata, and stratigraphic analysis of seismic reflection and refraction data) and from other geologic studies, such as geologic mapping completed in the structural geology and deformation studies, and results from geophysical surveys completed in the structural geology study.

This study component will supply thickness variations and distribution data of stratigraphic units that are important to design, hydrologic modeling, performance assessment, and characterization activities. The repository design requires knowledge of Cohassett flow thickness variations in the repository site and vicinity. Hydrologic modeling efforts require both thickness and distribution of units for groundwater flow models. These groundwater flow models will be used by performance assessment for calculations of radionuclide transport. Characterization activities use the results of this analysis for development of the geologic history of the site and for calculations of rates of deformation (see structural geology and deformation studies; Sections 8.3.1.2.3.3.4 and 8.3.1.2.4.3.1).

To assess the uncertainties of thicknesses of the Cohassett flow and Grande Ronde Basalt flows above and below the Cohassett flow and the Wanapum Basalt, a geostatistical analysis will be completed. The geostatistical technique to be used is kriging. The geostatistical analysis will yield uncertainty estimates of thickness variabilities. Estimates of errors will also be determined and reported.

8.3.1.2.3.3.1.4 Controlled area borehole inventory. This study component was established primarily to provide data to address Issue 1.8, PAC-19, "Evidence of Drilling for Any Purpose Within the Site." It will provide data on the location, drilled depth, construction details, and stratigraphic horizons encountered for all boreholes which have been drilled within the controlled area study zone. Drilling records of the Hanford Site

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and BWIP will be reviewed to determine the number of boreholes that could act as conduits for groundwater flow. This information will be used to determine the location, number, and characters of borehole seal requirements.

The existing borehole data base will be reviewed for completeness and data quality. A comprehensive data base for boreholes in the controlled area study zone will be developed providing location, depth, and condition for all known boreholes. The borehole data base will be maintained on a status current with site characterization and baseline activities through repository closure.

8.3.1.2.3.3.2 Intraflow structure study.

The intraflow structure study addresses performance and design issue parameters relating to the characteristics, thickness, and distribution of basalt intraflow structures. As such, the primary objective of the intraflow structure study is to establish the three-dimensional geometry of the internal characteristics of basalt flows at the site that results from the emplacement and cooling history of the flows. The focus of this study, therefore, is on the arrangement and characteristics of the intraflow structures within the Cohassett flow and the flows of the repository isolation zone as they occur in the repository site and the controlled area study zone.

Intraflow structures include flow top, flow interior and flow bottom and subdivisions of the flow interior: entablature, colonnade and columnar entablature (Fig. 8.3.1.2-10). Other primary features such as spiracles and pillow zones are also intraflow structures; however, their occurrence at the site is considered anomalous. Depending on the basalt flow in question, abrupt thickening of flow top or flow bottom or pods of internal primary breccia would also be considered anomalous intraflow structures. In general, the subdivisions of the flow interior are manifested through differences in cooling joint patterns visible in outcrop. It is the nature of occurrence and physical characteristics of these zones that are investigated in this study. Cooling joint characteristics are important in their own context and are the subject of a separate study (Section 8.3.1.2.3.3.3). Tectonic fractures and faults are secondary features formed by tectonic deformation or stress upon the flow. They are not classified as intraflow structures and are investigated in the structural geology study (Section 8.3.1.2.3.3.4).

In general, intraflow structures represent zones of different permeability and rock strength within a flow. The position of such zones, and their thickness and lateral extent, are the focus of this study.

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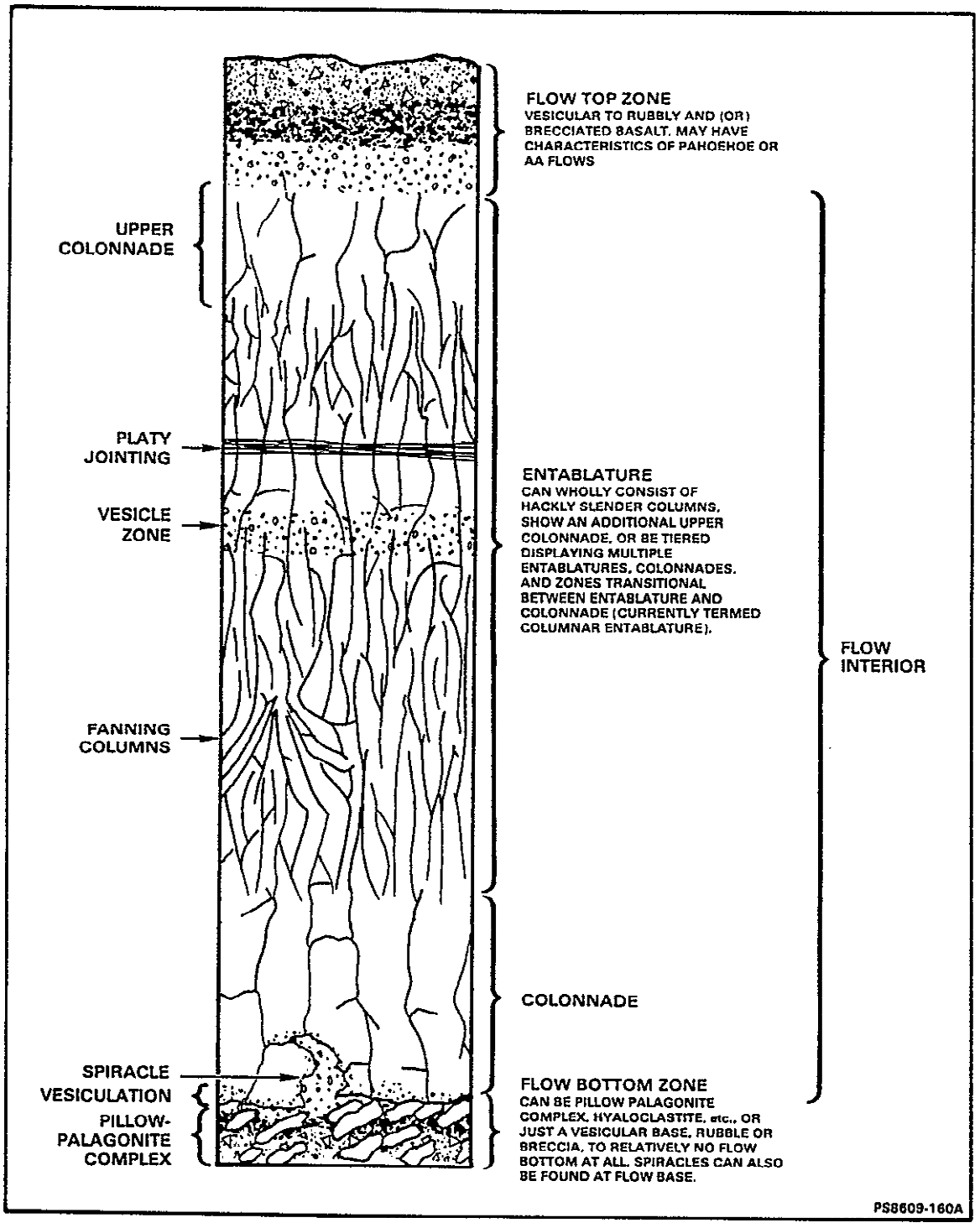

Figure 8.3.1.2-10. Idealized columnar section showing the range of intraflow structures possible in Columbia River Basalt flows.

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The study of intraflow structures comprises the following tasks and analyses:

- Borehole characterization and correlation of intraflow structures.
- Outcrop characterization and correlation of intraflow structure.
- Characterization of intraflow structures in exploratory shaft facilities.
- Analysis of intraflow structure data.

The first three tasks involve mainly data collection. The last will synthesize the information for data users.

The following are parameters to be obtained from the study of intraflow structures.

- Thickness.
- Position.
- Lateral continuity.
- Lithology.
- Occurrence of anomalous intraflow structures.

Table 8.3.1.2-3 in Section 8.3.1.2.3.1 shows the parameters that the intraflow structure study will supply and the issues from which these parameters originate. Some of the performance parameters specified by an issue are directly determined by the study. In other cases, supporting parameters are developed and supplied by the study to support a more generalized performance parameter. The most important scales (geographic areas and vertical packets of rock) at which each parameter is needed are also indicated on the table. Goals listed are based on current judgment and reflect the degree to which the parameter can be estimated at points unsampled over the area defined by the scale.

Specific technical considerations that deal with the nature, origin, and geometry of intraflow structures have been identified and help to further focus the investigative approach and activities within the intraflow structure study. These technical considerations include:

- Sufficient flow interior thickness and extent for repository layout.
- Identification, characterization, correlation, and predictability of thickness variations and lateral extent of intraflow structures of the Grande Ronde Basalt (i.e., Cohassett flow) across the controlled area study zone and vicinity.
- Origin of intraflow structures to aid in predicting their occurrence in the subsurface between boreholes.
- Characteristics of intraflow structures with respect to hydrologic properties.

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The technical considerations help focus the activities of the study because they describe specific topics that may need to be considered in evaluating the capability of the site to house a repository. For example, the characterization of the intraflow structures (variations in their thickness and their extent) is important. This is because the structures relate, in part, to the repository layout and whether the repository can physically be placed in sufficient thickness of basalt flow interior and maintain reasonable buffer thickness.

It is anticipated that intraflow structures can be measured by the various tests in this study to approximately one meter or less based on multiple geophysical logs, drill core, borehole deviation surveys, and planned and currently used methods of data collections at outcrop.

The tasks and analyses to be used in this study are summarized in Table 8.3.1.2-10. The table indicates the test methods, locations, number of tests, and the information generated. A brief description of each task is presented below. A more detailed discussion of the study and its component tasks and analyses are contained in the intraflow structure study plan.

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8.3.1.2.3.3.2.1 Borehole characterization and correlation of intraflow structures. Identification and measurement of intraflow structures will be conducted in all basalt flows penetrated by BWIP boreholes in the Pasco Basin. The identified intraflow structures will then be correlated with neighboring boreholes primarily in the repository site and controlled area study zone through the analysis portion of this study. Correlations of intraflow structures at Cold Creek syncline and Pasco Basin scales, where borehole spacing is less dense, will be attempted, as needed, but will contain higher uncertainties. The key intraflow structure parameters that will be determined from borehole studies are the position, thickness, lithologic characteristics, and the occurrence of anomalous primary features.

The borehole intraflow structure task consists of two interpretive techniques. One technique is the interpretation of intraflow structures from borehole core logging in new boreholes and relogging of the existing drill core. The other technique consists of the interpretation of intraflow structures from geophysical logging for both core and rotary-drilled boreholes. For rotary-drilled boreholes, downhole geophysical logging including borehole television is the only data source for interpretation of intraflow structures. Whereas, in cored boreholes, geophysical logs and basalt core logs are available data sources. All repository isolation zone flows penetrated by boreholes will be interpreted using one or both of the two techniques. Flow top, flow interior, vesicular zones, flow bottom, and anomalous primary features will be interpreted for all the applicable flows. An additional determination of intraflow structures in the flow interior will occur for the Cohassett flow in the repository site or in the controlled area study zone because of its prime importance as the host rock.

Table 8.3.1.2-10. Tasks/tests/analyses for the intraflow structures study (sheet 1 of 3)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Borehole characterization and correlation of intraflow structures	Core lithologic sampling Sampling for petrographic analysis of polished thin sections Association of like features in core	Exploratory Shaft Facility Controlled area study zone Cold Creek syncline Pasco Basin	Per cored borehole penetrating the repository isolation zone	Positions of intraflow structures in Cohassett and buffer flows Thickness of flow top, colonnade, entablature, vesicular zones, and flow bottom in Cohassett flow Occurrence of anomalous features in borehole core Lithologic characteristics of intraflow structures of Cohassett flow and buffer flows	Thickness variation Position Lithologic characteristics
	Borehole Geophysics: television, neutron/neutron, bulk density, sonic, passive gamma, and electric	Exploratory Shaft Facility Repository site Controlled area study zone Cold Creek syncline Pasco Basin	Per rotary borehole drilled during site characterization	Position and thickness of flow top Position and thickness of flow interior/vesicular zones Position and thickness of flow bottom	Thickness variation Position Physical property estimates
Outcrop characterization and correlation of intraflow structures	Geologic mapping Stratigraphic section measurements Sampling for polished thin section analysis Photo mapping	Sentinel Gap Sentinel Mountain McCoy Canyon Snake River Columbia Gorge/Deschutes River	Approximately 20 to 40 measured sections per location	Position of intraflow structures Lithologic characteristics of intraflow structures Thickness of flow top, entablature, colonnades, vesicular zones, and flow bottom in all flows examined	Lateral continuity Thickness variation Position Frequency of occurrence of anomalous features Lithologic characteristics

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CONSULTATION DRAFT

Table 8.3.1.2-10. Tasks/tests/analyses for the intraflow structures study (sheet 2 of 3)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Outcrop characterization and correlation of intraflow structures (cont.)	Possible core drilling and(or) detailed sampling of outcrop, especially flow top	Yakima River vicinity Vantage and North vicinity	Approximately 20 to 40 measured sections per location (cont.)	Observation of anomalous features in outcrop	
Characteristics of intraflow structures in the Exploratory Shaft Facility	Exposure and photo mapping/observation of mined openings	Exploratory Shaft Facility	NA	Position and thickness of intraflow structures in mined openings around shaft	Thickness variation
	Examination and interpretation of core from shaft and drift boreholes			Observation of entablatures and colonnades	Lateral continuity of intraflow structures over and around exploratory shaft area
	Polished thin section sampling of exposed surfaces and core			Lithologic characteristics Observation of anomalous features detected	Lithology
	Interpretation of geophysical data: cross-hole seismic; seismic reflection; ground probing radar; and borehole geophysical logging	Exploratory Shaft Facility	For all applicable Exploratory Shaft Facility boreholes, shafts, and drifts	Position of intraflow structures around the Exploratory Shaft Facility Thickness of intraflow structures around the Exploratory Shaft Facility	Position, thickness variation, lateral continuity, and physical property estimates of intraflow structures between boreholes and around the Exploratory Shaft Facility
				Anomalous occurrence of intraflow structures around the Exploratory Shaft Facility	Detection, delineation, and characterization of intraflow features encountered within logged core holes
Analysis of intraflow structures	Three-dimensional model development	Repository site Controlled area study zone Cold Creek syncline Pasco Basin	NA	Analysis uses data from all tests and analyses in this study	This allows development of a three-dimenstional model of the geometry of intraflow structures for any geographic area of concern

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CONSULTATION DRAFT

Table 8.3.1.2-10. Tasks/tests/analyses for the intraflow structures study (sheet 3 of 3)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Analysis of intraflow structures (cont.)	Development of intraflow structure classification system	Used for Repository Site	Apply to all cored boreholes	Textural characteristics of rock samples collected from all data collection tasks	Ability to identify intra-flow structures in flow interiors using drill core
	Geostatistics	Apply to all scales as needed, especially repository site	NA	Analysis provides both estimates of intraflow structure position and thickness at points unsampled and data between boreholes in the controlled area study zone	Analysis provides both estimates of intraflow structure position and thickness at points unsampled and data between boreholes in the controlled area study zone
				Analysis allows determination of uncertainty in the above estimates over the area modeled	Determination of uncertainties in the above estimates provide a measure of when needed confidences are achieved
	Modeling origins of intraflow structures, examination of young analogues to Columbia River Basalt flows	Not required for analysis	NA	Improved ability to predict: entablature and colonnade in subsurface; frequency of occurrence of anamalous intraflow structures; and resolution of feature origin (e.g., platy fracture zones)	Improved ability to predict: entablature and colonnade in sub-surface; areal distribu-tion of anomalous intra-flow structures; and resolution of feature origin (e.g., platy fracture zones)

NA = Not applicable.

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CONSULTATION DRAFT

8.3.1.2.3.3.2.1.1 Study locations

Intraflow structure studies supporting repository design currently define the need for one and possibly two additional host-rock-depth cored boreholes near the repository site (Fig. 8.3.1.2-11, boreholes RRL-18 and RRL-19). The need for these cored boreholes is based on a preliminary geostatistical analysis of borehole and outcrop data (Taylor, 1987). This analysis was conducted in support of repository design using repository elevations from RKE/PB (1985) with modifications to attempt to centralize the repository in the Cohassett flow. The geostatistical analysis also indicated the need for approximately 20 shallow, top-of-Pomona Member boreholes (6 to 8 per deep borehole) (see Fig. 8.3.1.2-11). These boreholes are needed to aid in reducing uncertainties in positions of bottom of flow top and top of flow bottom in the Cohassett flow at these locations in order to meet 80% confidence level requirements for repository advanced conceptual design. Additional cored boreholes may be needed if analysis demonstrates that areas having unacceptable levels of uncertainty continue to exist at Cohassett depths. Of the 20 shallow boreholes mentioned above, one set of six to eight shallow boreholes would be drilled near RRL-17 to aid in reducing intraflow structure uncertainties in that area.

When borehole DC-18 (see Fig. 8.3.1.2-11 for location, and Section 8.3.1.2.3.3.4 for a discussion of DC-18) is completed, core and geophysical logs will be interpreted to determine intraflow structures in all penetrated flows.

Additional intraflow structure data could be obtained from a deep borehole (through the basalt). The need for such a borehole is multidisciplinary and will be assessed in a position paper. Intraflow structures would be characterized in all basalt flows penetrated by this borehole to aid intraflow structure characterization and to support testing conducted by other studies such as site groundwater and resource potential.

Multiple hydrologic boreholes for emplacement of piezometers for pre- and post-exploratory shaft testing will be drilled starting with pre-exploratory shaft boreholes DC-23GR, DC-24CX, DC-25CX, DC-32CX, and DC-33CX (see Fig. 8.3.1.2-11). The post-exploratory shaft boreholes are DC-26, DC-27, DC-28, DC-29, DC-30, and DC-31. Other hydrology boreholes are planned to be drilled during site characterization including approximately 11 SC boreholes (site groundwater study plan). Also approximately seven boreholes are currently planned for hydrochemistry investigations. All these boreholes will also be used for interpretation of intraflow structures at controlled area study zone and Cold Creek syncline scales.

Several issues define the need for intraflow structure characterization of repository isolation zone flows in the controlled area study zone and the Cold Creek syncline. Currently, borehole DC-16A is the only borehole in the controlled area study zone that penetrates at least three flows below the very high Mg flow (definition of the lower buffer zone at the repository isolation zone). A number of existing boreholes in the controlled area study zone and several future boreholes drilled in the controlled area study zone should

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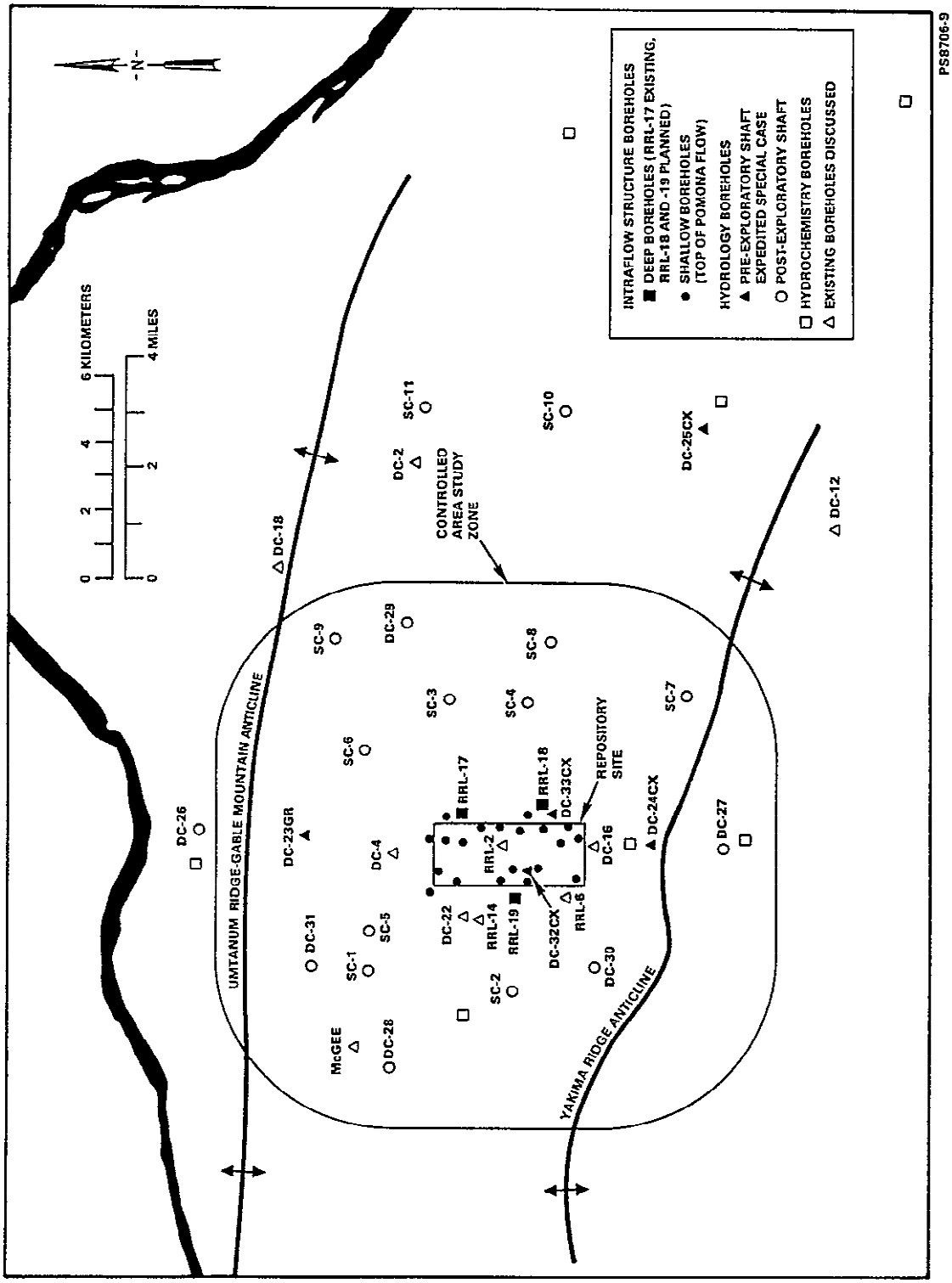

Figure 8.3.1.2-11. Location map of boreholes relevant to intraflow structure studies.

extend to at least three flows below the very high Mg flow to allow proper characterization of the lower buffer zone. Intraflow structure studies would occur in any boreholes deepened or drilled to those depths in the future in the controlled area study zone. Candidate boreholes for deepening are RRL-14 or DC-22, RRL-17 and McGee. A minimum of three to five boreholes penetrating the Grande Ronde Basalt in the controlled area study zone should be drilled to these depths including cored boreholes RRL-18 and RRL-19.

As studies progress during site characterization, the need for additional boreholes for intraflow structure studies will be assessed continually. If results indicate that uncertainties in intraflow structure parameters are unacceptably high, then additional boreholes will be drilled in locations to optimize reduction in those uncertainties.

8.3.1.2.3.3.2.1.2 Task methods

The borehole intraflow structure task consists of two interpretive techniques: geologic logging of core and geophysical logging.

8.3.1.2.3.3.2.1.2.1 Geologic logging. Core logs contain over forty separate items of information concerning physical characteristics of the core. The core logging is generic and multiple geologic studies use the information. Specific information on those logs that are used to make intraflow structure interpretations include fracture density, texture, color, vesiculation, and presence of and description of rubble or breccia. In addition, the core is physically examined and sampled at the Hanford Geotechnical Sample Library (where the core is stored) to aid in making intraflow structure interpretations.

Samples collected from the core are made into polished thin sections for petrographic analysis. Petrographic thin section analysis accomplished in the mineralogy and petrology study allows determination of microscopic textural characteristics which are correlated to intraflow structures.

Borehole core will also be sampled for laboratory measurement of physical properties to relate to geophysical logging. This work will be done by the physical rock properties study, but the information will be useful to intraflow structure applications. Core relogging will be conducted to replace old core logging information with information of the same level of detail and quality as new core logging. Borehole core currently scheduled for relogging are from boreholes DC-4, RRL-2A, RRL-6, RRL-14, DC-2 and DC-12 (see Fig. 8.3.1.2-11). This will upgrade core information from all cored boreholes in and near the controlled area study zone. Intraflow structure interpretations that currently exist for these boreholes will be re-evaluated based on the new data. Sampling for textural analysis of polished thin sections of this existing core will be conducted, as needed, for the Cohassett flow to aid in refining interpretations. Upgraded intraflow structure information for these key controlled area study zone boreholes will allow more reliable correlation of intraflow structures from borehole to borehole in the repository site and controlled area study zone. This correlation is accomplished by the analysis of the intraflow structures task.

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8.3.1.2.3.3.2.1.2.2 Geophysical logging. Geophysical logging will be performed in core and rotary drilled boreholes to aid in hydrologic testing and to provide basic data. Intraflow structure interpretations from geophysical logs delineate zones of flow top and bottom, vesicular zones, relatively dense interior, and, in some cases, anomalous zones. Interpretations of intraflow structures from geophysical logs primarily use television, neutron/neutron, and bulk density logs and involve standard geologic interpretation of the various geophysical tools' responses to changes in the physical characteristics of the rock as expressed on the logs. Intraflow structures are identified based on changes in porosity and bulk density of the rock with flow tops and bottoms typically having a lower bulk density and higher apparent porosity, and a neutron response indicative of higher water content. Vesicular zones typically exhibit similar responses but to a lower magnitude. Flow interiors characteristically display a higher bulk density and low apparent porosity. Rock property changes such as vesicular-to-brecciated flow tops and bottoms, stratified occurrences of vesicles and vugs in zones in the flow interior, and relatively dense rock displaying cooling fractures are usually visible on the television logs when hole enlargement is not excessive or when the borehole conditions are relatively clear. If adequate television logs cannot be obtained in future boreholes because of poor borehole conditions, the borehole acoustic televiewer log will be used to aid in making intraflow structure determinations.

Based on physical rock properties measurements of core samples, it should be possible to determine which geophysical logging techniques best delineate intraflow structures. This should allow better determination of intraflow structures in rotary boreholes.

Geophysical logging will also be conducted via the physical rock properties study to acquire data on bulk density, total porosity, electrical resistivity, gamma ray count rate, compressional and shear wave velocities, and any attribute that may be derived from a full waveform sonic log (e.g., Stoneley wave velocity, attenuation), if it is possible to obtain an adequate full wave form sonic log. Information from this work will be utilized to determine if more detailed delineation of intraflow structures may be performed using geophysical logging in rotary-drilled boreholes. It may aid in characterizing zones of porosity or permeability in flow tops/bottoms for support to hydrologic testing and modeling.

8.3.1.2.3.3.2.1.2.3 Constraints. A constraint for borehole intraflow structure studies is that most boreholes to be drilled during site characterization are for hydrology-related purposes. Most of these boreholes will be rotary drilled so no drill core will be obtained. Intraflow structure determinations for these boreholes rely on interpretation of geophysical logs. Only flow top, vesicular zones, flow interior thickness, and flow bottom can be interpreted with high confidence from geophysical logs, and there are larger uncertainties involved in these interpretations than equivalent interpretations from drill core.

New geophysical logging of existing cored surface boreholes in the controlled area study zone will be undertaken because some past geophysical

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logging in these cored boreholes is insufficient to allow determination of physical properties to relate to intraflow structures. Portions of past geophysical logging do not provide the required suite of logs, do not adequately assess tool drift during logging, and do not meet certain industry standards for calibration of tools and implementation of depth control. Improved geophysical logging will permit quantitative rock property estimates from the logged boreholes to be compared with information on drill core lithologic logs. Such comparisons will aid in interpreting intraflow structures in rotary boreholes where core is not available.

Adequate geophysical logging data can be acquired in previously drilled surface boreholes by relogging the well within intervals that have not been cased. The Site Groundwater Study plans to reinstrument some boreholes, which will be geophysically relogged with a complete suite of logs (physical rock properties characterization study plan) while the holes are open during a change in instrumentation.

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8.3.1.2.3.3.2.1.2.4 Tolerance, accuracy, or precision. Borehole core is logged every 0.06 m (0.2 ft). For intraflow interpretations these data are smoothed to approximately 1-m (3-ft) resolution to conform to interpretations at outcrop.

Current geophysical logs have an accuracy of depth control of approximately ±1 m (3 ft). Sharp delineations on a log from one intraflow structure to the next may be more precise.

8.3.1.2.3.3.2.2 Outcrop characterization and correlation of intraflow structures. Outcrop characterization and correlation of intraflow structures consist of the identification and measurement of intraflow structures at outcrops of the host rock and surrounding flows in and surrounding the Pasco Basin. Intraflow structures are correlated laterally between measurement sites to determine lateral continuity. The key parameters that will be determined from outcrop interpretations are the position of intraflow structures per flow, the thickness of each intraflow structure, the lateral continuity of intraflow structures over distances up to a few kilometers, lithology of intraflow structures, and the frequency and characteristics of occurrence of anomalous primary features.

The outcrop intraflow structure task consists of collecting a series of measured sections at each applicable outcrop location, recording the thickness, position, and lithologic characteristics of each intraflow structure, and interpreting the correlation and continuity of the intraflow structures from one measured section to the next. The measured sections will resemble stratigraphic sections; however, they will concentrate exclusively on intraflow structure measurement and interpretations up through the stratigraphic sequence of flows represented at each section location. Typically, approximately four to six upper Grande Ronde Basalt flows (including the Cohassett flow) are exposed and thus measured at a section. The number of sections measured at each outcrop location depends on the exposures of the

appropriate flows, access to the outcrop, and spacing of the exposures laterally. As a guide, an intraflow structure measured section is conducted, if possible, approximately every 200 m (~660 ft) of lateral distance of study location.

Platy jointing (see Section 1.2.1.2.2) has been observed and recorded in the Cohassett flow in intraflow structure sections collected at Sentinel Gap (see Fig. 8.3.1.2-12). These features are unknown in origin and require additional work to characterize their occurrence. Information concerning the occurrence of these features will continue to record at all study locations and in all flows observed. The behavior of cooling joints as they enter and pass through these zones, the potential occurrence of diktytaxitic laminae in association with platy jointing, and possible petrographic textural differences within these zones will be investigated. Recording their occurrence at measured sections will also result in information concerning the position within the flow, thickness of platy jointing zone, average size of plates, and lateral persistence. Because of their uncertain origin, these features will also be investigated for a possible tectonic genesis (see the deformation study plan).

Data collected at outcrop where great thicknesses of flow top breccia are observed, such as in the Umtanum flow at McCoy Canyon (see Fig. 8.3.1.2-12), will be used to understand this phenomenon. The lithology of the flow top will be described in detail. Samples for polished thin sections will be collected throughout this flow top to help evaluate origins. Also, core plugs may be taken to enable some physical property testing.

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8.3.1.2.3.3.2.2.1 Study locations

Eight study locations are currently identified for intraflow structure interpretations at outcrop studies (Fig. 8.3.1.2-12). The first four locations are in or on the margin of the Pasco Basin and are the only known outcrop occurrences of the Cohassett flow and primary isolation zone flows in the basin. There are no outcrops of the Cohassett flow or primary isolation zone flows in the controlled area study zone. The other four outcrop locations surround the Pasco Basin yet lie as close to the Pasco Basin as possible for their given direction. These locations encompass a range of environmental conditions encountered during emplacement and cooling of a Columbia River basalt flow. Variable conditions of emplacement and cooling influence the formation of intraflow structures. Examining multiple locations representing various emplacement environments will provide data necessary to interpret conditions that may be encountered in the site during borehole drilling, Exploratory Shaft Facility construction, and repository construction.

8.3.1.2.3.3.2.2.2 Task methods

Intraflow structure data are collected at outcrops using standard geologic measured section techniques. The stratigraphy is established first by measurement of one or more stratigraphic sections. Sites for intraflow structure section measurement are identified within a study area using large

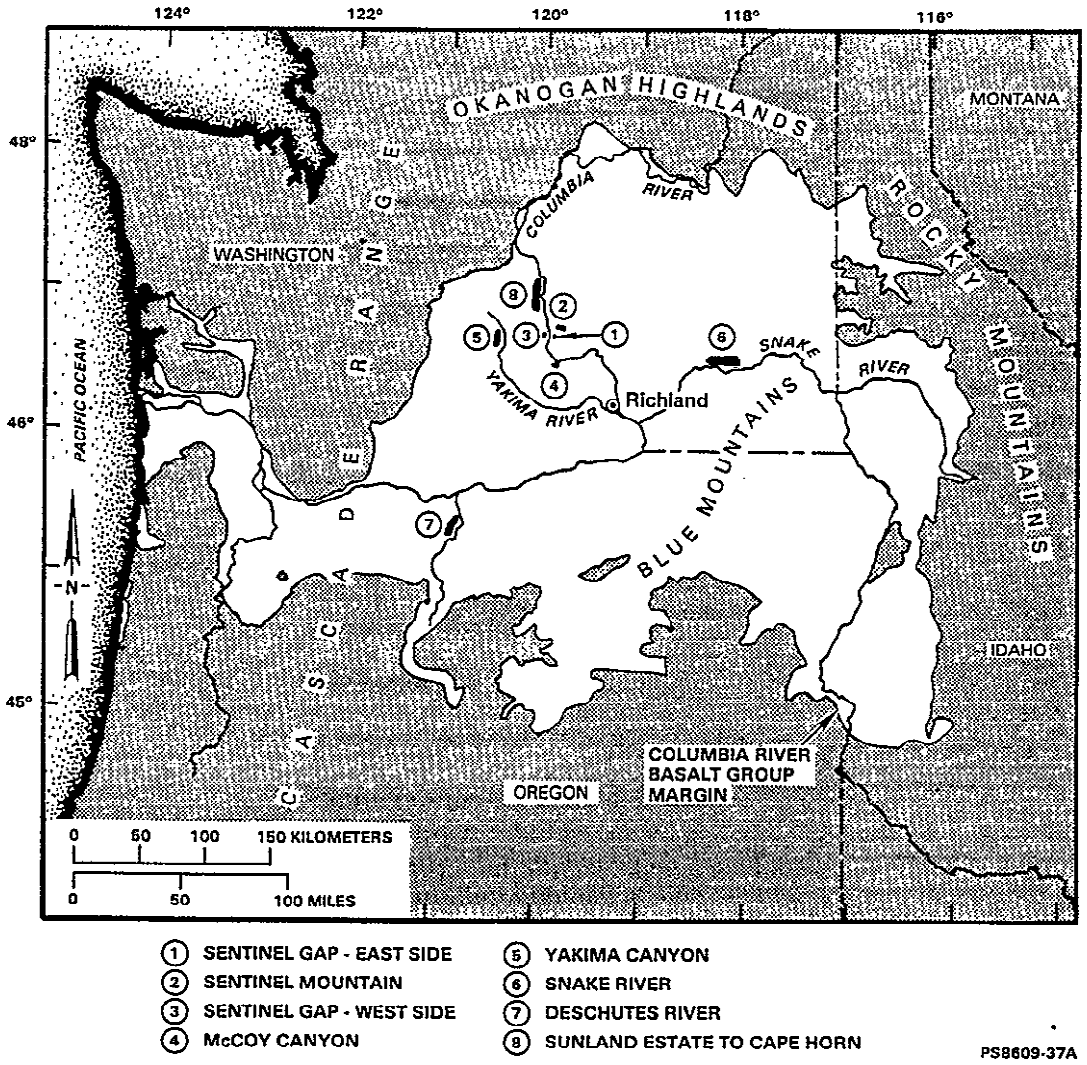

Figure 8.3.1.2-12. Eight locations for planned intraflow structure studies at outcrops.

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format photographs of the study area and by field reconnaissance of the study location. Measured section sites will be chosen based on the degree of exposure of Grande Ronde Basalt flows, access to exposures for measurements, and suitable spacing between measured section sites. Intraflow structure sections will be measured using the Jacobs staff/Abney level method, direct vertical measurement with a metric measuring tape or chain, or measurement along slope with tape or chain and Brunton compass.

Data collected per each intraflow structure encountered in the section include the intraflow structure type; measured thickness; color; average column diameter; percent abundance, size and distribution of vesicles and vugs; and the morphology of flow tops and bottoms. Anomalous intraflow structures such as spiracles, pillow zones, platy zones, or abrupt, significant thickening of flow top or bottom, are recorded along with other intraflow structure information at each measured section or when encountered on traverses between sections.

Lateral continuity of intraflow structures between sections is determined by walking contacts and use of large scale oblique-to-perpendicular aerial photographs of outcrop exposures.

Lithologic sampling is conducted at selected measured sections for creating polished thin sections. Textural information from the thin sections are used to further interpret intraflow structures observed in outcrop, especially where nondescript physical characteristics make determination of intraflow structures difficult. Petrographic textural information from outcrop sampling will also be used to develop a classification system. The classification system is needed as an aid in determining colonnade and entablature in the Cohassett flow interior in drill core so these features can then be correlated between boreholes in the repository site.

Short core plugs may be taken from various intraflow structures at measured section locations or from anomalous features to obtain samples suitable for physical properties testing. Results of this testing will be utilized with the core testing to guide borehole geophysical logging interpretation.

<u>8.3.1.2.3.3.2.3 Characterization of intraflow structures in the Exploratory Shaft Facility</u>. The characterization of intraflow structures in the Exploratory Shaft Facility consists of identifying and measuring intraflow structures in the Cohassett flow in situ. Intraflow structures will be mapped and presented in plan and cross-sectional views. This information will be subsequently correlated with surrounding surface borehole data.

The key parameters that will be determined from studying intraflow structures in the Exploratory Shaft Facility are the location, thickness, lateral continuity, character of any anomalous features, and lithology.

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The Exploratory Shaft Facility intraflow structure task consists of four activities as currently envisioned. The first activity will be to conduct intraflow structure characterization of the exploratory shaft. Intraflow structures will be interpreted from geophysical logging of the shaft walls similar to the method in any rotary-drilled borehole. The second activity will be to obtain and log borehole core from boreholes drilled out from the exploratory shaft or from probe holes drilled out from Exploratory Shaft Facility drifts and tunnels. Intraflow structures will be interpreted from the core logging data and core in the same manner as surface-based borehole studies discussed earlier. All Exploratory Shaft Facility borehole core will be logged and interpreted for intraflow structures. The third activity will be to map intraflow structures exposed in the walls, floor, and roof of Exploratory Shaft Facility drifts and tunnels during construction of the Exploratory Shaft Facility. Intraflow structure mapping of all mined surfaces in the Exploratory Shaft Facility will be performed. Lastly, intraflow structures will be detected and characterized to the degree possible by geophysical logging in boreholes drilled out from Exploratory Shaft Facility workings and by geophysical probing out from the drifts and tunnels.

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8.3.1.2.3.3.2.3.1 Task methods

Characterization of intraflow structures such as flow top and bottom, flow interior, and vesicular zones in the exploratory shaft can be achieved by use of borehole geophysical logging. The shaft drilling should provide rock chip samples that will be collected and logged as standard practice. These samples will be used as needed to further interpret intraflow structures or anomalous zones encountered in the exploratory shaft.

Mapping all mined surfaces of underground openings in the Exploratory Shaft Facility for intraflow structure determinations will be conducted in a manner similar to data collected at outcrops. It is currently envisioned that there will be three types or stages of geologic mapping in Exploratory Shaft Facility tunnels. The first stage is a quick turnaround approach where gross intraflow structure determinations will be made after each tunnel advance to aid in quickly determining initial rock support requirements. The second mapping stage, would be general mapping. In this stage intraflow structure data collection would consist of conducting a series of 360-degree measured sections at approximately 5- to 10-m (16- to 33-ft) increments along the tunnel. It is planned that 360-degree continuous coverage photography of the tunnels will be taken behind the advancing face, and the imagery will be available for mapping. The third stage of mapping is a detailed mapping stage. If anomalous intraflow structures are encountered during tunnel advance, then this stage may be utilized to do detailed intraflow structure data collection and sampling of these features.

Borehole geophysical logging will be performed in all NX size and larger boreholes drilled from drifts and tunnels within the Exploratory Shaft Facility. Information from techniques such as cross-hole seismic measurements, electromagnetic (radar) probing and seismic reflection/transmission tests to be performed at all available locations within the drifts, tunnels, and test boreholes of the Exploratory Shaft Facility will also be used to interpret intraflow structures.

Exposed surfaces and borehole core will be sampled for subsequent petrographic textural analysis to aid in interpreting intraflow structures in the Exploratory Shaft Facility.

8.3.1.2.3.3.2.3.2 Tolerance, accuracy, or precision

Intraflow structure positions and thicknesses measured on Exploratory Shaft Facility walls, roofs, and floors should be accurate to ±0.1 m (0.3 ft). It is currently anticipated that a tolerance of ±0.1 to 0.25 m (0.3 to 0.8 ft) will be acceptable.

It is currently believed that Exploratory Shaft Facility borehole core logging will be at an accuracy of ±0.06 m (0.2 ft), equivalent to present surface borehole core logging. Intraflow structure interpretations from this logging should have an accuracy of approximately ±0.5 m (1.6 ft) or less.

8.3.1.2.3.3.2.4 Analysis of intraflow structure data. There are four primary analysis techniques to be used for intraflow structure data. The first combines data from outcrop, borehole, and Exploratory Shaft Facility intraflow structure studies to develop a three-dimensional model of intraflow structure geometry in the host rock and other repository isolation zone flows for input to the stratigraphic and structural model. The second develops a classification system relating petrographic textural information from thin section analysis of outcrop samples to intraflow structures observed in outcrop and use this system to interpret the occurrence of host rock flow interior intraflow structures in cored boreholes. The third uses geostatistics to estimate values for intraflow structure parameters at points unsampled for interpolation in the repository site, controlled area study zone, and possibly Cold Creek syncline and Pasco Basin, and to quantify uncertainties for those estimated values. The fourth determines, to the degree possible, the origin of various intraflow structures observed in the host rock and surrounding flows to interpret the occurrence of intraflow structures and to aid in their prediction of probability of occurrence in the controlled area study zone or other areas of interest.

8.3.1.2.3.3.2.4.1 Three-dimensional model development

Development of the three-dimensional model of intraflow structures at various levels of detail and at various scales will include manual- and computer-assisted graphic techniques, geostatistics, classical statistics, and analyses of origins of intraflow structures. Development of a three-dimensional model requires stratigraphic correlations of flows over the area of concern. This is accomplished in stratigraphy studies. Given a stratigraphic framework, it is then possible to correlate intraflow structures between boreholes, interpolate variability, and project the occurrence of anomalous intraflow structures over the area of concern, all on a "per flow" basis.

Intraflow structures are correlated from one borehole to the next based on the sequencing, positions, thicknesses, lithologic characteristics, and textural characteristics of the intraflow structures per borehole. In all

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flows but the Cohassett flow, the only intraflow structures that data users will require to be correlated from one borehole to the next are flow top, flow interior, and flow bottom. Correlation of entablatures and colonnades will be undertaken in the Cohassett flow interior. This will provide a detailed intraflow structure geometry of the host rock for repository design and development activities. Correlation of intraflow structures for the host rock in the repository site will use the Exploratory Shaft Facility data also.

Interpolation of intraflow structures between boreholes will rely on interpretations of outcrop intraflow structure data, Exploratory Shaft Facility data, geostatistics, and the results of origin modeling. These will yield statistical and judgmental portrayals of the variability of intraflow structures between boreholes.

Projecting the occurrence of anomalous intraflow structures in a flow over a geographic area will again be based on outcrop data and on developed hypotheses of origin of these features. It will also use statistical techniques to aid in distributing these features at some frequency of occurrence. If anomalous features are encountered in the Exploratory Shaft Facility, this data will also be used for distributing features in the Cohassett flow.

The correlation of interpreted data between boreholes, the interpolations of variability between boreholes, and the distributions of anomalous features over an area together comprise a three-dimensional model of intraflow structure geometry per flow. A model will be created for each scale important to the data users. The three-dimensional model of intraflow structure geometry of these different scales will be input to the stratigraphic and structural model's corresponding scales. The model will be constructed using both manual- and computer-mapping techniques.

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8.3.1.2.3.3.2.4.2 Intraflow structure classification

Classification of intraflow structures is an analysis that aids in interpretation of host rock flow interior intraflow structures in drill core and facilitates their correlation between boreholes.

At outcrop colonnade, entablature, and columnar entablature are readily identified based primarily on column diameters, cooling joint patterns, and color. Samples taken from these identified zones in outcrop will provide a data base for thin section analysis to establish the range of petrographic textures observed per known intraflow structure. An attempt will then be made to discriminate the petrographic textural characteristics recorded per intraflow structure. If distinguishable fields can be obtained per colonnade, entablature, and columnar entablature, a system will then exist for classifying these intraflow structures in the host rock interior in borehole core.

Existing polished thin section samples from Cohassett flow drill core in the controlled area study zone will be supplemented by additional sampling based on core relogging. Petrographic analysis of these samples will then be

conducted and the resultant information input to the classification system. Where each sample plots on a textural triangle will classify the intraflow structure it represents. If this method is successfully developed, host rock flow interior intraflow structures can be quantifiably interpreted per borehole in the controlled area study zone. This technique would then be applied to the host rock interior samples for all future cored boreholes in the controlled area study zone.

To date, intraflow structures in the flow interior of the host rock in existing cored boreholes have been determined using color, cooling joint density, and macroscopic textural changes. Identifying and delineating intraflow structures using these criteria is difficult and has higher associated uncertainties than intraflow structure interpretations at outcrop. A quantitative classification system would make flow interior intraflow structure interpretations more certain and would facilitate the identification of the sequencing and thickness of these intraflow structures in cored boreholes thus allowing proper correlations.

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8.3.1.2.3.3.2.4.3 Geostatistical analysis

Geostatistical analysis is used to produce quantitative information to aid in interpolating intraflow structure variability between boreholes in model development.

The geostatistical technique of ordinary kriging (Journel and Huijbregts, 1978, pp. 303-410) has been used to date in intraflow structure analysis (Taylor, 1987) and will be used in site characterization.

Geostatistical analysis will use all the borehole data, in a specific geographic area, for a particular intraflow structure to estimate the distribution of its thickness, position, or some other characteristic over that area. It will also provide the uncertainty in that estimate per point of estimate. The spatial estimation of that data will be utilized for the interpolation process of three-dimensional model development.

Kriging-produced estimated values and uncertainties can be contoured to yield evaluations over geographic areas (contour maps). Gridded data files for the contour maps of estimated values will integrate well with other contoured information in Interactive Surface Modeling Software to develop the three-dimensional models of intraflow structures. Uncertainty estimates from geostatistics will allow evaluation of the confidence levels achieved by the various models. If uncertainties are too great in areas, geostatistics will be used to define the location and number of boreholes to be drilled to address those uncertainties.

Geostatistics may have to rely on judgmental use of outcrop data to appropriately define the short range variability of an intraflow structure in variogram development. This is due to the fact that most boreholes are not closely spaced and do not provide the closely spaced data needed to define short range variability.

Other geostatistical techniques that may be used if needed (and if data sets are large enough to permit their use) are listed below. The possibility of their use will be examined early in site characterization.

- Universal kriging.
- Indicator kriging.
- Soft kriging.
- Conditional simulation.

8.3.1.2.3.3.2.4.4 Analysis of origin

Analysis of origin of intraflow structures will supply information needed to aid in interpolating the variability of intraflow structures and aid in projecting the occurrence of anomalous intraflow structures.

Analysis of origin of intraflow structures will include several tasks. One task will be to identify the primary features commonly observed in basalt flows in or near the Pasco Basin. Another task will entail the development of thermal contraction/convection models. Thermal models may solely, or in combination with other possible models and (or) factors such as volatile content of a basalt flow, account for the occurrence of intraflow structures observed in Columbia River Basalt flows of interest to the BWIP. Development and evaluation (peer review in the external technical arena) of hypotheses to explain the origin of specific intraflow structures that arise from emplacement or consolidation of a basalt flow are other tasks in the analysis of origin of intraflow structures. Current primary features of concern are vesicular zones, anomalously thick flow top breccias, and platy fracture zones. An additional task may be to examine unique modern analog locations such as Iceland where environmental conditions of emplacement and post emplacement are known or readily interpreted for basaltic flows because of their relatively recent eruptions. Data on occurrence of spiracles, presence or absence of platy fracture zones, location and extent of entablatures and colonnades, occurrence of flow tops and bottoms, and occurrence of vesicular zones under the conditions and mechanisms that these flows were emplaced and consolidated will provide a basis to help evaluate the origin of intraflow structures observed in basalt flows in the Pasco Basin.

8.3.1.2.3.3.3 Cooling joint characteristics study.

the primary objective of the cooling joint characteristics study is to identify and characterize those cooling joint parameters important to the design and assessment of the performance of the repository. The specific cooling joint parameters under investigation were defined as support to design and performance issues. Characterizing the parameters includes statistical description of cooling joint parameter samples, comparison and combination of the samples into appropriate groups representing populations, and development of cooling joint models.

The study is confined to the characterization of one type of joint found in basalt flows--cooling joints. Cooling joints, like faults and tectonic joints, are discontinuities in the rock mass. Cooling joints are formed by

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the stress induced as lava cools and are ubiquitous. Tectonic joints and faults are caused by tectonic stress. The characterization of tectonic joints and faults is addressed in the structural geology study (Section 8.3.1.2.3.3.4) and the deformation study (Section 8.3.1.2.4.3.1).

Four tasks and analyses have been developed for the cooling joint characteristics study:

- Characterization of cooling joints in outcrop.
- Characterization of cooling joints in boreholes.
- Characterization of cooling joints in underground exposures of the exploratory shaft facilities.
- Cooling joint modeling.

The first three tasks and analyses include the collection of data that characterize cooling joints and the statistical summarization of the data. These tasks will focus on characterizing the following cooling joint parameters (see Section 1.2.1.2.3 for a description of each parameter):

- Persistence (crack length).
- Orientation.
- Frequency (or spacing).
- Width.
- Percent filled with secondary minerals.
- Type or composition of the secondary mineral infilling.
- Wall-rock alteration.
- Roughness.
- Termination type.
- Void geometry.
- Percentage of cooling joints that break in core.

The fourth task, cooling joint modeling, is designed to integrate the data derived from the first three tasks. Cooling joint modeling includes the development of three models.

- Geotechnical mapping units model.
- Pattern simulation model.
- Origin model.

The geotechnical mapping units model will be the end product of statistically comparing and combining the parameter measurement samples into the smallest number of appropriate populations that fit some kind of three-dimensional geological framework. Each geotechnical mapping unit will have a set of attributes making it unique but still useful to repository design or performance assessment. The pattern simulation model will be a two- or three-dimensional characterization of joint patterns using computer graphics. Patterns will be representative of typical cross sections through the rock

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mass, and the geotechnical mapping units will be the basic unit for the pattern simulations. The origin modeling efforts will include a literature search of what is known about cooling joint origin coupled with what has been learned in this study about joints and their relationships with other geologic characteristics. All three modeling efforts are highly interactive and together will provide predictive capabilities of cooling joints in portions of the rock mass where joint parameters can not be measured directly.

Cooling joint parameters, related performance issues, parameter data collection scales, and goals of data analysis are listed in Table 8.3.1.2-4. The table is subdivided into parameters and supporting parameters (e.g., persistence, orientation, width, etc., support the broader parameter term cooling joint geometry). The goals may be adjusted when design and performance assessment studies can provide more detail about exactly what is needed from cooling joint studies.

Technical considerations, regarding cooling joints, that have been used to further organize and focus activities within the cooling joint characteristics study include the following:

- Distinction between cooling and tectonic joints.
- Characterization of cooling joints with respect to hydrologic properties.
- Comparison of cooling joint data from vertical and horizontal boreholes to determine biases in sampling directions.
- Distinction between column-defining and column-dividing joints
- Characterization of cooling joint persistence when entire cooling joint is rarely visible.
- Correlation of cooling joints with respect to stability of basalt exposures.

It is important to distinguish between cooling and tectonic joints in boreholes because their existence and characteristics have potentially different implications to the repository, with respect to tectonic evolution of the basalt, and to groundwater flow. Cooling joints are confined to flows while tectonic joints are through-going, and the presence of tectonic joints implies a certain level or degree of tectonic deformation of the basalt. By acknowledging this technical consideration, the study can be focused to address significant problems related to repository design and performance and provide specific quantitive data as represented by the parameters. Considerations related to the identification and characterization of cooling joints in boreholes include the cooling joints characteristics of the flow interior of the Cohassett flow in the controlled area study zone. It is this flow interior that will actually contain the underground openings to house the wastes and provide the immediate barrier to waste migration. Characterization of cooling joints in this flow is very important in assessing rock strength

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and potential groundwater flow. However, the other flows in the primary isolation zone are important to characterize also. Although not primarily important for determining rock strength or integrity of underground openings, these other primary isolation zone flows are still part of the barrier to groundwater transport of radionuclides. These flows will provide additional information that may be useful to characterize the Cohassett flow, because they are genetically similar to the Cohassett flow in terms of close stratigraphic proximity and analogous formation environment.

Another portion of the total rock mass important to cooling joint characterization is the area immediately surrounding the drilled shafts which will access the Cohassett flow interior. The shafts must be sealed to the surrounding rock in order to prevent vertical groundwater movement along the shafts. Cooling joint information collected along the first exploratory shaft will be helpful in designing the backfill or sealing medium and in assessing the performance of the shaft sealing material. Therefore, cooling joint data must be collected and analyzed at the exploratory shaft site throughout the entire basalt section (the repository isolation zone).

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8.3.1.2.3.3.3.1 Measurements and sampling.

8.3.1.2.3.3.3.1.1 Accuracy and precision of measurement

Accuracy (or the closeness of the measurement to the true parameter value) is increased by eliminating measurement bias (which includes an efficient use of radomization) and refining the method of taking measurements. Studies of the accuracy will take place beginning with data collection and continuing on until adequate accuracy is achieved. Adequate accuracy is achieved when the instruments are calibrated to remove as much bias as possible (e.g., setting proper declination on compass), the samples are randomized, and the measurement resolution is fine enough to detect the variability within parameter samples.

Precision is dependent on the number of replicates collected or the degrees of freedom in the experiment. Obviously, the precision increases as the number of parameter measurements becomes greater. An important question then, is how many joints should be measured to characterize a particular parameter? When estimating the population mean, there is a known relationship between the upper limit to the error that can be tolerated in the estimate, the confidence level, the population variance, and the desired sample size (Snedecor and Cochran, 1980, p. 53). By setting the upper limit to the error (and setting the confidence level) and using the sample variance as an estimate of the population variance, the desired sample size can be calculated. The calculation requires some knowledge a priori about the variance (which could be estimated from preliminary data) and a decision on how close the resulting mean estimate should be to the population. The central limit theorem as applied to means states that by taking large sample sizes the distribution of the data is not important because the sampling distribution can be assumed to be approximately normally distributed. If the original estimate of the population variance is grossly in error, then when a new

sample of parameter measurements is collected, a new estimate of the population variance can be calculated and the sample size adjusted appropriately. By using this method of determining sample size, the precision is determined by the data (and the need for a certain confidence and accuracy) and arbitrary decisions are avoided.

8.3.1.2.3.3.3.1.2 Requirements of other studies

To ensure collection of cooling joint data from the proper basalt flows and intraflow structures at outcrop, in core, and at underground openings of the Exploratory Shaft Facility, the flows and intraflow structures must be identified. In the case of outcrop and some sections of core, this identification must be made in advance of data collection. The stratigraphy study (Section 8.3.1.2.3.3.1) will provide the identification of basalt flows and the intraflow structure study (Section 8.3.1.2.3.3.2) will provide the identification of intraflow structures. For identifications needed in advance of data collection or statistical summarization, the stratigraphy and intraflow structures studies must precede activities in the cooling joint characteristics study.

Data are also needed from the mineralogy and petrology study (Section 8.3.1.5) due to the nature of cooling joint infilling material. The identification of secondary minerals filling the joints in core and in underground exposure needs to be calibrated with the detailed identification provided in the above study. At times, the macroscopic identification of minerals in core is difficult without benefit of detailed analysis.

8.3.1.2.3.3.3.1.3 Randomness of the data

Many of the statistical tests used in the modeling portion of the study evoke a hypothesis of random sampling. This hypothesis requires that all members of a population have an equal chance of being chosen for the sample and that the chosen members of the sample are statistically independent. Therefore, it is important that random samples be collected if possible. Unfortunately, the area of basalt exposed at the surface relative to the basalt flows and intraflow structures of interest is very limited. Furthermore, jointing exposed at outcrop may not be representative of subsurface jointing in the controlled area study zone. The scanline and window locations will be chosen by a defined distance sampling scheme whenever possible, such that representative samples will be collected. For core samples, one must assume that the locations of the boreholes are representative with respect to cooling joint parameters even though their location may have been selected for other geologic or hydrologic reasons. During core logging cooling joint data are collected at every 0.06-m (0.2-ft) section of core with the cooling joint closest to the midpoint of the 0.06-m (0.2-ft) section being the one selected for characterization. The sample data collected in this manner are considered representative of the subsurface cooling joint population. When sampling selected portions of core, random number tables or grid sampling must be used to collect representative samples. Collecting representative samples underground poses similar problems to collecting representative samples at outcrop. When freedom is allowed

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underground, a sampling schedule based on defined spacing schemes or timing during construction will be used to collect representative samples of cooling joint data.

Statistical independence of the data will be investigated by the use of variograms. The ranges on the interpreted variograms will provide information about how far apart parameter measurements must be in order to prevent the bias of spatial dependence. However, if another geostatistical method such as kriging is used, the spatial dependency will be the basis for the methods.

8.3.1.2.3.3.3.2 Characterization of cooling joints in outcrop. During this task, cooling joint data will be collected at surface exposures of basalt and statistically summarized for use in cooling joint models or as direct input to hydrology or rock mechanics models.

Cooling joint parameters that will be collected at outcrops are as follows:

- Persistence (crack length).
- Orientation.
- Frequency or spacing.
- Roughness.
- Termination type.

Other cooling joint parameters such as width, infilling percent and type, wall-rock alteration, and void geometry are not possible to measure reliably at outcrops because of the extensive weathering and removal of secondary mineral infilling and the shifting of individual basalt blocks.

8.3.1.2.3.3.3.2.1 Study locations

The portion of the stratigraphic section of interest in the cooling joint characteristics study is primarily the flows in the primary isolation zone. These flows do not crop out in the controlled isolation study zone. The closest outcrops (Fig. 8.3.1.2-13) of flows in the primary isolation zone are isolated, small, highly weathered ones along Rattlesnake Hills (2 to 5 km (1.3 to 3.1 mi) from the controlled area study zone). Similar outcrops are along Yakima Ridge (14 to 17 km (8.8 to 10.6 mi) from the controlled area study zone). More extensive, less weathered outcrops are present along Umtanum Ridge (about 5 km (3.1 mi) from the controlled area study zone) and at Sentinel Gap (about 30 km (18.8 mi) from the controlled area study zone). The best outcrop exposure is at Sentinel Gap, a water gap through the Saddle Mountains anticline. Even though these outcrops are 30 km (18.8 mi) from the controlled area study zone, the basalt stratigraphy has been studied extensively during previous years, and the flows are correlated well to the flows in the controlled area study zone. All of these outcrops are within the Pasco Basin or on the perimeter of the Pasco Basin. It is also worthwhile to collect data from a few outcrops outside the Pasco Basin when these selected outcrops display obvious variability that may be beyond the variability displayed within the Pasco Basin.

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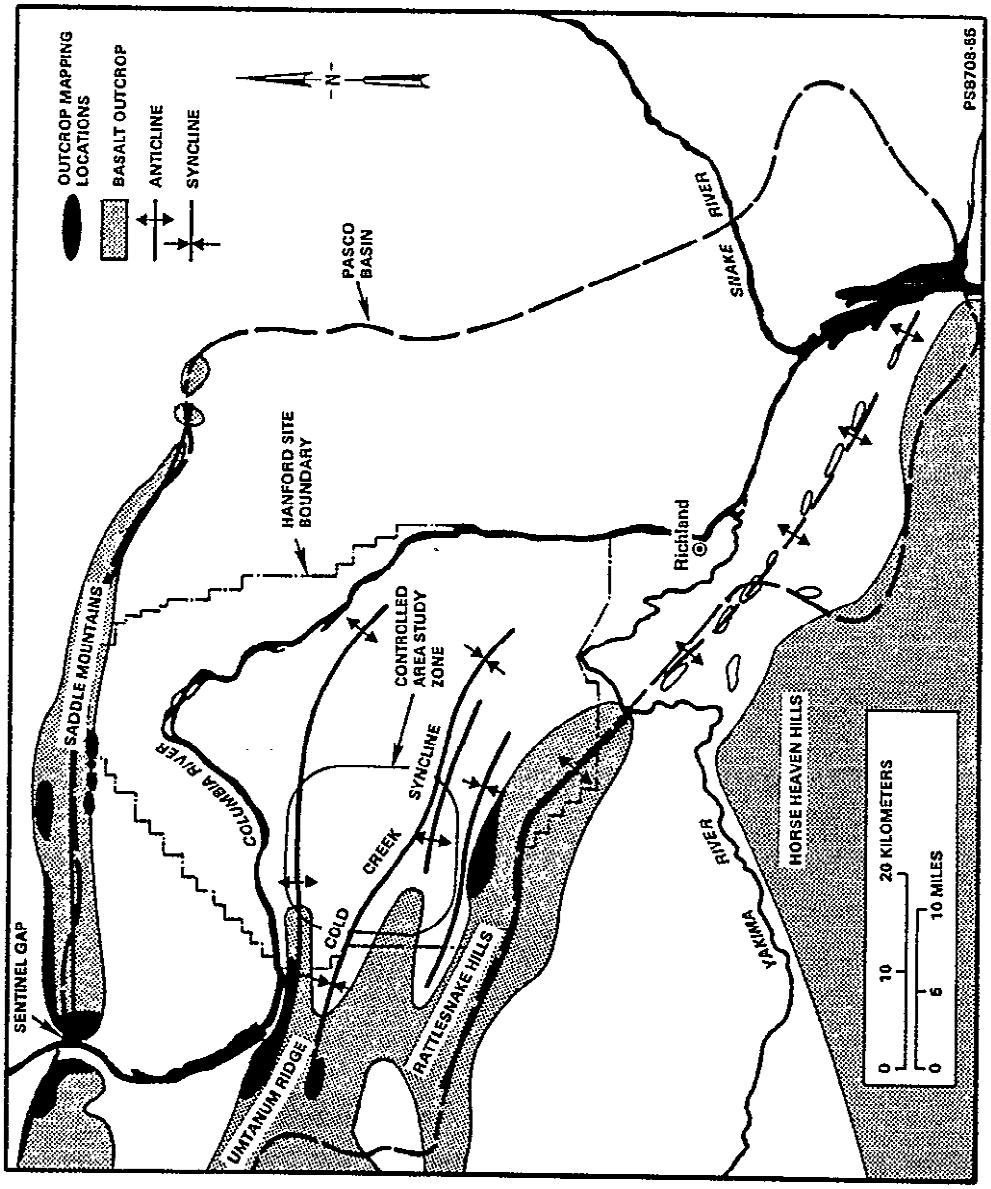

Figure 8.3.1.2-13. Location map of outcrops to be mapped in the cooling joint characteristics study.

8.3.1.2.3.3.3.2.2 Task methods

Cooling joint data will be collected from outcrops by two methods (Table 8.3.1.2-11) described in Call et al. (1976); Halstead et al. (1968); Piteau (1979, pp. 55-71); Call (1972); and Savely (1972):

1. Scanline mapping--a one dimensional collection method where parameters are measured on each joint encountered along a line that is scribed on the rock surface.

2. Cell or window mapping--a two dimensional collection method where parameters are measured on each joint in an area (like a circle or square) defined on the rock surface.

The scanline method is a systematic, one-dimensional, spot sampling technique where the sampling localities would be selected randomly. The scanlines should have a random orientation also. The window or cell mapping technique is a two dimensional sampling method where the locations are randomly selected also. In reality, however, the sites are determined by availability and accessibility of the exposure. In addition to cooling joint parameter measurements collected along the scanline or windows, other geologic features (like chisel marks, flutes, and anomalous intraflow structures) that may relate to the origin of cooling joints or correlate the parameter measurements with other basalt characteristics are noted to support the origin modeling of the cooling joint study. Scanline orientation and outcrop attitude data will be collected and used for joint spacing correlations analyses. Products include photographs of the outcrop, calculations and sketches of the outcrop showing the scanline and basalt features, and tables of raw cooling joint data.

Persistence, orientation, and frequency (spacing) are parameters in which measurement accuracy and experimental precision are important factors. Roughness and termination type are descriptive parameters where accuracy and precision are not of concern. At outcrop exposures the persistence of a cooling joint will be measured with a metal retractable ruler to the closest whole centimeter. Orientation is defined by strike and dip and will be measured with a Brunton Compass to the nearest degree. Frequency (or spacing) of cooling joints is measured by recording the location of joints along a scanline to the nearest whole centimeter. These measurement methods are now assumed to be accurate enough to capture the variability of the parameters.

The more descriptive parameters of roughness and termination type are not measured at outcrops but are described for each encountered joint. Roughness is described by using standardized terminology and charts from the International Society for Rock Mechanics (1981, pp. 22-30), and termination type is estimated by noting how each encountered joint terminates. The ratio of the number of joints that terminate in other joints to the number of those that are incipient is one factor in cooling joint connectivity.

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Table 8.3.1.2-11. Tasks/tests/analyses for the cooling joint characteristics study (sheet 1 of 2)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Characteristics of cooling joints in outcrops	Scanline and window (or cell) mapping at outcrops	Colonnades and entablatures of the Cohassett flow and adjacent flows as appropriate at Sentinel Gap, Yakima and Umtanum Ridges, and Rattlesnake Hills	To be developed	Cooling joint data: persistence, , strike/dip, roughness, termination type, and propagation features	Statistical characteristics: roughness, occurrence of propagation features, persistence, spacing, termination type, and orientation
Characteristics of cooling joints in core	Synthesis of cooling data from core logs	Boreholes in the geologic repository operations area, controlled area study zone, Cold Creek syncline, and Pasco Basin	NA	Cooling joint data: frequency, strike/dip, width, unevenness, wall rock alteration thickness, infilling type, percent filled with minerals, character of void space in joints, and percentage of intact joints	Statistical characteristics: width, aperture, roughness, wall rock alteration thickness, infilling type and percent filled, cooling joint spacing, geometry of voids orientation, and percentage of intact joints
	Borehole geophysical logging	Boreholes in geologic repository operations area, controlled area study zone, Cold Creek syncline, and Pasco Basin	Per borehole logged or relogged with appropriate geophysical logging techniques	Log responses of sondes	Characterization of fractures based on measured properties Frequency of joints
Characteristics of cooling joints in the Exploratory Shaft Facility	Mapping tunnel exposures: scanlines, cells (or windows), general walls, interpretation of Q-system parameters, synthesis of joint data	Exploratory Shaft Facility	NA	Geologic data: cooling joint persistence, frequency, strike/dip, width, percent filled, roughness, wall rock alteration thickness, infilling type, termination type, void geometry	Geologic--statistical characteristics: orientation, width, aperture, roughness, wall rock alteration thickness, infilling type, and percent, cooling joint persistence, spacing, termination type, and void geometry
				Engineering: joint pattern block interlocking features, joint alteration thickness, groundwater discharge, apparent stress/strain	Engineering--Q-system required: joint characteristics--set number, roughness, joint alteration, joint water, stress reduction factor
	Geophysical exploration methods	Not required for analysis	Not required for analysis	Log responses	Joint frequency

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Table 8.3.1.2-11. Tasks/tests/analyses for the cooling joint characteristics study (sheet 2 of 2)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Analysis of cooling joint characteristics	Geotechnical mapping units model	Not required for analysis	Not required for analysis	Collected outcrop, borehole, and Exploratory Shaft Facility data	Grouping parameter sample data into populations via statistical analysis. Populations will be associated with basalt flow, intraflow structure, structure, and other geological relationships
	Joint pattern modeling	Not required for analysis	Not required for analysis	Results of geotechnical mapping units model	Using stereology, fractal geometry, or geostatistics, a three-dimensional model of joint patterns will be developed. Output includes computer images of modeled patterns
	Cooling joint origin modeling	Not required for analysis	Not required for analysis	Results of geotechnical mapping units and pattern simulation models	Refined ability to predict jointing characteristics in geological repository operations area

NA = Not applicable.

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8.3.1.2.3.3.3.2.3 Analysis of existing data

There are some existing cooling joint outcrop data that were collected several years ago but were not analyzed. The data were collected at Sentinel Gap and Umtanum Ridge and may not meet present quality standards. The existing data will be assessed for quality and analyzed if appropriate before any new data are collected.

8.3.1.2.3.3.3.2.4 Statistical summaries

Histograms and cumulative frequency plots will be made for each sample of cooling joint parameter measurements collected at outcrop in order to determine and record the distribution of the data. In addition, the summary of each data set (sample) will include standardized measures of central tendency such as means, modes, and medians, and measures of variability such as standard deviations and ranges. Orientation data are not easily summarized by the standard methods just mentioned. Orientation data will be summarized by plotting the poles to joints on lower hemisphere stereo projections. The statistical summaries of the parameter measurements are the input data for the three models of the study and are occasionally transmitted directly to rock mechanics and hydrology studies.

8.3.1.2.3.3.3.3 Characterization of cooling joints in boreholes. In this task, cooling joint data will be collected from core and borehole geophysics (if possible) and statistically summarized. The cooling joint parameters that will be measured or described include the following:

- Orientation.
- Frequency.
- Width.
- Percent filled with secondary mineral infilling.
- Type or composition of secondary mineral infilling.
- Wall-rock alteration thickness.
- Roughness.
- Void geometry.
- Percentage of cooling joints that break in core.

Persistence cannot be measured in core because of the one-dimensionality of the rock material available for logging.

8.3.1.2.3.3.3.3.1 Study locations

Figure 8.3.1.2-6 shows the location of the McGee, DC-16A, and RRL-17 core holes. Additional new cored boreholes (RRL-18 and RRL-19) in the controlled area study zone are called for in the intraflow structures study as well as the relogging of existing core holes that were not geologically logged with the currently approved core logging procedure. The cooling joints characteristics study will use the core data from all these cored boreholes. It is considered that these core holes are adequate to characterize cooling joints in the controlled area study zone.

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Core that is drilled from the portholes and underground exposures of the Exploratory Shaft Facility will also be logged and the cooling joint data utilized. Much of the core will be taken from horizontal, subhorizontal, or inclined holes and will be useful to compare with the core from vertical, surface-based boreholes. The comparison will provide direct evidence of directional borehole bias.

All the core from the Exploratory Shaft Facility will be useful to this study because it will be from primary isolation zone flows. Core from surface-based core holes from primary isolation zone flows will be included in the study. In addition, core from the entire repository isolation zone flows will be included in the study when it is from core holes at or near where the access shafts (Exploratory Shaft Facility) will be located (this is for assisting in the design of seals and seals material).

8.3.1.2.3.3.3.3.2 Task methods

With the exception of joint frequency data (in which all joints are counted), the logging procedure requires that joint data be collected on only one joint in each 0.06-m (0.2-ft) section of core (see Table 8.3.1.2-11). The joint that is selected for measurement in each 0.06-m (0.2-ft) section will be the one that is closest to the midpoint of the section.

Measuring joint frequency in core may depend on the direction of the borehole. As stated in Section 1.2.1.2.3.1, vertical boreholes may observe horizontal joints more than vertical ones. Cosine correction computer programs are available that correct frequency measurements with the known borehole direction. However, these programs rely on the identification of joint sets. Joint sets have not been identified in basalts in the same manner as tectonic joints in other rock types. Should joint sets be identified, cosine correction techniques will be used to correct frequency measurements.

Strike and dip measurements on joints in core samples are meaningful only when the core are oriented. Meints (1986, pp. 52-69) demonstrated core orientation via paleomagnetics as a viable method and similar techniques will be employed in selected sections of core to collect strike and dip data. Strike and dip will be measured to the nearest degree with the aid of a plexiglas goniometer.

The current core logging procedure specifies that cooling joint width will be measured using a pocket ruler with the aid of a hand lens to the nearest 0.1 mm (0.0003 in.). Other parameters to be collected in the logging procedure are estimated percent infilling of secondary minerals, infilling type, and wall-rock alteration thickness. Also, the geometry of any observable voids will be examined and documented. For more detailed work, as deemed necessary in selected sections of core, a binocular microscope with a micrometer ocular will be used as in Lindberg (1986, p. 12). The microscope has a resolution to 0.01 mm (0.0003 in.).

Joint roughness in the core will be estimated as specified by the International Society for Rock Mechanics (1981, pp. 22-30) in a similar manner

as at outcrop. However, "waviness," which is roughness on a scale larger than 10 cm (3.9 in.), will not be measurable for many joints. That leaves "unevenness," which is roughness at a scale less than 10 cm (3.9 in.).

The geometry of the voids in cooling joints may be key to the way in which groundwater flows in the interior of a basalt flow. At present, little is known about the extent of a single void in the joints or about the geometry. Much could be learned through visual examination of joints that contain voids in an attempt to determine if there are any consistencies. The only source of data prior to the drifts of the Exploratory Shaft Facility is core. Unfortunately, core is a data source that is almost unidirectional. Voids in the cooling joints will be observed by examining the edges of the joints when they are still intact and the broken infilling material when the joints are separated. In some cases, intact joints may be purposely broken to examine the infilling material and voids. The extent of the voids will not be measurable in many cases. However, because the voids are very small, enough of any one void will be present to at least begin to get a picture of the geometry. A microscope will be used for magnification. One potential problem is locating the number of joints containing voids. Lindberg (1986, pp. 36-45) reported that only 19 out of approximately 3,200 measured in four Grande Ronde Basalt flows contained voids. Those 19 locations in core are known, and those joints will be reexamined. However, if 50 or so joints with voids are needed, then over 5,000 more joints will need to be examined to locate 31 more joints with voids.

Computer tomography is another technique that may be useful with core and should be considered for studying voids. This x-ray technique has already shown some promise for locating voids in rock (Flannery et al., 1987, pp. 1439-1444) and may also work well for isolated voids in cooling joints.

The use of borehole geophysics has not been shown to be a useful tool for cooling joint studies in Columbia River basalts. However, studies to fully assess the response of the tools to different fracturing characteristics have not been done. Borehole geophysics in basalt flows have been mainly used to assess the stratigraphy or the groundwater characteristics of the rock. The logs were not usually calibrated, and numerical analyses were rare. More recently, the value of borehole geophysics to assess the physical rock properties of basalts has been realized, and studies will be done to test and develop these capabilities. The physical rock properties study (Section 8.3.1.2.3.3.5) will assess geophysical logs taken in some of the earlier rotary holes as well as core holes. Should they show that borehole geophysics is useful to cooling joint studies, then the tools will be used to collect and analyze cooling joint data.

8.3.1.2.3.3.3.3.3 Analysis of existing data

Core from the McGee, DC-16A, and RRL-17 (Fig. 8.3.1.2-6) core holes has already been logged using approved procedures. Some of the data were cited in Chapter 1 of the SCP from the McGee and DC-16A core holes. None of the cooling joint data from RRL-17 have been analyzed. Prior to analyzing or statistically summarizing data from any new core holes, the statistical summaries of McGee, DC-16A, and RRL-17 core data will be completed.

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8.3.1.2.3.3.3.3.4 Statistical summaries

The statistical summaries will be accomplished in the same manner as was described for the outcrop test (Section 8.3.1.2.3.3.3.1).

8.3.1.2.3.3.3.4 Characterization of cooling joints in the underground exposures of the Exploratory Shaft Facility. This task constitutes the portion of the cooling joints study where data are collected from the underground exposures of the Exploratory Shaft Facility and statistically summarized.

The following cooling joint parameters will be measured or described underground or in rock samples taken from the underground exposures:

- Persistence.
- Orientation.
- Frequency or spacing.
- Width.
- Percent filled with secondary minerals.
- Type or composition of the secondary mineral infilling.
- Wall-rock alteration.
- Roughness.
- Termination type.
- Void geometry.

Macroscopic measurements of persistence, orientation, frequency, large thicknesses of wall-rock alteration, roughness, and termination type will be collected (see Table 8.3.1.2-11) by one or more of three underground mapping methods. Parameters that need to be measured with a microscope such as width, percent infilling, infilling type, thin wall-rock alteration thickness, and void geometry, will be measured on samples that are brought from the drifts to the surface.

8.3.1.2.3.3.3.4.1 Study locations

This study will take place only within the flow interior of the Cohassett flow in the Exploratory Shaft Facility, except for the measurements on samples that are brought to the surface from the Cohassett flow interior.

8.3.1.2.3.3.3.4.2 Task methods

Cooling joint parameter measurements will be collected (Table 8.3.1.2-11) underground by the use of three different mapping methods:

1. Rapid mapping method.
2. Standard mapping method.
3. Detailed mapping method.

These three methods are necessary because data collection must occur while the underground openings are being constructed. Increasing amounts of detail will be collected at different stages of the construction by using

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method 1 and then moving on to method 2 and method 3. By the use of three mapping methods, which interact with construction activities, the optimum amount and detail of data will be collected depending on the underground conditions. The multiple methods approach assures that at least a minimum amount of geologic data will be collected throughout the entire Exploratory Shaft Facility.

The rapid mapping method (or quick-turn-around method) will collect pertinent geologic data, including cooling joint data, during or immediately following each stage of drift advancement for the purpose of evaluating ground control. The data will support an empirical rock mass classification system, which in turn will affect any ground control measures that must be maintained or changed. The data need to be collected as soon as possible after the drifts have been advanced to each construction period so that decisions about ground control can be made quickly and proper methods of ground control can be used. At this time a decision has not been made whether to use the Q-system after Barton et al. (1974, pp. 189-236), the rock mass rating system after Bieniawski (1979, pp. 51-58), or a site-specific rock-mass classification system. As an example of the type of cooling joint data that will be collected for an empirical rock mass classification system, the cooling joint requirements for the Q-system are given below.

- RQD (related to joint characteristics) for boreholes drilled from the drift face.
- Number of joint sets.
- Joint roughness.
- Joint alteration.
- Joint water.

These parameters will be collected rapidly to avoid undue impact on drift construction or ground control activities. Measurements may be quick estimates to verify that geologic conditions have not changed prior to covering the drift exposures with shotcrete or some support that prevents further exposure mapping. It is hoped that extensive ground control will not be necessary and the other two mapping methods will be used, which will provide better geologic data including cooling joints. Collection of these parameter measurements should be considered the minimum acceptable during underground mapping. In some cases, rock samples containing intact cooling joints can be grabbed quickly from the exposures and taken back to the surface for examination, thereby allowing some collection of detailed cooling joint data.

The standard mapping method is the main method for collecting geologic data for the structural geology and intraflow structures studies. Some cooling joint data will be collected during this method. The method is accomplished by taking photographs of the exposures and using them as photo bases to map the geology. Faults, intraflow structure boundaries, anomalous

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intraflow structures, and other geologic features will be identified on the photo bases. Quick measurements of macroscopic cooling joint characteristics will be done periodically and noted on either the photo bases or on forms. The mapping relies on quick surveying of the underground exposures with the installation of location markers and a photographic technique that covers the entire drift exposure (perhaps as a mosaic or 360-degree photos) with a minimum of distortion and can be developed quickly to return to the underground for the mapping. Since minimum detail is gathered concerning cooling joints via this mapping method, it is hoped that enough time is available to use the third mapping method.

The third or detailed mapping method is used almost exclusively for collecting detailed cooling joint data or any other detailed geologic data. The method will be attempted after the construction activities are no longer in the mapping area, the exposures are stable yet exposed, and there is adequate time for detailed examination and measurement of the fine details of the rock. In this mapping method, all macroscopic parameter measurements may be collected along scanlines or windows, and rock samples may be collected for transport to surface laboratories for microscope examination. Included in this mapping method is mapping support to underground testing by the opening stability, mechanical properties determination, thermal and thermomechanical properties determination and other rock mechanics studies. Many of those tests require mapping of geologic features (including cooling joints) in areas of testing, both before and after the tests. In addition, many of those tests will require core holes that will have core that must be logged in the borehole test.

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8.3.1.2.3.3.3.4.3 Statistical summary

The statistical summaries will be accomplished in the same manner as was described in the outcrop and borehole tests.

8.3.1.2.3.3.3.5 Cooling joint modeling. Three cooling joint models will be developed using the data collected and statistically summarizing the three cooling joint tests (outcrop, borehole, and underground mapping tests), and by studying the literature available on cooling joints. The models are listed below.

- Geotechnical mapping units model.
- Pattern simulation model.
- Origin model.

8.3.1.2.3.3.3.5.1 Geotechnical mapping units model

The geotechnical mapping units model is the portion of the cooling joint characteristics study where data samples that were collected in the study are compared to see which samples are close enough to be considered statistically in the same population. The word "geotechnical" is used here because the resulting mapping unit breakdowns are made on the basis of cooling joint parameters geotechnically important to the design and assessment of the performance of the repository. These populations of cooling joints parameters

will probably be associated with basalt flows, intraflow structures, or some other geologic relationship. For instance, the study may discover that cooling joint persistence can be broken into two populations, one corresponding to column-defining joints and the other to column-dividing joints. Although column-defining versus column-dividing is not a flow or intraflow structure consideration, it is a known geologic way to classify joints. If persistence is significantly different in different types of cooling joints, it will be good to know and will be a significant part of the geotechnical model. Other cooling joint parameters (perhaps frequency) will be differentiated on the basis of the intraflow structure containing the joints (i.e., entablatures have more joints than columnar-entablatures, which have a greater frequency than colonnades).

When all the data samples within a parameter type have been compared and combined (where appropriate) into groups of samples belonging to the same population, then those populations are the beginnings of the geotechnical mapping units. Groups of different parameter populations (e.g., frequency and alteration thickness) may correspond or overlap in association with a identifiable geologic unit (perhaps an entablature). If the groups of parameter populations corresponding to a particular geologic structure cause that geologic unit to have unique cooling joint characteristics, then that geologic unit could be considered a separate geotechnical mapping unit.

An analysis of variance is the main statistical tool for comparing the parameter samples. By using this technique, an analysis of variance model can be developed to compare joint parameters between flows and within flows, between intraflow structures and within intraflow structures, and between and within locations or boreholes, and so on. Other tests may be performed for simpler models where means are compared between two samples. In cases like these, a simple Students t-test may be used. Sometimes the assumption must be made that two samples must have equal variances before testing is meaningful. In those cases, the variances will be compared. Other statistical tools are available for comparing measured parameter samples and may be used depending on the testing models that are developed.

Orientation data cannot be compared in the same way as other measurable parameters due to the nature of strike and dip. However, the lower hemisphere stereo projections of joint poles may be compared by using standard frequency statistics (Chi-square) on patch networks designated for the pole plots in a similar manner used in Meints (1986, pp. 70-76).

8.3.1.2.3.3.3.5.2 Pattern simulation model

As the geotechnical mapping units are being identified and characterized, drawings or plots of three-dimensional patterns will be used to synthesize and complement the many tables and graphs of statistics. To accomplish this task, computer simulations of cooling joints in each identifiable geotechnical mapping unit will be attempted. The simulations will be based on the populations of cooling joint parameters that were identified in the geotechnical mapping units modeling. As the simulations proceed and preliminary products are generated, the early results will be visually compared with actual

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outcrops or underground exposures. When inconsistencies are noticed, the specifics of parameter measurements can be fed back to the simulations to try to improve the results. These simulation products will be very useful and complementary to the other cooling joint models and may actually be used in hydrology models to define the network of discontinuities.

8.3.1.2.3.3.3.5.3 Origin model

Data collected from the literature will be combined with data collected during this study to sift and sort out cooling joint relationships and develop the best conceptual model for cooling joint formation. Recent work by DeGraff and Aydin (1978) helped identify certain joint characteristics that aid in pointing out the propagation direction of cooling joints. Additional studies are needed like the one of DeGraff and Aydin to get a more complete understanding of how cooling joints form. The modeling of cooling joint origin is important to the prediction of cooling joint parameters in areas or volumes of rock where an incomplete amount of cooling joint data are available. The origin model will correlate the cooling joint parameters with other important geologic characteristics that are indicative of the flow environment or the origin of the geologic feature of the flow.

8.3.1.2.3.3.4 Structural geology study.

The structural geology study addresses performance and design issue parameters relating to the location, geometry, characteristics, and extent of rock discontinuities of tectonic origin. Thus, the primary objective of the structural geology study is to conduct activities to locate and characterize tectonic structures within the controlled area study zone, Pasco Basin, and the region. This study description provides a discussion of tasks that will be used to determine the required parameters to describe the geologic and physical structure of the BWIP site and its environs. This study will provide the measured parameters that will be used in the construction of stratigraphic and structural and tectonic models and in the assessment of tectonic events and processes. Parameters relating to deep structure will also be used in assessing resource potential. This study is designed to address secondary features (i.e., fractures, faults, folds) of tectonic origin while primary cooling joints in basalt are discussed in Section 8.3.1.2.3.3.3.

The structural geology study is composed of four primary components that have 19 specific tasks. The first three study components are defined by geographic location with respect to the repository while the fourth component is topical and is related to deep geologic structure. This study organization was developed because the data application and level of detail required for each area are unique while the approach and methods used to obtain the data are similar within each component. The components and tasks are listed below.

1. Structural studies in the controlled area study zone:
   a. Identification and interpretation of geophysical and remote sensing anomalies.
   b. Characterization of tectonic fractures and faults in the Exploratory Shaft facilities.
   c. Analysis of basalt structure.

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2. Structural studies in the Pasco Basin:
   a. Studies of the central Pasco Basin.
   b. Studies of the Rattlesnake-Wallula alignment and southern Pasco Basin.
   c. Studies of the eastern Pasco Basin.
   d. Studies of the northern Pasco Basin.
   e. Analog area studies.

3. Studies of regional structures:
   a. Studies of the Hite fault system.
   b. Studies of the Service anticline.
   c. Studies of the northwest-trending Wrench fault systems.
   d. Studies of the western margin of the Yakima Fold Belt.
   e. Studies of the Frenchman Hills.
   f. Studies of the regional geophysics and remote sensing.

4. Deep structure of the Pasco Basin:
   a. Magnetic investigations.
   b. Gravity investigations.
   c. Magnetotelluric investigations.
   d. Exploration seismology investigations.
   e. Data from deep boreholes.

This study will emphasize the controlled area study zone, located within the Cold Creek syncline of the Pasco Basin as shown in Figure 8.3.1.2-14. Because the controlled area study zone is a part of the Cold Creek syncline, much of the mapping and surveying will be carried out as part of the investigation of the Pasco Basin. The Pasco Basin is contained within the Columbia Plateau and the Pacific Northwest region, and is shown in Figure 8.3.1.2-15.

Parameters to be determined using data from the structural geology study are listed in Table 8.3.1.2-5. The goal and confidence level that is required for each supporting parameter depends on the location at which that parameter is to be measured. Thus, the specific goal and confidence level will be defined in the plans for each task. Technical considerations that have been used to further organize and focus the structural geology study are listed below.

- Identification, location, type, geometry, structural characteristics, and extent of folds, faults and fractures (e.g., the nature of thrust-faulting in the area).

- Location, characteristics, and origin of geophysical (e.g., gravity, ground-level magnetic, aeromagnetic, seismic) anomalies and remote sensing lineaments and their relationship to geologic structure.

- Sub-basalt structures and their relationship to structures in basalt.

- Characteristics of tectonic structures with respect to their hydrologic properties.

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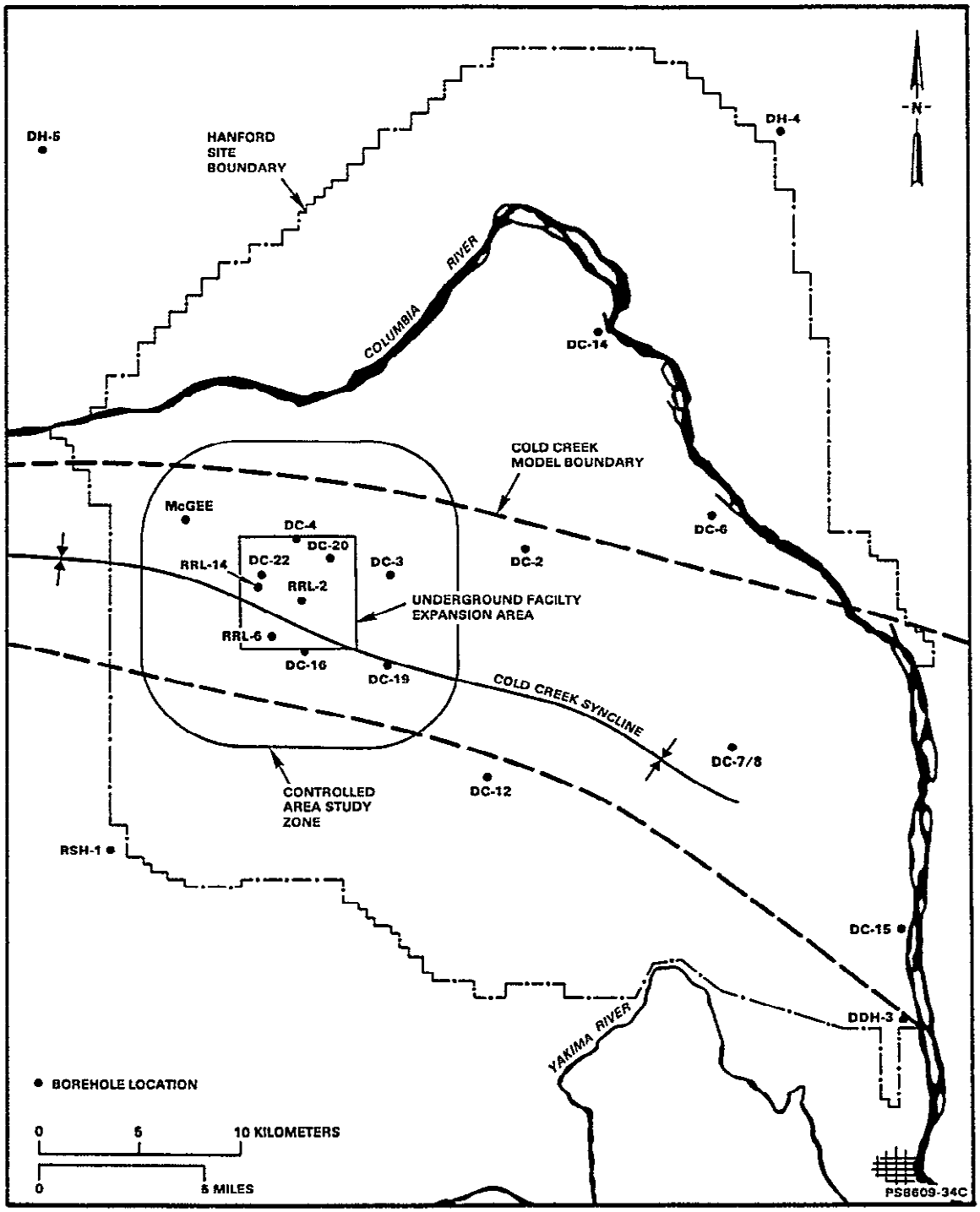

Figure 8.3.1.2-14. Location map of the Cold Creek syncline.

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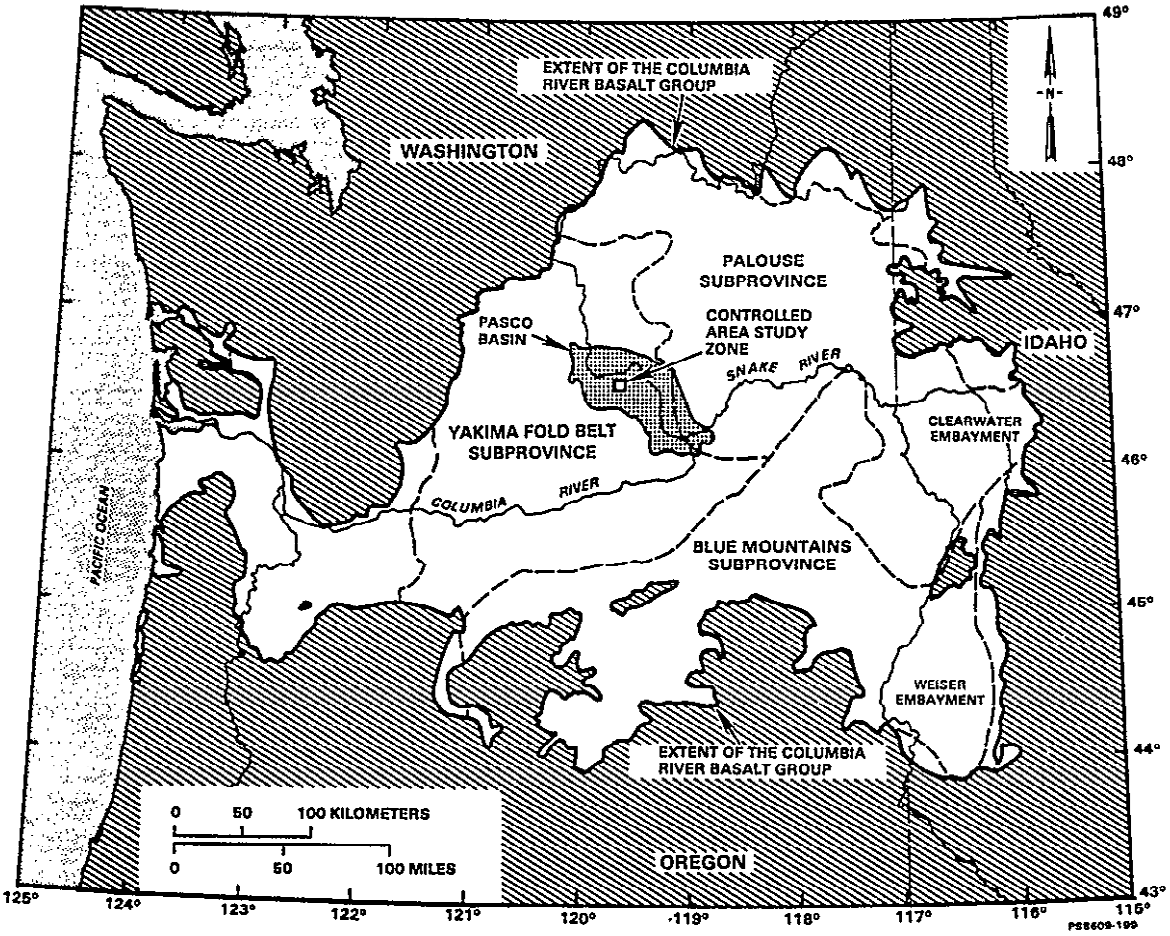

Figure 8.3.1.2-15. Index map to structural subprovinces of the Columbia Plateau.

For example, geophysical gradients (anomalies) have been identified in previous site investigations (Chapter 1). The tectonic significance of these features must be determined by collection of additional geophysical data and detailed modeling of the data. Based on the results of these studies, boreholes may be required to provide physical modeling parameters and (or) verify geophysical interpretations. If faults are identified, additional boreholes and trenches may be required to determine the geometry, physical characteristics, and age of the faults.

8.3.1.2.3.3.4.1 Structural studies in the controlled area study zone. The primary purpose of structural geology studies of the Columbia River Basalt Group within and near the controlled area study zone is to determine parameters describing structural discontinuities in the basalt layers. Because most of the controlled area study zone is covered with late-Cenozoic sediments, studies of the Columbia River Basalt Group will focus primarily on the results from boreholes that penetrate the suprabasalt cover, from the Exploratory Shaft Facility, and from geophysical data. An analysis of geologic structures, primarily in folds around the Cold Creek syncline (Yakima Ridge, Umtanum Ridge, Gable Mountain-Gable Butte, Rattlesnake Hills), will also be performed. Structural investigations near Vantage, the Deshutes Canyon, and other exposed synclinal areas will be evaluated as possible analogs for the Cold Creek syncline and the controlled area study zone. These studies, in combination with geophysical surveys, will provide the data which can be interpreted to assess the structural geology and tectonic history within the controlled area study zone. These interpretations will be performed in the stratigraphic and structural model study, Section 8.3.1.2.3.3.6; the deformation study, Section 8.3.1.2.4.3.1; and the tectonic assessment study, Section 8.3.1.2.4.3.3.

Three tasks have been developed to provide data and parameters in the controlled area study zone. These tasks are (1) identification and interpretation of geophysical and remote sensing anomalies, (2) characterization of tectonic fractures and faults in the Exploratory Shaft Facility, and (3) analysis of basalt structures. Many of the parameters determined by these tasks will be applicable to design of the underground facility. Thus, many of the activities of the tasks will concentrate much of the data acquisition and analysis in the repository site. This is the area of the controlled area study zone within which the underground facility could be located. One of the primary purposes of studies within the controlled area study zone is to determine which part of the repository site will have the most suitable structural properties for construction and waste isolation.

8.3.1.2.3.3.4.1.1 Identification and interpretation of geophysical and remote sensing anomalies

The purpose of this task is to identify and characterize structural features within the controlled area study zone that may affect the system isolation capabilities or the constructibility of the repository. The location of these structures may be expressed as anomalous features in geophysical surveys and remote sensing investigations. Anomalous features

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may be caused by actual structural features such as folds, fractures, or faults; they may also be caused by non-tectonic features such as flow fronts, variations in the susceptibility of basalt, or variations in the density or susceptibility of the suprabasalt sediments.

Previous work has identified a set of anomalous features within the controlled area study zone. These are discussed in general in Section 1.3 and specifically in Section 1.3.2.2.3.7 of Chapter 1. These anomalous features have been identified for the most part in the analysis of geophysical survey data.

Anomalous features that have been or will be identified will be characterized using the following sequence of activities:

1. Identify an anomalous feature using the analyses of geologic mapping, geophysical surveys, or remote sensing surveys.

2. Determine if complementary data also indicates an anomalous feature.

3. Using all available data, complete a preliminary characterization of the feature.

4. Determine what type and to what detail additional investigations need to be conducted to characterize the anomaly.

5. Conduct the investigations and characterize the anomaly.

Each activity will be uniquely structured around the anomaly's location, trend, length, interpreted depth, and possible hydrologic and geologic significance. The level of effort that is required to adequately assess each geophysical anomaly will vary. Assessments may range from brief reviews of available data to detailed studies requiring the collection of additional geophysical data and/or borehole support to obtain geophysical parameters for modeling or for verification of interpretations. The investigations to characterize the anomalous feature will usually be conducted as a phased process with items 4 and 5 being done several times until the specific technical issue is resolved. The phases and method used will usually proceed using the most cost effective methods first. This sequence of methods will usually be the following:

- Geological mapping.
- Reconnaissance-level potential field surveys.
- Detailed potential field surveys.
- Magnetotelluric, electro-magnetic, and electrical surveys.

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- Seismic reflection and refraction surveys.
- Boreholes, coreholes and trenching, and borehole logging including VSP surveys.

The following sections describe specifics of the data collection and analysis methods that will be used to characterize the anomalous features.

8.3.1.2.3.3.4.1.1.1 Geological mapping. Mapping and analysis of geologic structures in folds around the Cold Creek syncline (Yakima Ridge, Umtanum Ridge, Gable Mountain-Gable Butte, Rattlesnake Hills) will be conducted to determine their significance in relation to the controlled area study zone. Although these features extend into the controlled area study zone, it is more logical to investigate them as structural entities. Thus, this work will be accomplished in the Pasco Basin studies, as described in Section 8.3.1.2.3.3.4.2.

8.3.1.2.3.3.4.1.1.2 Gravity surveys. Within the controlled area study zone, gravity data will be acquired to address five technical considerations: (1) determination of the location of anomalous features that may be caused by tectonic structures, such as faults, within the basalt, (2) detailed investigation of anomalous features, which, from complementary geophysical data sources such as seismic and magnetic, have been interpreted to be potential tectonic structures, (3) calculation of the depth to top of basalt, (4) determination of the location of density anomalies in the supra-basalt sediments, and (5) location of structural trends within the controlled area study zone and Cold Creek syncline.

The BWIP has established a grid of gravity stations that covers much of the controlled area study zone and repository site as shown in Figure 8.3.1.2-16. This grid is on a regular 150-m by 150-m (500-ft by 500-ft) spacing, although several areas have no gravity data. Upon initiation of characterization activities, the areas with no data in the repository site will be filled, but not all areas can be covered with a regular grid. These uncovered areas are the sites of defense waste management facilities on the Hanford Site. Data will be acquired on roadways between these facilities, with additional points being established where possible. Additional gravity data will also be acquired around the exploratory shaft on a 50-m by 50-m (160-ft by 160-ft) grid to evaluate a seismic reflection anomaly located by Berkman (1983, pp. 101-110). This anomaly was interpreted to be the result of fluvial channels within the suprabasalt sediments; however, faulting may also be possible. Due to its proximity to the exploratory shaft, a detailed gravity survey will be conducted prior to start-up of exploratory shaft construction. The ground vibrations resulting from construction activities will prohibit acquisition during construction.

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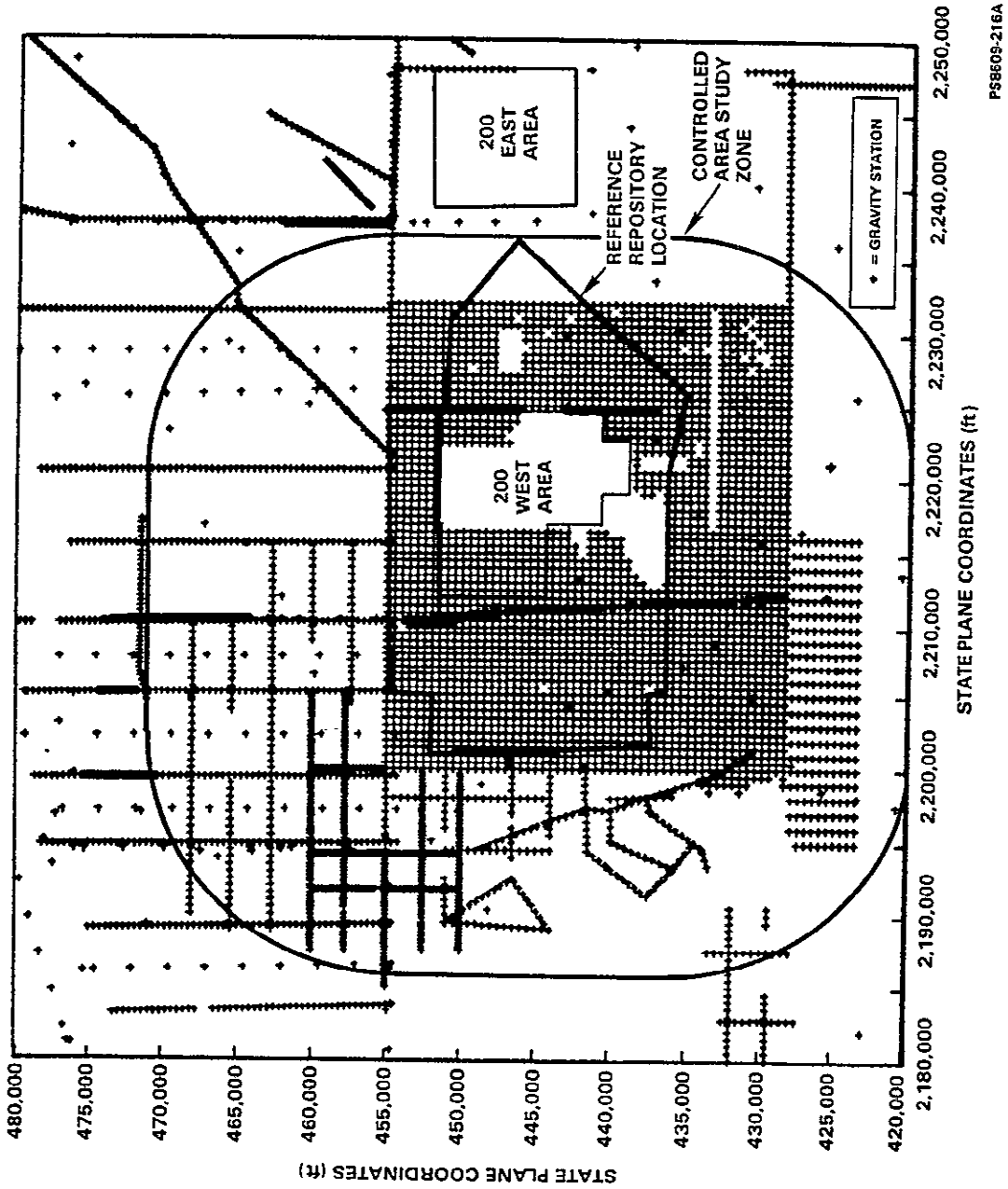

Figure 8.3.1.2-16. Location of currently available gravity stations within the controlled area study zone.

The acquisition of gravity data is also planned for the controlled area study zone outside of the repository site. The southern part of the controlled area study zone has inadequate data for evaluating the subsurface extension of Yakima Ridge. This area will be given high priority after completion of data acquisition in the repository site. Data will also be acquired along the western side of the controlled area study zone to study structural relationships between the upper Cold Creek Valley and the exposed portion of Yakima Ridge. The northern part of the controlled area study zone will also be the site of some new data collection, although this area is currently fairly well covered.

8.3.1.2.3.3.4.1.1.3 Magnetic surveys. The controlled area study zone has been covered with several levels of aeromagnetic data. These data have been collected at several hundred meters to more than a kilometer above the land surface. Data are required as near to the basalts as possible in order to accurately delineate structures at the top of the basalt and to further refine the location of features identified with the aeromagnetic surveys. The acquisition of magnetic data at the ground surface will yield these data.

Ground-level magnetic data will be acquired in the repository site on a regular 150-m (500-ft) grid. Due to underground pipes and cables, fences, power lines, and other surface facilities, some deviations to this pattern are anticipated. These data will provide a basic magnetic data set within 200 m (650 ft) of the buried basalt surface in the repository site.

Ground-level data also will be acquired along profiles using closer station spacings to investigate several geophysical anomalies located within the repository site. These anomalies include the possible fluvial channel in supra-basalt sediments proposed by Berkman (1983, pp. 101-110), and some Werner deconvolution anomalies (N-85, as described in Section 1.3.2.2.3.7). Specific line locations and station spacings cannot be given at this time for these studies. The location of underground pipes and cables, fences, power lines and other facilities will dictate where reliable data may be acquired. The locations, therefore, will be dependent upon in-field inspections prior to the data acquisition.

Ground-level data will also be acquired in other areas of the controlled area study zone, though acquisition in the repository site will be given the highest priority. Specific areas requiring additional data include Yakima Ridge and its buried extension, and the Umtanum Ridge to Gable Butte area. In general, magnetic data are collected along the same lines as gravity data and at the same points.

The interpretation of the magnetic data requires a better theoretical understanding of the interactions of multiple basalt flows with alternating polarities of remanent magnetization. Work will be carried out to determine these interactions and the interactions of closely spaced, three-dimensional magnetic sources that are predominate in this basaltic terrane. In conjunction with these studies, additional paleomagnetic samples will be collected and remanent magnetism and susceptibilities will be determined. With this better understanding of the magnetic regime, the validity of the

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so-called Werner deconvolution solutions will be examined and an integrated interpretation incorporating all information from geology and other geophysical data sets will be conducted.

8.3.1.2.3.3.4.1.1.4 Resistivity surveys. The specifics of electrical surveys employing artificially induced electrical fields have not yet been determined. However, it is expected that resistivity surveys will be useful to augment controlled area study zone characterization and to support other geophysical surveys in the controlled area study zone. The quantity, type, and locations of these surveys will become evident during the planning of the geophysical surveys discussed in this document.

8.3.1.2.3.3.4.1.1.5 Seismic reflection surveys. Seismic reflection data will also be used to assess the validity of anomalous features whether within the basalts or supra-basalt sediments. The location of two-dimensional and three-dimensional data to be collected is shown in Figure 8.1.3.2-17. Within the underground facility expansion area, enough three-dimensional or high-density, two-dimensional data will be acquired to address any anomaly. Outside the underground facility expansion area, but within the controlled area study zone the data will be obtained on a 0.5-km (0.3-mi) grid. This spacing will address many of the anomalous features within this area, but if data are of insufficient detail to address an anomaly then data of the required density spacing will be acquired.

The collection of seismic reflection data consists of two activities. The first will determine the lithologic properties of the basalt and sediments using cores and logs in boreholes. The second will extend these determinations between the boreholes in the controlled area study zone using seismic reflection measurements. These two activities are closely related to tasks described in the stratigraphy study (Section 8.3.1.2.3.3.1). The use of the structure and stratigraphy of sediments is also described in the deformation study (Section 8.3.1.2.4.3.1).

8.3.1.2.3.3.4.1.1.6 Seismic refraction data. The primary purpose of the collection of seismic refraction data is to measure and analyze the parameters that will be used to determine the structure of the supra-basalt sediments within the controlled area study zone. The structure determined by these parameters will (1) help to determine the location and nature of post-basalt deformation, (2) help to determine the effects that the sedimentary structures would produce in geophysical measurements, and (3) determine the necessary static corrections for seismic reflection surveys.

The seismic refraction data will complement the core and geophysical log data from boreholes that will be acquired as part of the Stratigraphy Study (Section 8.3.1.2.3.3.1). As a result of these analyses, the structural configuration of the anomalous features in the sediments will be addressed. In addition, the data needed for resolution of static correction problems caused by sedimentary features will also be estimated. This is discussed in detail in Section 1.3.2.2.3.4 and in the structural geology study plan.

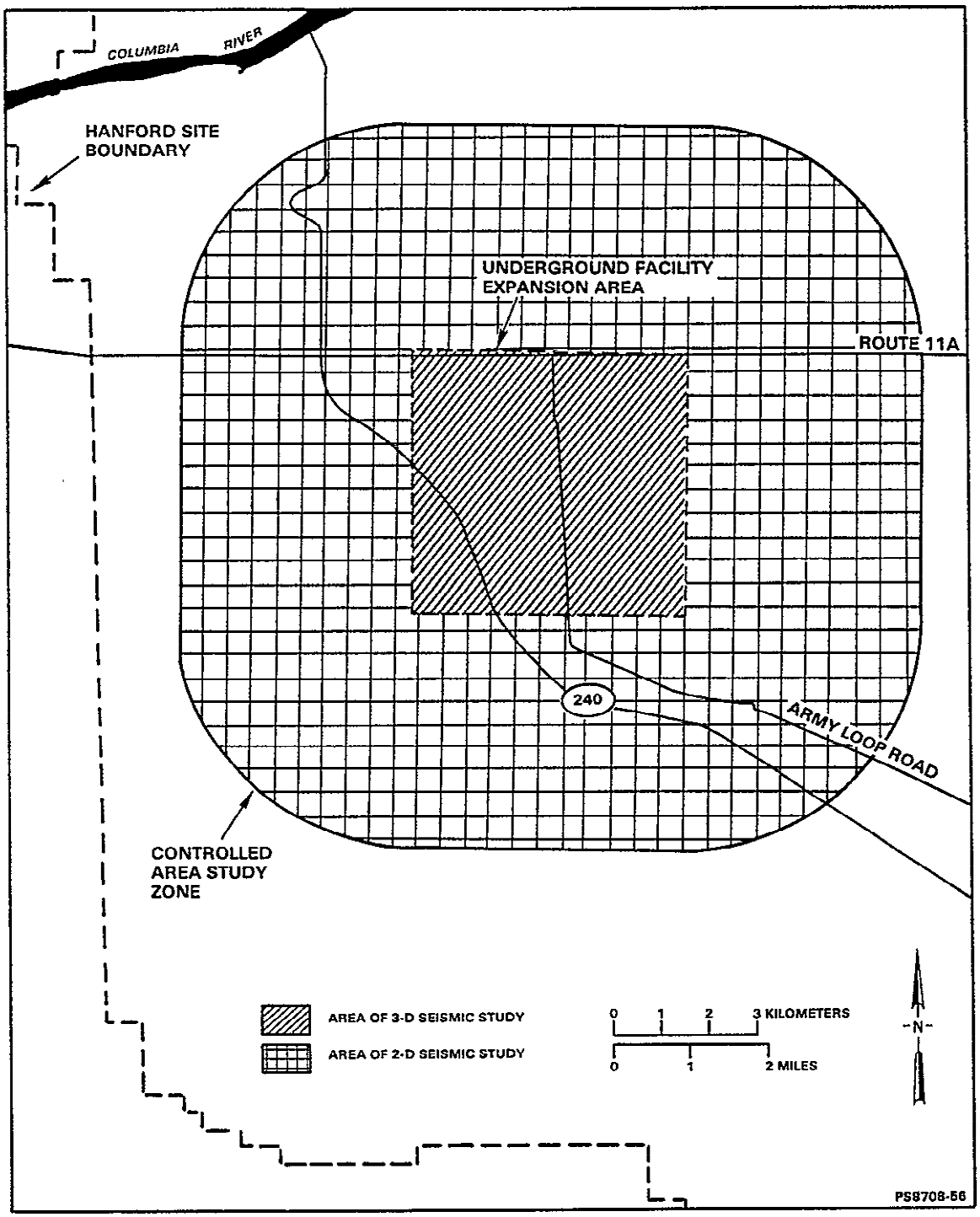

Figure 8.3.1.2-17. Location of 2-D seismic refraction lines and 3-D area diagonals in the controlled area study zone.

As discussed in Section 1.3.2.2.3.5, seismic refraction surveys have already been conducted within the controlled area study zone. The survey done by the BWIP (Weston, 1982) had a sufficient density of shots and receivers to allow the determination of relatively subtle variations in lateral structure. Additional refraction work has also been conducted as part of the FY 85 seismic reflection survey to determine static corrections. These refraction data were not, however, analyzed with the specific goal of determining sedimentary structure. Additional refraction data will also be collected as part of all of the seismic reflection surveys described herein. The activity described here is aimed at using the refraction data to determine sedimentary velocity structure.

Much of the data required to determine sedimentary velocity structure is available directly from the refraction statics analyses performed during reflection processing. These data need only be inverted to provide information for the interpretation of the structure. This process can be automated and the velocity structure sections produced by computer. The inversion process still requires the use of an interactive graphics display system for quality control of the refraction picks and inversion process. To determine the actual sedimentary structures, these data must be correlated with the data from boreholes described in the following section.

The results from this subtask will be a three-dimensional mapping of the seismic velocity structure of the suprabasalt sediments within the controlled area study zone. This mapping will consist of a set of structure sections along each refraction line and a computer file containing the velocity versus depth function for each refraction station. This is similar to that produced by Odegard and Mitchell (1988) for the previous BWIP refraction survey. These data will be interpreted as described in the Stratigraphic and Structural Model Study (Section 8.3.1.2.3.3.6).

<u>8.3.1.2.3.3.4.1.1.7 Borehole and core hole testing</u>. Geologic structures may be detected directly in cores or boreholes or indirectly between boreholes where significant differences in elevation and (or) thickness of stratigraphic units exist. For example, borehole DC-18 is being drilled near the Gable Butte-Gable Mountain structure to address the characteristics and orientation of faults and fractures within an anticline. Boreholes are also necessary to determine the physical characteristics of stratigraphic units in order to (1) calibrate and constrain geophysical models and (2) to evaluate other, possibly non-tectonic origins for geophysical anomalies (e.g., erosional cut and fill features, offlap/onlap relationships, facies variations).

Specific areas in the controlled area study zone where borehole coverage is not adequate or the current stratigraphic relations are unclear include the following:

- Areas of geophysical anomalies, the causes of which are not yet determined, including (1) Yakima Barricade, (2) DC-4/5, (3) DC-3, (4) selected Werner solutions, (5) selected seismic reflection anomalies.

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- The northeast flank of Yakima Ridge and the western Cold Creek syncline.
- The north and south side of the Yakima Ridge extension.
- In and near the repository site, to support the geostatistical analyses of the geometry of the host horizon.

During characterization of an anomalous feature, boreholes and coreholes will be the final test of its validity. The holes will be drilled to determine if features such as faulting or breccia zones are present. It is expected that up to 5 holes will be required for each anomalous geophysical feature to be examined. If the feature is found to exist, then additional holes may be required to map its extent. This, however, will generally be possible using the geophysical techniques. If the feature changes character over its length, then additional holes may be required to assess this change.

There has already been a number of geophysical anomalies identified and described in Section 1.3.2.2.3 of Chapter 1. Additional anomalies will be identified as site characterization proceeds. Based on the number of anomalous features that will require total characterization, it appears that up to 150 core and drill holes may be required for their characterization. Many of these boreholes will terminate in the Saddle Mountains Basalt (top of the Pomona flow).

Data from boreholes and core holes will also be used in the analysis of structures and anomalous features in the suprabasalt sediments. These data will be acquired and analyzed as part of the stratigraphy study as described in Section 8.3.1.2.3.3.1. These data will be combined with the seismic refraction and reflection data to produce cross sections of stratigraphy and sedimentary facies and lithology as outlined in Section 8.3.1.2.3.3.1.

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8.3.1.2.3.3.4.1.2 Characterization of tectonic fractures and faults in the Exploratory Shaft Facility

The task of determining the characteristics of tectonic fractures and faults in the Exploratory Shaft Facility consists of the identification and in situ investigation of the physical properties of these structures in the Cohassett flow, if encountered and in the repository layout area via the exploratory shaft and underground facilities. The identified structures will be mapped and presented in plan and cross sectional views of the major exploratory shaft workings. The information on orientation of the structures will be correlated with surrounding surface-based borehole data. The exploratory shaft tectonic fracture/fault investigations will evaluate whether or not these features are present. If such features are encountered, the key parameters determined from the exploratory shaft tectonic fracture/fault investigations are the following:

- The orientation of the feature(s).
- The width of the feature(s).

- Sense of movement on the feature (kinematic data).
- Amount of offset.
- Petrophysical properties of the gouge and in-filling material of the faults or fractures.

Characterization of tectonic fractures and faults in the Exploratory Shaft Facility consists of three parts. The first part consists of examining, for tectonic fractures, all borehole core from boreholes drilled out from the exploratory shaft or from probe holes drilled out from Exploratory Shaft Facility drifts and tunnels. If such features are encountered in the core, they will be described and characterized as discussed above. The second part of the task consists of examining all exposed surfaces in the shafts and facilities for tectonic structures. The third part of this task will consist of using geophysical techniques to characterize structures that may be encountered during drift mapping or in exploratory boreholes, and to detect and delineate structural features adjacent to the Exploratory Shaft Facility openings. The purpose of geophysical exploration in the Exploratory Shaft Facility will be to extend the mapping of structural features away from the underground openings and test boreholes and to detect and delineate structural features that cannot be directly observed during Exploratory Shaft Facility wall mapping or by core logging analysis. Geophysical methods that will be applied during construction of the Exploratory Shaft Facility will include borehole geophysical logging, cross-hole seismic measurements, radar probing, resistivity, and seismic reflection/transmission testing. Borehole geophysical logging, cross-hole seismic measurements, and radar and electrical probing are discussed in the physical rock properties study (Section 8.3.1.2.3.3.5). The geophysical surveys will be performed at all available locations within the drifts, tunnels, and test boreholes drilled within the Exploratory Shaft Facility. Refinement of these techniques and proof-of-principle testing will be performed in the Near-Surface Test Facility prior to development testing and applications within the Exploratory Shaft Facility.

Ground probing radar data have been used at waste isolation projects at Stripa in Sweden (Olsson et al., 1985) and at URL in Canada (Wright et al., 1986). These data have been used to locate faults and determine some of their characteristics at distances beyond 30 m (100 ft) in granites. Ground probing radar has not been tested as yet in the basalts of the Cohassett flow. Development tests are planned for the Exploratory Shaft Facility. Geological features targeted for investigation are (1) the Cohassett flow top and bottom, (2) thickness of water saturated zones, (3) basalt column distribution, and (4) stress distribution along the tunnel walls.

8.3.1.2.3.3.4.1.3 Analysis of basalt structure

Geologic analyses and correlations conducted in the stratigraphy study, Section 8.3.1.2.3.3.1, and the deformation study, Section 8.3.1.2.4.3.1, will be used to evaluate geophysical anomalies. This is accomplished by plotting and correlating lithologic, chemical, and geophysical log characteristics onto cross sections using the boreholes available in the vicinity of geophysical anomalies.

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Seismic reflection surveys will provide a three-dimensional description of the rocks, sediments, and structures in the controlled area study zone and provide a more detailed description in the repository site. This description will be in terms of seismic parameters, such as velocity and density, and the location and extent of interfaces and structures. Using data from boreholes and all other structural data, these parameters can be related to lithology, location of flow tops and bottoms, and location of interbeds. The location of structural features, such as faults that disturb the stratigraphic sequences will also be determined. These measurements are described in detail in the stratigraphy study, Section 8.3.1.2.3.3.1; the interpretation of the data is described in the stratigraphic and structural model study, Section 8.3.1.2.3.3.6.

Gravity, magnetic, and electrical surveys will also be used to determine the structure within the Columbia River Basalt Group. These surveys will be used first for identification of anomalous features that require additional study.

Structural investigations near Vantage and other exposed synclinal areas will be evaluated as possible analogs for the Cold Creek syncline and the controlled area study zone. Analog studies are discussed in more detail in Section 8.3.1.2.3.3.4.2.5.

<u>8.3.1.2.3.3.4.2 Structural tasks in the Pasco Basin</u>. This section describes the tasks in geology and geophysics that will be conducted for the study component structural studies in the Pasco Basin. The tasks are organized by geographic areas within the basin. The Pasco Basin, as used in this study plan, is the principal structural unit that contains the candidate site. It is defined as follows: on the west by the Hog Ranch-Naneum Ridge anticline; on the south by the Rattlesnake Hills and Rattlesnake-Wallula Alignment; on the east by the transition between the Yakima Fold Belt and the Palouse subprovinces, which generally coincides with the Ice Harbor dike system and Jackass anticline/monocline; and on the north by the Saddle Mountains. This is shown in Figure 8.3.1.2-18 and described in detail in Section 1.3.2.2.

Geologic mapping has been completed in the Pasco Basin at a scale of 1:62,500 (Myers/Price et al., 1979, Plate III) and in the Columbia Plateau at a scale of 1:250,000 (Swanson et al., 1979a, 1980, 1981). Several areas have been mapped in greater detail. See Section 8.3.1.2.3.3.4.3 for a summary of previous and planned mapping in the region. Within the Pasco Basin and Columbia Plateau, the quality and detail of mapping have been reevaluated by reconnaissance examinations. This reevaluation indicates that some areas may require additional field mapping to (1) resolve problems with previous mapping, or (2) address specific questions concerning the nature of the specific structures. Areas that have the highest priority for additional field mapping are those in the vicinity of the controlled area study zone.

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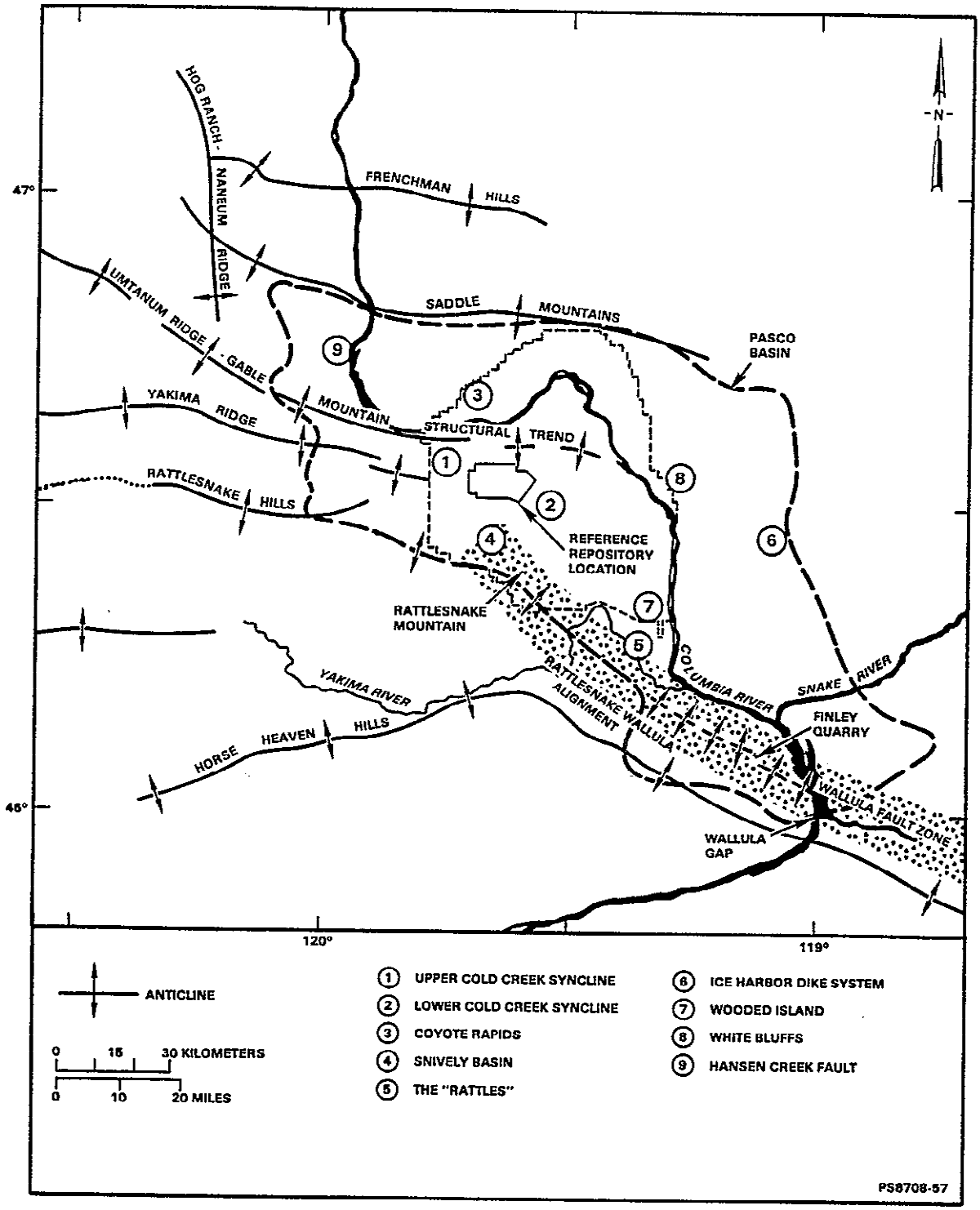

Figure 8.3.1.2-18. Location map for Pasco Basin field investigations.

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The structural features to be investigated using geophysical techniques are selected based on the needs for data for several types of investigations. These investigations include the development of structural and tectonic models in the region and site, the location of hydrological barriers and aquifers within the Pasco Basin, and the evaluation of the structural significance of seismicity.

The tasks of this study component are organized on the basis of geography and structure as follows:

- Studies of Central Pasco Basin--Field locations exclusive of those described for the controlled area study zone; features to be studied include the upper and lower Cold Creek syncline, the Umtanum Ridge-Gable Mountain structures, Yakima Ridge system, and an earthquake swarm area at Coyote Rapids.

- Studies of Rattlesnake-Wallula Alignment and Southern Pasco Basin--Features along the southern and southeastern boundary of the basin, including Snively Basin, the Rattlesnake Hills, Rattlesnake Mountain, "the Rattles," and the Horse Heaven Hills.

- Studies of Eastern Pasco Basin--Structural features that may be associated with the eastern boundary of the basin, the Ice Harbor dike system, an earthquake swarm area at Wooded Island, and suprabasalt stratigraphic studies at the White Bluffs along the Columbia River.

- Studies of Northern Pasco Basin--Various field locations in the Saddle Mountains, the Nancy and Juniper Springs linears, and the Hansen Creek fault.

- Analog Area Studies--Selected areas outside the Pasco Basin that aid in interpretation of data within the controlled area study zone and Pasco Basin.

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8.3.1.2.3.3.4.2.1 Studies of the central Pasco Basin

The areas of greatest concern, and thus highest priority, are those areas that include and surround the controlled area study zone because of their close proximity to the site. These areas are the Cold Creek syncline, the Umtanum/Gable Mountain area, the Yakima Ridge area, and the Rattlesnake-Wallula alignment. These areas have been mapped previously at 1:62,500 scale (Myers/Price et al., 1979, Plate III). However, this mapping was preliminary, and it is recognized that additional detail will be required to fully address the geologic problems in the Pasco Basin.

The principal geologic problems in the Pasco Basin have been summarized in Section 1.3. These problems generally deal with the nature of the ridges (the presence or absence of faults along the flanks, the angle of these faults at depth, the presence and nature of cross faults, and the presence of regional through-going structure); the age of deformation and, in particular,

the age of most recent deformation; and the processes of deformation. Listed below are some specific problems for each mapping area that the structural studies in the central Pasco Basin will address in conjunction with the deformation study (Section 8.3.1.2.4.3.1). This list is not meant to be complete but only to identify some of the more important structural considerations with reference to siting a repository in the Cold Creek syncline.

1. Cold Creek syncline.

   - The existence, nature, origin, and age of any faults including the Yakima hydrologic barrier.

2. Umtanum Ridge/Gable Mountain structures.

   - The geometry and extent of east-west trending faults on the north flank.
   - Faults identified by Goff (1981).
   - The structural intersection of the regional structure, the Hog Ranch-Naneum Ridge anticline, with the Umtanum fault and anticline.

3. Yakima Ridge system.

   - The geometry and extent of east-west trending faults on the north flank and south flank.
   - The Yakima Ridge extension and its hydrologic implications.
   - The southern portion of Yakima Ridge within the controlled area study zone, the fault along the south flank, the presence of cross faults and the geometry of the syncline that separates it from the main part of Yakima Ridge.

4. Coyote Rapids.

   - The continuity of exposed bedrock between Umtanum Ridge and the Columbia River.
   - The continuity of exposed Ringold sediments along the Columbia River.
   - The deformation and continuity of Quaternary sediments in the area.

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5. Rattlesnake-Wallula alignment and southern Pasco Basin.

   - Rattlesnake Hills/Snively Basin.

     - The geometry and extent of east-west trending faults along the Rattlesnake Hills/Snively Basin trend.

     - Nature of cross faults within the area.

     - Continuation of the northwest trend of Rattlesnake Mountain.

     - Structures that may trend northeast along the Rattlesnake/Wallula alignment trend.

     - The structural intersection of the regional structure, the Hog Ranch-Naneum Ridge anticline, with the Rattlesnake Hills fault and anticline.

   - Rattlesnake Mountain structure.

     - Geometry of Hodges Ranch extension anticline.

     - Presence of east-west trending fault along the north flank of Hodges Ranch extension.

     - Decrease in structural relief toward Yakima River Gap.

     - Geometry of cross fault on Rattlesnake Mountain.

     - Apparent absence of structural deformation at Yakima River Gap.

   - "The Rattles" structural trend.

     - Geometry of the doubly plunging anticlines termed "the Rattles."

     - Geometry and continuity of faulting along and between individual anticlines of "the Rattles."

     - Nature of convergence of "the Rattles" trend with the Horse Heaven Hills trend and Wallula Gap.

6. Eastern Pasco Basin boundary structure.

   - Location of structures which bound the Pasco Basin geohydrologic system.

   - Presence of folds or faults that mark the eastern edge of the Pasco Basin.

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- Presence of faults and folds along the Ice Harbor dike system.
- Presence and nature of any faults or folds in the area of Wooded Island.
- Presence and nature of faults or folds along the White Bluffs.

7. Northern Pasco Basin structure.

- Eastward extension of Hansen Creek fault.
- The structural intersection of the regional structure, the Hog Ranch-Naneum Ridge anticline, with the Saddle Mountains fault and anticline.

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8.3.1.2.3.3.4.2.1.1 Cold Creek syncline. The Cold Creek syncline is predominantly covered by sediments. It has been mapped previously by Lillie and others (1978) and Myers/Price et al. (1979, Plate III). New mapping in the Cold Creek syncline at a scale of 1:12,000 will concentrate on the suprabasalt sediments and geomorphic landforms. Mapping studies will be coordinated with geophysical studies, and areas where geophysical anomalies have been identified will receive more detailed attention. The Cold Creek syncline, exclusive of the controlled area study zone, is further divided into upper and lower portions for this discussion of field locations. The subdivisions are illustrated on Figure 8.3.1.2-19.

The upper Cold Creek syncline is west of the controlled area study zone. Studies in this area will address the continuation of mapped faults (Goff, 1981), Werner magnetic anomalies (Aero Service, 1980) and lineaments identified by Weston (1978b). Basalt outcrops are present in the western corner of the study area but the eastern part is largely sediment covered and will require geophysical surveys to investigate. Land access will involve private as well as public land. Initial examination of the area will use the data sets listed above as well as existing Washington Public Power Supply System aeromagnetic data. Further studies will be based on the result of this first-pass analysis. Preliminary plans require the extension of potential field (magnetic and gravity) profiles from the western boundary of the controlled area study zone at about one mile spacings east-west and two mile tie lines north-south. Profiles will extend to the western boundary of the study area with infilling as required. Supplementary electrical and refraction seismic studies will be in specific locations directed by initial gravity and magnetic studies. Confirmatory boreholes may be required in this area, but the locations will be determined during the study.

The lower Cold Creek syncline is southeast of the controlled area study zone and presents a considerably different situation for field work than the upper Cold Creek syncline. Outcrops are present only in the extreme southeastern portion. Sediment cover is considerably thicker, resulting in greater depths for confirmatory boreholes. Land access may be more difficult due to contaminated zones created by defense waste activities. Data sets currently

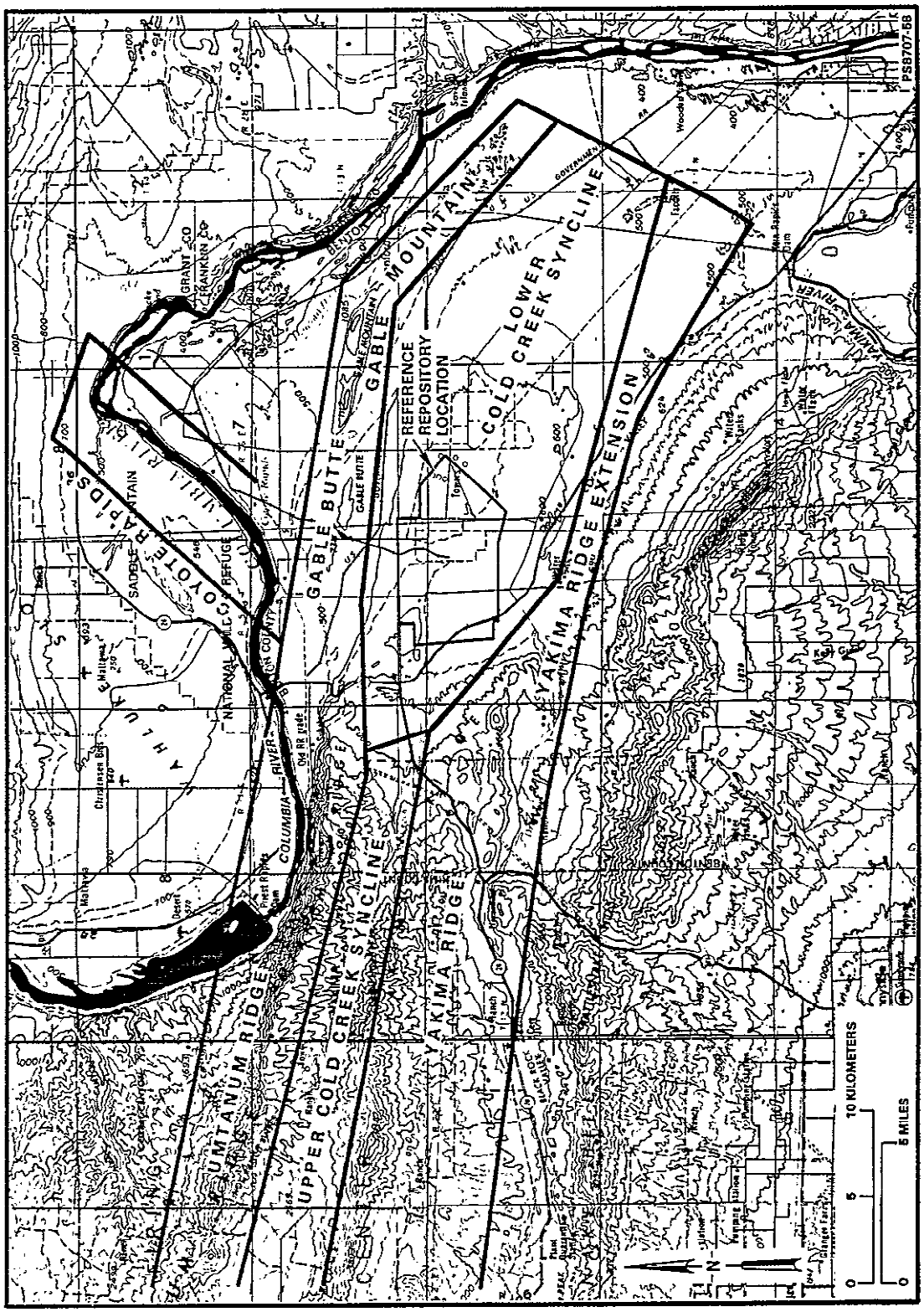

Figure 8.3.1.2-19. Subdivisions of the Cold Creek syncline.

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available for this area include those mentioned for the upper Cold Creek syncline and additional work conducted by Myers and Price (1981). Geologic problems to be addressed in this area are listed below:

- Geologic significance of a series of northeast-southwest trending aeromagnetic Werner deconvolution solutions, the N-71 (see Fig. 1.3-66) group, in the northeast segment of the study area.
- Significance of the N 243 (see Fig. 1.3-66) aeromagnetic Werner deconvolution group and the orientation of the Cold Creek syncline in the area. A northeast reorientation is indicated.
- The relationship between the reorientation of Gable Mountain and the May Junction Linear (see Fig. 1.3-66) and the Horn Rapids anticline (Myers/Price et al., 1979).

The initial investigation will involve the compilation and examination of existing data. Some additional potential field profiles are anticipated to fill in existing coverage. Seismic reflection surveys will require high energy sources in this area because of the thick sediment cover over the basalts. Boreholes to confirm structure may be required in this area, but the locations will be determined by the results of the geologic mapping and geophysical surveys.

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8.3.1.2.3.3.4.2.1.2 Umtanum Ridge/Gable Mountain structures. Umtanum Ridge has been mapped in detail between 120° west longitude and the eastern end of Gable Mountain (Fecht, 1978; Goff, 1981). New mapping will be conducted in the area between 120° west longitude and the Hog Ranch-Naneum Ridge anticline at a scale of 1:24,000 and will include the synclinal area between Umtanum Ridge and the Saddle Mountains. Geologic problems to be addressed by this mapping are the characteristics of the intersection between Umtanum Ridge structure, and the Hog Ranch to determine the structural style, age relationships, and potential for groundwater recharge along both structures.

8.3.1.2.3.3.4.2.1.3 Yakima Ridge system. Preliminary geologic mapping has been completed for Yakima Ridge from 120° west longitude to its eastern exposure in the controlled area study zone (Fig. 8.3.1.2-19). This area will be remapped at a scale of 1:12,000. The purpose of this mapping will be to provide information on the northwest extension of the Rattlesnake/Wallula alignment beyond Snively Basin, the structural style of the Cle Elem-Wallula disturbed zone northwest of the Rattlesnake/Wallula alignment and structural features associated with it, the nature of the intersection of the Hog Ranch-Naneum Ridge anticline with Yakima Ridge, and areas of potential groundwater recharge for the Pasco Basin.

Basalt outcrops are present throughout the Yakima Ridge area, but a considerable portion is sediment covered and will require geophysical surveys to investigate. Geophysical surveys will address the continuation of mapped faults (Goff, 1981), Werner magnetic anomalies (Aero Service, 1980), and

aeromagnetic lineaments identified by Weston (1978c). Preliminary plans are to extend magnetic and gravity survey lines oriented east-west from the western boundary of the controlled area study zone at about a one-mile spacing, with north-south tie lines at a two-mile spacing. The lines will extend to the western boundary of the study area, and a closer line spacing may be used for selected structures as required. Other geophysical studies will be conducted in locations where structure is suggested by the gravity and magnetic surveys. Boreholes to confirm structure may be required in this area, but the locations will be determined by the results of the geologic mapping and geophysical surveys.

8.3.1.2.3.3.4.2.1.4 Coyote Rapids. Microseismic swarm activity has been described near Coyote Rapids (Rohay and Davis, 1983, pp. 6-7; and Fig. 8.3.1.2-19). Most events in this area have been of magnitude 3.0 or less, although a magnitude 3.8 event occurred October 25, 1971, slightly to the northeast. Although this area is not as active as other swarm areas, its proximity to the candidate site requires investigation.

The basalt, Ringold sediments (see White Bluffs study), and Quaternary units in this area will be mapped at a scale of 1:24,000. Two- and three-dimensional seismic reflection methods will be considered as a possible means of delineating the source of the swarm activity. Interpretation of the potential relationship between microseismic activity and geological structures will be done by integrating the results of the above methods. The utility of using boreholes to assess the effects of earthquake swarms on rock properties will be further evaluated.

8.3.1.2.3.3.4.2.1.5 Rattlesnake/Wallula alignment and southern Pasco Basin. The Rattlesnake/Wallula alignment is subdivided into three areas for this discussion: Rattlesnake Hills/Snively Basin, Rattlesnake Mountain, and "the Rattles." The purpose of the study of the Rattlesnake/Wallula alignment is to provide structural geologic information on the southern boundary of the Pasco Basin.

Rattlesnake Hills/Snively Basin structures

The Rattlesnake Hills-Snively Basin area (Fig. 8.3.1.2-20) lies west of the Rattlesnake/Wallula alignment and terminates at the Rattlesnake/Wallula alignment. This area is currently being mapped at a scale of 1:12,000. This area will be mapped to the intersection with the Hog Ranch-Naneum Ridge anticline. Geophysical investigations in this area and for Rattlesnake Mountain are discussed in Section 8.3.1.2.3.3.4.4 (deep structure of the Pasco Basin).

The geologic problems addressed by this mapping activity are (1) the northern extent of the Rattlesnake/Wallula alignment and the its characteristics in Snively Basin, (2) the timing of deformation along the Rattlesnake/Wallula alignment and in Snively Basin (for input to the Deformation Study), (3) the nature of the intersection between the Rattlesnake Hills and the Hog Ranch-Naneum Ridge anticline, and (4) identification of areas of potential groundwater recharge.

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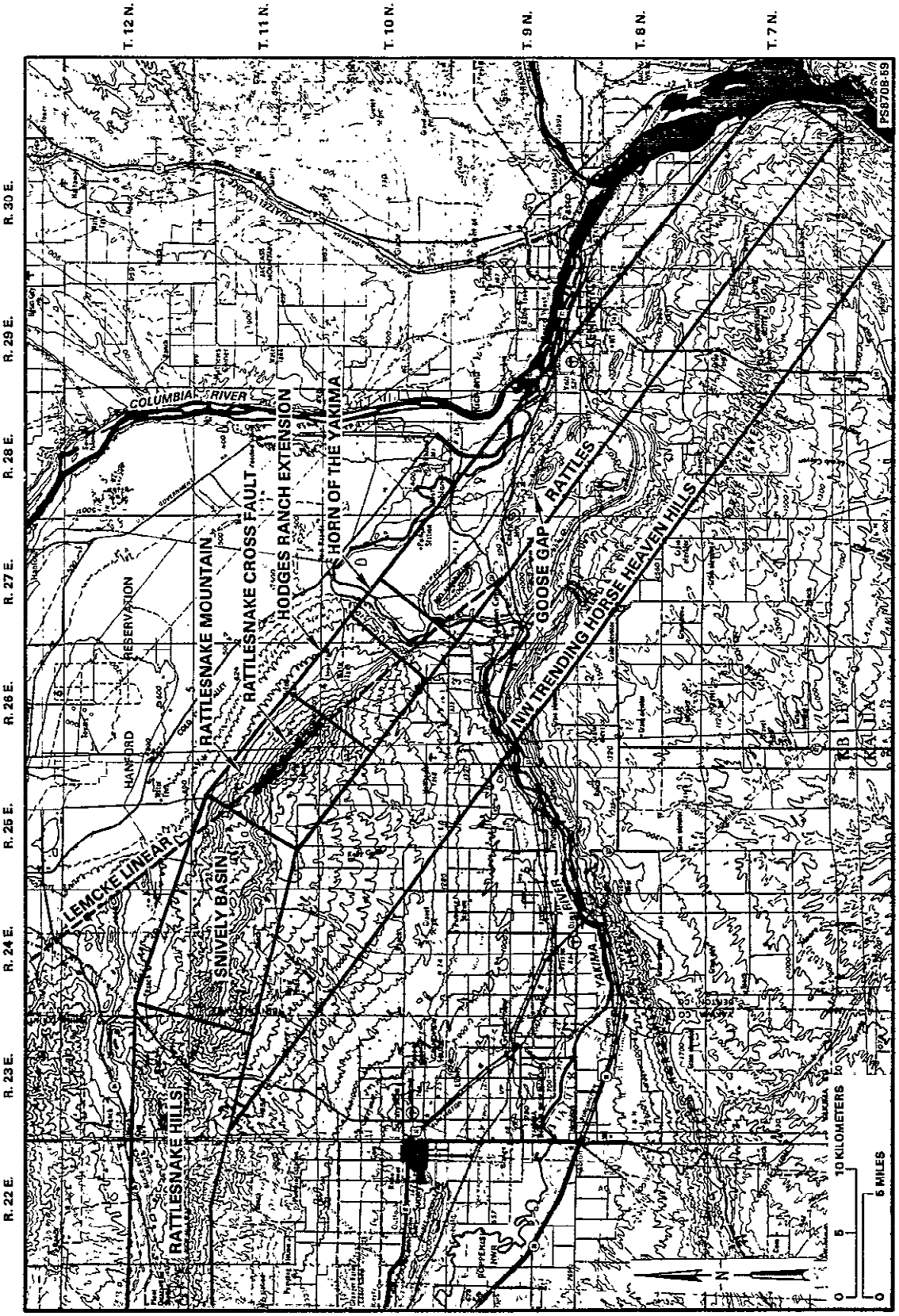

Figure 8.3.1.2-20. Rattlesnake/Wallula alignment-southern boundary of the Pasco Basin primary study areas.

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Rattlesnake Mountain structure

Three areas on Rattlesnake Mountain will be examined in detail to complement existing mapping: the Hodges Ranch extension, the "cross fault" on Rattlesnake Mountain, and the Horn of the Yakima (see Fig. 8.3.1.2-20). Studies in these areas are designed to determine the constraints on the length of the Rattlesnake Mountain fault, the amount of movement on the fault, and the age of faulting. Studies from these areas will also provide information on the geometry of Rattlesnake Mountain anticline to compare it with other Yakima folds and on the subsurface geometry of the Rattlesnake Mountain fault.

The Hodges Ranch extension. The Hodges Ranch extension is the southwestern portion of Rattlesnake Mountain. Mapping in this area will provide information on the continuation of the Rattlesnake Mountain fault between Rattlesnake Mountain and the Horn of the Yakima study area. This area will be mapped at 1:12,000 and, because of the limited exposures, geophysical studies will be required to help define the extent of faulting and the subsurface geometry of the fault. Trenching will be used to obtain evidence to determine the age of faulting.

Cross fault on Rattlesnake Mountain. Mapping currently in progress has shown that a fault previously mapped parallel to Rattlesnake Mountain (Bond et al., 1978; Bond and Wood, 1978) actually cuts across the Rattlesnake Mountain fault (see Fig. 8.3.1.2-20; Sections 29 and 30, T11N, R26E) and is overlain by apparently undisturbed sediments. The purpose of this study is to determine the age of last movement on this fault, determine the northwest extent of the fault, and determine the age amount and sense of movement. This area will be mapped in detail (1:500) with emphasis on determining the age relationships and constraints. First a geologic map of the surface units will be completed and followed by detailed ground geophysical studies that will delineate the fault location, length, and width. The geophysical surveys combined with the surface mapping will be used to locate trench sites that will then be used to determine the age of last movement as part of the deformation study (Section 8.3.1.2.4.3.1).

Horn of the Yakima. Previous mapping (Myers/Price et al., 1979, Plate III) has suggested the absence of any significant faulting associated with the continuation of the Rattlesnake Mountain fault along the Yakima River where it crosses the Rattlesnake/Wallula alignment. The Ice Harbor (8.5 m.y.B.P.), Elephant Mountain (10.5 m.y.B.P.), and Pomona (12 m.y.B.P.) Members of the Columbia River basalt do not appear to have been faulted along the Yakima River. The purpose of this study is to provide evidence for the extension, or lack of extension, of the Rattlesnake Mountain fault to the Yakima River and to determine the continuity, amount of fault movement (both strike-slip and thrust), and age of last movement. Geologic mapping will be at a scale of 1:24,000 with additional mapping at 1:12,000. This will be supported by ground geophysical studies and trenching where necessary. The geophysical studies will be designed to specifically locate structural offset in areas of poor exposure and to examine the subsurface for evidence of

faulting or folding that has been buried by later volcanism. Paleomagnetic data, as part of the deformation study, will also be collected to support studies in this area.

"The Rattles" structures

"The Rattles" extend from the east side of Wallula gap northwestward to the Yakima River. This area is part of the Cle Elem-Wallula disturbed zone and includes "the Rattles" trend, the series of domes northeast of "the Rattles" trend, and the northwest trend of the Horse Heaven Hills. The principle objectives of this study are to determine the geometry of the domal hills, determine the presence or absence of fault continuity between the domal hills, determine the age of last movement, determine the type of movement (strike-slip, thrust), and determine the structural relationship between the three trends that comprise the Cle Elem-Wallula disturbed zone here.

"The Rattles" will be mapped at 1:12,000 with emphasis on the faults and the extent of faults. Geophysical studies will be required to help prove or disprove the continuity of faulting between the structures. A combination of surface mapping and geophysical studies will be used to determine when trenching may be most beneficial to prove or disprove the continuity of faulting and, if present, the age of last movement for faulting.

Goose Gap is a structural gap between Badger Mountain and Candy Mountain (Section 20, T8N, R28E). Recent road building activity has exposed the northwest side of Badger Mountain providing an opportunity to examine the basalt geometry and potential fault displacement. The area has been mapped in a preliminary manner; additional mapping will concentrate on the area immediately around the exposure. Geophysical surveys will be required to see if mapped features extend along trend through sediments toward Candy Mountain. Fracture analyses and paleomagnetic studies for strain analysis will be performed as part of the deformation study (Section 8.3.1.2.4.3.1).

Geophysical surveys will address the continuation of structures both parallel and perpendicular to the Rattlesnake/Wallula alignment. The collection of geophysical data will address the continuity of northwest-trending faults and constrain strike-slip movement by investigation of cross-cutting features. The continuation of faulting along the north flank of Rattlesnake Mountain southeast to "the Rattles" and the presence of northeast-trending cross structures, as suggested by aeromagnetic surveys (Aero Service, 1980), are targets for this activity.

The Horse Heaven Hills have been mapped in detail from Webber Canyon to the intersection with the Hog Ranch-Naneum Ridge anticline (Hagood, 1986). This portion is complete and only that section from Webber Canyon to the intersection of the Horse Heaven Hills with the Rattlesnake/Wallula alignment needs to be completed (Fig. 8.3.1.2-20). This area will be mapped at a scale of 1:24,000 and will join to the north with mapping along the Rattlesnake/Wallula alignment; it will extend to the south to join with regional mapping on the Service anticline. The purpose of this mapping is to provide information on the nature of the intersection of the Horse Heaven Hills with

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the Rattlesnake/Wallula alignment, and to determine the nature of the intersection of the Horse Heaven Hills with the Service anticline.

Geophysical studies conducted as a part of the Horse Heaven Hills study will be in support of geologic mapping and the assessment of specific geophysical features. Features to be investigated initially include northeast- and northwest-trending linears interpreted by Aero Service (1980) and the continuation of signatures relating to sudden changes in fold geometry. The continuation of features to the northeast to "the Rattles" study area, or southwest across the Horse Heaven Plateau, would support the examination of the presence of northeast-trending faults. Magnetic and gravity surveys are the initial methods planned with other methods used selectively. Land access will be difficult due to private ownership of virtually the whole study area and cultural interference will be extensive in some areas.

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8.3.1.2.3.3.4.2.1.6 Eastern Pasco Basin boundary structures. The eastern boundary of the Pasco Basin (Fig. 8.3.1.2-21) is defined as the junction between the Yakima Fold Belt and the Palouse subprovince. This coincides with the Ice Harbor dike system and Jackass anticline/monocline, and a corresponding decrease in thickness of the basalt and sediments to the east. The purpose of this task is to further describe the structural features that might define the eastern hydrologic and structural boundary of the Pasco Basin. Emphasis will be placed on determining the style of deformation associated with the intrusion of the dikes and determining their potential as groundwater flow paths.

Since the eastern boundary of the basin is defined primarily by subsurface features, the use of geophysical methods will be emphasized. These geophysical surveys will help determine the configuration and continuity of the Ice Harbor dike system in areas of sediment cover and aid in the determination of the effectiveness of the dikes in acting as a barriers to groundwater flow. The dikes will be traced by cross traverses using various geophysical methods to define their continuity. Where offsets of the dikes are detected, additional geophysical profiles will be placed to determine the characteristics of cross-cutting structures.

Magnetic and electrical methods may prove to be the most effective in this activity due to the sharp magnetic contrasts between individual dikes and the possibility for the dikes to form electrical as well as hydrologic barriers. Aeromagnetic surveys (WPPSS, 1977; Myers and Price, 1981) illustrate these contrasts and will be used to direct ground-level magnetic line placement. Gravity and seismic methods are also potential contributors for this field work but will only be used after tests have been conducted in known dike locations. Existing regional data sets will also be examined for possible evidence of deep structures since the continuation of dikes south of the Rattlesnake/Wallula alignment is a major question to be addressed in this study as well.

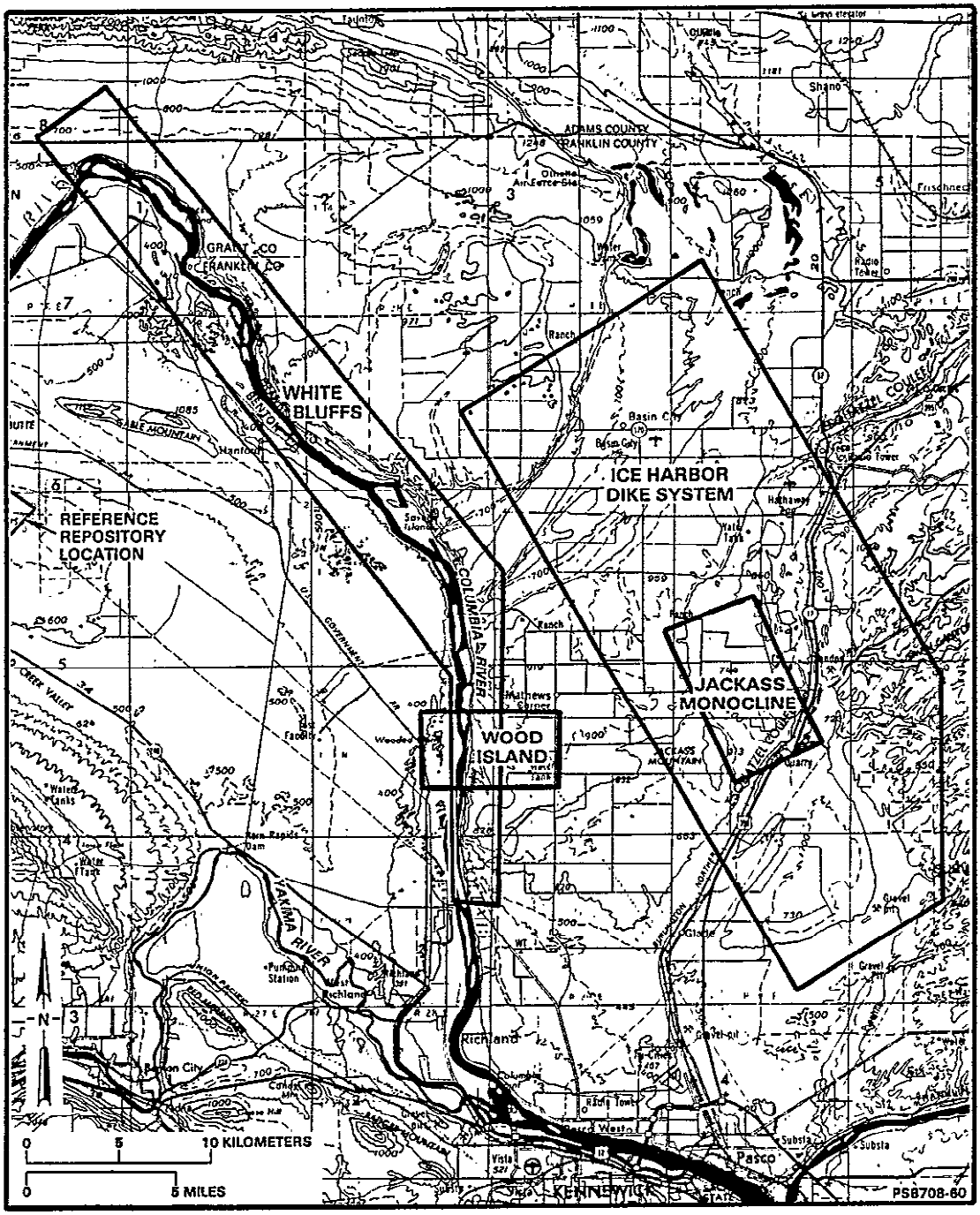

Figure 8.3.1.2-21. Eastern Pasco Basin primary areas of investigation.

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The field work will be conducted in four phases:

1. Compilation of geologic and geophysical maps to determine suitable locations for methods, tests, and to direct placement of initial traverses.

2. Geophysical tests of various methods on known dike locations.

3. Initial traverses to trace dikes and locate structural discontinuities in structures.

4. Detailed analysis, using all available geologic and geophysical information, to identify the nature of discontinuities, and to evaluate the lateral extent of the structures.

This task's field work will be conducted entirely on private land and access rights are constraints. Few boreholes are presently available to aid in interpreting results.

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Ice Harbor dike system

The area of the Ice Harbor dike system (see Fig. 8.3.1.2-21) will be mapped at a scale of 1:24,000 with emphasis on the area between the Horse Heaven Hills and the Saddle Mountains. Mapping will concentrate on the structural setting of the dikes, with specific emphasis on faults, tectonic joints, and minor folds. Spatial relationships between these features and the dikes will be analyzed. Because most of the area is covered by Quaternary cataclysmic flood deposits, geophysical surveys will play an important role in defining structures.

Wooded Island

The area near Wooded Island has been the location of numerous swarms of microearthquakes, with all events having a magnitude of less the 3.0 (Rohay and Davis, 1983, pp. 6-7). Geologic mapping in this area is discussed in the White Bluffs subtask. This mapping effort will be supplemented with geophysical surveys. Gravity, ground magnetic, and possibly electrical data will be acquired to interpret the possible relationship between swarm activity and anomalous drainage patterns identified on the east side of the Columbia River in this area. The utility of using boreholes to assess the effects of earthquake swarms on rock properties will be further evaluated.

White Bluffs

Geologic mapping of Ringold Formation exposures is required to look for evidence of tectonic deformation and to either confirm or reject the presence of a long-lived lake within the Pasco Basin during late Pliocene time. A geologic and tectonic map of Ringold exposures at White Bluffs, Smyrna Bench, and Taunton Bench are to be compiled at a scale of 1:12,000, based on field mapping , stratigraphic section measurements, and air photo interpretation. Emphasis will be placed on mapping lithofacies and tracing key marker

horizons. Paleomagnetic samples for analysis and for age dating will be collected to help correlate units as well as to support assessment of deformation in the basin analysis of the suprabasalt sediments study (i.e., sedimentation).

Two areas along the White Bluffs are of particular interest and require more detailed mapping. One area lies directly above the straight, north-south trending reach of the Columbia River (Fig. 8.3.1.2-22, area A). Mapping of the well-exposed bluffs in this area will examine evidence, if any exists, that the Columbia River is fault controlled to the south. If a high-angle fault has been active since upper Ringold time (3.5 m.y.B.P.), then it should be apparent in the well-exposed Ringold sequence above the river in area A (see Fig. 8.3.1.2-22). Similar mapping will be carried out in another area, near Wooded Island (see area C, Fig. 8.3.1.2-22), where there are several short northwest-trending tributaries which run parallel to each other at an anomalous (obtuse) angle with the Columbia River. These streams are aligned with, and therefore may be related to, the southeastward extension of the Gable Mountain structure, discussed in Section 1.3.2.2.2.3.

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8.3.1.2.3.3.4.2.1.7 Northern Pasco Basin structure.

Saddle Mountains

The Saddle Mountains have been mapped in detail from 120° to 119° west longitude (Reidel, 1986). The area between 120° west longitude and the Hog Ranch-Naneum Ridge anticline will be mapped at a scale of 1:24,000 (Fig. 8.3.1.2-23). The purpose of this study is to examine the intersection of the two structures and to determine the structural style, the age relationships, and the potential for groundwater recharge along both structures.

Geophysical surveys of the Saddle Mountains will also be conducted with the following objectives: (1) to investigate the relationship between microearthquake swarms and structures, (2) to obtain further detailed field evidence for structural analysis of a Yakima fold, and (3) to correlate magnetotelluric data with data from the Saddle Mountains hydrocarbon exploration well (Campbell, 1985). The eastern end of the Saddle Mountains (Smyrna Bench area) has one of the highest concentrations of seismic swarm activity in the Columbia Plateau (WCC, 1980b). From surface geologic mapping of the Saddle Mountains and aeromagnetic data (Reidel, 1984), it has been interpreted that a structure in the basalt crosses the Saddle Mountains (Smyrna Anticline) on a northwest orientation that generally corresponds to the trend of mapped swarm activity located several kilometers to the east. The swarm activity occurs along a narrow zone where the Saddle Mountain fault geometry changes, also suggesting structural control.

The initial effort of this task activity will be to grid the survey area with 20 to 25 magnetotelluric sites (or an equivalent resistivity survey) and an undetermined number of additional gravity stations. The data will then be analyzed and supplemental sites will be selected based upon the initial results. Precise recording locations have not yet been determined. The gravity station spacing will be selected to optimize interpretation of the base of the basalt.

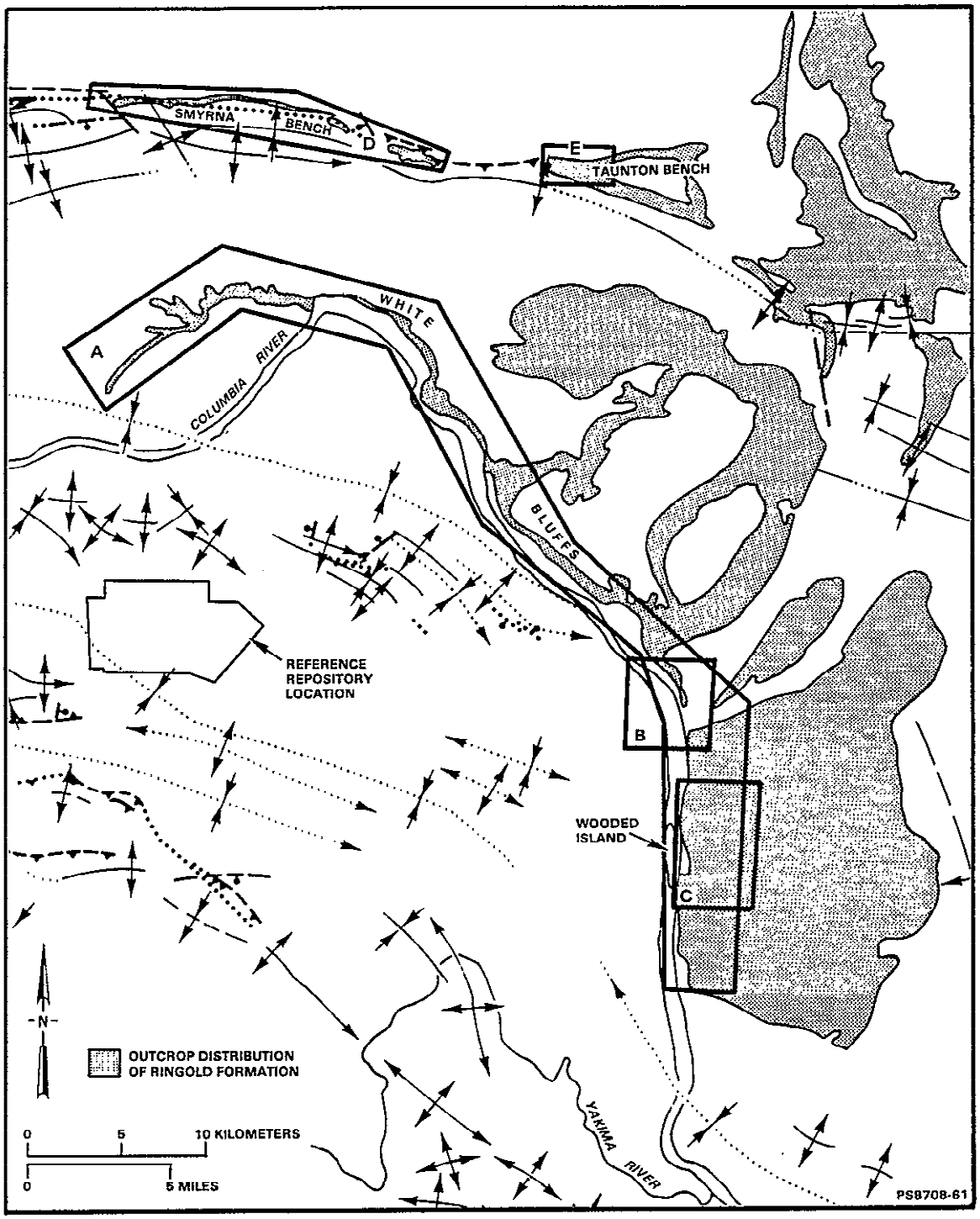

Figure 8.3.1.2-22. Ringold Formation distribution and relationship to tectonic structures in and adjacent to the Pasco Basin.

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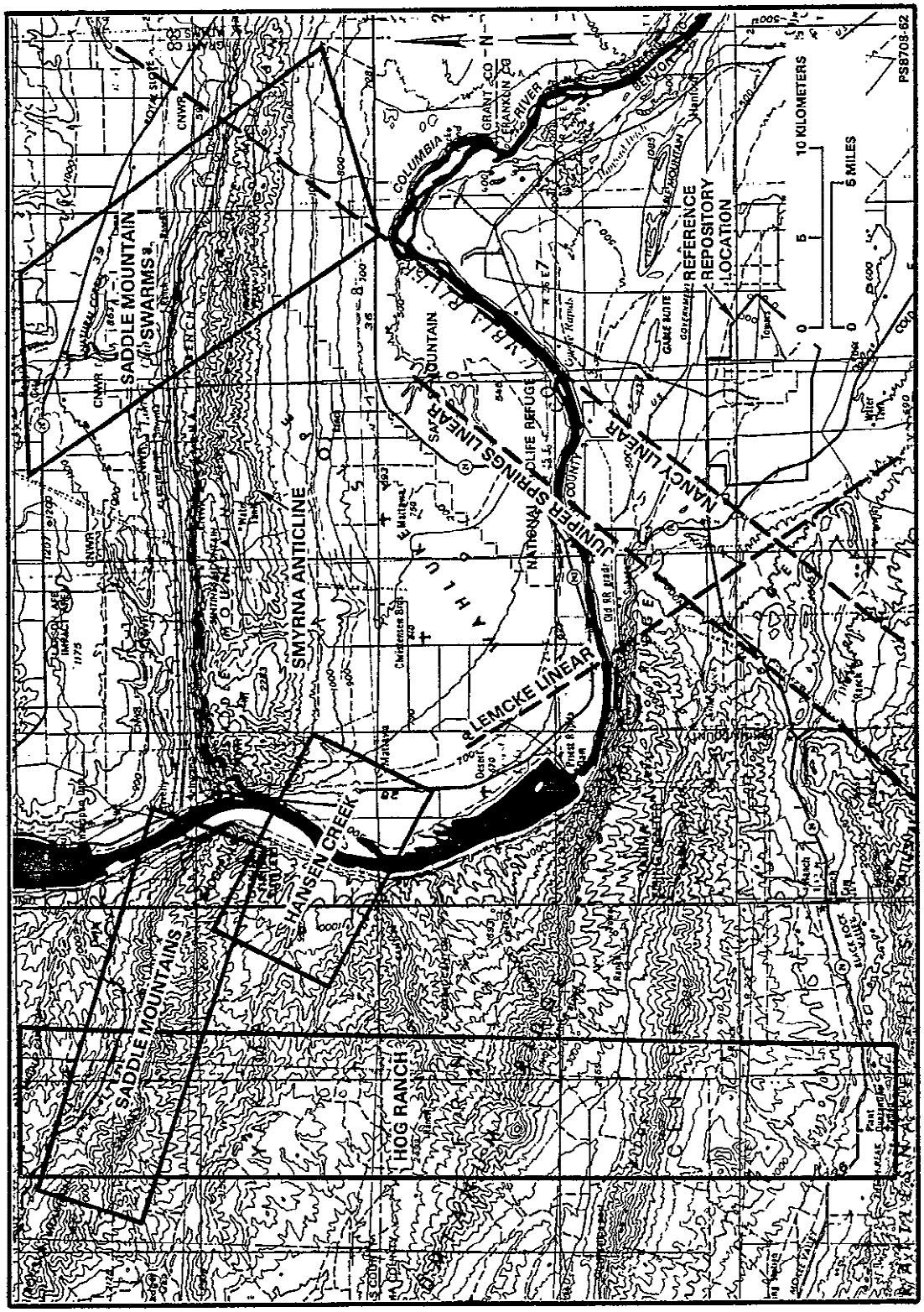

Figure 8.3.1.2-23. Northern Pasco Basin primary areas of investigation.

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Magnetotelluric sites will also be used to make a traverse from the survey area to the 1-9 BN Saddle Mountains well. It is anticipated that the survey will consist of 25 to 50 magnetotelluric sites and a corresponding number of gravity stations depending on the complexity of the structure encountered.

Nancy and Juniper Springs linears. The Nancy and Juniper Springs linears were identified on the basis of several gradients in the data from an aeromagnetic survey (WPPSS, 1977). They trend northeast across the Pasco Basin (see Fig. 8.3.1.2-23). The possible extension of the linears to the southwest near the controlled area study zone places importance on their geologic interpretation. The relationship, if any, of earthquake swarm activity to these linears will be examined.

Portions of these linears occur in areas of minimal sediment overburden, which improves conditions for examining these features in greater detail. It is not certain whether or not the lineaments reflect structural feature; however, surface outcrop data along the trend of the Nancy linear suggest that it is not a continuous structural feature. The principal elements in their investigation are as follows:

1. Reevaluate existing data, including geologic maps; seismicity; seismic reflection, gravity, and magnetic data from the Rockwell Wahluke Slope Study, Aero Service (1980), and WPPSS (1977), aeromagnetics.

2. Collect additional ground magnetic and gravity data to supplement the existing data base. The use of other geophysical methods is not anticipated, although the results of initial studies may require them.

3. Conduct confirmatory drilling, if necessary.

Hansen Creek fault.

Thrust faulting mapped south of Sentinel Gap on the west side of the Columbia River is part of a continuous zone of faulting nearly 75 km (47 mi) long (Tolan, 1986). The Hansen Creek fault, the easternmost expression of this zone, apparently terminates abruptly at its intersection with the Columbia River south of Sentinel Gap. This termination, as mapped, may be due more to the lack of exposures to the east than to actual structural changes. The possibility for a change in the fault trend to a more southeasterly trend that intersects the controlled area study zone makes the Hansen Creek fault important to the investigation of the controlled area study zone. This possible reorientation is supported by the presence by an unnamed aeromagnetic lineament interpreted by Weston (1978c) and two aeromagnetic lineaments from the Aero Service (1980) study (see Fig. 8.3.1.2.23). The Weston lineament, referred to as the Lemcke lineament, originates near the eastern end of the Hanson Creek fault as mapped and extends southeast to near Benton City. The Aero Service (1980) N-91 and N-92 lineaments support the presence of the Lemcke lineament north of the Umtanum Ridge.

The close proximity of the Lemcke lineament to eastern Yakima Ridge may be important to understanding the formation of the ridge. Two areas along the Lemcke lineament exhibit seismic activity. The northernmost area is near the intersection of the Hansen Creek fault and the other area is southeast of Yakima Ridge.

The Hansen Creek fault will be further studied by re-evaluating the existing geologic maps, the seismicity of the area, and magnetic survey data (Aero Service, 1980; WPPSS, 1977). Additional data will be collected to supplement and confirm existing information (see Fig. 8.3.1.2-23). This study will proceed in two phases. Phase one will determine the geophysical characteristics of the Hansen Creek fault. Phase two will extend the investigation to the south and east and determine the relationship of the fault to the Lemcke linear. The investigation will rely primarily on geologic mapping(1:12,000), ground magnetic and gravity surveys, and other geophysical methods as necessary.

This task activity covers only the northern segment of the Lemcke lineament. The southeastern segments are examined as part of the central Pasco Basin and Rattlesnake/Wallula alignment tasks.

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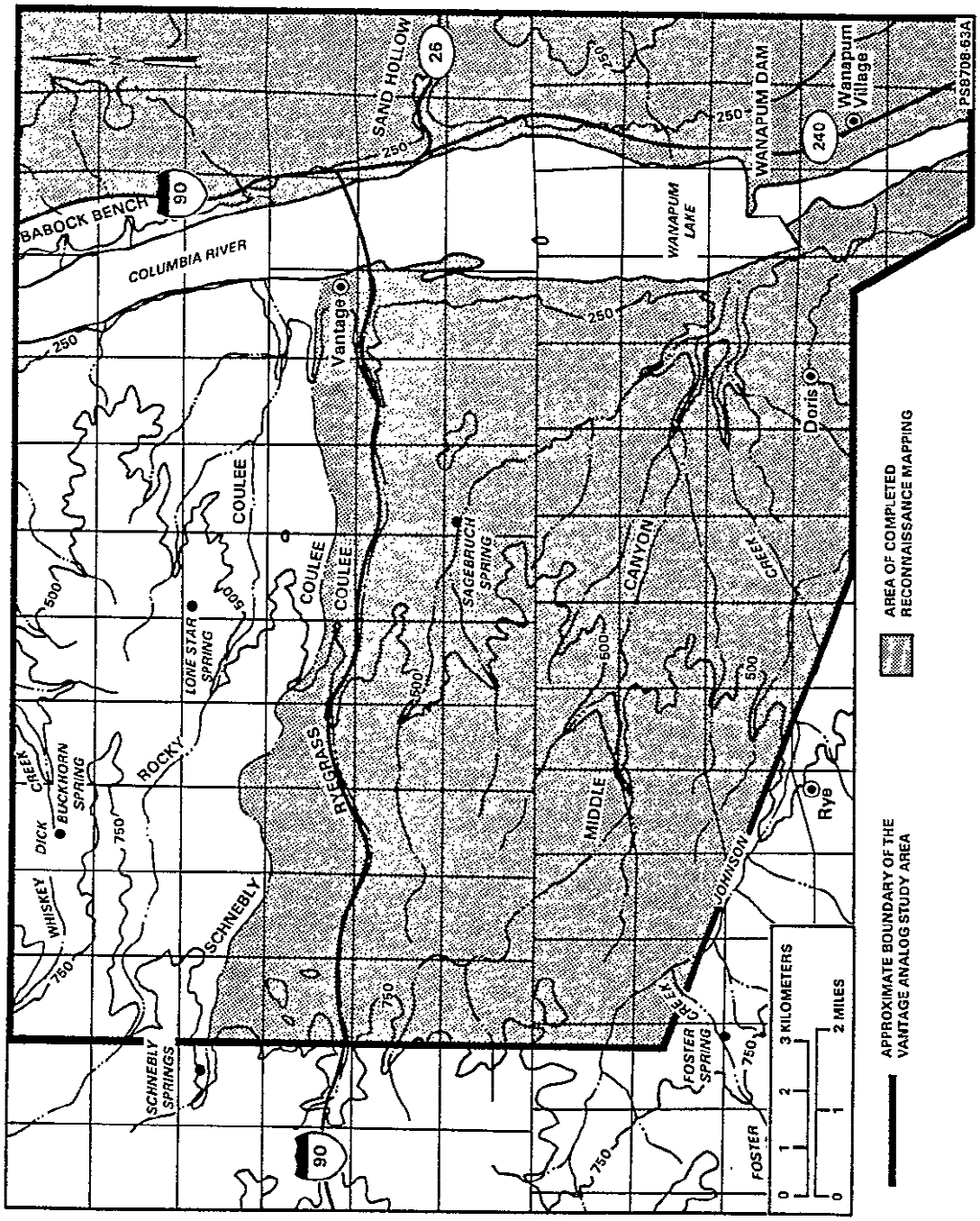
8.3.1.2.3.3.4.2.2 Analog area tasks

Selected areas outside the Pasco Basin will be used to conduct analog tasks. These tasks will provide analyses to aid in the interpretation of data from the controlled area study zone and Pasco Basin that cannot be evaluated directly. The two analog area tasks described below are also analogs for the stratigraphy study (Section 8.3.1.2.3.3.1).

8.3.1.2.3.3.4.2.2.1 Vantage analog subtasks. The purpose of this subtask is to examine and describe faults found in surface exposures within a synclinal area similar to the Cold Creek syncline. Such surface exposures may provide baseline data on the origin, density, distribution, and physical properties of faults. Such data would supplement borehole and geophysical information from the controlled area study zone/Cold Creek syncline and may provide an early indication of the range of possible tectonic conditions that could be encountered in the repository area.

The use of the Vantage area as an analog to the Cold Creek syncline began in 1983 (Chamness and Tolan, 1983). The study area is located 48 km (30 mi) to the northwest of the reference repository location, near Vantage, Washington (Fig. 8.3.1.2-24), which is in the synclinal area between the Saddle Mountains and the Frenchman Hills. The Vantage area was selected for the following reasons:

- Based on existing regional geologic maps, the Vantage area appears to have some structural similarities to the Cold Creek syncline area. Faults exposed in the Vantage area may be physical property analogs for faults in the Cold Creek syncline.



8.3.1.2-24. Vantage analog study area

- The Vantage area is relatively close to the Cold Creek syncline, thus increasing the probability that similar tectonic stresses have been acting on both areas and producing similar strain features.

- The Vantage area has excellent bedrock exposures within the syncline and good accessibility.

Initially, the Vantage area was mapped at a scale of 1:24,000 to better understand the structural geology of the area and to locate faults and folds that could be studied. As a result of this mapping, a number of faults have been identified for further detailed study.

Physical changes resulting from deformation of basalts in fault zones and the juxtaposition of units with contrasting physical properties along faults will make these structures detectable with geophysical methods. The Vantage analog area provides a number of structures that can be examined with geophysical methods, the results of which can be compared to the Cold Creek syncline, which lacks direct exposure of tectonic features. The objective of such geophysical studies in the analog area is to select a variety of fault configurations to test magnetic, gravity, electrical and seismic refraction methods across their traces. The Vantage area offers the following fault configurations:

- Thrust faults.
- Normal faults.
- Tear faults.
- Faults with and without apparent stratigraphic contrast.
- Topographic effects on unfaulted strata.

The geophysical responses to these structures will allow interpreters to evaluate data from the controlled area study zone and other regional investigations for the presence of similar structures.

Figure 8.3.1.2-24 shows the general study area within which specific geophysical profiles will be placed. The individual geophysical surveys will be designed to examine a sufficient lateral extent of each feature to determine variability of responses and to extract any regional components. The study will consist of the following activities.

1. Geologic mapping at 1:6000 scale.

2. Coordinate surveying of station locations.

3. Supplemental gravity, electrical, or seismic data collection/analysis to determine basalt geometries.

4. Magnetic parameter sampling and analysis of units involved.

5. Modeling of hypothetical geometries and comparison with observed values.

8.3.1.2.3.3.4.2.2.2 Deschutes Canyon analog subtask. The Deschutes Canyon south of The Dalles, Oregon, shown in Fig. 8.3.1.2-25, is an analog area that will provide additional verification of techniques used to examine the Cold Creek syncline. This subtask supports the Vantage analog subtask in that it allows deeper Grande Ronde Basalt units to be examined and allows simple anticlines and synclines to be examined for their geophysical signatures. This area is one of the few areas that has exposures of thick sections of Wanapum and Grande Ronde Basalts including the N2 flows which contain the Cohassett flow. In addition there are simple structures within the basalts which are also exposed. Thus this area can be used to study (1) the structure and stratigraphy of the Wanapum and; (2) the interaction of the Gordon Ridge anticline with these flows; (3) the interaction of the Grass Valley syncline with these flows; (4) the interaction of the fault between the syncline and anticline; (5) the tectonic stress regime; (6) the seismic response of flows within the N2; and (7) the in situ physical parameters of the flows including density, remanent magnetism, seismic velocities, and rock strength.

8.3.1.2.3.3.4.3 Studies of regional structures. The extent of the studies of regional structures is essentially the Columbia Plateau and the rocks and structures exposed around its perimeter. Several characteristics suggest that this area is an appropriate scale for regional studies. First, current evidence indicates that the basalts throughout the region have been subjected to a similar or related stress regime. Second, two major geologic features, the Cle Elum/Wallula Lineament and Yakima Fold Belt, are contained within the region. Third, the investigations of sub-basalt rocks must include the margins of the Province, since that is the only place where these rocks can be observed in outcrops. Finally, regional studies are required because the structures in and around the controlled area study zone are larger in scale than the limited area covered by the controlled area study zone and the Pasco Basin.

A considerable portion of the regional geologic and geophysical data base has already been compiled (Chapter 1 Section 1.3). Analysis of these data has revealed several areas where there are insufficient geologic data (Fig. 8.3.1.2-26). Many of these areas are bounding structures to the Pasco Basin and therefore are discussed in the Pasco Basin studies (Section 8.3.1.2.3.3.4.2). The deep structure studies (Section 8.3.1.2.3.3.4.4) also include several studies appropriate to the regional studies. The reader is referred to these sections for additional regional plans. Areas of insufficient data outside the boundaries of the Pasco Basin and not discussed in those sections are discussed below.

Geologic and geophysical data will be collected and analyzed in an iterative manner. The primary source of geologic data are geologic maps from which cross sections and various interpretive maps are made (e.g., fence diagrams, isopach and contour maps). Other sources include stratigraphic sections, boreholes, geochemistry, and air photos. Mapping will provide analysis on the detailed geometry of folds and faults in critical areas. Reconnaissance mapping will provide examinations of areas where extensive detail is not needed.

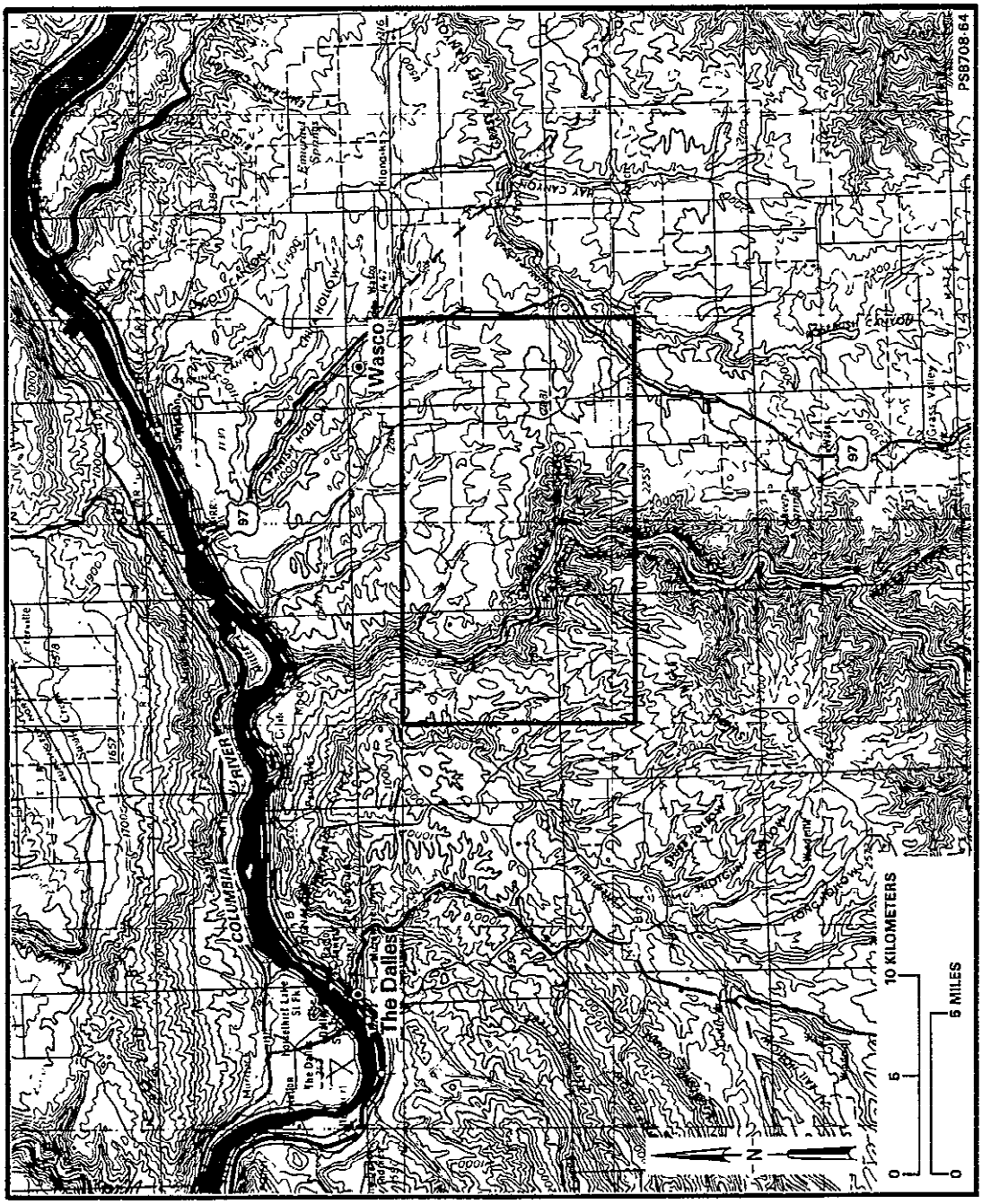


Figure 8.3.1.2-25. Deschutes Canyon analog study area.

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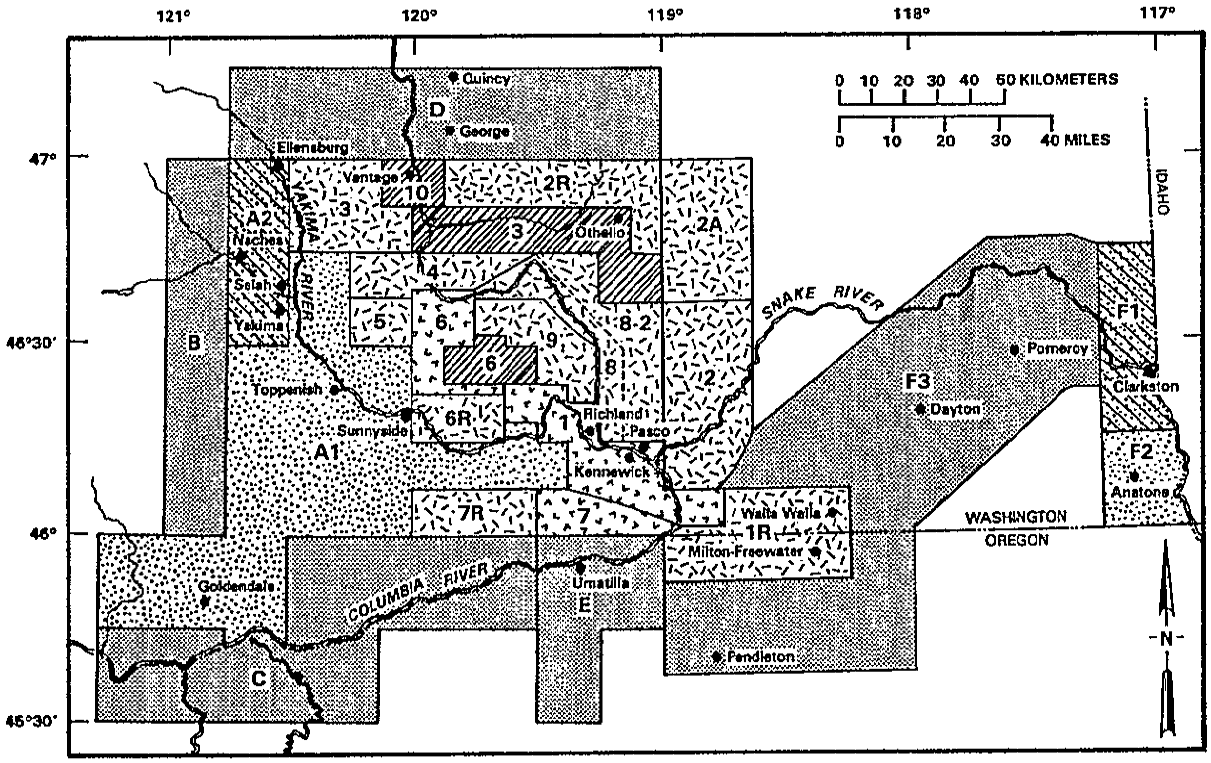

EXPLANATION TO MAPPING INDEX

PATTERN EXPLANATION FOR PASCO BASIN

- = MAPPING COMPLETED; IN PRESS OR READY FOR PUBLICATION
- = FIRST PRIORITY WORK; EITHER WORK IN PROGRESS OR WORK TO BE STARTED NEXT FIELD SEASON
- = NEXT PRIORITY (SEE SCHEDULE FOR TIMING)

PATTERN EXPLANATION FOR REGION

- = PUBLISHED MAPS
- = COMPLETED BUT NOT PUBLISHED; OPEN-FILED MAPS BY WASHINGTON DEPARTMENT OF NATURAL RESOURCES
- = TO BE MAPPED (SCALES VARY)

NUMERICAL EXPLANATION FOR PASCO BASIN

1 = RATTLESNAKE-WALLULA ALIGNMENT (1:12,000)

2 = EAST PASCO BASIN (1:24,000); SOME OVERLAP WITH WHITE BLUFFS

2A = EAST PASCO BASIN (RECONNAISSANCE; COMPILE AT 1:24,000)

* = WEST PASCO BASIN MARGIN; AREAS 3, 4, 5, 6, 6R, AND 7R

3 = SADDLE MOUNTAINS; COMPLETED EAST OF 120°; TO BE COMPLETED TO WEST (1:24,000)

4 = UMTANUM RIDGE (1:24,000)

5 = YAKIMA RIDGE (1:24,000)

6 = RATTLESNAKE HILLS-SNIVELY BASIN; PARTLY COMPLETE (1:12,000)

7 = HORSE HEAVEN HILLS-SERVICE BUTTE ANTICLINE (1:12,000)

8 = WHITE BLUFFS (1:12,000) OVERLAPS WITH EAST PASCO BASIN (8-2)

9 = COLD CREEK SYNCLINE (1:12,000)

REGIONAL GEOLOGIC MAPPING

ROCKWELL HANFORD OPERATIONS (ROCKWELL)

1R = EXTENSION OF RATTLESNAKE WALLULA ALIGNMENT INTO BLUE MOUNTAINS (SEE SCALE TO BE DETERMINED)

2R = FRENCHMAN HILLS (SCALE TO BE DETERMINED)

6R = SOUTH SLOPE OF RATTLESNAKE HILLS-SNIVELY BASIN (1:24,000; LOW PRIORITY)

7R = SOUTH SLOPE OF HORSE HEAVEN HILLS (1:24,000; LOW PRIORITY) NONROCKWELL MAPPING

REGION A1 AND A2 = YAKIMA FOLD BELT; COMPLETED, IN PRESS OR PUBLISHED; SOME OPEN-FILED MAPS

REGION B = WESTERN MARGIN OF COLUMBIA PLATEAU (1:48,000)

REGION C = NORTHWEST TRENDING STRIKE-SLIP FAULTS IN YAKIMA FOLD BELT (SCALE AND MAP AREAS TO BE DETERMINED)

REGION D = FRENCHMAN HILLS

REGION E = SERVICE BUTTE ANTICLINE (1:24,000)

REGION F = BLUE MOUNTAINS-HITE FAULT SYSTEM

F1 = LEWISTON BASIN AREA; PUBLISHED

F2 = SOUTHERN LEWISTON BASIN-CHIEF JOSEPH DIKE SWARM; COMPLETED, TO BE OPEN FILED

F3 = HITE FAULT AND INTERSECTION WITH BLUE MOUNTAINS AND CLEW (MAP AREAS AND SCALE TO BE DETERMINED); SOME ROCKWELL WORK ALREADY BEGUN)

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Figure 8.3.1.2-26. Regional geologic mapping on the Columbia Plateau.

CONSULTATION DRAFT

Regional geophysical data collection and analysis will provide reconnaissance assessment of the Columbia Plateau. Site specific geophysical studies are needed to aid geologic investigations in critical areas. Regional geophysical data is also essential for analysis of deep structure in the Pasco Basin. The geologic and geophysical investigations will be integrated in an iterative manner to provide the structural and stratigraphic characteristics of the Columbia Plateau. This section describes only those specific tasks for regional geologic and geophysical investigations that are not discussed in other sections.

The following sections describe the tasks that need to be completed to develop a general structural description of the Columbia Plateau. The general plan for geological mapping of the region is shown in Figure 8.3.1.2-26.

8.3.1.2.3.3.4.3.1 Studies of the Hite fault system

The Hite fault system (Fig. 1.3-9) is a major potentially seismogenic structural feature that lies southeast of the Pasco Basin and contains faults which display evidence of Quaternary-to-Holocene-age movement (Shannon and Wilson, 1979; Kienle, 1980; Slemmons and O'Malley, 1979). Its association with the epicentral location of the 1936 Milton-Freewater earthquake has been suggested by Woodward-Clyde Consultants (WCC, 1980c) and they now place the epicenter for this event within this system (WPPSS, 1981). The nature, length, and age of movement of this fault system have not been resolved and, thus, its potential impact on siting a repository at Hanford.

Previous reconnaissance-level studies of the Hite fault system by Shannon and Wilson (1979), Kienle (1980), and Slemmons and O'Malley (1979), Kendall and others (1981), and Swanson and others (1981) have presented conflicting information and interpretations of the structural geology and age of this fault system. These conflicting interpretations include such fundamental properties as the location, length, and sense of movement (i.e., dextral versus sinistral strike-slip) on major faults within the fault system (Kienle, 1980; Kendall and others, 1981) as well as the age and kinematic relation of the Hite Fault System to both the Cle Elem-Wallula disturbed zone and La Grande Fault Systems (Kienle, 1980; Kendall and others, 1981; Davis, 1981; Swanson and others, 1981). Until these conflicts are resolved, it will not be possible to assess the role this fault system has in the tectonics of the central Columbia Plateau or to accurately assess its seismogenic nature and possible impact on a geologic repository in the Cold Creek syncline.

In an attempt to resolve conflicting interpretations a two-part study of the Hite Fault System is planned in two sections:

- Part 1--Produce a geologic map of the portion of the Hite Fault System shown in area F3 (see Fig. 8.3.1.2-26). This mapping will be done at a scale of 1:24,000. This phase of the investigation will also reassess existing small-scale geologic and geophysical maps of the Hite Fault system that have been previously produced (e.g., Shannon and Wilson, 1979; Swanson et al., 1980; WPPSS, 1981). These maps

serve as a basis for some of the interpretations previously made about this structure. Final published map scale of this area will be 1:48,000 to be compatible with other published maps of the region.

- Part 2--Structural data and mapping produced in part 1 will be evaluated to determine if data and (or) mapping are providing the necessary input data for other planned tasks. This work will be conducted concurrently with the mapping activities in part 1. These evaluations will help determine if the data required is being obtained by field mapping.

8.3.1.2.3.3.4.3.2 Studies of the Service anticline

The Service anticline consists of a series of north-south-trending, doubly-plunging anticlinal folds that can be traced from the northern flanks of the Blue Mountains to north of the Columbia River. A description of this feature is given in Section 1.3. This regional structure trends north and intersects the Pasco Basin along the Horse Heaven Hills. No detailed studies of this feature have been conducted, and the only mapping that exists is small-scale (Kienle, 1980; Swanson et al., 1981; see Fig. 8.3.1.2-26). Many uncertainties exist concerning the length of this feature (i.e., does it extend northward into the Pasco basin?), its sense of movement on faults within this trend (i.e., dextral or sinistral strike-slip?), and age of last movement on these faults (possible Quaternary-to-Holocene-aged faulting/deformation has been reported by Kienle (1990) and Slemmons and O'Malley (1979)).

As a result of these unresolved questions it is uncertain how this structural feature fits into the regional tectonic picture for the central Columbia Plateau. For example, Kienle (1980) postulated that the structural data from the Service anticline indicated that this feature formed under east-west compression and not under north-south compression. If this hypothesis is correct, then there is a fundamental change in the direction of maximum horizontal compression over a very short distance. Ascertaining whether Kienle's hypothesis is correct and, if correct, understanding the reason why this change occurs would be one critical aspect in developing a tectonic model for the Pasco Basin.

In an attempt to resolve these conflicts a two-part investigation of the Service anticline is planned:

- Part 1--Produce a geologic map of the Service anticline shown in area E (see Fig. 8.3.1.2-26). This mapping will be done at a scale of 1:24,000. This phase of the investigation will also reassess existing large-scale maps of the Service anticline that have been previously produced (e.g., Kienle, 1980; Swanson et al., 1981), which serve as a basis for some of the interpretations previously made about this structure. Final published map scale of this area will be 1:48,000 to be compatible with other published map within the region.

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- Part 2--Structural data and mapping produced in part 1 will be evaluated to determine if data and or mapping are providing the necessary input data for other planned tasks. This work will be conducted concurrently with the mapping activities in part 1. These evaluations will help determine if the data required is being obtained by field mapping.

8.3.1.2.3.3.4.3.3 Studies of the northwest-trending wrench fault systems

Reconnaissance geologic mapping in the Columbia Plateau west of approximately 120° west longitude has revealed numerous, northwest-trending, dextral strike-slip faults (Newcomb, 1969, 1970; Kienle, 1973; Bentley et al., 1980; Swanson et al., 1979a, 1981). These structures are classified as "wrench faults" by several workers (e.g., Bentley et al., 1980; Anderson, 1985; Anderson and Tolan, 1986) on the basis of several characteristics including:

- Conjugate en echelon faults.
- Genetically related en echelon folds, which typically have amplitudes greater than 100 m.
- Reversal of apparent normal separation along strike.

The mean strike direction of these faults is 320° (Anderson and Tolan, 1986). At least four of these faults zones can be traced for more than 100 km, and they cross several Yakima fold trends (Swanson et al., 1979a, 1981: Bentley et al., 1980; Anderson and Tolan, 1986). Recent work by Anderson and Tolan (1986, p. 82) has shown that the wrench faults of regional extent developed contemporaneously with the Yakima folds and that the deformation apparently continued into the Holocene.

Many questions, however, remain concerning the structures. These questions include the following:

- What is the reason for the apparent absence of these structures east of 120° west longitude?
- What types of features do these fault systems display in synclinal areas?
- Can the apparent Holocene-age deformation reported by Anderson and Tolan (1986) be confirmed, and if so, can any other locations of Quaternary/Holocene deformation be found?
- What is the role of these structures in the tectonic evolution of the western and central portions of the Columbia Plateau?

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To begin to resolve these questions, detailed geologic mapping of the Washington portion of the western Columbia Plateau needs to be completed. A portion of this mapping has been done (areas A1 and A2 on Fig. 8.3.1.2-26) and will be published at a scale of 1:48,000 by the Washington State Department of Natural Resources. The remaining area (area C on Fig. 8.3.1.2-26) contains several of the major, regional-scale wrench faults that also need to be mapped in detail. Completion of this mapping would help to answer the question of whether or not these features are present east of 120° west longitude.

The results of the detailed mapping of areas A3 and C will be evaluated to determine what, if any, additional studies need to be done. These additional studies might include, but are not limited to the following:

- Trenching.
- Paleomagnetic studies.
- Geophysical surveys.
- Seismic refraction or reflection surveys.
- Earthquake monitoring.

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8.3.1.2.3.3.4.3.4 Studies of the western margin of the Yakima Fold Belt

The western margin of the Yakima Fold Belt is defined as the western margin of the Columbia Plateau where the Yakima folds in the Columbia River basalt border the underlying rock that is exposed along the east flank of the Cascade range. The purpose of the study of this area is to examine the junction between the basalt and the underlying rock west of the basalt and resolve the structural nature of the Yakima folds, the Hog Ranch-Naneum Ridge anticline, and Cle Elum/Wallula disturbed zone below the Columbia River basalt and determine if these are basement controlled structures. The presence or lack of structural interaction between the rock underlying the basalt and the basalt is important to BWIP for several reasons. The thick skin or thin skin nature of the Yakima folds is a fundamental aspect of tectonic model development and will provide structural control on assessing the seismic potential of the Columbia Plateau. The structural nature of probable basement controlled structures such as the Cle Elum/Wallula and the Hog Ranch-Naneum Ridge anticline provide key information on the tectonic development of the Columbia Plateau prior to the Miocene and thus provide important data on the potential for major basement structures that could control the location of future deformation and deep seismic events.

Tabor et al. (1984) have shown that Manastash Ridge can be directly related to geologic structures mapped in the northern Cascade Range and have argued for basement control on the Yakima folds. They have also argued for basement control of the Hog Ranch-Naneum Ridge anticline and the Cle Elum/Wallula. Beeson and Tolan (1984), Beeson et al. (1985), and Tolan (1982) have also shown basement control on Yakima folds. They have shown that the Horse Heaven Hills structure trends through the Cascade Range and terminates near the Portland Hills demonstrating that this Yakima fold is controlled by structures in rock older than Columbia River basalt. Presently both the Cle Elum/Wallula disturbed zone and Hog Ranch-Naneum Ridge anticline are considered to have basement control (Chapter 1, Section 1.5), but their

relationship to the other Yakima folds is not known. Not all Yakima folds can presently be shown to be controlled by basement structures and, either basement control or lack of it can presently explain the structural trends.

This task will involve reconnaissance mapping along the margin of the basalt and detailed mapping in specific areas where exposure permits determination of the nature of the Yakima fold-basement interaction. The reconnaissance mapping will first be conducted to identify locations that will permit the detailed studies. It is anticipated that geophysical methods will be used in conjunction with detailed mapping to provide control on any possible structures at depth (see the deep structures studies, Section 8.3.1.2.3.3.4.4). The area designated for reconnaissance mapping is shown in Figure 8.3.1.2-26, Area 2R.

Data from this task will be incorporated with data from studies in the fold belt adjacent to the margin and integrated into the tectonic model for the Columbia Plateau.

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8.3.1.2.3.3.4.3.5 Study of the Frenchman Hills

The Frenchman Hills is an east-west-trending anticlinal uplift that lies about 20 km (12 mi) north of the Saddle Mountains (Fig. 8.3.1.2-26, area D). Several important structural features are found within this area. In the western portion of the study area the Hog Ranch-Naneum Ridge Structure crosses the Frenchman Hills uplift and is well exposed. In the eastern portion of the area at Lind Coulee, Grolier and Bingham (1978) reported evidence of possible Quaternary-age faulting associated with the Frenchman Hills uplift.

Various portions of the Frenchman Hills uplift have been mapped by Grolier and Bingham (1978), WPPSS (1977), Swanson et al. (1979), and Tabor et al. (1980). There is some lack of agreement among the various maps in areas of overlap regarding structural and stratigraphic interpretations. For example, some faults along the northwestern portion of the Frenchman Hills have been variously mapped as thrust and strike-slip. These different structural interpretations have very different impacts with respect to the development of structural models of the Yakima Fold Belt. The inconsistencies, therefore, make it difficult to rely on the presently existing mapping and mean that the map information cannot be readily used in the development of a structural and (or) tectonic model until it has been reevaluated.

The purposes of this task will be to (1) attempt to resolve the conflicting map interpretations of this structural feature so that structural information with a lower degree of uncertainty can be used in structural model development and (2) to provide additional information on the Hog Ranch/Naneum Ridge structure. This will be done by field checking existing geologic mapping of the area and remapping of areas that may require it. The remapping of this area will be done at a 1:24,000 scale. Results of this field checking/remapping effort will be reviewed and evaluated to determine whether or not the existing level of information is sufficient to satisfy informational requirements for the development of structural and (or) tectonic models.

8.3.1.2.3.3.4.3.6 Regional geophysics and remote sensing task

Regional geophysical studies include compiling and integrating existing data from the BWIP, state and federal agencies, academic studies, and private industry sources. These data will be evaluated for content and quality. In areas where there are insufficient data for analysis, additional data will be collected. Additional regional data will become available as part of structure-specific investigations.

The data will be analyzed for major structures, regional trends, and for areas where there are insufficient data. If the major structures, regional trends, or areas lacking data become critical to site characterization, then additional geophysical data will be collected. The type of method(s) that will be used will depend upon the resolution required and the characteristics of the feature area. Those areas that have been identified needing additional data fit within the context of the Pasco Basin and are discussed in those studies.

The following types of data will be used in these analyses:

- Magnetic.
- Gravity.
- Magnetotelluric/electrical.

Remote sensing techniques applicable to regional geologic studies have evolved rapidly and now include many electronic and electro-optical-mechanical imaging systems, in addition to advanced photographic techniques. These systems include passive and active imaging capabilities that provide spectral coverage from the ultraviolet to microwave wavelengths and spatial resolution of less than 10 m from space platforms down to a few centimeters from aerial platforms. Passive imaging uses reflected solar radiation or emitted long wavelength infrared and microwave radiation; active imaging uses manmade sources such as lasers, arc lamps, or radar. The utility of data collected by these systems will be assessed and used, where appropriate, to interpret the regional structure. Side-booking airborne radar (SLAR), flown by the U.S. Geological Survey (USGS) in 1987, will be available for use by the BWIP. Conventional photo imagery will be used to support routine mapping.

8.3.1.2.3.3.4.4 Deep structure of the Pasco Basin. The objective of the deep structure component of the structural geology study is to determine the configuration of the structures within the Pasco Basin below the repository depth. These structures include those occurring within the Columbia River Basalt Group, those in the middle Miocene to late Cretaceous sedimentary rocks underlying the Columbia River Basalt Group, and those in the crystalline basement and deeper crustal rocks. These structures may not in themselves have surface expressions, but they may be the fundamental control on the development of structures at the surface. The investigation of these structures is required for the development of structural, deformational and tectonic models of the Pasco Basin. Delineation of these structures is also required for the evaluation of hydrocarbon potential.

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Preliminary interpretations can be made using the available data and a summary of these interpretations is given below and in more detail in the structural geology study plan (Odegard, 1987):

1. The magnetotelluric data show a significant thickening of the Columbia River Basalt Group beneath the Cold Creek syncline. The seismic refraction data show the thickening to be a broader and less significant than the magnetotelluric data. The gravity and magnetic data do not support any significant thickening of the Columbia River Basalt Group.

2. Gravity, magnetic, magnetotelluric and seismic data show a significant thickening of the Columbia River Basalt Group to the south of the Cold Creek syncline. This thickening appears to be truncated by the Rattlesnake/Wallula alignment-Cle Elum-Wallula disturbed zone. This indicates that the northwest-southeast trending fold and fault system of the Rattlesnake/Wallula alignment probably extends into the crystalline basement. The exact geometry of this system is unclear.

3. Gravity and magnetic data show anomalous features associated with the Saddle Mountains while magnetotelluric and seismic refraction data show little if any anomalies. The lack of an anomaly in the magnetotelluric data may be due to the lack of, and the poor quality of, existing data in that area. The lack of an anomaly in the refraction data may be due to the low resolution and lack of coverage in the seismic refraction data.

4. The seismic refraction data show a thick (3 to 7 km (1.8 to 4.3 mi)) section of Miocene to late Cretaceous or older sediments overlying the crystalline basement. Logs from the Shell Oil Company 1-9 BN well in the Saddle Mountains show the sediments to be primarily fluvial with some volcaniclastics (see Chapter 1, Sections 1.2.1.1 and 1.7.2.2). The deeper portions of the section may possibly be marine although there is little evidence for this. Thus, these sediments appear to be a potential hydrocarbon source region and a possible reservoir region for accumulation. In addition, the sediments possibly uncouple local deformation in the Columbia River Basalt Group from deformation in the crystalline basement.

5. Geophysical methods used to date show only potential field anomalies associated with the shallow structures of the Umtanum-Gable and Yakima Ridges. The lack of any anomaly due to deeper structure may be due to a lack of data in the appropriate areas or to a lack of significant disturbance in the base of the Columbia River Basalt Group. Effects of the deep Yakima Ridge structure may also be masked by the close proximity of the Rattlesnake/Wallula alignment.

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Based on the above interpretations and the recognition of technical considerations expressed for the structural studies of the Pasco Basin, the following questions related to deep structure can be posed:

1. What is the deep structure of the Cold Creek syncline and Pasco Basin, and will this deep structure have a significant effect on waste isolation?

2. Is there active deep faulting or other tectonic structures within the Cold Creek syncline?

3. Does the Columbia River Basalt Group thicken significantly below the Cold Creek syncline?

4. Are there significant structures in the sub-Columbia River Basalt Group sediments below the Cold Creek syncline that could contain significant accumulations of hydrocarbons (also see Mineral, Hydrocarbon, and Geothermal Resource Study, Section 8.3.1.6).

5. What is the structure and method of formation of the Rattlesnake/Wallula alignment-Cle Elum-Wallula disturbed zone?

6. What role does the Rattlesnake/Wallula alignment-Cle Elum-Wallula disturbed zone play in the thickness distribution of the Columbia River Basalt Group?

7. Does the Rattlesnake/Wallula alignment-Cle Elum-Wallula disturbed zone structure extend into the crystalline basement?

8. Does the Rattlesnake/Wallula alignment form structures near or below the Cold Creek syncline that could contain significant accumulations of hydrocarbons (also see Mineral, Hydrocarbon, and Geothermal Resource Study, Section 8.3.1.6)?

9. Do the Yakima Ridge or Umtanum-Gable Ridge systems involve significant structures within and at the base of the Columbia River Basalt Group?

10. To what extent does deformation of the crystalline basement affect the Columbia River Basalt Group tectonics and structure?

11. Is the Pasco Basin continuing to subside and what is the reason for subsidence? Is subsidence related to the decreasing thermal regime of the Miocene and can subsidence account for compression and the present stress regime?

12. Are the sub-Columbia River Basalt Group sediments structurally decoupled from the Columbia River Basalt Group?

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13. Are the sub-Columbia River Basalt Group sediments structurally uncoupled from the crystalline basement and the Columbia River Basalt Group?

14. What potential does the Rattlesnake/Wallula alignment-Cle Elum-Wallula disturbed zone structure have for producing a major earthquake close to the Cold Creek syncline?

15. To what extent do deep structures and tectonics east of the Cold Creek syncline affect the structures and tectonics within the Cold Creek syncline?

The following discussions describe the tasks that will be undertaken to determine the deep structure of the Pasco Basin. The tasks are described by discipline rather than by geographic area. Much of the data will be collected as part of tasks described in the Pasco Basin and regional studies. The emphasis in the following tasks is on analysis of these same data with the objective to evaluate deep structure.

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8.3.1.2.3.3.4.4.1 Magnetic investigations

The purpose of this task is to determine the location of possible deep structures and deep variations in structures with respect to possible surface expression. These identified areas will then be subjected to more intensive investigation using other geophysical methods. The work will be accomplished primarily with data that already exist. These data are described in Section 1.3.2.2.3.2.

The use of magnetic data in volcanic covered areas for deep structural characterization is complicated by the sizable component of natural remanent magnetization, with varying polarities and intensities of the different Columbia River Basalt Group flows; therefore, the magnetic data must be used with caution.

Current aeromagnetic data provide good areal coverage of the Columbia Plateau as shown in Figure 8.3.1.2-27. These data will be used primarily as a reconnaissance tool. However, the applicability of the aeromagnetic data for more detailed quantitative, deep structural analyses will be examined. If these examinations show that the magnetic data provide good quantitative results, then a concerted effort will be expended upon these data and they will play a more predominate role in the integrated characterization of the deep structural features. Additional magnetic data may be collected where the present data base is insufficient, and additional existing data acquired, reprocessed, and interpreted. The magnetic stratigraphy of the Columbia River Basalt Group is needed for quantitative analysis of the magnetic data. Questions concerning the contrasts present at the base of the Columbia River Basalt Group, as well as the effects of temperature and pressure on magnetic parameters at depth, must be addressed. Interpretations of the data will emphasize modeling and filtering that will isolate the long-wavelength portion

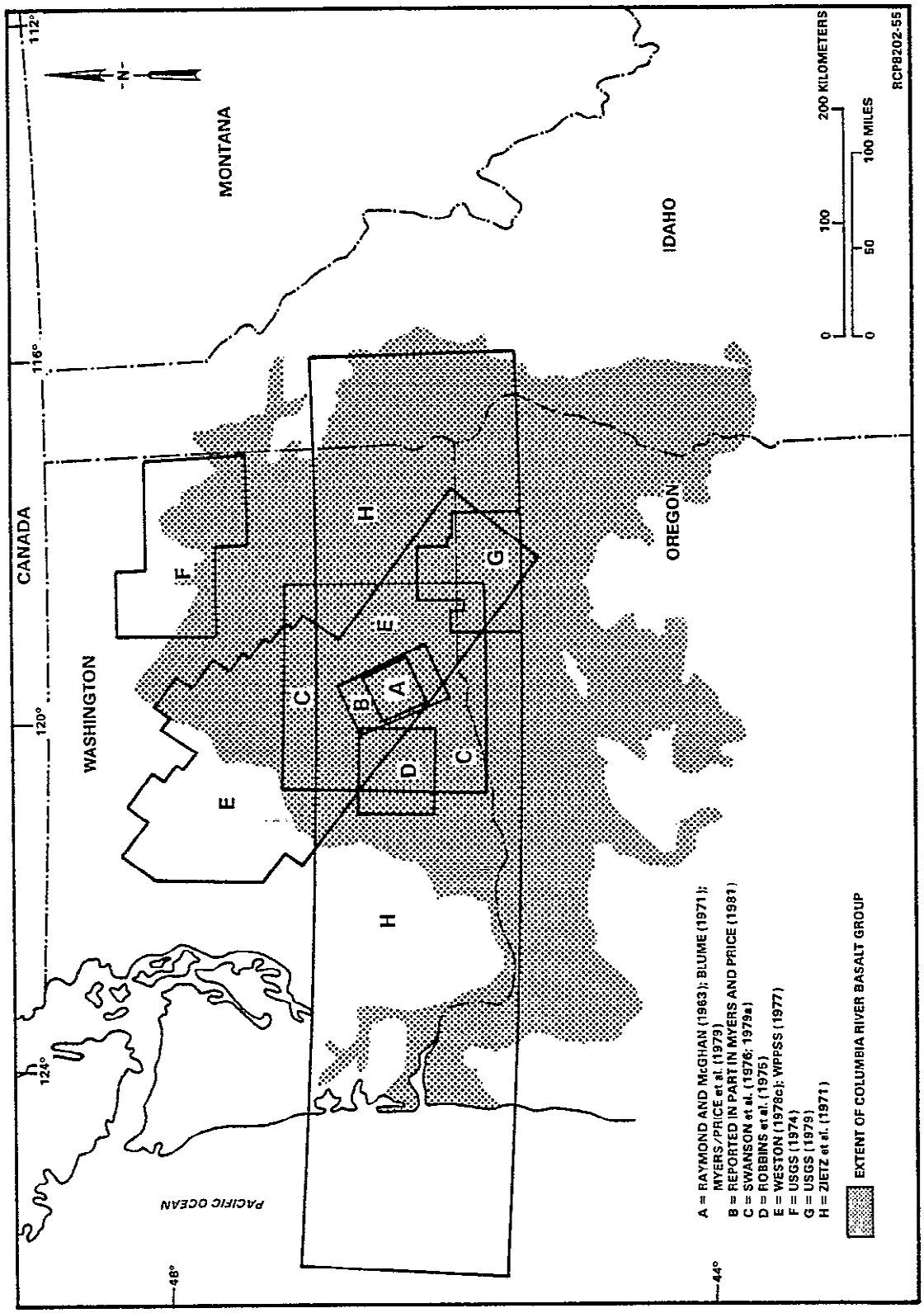

Figure 8.3.1.2-27. Aeromagnetic surveys over the Columbia Plateau.

of the data for which the causative source is deep. Magnetic parameters for inversion of the data will be determined during the analog studies described in Section 8.3.1.2.3.3.4.2.2.

8.3.1.2.3.3.4.4.2 Gravity investigations

The gravity geophysical method is used to locate and characterize deep structures. The gravity data task, as applicable to deep structural studies, includes data acquisition, parameter (density) studies, and data analysis and interpretation.

The presently available gravity data base is discussed in Section 1.3.2.2.3.1 of Chapter 1 and shown in Figure 8.3.1.2-28. These data will be evaluated to determine their adequacy for assessing deep structures in and near the Pasco Basin as well as regional features and to determine the station spacings needed for investigating each of the structural elements associated with the Pasco Basin. The data will be evaluated to determine the largest structure that may be present but not observable with the present data. The major structural elements to be addressed will include all the structures which bound the Pasco Basin.

The station spacings determined from this investigation will be used to direct acquisition of additional gravity data throughout the Pasco Basin and region. The acquisition of data around the Pasco Basin may use inertial guidance and (or) global positioning systems to locate the station positions and use helicopters to reach remote areas. This method will result in a type of grid pattern of data over the structures. The acquisition of these data should be performed as early as possible to allow the data to be used for siting magnetotelluric stations and locating areas where detailed investigations are required.

8.3.1.2.3.3.4.4.3 Magnetotelluric investigations

Magnetotelluric data generally provide a more unique interpretation of structural features than magnetic or gravity data. Thus magnetotelluric surveys, in conjunction with or replaced by other electrical methods as appropriate, will be used as the second step in further delineating anomalous features which may be related to deep structures. Structural features that have been identified with magnetotelluric will then be geometrically defined with seismic reflection and (or) refraction methods, as appropriate. Even though magnetotelluric is a useful tool for locating structural features at the base of the Columbia River Basalt Group, geometric definitions of the features based on magnetotelluric alone will not satisfy BWIP objectives.

Several investigation areas have been identified for magnetotelluric characterization. These areas are shown in Figure 8.3.1.2-29.

The investigation of these areas using the magnetotelluric method should delineate the general features of each structure at depth and determine how and if additional investigations need to be conducted.

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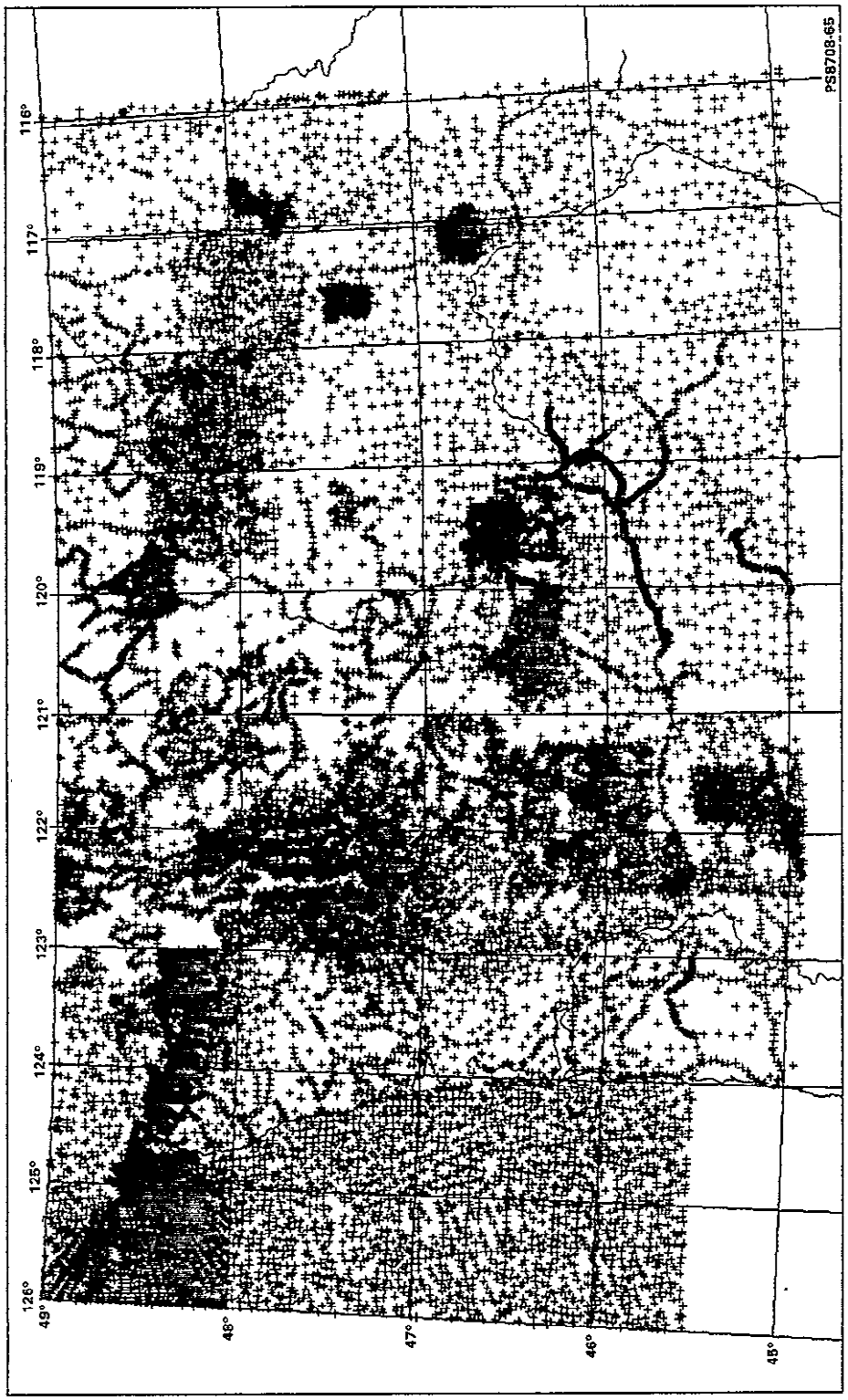

Figure 8.3.1.2-28. Currently available gravity data base.

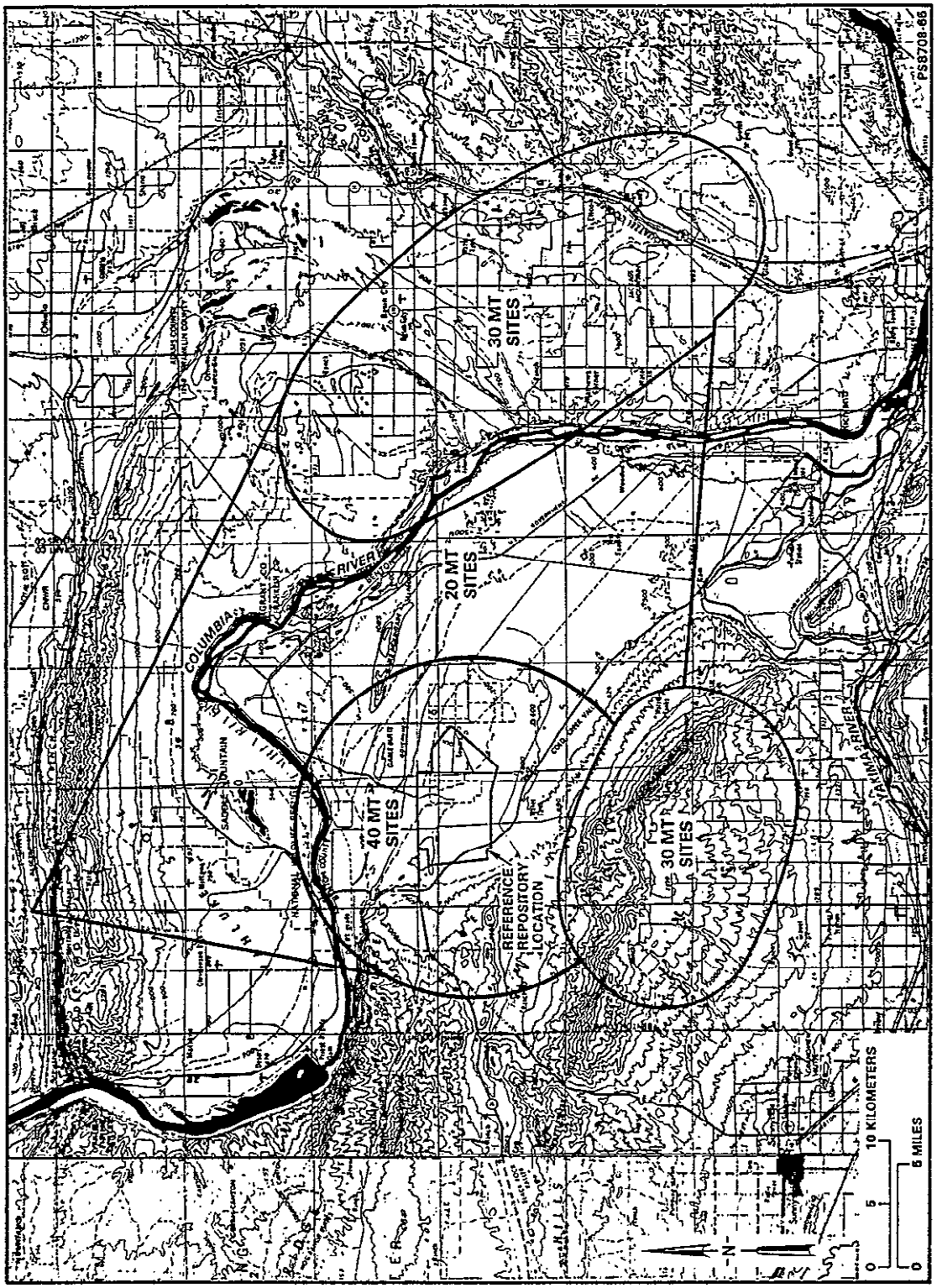

Figure 8.3.1.2-29. Magnetotelluric study areas.

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Because there are lateral resistivity variations in the near-surface strata there is anisotropy at the higher frequencies in the magnetotelluric data. This anisotropy can lead to erroneous interpretations. Corrections for this near surface distortion are called static corrections. Several methods exist to determine the proper correction. To determine which method is the best to use in the Pasco Basin two surveys will be conducted in areas where structure is better known. These areas are the Yakima Barricade geophysical anomaly, and the buried extension of the Yakima Ridge.

8.3.1.2.3.3.4.4.4 Exploration seismology investigations

The purpose of this task is to further characterize the deep structure of the Columbia Plateau, Pasco Basin, Cold Creek syncline, and controlled area study zone using a variety of seismic exploration methods. The emphasis is on deep structures that may be the source of earthquakes, that may bound the hydrological system, or may influence resource potential.

8.3.1.2.3.3.4.4.4.1 Seismic refraction and earthquake data. The purpose of this task activity is to determine the location of deep structural boundaries of the Pasco Basin and the Columbia Plateau using seismic refraction methods. The boundaries of interest include the contacts between the base of the sub-Columbia River Basalt Group sediments, top of the crystalline basement, and the base of the crust. Using wave-form analysis of the refraction data, in conjunction with deep well logs and magnetotelluric data, the location of the interface between the Columbia River Basalt Group and sub-Columbia River Basalt Group sediment boundary can also be inferred. Because the top of the sub-Columbia River Basalt Group sediments is a low velocity zone relative to the basalts, the boundary cannot be determined precisely, due to weak reflections.

The results from this activity will be integrated with results from other methods to map the deep, generalized structure of the Columbia Plateau. Seismic refraction data are essential for determining the location of the deep structural boundaries of the Columbia Plateau. Seismic data are the least ambiguous of all geophysical data. Thus, they provide the principal constraint on the structural evaluations. Without other supporting data, however, interpretation of the seismic data could be ambiguous.

The major portion if not all of the long-range refraction work has been completed as described in Section 1.3.2.2.3.4 of Chapter 1 and the structural geology study plan (Odegard, 1987). Additional seismic work may be required if near-surface investigations of other structural features indicate the need for a more detailed understanding of the deep structure. At the present time candidate areas for additional work would include the Hog Ranch-Naneum Ridge anticline, the Saddle Mountains, and the eastern boundary of the Pasco Basin. In the near future, however, the only work that is planned is a reinterpretation of already acquired long offset refraction data, continued analysis and interpretation of earthquake travel-time data (Section 8.3.1.2.4.3.2.2), and the integration of seismic data with other geophysical and regional geology data. Additional work aimed at the delineation of deep structures near the controlled area study zone will also be accomplished as described.

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The sources for seismic refraction data used in this method to date have been either naturally occurring earthquakes or detonations from large explosions. Data are recorded using the earthquake monitoring network and self-contained seismometer systems deployed for the particular survey. The analysis and interpretation procedures used to date have included travel-time inversion methods, time-term analysis, and heterogeneous ray-tracing. In the future, it is anticipated that more sophisticated inversion techniques using the generation of synthetic seismograms in heterogeneous media will be used (Odegard, 1977; Odegard and Ambos, 1978).

8.3.1.2.3.3.4.4.4.2 Seismic reflection data. The seismic reflection method has the capability to provide the highest resolution image of deep structures. The ability to acquire this type of data is limited by the seismic environment of the Pasco Basin, which is described in the structural geology study plan (Odegard, 1987) and Chapter 1. Major oil companies, including Shell, Arco, Chevron, Amoco, and Exxon, have acquired data in the areas around the Hanford Site. Their continued operations indicate at least some level of success in acquiring data. Thus, it is expected that reflection surveys will be productive in the Pasco Basin as well.

From analysis of existing BWIP data, and from observation of how the oil companies have conducted their operations, it appears that the major problem associated with the acquisition and analysis of deep seismic reflection data is scattering. This scattering occurs in the near-surface sediments overlying the Columbia River Basalt Group and within the Columbia River Basalt Group sequence. Other problems, such as ground role and statics, complicate the scattering process. The solution to these problems may be the use of large, two dimensional spatial arrays which attenuate on- and off-line scattering, as well as large energy sources. The utility of two-dimensional arrays will be tested as a part of the program described in the stratigraphy study (Section 8.3.1.2.3.3.1). Based on the results of this testing, surveys will be designed for application to specific geologic areas.

Two technical considerations to be addressed in the deep structure study are (1) the relationship of deep structures to surface structures and (2) the hydrocarbon resource potential of deep structures. These concerns are closely related to each other so that the resolution of one is expected to involve the other. Thus, the location of seismic reflection lines will address both concerns. Because the acquisition and analysis of the potential field data (gravity, magnetic, and magnetotelluric) has not been completed, it is not possible to precisely identify all the locations of required seismic reflection lines. Some of the required lines, shown in Figure 8.3.1.2-30, can be located, using known surface structures, available geophysical interpretations, and speculation on the probable locations of deep structures.

Lines A_1, A_2, and A_3 are designed to provide cross sections of the Cold Creek syncline, the Pasco syncline, and bounding structures from north of the Saddle Mountains to southwest of the Yakima Ridge. Line A_1 will tie with the Shell/ARCO BN No. 1-9 well in the Saddle Mountains. Lines B_1 and B_2 are designed to provide cross sections across the Cold Creek and Pasco synclines from northeast of the White Bluffs area to south of the Rattlesnake/Wallula

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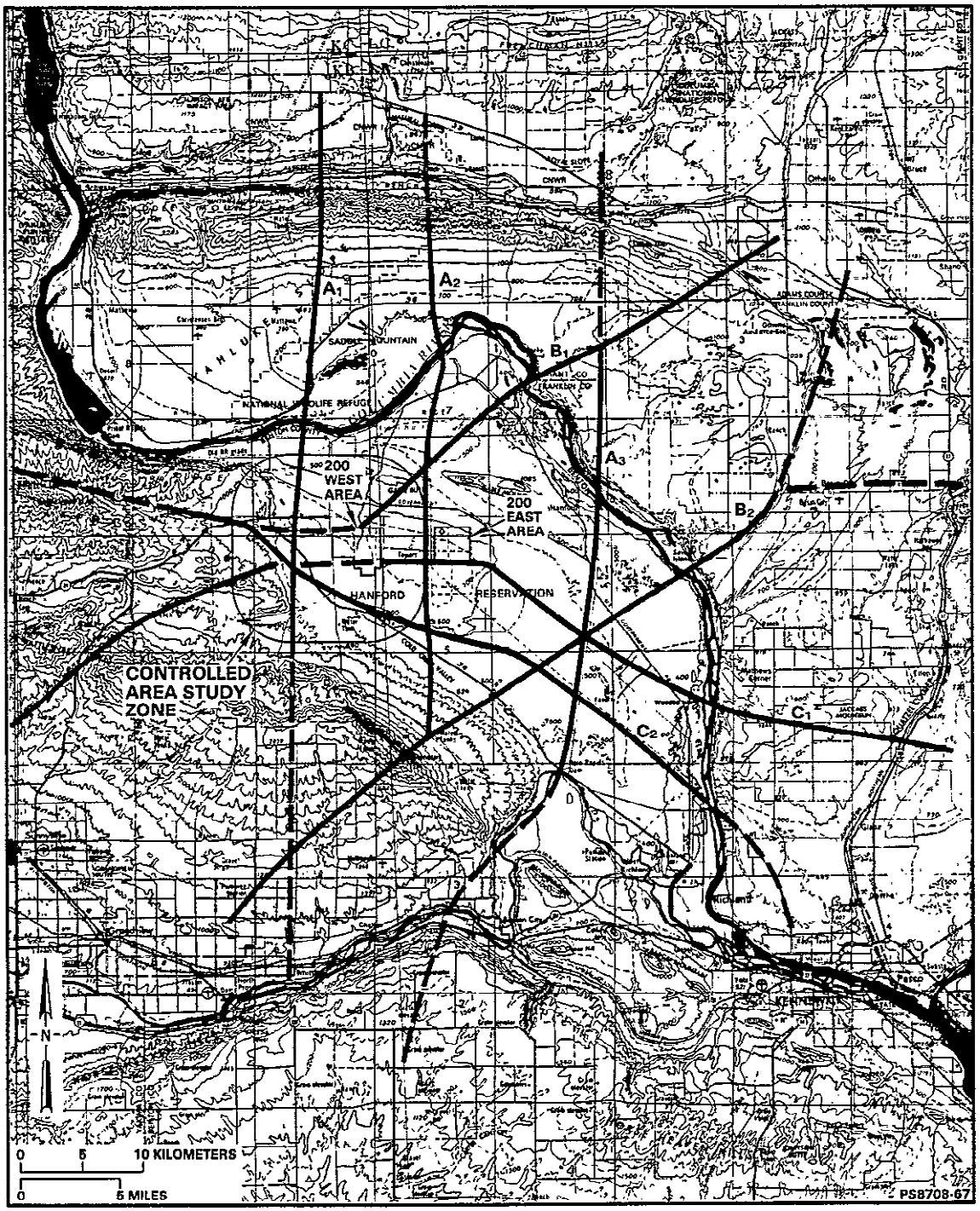

Figure 8.3.1.2-30. Proposed seismic reflection profiles to evaluate deep structures.

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alignment. Lines C_1 and C_2 are designed to be along axis profiles of the Cold Creek syncline. Line C_1 will also investigate the structure below Wooded Island and the Ice Harbor dike system. Lines A_3, B_2, and C_1 will be used to investigate the decrease in amplitude of anticlinal and synclinal structures to the east of the Rattlesnake/Wallula alignment. Additional discussion of the location of these lines is given in the mineral, hydrocarbon, and geothermal resource study, Section 8.3.1.6.

The lines in Figure 8.3.1.2-30 represent 180 km (112 mi) of seismic reflection data. These data will probably be sufficient to define the broad aspects of the deep structure of the Pasco Basin and its bounding structures. It will not, however, be sufficient to define complex variations in the major structures. If, after conducting the initial deep seismic reflection program, a structure becomes important to investigate for resource potential, then additional lines may be required.

At the present time the BWIP and the DOE are investigating the possibility of participation of oil companies in the deep seismic reflection survey. If this becomes a reality, the location of lines and the acquisition configuration may change.

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8.3.1.2.3.3.4.4.4.3 Exploratory shaft facility explosion data. The ability to image deep reflectors is severely limited by the highly attenuative properties of the layered basalt and interbeds. It is expected, however, that the deeper structures and their major boundaries can be identified and mapped using reflection and refraction methods with explosive sources such as those which will be used in the construction of the Exploratory Shaft Facility. Additional large shots may also be necessary to obtain the appropriate areal coverage. The large shots will be useful because conventional seismic reflection sources, such as vibrators and air guns, do not create sufficient energy to penetrate and imagine at depth. Thus, data from large explosions, coupled with deep borehole data, will provide baseline information that will aid in the interpretation of the conventional seismic reflection data. It may also provide the only high resolution data for deeper sedimentary sections near the crystalline basement. These data will be most useful in the area of the controlled area study zone, although refraction data may extend coverage to greater distances.

8.3.1.2.3.3.4.4.5 Data from deep boreholes

Geologic data from deep boreholes are used to calibrate the geophysical methods described above, and to provide additional geological information on which deep structural and stratigraphic interpretations can be based. The geologic interpretation of geophysical data requires a knowledge of the properties of the rocks in which the geophysical method is being used. If the physical properties of the rocks can be determined from nearby exposures and boreholes, interpretations can be made with increased confidence. The most effective method available to obtain these data in the central Pasco Basin are boreholes that penetrate through the Columbia River Basalt Group and, at a minimum, several thousand meters into the sediment below.

There have been only a few boreholes drilled in the Columbia Plateau that penetrated into sub-Columbia River Basalt Group rocks (Fig. 8.3.1.2-31). All have been drilled for the purpose of hydrocarbon exploration. The closest of these deep boreholes to the controlled area study zone is the Shell/ARCO BN No. 1-9 located about 20 km (12 mi) to the north. Borehole RSH-1, located to the west of Rattlesnake Mountain, was drilled to a depth of over 3,000 m (10,500 ft) without going through the Columbia River Basalt Group. Recently, chip samples and geophysical logs have been released from proprietary status for wells drilled by Shell (see Fig. 8.3.1.2-31) and are now available for study. The data provided by deep boreholes are essential to the evaluation of geophysical data collected for deep structural characterization.

Data from these existing boreholes will aid in the evaluation of the basement on a regional scale but may be too distant to address issues directly related to the controlled area study zone. To adequately obtain the necessary parameters, a deep borehole in the vicinity of the controlled area study zone is being considered. This borehole would be multidisciplinary in purpose and would also provide hydrologic, geochemical, rock deformation, mineralogy and petrology, and resource potential data; its need will be addressed in a position paper.

Key structural information that can be gained from the borehole include the following:

- Rock velocities.
- Rock densities.
- Rock resistivities.
- Polarization of lower Columbia River Basalt Group units.
- Depth to contact between stratigraphic units (thicknesses).
- Detailed stratigraphy.
- Vertical seismic profiling data.
- Verification of previous interpretations.

These data would be used for modeling, analyzing, processing, and interpreting the geophysical data. The degree of resolution possible from geophysical methods is directly related to the accuracy of the borehole parameters that go into the modeling of the data. The accuracy is also proportional to the number of boreholes used.

The deep exploratory borehole under consideration would be drilled through the sub-Columbia River Basalt Group sediments and possibly into the basement rock beneath the sediments. This borehole would not only provide data on the rock parameters that are needed to verify and improve interpretations of geophysical data, but would also provide direct sampling of stratigraphic units beneath the Columbia River Basalt Group for resource potential evaluation. Geologic surface mapping--and the potential field methods, gravity, magnetics, and magnetotelluric--could provide the original reconnaissance data. Seismic reflection data would be then used to refine the location for the borehole.

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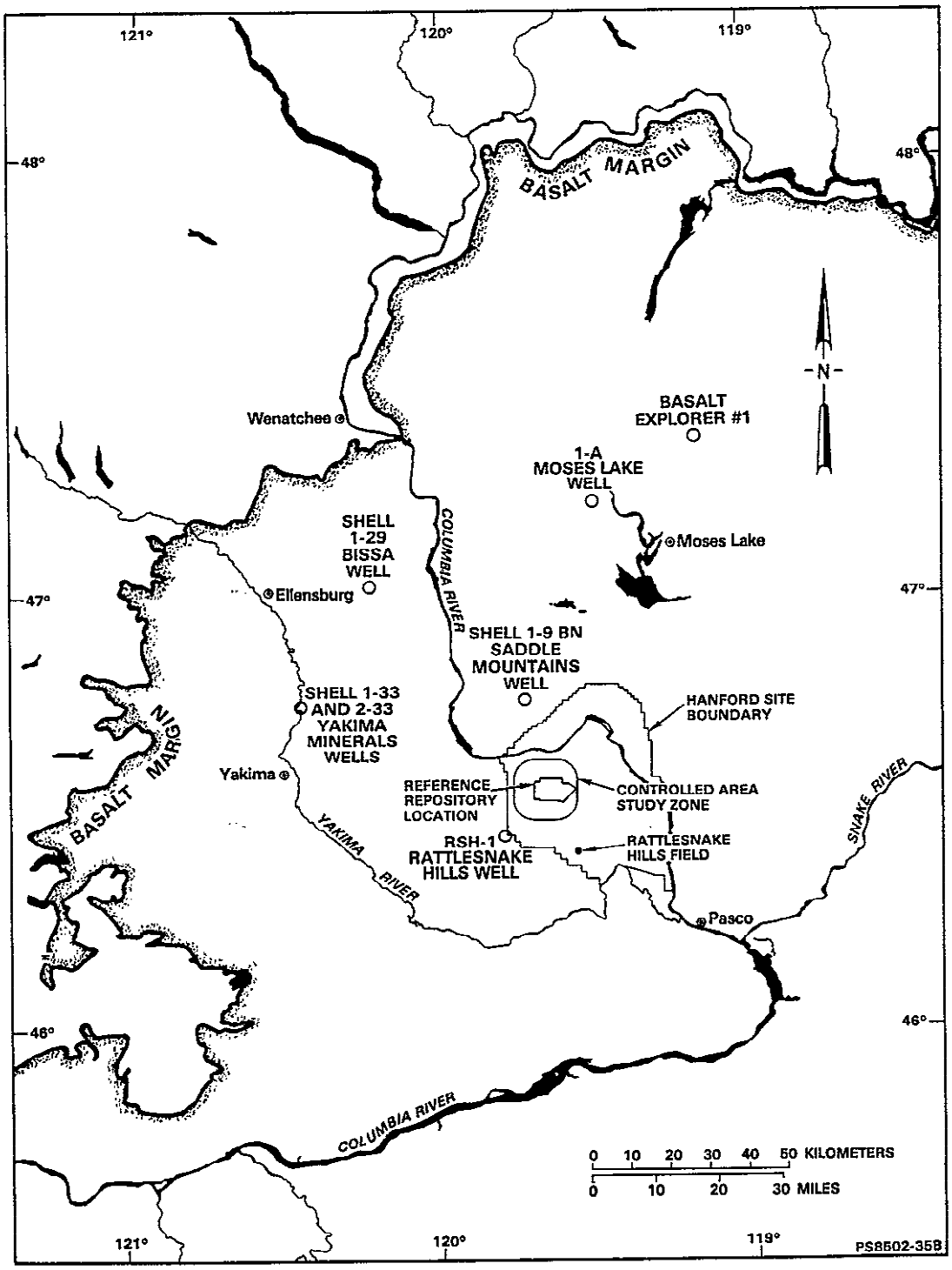

Figure 8.3.1.2-31. Location map showing key boreholes and Columbia River basalt margin, northwest Columbia Basin.

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Information from all deep boreholes drilled in the area for hydrocarbon exploration will be incorporated into the analysis of the need for a sub-basalt borehole. At present, the BN No. 1-9 Saddle Mountains well is the closest sub-basalt borehole. As additional wells are drilled, analyses of well cuttings and data from geophysical logs will be interpreted. Future wells drilled by organizations other than the BWIP will be monitored closely. Assessment of the need for a deep borehole within the vicinity of the controlled area study zone will be evaluated in a future position paper (also see Resource Potential, Section 8.3.1.6).

8.3.1.2.3.3.4.5 Methods used in structural investigations. Because each method used in geological mapping and geophysical surveying will be applied in many of the tasks in each component of the structural geology study, the method and its application in each task will be summarized here. A detailed description of each method and its particular application to site characterization is given in the structural geology study (Odegard, 1987). Table 8.3.1.2-12 gives the methods and their relationship to tests and analyses.

8.3.1.2.3.3.4.5.1 Geological methods

8.3.1.2.3.3.4.5.1.1 Geologic mapping. Geologic mapping is a fundamental method for discovering and describing geologic structures exposed at the surface. Depending on the degree of rock exposure, a considerable amount of data from field observations can be compiled onto a map and then interpreted to reveal possible structures of tectonic origin. The Pasco Basin offers abundant outcrops for mapping in anticlinal areas, and its topography provides fairly easy access by vehicle or foot. Aerial photography and satellite imagery are used to supplement observations made at outcrops. Large structural features may be revealed by these remote sensing products that are not obvious to the mapper on the ground. Geologic maps at various scales and levels of detail are fundamental elements of the data base for the site characterization program.

A problem that is unique to mapping layered basalt regions is that of identifying individual flows, many of which are very similar in lithology. Two additional analytical methods used on the Columbia Plateau to supplement field observations are major element geochemical analysis of basalt samples and a field determination of the polarity of remanent magnetism of the flow.

8.3.1.2.3.3.4.5.1.2 Borehole observations. Various types of data must be collected in order to characterize the BWIP site, but borehole data and geologic mapping will be the only direct data acquired. Boreholes provide data in the vertical dimension and therefore are an important component of the data acquisition and interpretation program. The rock parameter measurements and actual depth measurements of the various rock units are used to calibrate each of the geophysical methods. The borehole measurements are also useful to determine the accuracy and predictive ability of the geophysical methods.

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Table 8.3.1.2-12. Tasks/tests/analyses for the structural geology study (sheet 1 of 4)

Task/test or analysis[a]	Methods	Location/scale	Number of tests	Information (for analyses)	
				Data	Results
Location and mapping of structures by geophysical surveys	Geophysical surveys: seismic reflection, seismic refraction, gravity, magnetics, magnetotellurics, borehole geophysics, vertical seismic profiling	West Pasco Basin Snively Basin Yakima Ridge Umtanum/Gable Ridge Hog Ranch anticline Rattlesnake Hills South Pasco Basin Rattlesnake-Wallula alignment/Cle Elem-Wallula alignment Horse Heaven Hills Rattlesnake Mountain Wallula Gap East Pasco Basin Ice Harbor Dikes Wooded Island White Bluffs North Pasco Basin Saddle Mountains Vantage syncline Coyote Rapids	(c)	Seismic structure and subsurface map of structural features Density map of structural features Magnetic field map of structural features Conductivity map of structural features Velocity, density, conductivity, dip orientation, porosity, determinations at drill holes	(b)
Identification and mapping of structures in boreholes	Single vertical, or deviated boreholes • Core analysis of fractures, breccia, and (or) gouge	• Layout area, controlled area study zone, Cold Creek syncline, Pasco Basin	• All cored boreholes	• Physical descriptions, clay mineralogy, alteration, thickness, attitude	(b)
	• Borehole geophysical, television, and dipmeter logs	• Layout area, controlled area study zone, Cold Creek syncline	• All boreholes	• Calibrated geophysical log versus depth, television log versus depth, and oriented strike and dip versus depth	(b)
	• Vertical seismic profiling	• Layout area, controlled area study zone	(c)	• Vertical seismic profiling logs/profiles	(b)

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Table 8.3.1.2-12. Tasks/tests/analyses for the structural geology study (sheet 2 of 4)

Task/test or analysis[a]	Methods	Location/scale	Number of tests	Information (for analyses)	
				Data	Results
Identification and mapping of structures in boreholes (cont.)	Multiple vertical boreholes • Measured differences in elevation and thickness of strata	Layout area, controlled area study zone, Cold Creek syncline, Pasco Basin	(c)	Depths, casing elevations, and thicknesses	(b)
Mapping of structures in outcrop	Geologic mapping (cont.)	Layout area/controlled area study zone Rattlesnake-Wallula alignment 1:12,000[d] Eastern Pasco Basin Jackass anticline/ monocline area 1:24,000[d] Western Pasco Basin and Yakima Fold Belt Saddle Mountains 1:24,000[d] Umtanum Ridge-Gable Mountain 1:12,000[d] Yakima Ridge 1:12,000[d] Snively Basin-Rattlesnake Hills 1:12,000[d] Cold Creek syncline 1:12,000 Horse Heaven Hills 1:24,000[d] White Bluffs 1:12,000[d]	(b)	Outcrop patterns of basalt and sediments; structural attitudes; location of anticlines, synclines, faults, and dikes; age relationships of mapped structures; size of anticlines, synclines, dikes/faults, (includes wavelength, amplitude of folds, width of faults)	(b)

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Table 8.3.1.2-12. Tasks/tests/analyses for the structural geology study (sheet 3 of 4)

Task/test or analysis[a]	Methods	Location/scale	Number of tests	Information (for analyses)	
				Data	Results
Mapping of structures in outcrop (cont.)	Geologic mapping (cont.)	Regional Vantage area[d] 1:24,000 Yakima Fold Belt (Region A) 1:48,000 Margin of Yakima Fold Belt (Region B) 1:48,000 Northwest trending strike-slip faults and related folds (Region C) (scale to be determined) Northern Yakima Fold Belt and Hog Ranch Naneum Ridge anticline (Region D) (scale to be determined) Service anticline (Region E) (scale to be determined) Lewiston Basin (Region F_1 and F_2) (1:48,000 and 1:62,000) Blue Mountains/Hite fault (Region F_3) (scale to be determined)			
Characteristics of faults and tectonic fractures in the Exploratory Shaft Facility	Exposure and photo mapping/observation of mined openings Examination of core from shaft and drift boreholes Sampling of exposed zones Geophysical logging of boreholes and shaft walls	Exploratory Shaft Facility including all mined openings and boreholes	(f)	Orientation of zone in mined openings Physical characteristics of zone(s) in mined openings and boreholes Length, width, offset, breccia/gouge physical properties	(f)

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Table 8.3.1.2-12. Tasks/tests/analyses for the structural geology study (sheet 4 of 4)

Task/test or analysis[a]	Methods	Location/scale	Number of tests	Information (for analyses)	
				Data	Results
	Geophysical exploration methods	(c)	(c)	See discussion under "Characteristics of Intraflow Structures in the Exploratory Shaft Facility"	See discussion under "Characteristics of Intraflow Structures in the Exploratory Shaft Facility
Pasco Basin and Cold Creek syncline (8.3.1.2.2.3.2.2)	Compilation of geologic mapping and geophysical survey information into maps (geologic, structure contour, and tectonic) and balanced cross sections	(e)	(e)	These maps will provide significant constraints on possible styles and characteristics of deformation for the geologic repository operations area, controlled area study zone, Cold Creek syncline, and Pasco Basin. Both borehole and geophysical data will be integrated with the geologic mapping to provide a three-dimensional model of the areas	These maps will provide significant constraints on possible styles and characteristics of deformation for the geologic repository operations area, controlled area study zone, Cold Creek syncline, and Pasco Basin. Both borehole and geophysical data will be integrated with the geologic mapping to provide a three-dimensional model of the areas

[a]Test unless identified as an analysis.
[b]Not applicable.
[c]To be developed.
[d]Identified in Figure 8.3.1.2-3.
[e]Not required for analyses.
[f]Not available.

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Considerable information is available to geologists from data collected as part of drilling a borehole. Cores and cutting samples reveal the lithology of strata at various depths. Tectonic features such as faults can be observed directly in cores or inferred from stratigraphic relationships (e.g., DC-18 on Gable Mountain). Measurements of various rock parameters of importance to modeling geophysical data can be obtained through the use of geophysical logging tools. All of this information may aid the geologist in interpreting observations of field exposures. The stratigraphy study plan provides a complete description of the geological methods used during borehole investigations.

The sites and drilling methods of future boreholes will be varied, depending on the primary data needs to be met by the borehole. Examples of primary data include lithologic samples, stratigraphic boundaries, hydrologic parameters, and physical properties of the rocks. The location and drilling method used for multipurpose boreholes is determined by the primary data needs. The drilling method used dictates the methods of study and the reliability of data obtained. For example, structures and stratigraphic boundaries are more clearly and reliably defined from continuous core samples than from chip samples which are normally collected at 1.5-m (5-ft) intervals. Analyses based on chip samples require more assumptions and are more subjective. Therefore, the borehole drilling methods are identified in all interpretations.

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8.3.1.2.3.3.4.5.1.3 Trenching. Evidence for Quaternary deformation may be recorded in small, detailed features in recent sediments. Trenching the layers that contain horizons of known age, such as the various ash horizons from Cascade Range volcanoes that overlie structural features such as faults, provides a fresh cross section of the sedimentary units, useful in assessing the age and characteristics of deformation.

8.3.1.2.3.3.4.5.1.4 Stratigraphy. Stratigraphy will be used in structural studies to determine the correlation of rock sequences among structural units. The determination of the stratigraphic sequences needed on the controlled area study zone, Pasco Basin, and regional scales is discussed in detail in the stratigraphy study, Section 8.3.1.2.3.3.1.

8.3.1.2.3.3.4.5.2 Geophysical methods

Geophysical surveys are used to identify buried structures and to map the geometry of structures and tectonic features not directly observable at the surface. Structural profiles derived from geophysical data also allow the geologist to extend features mapped at the surface into the subsurface. Several geophysical techniques are generally used, together with geological methods, to delineate subsurface structures and stratigraphy. Various geophysical methods are often complementary and provide different insights at different scales. The level of use and the density of observations are, however, refined by the geophysicist to solve the particular problem at hand. The following techniques will be used in the geophysical surveys conducted for site characterization.

8.3.1.2.3.3.4.5.2.1 Gravity method. Changes in density produce changes in the earth's gravity field, which can be detected to locate the position of geologic structure. Also, structures often have lateral density changes associated with them. For example, a fault may have rock units of differing densities side-by-side along the scarp, a syncline may have lower or higher density material in the trough, and an anticline may have higher or lower density fill on its limbs. The gravity method thus provides an indirect means of locating possible geologic structures, especially when burial of the structures has concealed them from geologic mapping.

The gravity method can be used in both a reconnaissance and a detailed fashion. Reconnaissance surveys are used to evaluate large geologic features and to locate areas for further detailed investigations. Detailed surveys are used to evaluate smaller, more subtle geologic features.

8.3.1.2.3.3.4.5.2.2 Magnetic method. The magnetic method uses variations in the Earth's magnetic field to locate structural and stratigraphic features. Igneous rocks, such as basalt, affect the magnetic field of the earth. The magnetic parameters that control the amount of effect are the susceptibility and remanent magnetization. Susceptibility is the degree to which a material may be magnetized when placed in a magnetic field. Susceptibility for basalts is rather high while sediments usually have low susceptibilities.

The basalt flows also exhibit their own magnetic field or remanent magnetization. The alignment of the magnetic domain of the particles in the basalts are frozen in the direction of the field in which they were cooled. This property is useful in the interpretation of magnetic data and is useful to the field geologist as discussed in the structural geology study plan. Additional uses or applications of the magnetic method are listed below.

- Satellite magnetic--deep crustal structure; Curie Point depths.
- Aeromagnetic--crustal structure and lithology; Curie Point depths; reconnaissance-level surveys.
- Surface surveys--detailed structure and stratigraphy.
- Borehole surveys--magnetic parameters, stratigraphy, and intraflow structure.
- Paleomagnetic studies--magnetic parameters, stratigraphy, and structural rotation.

8.3.1.2.3.3.4.5.2.3 Magnetotelluric method. Magnetotelluric surveying is a geophysical technique used to obtain an apparent resistivity versus frequency sounding of the Earth. It is the most commonly used electrical method capable of obtaining information at the depths necessary for deep structural characterization.

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An increasing interest in the magnetotelluric method during the 1980s has led to considerable development of data collection, processing, and interpretation techniques. The magnetotelluric method has been used extensively throughout the Columbia Basin in hydrocarbon exploration because it is sensitive to strata and structure at depth beneath the thick electrically resistive basalts. The magnetotelluric method is an effective reconnaissance method because the equipment is portable and a large area can be covered in a relatively short period of time. In addition, there is little environmental disturbance from the magnetotelluric method.

The BWIP plans to rely heavily on the magnetotelluric method for studying the deep structure. Other electrical techniques (e.g., controlled source electromagnetic methods) may be more effective in some areas, and are also being considered. Magnetotelluric data must be supplemented with other geophysical and geologic data as part of the interpretation process.

Magnetotelluric data are acquired by measuring the natural fluctuations in the Earth's magnetic and electric fields. Typically, five field components are measured over a frequency range from 300 Hz to approximately 0.002 Hz. These five components are two perpendicular horizontal electric fields, two perpendicular horizontal magnetic fields, and one vertical magnetic field. An apparent resistivity versus frequency sounding curve is generated by performing a frequency analysis on the horizontal fields, and then calculating the ratio of the electric to the magnetic field. The vertical magnetic field is used as an indicator of horizontal variations in resistivity.

The magnetotelluric data will be collected using the remote reference technique that requires two additional channels of data be measured simultaneously with the measurement of the five normal magnetotelluric fields. These two additional reference channels are located a few hundred meters to several kilometers away from the main site. The minimum distance between the site and its reference is set by the requirement that any electromagnetic noise present at the site itself must be uncorrelated with any electromagnetic noise present at the reference location. If this requirement is met then the data quality is much higher.

Real-time processing in the field will be used for all data acquired. Real-time processing results in the sounding curve (and other pertinent information) being produced at the site as the electric and magnetic fields are measured. This is a great improvement over older systems where there was often a delay of weeks to months between data recording and calculation of final results. Real-time processing allows more time to be spent on those sites where the data is particularly important or where there are higher noise levels. It also allows a survey to be redesigned as it progresses, thereby eliminating unnecessary sites and concentrating sites in the most important areas.

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8.3.1.2.3.3.4.5.2.4 Borehole geophysics. These methods include vertical seismic profiling (VSP), borehole gravity, and various types of well logs to quantitatively determine seismic velocities, density, conductivity, porosity, and dips of interfaces at the borehole. These tools are used to provide a detailed description at a specific location within a feature and determine specific parameters within a stratigraphic section. They are also used to calibrate the other geophysical techniques at a well site.

Geophysical well logging provides information on physical properties of stratigraphic units including changes in texture or rock type, density, porosity, fluid content, clay content, seismic wave velocities, fracturing, and orientation of planar features penetrated by the borehole. The occurrence of structural features such as faults and shear zones can be expected to affect most or all of these geological properties. Interpretation of structural features intersected by the borehole, especially when core data is not available, is a primary purpose in acquiring geophysical well logging data. Also, the physical measurements obtained from geophysical logging are typically used as constraints in the acquisition and interpretation of other geophysical data.

Boreholes drilled by the BWIP during site characterization will be used to acquire a suite of quantitative geophysical logging data. Borehole geophysical logging data will include quantitative measurements of bulk density, total porosity, electrical resistivity, compressional and shear wave velocities derived from sonic waveform data, passive gamma ray count rate, and formation temperature. Acquisition of borehole dipmeter data is desirable, although technical problems with dipmeter logging in strongly magnetized basalts may prohibit this application. Geophysical logging data must be acquired in both small-diameter cored boreholes and large-diameter rotary drilled boreholes.

The VSP surveying is a borehole geophysical method that provides information regarding the seismic velocity of geological formations adjacent to a surface borehole and a direct measure of the seismic reflection response of these formations. The VSP data must be used in planning the acquisition parameters of a seismic reflection survey, and are also necessary for interpretation of reflection events observed in the seismic reflection data in terms of their geologic origin. Vertical seismic profile surveys provide a measurement of the seismic wave velocity of stratigraphic units within approximately 200 m of measured boreholes. These measurements are critical in the acquisition and interpretation of seismic reflection and refraction data obtained for site characterization.

Modification of the VSP method, termed walk-away VSP, can be used to delineate faulting and bedding orientation up to 1,000 m from the surface borehole. Walk-away VSP requires that the seismic wavefield recorded by the borehole receivers be measured with the surface seismic energy source located at varying distances from the borehole. The use of multiple surface source locations allows for detailed estimation of the velocity structure in the region bounded by the surface sources and the borehole.

8.3.1.2.3.3.4.5.2.5 Reflection and refraction seismology. Reflection and refraction seismology have been the principle methods with which the exploration geophysicist has imaged the interior of the earth. This predominance over other methods is primarily due to the increased resolution and precision with which the structure and stratigraphy of geological formations can be determined. The surveys using this method will be concentrated primarily in the controlled area study zone, but may also be used in studies of specific features in other tasks. The structural geology study plan describes in detail the seismic reflection and refraction methods. More detailed descriptions of these methods and techniques are given in books by Dobrin (1976), Helbig and Tritel (various dates), Waters (1978) and Claerbout (1985a and 1985b).

8.3.1.2.3.3.4.5.2.6 Earthquake seismology. The location, size, and focal mechanism of earthquakes are indicators of structures that contain active faulting and are deforming. These structures are essential elements in evaluating the suitability of the site. The detection and investigation of earthquakes, and the correlation of earthquake seismicity with geologic structures are discussed in the earthquake seismology study (Section 8.3.1.2.4.3.2).

8.3.1.2.3.3.4.5.2.7 Other geophysical methods. Electrical techniques using an active source of electrical current have been developed to investigate geological features at all scales, ranging from shallow, detailed studies to deep, regional scale studies. The resolution available from these techniques is not significantly better than the other geophysical methods now used. They will be considered for use, however, when it is evident that the electrical techniques may provide substantially different or complementary data.

8.3.1.2.3.3.4.5.3 Remote sensing

The term "remote sensing" usually refers to the gathering and processing of information about the Earth's surface through the use of photographs and related image data acquired from an aircraft or satellite. Remote sensing techniques applicable to structural geologic studies have evolved rapidly from standard aerial photographic techniques to now include many advanced electronic and electro-optical mechanical image recording systems. These systems image reflected and emitted electromagnetic radiation from the ultraviolet, visible, infrared, and microwave wavelengths. Spatial resolution from satellite platforms varies from over 1,000 m (3,300 ft) for global coverage, to less than 10 m (33 ft) providing imagery capable of identifying individual outcrops. Imagery from aerial platforms have spatial resolutions from tens of meters to a few centimeters and are now being developed with spectral resolution comparable to laboratory spectrometers. Most systems are passive imaging systems that detect reflected solar radiation or emitted thermal infrared and microwave radiation.

A few active imaging systems are in operation using manmade sources such as lasers, arc lamps, or radar. Spectral and spatial measurements of surface material are strongly affected by the material types, orientation of the surface, observation angle, and surface roughness. These unique spectral and

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spatial characteristics provide remote sensing signatures that allow many geologic materials and structures to be identified. Also, the stereo parallax provided by the imagery allows the topographic relief to be quantitatively mapped.

The following sensor systems are available for use in applications related to site characterization:

- Aerial Photography.
- Aerial Multichannel Scanners UV-VIS-IR.
- Airborne Visible/Infrared Imaging Spectrometer.
- Aerial Multipolarization and multifrequency Synthetic Aperture Radars.
- Satellite Photography.
- Sky Lab Photography/Imagery.
- Shuttle Photography (Large Format Camera).
- Landsat Multispectral Imagery.
- NOAA (Very High Resolution Radiometer).
- Nimbus (Coastal Zone Color Scanner).
- Tiros (Advanced Very High Resolution Radiometer).
- Heat Capacity Mapping Mission.
- SEASAT Synthetic Aperture Radar.
- Shuttle Imaging Radars (SIR-A, SIR-B, SIR-C).
- MAGSAT.
- GRAVSAT.
- MOS-1 (Multispectral Ocean Scanner).
- SPOT (Multispectral/Panchromatic Scanner Stereo).

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8.3.1.2.3.3.5 Physical rock properties study.

The physical rock properties study addresses performance and design issue parameters relating to rock density, porosity, elastic constants, and electromagnetic properties. Thus, the objective of this study is to provide geophysical data from which physical properties of rocks within selected stratigraphic units will be derived. These properties will be deduced from data gathered primarily through tests that will be conducted in the Exploratory Shaft Facility. Measurements will be accomplished by borehole logging, cross-hole seismic surveys, and electromagnetic and acoustic surveys on the surfaces of excavated openings in the Exploratory Shaft Facility. A comprehensive program that determines the rock properties parameters from core samples taken from selected locations and rock types will be conducted to build a baseline for comparison with the more numerous geophysical measurements taken. Another source of log data will be drill holes that penetrate the formations of interest from the ground surface.

The geophysical measurements will also provide a basis for studies of a number of other structural parameters such as bed boundary locations, flow thicknesses, the extent and characteristics of the disturbed rock zone, and the presence and extent of permeable zones.

The parameters this study will evaluate are listed in Table 8.3.1.2-6. These parameters are directly linked to the issues. In particular, bulk density of the host rock and the disturbed rock zone is inferred from issue resolution strategies for Issues 1.1, 1.11, 2.7, and 4.2, and porosity of the host rock and the disturbed rock zone is inferred from issue resolution strategies for Issues 1.1 and 4.2. In addition, issue resolution strategies for Issues 1.1, 1.11, and 4.2 propose evaluation of the radial extent of the disturbed rock zone, issue resolution strategies for Issue 1.11 propose determination of flow thicknesses, and issue resolution strategies for Issues 1.11, 2.7, and 4.2 propose permeability assessments.

Other studies that will derive advantages from this information include stratigraphy, structural geology, intraflow structures, cooling joint characteristics, mechanical properties determination, evaluation of opening performance, in situ stress, and various studies conducted under hydrology and seals.

Information will be compiled in several formats. Borehole log data will yield parameter profiles along drill holes, refraction/reflection profiles along excavation walls will be obtained from seismic and electromagnetic surveys, and three-dimensional parameter profiles over large blocks will be obtained from tomographic processing of cross-hole survey data.

Many of the measurement techniques to be used in this study have not been demonstrated in basalt. For these reasons, the present discussion emphasizes methods development to a greater degree than other studies. In fact, preliminary investigations, including evaluation and development of methods for data collection, data analysis, and data interpretation, will comprise the principal activities for the first 2 yr of this study. The study has been divided into three groups of tasks and analyses that are listed and briefly described below (Table 8.3.1.2-13). More complete discussions are presented in Sections 8.3.1.2.3.3.5.1 through 8.3.1.2.3.3.5.3.

1. Finish preparations for geophysical measurements.

   These activities include (1) field trials in the Near-Surface Test Facility, (2) refinement of hardware designs and data interpretation methods, (3) procurement, acceptance testing and modification of software for data analysis, and (4) preparation of procedures for data acquisition, analysis, and interpretation. If it appears difficult to prove the methods in the unsaturated Near-Surface Test Facility basalts, additional testing may be done in surface boreholes that encounter basalt below the water table.

2. Gather, analyze, and interpret geophysical data.

   These activities pertain to measurements that will be performed in the Exploratory Shaft Facility and surface drill holes after all of the feasibility evaluations, preliminary investigations, tool and methods modifications, and software acceptance tests have been completed.

Table 8.3.1.2-13. Tasks/tests/analyses for the physical rock properties study

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Quantify basic host rock parameters	Borehole logging	Exploratory Shaft Facility	Not specified	Resistivity logs, density logs, porosity logs, and acoustic logs	Spatial distribution of values for resistivity, bulk density, total porosity, and elastic constants
Determine properties of disturbed rock zone	Borehole logging, seismic surveys, and ground-probing radar surveys	Exploratory Shaft Facility	Not specified	Resistivity logs, density logs, porosity logs, acoustic logs, cross-hole seismic data, seismic refraction/reflection data, borehole radar data, and ground-probing radar refraction/ reflection data	Radial extent of disturbed rock zone Physical properties of rock within disturbed rock zone
Detect and delineate structural features	Borehole logging, seismic surveys, and ground-probing radar surveys	Exploratory Shaft Facility	Not specified	Resistivity logs, passive gamma-ray logs, density logs, porosity logs, acoustic logs, cross-hole seismic data, seismic refraction/ reflection data, borehole radar data, and ground-probing radar refraction/ reflection data	Location and spatial extent of large fractures, flow boundaries
Monitor changes in rock properties induced by rock mechanics tests and other tests	Borehole logging Seismic surveys	Exploratory Shaft Facility	Not specified	Resistivity logs, density logs, porosity logs, and acoustic logs, temperature logs, and cross-hole seismic data	Time- and space-dependent changes in resistivity, bulk density, water content, and elastic constants for rock mechanics tests

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3. Document and distribute data and conclusions.

   Data and conclusions will be summarized in reports. Packages of selected data and conclusions will be used to support appropriate other studies.

8.3.1.2.3.3.5.1 Finish preparations for geophysical measurements.

8.3.1.2.3.3.5.1.1 Field trials

8.3.1.2.3.3.5.1.1.1 Electromagnetic surveys. Electromagnetic surveys are responsive to spatial variations in electromagnetic properties of rock, such as occur at a fracture that is filled with a fluid. These surveys, in particular resistivity and ground-probing radar, should therefore be evaluated for use in detecting and mapping fractures and other features associated with strong gradients in electromagnetic properties.

It is presently planned that preliminary field trials will be conducted in the Near-Surface Test Facility. It is recognized that a limitation of the Near-Surface Test Facility is that the stress levels and degree of water saturation may not approach the values that will be encountered in the Exploratory Shaft Facility; therefore, additional final-determination tests will need to be conducted in the Exploratory Shaft Facility. Due to the higher stress levels, temperatures, and water saturation in the Exploratory Shaft Facility, final field trials will probably be required for some, or all, techniques.

8.3.1.2.3.3.5.1.1.2 Seismic surveys. Seismic P- and S-wave travel time surveys of the reflection/refraction and transmission (crosshole) types have been demonstrated in engineering applications. Field trials are planned in the Near-Surface Test Facility to ensure that no unexpected problems will be encountered due, for example, to high seismic velocities in the basalts.

8.3.1.2.3.3.5.1.1.3 Borehole logging. Borehole logging is, in general, a proven technique that will be done for the BWIP with commercial hardware. Limited field trials may be undertaken to develop procedural details and hardware/software refinements.

8.3.1.2.3.3.5.1.1.4 Task summary. The usefulness of electromagnetic surveys will be assessed through tests in the Near-Surface Test Facility and water-saturated boreholes, if necessary. Preliminary testing of ground-probing radar will be conducted. Evaluations will lead to decisions whether or not to implement the methods or to conduct additional testing in the Exploratory Shaft Facility. If the methods are implemented, programs for data collection and data analysis and interpretation will have to be formulated.

Seismic survey tests will be conducted in the Near-Surface Test Facility as insurance against unforeseen problems attributable to the high seismic velocities in basalt. The feasibility and usefulness of recording full-waveform data will be assessed.

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8.3.1.2.3.3.5.1.2 Refinements of hardware designs and data interpretation methods

8.3.1.2.3.3.5.1.2.1 Electromagnetic surveys. Conventional resistivity surveys on surfaces of Exploratory Shaft Facility excavations will be evaluated for use in the detection and delineation of structural features associated with gradients in electromagnetic properties. Ground-probing radar development depends on the outcome of field trials.

8.3.1.2.3.3.5.1.2.2 Seismic surveys. Additional parameters of interest may be accessible to study if amplitudes and frequency spectra can be determined for survey signals. The computational tools exist for calculating amplitudes and frequency spectral composition if full-waveform data can be recorded. Full-waveform survey equipment and data analysis programs will be evaluated. Development of field trial test plans will follow a decision to further investigate this technology. Cross-hole seismology methods (e.g., tomography) are proven techniques and should require little refinement.

8.3.1.2.3.3.5.1.2.3 Borehole logging. Many of the Exploratory Shaft Facility drill holes to be logged will be horizontal or upward-trending. A necessary precursor to logging will therefore be the development of a portable instrument support unit. This unit will serve as a field base for data acquisition and will also transport the logging tools, cable, and the hardware for inserting logging tools into the boreholes, withdrawing the tools from the holes, and maintaining liquid in the holes during the logging runs. Prototype instrument support units will be tested in the Near-Surface Test Facility prior to deployment in the Exploratory Shaft Facility.

The petroleum industry has accumulated a significant volume of knowledge regarding logging in limestone, dolomite, sandstone, and shale, but information about logging in basalt is scarce. The unavailability of lithology corrections for basalt is a potential source of problems for the analysis of log data. For the nuclear logs in particular, the lithology effect is expected to be pronounced in the neutron porosity logs, but less severe in the gamma density logs.

Preliminary evaluations of the nuclear log lithology effects will be accomplished through radiation transport calculations. The ability to model responses of nuclear logging tools with the Los Alamos MCNP computer code has been demonstrated, and this code was recently installed on the U.S. Department of Energy-Richland Operations (DOE-RL) Cray XMP. The calculations will indicate the scope of follow-up work required.

If the computer modeling reveals that lithology effects produce significant log corrections, then the construction of a test facility will be considered. This would consist of several boreholes that penetrate carefully and thoroughly characterized basalts. Lithology corrections will be derived by logging the test boreholes and correlating the logging tool responses with the established physical properties of the basalts. These boreholes would also be used to refine borehole electromagnetic and acoustic techniques.

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There are other potential refinements that may be evaluated and implemented. For example, the spatial resolution of the density tool could be improved by shortening the source-detector spacing and modifying the collimating shields. Whether these tool modifications would improve the fracture-detecting ability is a question that might be pursued.

8.3.1.2.3.3.5.1.2.4 Task summary. Evaluation of full-waveform sonic technology will be an ongoing activity.

A portable logging instrument support unit must be designed, built, and tested prior to production logging in the Exploratory Shaft Facility. Units with some of the required features have been designed and marketed by at least one supplier of borehole logging equipment.

Preliminary lithology effects on nuclear borehole logging data will be studied through radiation transport calculations. If necessary the effects will be assessed through borehole measurements in special test facilities constructed in extremely well-characterized basalt.

Other refinements, such as improvements in spatial resolution gained by changing source-detector spacings or shielding geometries of logging tools, may be evaluated through radiation transport calculations. Plans for follow-up work, such as field trials, will depend on the results of the calculations.

8.3.1.2.3.3.5.1.3 Procurement, acceptance testing, and modification of software for data analysis

Data analysis will be accomplished primarily with commercially-available software. This software will be acceptance-tested by procedures that are currently being developed for acceptance testing of logging subcontractor software.

8.3.1.2.3.3.5.1.4 Preparation of procedures for routine data acquisition

Procedures governing the acquisition of production geophysical data will be prepared. Appropriate calibration and test methods will be incorporated, and data quality levels will be assigned.

8.3.1.2.3.3.5.2 Gather, analyze, and interpret geophysical data.

8.3.1.2.3.3.5.2.1 Test settings

Some borehole log data will be taken from conventional surface drill holes that penetrate the rock formations of interest.

Most of the data will be recorded from the Exploratory Shaft Facility. All of the electromagnetic surveys, ground-probing radar reflection/refraction surveys and seismic reflection/refraction surveys will be done on walls of the excavation. Cross-hole resistivity, cross-hole radar, and cross-hole seismic

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surveys will be based in pairs of boreholes that will be drilled from the Exploratory Shaft Facility. Most of the borehole logging data will be gathered from boreholes that will be drilled from the Exploratory Shaft Facility. Some of the boreholes will be drilled specifically for the interrogation of host rock parameters; others will be drilled in locations near certain tests, such as heater tests, rock deformation tests, and excavation tests. An advantage of the geophysical techniques is the capability for repetition of measurements over time; this permits the monitoring of changes in physical properties over the duration of a test.

During the construction of the Exploratory Shaft Facility, borehole logging and ground-probing radar will be employed at the excavation face and in a pilot borehole which will be drilled into the excavation face. These techniques will interrogate the rock ahead of the excavation to detect features that may be cause for modifying the excavation methods.

Many measurement factors, such as depth of penetration of radar signals and interrogation volumes of borehole logging tools, are not known a priori for basalt. It is not possible at present, therefore, to specify the required numbers of tests and the test locations in the Exploratory Shaft Facility. The development of these factors awaits interpretation of data from preliminary geophysical tests and information exchanges with other investigators whose studies will benefit from rock properties information.

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8.3.1.2.3.3.5.2.2 Test methods

8.3.1.2.3.3.5.2.2.1 Electromagnetic surveys. Resistivity surveys are executed by passing electric currents into rock in the test area with two or more current electrodes, then recording the resultant potential differences across one or more pairs of voltage electrodes. The (apparent) resistivity is determined from the currents, the potential differences, and geometric constants which depend on the spatial arrangement of the survey electrodes.

Resistivities of rocks in the Exploratory Shaft Facility will be primarily governed by the porosity. The ability of the method to detect and delineate flow tops, flow bottoms, vesicular zones, and the disturbed rock zone will be evaluated.

Ground-probing radar surveys involve the introduction of radar signals into rock by radar transmitters and the recording of transmitted, reflected, and refracted signals by radar receivers and associated electronics. The rock parameters that influence the propagation of radar signals are rock capacitance and matrix conductance. Rock capacitance is a function of mineralogy and stress state, and matrix conductance is a function of mineralogy, porosity, and fluid salinity. Radar surveys would therefore be expected to respond to mineralogical anomalies and changes in porosity. The sensitivity to porosity changes would imply that radar will be a useful tool for the detection and delineation of flow tops, flow bottoms, vesicular zones, large water-filled joints and faults, and the disturbed rock zone.

Although rock capacitance is influenced by stress, the few studies that have been described in the literature imply that radar transmission is insensitive to stress changes at the stress levels that are expected at the repository horizon.

8.3.1.2.3.3.5.2.2.2 Seismic surveys. Seismic surveys are performed by directing seismic energy into the rockmass of interest then recording transmitted, reflected, or refracted signals at selected locations. Basic seismic surveys record travel times of P- and S-waves and various reflected and refracted phases. These travel times are influenced by the seismic velocities of the rock and by the orientations and extents of velocity discontinuities, such as fracture zones and flow boundaries. Flow boundaries and large planar features, such as fractures, will be detected and mapped by reflection/refraction surveys. Cross-hole survey data will be tomographically analyzed to delineate fractures and fracture zones in large blocks of rock.

If the bulk density of the rock can be established, by density logging for example, then this parameter can be used with the seismic travel times to derive the dynamic elastic constants known as Poisson's ratio, Young's modulus, shear modulus, and bulk modulus.

8.3.1.2.3.3.5.2.2.3 Borehole logging. Six classes of measurements will be accomplished by borehole logging: resistivity, gamma-ray, density, porosity, acoustic, and auxiliary.

Resistivity logging is responsive to the resistivity of material being tested. This will be composed of the rock and the fluid in the pore spaces. Since the basalt has high resistivity, tool responses will be sensitive to the presence of conductive pore fluid. The resistivity log will serve to detect and delineate flow boundaries, zones of high porosity/permeability, and joints and faults of sufficient aperture.

The gamma-ray log response is proportional to the gamma-ray intensity in the borehole. The gamma rays originate in naturally-occurring radioelements, notably ^{40}K, ^{238}U, and ^{232}Th. Early gamma-ray logging on the Hanford Site indicated the utility of the gamma-ray log for detecting interflow zones that contain potassium-bearing alluvial material. The measurement may also possess sufficient sensitivity and spatial resolution to permit study of potassium-rich minerals in large clay-filled fractures.

The gamma density tool irradiates the formation of interest with gamma rays and simultaneously detects photons that have been Compton-scattered within the rockmass of interest. The intensity of scattered radiation is governed by the average electron density, which is proportional to the bulk density. Since the bulk density is affected by porosity, the bulk density log will respond to interflow zones, fracture zones, and joints and faults of sufficient aperture that intersect the borehole. Borehole gravity data would be a useful alternative to gamma density data. However, it is believed that no tool exists for collecting such data in small-diameter, horizontal boreholes, and none is likely to be developed during the life of this program. However, the literature will be closely monitored concerning such instruments.

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The neutron porosity tool irradiates the formation of interest with energetic neutrons, and simultaneously detects epithermal or thermal neutrons which have lost most of their kinetic energies within the rockmass of interest. The epithermal or thermal neutron flux is controlled by the density of hydrogen in the rockmass, which in turn is proportional to the porosity. The log will reveal the presence of water-filled features such as vesicular zones, interflow zones, fracture zones, and individual joints and faults of sufficient aperture. Preliminary studies indicate that zones with unconnected porosity can be differentiated from permeable zones through the use of a porosity-resistivity cross plot. The delineation of permeable zones is of obvious value to hydrologic studies; these zones can be isolated with packers and subjected to permeability tests.

Acoustic logs resemble surface seismic surveys, except the log measurements are done with sources and receivers installed in a single logging tool. In a sense, acoustic logs provide point-by-point assessments of the acoustic rock qualities, whereas the seismic surveys provide information on qualities averaged over large blocks of rock. As is the case with the seismic surveys, the acoustic logs will be responsive to velocity discontinuities, due for example, to fracture zones. Present plans anticipate the collection of P- and S-wave travel time data, and full-waveform data if possible.

Auxiliary logs do not supply data from which rock properties are derived; instead, these logs furnish borehole and environmental data which are required to correct the data gathered by the other logs. Examples are the caliper log and the temperature log.

<u>8.3.1.2.3.3.5.2.2.4 Task summary</u>. Electromagnetic surveys, seismic surveys, and borehole logging will be executed in the Exploratory Shaft Facility settings described in Section 8.3.1.2.3.3.5.2.1 and surface boreholes. It is expected that contractors, which have not yet been selected, will conduct some of the surveys. The BWIP staff will be primarily responsible for data analysis, interpretation, and documentation.

<u>8.3.1.2.3.3.5.3 Document and distribute data and conclusions</u>. Whenever possible, data will be transmitted directly from the various test sites to the data acquisition system. Data and conclusions drawn from data interpretation will be presented in reports. Where appropriate, packages of selected data will be delivered to study units having specific interests in them. It is presently anticipated that information gathered under physical rock properties characterization will be particularly useful to the following studies: stratigraphy, structural geology, intraflow structures, cooling joint characteristics, mechanical properties determination, evaluation of opening performance, in situ stress, and various studies conducted under hydrology and seals. The interfaces with other studies will be reviewed and adjusted as an ongoing process.

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8.3.1.2.3.3.6 Stratigraphic and structural model study.

The stratigraphic and structural model study addresses performance and design issue parameters relating to the geometry of the site and surrounding area. Thus, the primary objective of the stratigraphic and structural model study is to provide a three-dimensional depiction of the present geologic conditions of the repository site, controlled area study zone, Cold Creek syncline, Pasco Basin, and the region. The study will use and interact with five other studies of the geologic program of investigations in order to develop the geometric depiction of the stratigraphy and structure. These five studies are (1) stratigraphy study, (2) intraflow structure study, (3) cooling joint characteristics study, (4) structural geology study, and (5) physical rock properties study.

The information produced in the stratigraphic and structural model study will be used to provide the geologic framework for conceptual and numerical models of the site and regional groundwater flow systems and for numerical groundwater flow models, the stratigraphic and structural model will be used directly to generate nodal grid elements for these models. The detailed models produced in this study will provide the necessary data for design purposes, particularly in the repository layout area, for elevations of mined openings and the spatial positions of zones requiring differing rock support requirements or zones of high permeability. The information produced in this study will also be used in the development of tectonic models and in the assessment of tectonic processes (tectonic assessment study, Section 8.3.1.2.4.3.3). The two stratigraphic and structural model tasks are to (1) develop and document the stratigraphic and structural model, and (2) document the engineering geology characteristics (Table 8.3.1.2-14). The stratigraphic and structural model task will provide the three-dimensional depiction of the present geologic conditions of the site by combining stratigraphic, structural geology, deformation and intraflow structure data into one package. The output of this task will be stratigraphic unit and subunit spatial configurations along with structural features.

The engineering geology characteristics task will result in description of features of the site which are on a more detailed scale than those depicted in the stratigraphic and structural model component. The characteristics described will be, for example, statistical description of physical characteristics of cooling joints, physical characteristics of flow tops and bottoms, or characteristics of faults or shear zones. Parameters to be collected in the stratigraphic and structural model study are listed in Table 8.3.1.2-7.

Technical considerations that have been used to organize and focus the stratigraphic and structural model study include the following questions:

- What are the current geologic conditions of the controlled area study zone, Cold Creek syncline, Pasco Basin, and region?
- What are the alternative models that may have an impact on the geologic and hydrologic performance of the site (i.e., differing styles of faulting, differing models of unit distribution)?

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Table 8.3.1.2-14. Tasks/tests/analyses for the stratigraphic and structural model

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Stratigraphic and structural model	Contour maps Cross sections	At scale specified in Table 8.3.1.2-15	Not required for analyses	Structure model stratigraphic model, intraflow structure model	Model will provide the spatial positions of geologic features
Engineering geology characteristics	Structure contour maps Cross sections Statistical description	Repository site/CASZ	Not required for analyses	Spatial position of Cohassett flow intraflow structures, cooling joint characteristics, fault and shear zone characteristics	Physical and verbal description of the engineering geology characteristics of the Cohassett and surrounding flows

CASZ = Controlled area study zone.

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The technical considerations focus the work within the study by helping to define the objectives and the scope of specific tasks. For example, several alternative stratigraphic and structural models may be developed, each with its own likelihood of being real and each with its own potential impact on design and overall performance of the repository. The acknowledgment of such a technical consideration forces the development of tasks within the study that address and attempt to resolve the applicability of alternative models.

8.3.1.2.3.3.6.1 Stratigraphic and structural model task. This task will provide the spatial positions of sedimentary units (both suprabasalt and interbedded), basalt units, and major intraflow structures of basalt units. The results from three other studies will be used to produce the three dimensional geologic description of the site. These three studies are (1) stratigraphy, (2) structural geology, and (3) intraflow structure studies.

In general, five different areas or scales will be used in the stratigraphic and structural model task. The approximate extent of the areas to be mapped at the different scales are illustrated in Figures 8.3.1.2-32 and 8.3.1.2-33. The stratigraphic units and level of detail to be used in each area are given in Table 8.3.1.2-15. The scales or areas are as follows:

- Repository site. This corresponds to the area of detailed geologic information needed to support the design of repository subsurface and surface facilities. The data produced at this scale will also be used for hydrologic testing purposes in the Exploratory Shaft Facility. Structure contour maps will be produced for individual basalt flows and their associated flow top and bottom zones. Sedimentary units will be shown down to the stratigraphic level of beds. Faults and shear zones will be shown on structure contour maps and cross sections as well. Structure contour maps and cross sections will generally be produced at a scale of 1:5,000. Larger or smaller scales will be used if particular features need to be further detailed for the repository site. Vertical exaggeration will also be used to show features in cross section. It should be noted that the internal features of the Cohassett flow and immediately surrounding flows and the characteristics of faults and shear zones will be described and depicted in the second component of this study, engineering geology characteristics.

- Controlled area study zone. This scale is required to evaluate groundwater flow, radionuclide transport, and design needs. Structure contour maps will be produced for individual basalt flows within the N_2 magnetostratigraphic unit and their associated flow top and bottom zones. Structure contour maps will be produced for magnetostratigraphic units within the Grande Ronde Basalt and for major subbasalt units (on an as-needed basis). Structure contour maps of sedimentary units will be constructed down to the bed level. Faults and shear zones will be shown on maps and cross sections.

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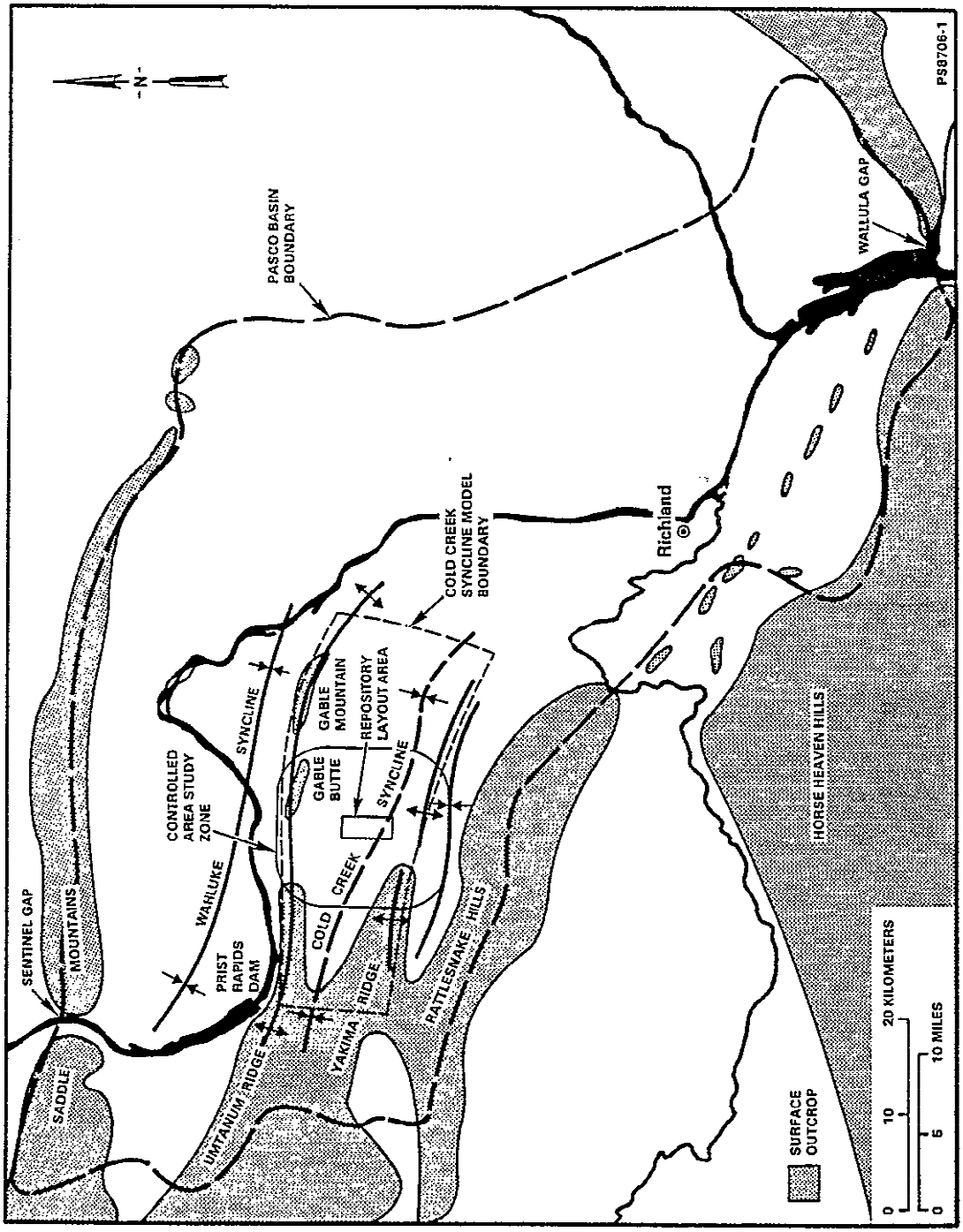

Figure 8.3.1.2-32. Location map showing scales for the repository site, the controlled area study zone, and the Cold Creek syncline.

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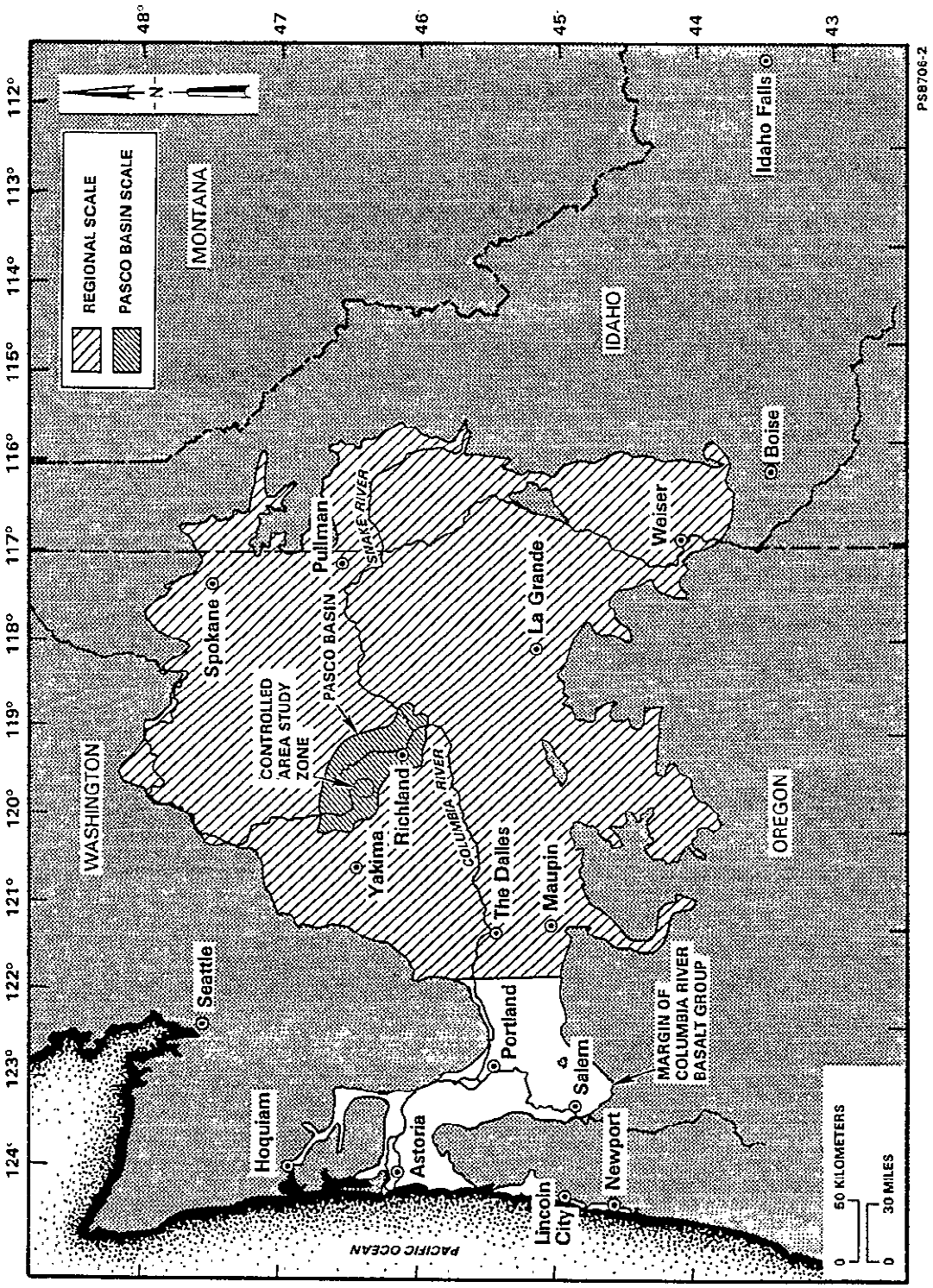

Figure 8.3.1.2-33. Location map showing approximate extent of study plan scales for the region and Pasco Basin.

Table 8.3.1.2-15. Level of detail for the stratigraphic and structural model study[a] (sheet 1 of 2)

General area of model	Units included	Level of detail
Repository site[b] (1:1,000, 1:12,000)	Suprabasalt sediments	Beds
	Interbedded sediments	Beds
	Saddle Mountains Basalt	Flow
	Wanapum Basalt	Flow
	Top of Grande Ronde Basalt to base of Grande Ronde N2 Basalt	Flow
Controlled area study zone (1:12,000 to 1: 24,000)	Suprabasalt sediments	Beds
	Interbedded sediments	Beds
	Saddle Mountains Basalt	Flow
	Wanapum Basalt	Flow
	Grande Ronde N2 Basalt	Flow
	Remainder of Grande Ronde Basalt to base of basalt (as needed)	Magnetostratigraphic units
Cold Creek syncline (1:12,000 to 1:62,500)	Suprabasalt sediments	Member
	Interbedded sediments	Bed
	Saddle Mountains Basalt	Member
	Wanapum Basalt	Flow
	Grande Ronde N2 Basalt	Flow
	Remainder of Grande Ronde Basalt to base of basalt (as needed)	Magnetostratigraphic units
Pasco Basin[b] (1:24,000 to 1:100,000)	Suprabasalt sediments	Member
	Interbedded sediments	Bed
	Saddle Mountains Basalt	Member
	Wanapum Basalt	Member
	Grande Ronde N2 Basalt	Sequence to flow
	Remainder of Grande Ronde Basalt to base of basalt (as needed)	Magnetostratigraphic units

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Table 8.3.1.2-15. Level of detail for the stratigraphic and structural model study[a] (sheet 2 of 2)

General area of model	Units included	Level of detail
Region[b] (1:100,000 to 1:500,000)	Suprabasalt sediments	Formation
	Interbeds	Formation to member
	Saddle Mountains Basalt	Formation to member
	Wanapum Basalt	Formation to member
	Grande Ronde Basalt	Formation
	Picture Gorge Basalt	Formation
	Imnaha Basalt	Formation

[a] Typical range of working scales given in parentheses. Other scales to be developed as needed for engineering design or publication of results. PST87-2005-8.3.1.2-32

[b] Additional detail may be necessary in portions of the Pasco Basin and region to satisfy special requirements of a particular study.

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Structure contour maps and cross sections will generally be displayed at a scale of 1:24,000, although larger or smaller scales may be used to display portions of the controlled area study zone if additional detail is needed. Vertical exaggeration will be utilized to show features in cross section that are too small to be shown without vertical exaggeration.

- Cold Creek syncline. This scale is required to provide input to groundwater flow models used in the overall assessment of the performance of the site. Structure contour maps will be constructed for stratigraphic units at a lower level of detail than for either the repository site or the controlled area study zone. This is due to the reduced needs of the groundwater flow models within the Cold Creek syncline. Structure contour maps will be constructed for the tops of all Grande Ronde Basalt magnetostratigraphic units and for major sub-basalt units as needed. Structure contour maps of individual flows and their associated flow top and bottom zones within the Grande Ronde Basalt N_2 magnetostratigraphic unit and the Wanapum Basalt will be constructed. Within the Wanapum and Saddle Mountains Basalts, maps will be constructed for units at the member level. Interbedded sedimentary units will be displayed at the bed level and suprabasalt sediments at the member level. Map and cross section scales will range from 1:24,000 to 1:100,000, depending on what level of detail is needed to display features. Vertical exaggeration will be utilized to display features which are too small to be shown without vertical exaggeration.

- Pasco Basin. This scale is required to provide the current geologic setting for interpretation of the tectonic setting of the site. The data produced at this scale will also provide a basis for groundwater flow models. Structure contour maps will be constructed at a lower level of detail than those produced at the scales discussed above. This is due to reduced needs of the groundwater flow models within the Pasco Basin. Structure contour maps will be constructed for the tops of all Grande Ronde Basalt magnetostratigraphic units, and for the tops of the Schwana and Sentinel Bluffs sequences in the N_2 unit. Structure contour maps of the top of some Grande Ronde N_2 flows may be required in addition to satisfy needs from other studies. Unit structure contour maps of Wanapum and Saddle Mountains Basalts will be constructed for units at the member level. Interbedded sedimentary unit maps will be constructed for beds within each interbed. Suprabasalt sediment maps will be constructed for units at the member level. Maps and cross section scales will be produced primarily at a scale of 1:100,000. Other scales will be used if necessary. Vertical exaggeration will be used to display features which are too small to be shown without vertical exaggeration.

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- Region. The regional scale is required in order to test tectonic models of the site geologic setting of the site. Such models must be developed on a regional scale in order to capture the full range of potentially disruptive scenarios needed to evaluate long term site performance. The regional scale also provides boundary conditions for the Pasco Basin models. Maps produced at the regional scale will display much less detail than the previous four scales because of the areal size of the region (see Fig. 8.3.1.2-3). Structure contour maps and cross sections of the region will be produced for units of formational status; however, these maps and sections may be produced for smaller local areas displaying stratigraphic units at a lower level than formation. Maps and cross sections constructed for the region will be produced at a scale of 1:500,000 or smaller. This scale was chosen to enable displaying all of the region on one map.

The development of the above models will entail construction of structure contour maps and cross sections using both hand and computer mapping techniques. The data to be used will originate from the stratigraphy, structural geology, and intraflow structure study plans.

The methodology used will be to obtain from the structural geology study structure contour maps of key stratigraphic horizons. From these maps, isopach maps of stratigraphic units or intraflow structures will be subtracted to produce underlying structure contour maps. Tectonic structures such as faults will be superimposed on structure contour maps as appropriate.

A preliminary stratigraphic and structural model of the reference repository location has been completed (Landon and Bjornstad, 1986) and provides an example of the type of models that will be produced under this study.

8.3.1.2.3.3.6.2 Engineering geology characteristics task. This task will result in detailed descriptions of internal flow characteristics and their spatial positions within the flow. The primary emphasis of this task will be on the Cohassett flow. Information also will be provided for the Birkett flow below the Cohassett flow, and the Levering and Rocky Coulee flows above the Cohassett flow, but at lesser detail.

This task will use the structure contour maps of the top of the Cohassett flow and of the top of the Cohassett flow interior produced in the stratigraphic and structural model component above. The structure contour maps will form a basis from which finer detailed descriptions of the flow interior will be produced. The maps will be used to produce cross sections on which entablature, colonnade, flow top and bottom, and vesicular zones will be positioned. Cooling joint distributions will be illustrated as well. Positions of known faults and shear zones will also be shown on the cross sections.

Accompanying the cross sections will be a written report providing descriptions of the physical characteristics of the internal features of the flow that are important to repository design and to assessment of the

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performance of the site. Features that will be described are flow tops and bottoms, entablatures, colonnades, spiracles, cooling joint parameters, and fault and shear zone characteristics.

Descriptions of intraflow structures will be taken from the intraflow structure study (Section 8.3.1.2.3.3.2) descriptions of the distribution, lateral continuity, and thickness variability of intraflow structures along with lithologic and petrologic descriptions of the units.

Cooling joint characteristics will be described using the geotechnical mapping units and the pattern simulation models developed in the cooling joint characteristics study (Section 8.3.1.2.3.3.3). The geotechnical mapping units model will provide a statistical evaluation of cooling joint data per geotechnical mapping unit. Parameters to be described are persistance, orientation, frequency or spacing, width, percent filled with secondary mineral, type of secondary mineral, wall rock alteration, roughness, connectivity, void geometry, and percent of cooling joints that break in core. The pattern simulation model will provide a graphic representation of the distribution of cooling joints per geotechnical mapping unit.

Descriptions of tectonic features such as faults, tectonic fractures, and shear zones will be provided from the structural geology study (Section 8.3.1.2.3.3.4). Characteristics to be discussed are the location, orientation, areal extent, and type and amount of offset of faults, fractures and shear zones, and descriptions of fault breccia and secondary minerals.

8.3.1.2.3.4 Application of results

The stratigraphy and structure investigation will primarily support investigations in hydrology, rock mechanics, seal design, and repository design. Performance assessment uses will be primarily based on a hydrologic interpretation of the stratigraphic and structural model.

8.3.1.2.3.4.1 Applications of the stratigraphy study.

The stratigraphy study provides input to conceptual models of site layering. The stratigraphic model also has specific characterization, performance assessment, and design uses.

Characterization uses are for hydrologic interpretation and data collection; the stratigraphy of each borehole with hydrologic objectives must be determined before achieving those objectives. Continuity and lithology of layers is important to interpretation of groundwater flow paths and to the design of the layout of a repository. Similarly, tectonic investigations require stratigraphic interpretations for input to tectonic history (e.g., the extent of thinning of basalt flows or sediments across an anticline forming during eruption of the basalt).

Performance assessment uses are related to the use of layered models of the site to calculate both groundwater travel times and radionuclide transport.

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Design uses of stratigraphy are principally incorporated into the site structural and stratigraphic model at the repository site scale. Identification of the Cohassett flow and layers above and below it is needed for location of the geologic repository operations area and for design and placement of shaft seals.

8.3.1.2.3.4.2 Applications of the intraflow structure study.

The intraflow structure study provides the detail of the primary internal characteristics of basalt flows in the stratigraphic and structural model of various regions such as the repository site and controlled area study zone. The stratigraphic and structural model, in turn, is fundamental to hydrologic and performance assessment modeling and to repository design. Intraflow structures define zones of groundwater flow (flow tops and bottoms) and zones that act as impediments to groundwater flow (generally flow interiors). Anomalous intraflow structures could act as pathways for accelerated groundwater flow. As such, these zones are important to hydrologic modeling and to radionuclide migration in performance assessment modeling. Because intraflow structures define potential hydrologic pathways or possibly zones of differing rock strength, they delimit the available host rock interior for design flexibility and may influence rock support considerations.

Direct users of intraflow structure data include hydrology for identification of testing horizons. Intraflow structure studies provide the framework for cooling joint and rock mechanical studies. Borehole intraflow structure information in the controlled area study zone provides key information for placement and thickness of borehole and shaft seals. The Exploratory Shaft Facility intraflow structure studies provide information for interpretation of hydrologic and rock mechanics Exploratory Shaft Facility testing.

8.3.1.2.3.4.3 Applications of the Cooling Joint Characteristics Study.

In the study for evaluation of opening performance (Cramer, 1987, pp. 95-99) the statistical models describing the three-dimensional arrangement of cooling joints will be applied to the analyses of the following:

1. Damaged rock zone.
2. Rock mass-construction interaction.
3. Rock mass-thermal response.

Cooling joint data (along with other geologic data) will also be used to implement a rock mass classification scheme including the Q system, RMR, and a site-specific system. Data from the classification and quality rating systems will allow initial estimates of ground support requirements by the Architect/Engineer during Exploratory Shaft Facility construction. Also the data will help in an examination of the adequacy of the selection method for the ground support requirements and recommendations can be made to modify the support selections.

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Geologic data (including cooling joints) coupled with data from the in situ stress study and mechanical properties determination study will provide important information to waste package studies about the load that the rock mass will place on canisters in the repository. The load will possibly be influenced by rock creep or more active rock strain which requires knowledge of rock discontinuities.

Although not evident in prior Near-Surface Test Facility testing, joints may affect the thermal properties of the rock mass. Planar features exhibiting a preferred orientation may cause a high degree of anisotrophy to another size isotropic rock mass. Cooling joints may influence the thermal and thermomechanical properties of the rock as a function of joint width, characteristics of joint infilling materials, and the water content of the joints. Cooling joint data need to be collected and used to interpret thermal tests on small- and large-scale rock samples and to interpret larger-scale in situ tests.

Cooling joint data are needed to interpret the results of hydraulic fracturing test results in the in situ stress determination study (McCain, 1987). Existing joints (cooling joint) may reopen during the test rather than create new fractures, and the possibility exists that fracture orientations may change as the induced joints propagate away from the borehole. Careful logging of the core or use of borehole geophysics before and after conducting the tests will help interpret the results.

Mechanical properties of the rock mass are dependent on discontinuities and properties of the intact rock. Therefore, cooling joint characteristics will be needed to interpret the results of mechanical properties tests on the rock mass and on tests of individual joints. Joints will be mapped in the tunnel exposures where mechanical properties tests will be located and individual cooling joints will be characterized before testing in core samples.

Discontinuity characteristics have been identified in the constitutive model development study plan (Donovan, 1987) as factors that may influence rock mass constitutive behavior. Therefore, basic cooling joint data such as spacing, orientation, and persistence are needed as input to constitutive models.

Assessment of the performance of the repository will greatly depend on groundwater flow and transport models. At this point in time, the detail that is necessary in those models is not known. It is possible that continuum models are all that is needed. However, in the very near-field environment surrounding a waste canister, the waste barrier system may be analyzed best by the use of discrete fracture models. Because the decision has not been made to discontinue any plans for discrete fracture modeling, the study currently includes the collection of detailed joint data that would be appropriate for discrete joint modeling.

9 2 1 2 3 5 4 1 9 4 2

8.3.1.2.3.4.4 Applications of the structural geology study.

The structural geology study provides key input to conceptual models of the geometry of tectonic structures of the site. The structural geology study is an important basis for evaluating tectonic events and processes. It also has specific characterization, performance assessment, and design uses particularly as a key element of the stratigraphic and structural model.

Characterization uses are for hydrologic data collection and interpretation. Location of folds in the stratigraphic layers is inextricable from the interpretation of hydraulic head data in the controlled area study zone and the location of faults and tectonic fractures must be a key factor in plans for hydraulic testing and interpretation of large-scale hydrologic stress tests. These data also will provide information for identifying which faults are important, the age and recurrence of faulting, and the earthquake potential of faults.

Performance assessment uses are related to the estimate of sensitivity of groundwater travel-time models to the effect of subvertical faults. Faults may increase vertical hydraulic conductivity of basalt flow interiors, and a range of possible frequency of such faults can be modeled by varying the vertical hydraulic conductivity of confining layers. The principal performance assessment use of structural geology data will be as part of the combined stratigraphic and structural model, especially for the controlled area study zone. These data will provide input to determine the location and probability of disruptive events.

Design uses for structural geology are based on the structural and stratigraphic model of the site at the repository site scale. In addition to input for seismic design, the estimated frequency of faults and tectonic fractures is of paramount importance for design of roof support systems to ensure both stable openings and design of mine pumping capacity and for design and placement of shaft seals. Structural geology, specifically the dip of the north limb of the Cold Creek syncline, also plays a key role in the geologic repository operations area design, particularly since the repository workings and surrounding buffer zones must stay within the flow interior. Consequently, mine drainage and mine transportation (e.g., use of track versus rubber tire vehicles) are tied closely to Cold Creek syncline structure.

8.3.1.2.3.4.5 Applications of the physical rock properties characterization study.

8.3.1.2.3.4.5.1 Support for other studies. Studies that express specific requests for physical rock parameters are stratigraphy (Landon, 1987), structural geology (Odegard, 1987), intraflow structures (Cross, 1987), cooling joint characteristics (Lindberg, 1987), mechanical properties determination (Wittreich and Skelly, 1987), and evaluation of opening performance (Moore and Lahr, 1987).

The first four studies listed above strongly support a comprehensive program of geophysical measurements to detect and delineate structural features. For example, the intraflow structures study plan proposes geophysical surveys to detect and delineate structures not accessible to direct observation in the Exploratory Shaft Facility. Employment of the entire suite of geophysical techniques is involved.

The studies for mechanical properties determination and evaluation of opening performance depend on the physical rock properties characterization study to monitor rock properties during various rock mechanics tests. For example, the evaluation of opening performance study plan proposes geophysical monitoring of rock properties during the mine-by test. These study plans also emphasize the importance of determining the radial extent of the disturbed rock zone and the physical properties of the rock within that zone.

Hydrology and seals studies emphasize the in situ porosity measurements. Interpretation of geophysical borehole logs will also delineate zones of high permeability. Permeability cannot be quantified from borehole log data, but the zone delineations will assist hydrologic in selecting appropriate zones for permeability measurements.

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8.3.1.2.3.4.5.2 Construction and design. Exploratory Shaft Facility construction methods will be evaluated, and possibly modified, on the basis of information derived from the geophysical surveys in the Exploratory Shaft Facility. One category of information relevant to construction methodology includes basic parameters related to the strength of the host rock (i.e., density, porosity, and elastic constants). Data from pilot borehole logging may comprise a basis for on-site adjustments of construction methods. Another information category consists of rock property changes induced by the construction. This category includes the radial extent of the disturbed rock zone, and the density, porosity, and elastic constants of rock within this zone.

The information cited as applicable to construction method evaluations will also have a role in repository design. Other information produced by the geophysical surveys will influence design. The major examples are flow boundary delineations, locations of anomalous rock zones, and physical properties of rock within anomalous zones.

8.3.1.2.3.4.5.3 Performance assessment analyses. Porosity, one geophysically-determined parameter, is a component in the modeling equations for groundwater migration, and is, therefore, a key parameter for performance assessment.

Other performance assessment information will come from the geophysical monitoring of tests like the full-scale heater test (Moore and Lahr, 1987). Changes in rock properties will be recorded over time, with particular attention to parameters, such as porosity and resistivity, that are indicative of groundwater movement.

8.3.1.2.3.4.6 Applications of the stratigraphic and structural model study.

The information produced in this study will be used to supply the geologic framework for conceptual and numerical models of the site and regional groundwater flow systems. For numerical groundwater flow models, the stratigraphic and structural model will be used directly to generate nodal grid elements. The detailed models produced in this study will provide necessary data to be used for design purposes particularly in the repository layout area for elevations of mined openings and for the spatial positions of zones requiring differing rock support requirements or zones of high permeability. The model will also be used to help further develop tectonic models.

8.3.1.2.3.5 Schedules and milestones

Generalized schedules and major milestones for the stratigraphy and structure investigation (stratigraphy study, intraflow structure study, cooling joints characteristics study, structural geology study, physical rock properties study, and stratigraphic and structural model study) are shown in Figure 8.3.1.2-34.

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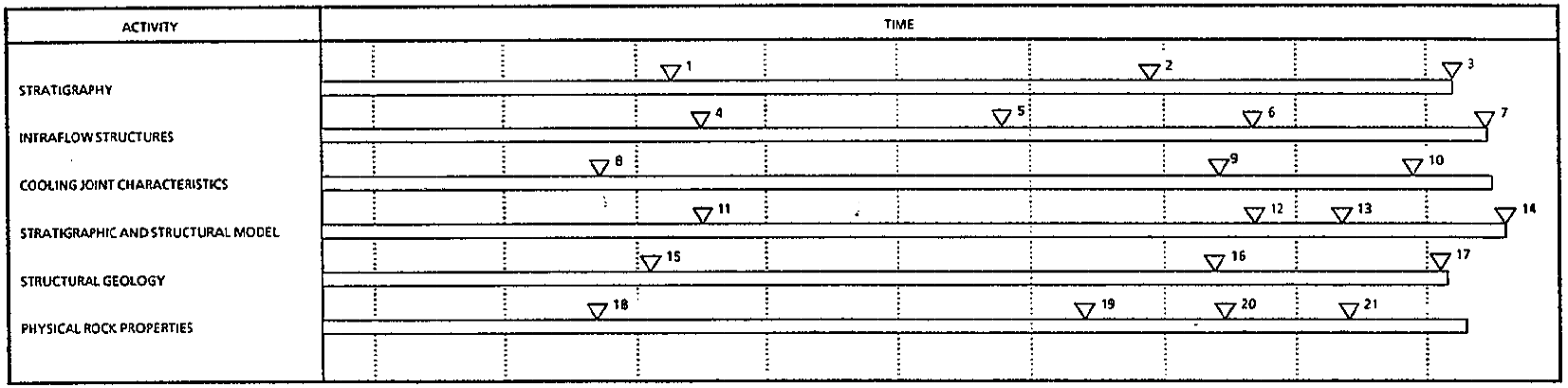
8.3.1.2.4 Tectonic events and processes investigation

8.3.1.2.4.1 Purpose and objectives

The purpose of the tectonic events and processes investigation is to determine the tectonic, volcanic, and geomorphic stability of the site and surrounding area, including a projection of future processes and rates. This information is required to resolve issues relating to qualification of the site, design, and long-term performance. Adequate numerical for repository design and site performance is dependent, therefore, on an assessment of tectonic processes of the past, present, and future.

The tectonic events and processes investigation uses structural and stratigraphic data (e.g., location, geometry, physical characteristics of tectonic structures, and basalt and sedimentary units) obtained from the stratigraphy and structure investigation (Section 8.3.1.2.3) to develop the deformational history of the rocks in the repository, controlled area study zone, Pasco Basin, Yakima Fold Belt, and region. The deformational history includes an evaluation of the styles and rates of deformation and the volcanic history of the site and region. Historic and instrumental earthquake data and geodetic survey data will be supplemented with in situ stress data and structural interpretations to determine the current stress regime. All these data will provide the basis for the assessment of tectonic stability, and allow the identification and evaluation of tectonically induced potential disruptive processes that are the primary objectives of the tectonic events and processes investigation. These will be used in the performance of sensitivity studies as well as analyses of the anticipated (nominal) and



1 COMPLETE UPDATE OF BASALT UNIT DISTRIBUTION.

2 COMPLETE STRATIGRAPHIC MODEL TO SUPPORT LAD.

3 COMPLETE UPDATE OF STRATIGRAPHIC MODEL FOR DEIS.

4 COMPLETE DETERMINATION OF INTRAFLOW STRUCTURE GEOMETRY OF THE REPOSITORY SITE/CASZ FOR ACD AND PERFORMANCE ASSESSMENT MODELING (ISSUES 1.6 AND 1.1).

5 COMPLETE INTRAFLOW STRUCTURE INTERPRETATION OF THE EXPLORATORY SHAFT (JUST THE SHAFT).

6 COMPLETE DETERMINATION OF INTRAFLOW STRUCTURE GEOMETRY OF THE REPOSITORY SITE/CASZ/COLD CREEK SYNCLINE FOR LAD AND PERFORMANCE ASSESSMENT MODELING (ISSUES 1.6 AND 1.1).

7 COMPLETE DETERMINATION OF INTRAFLOW STRUCTURE GEOMETRY OF THE REPOSITORY SITE/CASZ/COLD CREEK SYNCLINE/PASCO BASIN (AS NEEDED) FOR DEIS AND PERFORMANCE ASSESSMENT MODELING (ISSUES 1.6 AND 1.1).

8 RESULTS OF STATISTICAL SUMMARIES OF EXISTING OUTCROP AND BOREHOLE DATA. DESIGNED TO BE INPUT TO STRATIGRAPHIC AND STRUCTURAL MODEL STUDY AND ACD

9 RESULTS OF COOLING JOINT MODELING FOR INPUT TO STRATIGRAPHIC AND STRUCTURAL MODEL STUDY AND LAD.

10 RESULTS OF COOLING JOINT MODELING FOR INPUT TO STRATIGRAPHIC AND STRUCTURAL MODEL STUDY AND DEIS.

11 UPDATE STRATIGRAPHIC AND STRUCTURAL MODEL FOR CASZ OF ACD

12 UPDATE STRATIGRAPHIC AND STRUCTURAL MODEL FOR CASZ OF LAD

13 UPDATE STRATIGRAPHIC AND STRUCTURAL MODEL OF COLD CREEK SYNCLINE AND PASCO BASIN FOR DEIS

14 UPDATE STRATIGRAPHIC AND STRUCTURAL MODEL OF CASZ FOR DEIS

15 PROVIDE STRUCTURAL MODEL OF CENTRAL PASCO BASIN FOR ACD AND PERFORMANCE ASSESSMENT MODELING

16 UPDATE AND ENLARGE STRUCTURAL MODEL FOR LAD AND PERFORMANCE ASSESSMENT MODELING

17 COMPLETE DETERMINATION OF THE STRUCTURAL MODEL FOR THE CASZ, PASCO BASIN, AND REGION (AS NEEDED) FOR DEIS AND PERFORMANCE ASSESSMENT MODELING

18 START DEVELOPMENTAL ROCK PROPERTIES TESTING IN THE NSTF.

19 BEGIN GEOPHYSICAL ROCK PROPERTIES MEASUREMENTS IN THE ESF.

20 COMPLETE PHYSICAL ROCK PROPERTIES TESTING IN THE ESF FOR THE LAD.

21 COMPLETE PHYSICAL ROCK PROPERTIES TESTING IN THE ESF FOR DEIS

ACD = ADVANCED CONCEPTUAL DESIGN
CASZ = CONTROLLED AREA STUDY ZONE
DEIS = DRAFT ENVIRONMENTAL IMPACT STATEMENT
ESF = EXPLORATORY SHAFT FACILITY
LAD = LICENSE APPLICATION DESIGN
NSTF = NEAR-SURFACE TEST FACILITY

Figure 8.3.1.2-34. Schedules and milestones for the stratigraphy and structure investigation.

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unanticipated (disruptive) cases. Prediction of preclosure disruptive conditions (earthquake vibratory ground motion and (or) fault displacement) will be used for safety analyses of Q-listed items for design.

The information obtained from this investigation will receive broad application within the BWIP, primarily in design and performance assessment. The characterization and evaluation of tectonic and volcanic disruptive scenarios will provide a key element in site subsystem performance assessment. The studies pertaining to earthquake seismology, specifically ground motion and fault source parameters, will be used to support repository design and safety engineering.

Justification for obtaining information pertaining to tectonic events and processes is based on performance measures and parameters derived to address issues discussed in Section 8.2.2. Tables 8.3.1.2-16 through 18 present the relevant issue-identified parameters associated with the three studies within the tectonic events and processes investigation. These parameters deal with the location, style, and rates of deformation, seismicity, and the probability and nature of future tectonic events and processes.

The tectonics events and processes investigation provides key input to address performance measures and parameters associated mainly with the following issues:

8.3.1.2.4.1.1 Issue 1.1.

The tectonic events and processes investigation will determine the location, spatial orientation, and characteristics of geologic structures that could serve as groundwater flow impediments/flow boundaries within the controlled area study zone, disruptive tectonic and volcanic events and processes within the controlled area study zone and beyond, and the likely future behavior of these tectonic and volcanic phenomena. These data will be provided to performance assessment for modeling of the anticipated (nominal) case as well as the unanticipated (disruptive) case. For each potentially disruptive event/process that could be significant to system performance, data will be provided to conduct sensitivity studies. If the performance of the system is sensitive to scenarios involving these processes/events, they will be further characterized; i.e., the probability of occurrence of the event and likely geologic consequences will be determined for use in modeling the future performance of the repository in the controlled area study zone.

8.3.1.2.4.1.2 Issue 1.6.

The location and characteristics of geologic structures in the controlled area study zone and beyond will be determined for development and analyses of conceptual and numerical groundwater flow models. A probability distribution of structural features will be provided as well as values for parameters needed for modeling pre-emplacement groundwater travel time.

Table 8.3.1.2-16. Parameters addressed by the deformation study (sheet 1 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal/needed accuracy	Current estimate of goal/accuracy	Confidence	
						Needed	Current
Probability of occurrence of faulting in the region	1.1, 1.8	Pasco Basin/ Region	Stratigraphy: extent of units, age of stratigraphic units, control by structure	Use stratigraphy to constrain the ages of the structures and rates of growth	Not applicable	High	Medium to low
			Structural features: location of faults and folds, orientation of faults and folds	Use geologic maps and data to constrain areas of deformation	Not applicable	High	Medium to low
			Thickness of stratigraphic units (Miocene to Quaternary)	Use isopach maps to constrain ages of structures and rates of deformation	Not applicable	High	Medium to low
			Variations in structural features	Use structure contour maps to constrain locations of structures	Not applicable	High	Medium to low
			Current rates of extension, shortening, uplift, and subsidence	Determine current growth rates of structures	Not applicable	High	Medium
			Quaternary offset	Measure Quaternary deformation rate	Not applicable	High	Medium to low
			Pre-Quaternary offset	Measure pre-Quaternary deformation rate	Not applicable	High	Low to medium
			Quaternary slip rate	Measure Quaternary deformation rate	Not applicable	High	Low
			Fault zone characteristics - Texture - Compaction - Cementation	Measure styles of deformation	Not applicable	High	Low
			Mechanisms of fold deformation	Determine style of deformation	Not applicable	High	Medium to low
			Relationship of physical characteristics of fault to slip	Determine style of deformation	Not applicable	High	Low to medium
			Deformational characteristics of Pasco Basin	Determine the relationship between styles, rates and mechanisms of deformation	Not applicable	High	Low to medium

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Table 8.3.1.2-16. Parameters addressed by the deformation study (sheet 2 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal/needed accuracy	Current estimate of goal/accuracy	Confidence	
						Needed	Current
Probability of occurrence of faulting in the controlled area	1.1, 1.8	Controlled area study zone	Stratigraphy - Extent of units - Age of stratigraphic units - Control by structure	Use stratigraphy to constrain the ages of the structures and rates of growth	Not applicable	High	Medium to low
			Structural features - Location of faults and folds - Orientation of faults and folds	Use geologic maps and data to constrain areas of deformation	Not applicable	High	Medium to low
			Thickness of stratigraphic units (Miocene to Quaternary	Use isopach maps to constrain ages of structures and rates of deformation	Not applicable	High	Medium to low
			Variations in structural features	Use structure contour maps to constrain locations of structures	Not applicable	High	Medium to low
			Current rates of extension, shortening, uplift, and subsidence	Determine current growth rates of structures	Not applicable	High	Medium
			Quaternary offset	Measure Quaternary deformation rate	Not applicable	High	Medium to low
			Pre-Quaternary offset	Measure pre-Quaternary deformation rate	Not applicable	High	Low to medium
			Quaternary slip rate	Measure Quaternary deformation rate	Not applicable	High	Low
			Fault zone characteristics - Texture - Compaction - Cementation	Measure styles of deformation	Not applicable	High	Low
			Mechanisms of fold deformation	Determine style of deformation	Not applicable	High	Medium to low
			Relationship of physical characteristics of fault to slip	Determine style of deformation	Not applicable	High	Low to medium

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Table 8.3.1.2-16. Parameters addressed by the deformation study (sheet 3 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal/needed accuracy	Current estimate of goal/accuracy	Confidence	
						Needed	Current
Probability of occurrence of faulting in the controlled area (cont.)	1.1, 1.8 (cont.)	Controlled area study zone	Deformational characteristics of the controlled area study zone	Determine the relationship between styles, rates and mechanisms of deformation	Not applicable	High	Low to medium
			In situ stress state evaluation	Estimate the present regional stress field and determine stress field in the controlled area study zone	Not applicable	High	Low
Probability of occurrence of faulting in the underground facility	1.1, 1.8	Underground facility (RRL)	Structural features - Location of faults and folds - Orientation of faults and folds	Use geologic maps and data to constrain areas of deformation	Not applicable	High	Medium to low
			Variations in structural features	Use structure contour maps to constrain locations of structures	Not applicable	High	Medium to low
			Current rates of extension, shortening, uplift, and subsidence	Determine current growth rates of structures	Not applicable	High	Medium
			Quaternary offset	Measure Quaternary deformation rate	Not applicable	High	Medium to low
			Pre-Quaternary offset	Measure pre-Quaternary deformation rate	Not applicable	High	Low to medium
			Quaternary slip rate	Measure Quaternary deformation rate	Not applicable	High	Low
			Fault zone characteristics - Texture - Compaction - Cementation	Measure styles of deformation	Not applicable	High	Low
			Relationship of physical characteristics of fault to slip	Determine style of deformation	Not applicable	High	Low to medium

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Table 8.3.1.2-16. Parameters addressed by the deformation study (sheet 4 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal/needed accuracy	Current estimate of goal/accuracy	Confidence	
						Needed	Current
Probability of occurrence of faulting in the underground facility (cont.)	1.1, 1.8 (cont.)		Deformational characteristics of the reference repository location	Determine the relationship between styles, rates, and mechanisms of deformation	Not applicable	High	Low to medium
			In situ stress determinations	Determine present stress field in the controlled area study zone	Not applicable	High	Low
Probability of occurrence of significant erosional incision of the Columbia River	1.1, 1.8	Pasco Basin/Region	Thickness of stratigraphic units, Miocene to Quaternary	Determine location, age, erosion, and downcutting since Columbia River basalt time	Not applicable	High	Medium
			Topography and Grande Ronde Basalt exposure	Determine location and rate of downcutting of Grande Ronde Basalt by geomorphic processes	Not applicable	High	Medium

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Table 8.3.1.2-17. Parameters addressed by the seismology study (sheet 1 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal/needed accuracy	Needed confidence	Current estimate of goal/accuracy	Current confidence	Study/investigation
Cumulative release to the accessible environment	1.1	Within the underground facility (M>4)	Probability of faulting	<1%	High	0% to 1%	Low	Tectonic events and processes investigation
		Within the controlled area (M>4)	Probability of faulting	<1%	High	0% to 1%	Low	
		Within the region (M>4)	Probability of faulting	<1%	High	0% to 1%	Low	
Basalt dynamic properties	1.12	Underground facility	Shear-wave velocity	±25%	Medium	TBD	Low	Tectonic events and processes investigation
			Compression-wave velocity	±25%	Medium	3 to 6 km/s (1 8 to 3.7 mi/s)	Low	
			Damping	±25%	Medium	TBD	Low	
Surface and underground seismic characteristics	2.3			TBD	High		High	Earthquake seismology study
Seismicity data	2.4			TBD				Earthquake seismology study
Surface/subsurface seismic potential (design function 2.7 5)	2.7	Repository/controlled area		Magnitude <2.5 at 4 km (2.5 mi) from repository	High		High	Earthquake seismology study
Data relevant to design of shaft lining (PM 10)	4.2	Repository	Seismic activity	Within range (see PM 15)	High		High	Earthquake seismology study
Seismic effect on shaft liner above the basalt (PM 14)	4.2	Repository	Peak particle velocity, acceleration, displacement, time history	Within range (see PM 15)	Medium		Medium	Earthquake seismology study
Seismic activity (underground response to seismic events) (PM 15)	4.2	Repository		Within range comparable to magnitude <2.5 at >4 km (2.5 mi) from repository	High		High	Tectonic events and processes investigation
Subsurface physical parameters	4.2		Shear- and compression-wave velocities and attenuation factors Bulk rock density					Tectonic events and processes investigation
Maximum credible earthquake	4.2		Magnitude direction duration location recurrence source characteristics (e.g., seismic moment)	Within range comparable to magnitude <2.5 at >4 km (2.5 mi) from repository				Tectonic events and processes investigation

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Table 8.3.1.2-17. Parameters addressed by the seismology study (sheet 2 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal/needed accuracy	Needed confidence	Current estimate of goal/accuracy	Current confidence	Study/investigation
Combine the above two parameters to estimate maximum credible ground motion	4.2		Peak acceleration, peak velocity, dominant frequency	Within range comparable to magnitude <2.5 at >4 km (2.5 mi) from repository				Tectonic events and processes investigation
Effect of seismic events on shaft hoisting components (PM 16)	4.2		(See PM 15 and Issues 2.4 and 2.7)		High		Medium	Tectonic events and processes investigation
Effect of seismic events on shaft seals (PM 17)			(See PM 15 and Issues 2.4 and 2.7)		High		Medium	Tectonic events and processes investigation
Effect of seismic events on opening stability (PM 18)			(See PM 15 and Issues 2.4 and 2 7)		Medium		Medium	Tectonic events and processes investigation
Earthquake swarms at the repository location (PM 18)		Ground motion for a micro-earthquake of magnitude =4.4 at a distance of 800 m from exploratory shaft location	Peak horizontal acceleration at surface	0.25 to 1.0 g	Medium		Low	Tectonic events and processes investigation
		Total vector acceleration underground	0.50 to 1.0 g (+ 1 g for 0.1 s duration)					
		Peak horizontal velocity-surface	15 to 40 cm/s					
		Total vector velocity underground	11 to 30 cm/s					
		Duration of strong motion	0.5 to 0.8 s					
		Dominant frequency of velocity	1.3 to 2.0 Hz					
		Longest apparent wave length	1.5 to 2.3 km					
		Magnitude range 4.4 only 3.9 to 4 4 3.4 to 4.4 2.4 to 4.4	Return periods 480,000 yr 300,000 yr 100,000 yr 38,000 yr					

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Table 8.3.1.2-17. Parameters addressed by the seismology study (sheet 3 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal/needed accuracy	Needed confidence	Current estimate of goal/accuracy	Current confidence	Study/investigation
Probability of faulting	1.8 (PAC 4)	Region	Earthquake locations	Locations within 2 to 4 km (1 to 2.5 mi)	High		High	Earthquake seismology study
		Cold Creek syncline	Earthquake locations	Locations within 1 to 2 km (1 to 2.5 m)	High		High	Earthquake seismology study
		Region	Earthquake magnitudes	Magnitudes within 0.2 accuracy	Medium		Low	Earthquake seismology study
		Cold Creek syncline	Earthquake magnitudes	Magnitudes within 0.1 accuracy	High		Low	Earthquake seismology study
			Fault plane solutions	10° to 20°				Earthquake seismology study
		Region	Earthquake recurrence	Determine recurrence rates	High		Medium	Earthquake seismology study
		Cold Creek syncline	Earthquake recurrence	Determine recurrence rates	High		Low	Earthquake seismology study
		Region and Cold Creek syncline	Fault parameters with respect to seismicity (see PAC 11 for fault parameters with respect to seismicity)	Determine parameters of instrumentally recorded seismicity	Medium		Low	Earthquake seismology study
Probability of faulting	1.8 (PAC 11, 12, 13, 14)	Underground facility	Earthquake locations	Locations within 50 to 100 m (164 to 328 ft)	High		Medium	Earthquake seismology study
			Earthquake magnitudes	Magnitudes within 0.1 accuracy	High		Low	Earthquake seismology study
			Earthquake recurrence	Determine recurrence rate	High		Low	Earthquake seismology study
			Earthquake focal mechanisms	10° to 20°	High		Medium	Earthquake seismology study
			Earthquake parameters with respect to seismicity (see PAC 11 for fault parameters with respect to seismicity)	Determine parameters for instrumentally recorded earthquakes in underground facility	High		Low	Earthquake seismology study

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Table 8.3.1.2-17. Parameters addressed by the seismology study (sheet 4 of 4)

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal/needed accuracy	Needed confidence	Current estimate of goal/accuracy	Current confidence	Study/investigation
Probability of faulting in the controlled area study zone	1.8 (PAC 11, 12, 13, 14)	Region	Earthquake rates of deformation		High		Medium to low	Earthquake seismology study
		Region	Historic earthquake records:					Earthquake seismology study
			Locations		High	High		
			Intensities		Medium	Medium		
			Magnitudes		Medium	Low		
			Fault plane solutions		Low	Low		
		Region/Pasco Basin/ Cold Creek syncline/scale/location underground facility	Instrumental earthquake records	See PAC 4				Earthquake seismology study
			Fault parameters with respect to seismicity:	See PAC 4				
			Fault rupture area/dimensions					
			Fault displacement					
			Seismic moment					
			Stress drop					
			Recurrence curves					
		Outside data	Worldwide seismic data					Earthquake seismology study
			Fault/seismic event relationship					
			Potential seismogenic fault characteristics					
			Predicted ground motion					

PAC = Potentially adverse condition.
PM = Performance measure.
M = Magnitude.

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Table 8.3.1.2-18. Parameters addressed by the Tectonic Assessment Study

Performance parameter	Issue	Scale/location	Supporting parameter	Tentative parameter goal/needed accuracy	Needed confidence		Current estimate of goal or accuracy
					Needed	Current	
Probability of fault slip within underground facility	1.1, 1.8, 1.2, 1.3	Layout area	--	<1%	High	Low	Moderate
Probability of fault slip within controlled area study zone	1.1, 1.8, 1.2, 1.3	Controlled area study zone	--	<1%	High	Low	Moderate
Probability of significant* fault slip in region	1.1, 1.8, 1.2, 1.3	Region (Columbia Plateau)	--	<1%	High	Moderate	Moderate
Probability of Cascade Range volcanic activity that could dam Columbia River and change hydrologic regime in Pasco Basin	1.1, 1.8, 1.2, 1.3	Cascade Range	--	<1%	High	Moderate	Moderate

*Faults of location, geometry, and extent such that should slip occur on them, they could potentially affect the ability of the repository to isolate the waste for the required 10,000 yr.

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8.3.1.2.4.1.3 Issues 1.8 and 1.9.

The tectonic events and processes investigation will provide earthquake and tectonic data for the natural system as required to address 10 CFR 60.122 (NRC, 1987) and 10 CFR 960.4 and 10 CFR 960.5 (DOE, 1987) siting criteria as well as data needed to determine the past tectonic/structural development of the controlled area study zone and surrounding area. The latter is required to provide reasonable assurance that the tectonic evolution of the site is sufficiently well understood so as to predict, with reasonable certainty, future events and processes that are relevant and appropriate for assessment of long-term repository performance. Geologic structural data as needed for the geometry of regional and Pasco Basin groundwater flow models will also be provided as boundary conditions to allow the development and analyses of conceptual and numerical groundwater flow models. Earthquake recurrence and source parameter data will be determined to allow estimation of future displacement in the controlled area study zone for both the anticipated and unanticipated cases as needed to assess system and subsystem performance. Past volcanism in the Columbia Plateau and Cascade Range will be assessed so as to predict likely future events and their effects on repository performance.

8.3.1.2.4.1.4 Issue 1.11.

The tectonic events and processes investigation will provide estimates of anticipated and unanticipated displacement for use in design and analyses of engineered barrier systems. These data will be needed to assess the likelihood of premature release of radionuclides from waste packages and to assure retrievability of waste packages during repository operation.

8.3.1.2.4.1.5 Issue 1.12.

The tectonic events and processes investigation will provide estimates of future ground shaking and displacement as needed to assess future performance of repository, shaft, and borehole seals.

8.3.1.2.4.1.6 Issues 2.3 and 2.4.

The tectonic events and processes investigation will provide estimates of expected earthquakes in the controlled area study zone and vicinity so as to predict anticipated levels of ground motions for seismic design and analyses of Q-listed structures, systems, and components of the surface and subsurface environments of the repository. Possible displacements will also be supplied for design of Q-list items.

Potential displacement arising from possible future faulting will be assessed in the tectonic events and processes investigation to determine the impact of such slip on the retrievability of waste from narrow-diameter, waste emplacement boreholes.

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8.3.1.2.4.1.7 Issues 2.7 and 4.1.

The tectonic events and processes investigation will provide structural/tectonic data and potentially disruptive events for use in design as needed to satisfy 10 CFR 60.131 an 10 CFR 60.133. Anticipated levels of vibratory ground motion and displacement as stipulated in Issue 2.3 (above) will be provided for preclosure safety analyses needed for design.

The tectonic events and processes investigation will be used to assess the higher level finding for preclosure conditions relative to the design and constructibility of a nuclear waste repository; i.e., can the repository be designed and built to accommodate the anticipated tectonic conditions with available technology?

8.3.1.2.4.1.8 Issue 4.2.

The tectonic events and processes investigation will address the information needs for Issue 4.2 under the technical guideline on rock characteristics and under the technical guideline on tectonics.

8.3.1.2.4.1.9 Issue 4.4.

Anticipated levels of vibratory ground motion and displacement will be provided for repository design to assure that the technology to construct the repository to accommodate these characteristics is available.

8.3.1.2.4.2 Rationale

The principal technical problem addressed by the tectonic events and processes investigation is the definition of tectonic features, events, and processes that might affect the repository during the preclosure and postclosure periods. This includes the identification and characterization of potential seismogenic structures, the development of tectonic models that explain the tectonic elements and evolution of the elements in the site and region, and the development of seismic design parameters. Discussion of technical considerations used to further organize and focus the studies of the investigation are given below under the description of the individual studies.

This investigation was developed to provide the data and interpretations required to assess the tectonic stability of the site. The topics under consideration include the following:

- Geologic structure as it exists today (static stratigraphic and structural model).
- Deformational history including both styles and rates of deformation based on the interpretation of existing structures.
- Current tectonic stress regime.

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- Probability of earthquake faulting.
- Integrated interpretation of the tectonic data to develop dynamic conceptual models of the tectonic processes of the site and surrounding area.

Conceptual tectonic models will be used as a tool to project tectonic processes and rates into the future to identify and characterize disruptive scenarios. The studies presented under this investigation are interrelated and the development of a tectonic model(s) is iterative, requiring a continuing reassessment of data needs throughout the development. The investigation includes studies to establish the link between potential deformation at the site and the regional tectonic regime.

Three component studies of the tectonic events and processes investigation have been developed to address the design and performance issue parameters related to the tectonic stability of the site. The approach and specific methods within these studies have been developed in response to the nature of the geologic system and pertinent technical considerations. The studies comprising the investigation are as follows:

- Deformation study (Section 8.3.1.2.4.3.1).
- Earthquake seismology study (Section 8.3.1.2.4.3.2).
- Tectonic assessment study (Section 8.3.1.2.4.3.3).

The deformation study is needed to define deformation styles and rates. The geologic history of deformation provides information on past strain distribution at and around the site. Geodetic strain measurements, in situ stress measurements, and Quaternary fault displacement characteristics and rates provide information on the past and current state of stress. The styles and rates of deformation are fundamental to the tectonic stability assessment and to the prediction of structures in the geologic repository operations area and the controlled area study zone.

The earthquake seismology study defines the microseismic patterns within and below the basalt flows as well as the regional macro- and microseismicity. Data collection and analysis reflect the requirements to address both types of seismicity. Earthquake data analysis includes the correlation of seismicity with geologic structures and the determination of surface and subsurface site ground motion from both microseismicity proximal to the repository and potential earthquakes on structures. Earthquake parameters (i.e., stress drop, displacement, and fault area) are determined to support seismic design and safety and to provide parametric data for performance assessment. The characterization of the seismicity of the site and region also is a fundamental element of the overall tectonic stability assessment of the site.

The tectonic assessment study is needed because of the requirement to predict the tectonic stability of the site, identify potential disruptive tectonic and volcanic scenarios, and identify additional parametric data required to characterize those scenarios that may affect the performance of the repository.

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Areas of study or scales for the tectonic events and processes investigation match those of the stratigraphic and structural model study (Section 8.3.1.2.3.3.6) and are (1) the repository site, (2) the controlled area study zone, (3) the Cold Creek syncline, (4) the Pasco Basin, and (5) the region. The approximate areal extents of the five scales are illustrated in Figures 8.3.1.2-32 and 8.3.1.2-33. The term "scale" is used loosely here to mean "level of detail." Mapping of specific structures critical to the tectonic assessment will be conducted at appropriate scales regardless of their location. A discussion on scale applications for structure location and characterization is included in Section 8.3.1.2.3.3.4.

8.3.1.2.4.2.1 Constraints on the investigation.

The principal constraint on the investigation is that the rocks in the controlled area study zone cannot be observed directly except where exposed in the Exploratory Shaft Facility or at the surface, primarily in anticlinal ridges at some distance. Another constraint is imposed by an incomplete Quaternary record in many parts of the study area due to Plio-Pleistocene incision and cataclysmic flooding (see Section 1.1.3) that limits the resolution of timing for the deformation history. These constraints more appropriately affect the organization and conduct of the stratigraphy and structural geology studies of the stratigraphy and structure investigation and are discussed in more detail in Section 8.3.1.2.3.3. However, in summary, geophysical exploration, boreholes, and trenches will address the interpretation of buried structures. Basalt terranes present specific problems in the use of magnetic and seismic exploration methods requiring specialized processing and interpretive methods. Special effort also will be required to develop the Quaternary stratigraphy and lateral correlations and trace potential seismogenic structures to areas where Quaternary strata overlie the structures.

The historical infrequency of even moderate-sized earthquakes in the Columbia Plateau limits the determination of recurrence for events much above magnitude 3 within the Pasco Basin. The low, long-term average rate of deformation limits the detection of contemporary strain because current measured strain is within the range of daily Earth tides and instrumental error of the geodetic surveying equipment. World-wide data on strong ground motions will be used to supplement local ground motion records which are anticipated to be sparse because of levels of instrumentally recorded seismicity.

Seismic monitoring within the controlled area study zone will continue during the drilling of the exploratory shaft. Minimal disruption in earthquake recording is anticipated because the local seismic network was designed to record natural and induced seismicity during drilling of the exploratory shaft and construction of the Exploratory Shaft Facility. Measurement of the hydrologic baseline and conduct of the large-scale hydrologic stress tests will preclude drilling boreholes deeper than Wanapum Basalt for an unspecified period of time before execution of the large-scale hydrologic stress tests. Drilling of deep boreholes will be performed before and, if necessary, after hydrologic stress tests.

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8.3.1.2.4.3 Description of studies

8.3.1.2.4.3.1 Deformation study.

The deformation study addresses performance and design issue parameters relating to the style, age, and rate of tectonic deformation. Thus, the primary objectives of the deformation study are to determine the evolution of existing geologic structures in south-central Washington and to evaluate the potential for future deformation under the present stress field. Sub-objectives of the deformation study include the following:

- Determine the locations and deformation characteristics of geologic structures.
- Determine the mechanisms by which the deformation occurred.
- Determine the ages and rates of past geologic deformation.
- Determine the orientations of past stress fields.
- Determine the nature and rate of present geologic deformation.
- Determine the orientations of present stress fields.
- Develop mechanical models of the deformation.

Six tasks and analyses (Table 8.3.1.2-19) have been developed to fulfill the objectives and sub-objectives of the deformation study. These are listed below and discussed in more detail in succeeding sections of this study description.

1. Location, age, and rate of fault offset and fold growth.
2. Geomorphic analysis of deformation, aggradation, and denudation.
3. Geodetic data analysis.
4. Evaluation of in situ stress state.
5. Structural analysis of deformation.
6. Paleomagnetic analysis.
7. Remote sensing.
8. Synthesis of styles, mechanisms, and rates of deformation.

The tasks and analyses of the deformation study will provide information required to assess the tectonic stability of the site; evaluate the potential for the presence of geologic structures (for example, faults) at the planned site of the repository; estimate the present and future stress regimes;

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Table 8.3.1.2-19. Tasks/tests/analyses for the Deformation Study (sheet 1 of 3)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Location, age, and rate of fault offset and fold growth					
• Analysis of mapped structures	Analysis of geologic maps, trench logs, age determinations, and structures identified in boreholes	CASZ/Pasco Basin/ Region	NA	Geologic maps, trench logs, age determinations, and borehole descriptions	Range of ages for mapped structures and structure contour maps
• Analysis of basalt flow distribution	Interpretation of thickness and distribution of Columbia River basalt flows	CASZ/Pasco Basin/ Region	NA	Thickness measurements from outcrop and from boreholes	Isopach maps, age range of structures for pre-Pliocene, rate of growth of structures, and amount of uplift and subsidence from 17 to 6 m.y.B.P.
• Basin analysis of suprabasalt sediments	Analysis of geologic maps, subsurface borehole and geophysical logs, and laboratory techniques--paleomagnetism, absolute age dates, and tephrochronology	CASZ/Pasco Basin/ Region	NA	Surface sediment maps, subsurface maps, trench logs, age determinations, and stratigraphic determinations	Analysis of post Miocene tectonism in Cold Creek syncline/Pasco Basin Rate of uplift and subsidence from 6 m.y.B.P. to present
Geomorphic analysis of deformation, aggradation, and denudation					
• Analysis of paleo base levels	Analysis of geologic maps, topographic maps, and laboratory techniques--paleomagnetism, absolute age dates, and tephrochronology	Pasco Basin/Region	NA	Locations, elevations, and ages of geomorphic surfaces	Evaluation of evidence for deformation across correlative geomorphic surfaces and of tectonic, climatic, and geomorphic events
• Geomorphic analysis of remote sensing and topographic data	Analysis of Landsat thematic mapper images, Seasat data, U-2 photographs, and geologic spatial analysis	CASZ/Pasco Basin/ Region	NA	Lineament maps, geologic maps, topographic maps, and landform maps	Relationship of lineaments to mapped structures and landforms

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Table 8.3.1.2-19. Tasks/tests/analyses for the Deformation Study (sheet 2 of 3)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
• Probability and effects of isostatic loading by ice sheet or floodwaters	Review of existing literature. Sensitivity analysis. Probability assessment	CASZ/Pasco Basin	NA	Literature	Assessment of probabilities and effects of crustal displacement and likelihood of new fracture networks, crustal movements and seismicity
• Probability and effects of proglacial aggradation in the Pasco Basin	Sensitivity analysis Geologic maps Analysis of future climate model Additional modeling of effects of proglacial aggradation	CASZ/Pasco Basin/Region	NA	Future climate model Geologic evidence for older outwash plains	Amount of glacial fluvial aggradation possible over site Possibility of diversion of Columbia River closer to site
• Sensitivity analysis and effects of incision and new exposures of Grande Ronde Basalt in upland areas	Sensitivity study of groundwater recharge Measurement of amount and rate of downcutting into basalt Input from cataclysmic flood model Analysis of effects of mass wasting Determination of changes in surface recharge	Pasco Basin/Region	NA	Geologic maps, topographic maps, and landform maps Future climatic change model	Sensitivity of groundwater model to increased recharge from new exposures of Grande Ronde Basalt Rates and amounts of incision into sediments and Grande Ronde basalts Analysis of area available for recharge to Grande Ronde Basalt in 10,000 yr
Geodetic data analysis	Trilateration survey	Pasco Basin	One every 3 yr	Changes in line lengths of trilateration network	Rate and direction of current shortening and extension
	Leveling survey	Pasco Basin	One every 3 yr	Changes in leveling line	Rate of current uplift and subsidence
Evaluation of in situ stress state	In situ stress measurements in boreholes; see study plan for in situ stress determination	CASZ	See study plan for in situ stress determination	See study plan for in situ stress determination	Magnitude and orientation of in situ stress

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Table 8.3.1.2-19. Tasks/tests/analyses for the Deformation Study (sheet 3 of 3)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Structural analysis of deformation					
• Observational analysis of deformation	Description, measurement, and mapping of the geometry of geologic structures Observation and description of macroscopic deformation mechanisms	CASZ/Pasco Basin/Region	NA	Description, measurements, and maps of geometry of folds, tectonic joints and fractures, and breccia zones Descriptions of macroscopic deformation mechanisms (e.g., layer-parallel slip or flowage, core disking, and borehole spalling)	Rheological behavior of rock and variation of rheology with structural style Relationship to macroscopic deformation mechanisms and stress-strain responses
• Observational analysis of deformation (cont.)	Observation and description of microscopic deformation mechanisms	CASZ/Pasco Basin/Region	NA	Descriptions of microscopic deformation mechanisms (e.g., microcracking and grain boundary sliding)	
• Paleomagnetic analysis	Field sampling Standard laboratory analysis	Pasco Basin	NA	Declinations and inclinations Geologic maps	Direction and scale of rock movement with respect to geologic structures
• Remote sensing	See structural geology and geophysics study plan	Pasco Basin/Region	NA	Lineaments	Integration of lineament analysis with structural style
Synthesis of styles, mechanisms, and rates of deformation	Input from all tasks	CASZ/Pasco Basin/Region	NA	Data on locations, styles, geometries of structures, age and timing of deformation, growth rates, nature and mechanical analysis of geologic structure growth	Synthesis of styles, mechanisms, and rates of deformation

NOTE: CASZ = Controlled area study zone.
NA = Not applicable.

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predict the magnitude, type, and rate of deformation expected for the 10,000-yr period following emplacement of the waste material; and construct tectonic and geohydrologic models.

Understanding the ongoing geologic deformation of the Hanford Site is required to assess the ability of the geologic system to contain high-level nuclear waste for the next 10,000 yr. The configuration of the geologic units and structural elements changes over time and space in response to the magnitude, distribution, and loading rate of the prevailing stress regime. The prediction of the future types and rates of deformation is based on an understanding of the deformation history and the current stress regime. Therefore, the tasks and analyses described in the deformation study are designed to characterize the past and present types and rates of deformation and to infer the stress regimes and rock properties responsible for the geologic structures.

All of the field investigations described in the deformation study will make use of the geologic maps and cross-sections generated by the structural geology study (Section 8.3.1.2.3.3.4) and the stratigraphic and structural model study (Section 8.3.1.2.3.3.6). The field investigations and analysis of geologic maps may require additional, detailed data collection.

The Quaternary record of deformation is the most significant for determining the type and magnitude of deformation likely during the post-closure period (the next 10,000 yr). This record is not well preserved across most geologic structures in the Pasco Basin. Therefore, the Quaternary record will be evaluated where present, including areas around the site. The record of deformation extending back to the Miocene will also be analyzed to add confidence to predictions of future deformation.

Performance parameters, related to the deformation study, have been identified for the Issue Resolution Strategies (Section 8.2) and are listed in Table 8.3.1.2-16 along with supporting parameters developed specifically for this study. The parameters are listed by the geographic scale or location where their individual confidence goals or accuracy requirements must be satisfied.

In addition to the objectives and parameters, technical considerations specific to the BWIP repository have been identified that help to further organize and focus investigative activities within the tasks of the deformation study. Listed below are these concerns:

- Identification, location, type, extent, and characteristics of Quaternary faults in the controlled area study zone, Pasco Basin, and Yakima Fold Belt (e.g., Gable Mountain faults, Rattlesnake/Wallula alignment, Lind Coulee, Toppenish Ridge, Union Gap).

- Characteristics and tectonic mechanism of microearthquake swarms and location of future swarms with respect to the repository.

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- Location, nature, and rate of tectonic deformation (anticlines and synclines; Ringold Formation overlying basalt in the controlled area study zone).
- Location, type, characteristics, and age of volcanism in region of site and volcanic processes (hazards) that may occur within or affect the site.
- Effects of isostatic loading/unloading of the crust resulting from renewed glaciation or cataclysmic flooding.
- Secondary effects of tectonic processes or deformation (e.g., erosion/aggradation, new or enhanced groundwater pathways).

8.3.1.2.4.3.1.1 Location, age, and rate of fault offset and fold growth. The purposes of this task are to collect data which constrain the ages of geologic structures in the Pasco Basin and surrounding region and to determine the rates of growth of these structures. Special emphasis is placed on the identification of Quaternary faulting. This task will be implemented using three methodologies: analysis of mapped structures, analysis of basalt flow distributions, and basin analysis of suprabasalt sediments.

Previous investigations of the areal distributions and thickness variations of the Columbia River basalt flows have suggested that Yakima folds within the Pasco Basin were growing at the same time that the basalt flows were being emplaced (Caggiano and Duncan, 1983; Reidel, 1984; Chapter 1, Sections 1.3.2.2.1.3, 1.3.2.4.1, and 1.5.2.4.2.3). Thus, deformation appears to have been in progress since the early Miocene. Estimates of the rates of deformation since the early Miocene are discussed in Chapter 1, Sections 1.3.2.2.1.3 and 1.3.2.4.1. Anticlines of the Yakima Fold Belt are described in Chapter 1, Section 1.3.2.2.2.3 and Table 1.3-3. Characteristics of the synclines within the Pasco Basin are summarized in Section 1.3.2.2.2.4.

Secondary structures, such as tectonic fractures, in the Pasco Basin can be seen on the anticlinal ridges, and they may also be present in the adjacent synclines. The characteristics, including age of latest displacement, if any, of these tectonic fractures are listed in Table 1.3-3 and described in Sections 1.3.2.2.2.6 and 1.3.2.2.2.7.

Suprabasalt sediments were deposited in most synclinal valleys of the Yakima Fold Belt and within other structural basins on the Columbia Plateau during late Miocene to Pliocene time. A general discussion of the regional suprabasalt sedimentary units is presented in Sections 1.2.1.3.2, 1.2.1.3.3, 1.2.1.3.4., and 1.2.1.3.5; the characteristics of the suprabasalt sediment within and immediately adjacent to the controlled area study zone are summarized in Section 1.2.2.2.2.

This task will continue the studies of the ages of structures and rates of deformation in the Pasco Basin. The existing data base (see Table 1.3-3) for the Miocene will be expanded to include the structural history from the Miocene to the Quaternary in order to verify the estimates of the style and

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rate of deformation already published (i.e., Reidel et al., 1983; Reidel, 1984; Hagood, 1986; Chapter 1, Sections 1.3.2.2.1.3 and 1.3.2.4.1). Data from individual structures will be analyzed and compared to investigate whether deformation rates have differed for different structures, areas, or geologic time intervals.

The principal geologic methods of investigation include geologic mapping and measurement of stratigraphic sections. Specific areas targeted for mapping and section measurement are discussed in two following subsections, Analysis of basalt flow distributions and Basin analysis of suprabasalt sediments, and in the structural geology study (Section 8.3.1.2.3.3.4). The field analysis may require trenching to increase the area of exposure and to document fault offset, recurrence, and slip-rate. Determination of current locations and rates of deformation will use data on earthquake locations and magnitudes and recurrence rates, fault plane solutions, and fault slip areas (earthquake seismology study, 8.3.1.2.4.3.2). Hence, activities in this task will be coordinated with those of the structural geology study and the earthquake seismology study. The particular design of the data collection will depend on the current results of geologic mapping.

Following are primary data requirements: (1) a well-established stratigraphy, (2) a complete, or as complete as possible, time sequence to constrain the age of deformation as narrowly as possible, and (3) exposures which allow access to sufficient structural information to document the age and rate of deformation of structures.

The principal products of this task will be a series of geologic maps, isopach maps, cross sections, diagrams, trench logs, and photographs that depict the geometry of the geologic structures. The accompanying reports will include estimates of the timing and rates of deformation of these structures, descriptions of the data constraining the evolution of the structures, and an interpretation of the growth history of the structures.

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8.3.1.2.4.3.1.1.1 Analysis of mapped structures

The primary purpose of this activity is to take the data collected on the geologic structure of the Pasco Basin and region (Sections 8.3.1.2.3.3.4.1. through 8.3.1.2.3.3.4.3) and analyze it with respect to siting a repository in the Cold Creek syncline. In addition this study will determine those areas where additional studies of basalt flow distributions and basin analysis of suprabasalt sediments will be carried out. The current status of data collection for the basalts and the sediments, including specific examples of structures and areas to be investigated, is discussed in the next two subsections.

The analysis of mapped structures will also be used to identify critical areas where trenching could provide information to further constrain the ages of fault offset. For example, trench sites that will be used to investigate the age of last movement on a cross fault on Rattlesnake Mountain will be located after analysis of the geological mapping and geophysical surveys conducted within the structural geology study (Section 8.3.1.2.3.3.4).

Trenching will be particularly valuable as an aid in documenting Quaternary offset on both previously mapped and newly mapped faults.

The primary area of concentration for this activity is the Pasco Basin, with emphasis on the controlled area study zone. Areas throughout the region will be examined as needed, after geologic mapping of an area has been completed.

Because this activity will act to support all the geologic deformation investigations, there will be no written product.

8.3.1.2.4.3.1.1.2 Analysis of basalt flow distributions

The primary purpose of this activity is to develop a data base containing information on the areal extents and thickness variations of Columbia River basalt flows on the Columbia Plateau. This information will be used to assess the locations and rates of uplift and subsidence in the Columbia Plateau during the Miocene. The method of analysis will be similar to that used by Reidel et al. (1983) and Reidel (1984). Sources and estimates of error possible in calculating paleostructural relief and assumptions made in estimating uplift rates are outlined by Reidel (1984, pp. 969-973).

This activity will involve the compilation of key Columbia River basalt flow stratigraphic sections from the anticlinal ridges and synclinal valleys. Data from synclinal valleys will be collected primarily from boreholes; data from anticlinal ridges will be collected principally from outcrops but also from boreholes which intersect buried extensions of exposed anticlines (for example, Yakima Ridge).

The status of data collection, including unpublished data, is indicated in Figure 8.3.1.2-35. Priority for data collection will be in the Pasco Basin because it is the principal area of bedrock exposure surrounding the proposed repository site (see Section 1.3.2.2.2). Areas identified for study include Rattlesnake Mountain, Umtanum Ridge, Gable Mountain, and Yakima Ridge. Additional control and verification of results for the Pasco Basin will require investigation of the Columbia Plateau region.

Calculation of growth rates requires information on the absolute ages of the basalt flows. Absolute age dates for Columbia River basalt flows are determined using K-Ar and Ar-Ar dating techniques. Data on the ages of the flows will be acquired by laboratory analysis of selected basalt flows. The selection of exposures to be sampled will be guided by two criteria: (1) the condition of the exposures must be adequate for detection both of possible erosion of basalt flows and of geologic structures across which basalt flows may thicken or thin; (2) the location of the exposures must be adequate to test and verify working hypotheses during data collection. The specific outcrops to be sampled will be determined during field work.

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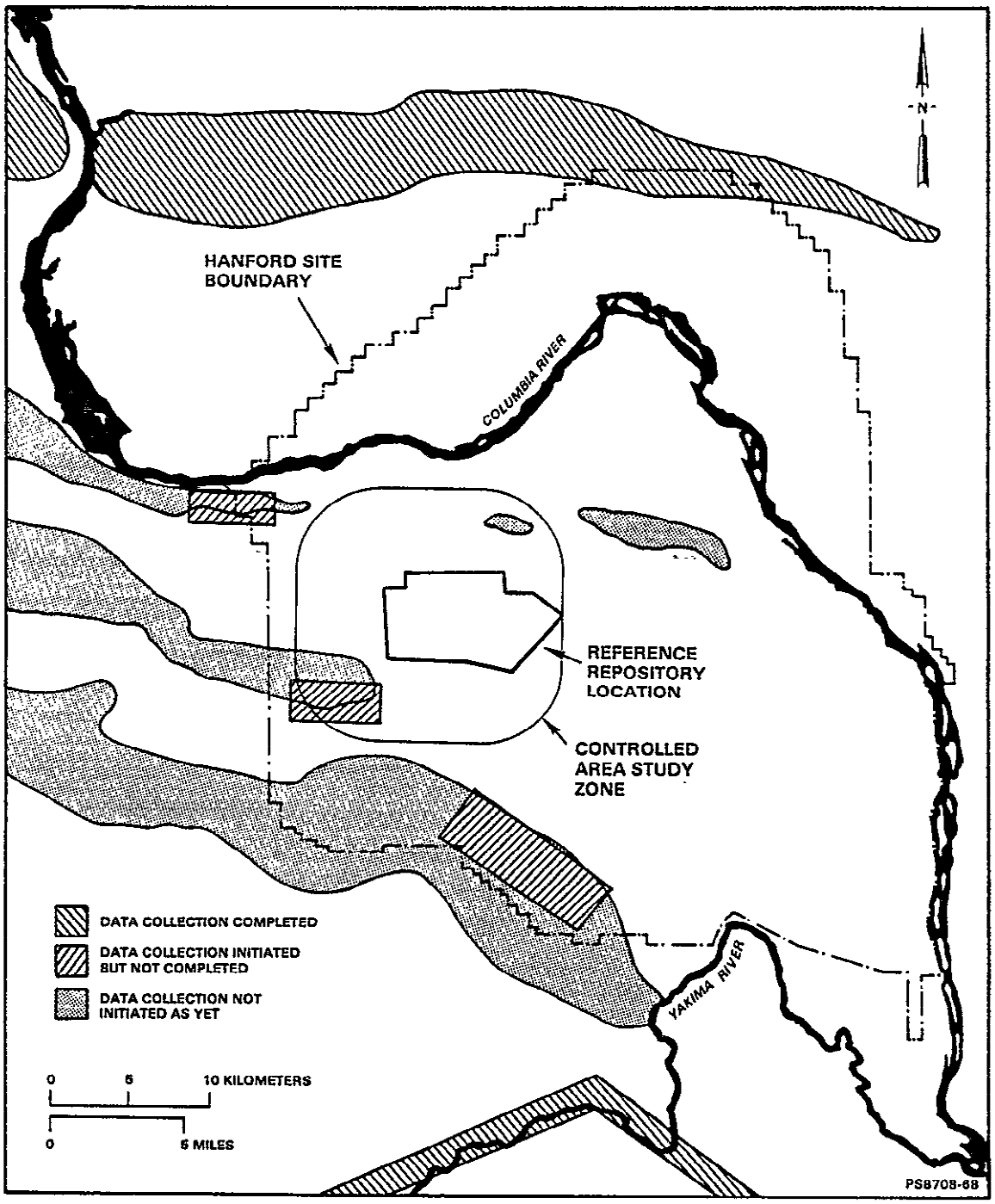

Figure 8.3.1.2-35. Status of area where basalt flow thickness data can be collected from field exposures.

8.3.1.2.4.3.1.1.3 Basin analysis of suprabasalt sediments

The primary purpose of this activity is to determine the deformation history recorded in the suprabasalt sedimentary deposits. This activity complements the analysis, described in the previous subsection, of flow distributions and thickness variations of Columbia River basalts. The basin analysis will be based on outcrop and borehole data identified and discussed in the stratigraphy study (see Section 8.3.1.2.3.3.1). The analysis of the distribution, geometry, composition, texture, and provenance of sedimentary deposits overlying the basalt is designed to accomplish the following: (1) detect evidence of uplift or subsidence of the Pasco Basin since extrusion of the basalt flows; (2) detect the location of buried faults and folds in the Pasco Basin; (3) provide information which can be used to date deformation; and (4) help characterize, correlate, map, and date lithofacies for incorporation into the stratigraphic and structural model.

A basin analysis that incorporates all present and future borehole, geophysical, and analytical data, with emphasis on correlation and dating of sedimentary facies, is needed to adequately constrain location and rates of tectonic deformation. The following data are necessary for a sedimentary analysis of the Pasco Basin: (1) surface sediment mapping, (2) subsurface borehole and geophysical logs, and (3) laboratory analyses (e.g., paleomagnetics, absolute age dates, tephrochronology). Surface and subsurface characterization of sedimentary units has been completed for a few portions of the Pasco Basin (Lillie et al., 1978; Tallman et al., 1979; Myers/Price et al., 1979; Routson and Fecht, 1979; PSPL, 1982; Bjornstad, 1984; Section 1.2.2.2.2) and will be expanded in this study to include all available surface and subsurface data within the Pasco Basin.

The two activities described in the following subsections are designed to address the age and rate of deformation recorded by the suprabasalt sediments: (1) correlation of subsurface boreholes to obtain data on thicknesses, distributions, and types of sedimentary deposits which will be interpreted in light of paleodrainage patterns and evidence for past tectonic, geomorphic, and climatic events affecting the Pasco Basin; (2) evaluation of post-Miocene deformation rate represented in the White Bluffs.

8.3.1.2.4.3.1.1.3.1 Subsurface borehole correlation. Correlation of suprabasalt sediments will be performed on all boreholes within the Pasco Basin, as discussed in the stratigraphy study (see Section 8.3.1.2.3.3.1). Data on thicknesses, distributions, and types of sedimentary deposits will be interpreted in light of paleodrainage patterns and evidence for past tectonic, geomorphic, and climatic events affecting the Pasco Basin. The results of these analyses will be integrated with geophysical data to differentiate stratigraphic discontinuities of nontectonic origin, such as erosional features or facies changes, from those of tectonic origin, such as faults and folds. Where tectonic deformation is suspected, sites will be located for verification boreholes that would provide data to constrain the timing and rate of deformation.

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8.3.1.2.4.3.1.1.3.2 Evaluation of deformation. Deformation within the Pasco Basin has persisted--either continuously or episodically--from the Miocene to the present (Reidel et al., 1983, p. 5-1 to 5-19; Reidel, 1984, p. 966-973; Bjornstad, 1985; Section 1.3.2.4.1). At the present time, however, it is not possible to establish a post-Miocene rate of deformation using the suprabasalt sediments because of a lack of traceable marker horizons and reliable age dates.

The White Bluffs, a series of cliff exposures of Pliocene Upper Ringold sediments along the Columbia River in the Pasco Basin (Fig. 8.3.1.2-36), is a potential site for assessing a rate of late Neogene deformation. First, however, it must be demonstrated that sedimentation of the upper Ringold was the result of relatively continuous deposition within a downwarping basin. Deformation of the upper Ringold unit will be evaluated based on the results of age dating and geologic mapping performed as part of the structural geology study (see Section 8.3.1.2.3.3.4).

8.3.1.2.4.3.1.2 Geomorphic analysis of deformation, aggradation, and denudation. The purpose of this task is to use geomorphic studies to analyze evidence of tectonic deformation, to predict future sediment aggradation, and to assess rates of denudation within the Pasco Basin. This task will be implemented using five activities: (1) analysis of paleo base levels; (2) geomorphic analysis of remote sensing and topographic data; (3) probability and effects of isostatic loading by ice sheets or floodwaters; (4) probability and effects of proglacial aggradation in the Pasco Basin; and (5) sensitivity analysis and effects of incision and new exposures of Grande Ronde Basalt in recharge areas.

8.3.1.2.4.3.1.2.1 Analysis of paleo base levels

This activity is designed to examine evidence of former base levels in and adjacent to the Pasco Basin (discussed in Chapter 1, Section 1.1.3.4). Evidence for former base level may be preserved as low-relief planar surfaces on the flanks of Yakima folds (Waters, 1955, pp. 676-678) or as elevated terraces along rivers and streams. For example, the elevated, truncated alluvial fans along the walls of the Columbia River Gorge may represent talus deposits that developed at a time when the paleodrainage was adjusted to a higher base level.

An evaluation of the history of base level is also possible for the suprabasalt sediments where there are significant erosional unconformities or weathered horizons (paleosols) in the stratigraphic record. If unconformities and paleosols can be correlated within and adjacent to the Pasco Basin, they may reveal the nature and cause of base level change. Therefore, reconnaissance studies of Ringold-equivalent Pliocene deposits in adjacent basins, especially downstream in the Umatilla Basin and the Columbia River Gorge, will be investigated for evidence of base level change.

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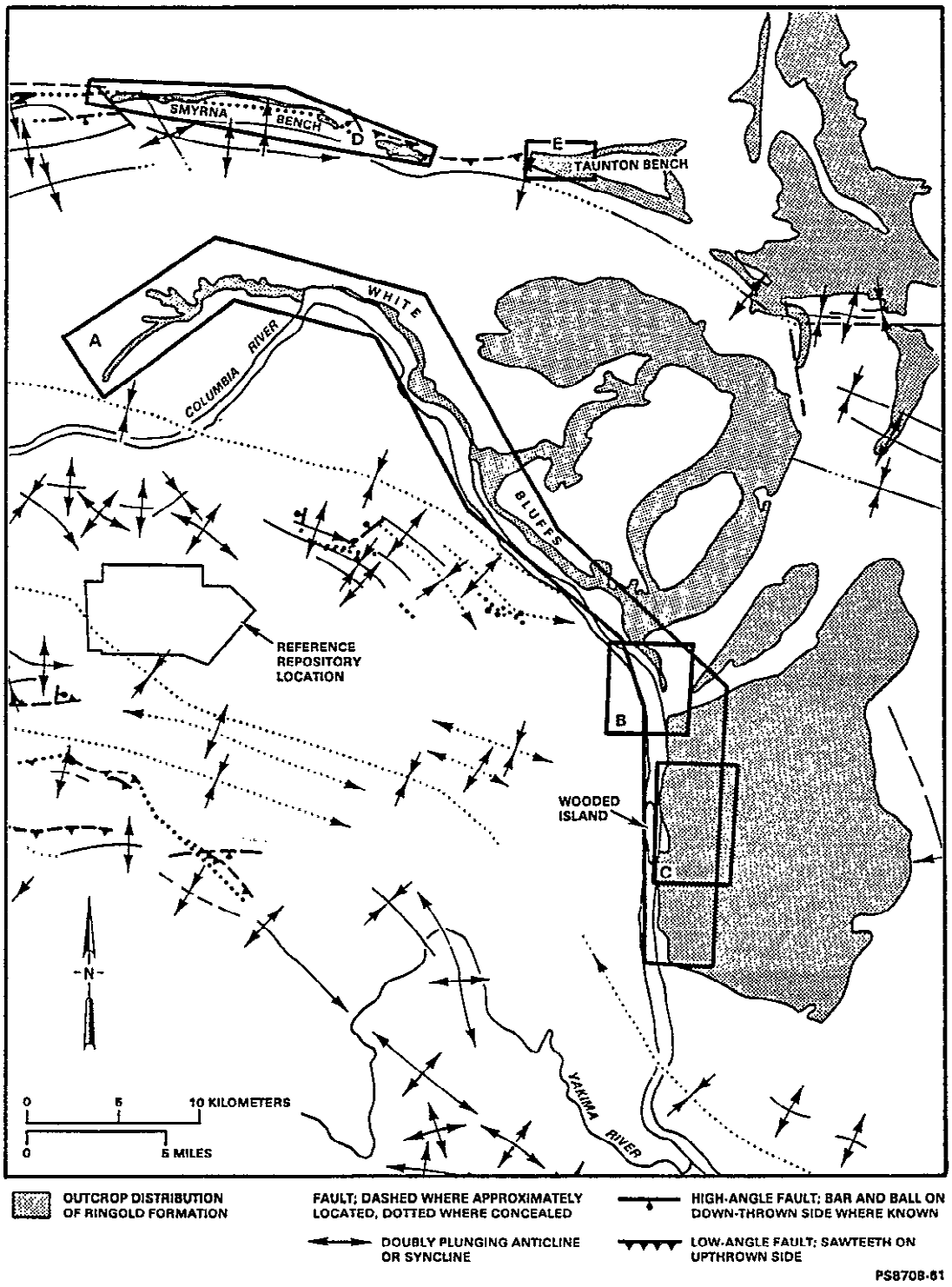

Figure 8.3.1.2-36. Location of the White Bluffs.

8.3.1.2.4.3.1.2.2 Geomorphic analysis of remote sensing and topographic data

The purpose of this activity is to aid in the mapping and location of tectonic features based on analyses of remote sensing and topographic data. Evidence for vertical tectonic features (for example, tectonic joints and faults) may appear as lineaments on Landsat Thematic Mapper (TM), side-looking airborne radar (SLAR) and Seasat data, high altitude photographs, and other types of remote sensing. As well as forming a basis for lineament analysis, these images will be used to construct a detailed stream-drainage-network map for the Pasco Basin and adjoining areas. Stream drainage anomalies (for example, knickpoints, offset drainages, linear stream segments) identified on this map will be evaluated to determine (1) their possible relationships to previously mapped structures; (2) their longitudinal and cross-sectional profiles; and (3) associated fluvial landforms.

The use of air photos and stream drainage anomalies is limited to locating vertical or near-vertical tectonic structures. However, a method based on digitized topographic and remote sensing data has recently been developed which can detect both vertical and non-vertical, coplanar features (Eliason and Thiessen, 1986). This method, referred to as geologic spatial analysis (GSA), will be used to detect and analyze discontinuities in three dimensions near the surface within the Pasco Basin.

8.3.1.2.4.3.1.2.3 Probability and effects of isostatic loading by ice sheet or floodwaters

This activity is designed to evaluate effects such as uplift, subsidence, faulting, and seismicity resulting from isostatic loading of the Pasco Basin. Isostatic loading could be caused by the advance and retreat of an ice sheet in or near the Pasco Basin or by the rapid filling and draining of the Pasco Basin with proglacial cataclysmic floodwaters. Tectonic movement and seismicity may be associated with rapid deglaciation (Morner, 1978, pp. 41-45; Lagerbach and Henkel, 1979; Stephansson and Carlsson, 1980, p. 327); isostatic adjustment may occur as rebound in areas formerly glaciated (Brotchie and Sylvester, 1969, p. 5240; Morner, 1980, p. 251) or as forebulging followed by subsidence around the periphery of an ice sheet (Cathles, 1980, pp. 11-14; Clague, 1983, p. A-12). The glacial and proglacial activity of the Columbia Basin subprovince is discussed in Section 1.1.3.3.

The activity will address deformation induced by a potential advance and retreat of the Cordilleran ice sheet over the next 100,000 yr. The maximum extent of the Cordilleran ice sheet in the late Pleistocene is marked by the Withrow Moraine, which lies approximately 110 km north of the Pasco Basin. However, future ice sheets may extend further south. Therefore, the geologic effects of isostatic loading of the Pasco Basin by a continental ice sheet near the repository site will be modeled by assuming the maximum extent and thickness of an ice sheet over the next 100,000 yr as derived from future climatology studies.

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The analysis will begin with a review of the existing literature on the reported effects of glacially induced isostatic movements in Canada and Fennoscandia (e.g., Morner, 1980) as an analog for the Pasco Basin. Then various scenarios--isostatic rebound due to loading by an ice sheet, peripheral bulging around an ice sheet, and isostatic effects due to rapid loading and unloading by proglacial floodwaters--will be modeled to assess their effects on the Pasco Basin.

Most of the data required to evaluate the potential for glacially-induced isostatic adjustment within and near the Pasco Basin is in the literature (e.g., Brotchie and Sylvester, 1969; Waitt and Thorson, 1983). Response of the layered sequence of Columbia River basalt flows and sedimentary interbeds to isostatic loading will be modeled with information from rock mechanics studies and structural analysis of deformation (Section 8.3.1.2.4.3.1.5). There is no evidence to suggest that fractures or faults within the Pasco Basin are directly or indirectly related to glacially induced loading. However, there has been no attempt to differentiate fractures or faults of endogenetic origin (regional tectonic compression associated with Yakima fold development) from those of possible exogenetic origin (loading by ice or floodwaters).

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8.3.1.2.4.3.1.2.4 Probability and effects of proglacial aggradation in the Pasco Basin

The effects of future glacially derived sedimentary deposits in the Pasco Basin will be evaluated to assess the possibility of aggradation of a proglacial outwash plain leading to diversion of the Columbia River into the Cold Creek syncline. Much of the information required to perform this evaluation will be gathered through the modeling of future climates over the next 100,000 yr described in the future climate study. The data will provide input to the model of regional groundwater flow.

8.3.1.2.4.3.1.2.5 Sensitivity analysis and effects of incision and new exposures of Grande Ronde Basalt in recharge areas

This activity is designed to provide information on the expected changes due to continued fluvial incision and denudation (mass-wasting, weathering, and erosion) of anticlinal ridges in the Pasco Basin (see Sections 1.1.3.4 and 1.1.3.6). The study of denudation in upland areas, however, will be implemented only if a sensitivity study shows that groundwater movement through the deeply confined aquifers would be adversely affected by the denudation-induced changes in the location and amount of surface recharge. This additional study will include measuring the amount and rate of downcutting into Saddle Mountains Basalt on Yakima folds; determining the relationship of downcutting to the slope, elevation, and relief along ridges; analyzing the effect of mass-wasting; and, finally, providing data on changes in surface recharge for the regional groundwater flow model.

Long-term rates of denudation in upland areas around the Pasco Basin can be determined from measurements of downcutting estimated from topographic and geologic maps. If it appears that downcutting over the next 100,000 yr could alter the deep groundwater flow system, then additional analyses will be performed to determine likely locations and amounts of recharge in upland areas.

Estimation of short-term rates of denudation may not be possible due to the incomplete stratigraphic record and lack of dated sedimentary deposits overlying basalt on ridges. However, the established stream drainage network will probably continue to erode in its present position over the next 100,000 yr. Therefore, the amount of downcutting and its relationship to slope, relief, and elevation may provide information sufficient to reliably estimate relatively short-term changes to the ridges due to headward erosion as well as to valley widening and deepening.

Dramatic short-term changes resulting from massive landslides on Yakima folds could expose large new areas to surficial processes and lead to changes in groundwater recharge. Therefore, an understanding of the relationship of landslides on Yakima fold ridges to topography, structure, and climate may be required to predict the size and location of future landslides.

The analysis of denudation may ultimately require a model that can predict landform evolution and identify areas where new exposures of basalt may be uncovered, either from fluvial incision or mass wasting processes, over the next 100,000 yr. These data, combined with structural data (for example, attitudes of bedding, fractures, faults) for the basalt flows, will provide input to the model of regional groundwater flow.

Uncertainties associated with this analysis include those inherent to predicting erosion based on limited observations and an incomplete stratigraphic, structural, and geomorphic record.

<u>8.3.1.2.4.3.1.3 Geodetic data analysis</u>. The purpose of the geodetic data analysis is to determine current rates of crustal deformation by measuring temporal changes in the horizontal and vertical positions of fixed points in the vicinity of the controlled area study zone. Following are two types of surveys that will be conducted: (1) trilateration surveys to determine the current rate of horizontal movement and (2) leveling surveys to determine the current rate of vertical movement. Both studies will be performed and reported on by the USGS at 3-yr intervals.

The Hanford geodetic system consists of a trilateration network in the Pasco Basin and a leveling line across the Cold Creek syncline. Discussions of the geodetic survey system and measurements at the Hanford Site are described in Sections 1.3.2.3.2 and 1.3.2.4.2, and by Rohay and Davis (1983, pp. 6-21 to 6-29).

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Geodetic surveys in the Pasco Basin and Hanford Site are designed to determine the following:

1. Whether horizontal and vertical changes in monument position are consistent with deformation patterns determined from geologic and seismologic evidence. The answer has implications involving the continuity in style and rates of deformation since the mid-Miocene, which influences predictions for future conditions at the site.

2. Whether the results of the geodetic survey can be correlated with recent seismicity. This analysis may aid in identifying seismogenic structures or zones.

The following description contains the plans for continued surveillance of the existing trilateration network and leveling line at the Hanford Site.

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8.3.1.2.4.3.1.3.1 Trilateration surveys

The 19-station, 29-line Hanford trilateration network, shown in Figure 8.3.1.2-37, extends across the Pasco Basin. The changes in line length of the trilateration net that have been measured since 1972 are of the same order of magnitude as the precision of the methods and instruments (Prescott and Savage, 1984, p. 4; and Section 1.3.2.4.2). Consequently, additional surveys, over a longer period of time, are needed to determine if the magnitude of geodetic strain represents current deformation or remains within instrumental errors.

In addition to the main Hanford network, three small triangular networks were installed in 1980 along the Wallula fault system to the east of Wallula Gap (Fig. 8.3.1.2-38). These small networks were designed to detect horizontal changes along this major structural feature in the geologic setting. They were surveyed in 1981 and 1983, and while some changes in line length were noted, no well-defined pattern could be discerned (Prescott and Savage, 1984, p. 6). Additional surveys of these more recently installed monuments are required before the data can be reliably interpreted.

8.3.1.2.4.3.1.3.2 Leveling surveys

Leveling surveys have been conducted by the USGS along a line of bench marks in the central Pasco Basin from Snively Basin across the Cold Creek syncline (which includes the controlled area study zone and geologic repository operations area) to Gable Mountain/Gable Butte (Fig. 8.3.1.2-39). This line was established and surveyed in 1982 and 1983 to first-order standards, but technical problems, including the need to reset several bench marks during the 1983 survey, prevented unequivocal interpretation of these initial results. A baseline for future leveling surveys is now believed to exist, and a data base can now be developed to determine the amount of vertical movement occurring today (Prescott and Savage, 1984, pp. 22-24; Section 1.3.2.4.2).

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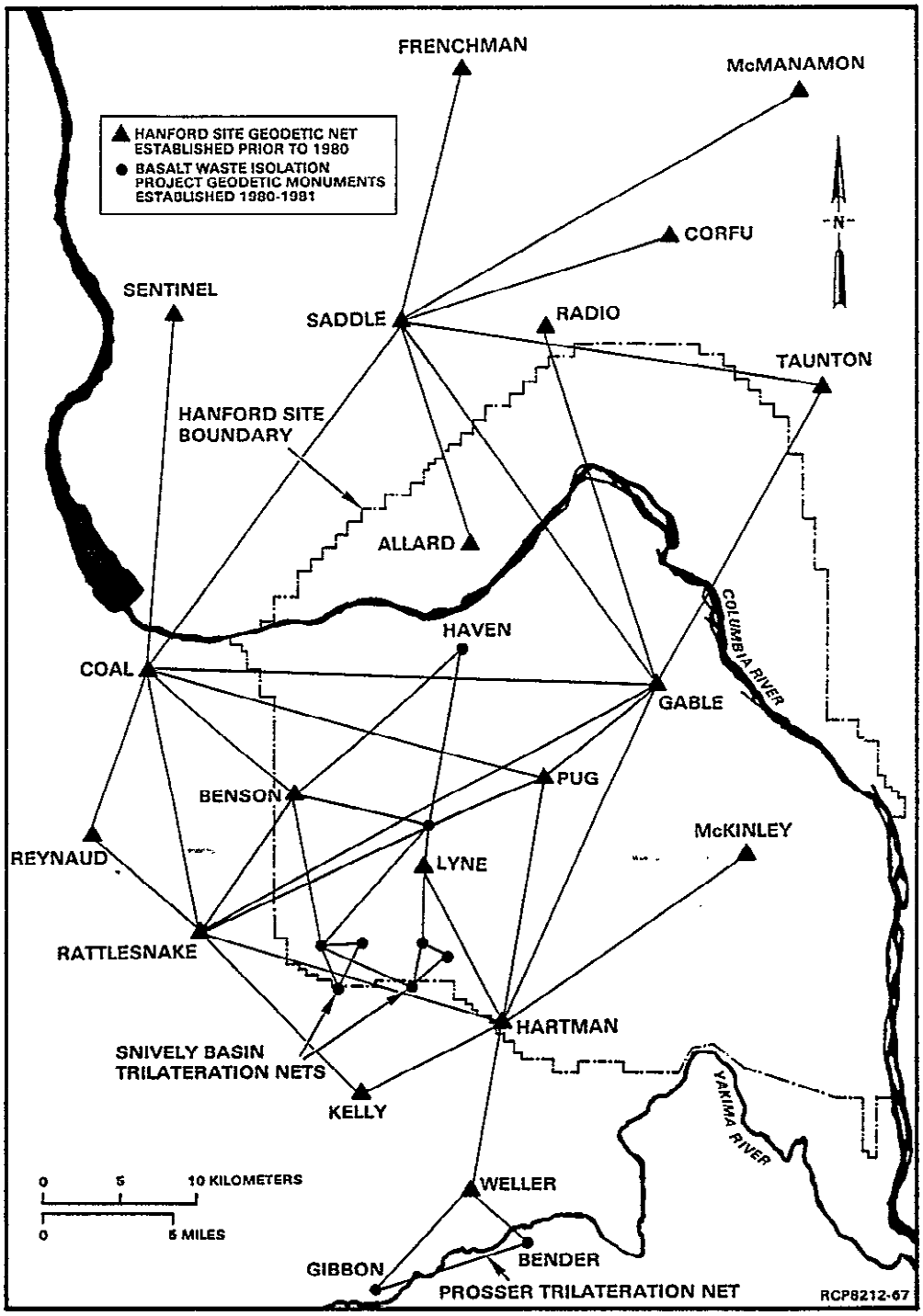

Figure 8.3.1.2-37. Location of Hanford trilateration survey lines across the Pasco Basin.

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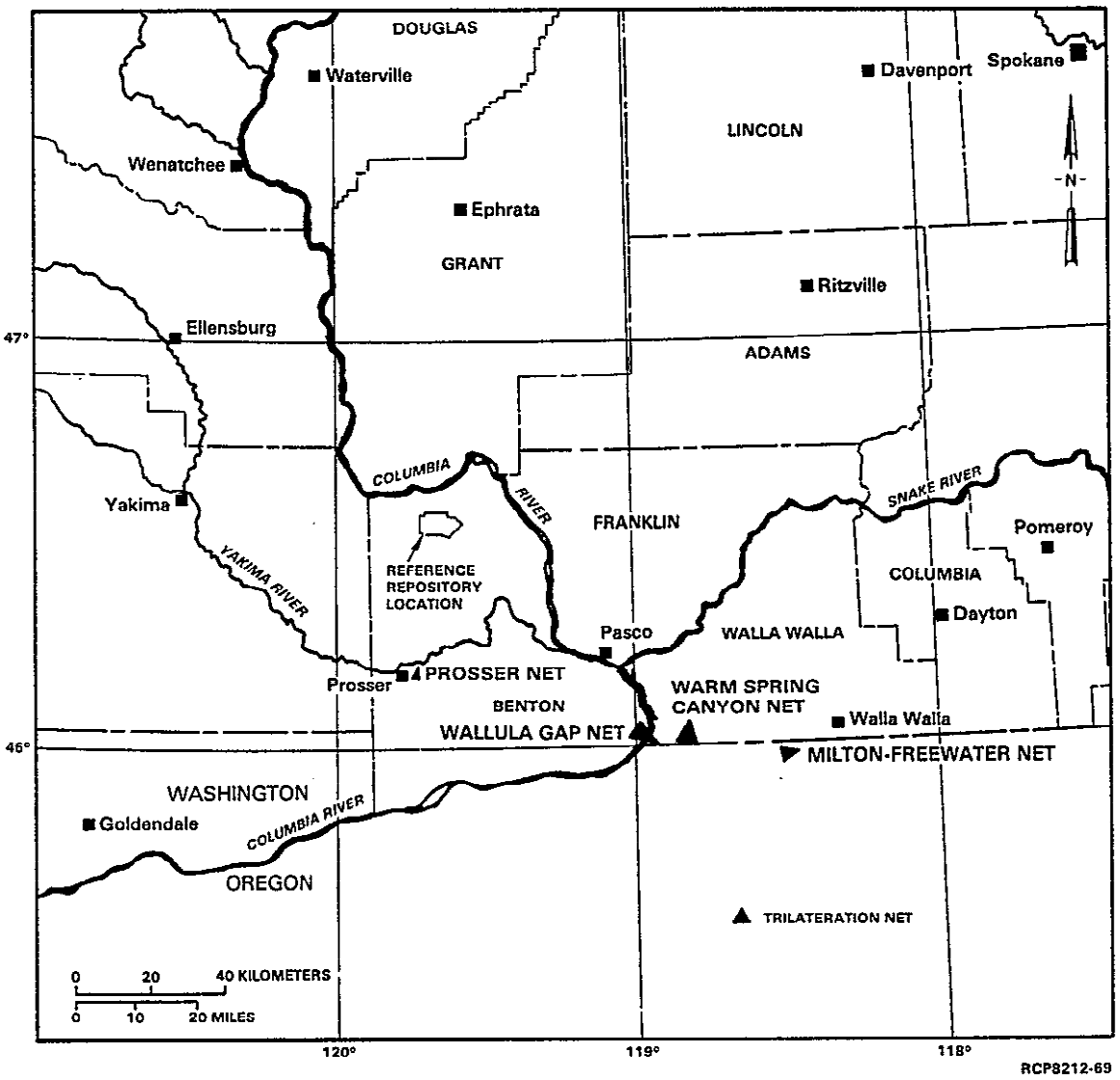

Figure 8.3.1.2-38. Location of three small trilateration survey networks along the Wallula fault system.

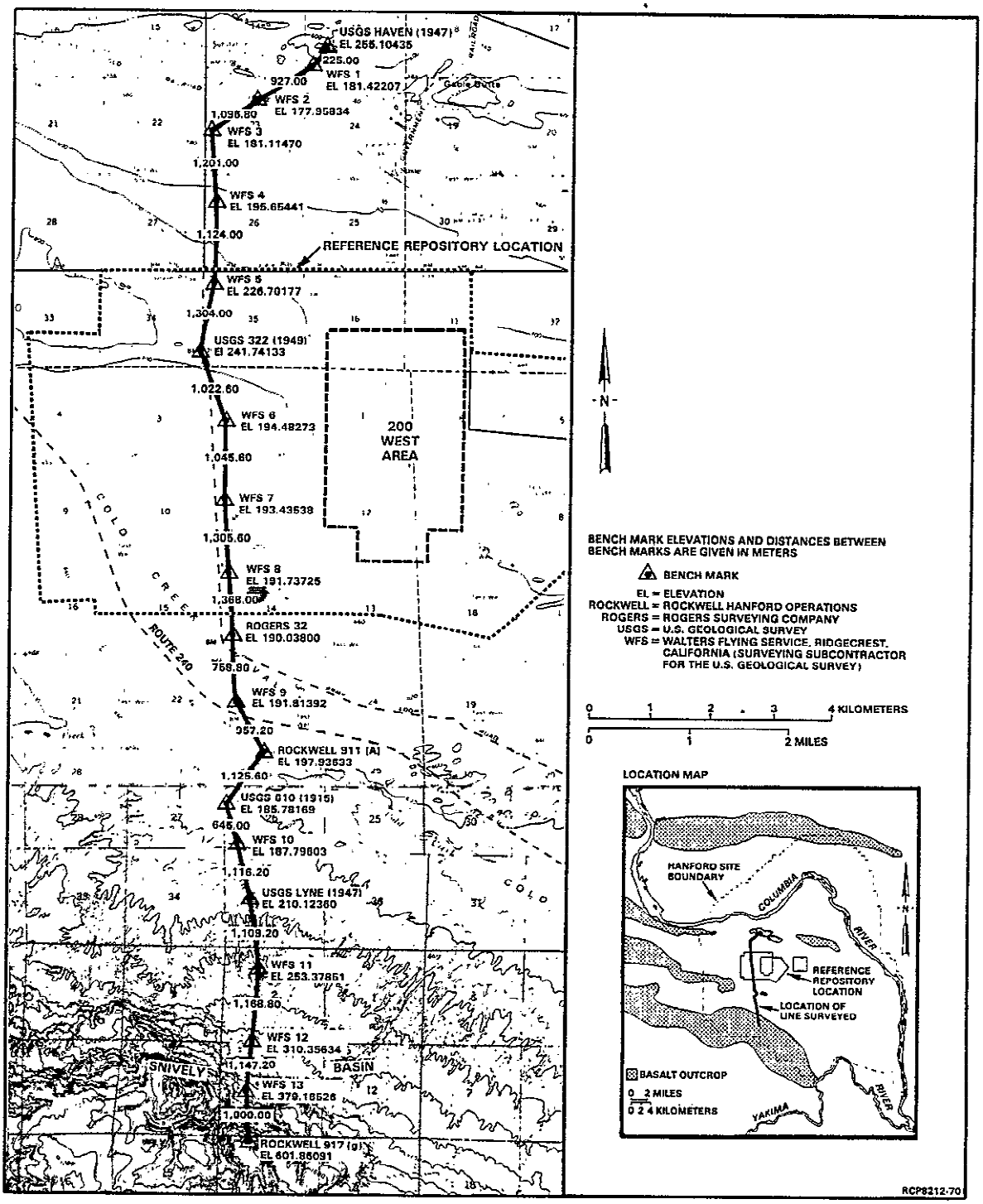

Figure 8.3.1.2-39. Location of leveling survey line across the Cold Creek syncline.

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8.3.1.2.4.3.1.3.3 Planned geodetic surveys

The USGS has recommended an interval of 3 yr for surveys of the trilateration network and leveling line at Hanford (Prescott and Savage, 1984, p. 24). The trilateration network will be surveyed using the standard geodetic method employed by the USGS in the previous surveys (Savage and Prescott, 1973; Prescott et al., 1979; Savage et al., 1981). In addition, all of the network stations will be occupied with Global Positioning System (GPS) receivers. For the leveling surveys, elevation differences among bench marks are obtained using a spirit level.

The horizontal changes observed during an eleven-year interval in trilateration data are comparable (within an order of magnitude) to rates deduced both from geologic evidence since the late Miocene and from current seismicity. However, the changes observed in the trilateration survey are also the same order of magnitude as the level of accuracy associated with instrumental and systematic errors and therefore should not be viewed as evidence for current deformation. Application of new technology in surveying and a longer period of network surveillance are required to reduce this uncertainty.

8.3.1.2.4.3.1.4 Evaluation of in situ stress state. The in situ stress evaluation task is designed to determine in situ stress magnitudes and orientations in the controlled area study zone and at additional locations as required for determination of the regional stress field. This study will be carried out by rock mechanics and is described in detail in the study for in situ stress determination (Section 8.3.1.5). The existing stress regime is discussed in detail in Section 2.6 and summarized in Section 1.3.2.3.

Determination of the natural in situ stress will provide information on the present-day stress field in the controlled area study zone. Study of the geologic deformation will provide qualitative evaluation of both the past and present regional stress fields. Integration of the results of studies for in situ stress evaluation and geologic deformation is discussed in a following section.

Data obtained on the in situ stress state will be used in interpretation of the tectonic regime for the Columbia Plateau. Development of tectonic models which are consistent with in situ stress determinations and analyses of geologic deformation, earthquake seismology, and tectonic activity are described in the tectonic assessment study (Section 8.3.1.2.4.3.3).

8.3.1.2.4.3.1.5 Structural analysis of deformation. This task is designed to identify and measure the magnitude and mechanisms of deformation. Field observations will be used to deduce the rheology of the affected rocks, to constrain the orientation of the principal stresses at the time of deformation, and to determine the boundary conditions on the deformation processes. Determination of rheology, tectonic boundary conditions, and structural geometries are required for numerical models. Previous structural analyses and studies of deformation mechanisms are described in Section 1.3.2.2.2.7.

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Three environments--the anticlinal ridges surrounding the Pasco Basin and Cold Creek syncline, the intervening synclinal areas, and the relatively undeformed areas on the Palouse Slope to the east--will be examined. The anticlines exhibit the greatest degree of deformation and contain the most complete exposures, allowing direct measurements to be made in the field. Structures are poorly exposed in the synclines and, therefore, will be studied via boreholes, the exploratory shaft and breakout area, and analog areas. Exposures on the Palouse Slope are provided by the Snake River and by channels scoured by glacial floodwaters.

Data for these analyses will be collected primarily as part of the structural geology study (Section 8.3.1.2.3.3.4). Additional data, which will provide further detail, will be collected as part of the deformation study. The first activity of this task of the deformation study is to determine what additional detail is required and which field localities are suitable for providing access to it.

Three activities used to gather data and analyze deformation are observational analysis of deformation, paleomagnetic analysis, and remote sensing. Observational analysis entails detailed field observations, descriptions, and measurements of geologic structures, deformation mechanisms, and strain distributions. The field observations are required in order to assess the roles played by different deformation mechanisms during formation of the structures. Paleomagnetic analysis includes the collection of rock samples for measurement of the inclination and declination of the paleomagnetic pole in a rock body. The measured pole position is then compared to the reference pole position to determine any relative rotation of that rock body. Remote sensing can detect joints, faults, and other lineaments. Lineament patterns can be interpreted to infer the orientations of the local and regional stress field.

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8.3.1.2.4.3.1.5.1 Observational analysis of deformation

Observational analysis involves the identification, description, measurement, and interpretation of the geometries and deformation mechanisms associated with geologic structures in the vicinity of the Pasco Basin. This activity includes the following:

1. The description, measurement, and mapping of the geometries of geologic structures, including folds, tectonic joints and fractures, and breccia zones. Geologic structures available for field study are primarily anticlines of the Yakima Fold Belt, which are exposed at the scale of the Pasco Basin. Mapping of these Pasco Basin geologic structures will help guide investigation of structures in the controlled area study zone and in the Columbia Plateau region. Specific anticlinal ridges to be studied include the Yakima Ridge, Umtanum Ridge, Gable Mountain-Gable Butte, and Rattlesnake Hills.

Special attention will be paid to accurate determination of the geometries of the folds. Detailed investigation will include the description and mapping of any smaller-scale structures, such as folds or faults, occurring in the folded basalt layers or sedimentary interbeds. Dimensional parameters relevant to mechanical analyses--such as thicknesses of structural units, compositions of individual layers composing the structural units, and wavelengths and amplitudes of folds--will be measured.

Tectonic fractures, faults, and joint sets in the controlled area study zone will be studied by investigating analogous areas with suitable rock exposures, by observing oriented cores in the Cold Creek syncline, and by observing the exploratory shaft and underground facilities. The synclinal area near Vantage, Washington, is presumed to be structurally analogous to the Cold Creek syncline (Chamness and Tolan, 1983). Mapping tectonic fractures at Vantage and in the exploratory shaft exposures will be conducted as part of the structural geology study (see Section 8.3.1.2.3.3.4).

Zones of platy jointing have been observed in the Cohassett flow in outcrops on the flanks of anticlines but have not been detected in cores taken from synclines within the Pasco Basin. Characterization and descriptions of these zones will be provided by the intraflow structure study (Section 8.3.1.2.3.3.2). Analysis of this information will focus on understanding the origin of platy jointing and, in particular, determining whether platy jointing is a primary or secondary feature of the flow.

2. Observation and description of macroscopic deformation mechanisms, such as layer-parallel slip or flowage of relatively incompetent interbeds. Price (1982) and Barsotti (1986) studied some of the anticlinal ridges in the Pasco Basin. They concluded that the deformation mechanisms consist of localized intra-layer and limited layer-parallel faults and other shear zones, tectonic joints, and shatter breccias and that the distribution and orientation of each deformation mechanism is systematically related to its position on the fold (Section 1.3.2.2.2.7).

   This activity will expand the studies that were begun by Price (1982) and Barsotti (1986) on Umtanum Ridge to other anticlinal ridges and to synclinal valleys, if possible. The field work will be designed to identify deformation mechanisms; to determine if certain deformation mechanisms are characteristic of certain structures, rock types, multilayered sequences, or structural domains; to determine whether the deformation mechanisms are localized as deformation bands; and to determine if different deformation mechanisms were active at different stages in the evolution of the structures.

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Deformation mechanisms are an indication of the rheological behavior of the rocks during deformation. The information on deformation mechanisms will be analyzed to determine the rheology of the rocks and how the rheology varied with structural style of deformation or with changes in boundary conditions. By understanding how the multilayer and the individual component layers of rock deform, the likelihood of various deformation mechanisms--such as faults--at depth may be predictable.

Deformation mechanisms in synclines can be studied in part by observing the boreholes and drill core. Both may fracture in response to stress: the core may fracture, apparently as the result of preferential stress relief, into saddle-shaped disks approximately normal to the axis of the core; the borehole may fracture, as a result of stress redistribution about the borehole, such that the hole becomes elongated in the direction of maximum stress concentration around the hole. These two stress-related phenomena--core disking and borehole spalling--are being studied by rock mechanics because they are thought to be indicators of high in situ stresses. They may also be of value as deformation mechanisms indicating rheology of the rocks under those high stress conditions. Evaluation of the horizontal and vertical variability of core disking and borehole spalling will be coordinated with the studies in the study for in situ stress determination (Section 8.3.1.5). Core disking and borehole spalling are described in Section 2.6.2.1, and briefly in Section 1.3.2.3.4.

3. Observation and description of microscopic deformation mechanisms, such as microcracking or grain boundary sliding. Understanding the mechanisms by which a rock layer responds to deformation on a microscopic scale is important for these reasons:

   a. Microscopic deformation mechanisms may reveal a systematic relationship to the macroscopic deformation mechanisms.

   b. Microscopic deformation mechanisms provide a link between the stress-strain curves determined for rock samples in the laboratory and the macroscopic deformation mechanisms observed in the field.

<u>8.3.1.2.4.3.1.5.2 Paleomagnetic analysis of deformation</u>

The purpose of this activity is to provide a method independent of the observational analysis for determining the location and magnitude of strain in geologic structures. This activity will complement the observational analysis by providing a resultant vector in a rock body that can be used to determine the relative rotation of that rock body as a result of geologic deformation.

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Data have been collected for Saddle Mountains Basalt and Wanapum Basalt, primarily from the anticlinal ridges but also from the synclinal valleys. These paleomagnetic data are discussed in Chapter 1, Section 1.3.2.2.2.7. Future data collection will be directed toward detailing the pattern of current information and adding data from the Grande Ronde Basalt.

Collecting additional data will serve two purposes. Establishing greater detail for the present paleomagnetic data set will provide tighter control on the pattern of deformation that has been observed (Reidel et al., 1984; Barsotti, 1986) and thus better constrain the model of the deformational history of the fold belt. Expanding the paleomagnetic data base to include the Grande Ronde Basalt will also provide information on the effect of deformation on rock units older than those presently sampled and will provide information on deformation in a rock unit that lacks sedimentary interbeds between flows.

8.3.1.2.4.3.1.5.3 Remote sensing analysis of deformation

Remote sensing images of lineaments will be collected as part of the structural geology study (Section 8.3.1.2.3.3.4). That study is designed to detect patterns of lineaments and to determine if the patterns vary significantly with structural domain, rock type, rock age, type of structure, or position on a structure. The data will be considered for use in interpreting orientations of past local and regional stress fields.

8.3.1.2.4.3.1.6 Synthesis of styles, mechanisms, and rates of deformation. The purpose of this task is to integrate the results of the previous tasks and analyses of the deformation study into a deformational history of the Pasco Basin and Columbia Plateau region. Such a history will outline the locations and rates of deformation from the Miocene to present and will provide a basis for predicting the existence of structures at depth and the locations and rates of future deformation. This deformational history will be used to constrain the structural geology model of the Pasco Basin and the regional tectonic models of the Columbia Plateau.

Information from each task of the deformation study will be used to construct a deformational history for a particular structure or area. The deformational history will consider both vertical (uplift or subsidence) and horizontal (shortening or extension) displacements. The combination of individual deformational histories will outline the variation of deformation throughout the region over time.

A prediction of future deformation can be made by numerical analysis of mechanical models of the Pasco Basin. The models require information on structural and stratigraphic geometries, material properties and mechanical roles played by deformation mechanisms, and tectonic boundary conditions. The models would investigate the response of the layers to various boundary conditions as functions of their rheologies and thicknesses. The initial conditions might be chosen to represent the Miocene configuration of geologic units and inferred stress field. Allowing these rock layers to deform in response to the applied stresses should produce the location and geometry of

the structures observed today. The processes by which the layers deform should be consistent with the field evidence of deformation mechanisms and the current deformation modes recorded by geodetic surveys and studies of earthquake seismology (Section 8.3.1.2.4.3.2). In addition, the local stresses calculated in the model should correspond to the in situ stresses. Simulation by the model of the observed orientation and geometry of structures would lend credence to a projection of the location and geometry of structures expected in the future.

The several different approaches to determining deformation rates--geologic evidence, current seismicity, and geodetic surveys--are characterized by different time and space scales. This variation in the resolution of information complicates direct comparison of the results of these different analyses. Furthermore, the intervals of time for which predictions of future conditions at the candidate site must be considered are intermediate between the time scales for geologic evidence on the one hand and geodetic and seismologic evidence on the other. This scale difference will cause an inherent uncertainty in predictions based on either type of data.

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8.3.1.2.4.3.2 Earthquake seismology study.

The earthquake seismology study addresses performance and design issue parameters relating to earthquake characteristics of the site and region. As such, the primary objective of the earthquake seismology study is to provide site-specific data on the magnitudes, spatial distribution, and rate of earthquake occurrences. In addition, this study provides estimates of ground-motion attenuation and seismic source parameters. The data developed from this study are used in combination with data from other geologic, geophysical and tectonic studies, to estimate the probability of future occurrence and the potential effects of earthquakes on the repository systems. These estimates will be used in design and performance assessment of the repository facilities, waste package, and seals, in addition to performance assessment of the geologic environment.

Sub-objectives of the earthquake seismology study include the following:

- Determine the locations, rates of occurrence, and magnitudes of earthquakes in the region.
- Investigate the relationships between earthquakes and geologic processes, geologic structures, and in situ stress.
- Provide accurate and precise locations of earthquakes in the controlled area study zone.
- Investigate the causes and mechanisms of earthquake swarms in the basalts.
- Determine if earthquake activity is induced by construction of the repository.

- Estimate the locations, magnitudes, and probabilities of potential future earthquakes.
- Determine the ground motion parameters for design of surface and subsurface repository components.
- Estimate the changes in in situ stress associated with earthquakes.
- Calculate if potential future earthquakes would be likely to prevent retrieval of emplaced wastes.
- Calculate if potential future earthquakes would be likely to disturb backfill and seals, or rupture waste canisters.
- Estimate the characteristics of hydrologic pathways which could be created by potential future earthquakes.

Six tasks and analyses (Table 8.3.1.2-20) have been developed to satisfy the objectives and sub-objectives of the earthquake seismology study. They are listed and briefly described below, and are described in more detail in succeeding sections of this study description.

- Seismic surveillance--The seismic surveillance test is the main data collection activity. Seismic networks include a regional network operated by the University of Washington, and several BWIP-operated, calibrated networks. These include permanent and portable surface networks in the Pasco Basin, an array of shallow-borehole seismometers in the controlled area study zone, and a repository-depth borehole accelerometer. Routine processing of the data for preliminary determination of the magnitudes and locations of the recorded earthquakes is included.
- Analysis of seismic velocity structure--Analysis of the seismic velocity structure refines the model used to accurately and precisely locate the earthquakes, and for understanding the geologic configuration and geophysical properties of the region. Special studies will be made using borehole velocity measurements and regional refraction data. Detailed location processing will be conducted to refine earthquake locations using these models.
- Analysis of ground motion characteristics--Analysis of ground motion characteristics will determine the effects of geologic structure, geophysical properties, and depth of measurement on the amplitude (acceleration, velocity, and displacement) and frequencies of the seismic waves.
- Analysis of seismic source parameters--Analysis of seismic source parameters will investigate the scaling relationships between earthquake magnitude, seismic moment, fault dimensions, stress drop, and displacement. The source parameters and the ground motion characteristics provide the basis for predicting ground motion and fault displacements of design earthquake scenarios.

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Table 8.3.1.2-20. Tasks/tests/analyses for the earthquake seismology study (sheet 1 of 2)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Seismic surveillance	Operation of seismic network and preliminary data analysis	Controlled area study zone	8 shallow borehole sites Record approximately 10 events per year Surface and repository depth three-component sites for strong motion	Recorded at 400 samples per second Calibrated Includes three-component sites	Origin time, earthquake location, depth, magnitude, and focal mechanisms
Seismic surveillance	Operation of seismic network and preliminary data analysis	Cold Creek syncline	4 baseline stations to record approximately 20 events per year	Recorded at 400 samples per second Calibrated Includes three-component sites	Origin time, earthquake location, depth, magnitude, and focal mechanisms
Seismic surveillance	Operation of seismic network and preliminary data analysis	Pasco Basin	15 additional surface stations record approximately 20 events per year Portable network	Recorded at 200 samples per second Includes three-component sites	Origin time, earthquake location, depth, magnitude, and focal mechanisms
Seismic surveillance	Operation of seismic network and preliminary data analysis	Eastern Washington	38 additional surface stations (University of Washington) record approximately 100 events per year	Recorded at 100 samples per second	Origin time, earthquake location, depth, magnitude, and focal mechanisms
Seismic velocity structure	Seismic refraction time terms Ray tracing	Controlled area study zone/Cold Creek syncline/Pasco Basin	NA	Seismic refraction data	Earthquake location model
Seismic velocity structure	Earthquake relocations Relative event locations	Cold Creek syncline Pasco Basin	NA	Earthquake travel times	Detailed earthquake locations

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Table 8.3.1.2-20. Tasks/tests/analyses for the earthquake seismology study (sheet 2 of 2)

Tasks/tests/analyses	Methods	Location/scale	Number of tests	Information for analyses	
				Data	Results
Analysis of ground motion characteristics	Ground motion versus depth of recording Ground motion versus depth of earthquake Ground motion versus distance	Controlled area study zone/Cold Creek syncline/Pasco Basin	Analysis will require approximately 100 well-recorded events	Earthquake recordings from seismic surveillance	Attenuation, anisotropy, wave guides, impedance amplification, surface waves attenuation, acceleration, velocity, displacement, and duration
Analysis of ground motion characteristics	Compare to ground motion data, data from other sites	Locations and tectonic environments similar to above	Approximately 50 records	World-wide ground motion data	Attenuation, anisotropy, wave guides, impedance amplification, surface waves attenuation, acceleration, velocity, displacement, and duration
Estimate seismic source parameters	Analysis of earthquake recordings for source determination parameters	Controlled area study zone/Cold Creek syncline/Pasco Basin	Analysis will require approximately 100 well-recorded earthquakes	Earthquake recordings from seismic surveillance corrected for wave propagation and attenuation (see ground motion study)	Seismic moment, stress drop, fault displacement, fault dimensions/ areas, and seismic source models
Correlate seismicity and geologic structures	Analysis of three-dimensional distribution and analysis, magnitude distribution, focal mechanisms	Controlled area study zone/Cold Creek syncline/Pasco Basin/ Eastern Washington	NA	Earthquake locations, magnitudes, focal mechanisms, earthquake swarm studies, historical data	Subsurface faults, recurrence rates, and in situ stress Swarm model
Correlate seismicity and geologic structures	Regional difference in rate of earthquake activity	Columbia Plateau/Pacific Northwest	NA	Historical and instrumental earthquake catalog	Felt area, intensity, magnitude, recurrence
Estimate future seismicity	Projection of observed earthquake recurrence to the future Use of world-wide data based on large earthquakes Expert panel	Controlled area study zone/Cold Creek syncline/Pasco Basin/ Eastern Washington/ world wide	NA	Seismic source parameters, ground motion characteristics, earthquake recurrence rates, and tectonic models	Earthquake scenarios: type of faulting, location and magnitude of potential earthquakes, and ground motion and stress/strain changes in subsurface

NA = Not applicable.

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- Correlation of seismicity with geologic structures--Correlation of seismicity with geologic structure involves estimating probabilities of earthquakes based on the instrumental and historical record of earthquakes. Detailed location processing will be used to detect hypocenter alignments, correlations with mapped or geophysically-inferred faults, and induced seismicity. The magnitude distribution, temporal and spatial hypocentral distributions, and focal mechanisms will be examined to develop models of earthquake swarms and estimate recurrence rates of earthquakes which are related to geologic processes and tectonic models.

- Estimation of future seismicity--Estimation of future seismicity (seismic risk analysis) uses the results of the previous tests and analyses to predict the probability of future earthquakes and their effects at the repository site. Deterministic and probablistic methods will be used for design and performance assessments of surface and subsurface repository components and the surrounding geologic/hydrologic system.

Performance parameters have been identified in the issue resolution strategy section, and those which require input from the earthquake seismology study are listed in Table 8.3.1.2-17. The parameters are described by the geographic scale or location where their confidence goals or accuracy requirements must be satisfied. The tables also give lists of supporting parameters derived in the earthquake seismology study for each of the performance parameters.

Several specific technical considerations regarding a repository at the BWIP have been used to further organize and focus the earthquake seismology study and are listed below:

- Correlations of swarm activity with geophysical and structural features.

- Mechanism, effects and potential for future microearthquake swarms within the repository.

- Location, characteristics, and potential for induced seismicity within the Pasco Basin.

  For example, the cause(s) and mechanism of microearthquake swarms are poorly understood, but are particulary important because some of the swarms occur in synclinal areas and at repository depths. An assessment of the performance of a repository, with respect to future microearthquake swarms, is thus dependent on a knowledge of how, why, and where the swarms occur and the potential for their occurrence within the repository. The earthquake seismology study addresses these technical considerations by including an analysis dealing with microearthquake swarms (correlation of seismicity with geologic structures 8.3.1.2.4.3.5, and estimation of future seismicity 8.3.1.2.4.3.6).

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8.3.1.2.4.3.2.1 Seismic surveillance. Seismicity will be monitored by regional seismometer networks, a BWIP surface network deployed in the Pasco Basin, an array of shallow-borehole seismometers placed at the top of basalt in the controlled area study zone, and a repository-depth borehole accelerometer. Additional surface instrumentation includes a portable seismic network deployed during earthquake swarms, and a strong-motion accelerometer above the deep-borehole instrument. The locations of these arrays are shown in Figures 8.3.1.2-40, 8.3.1.2-41, and 8.3.1.2-42, and the types of equipment are described below. Data are telemetered to central sites and are recorded digitally on event-triggered seismic recording systems. These data are analyzed to determine preliminary earthquake locations, magnitudes, and focal mechanisms.

8.3.1.2.4.3.2.1.1 Instrumentation

The regional array was installed on the Hanford Site in 1969 by the USGS and expanded by the University of Washington from 1975 to present. This array records earthquake activity over the entire Columbia Plateau in eastern Washington and northeastern Oregon. The regional array includes approximately 38 short-period vertical surface seismograph stations, which have a geographic spacing of about 20 to 75 km. All earthquakes having a coda-length magnitude (M_C) 2.0 and larger can be located (see Section 1.4.1.1.2).

The BWIP surface array was installed in 1980 in the Cold Creek syncline and Pasco Basin. This network consists of 12 short-period vertical seismograph stations and five three-component short-period seismograph stations. All stations of this surface array are calibrated and have a geographic spacing of 5 to 8 km. Data from this array provide more precise locations, magnitudes, and focal mechanisms of earthquakes having coda-length magnitudes of M_C 1.0 and larger. Ground motion amplitudes can be recorded up to approximately 4×10^{-3} cm/s (1.3×10^{-4} ft/s) with a dynamic range of 40 to 44 dB. True ground motion can be calculated between approximately 0.5 and 70 Hz.

In 1984, the BWIP installed an eight-station, shallow- borehole, short-period vertical seismometer network. The sensors are approximately 200 m (656 ft) below the ground surface in the top of the basalt at the reference repository location, Cold Creek syncline. The geographic spacing of this array is 0.5 to 1.5 km (.3 to .9 mi). This array was specifically designed to record data required to locate earthquakes to a 50 to 100 m (164 to 328 ft) precision in the reference repository location for earthquakes with coda-length magnitudes (M_C) from 0.0 to 2.0 (Rohay et al., 1983). The high noise levels at the surface of the reference repository location are reduced by a factor of approximately six at depth. The shallow borehole array records up to a maximum of 2×10^{-3} cm/s (6.6×10^{-5} ft/s) with a dynamic range of approximately 44 dB. True ground motion can be calculated for frequencies between 0.5 and 70 Hz.

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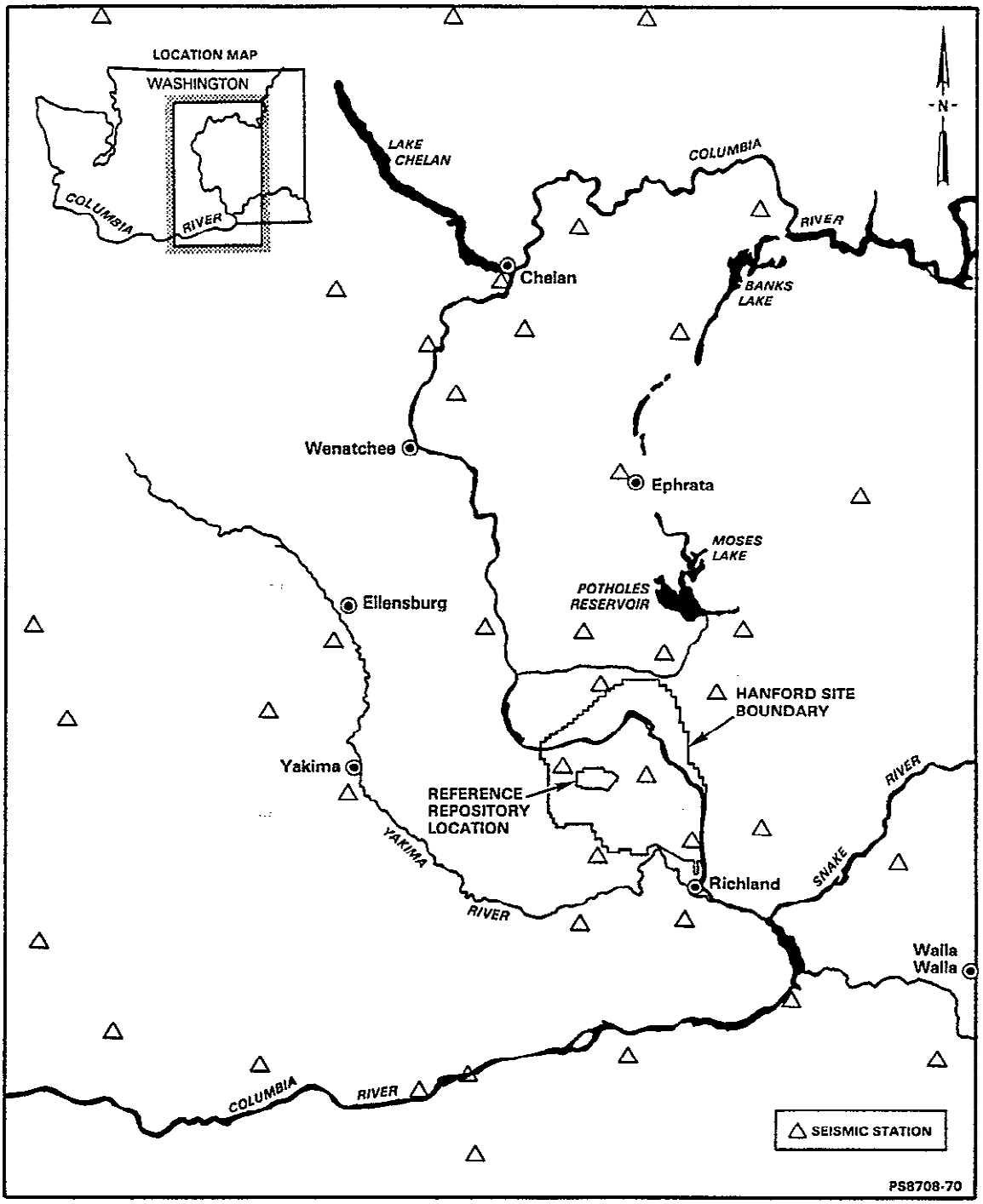

Figure 8.3.1.2-40. Eastern Washington-northern Oregon surface seismic network.

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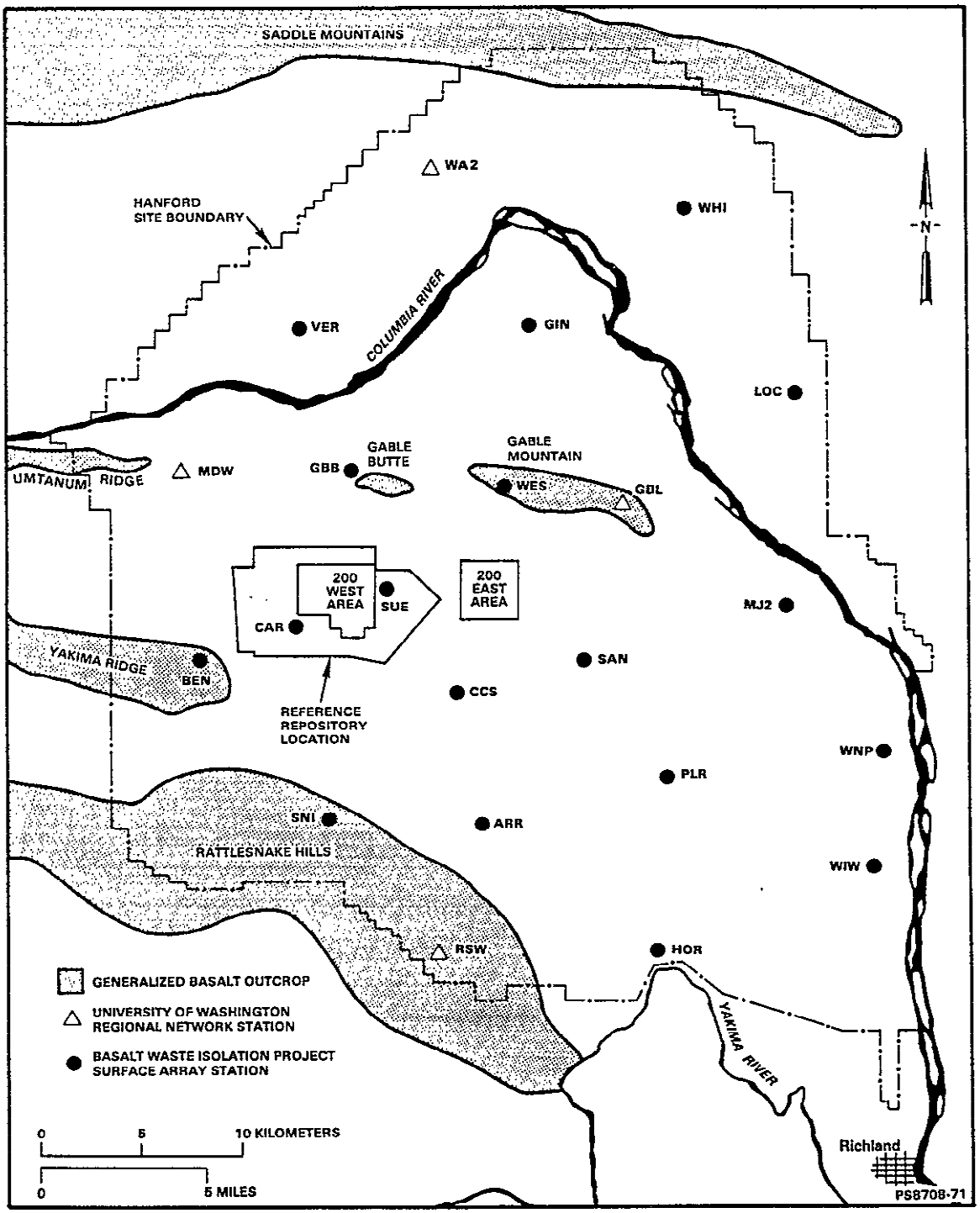

Figure 8.3.1.2-41. Location map of the Basalt Waste Isolation Project surface seismic network.

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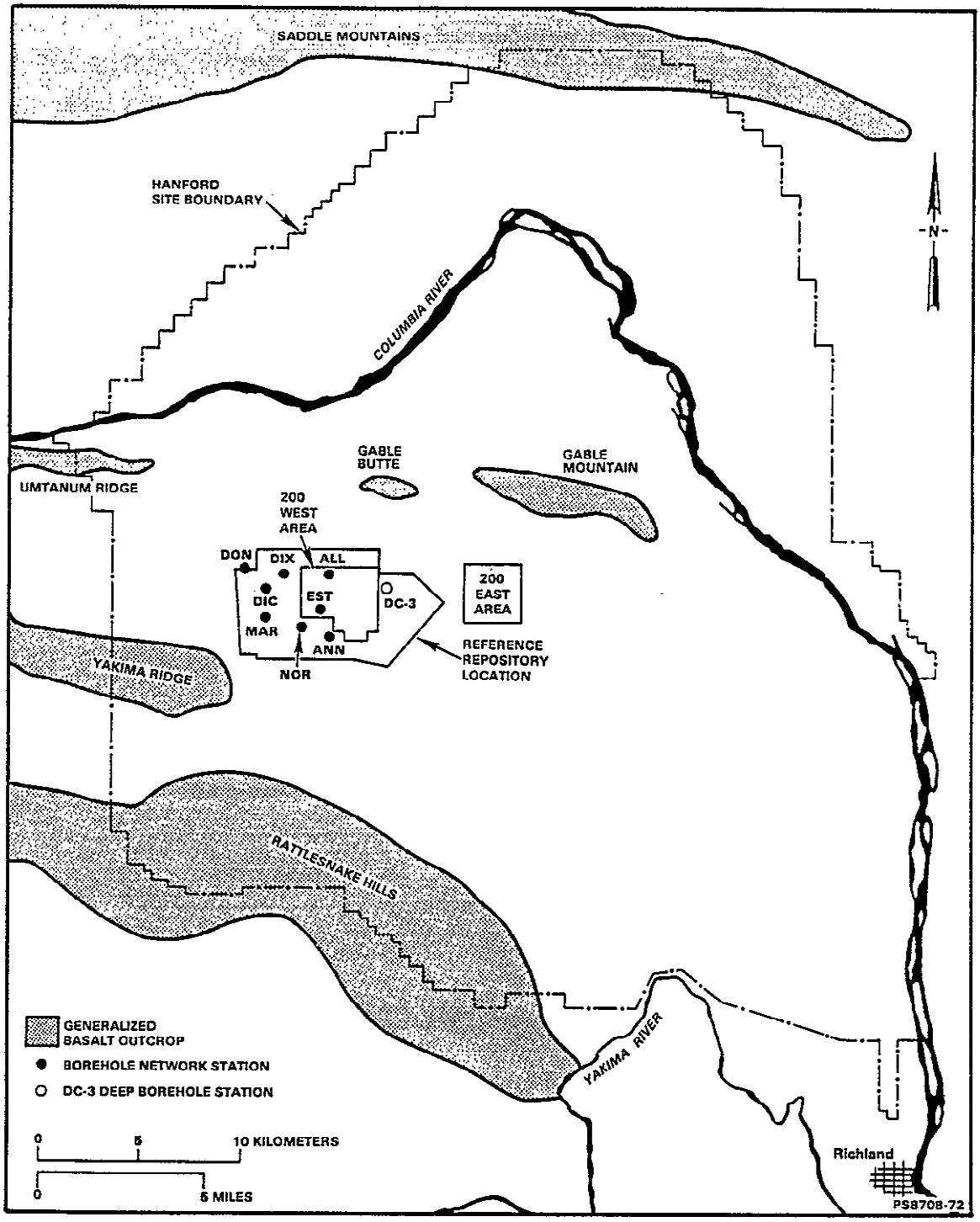

Figure 8.3.1.2-42. Location map of the Basalt Waste Isolation Project subsurface seismic array.

In 1985, the BWIP installed a calibrated dual gain three component accelerometer at 1,160 m (3806 ft) below the ground surface (approximately repository depth) in the reference repository location. The recordings from this deep borehole seismic system will be used to measure accelerations between 10^{-5} and 0.5 g. The acceleration frequency response of this instrument is constant between 0.1 and 100 Hz. A calibrated three-component strong motion accelerometer has also been installed at the ground surface directly above the deep borehole system. This surface accelerometer will record accelerations between 0.01 and 0.5 g, for frequencies between 0 and 50 Hz.

The BWIP portable network consists of 6 field systems that can be deployed rapidly in a tight (1- to 2-km (0.6 to 1.2 mi) station spacing) network in the event of significant earthquake swarms. One of these stations is a three-component station with electronics and sensors similar to the BWIP-operated surface network.

Calibration of the above-described BWIP arrays consists of three basic techniques: (1) input of sinusoidal waveforms to calibration coils, (2) step offset input to calibration coils, and (3) weight lift tests. Amplitude and phase response measurements at low frequencies are accomplished with sinusoidal inputs, and with digital processing of the step offset or weight lift tests. The high-frequency response of seismometers is theoretically constant but difficult to measure above approximately 5 Hz. The response of the amplifiers and filters dominates the high-frequency system response, which can be easily measured with sinusoidal inputs. The total system response of any seismograph will be maintained within 20% of an established standard for that array.

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8.3.1.2.4.3.2.1.2 Recording system

Two digital recorders are operated: the first, operated since 1982, records 52 channels of seismic data at a present rate of 350 samples per second. Prior to installation of the shallow borehole network, it recorded at 200 samples per second. The shallow borehole network data is actually transmitted digitally at 343 samples per second. These rates provide a four-to-one ratio of the sample rate to the upper frequency limit of the seismic systems. The seismic systems' response is attenuated approximately 40 dB at one-half the digitizing rate (or Nyquist frequency) to prevent aliasing.

The second digital recording system, installed in 1986, records 16 channels at 400 samples per second. It records the shallow borehole network at the site of the deep-borehole accelerometer, avoiding signal telemetery limitations for the dual-gain, three component acceleration data. The acceleration data amplifiers have 10-pole anti-alias filters with a 6 dB attenuation at approximately 85 Hz. The response is attenuated by approximately 60 dB at 200 Hz.

Analog to digital conversion by the digital recording system is accomplished with 12 bit resolution. Calibration of the fixed-gain analog-to-digital conversion has been completed by applying calibrated voltages to the digital recorder and then obtaining the resultant voltage displayed by the off-line analysis system. All measurements show less than 1% errors.

Timing standards are provided by the National Bureau of Standards, the WWVB radio station, and GOES satellites. The digitizing rates of the computer recording systems calculated from these standards are constant to within 0.05% or less. The off-line process also detects any gaps in data recording during recorder malfunctions, which are normally reported by the data acquisition systems, and are compensated for by the off-line data analysis software.

Event detection by the digital recording systems uses the ratio of short-term to long-term rectified amplitude averages on selected subsets of the data channels (Johnson, 1979). These subnets are designed to reject artificial seismic events such as sonic booms, thunder, and artillery testing at the nearby Yakima Firing Center. Events are unavoidably missed during computer downtime, but comparisons to continuous analog recordings made on 18 helicorders indicate that very few actual seismic events are missed. The operation of two recording systems now aids in the evaluation of the detection efficiency or consistency. In addition, the independent system operated by the University of Washington provides additional checks.

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8.3.1.2.4.3.2.1.3 Preliminary analysis

The AUTOSEIS software package is used to process the digitally recorded data on a PRIME 750 computer. Digital seismic data is read, header block information assembled, and the data structure converted to be PRIME compatible. These event data files are plotted and those events identified as true earthquakes are demultiplexed. The event waveform data can be examined in detail, locations and magnitudes are computed, and focal mechanism plots obtained.

Recordings of calibration voltages and frequencies are also read from the digital data and the total response of the system calculated. The data are written to archive tapes for permanent storage and the earthquakes' attributes are entered into a catalog file used for production of earthquake maps and catalogs. Teleseismic and regional earthquake data are also archived for future seismic velocity analyses.

The computer program HYPO71 (Lee and Lahr, 1975) is currently being used for routine locations. Additional study and refinement of earthquake location accuracy and precision must be conducted, including improvement of the earthquake location model. Additional earthquake location codes that will be used include HYPOINVERSE (Klein, 1985), HYPOCENTER (Lienert et al., 1986), and LQUAKE (Crosson in UWGP, 1987). The relocation of earthquakes using refined velocity models and location programs will be described in the next section (Section 8.3.1.2.4.3.2.2).

Earthquake magnitudes are calculated using the coda duration method of the University of Washington (UWGP, 1986, pp. 27-29) and a coda amplitude decay method (Johnson, 1979) modified for use on small, local earthquakes. Refinement of the coda amplitude scale to agree with the coda duration magnitudes has not been completed, but magnitude comparisons made to date suggest that the magnitude scales are consistent to within 0.3 magnitude units. The objective of the refinement of the coda amplitude coefficients is to obtain a consistency of 0.1 magnitude units.

Coda-length magnitude M_C is calculated by the equation

$$M_C = 2.82 \log C - 2.46,$$

where C is the signal duration in seconds from the onset of the P-wave to when the signal is reduced to two times the pre-event seismic background. The constant term in the above equation (2.46) is modified for each station using an additional correction term.

Coda-amplitude magnitude M_{Ca} is calculated from the equation

$$M_{Ca} = \log A + q(t) - A_o$$

where A is the rectified signal amplitude averaged over short duration windows. The parameter q is the exponential decay envelope of A with lapse time t in seconds, measured from the P-wave arrival time or origin time. Adjustments to q are made to give a constant magnitude with lapse time and A_o is adjusted to give approximate agreement with M_C. Both A_o and q depend on station gain and response, and on the geologic conditions at the station. Magnitude determinations will be modified based on additional studies of coda decay rates and site response effects described in Section 8.3.1.2.4.3.2.3 (Ground motion) and the relationships of the above magnitudes to the Richter and moment magnitude scales will be determined as described in Section 8.3.1.2.4.3.2.3.

Earthquake focal mechanisms will be routinely calculated, during routine processing of the data, using the program FPFIT (Reasonberg and Oppenheimer, 1985). Additional codes that will also be used for focal mechanism determinations in later detailed analysis (Section 8.3.1.2.4.3.2.5) include AMPRAT (Kisslinger et al., 1981) (which includes amplitude ratios in the fitting process), and MECSTA (Brillinger et al., 1980), which groups events for composite focal mechanism analyses.

8.3.1.2.4.3.2.1.4 University of Washington data

The University of Washington independently processes the data from the regional array. Similar procedures are used to determine the locations, magnitudes, and focal mechanisms of regional earthquakes. The annual catalogs

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and results of topical studies (i.e., seismic velocity structure investigations) are reported annually. Data are exchanged between the University and BWIP in cooperative studies.

8.3.1.2.4.3.2.2 Analysis of seismic velocity structure. This analysis provides refinements to the seismic velocity model used in the location of earthquakes and describes the application of supplementary earthquake location programs.

Seismic velocity studies use the data collected from blasts and earthquakes to infer the seismic velocity of the rock layers. Regional variations in velocity structure can be related to the geologic evolution of the region and thus provide input to tectonic and structural models. Detailed earthquake locations are needed to detect hypocenter alignments (subsurface faults) and to study earthquake swarms (Section 8.3.1.2.4.3.2.5).

Geometrical spreading and site-response models are needed to explain measured site response effects (Section 8.3.1.2.4.3.2.3). These are based upon the seismic velocity models developed here, but the detailed earthquake locations in the controlled area study zone will also require additional data from subsurface geophysical measurements.

The results of this analysis may require modification of the location procedures used in the seismic surveillance test (Section 8.3.1.2.4.3.2.1). Updates to the velocity model used will be finalized as required and used to produce a uniform catalog (based on the updated earthquake location models).

8.3.1.2.4.3.2.2.1 Analysis of blast data

Measurement of the arrival times of earthquake- and blast-generated seismic waves are analyzed to determine the P- and S-wave velocity structure of the region. Blasts are especially useful because of their known location and have been used extensively to determine the structure of the region (Rohay et al., 1985). Recent studies are at least partially based on analysis of data from a 1984 long-range refraction experiment conducted across the Pasco Basin. These data are augmented by recordings of construction blasts, which occur frequently throughout the region, and which can often be precisely located. In most cases, blast data are most useful for measuring the P-wave velocity structure of the earth.

Catchings et al. (1985) and Catchings (1987) conducted a detailed analysis of the 1984 refraction data. Specific aspects of this data set (which was collected with a 1- to 2-km (1.2- to 2.4-mi) station spacing on a 200-km (124-mi) long line) that will be further analyzed include the resolution of alternating high/low velocity zones within the basalts, the potential for detecting offsets in such horizons, refinement of the total thickness of the basalts and sub-basalt sediments, and resolution of deep (lower-crustal) structure inferred from the refraction data. Two-dimensional ray tracing (e.g., Glover, 1985) will be used to model the arrival times and amplitudes of primary and secondary arrivals. This analysis will incorporate

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information from seismic-velocity measurements in deep boreholes, including the data recently released from Shell's exploratory well in the Saddle Mountains.

The need for additional seismic refraction lines will be evaluated if further analysis of the 1984 refraction data indicates such a need. If a dense line (station spacing of less than 0.5 km) could be used to detect structures within the basalts, additional reflection or refraction data may be collected to resolve the structure of the Cold Creek syncline and its boundaries in greater detail. Additional work of this type will be considered in conjunction with the structural geology study (Section 8.3.1.2.3.3.4.5).

Additional analyses are also planned using construction blast data recorded on BWIP and University of Washington networks. These analyses will extend the two-dimensional ray-tracing and time-term analyses which have been conducted to date (Glover, 1985; Rohay et al., 1985).

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8.3.1.2.4.3.2.2.2 Analysis of local earthquake data

Earthquake data can also be used to infer the velocity structure of the region. Earthquake data have the advantage of being located at various depths and generally provide better S-wave data than do blasts. However, the absolute locations of the earthquakes are not known, so that more effort is involved in separating the effects of location errors. Local earthquake data will be used to simultaneously estimate the locations of the earthquakes and the velocity structure (Pavlis and Booker, 1980). A suite of earthquakes provides enough information to infer the velocity structure and the locations of the events. Blast data collected and analyzed as described above will also be used in the simultaneous inversions. Local earthquake data will also be analyzed for S-wave velocity structure using graphical methods and the simultaneous inversion for locations, P-wave, and S-wave velocities.

8.3.1.2.4.3.2.2.3 Analysis of regional seismic velocity structure

Regional earthquake data collected from the eastern Washington seismic network can be used to determine changes in crustal thickness and seismic velocity anisotropy in the upper mantle (Zervas and Crosson, 1986). Teleseismic residual analyses using three-dimensional inversion (Michaelson and Weaver, 1986) provide additional data on lateral variations in crustal thickness and upper mantle velocity variations.

Regional seismic velocity studies of this type are related to the general tectonic evolution of the Columbia Plateau and complement the interpretation of regional geophysical data and local seismic velocity structure studies. Analysis of regional earthquakes and teleseisms recorded on the seismic networks will be continued by the University of Washington and the BWIP.

8.3.1.2.4.3.2.2.4 Analysis of special precision locations

Data collected on the shallow-borehole seismic network from blasting during repository construction would provide ideal data which would be used in

a relative location process for near-mine or mining-induced seismic events. Special studies to refine the precision and accuracy of locations within the controlled area study zone, and especially in the near vicinity of the planned underground facility, will be conducted.

Earthquakes within earthquake swarms will also be studied using relative event location. Relative arrival time picking using time-series cross-correlation (Fremont and Malone, 1987) will also be applied to earthquake swarm data. Data from earthquakes with aftershocks can also be studied using these methods.

The data collected by operation of the portable network during swarm activity will also be analyzed using more detailed velocity models, station corrections, and high-precision relative location techniques.

The location program HYPO71 (Lee and Lahr, 1975) is currently used for routine hypocenter calculations. This program provides for two sets of station corrections which can account for simple changes in layer thicknesses and velocities. The program HYPOINVERSE (Klein, 1985) provides a number of improvements in its statistical approach, the way in which it accounts for velocity model changes in the region, and especially, includes the capability for including a low-velocity zone below the basalts. The program HYPOCENTER (Lienert et al., 1986) provides some additional improvements in statistics, and the program LQUAKE (UWGP, 1987) provides for a low velocity zone similar to the HYPOINVERSE program. All of these programs have been used at BWIP, and comparisons of the locations from each of these programs will provide additional insight into the accuracy of the earthquake locations.

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8.3.1.2.4.3.2.2.5 Special analysis of three-component data

The multiple-layered basalts may produce complex effects in the recorded ground motion. At low wave frequencies (long wavelengths), the effect of layering is hypothesized to induce anisotropy, while at high frequencies (wavelengths of the same order as the thickness of the layers), the layering may create wave-guides. Geometrical spreading may be affected by wave-guide effects, effectively channeling seismic waves horizontally. The basalts may be anisotropic (Rothe, 1978), which would change geometrical-spreading relationships, and could be observed as different shear-wave velocities for horizontally- and vertically-polarized waves. Attenuation of vertical and horizontal components of ground motion might be different as a result (see Section 8.3.1.2.4.3.2.3).

Polarization hodograms will be created from three-component records of earthquakes to detect shear-wave polarization and splitting and to determine whether anisotropy is a significant feature of the basalts.

8.3.1.2.4.3.2.3 Analysis of ground motion characteristics. This task will use the site-specific data collected from the seismograph networks to determine the characteristics of ground motion that results from earthquakes. The recorded ground motion is due to source, propagation, site response, and instrument response effects. This task deals with the propagation and site response effects.

Effects of propagation which will be studied include the attenuation and scattering properties of the rock layers along the wave path, and recording site effects such as near-surface attenuation, impedance and free-surface amplification, and resonant amplification within near-surface layers.

Determination of seismic source parameters (Section 8.3.1.2.4.3.2.4) requires the results of this study.

The geometrical spreading, attenuation, and site response models will be used to predict the ground motion during future potential earthquake occurrences (Section 8.3.1.4.3.2.6) that would be experienced by the various elements of the repository system. Although several instruments operated by the BWIP have strong-motion capability, it is not expected that a significant amount of such data will be collected. Strong motion data from other regions will be used to model potential design-basis earthquakes (Section 8.3.1.2.4.3.2.6). Site-specific strong-motion data collected by BWIP, if any, and data from other regions may also be processed using the spectral analysis methods described below.

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8.3.1.2.4.3.2.3.1 Calculation of true ground motion

The amplitude of ground motion can be defined in terms of acceleration, velocity, or displacement. All of these measures of ground motion depend upon the distance to and the depth of the earthquake relative to the location of measurement. Different relationships exist for each measure of ground motion due to the frequency dependence of many of the wave-propagation and site effects. Because of this frequency dependence, spectral analysis methods will be used extensively in this analysis.

Instruments used to record seismic data detect acceleration, velocity, or displacement in a limited band of frequencies. Subsequent electronic amplification, transmission, and digitizing also affect the data which is ultimately recorded and analyzed. These effects must be removed or compensated for in the analysis of the data. Calibration records induce known equivalents of simple ground motion inputs, and are analyzed to determine the response of each seismic system.

The methods used to calculate instrument response are described in the previous section (see Section 8.3.1.2.4.3.2.2). Calculation of the actual ground motion (acceleration, velocity, or displacement) using time- and frequency-domain methods are described below.

The software that will be used for processing the ground motion data are contained in the seismic analysis code, which has been obtained from Lawrence Livermore National Laboratory. In addition to the FFT methods, more robust methods of spectral estimation are available, and are provided in Seismic Analysis Code. These spectrum estimation programs (or others) will be considered if FFT analysis does not provide sufficient resolution or accuracy. Instrument response was measured by analyzing the calibration records collected as described in the seismic surveillance section (Section 3.1 above). The seismic analysis code software will be applied to the digitally recorded calibration records as a check on the analog calibration records.

Time-domain methods will be used when correcting recorded voltages over a large number of samples or an entire record. Several different approaches will be used and compared. Methods that will be used include circular convolution with the impulse response of the system (which is the output of step-offset calibration), or construction of recursive filters designed with the inverse fourier- and z-transform of the impulse response. Frequency domain methods will be used when a short window of the data is to be corrected. This method simply takes the fast fourier transform (FFT) of the data sample and divides the resulting complex spectrum by the complex spectrum measured from step offset or constructed from amplitude and phase measurements from sinusoidal calibrations. Performing the inverse FFT corrects for the frequency and phase response of the system.

Conversion of velocity to acceleration time-histories or to displacement merely involves differentiating or integrating the original record. These conversions generally require additional filtering to eliminate high-frequency noise introduced in the differentiation process and low-frequency instabilities in the integration process. Integration and differentiation will also be done in the frequency domain using the FFT, dividing or multiplying the amplitude components by the angular frequency, applying a negative or positive phase correction of 90 degrees, then applying the inverse FFT. These methods are described in Aki and Richards (1980, p. 585).

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8.3.1.2.4.3.2.3.2 Ground motion amplitude measurements

This analysis consists of determining the effects of source-to receiver distance on the amplitude of seismic waves. It includes the effects of geometric spreading and attenuation. Plots will be constructed of the peak amplitude of the P- and S-wave arrivals as a function of distance, with consideration of the frequency band of the instruments. Measurements will be made from acceleration, velocity, and displacement time-histories.

Band-pass filters will be used to create plots of amplitudes in specific frequency bands, or which represent the response of particular instruments. For example, determination of Richter magnitude requires determination of the response of a Wood-Anderson seismograph system (e.g., Kanamori and Jennings, 1978; Bakun, 1984). In addition, measurements from the calculated response of narrow band-pass filters and single degree-of-freedom oscillators will be made to construct response spectrum diagrams as a function of distance (e.g., Joyner and Boore, 1982).

Modeling of the ground motion versus distance plots will be conducted to determine the separate effects of geometrical spreading and attenuation. Because of the frequency-dependence of attenuation, it affects the peak motion of acceleration more strongly than velocity or displacement. Independent measurement of attenuation is described below. The ground motion amplitude measurements will be analyzed by using regression equations for the coefficient of geometrical spreading, the specific attenuation parameter, and a site-response amplification parameter (Joyner and Boore, 1981; Brillinger and Preisler, 1984; 1985).

Acceleration amplitudes will also be analyzed using methods developed from random vibration theory (e.g., Boore, 1983; 1986a). Acceleration records indicate that acceleration time histories can be modeled by a white noise series which has a spectrum that is constant above the characteristic frequency of the source, and that the peak amplitudes may be controlled by attenuation along the wave path or near the recording site. This makes application of the existing strong-motion data base (collected at the surface) to subsurface locations uncertain, especially at high frequencies.

8.3.1.2.4.3.2.3.3 Measurement of attenuation and scattering

Attenuation is the measure of intrinsic absorption and scattering of seismic-wave energy as a result of transmission through the rock layers. The specific attenuation parameter Q measures the amplitude reduction per cycle. Intrinsic attenuation measures the energy absorbed by the medium; scattering attenuates the direct waves, but the scattered (multiply refracted and reflected) waves arrive later in time producing the seismic coda. Attenuation measurements will be made from direct P- and S-waves and coda waves.

Measurement of P- and S-wave attenuation will use the spectral ratio method by measuring the amplitude spectrum of the wave group of interest as a function of distance (Aki and Richards, 1980, p. 636; Bor, 1977). The loss of energy not accounted for by geometrical spreading is attributed to the combined effects of intrinsic and scattering attenuation. Scattering produces the seismic coda, which is the basis for the coda length and coda amplitude magnitude scales used in characterizing the sizes of earthquakes. The amplitude of the seismic coda (compared to the direct waves) is a measure of the strength of velocity and density variation of the medium. The decay rate of the amplitude of coda waves provides an independent measurement of attenuation which will be used to confirm estimates made from direct shear waves. Amplitude measurements will be made from the output of narrow band-pass filters and using moving-window FFT analysis (e.g., Aki and Chouet, 1975; Phillips and Aki, 1986).

These measurements will determine the specific attenuation Q of the basalts and near-surface sediments, and possibly other sub-basalt layers. These results will be compared to the measurements of coda amplitude and coda-length magnitudes.

8.3.1.2.4.3.2.3.4 Site response effects

Comparison of ground-motion amplitudes and spectra of earthquakes and blasts recorded in different geologic media will determine the site-response models used in calculating ground motion for design-basis earthquakes. Near-surface sediments are expected to create differences in the amplification of seismic waves based upon the product of seismic velocity and density, termed impedance amplification. The impedance also determines the relationship between ground-motion-velocity and the stress and strain induced in the medium during wave passage (e.g., Boore, 1986a, Phillips and Aki, 1986; Shearer and Orcutt, 1987).

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The detailed surficial velocity and density structure of the controlled area study zone will be derived from a combination of velocity modeling contained within this analysis and borehole geophysical measurements. These data will be used to make predictions regarding the amplitude ratio of P- and S-waves between recording sites at the surface (both on basalt and on sediments), at the top-of-basalt, and at the deep-borehole seismometer site.

Comparisons will also be made using spectral analyses to determine the attenuation characteristics of the surficial sediment layers. This attenuation may create an upper limit to the acceleration spectrum of earthquake recordings, limiting the peak acceleration which will be recorded (e.g., Boore, 1986b). Conversely, resonant effects due to multiple reflections within the sediments may produce amplification of ground motion at particular frequencies, or at particular horizons within the sediments. In addition, the free-surface in some cases is theoretically expected to produce a doubling of the ground motion amplitudes. Spectral ratios will be calculated to investigate these site response effects, and, compared to the calculated effects of impedance amplification, free surface amplification and reverberation or resonant effects based upon the velocity and density structure of the site.

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8.3.1.2.4.3.2.4 Analysis of seismic source parameters. The purposes of seismic source parameter estimation are to determine the deformation on faults in the site region and the ground motion in the near-field of the faults due to earthquakes. This task will determine fault parameters from the recordings of local earthquakes recorded on the seismic networks incorporating corrections for wave propagation as described in Section 8.3.1.2.4.3.2.3.

In Section 8.3.1.2.4.4.1.6, the seismic source parameters will be used to estimate the subsurface effects of small earthquakes that could occur close to repository openings, or which could occur in the nearby geologic horizons upon which long-term waste isolation depends. The seismic source parameters determined from small earthquakes will be used as a guide in selecting faulting parameters for potential future earthquakes (design-basis earthquakes) that could occur on geologically-mapped or geophysically-inferred faults or structures. Seismic source parameters are also needed to develop models for spatial and temporal characteristics of earthquake swarms (Section 8.3.1.2.4.4.2.6).

The fault parameters determined in this analysis will include:

- Seismic moment.
- Fault dimensions.
- Fault displacement.
- Time-history of slip.
- Static stress drop.
- Effective stress.
- Dynamic stress drop.
- Apparent stress.
- Static stress changes.

The seismic source parameters determinations will be used to estimate their scaling interrelationship, and their relation to earthquake magnitude. It is important that the span of event magnitudes be large. This analysis is to be applied to only selected events that are well-recorded by numerous stations. This redundancy is essential in identification of the proper source models. For the selected group of recorded seismic events, the following outputs will be provided:

- Seismic moment versus magnitude relationship.
- Spectral model appropriate for fault dimension and stress drop determinations.
- Stress drop versus moment dependence.
- Fault displacement versus moment (or fault dimensions).
- The variability of stress drops and dynamic stress drops.

Most of the parameters to be estimated are derived from one or more models of seismic processes. Thus, an inherent sensitivity to the model assumptions exists. Parameters will therefore be estimated with multiple methods based on the characteristics of observed waveforms and frequency spectra. The uncertainties of the estimates will assess the model dependence and data accuracy.

Both time- and frequency-domain analyses of earthquake recordings shall be performed. The time-domain methods involve a direct analysis of the recorded waveforms, where the peak amplitude and duration of the primary seismic phases are measured and compared to model predictions. Frequency-domain methods estimate source parameters in a similar way from the Fourier spectra of the recorded waveforms. Waveform modeling and synthesis of ground motion for design-basis earthquakes may be required to provide time-histories of faulting and ground motion.

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8.3.1.2.4.3.2.4.1 Time domain methods

Source parameter estimates will be made in the time domain for comparison to estimates made using spectral analysis. The area of either the direct P- or S-wave displacement pulse can be measured and interpreted in terms of seismic moment (Brune, 1970; 1971; Frankel, 1981). The pulse width, or characteristic frequency of the pulse, is again interpreted in terms of faulting duration, and the source parameters stress drop, displacement, and fault plane dimensions are inferred.

This method will be used to cross-check the moment determined from the low frequency spectral level (described below). Pulse widths and areas are expected to vary with source-to-receiver wave direction, providing constraints on the appropriate source model.

The peak velocity and acceleration from earthquakes will be empirically related to the seismic moment, fault dimensions, and earthquake depth. It is frequently observed that the stress drop is independent of seismic moment. However, the peak velocity and acceleration have been observed elsewhere to have a dependence on the in situ stress, and thus on the depth and focal mechanism of the earthquakes (McGarr, 1984; 1986). Ground motion from events in a compressional tectonic regime (appropriate to the site) is larger than for extensional regimes.

If the faulting is inhomogeneous (e.g., McGarr, 1981), high-frequency peak ground motions are expected to be due to the inhomogeneities. Dynamic effects of rupture initiation and propagation on a fault with stress and strength inhomogeneity will be characterized (in the time domain) by determination of dynamic stress drop. Peak acceleration measurements and acceleration measurements made from the initial slope of velocity waveforms will be used to determine dynamic stress drops. Determination of the apparent stress will be made from the root-mean-square of acceleration (see Boatwright, 1984 for a review).

Other measurements of the seismograms can contribute to determining source parameters and selecting appropriate faulting models (e.g., Boatwright, 1984). Calculation of radiated seismic energy can aid in the model selection by observing the temporal and spatial patterns of energy release during the rupture process, and the variations in energy with radiation direction. Measurement of seismic energy involves integrating the squared ground velocity over short time windows. The peak amplitude of acceleration and velocity, or the amplitude envelope, is constrained by theoretical energy-magnitude relationships.

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8.3.1.2.4.3.2.4.2 Frequency domain methods

Numerous models for the faulting process exist in the literature. Most of the models give source parameter estimates that are in reasonable agreement with one another, although substantial ambiguity remains as to which is the most accurate representation of the faulting process. The most widely used method of determining seismic source parameters consists of analyzing the amplitude spectrum of the direct shear wave (Brune, 1970; 1971).

Earthquake source models predict a constant low-frequency level of the spectrum determined by the total seismic moment. At the higher frequencies, the source spectrum decreases above a "corner" or characteristic frequency. This frequency is related to the duration of the faulting process. Duration is then used to infer the characteristic spatial dimension of the fault surface, using an appropriate source model. The stress drop and average displacement are also determined from the moment and fault dimensions. A large number of source parameter determinations must be made to provide a statistical average and range.

Additional measurements of spectra must be used to aid in selecting the source models. Spectral analysis of the compressional waves may complement the analysis of shear waves. Details of the high frequency decay in spectral

amplitudes may aid in selecting the best models for earthquakes in this region. Various models predict different decay constants, or in some cases, predict more than one characteristic frequency or decay constant for a particular event.

Analysis of many spectra recorded at different receivers from a single event can substantially reduce the ambiguity in model selection and data interpretation. Variations in the spectra with source-to-receiver wave direction (i.e., changes in corner frequency, low frequency level, and the high frequency decay) are the primary constraints for model selection.

The most widely used and generally applicable source model spectrum is that formulated by Brune (1970; 1971). Similar models have been derived with other high-frequency exponential decay coefficients and for parallel analysis of the compressional P-wave. Although it is anticipated that the Brune spectrum will be applied first, other source spectrum models will be employed if the spectral decay measurements indicate that other models are most appropriate to the microearthquakes occurring at the site (see Brune et al., 1979 for a review). This selection will also be based upon the interrelationships of the different measures of stress drop.

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8.3.1.2.4.3.2.4.3 Waveform modeling

Waveform modeling will be used to numerically compute waveforms (synthetic seismograms) for comparison to the seismograms actually recorded from earthquakes. The velocity and attenuation models are combined with a seismic source model to produce synthetic seismograms. Waveform modeling will also be used in calculating ground motion time-histories of design-basis earthquakes. Selection of synthetic seismogram computer codes will depend upon the quality of the recorded data, the degree of complexity required in the modeling, and the availability of computational resources. The history of slip on the fault, rupture propagation direction, and inhomogeneities on the fault can be modeled in more complex synthetic seismogram codes.

A similar semi-empirical technique which may be attempted is to use the recorded data from local earthquakes directly by adding or stacking the waveforms of small earthquakes to simulate a larger one (Joyner and Boore, 1986). The application of this method requires knowledge of the proper scaling relationships, and a model for the propagation of fault slip as a sequence of smaller events. This removes some of the uncertainty involved in wave propagation effects, assuming that wave paths from the recorded earthquakes and the design-basis event are equivalent.

Synthetic seismograms can also be adequately modeled using a random vibration approach (e.g., Boore, 1983). Acceleration records can be characterized as a random time series, modified by filtering to simulate attenuation and site response. This method uses the dynamic stress drop and apparent stress parameters to control the strength of the ground motion. Integration of the simulated acceleration time histories also produces realistic approximations to velocity time-history observations.

8.3.1.2.4.3.2.5 Correlation of seismicity with geologic structures. This task includes special studies of the location and magnitude distribution and the focal mechanisms of earthquakes. The seismic activity observed in the Columbia Plateau, the Pasco Basin, and in the central Cold Creek syncline is not clearly related to the locations of geological structures. The purpose of this study is to systematically test hypotheses, which have been or could be proposed that explain the various spatial and temporal patterns of earthquake occurrences. If conceptual models can be developed for the observed seismicity, they may be used in refining more general tectonic models and in estimating the magnitudes and recurrence rates needed for seismic risk analysis (Section 8.3.1.2.4.3.2.6).

This analysis is designed to determine if instrumentally recorded earthquake activity can be correlated with geologic structures for which there is evidence from geologic mapping, borehole observations, and geophysical surveys. Correlations will be sought on a variety of scales, ranging from individual swarm dimensions (1-5 km (6-3.0 mi)) to the length of anticlinal ridge segments (50 km (30 mi) and greater).

Earthquake alignments may indicate subsurface structures not observed in other studies, and may require additional geophysical or geological studies to determine the source of these earthquake alignments.

Earthquake focal mechanism studies are included to provide additional data about the orientation and variability of fault planes. The variability of the stress field producing earthquakes and the presence of pre-existing fractures or faults are interrelated; potential earthquake swarm scenarios for design and performance assessment need to be defined.

The effect of pore pressure changes or aseismic deformation within interflow zones will be evaluated as physical mechanisms producing the spatial and temporal clustering which characterizes earthquake swarms. The hypothesis of irrigation-induced seismicity will also be considered and tested.

Historical earthquake catalogs will be analyzed in addition to the instrumental record. The large uncertainties in the locations of historical earthquakes may preclude unambiguous correlations with structures (or faults). However, the magnitudes of historical earthquakes can be estimated from intensities and compared to the recurrence rates estimated from instrumental data.

8.3.1.2.4.3.2.5.1 Hypocentral distribution

The hypocentral distribution of earthquakes will be examined for visual and statistical correlation of earthquake alignments. Spatial and temporal characteristics of earthquake swarms will be analyzed for defining swarm versus non-swarm activity (i.e., migration of swarm activity, the depth distribution of swarm events).

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Graphical methods include epicentral maps, cross-sections, oblique projections, and stereo pairs. Finding evidence for correlations between seismic activity and geologic structures will rely heavily on graphical methods. Epicenter plots, with earthquakes sorted by a variety of parameters such as focal depth, magnitude, and time of occurrence, will be overlaid on geologic and structure maps. Hypocenters will be projected onto vertical sections and compared with geological and geophysical cross sections for the same locality.

The relationship between various earthquake parameters, the occurrence of disking phenomena in boreholes, data from in situ stress measurements, and other miscellaneous geologic features (such as landslides) will be compared using graphical plots. Where appropriate, scatter plots and histograms will be used to search for potential relationships between earthquake parameters and geological characteristics.

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8.3.1.2.4.3.2.5.2 Statistical methods

Various statistical methods will be applied to the search for trends in earthquake parameters. In defining earthquake swarms, two-point correlation functions will be used and compared to random (Poisson) distributions of inter-earthquake occurrence times and distances (Reasonberg, 1985). Three-point correlation methods will be used to search for earthquake alignments (Fehler et al., 1987). Other simple techniques include various binning methods and analyses of histograms. These methods may be most useful in determining the confidence in attributing seismic zones to geologic structures or regions. Temporal migrations of seismic activity may also be detected.

8.3.1.2.4.3.2.5.3 Magnitude distributions

Recurrence curves for earthquakes will be analyzed to estimate the magnitude distribution of swarm or non-swarm earthquakes and basalt or subbasalt earthquakes. Magnitudes will be determined using ground motion and seismic source parameter estimates produced in the previous two analyses. Seismic moment estimates and the recurrence curves will be used to estimate seismic moment release rates.

Recurrence rates will be compared for various categories of geologic structures (e.g., mapped folds and faults, stratigraphic units, and structural regions). Seismic moment release rates will be estimated and compared to these categories or as functions of depth. Differences in the slopes of the recurrence curves may indicate bends or kinks that may indicate characteristic and (or) maximum magnitudes (or fault dimensions interpreted from seismic moment), and changes in stress drop for small earthquakes (e.g., Rothe, 1978; McGarr, 1986; Aki, 1987).

8.3.1.2.4.3.2.5.4 Focal mechanisms

Detailed earthquake focal mechanism analyses, derived from the detailed location process and analyzed in spatially or temporally associated groupings, provides additional information on the orientation of fault planes. Special

studies of earthquake focal mechanisms will be conducted to determine composite focal mechanisms from spatially or temporally associated earthquake sequences, especially for swarm earthquakes in basalts and earthquakes within the controlled area study zone (e.g., Malone et al., 1975; Brillinger et al., 1980). Focal mechanism determinations can in some cases be improved using amplitudes (or ratios of amplitudes) of ground motion (Kisslinger et al., 1981). Focal mechanisms may also provide a potential discrimination method given an understanding of stress changes causing induced seismicity.

8.3.1.2.4.3.2.5.5 Historical earthquakes

A historical earthquake catalog was produced by the Washington Public Power Supply System for the Pacific Northwest. The historical earthquake catalog will be searched for earthquakes in the geologic setting and surrounding regions.

The geologic setting is interpreted to be the Columbia Plateau, generally defined as the area covered by the Columbia River basalts. Surrounding adjacent geologic settings include the Okanogan Highlands (north), the Cascade Range (west), the Blue Mountains (south), and the Rocky Mountains (east).

The frequency of occurrence of earthquakes and the magnitudes of the earthquakes are fundamentally interrelated. A determination and comparison of the recurrence relationships for earthquakes in the Columbia Plateau and other geologic settings in surrounding areas defined above will be made.

Updates have been made to the Final Safety Analysis Report (WPPSS, 1981 historical earthquake catalog to include all earthquakes that have occurred in the Pacific Northwest since 1980. Earthquake magnitudes will be estimated from Modified Mercalli Intensity for pre-instrumental earthquakes (e.g., Bender, 1987). Recurrence curves will be constructed for the Columbia Plateau and other geologic settings in the Pacific Northwest.

The recurrence curves will be compared in terms of the frequency of occurrence of earthquakes, the maximum magnitudes observed, and the sizes of the areas of each of the other geologic settings being considered.

8.3.1.2.4.3.2.6 Estimation of future seismicity (seismic risk analysis). This task combines the results of the previous tasks with outside data to estimate the size and frequency of potential earthquakes that could occur during the various phases of repository operation. The ground motion parameters (time histories, peak motions, and frequency spectra of acceleration, velocity, and displacement) for the design-basis earthquakes will then be calculated for surface and subsurface repository horizons.

Estimates of in situ stress or static strain changes will be made. Estimates of fault zone properties will be made from model parameters and correlation with known fractures in basalts. The hydrologic effects of stress changes or slip on fault zones within the geologic environment must be estimated for the repository postclosure time period.

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Uncertainty and sensitivity will be predicted using a combination of deterministic and probabilistic seismic design methodologies. Probabilistic analysis inherently incorporates the uncertainty in all input parameters and sensitivity to the assumptions. Deterministic analyses will be used to limit the range of probabilistic analyses to earthquake scenarios that may adversely impact repository performance.

8.3.1.2.4.3.2.6.1 Approach

The methods for seismic risk assessment are guided by a report on seismic design by Woodward-Clyde Consultants (WCC, 1985). They suggested a combination of deterministic and probabilistic methods for tectonic earthquakes (on known structures, faults), and for basalt earthquakes (random locations).

State-of-the art professional practice will use techniques involving fault and earthquake hazard assessment, and as appropriate, probabilistic seismic hazard assessment. The current strategy calls for both deterministic (defined to be specific earthquake scenarios) and probabilistic approaches to be used to evaluate vibratory ground motion. The definition of the vibratory ground motion associated with the design basis earthquake will be based on specific deterministic scenarios. The intent of using probabilistic approaches will be to characterize more fully alternate hypotheses on what potential seismogenic sources exist, explicitly to account for uncertainty, and to provide an overall check on the appropriateness of deterministic scenarios. As site characterization proceeds, collected geologic and seismic information will be analyzed to insure that this general strategy using deterministic and probabilistic techniques to evaluate seismic hazard remains adequate to address the performance and design issues.

The results from previous licensing studies (WPPSS, 1981; NRC 1981a, 1981b) will be used in estimating the sizes of tectonic earthquakes. Empirical ground motion relationships derived from selected strong-ground-motion data sets will be used for estimating ground motion for tectonic earthquakes; analytical models may also be required. Potential design basis earthquakes will be compared based on their potential for creating vibratory ground motion at the repository site. This comparison may allow for detailed evaluation of only the most significant potential design basis earthquakes. Subsurface ground motions will be estimated based on the depth dependence of ground motion observed world-wide and using analytical wave propagation techniques calibrated with the data from the borehole seismic arrays.

Basalt earthquakes will be characterized by assuming that such earthquakes could occur within or adjacent to the repository, and will use estimates of source parameters (maximum magnitude, displacement, rupture area, and recurrence) based on the observed earthquakes in the Columbia Plateau basalts and possibly similar earthquakes in other similar tectonic environments. Earthquake source characteristics will be obtained through analysis of the BWIP seismic data. The source parameters will also be based on geological studies of tectonic fractures and other small-scale fault features. A study of the influence of faulting and ground shaking on hydraulic conductivity of the rock will be considered.

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Additional recommendations made by Woodward-Clyde Consultants (WCC, 1985) were made that relate to the degree of conservatism required for seismic parameters and to analysis methods for the response of repository facilities.

8.3.1.2.4.3.2.6.2 Deterministic models of tectonic earthquakes on structures

The methods used by the NRC (1982) in reviewing the Final Safety Analysis Report (WPPSS, 1981) will be reviewed as a starting point for selecting design-basis earthquakes which could be associated with tectonic features.

Statistical relationships exist between earthquake magnitude and various fault parameters, including fault type (strike-slip, reverse), the length and displacement of the surface rupture, and total fault length (e.g., Bonilla et al., 1984; Kanamori and Allen, 1986). These or other relationships (as new information becomes available) will be used to estimate the magnitude of earthquakes which could occur on structures and faults.

Statistical relationships between fault types and earthquake magnitudes are based upon fault areas, seismic moment, and fault length and width. These relationships will be used to estimate the seismic moment of design-basis earthquakes based on geologic models of faults which have the potential for tectonic earthquakes.

Recurrence rates for tectonic earthquakes will be estimated from geologically determined slip rates, geodetic strain measurements, extrapolation of microseismicity recurrence curves, and historic earthquake recurrence rates for the region. The relationships developed for fault displacement versus magnitude or fault displacement versus seismic moment will then be used to aid in determining return periods for the various magnitudes of assumed tectonic earthquakes.

Ground motion for tectonic earthquakes will be calculated using empirical relationships and analyses of strong-ground motion records for earthquakes in similar tectonic environments and having similar magnitudes. The location and orientation of the hypothetical earthquake fault on which the design-basis earthquake is presumed to occur must be specified relative to the location of the repository systems. Acceleration, velocity, and displacement ground motion will be calculated. Peak ground motions, response spectra, and time histories will be provided to base the design of repository systems or to assess long-term performance.

Surface ground motions will be modified as a function of depth based upon site response models. A model for design-basis earthquakes, which estimates permanent changes in in situ stress, induced fluid flow, or fracturing of rock, will be produced if these changes could be significant at the repository site.

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8.3.1.2.4.3.2.6.3 Basalt earthquakes (random)

Small earthquakes occur most frequently in the region of the Hanford Site as earthquake swarms in the basalt layers. The scaling of these small earthquakes in terms of seismic moment, ground motion, stress and strain changes, and static offsets are not well-known or are regionally variable, so that more emphasis will be placed on locally collected data as input to models of basalt earthquakes. Estimates must be made as to the randomness of shallow earthquakes. There is no one-to-one correlation of earthquakes to faults, structures, or the thickness of the basalts, although tendencies to correlate with some of these features may be refined. Therefore, the average rates of earthquake occurrences in the basalts may be described as an average rate per unit volume or area of basalts, the area or volume possibly being selected based on the observed pattern of earthquakes.

Recurrence curves based on the observed rate of seismic activity will be used to estimate recurrence rates for events at a random location. The recurrence relationship will be truncated at a maximum magnitude event, which is based on the largest earthquake that could be expected to occur without having any surface geological or geophysical expression.

Alternatively, the maximum magnitude event may be estimated by extrapolation of recurrence curves until the total strain rate (estimated independently) is exceeded (e.g., Anderson and Luco, 1983). The frequency of occurrence of random earthquakes will be estimated as a function of distance from shafts and repository horizons, to estimate the possibility of significant ground motion (or other earthquake effects in the subsurface).

This approach to seismic design will necessarily involve a partially probabilistic approach described in more detail below. Random events in sub-basalt horizons may also be similarly analyzed if required, although the effects of deep earthquakes are not as likely to influence seismic design. The frequency of occurrence estimates must then be combined with estimates of ground motion (surface and subsurface) for basalt earthquakes as a function of the distance and depth distribution of the earthquakes. Ground motion predictions will include peak velocity, acceleration, displacements, near-field stresses and strains, ground motion impedance effects, and measures of the variability in source strength via the stress drop distribution for small earthquakes.

8.3.1.2.4.3.2.6.4 Probabilistic models

Sensitivity analyses are an integral part of probabilistic ground motion calculations. These analyses will be conducted by exercising the theoretical and empirical models through a range of magnitudes, moments, or other fault parameters (e.g., length, width, area, slip, stress drop). The range of input parameters will be based upon the precision and accuracy of the projected event sizes and the variability of earthquake source parameters determined from data analyses.

A probilistic approach uses the sensitivity approach to determine the joint probability function for a specified measure of earthquake damage (e.g., peak acceleration, velocity, or response) by combining the probability functions for earthquake magnitudes, earthquake locations, and ground motion variability. Additional uncertainty will result from complex site-response effects at the surface, and when estimating high-frequency strong ground-motion, especially at subsurface location (e.g., Bender, 1984; 1986).

The results of a probabilistic risk assessment for the Hanford region is given in WPPSS, 1981, Appendix 2.5 K. These methods will be used for analysis of probabilistic risk assessment in this analysis.

The locations and association of design basis earthquakes with known or inferred geologic structures will require assumptions based upon geologic and tectonic models for deformation in the region and on the structures. The projection or estimation of recurrence rates for such events and the maximum magnitude events possible require selection of appropriate data, much of which will be based on data analysis discussed previously. Actual input to the probabilistic calculations may use expert opinion as needed.

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8.3.1.2.4.3.3 Tectonic assessment study.

The tectonic assessment study addresses performance and design issue parameters relating to the style, location, characteristics, and probabilities of tectonic events and processes. Thus, the primary objectives of the tectonic assessment study are to develop tectonic models that satisfactorily explain the structural evolution of the crust in the Columbia Plateau and surrounding terrain over the last 15 m.y. and to develop disruptive event or process scenarios. Tectonic models can be used to estimate future tectonic processes and events over the preclosure and, especially, postclosure periods. The models can be further used in assisting in the development of design-basis ground motions and estimating fault displacement associated with earthquakes. These parameters can be used for the surface and subsurface environments of a repository in stability analyses and design of such facilities for the preclosure period. Models also can be used to estimate the frequency and amount of offset on faults during postclosure time for input to numerical models of groundwater flow. Because volcanism is related to tectonic processes, the frequency and likely products of Columbia River basalt and Cascade volcanism can be estimated for disruptive scenario development. The purpose is to determine whether tectonic processes could significantly alter the travel paths and travel times of groundwater and, thus, affect long-term waste isolation. Tectonic models also can be used to identify and characterize disruptive event and process scenarios to determine whether the repository can meet long-term conditions for waste isolation in accordance with the requirements of 10 CFR 60 (NRC, 1986) and 40 CFR 191 (EPA, 1985).

In order to achieve the above objectives, this study is divided into three tasks and analyses:

1. Analysis of tectonic models and constraints using available data.

2. Development of tectonic and volcanic disruptive scenarios from models and available data.

3. Preparation of an engineering geology report. The information to be obtained is identified in Table 8.3.1.2-21. The analyses are discussed below.

Parameters required for analyses of the system and site subsystem performance are listed in Table 8.3.1.2-18.

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8.3.1.2.4.3.3.1 Development and analysis of tectonic models and constraints using available data. Tectonic models for the Pacific Northwest, Yakima Fold Belt, and the region will be evaluated for relevance to the controlled area study zone and vicinity. The models will be categorized according to the type of data on which they are based, and their potential impact on a repository in the controlled area study zone. Models will be evaluated and tested with data in the literature and BWIP data base. Models that best fit these data will be used to help evaluate resource potential, to characterize expected events and processes for nominal case analyses, and to develop scenarios for disruptive events. Models that best fit the data will be tested at scales appropriate to the size of the area being modeled. Thus, large-scale models will be used for the controlled area study zone and smaller scale models will be used for scenarios of a more regional nature. Faulting, folding, subsidence, uplift, volcanism, and flooding are among the processes that will be evaluated.

The general approach for development and testing of tectonic models is the method of multiple working hypotheses elucidated by Chamberlain (1890). Data to be evaluated will be gathered in other studies and will include geologic maps and cross sections at various scales, borehole geologic and geophysical data, exploratory shaft mapping and test data, ground and aerial remote-sensing techniques (data from exploration geophysical surveys and aerial photographic, radar, and other imagery), seismological data, data from trenching, and geodetic data. In addition, similar types of data in available published literature (journals, consultant reports, state and Federal surveys and agencies, utility studies for nuclear powerplants) also will be gathered, so that working hypotheses can be formulated and tested with data and interpretations in the BWIP system. The general sequence of evaluating these data is shown on Figure 8.3.1.2-43.

Table 8.3.1.2-21. Contents of engineering geology report

Dynamic characteristics of surface environment
Vibratory ground motion (particle acceleration, velocity, and displacement, frequency, and time history for expected maximum near- and far-field event(s) for use in preparing response spectra for engineering design)
Surface faulting (potential amount, location, extent, and type of displacement)
Dynamic characteristics of subsurface basalt environment
Vibratory ground motion (particle acceleration, velocity, and displacement, frequency, and time history for expected maximum near- and far-field event(s) for use in preparing response spectra for use in engineering design)
Fault displacement (location, areal extent, type and amount of displacement and slip frequency) on any faults within layout area
Elastic properties of layers in dynamic analyses models
Basalt and interbed stratigraphic units above Cohassett flow (thickness, density, shear and compressional wave velocities)
Sediment (soil) strata in Ringold and Hanford Formations
Fault data
Location, orientation, areal extent, width, type and amount of displacement, characteristics of fault-filling material for any faults within the controlled area study zone or beyond that influence groundwater flow models or boundary conditions thereto

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Table 8.3.1.2-22. Data needed for analyses of system performance (nominal case and disruptive scenario analyses)

Fault characteristics		
Static	Preclosure	Postclosure
Location	•	•
Orientation (strike, dip)	•	•
Areal extent	•	•
Fault zone width	•	•
Type of fault	•	•
Total displacement	•	•
Transmissivity of fault-filling material	--	•
Sorption of fault-filling material	--	•
Geochemistry of fault-filling material	--	•
Dynamic		
Slip rate	•	•
Displacement per event	•	•
Earthquake size	•	•
Source parameters	•	•
Volcanism		
Columbia River Basalt		
Location of vent	•	•
Extent and width of vent	•	•
Frequency of eruption	•	•
Volume of eruption	•	•
Direction of flow	•	•
Cascade volcanism	--	--
Location of vent	•	•
Type (viscosity) of lava	--	•
Eruption character	--	•
Volume of eruption	•	•
Frequency of eruption	•	•
Direction and extent of lava or mud flow	--	•
Volume and type of ejecta	•	--
Height of ejecta column	•	--
Wind characteristics (direction, speed, duration, frequency)	•	--

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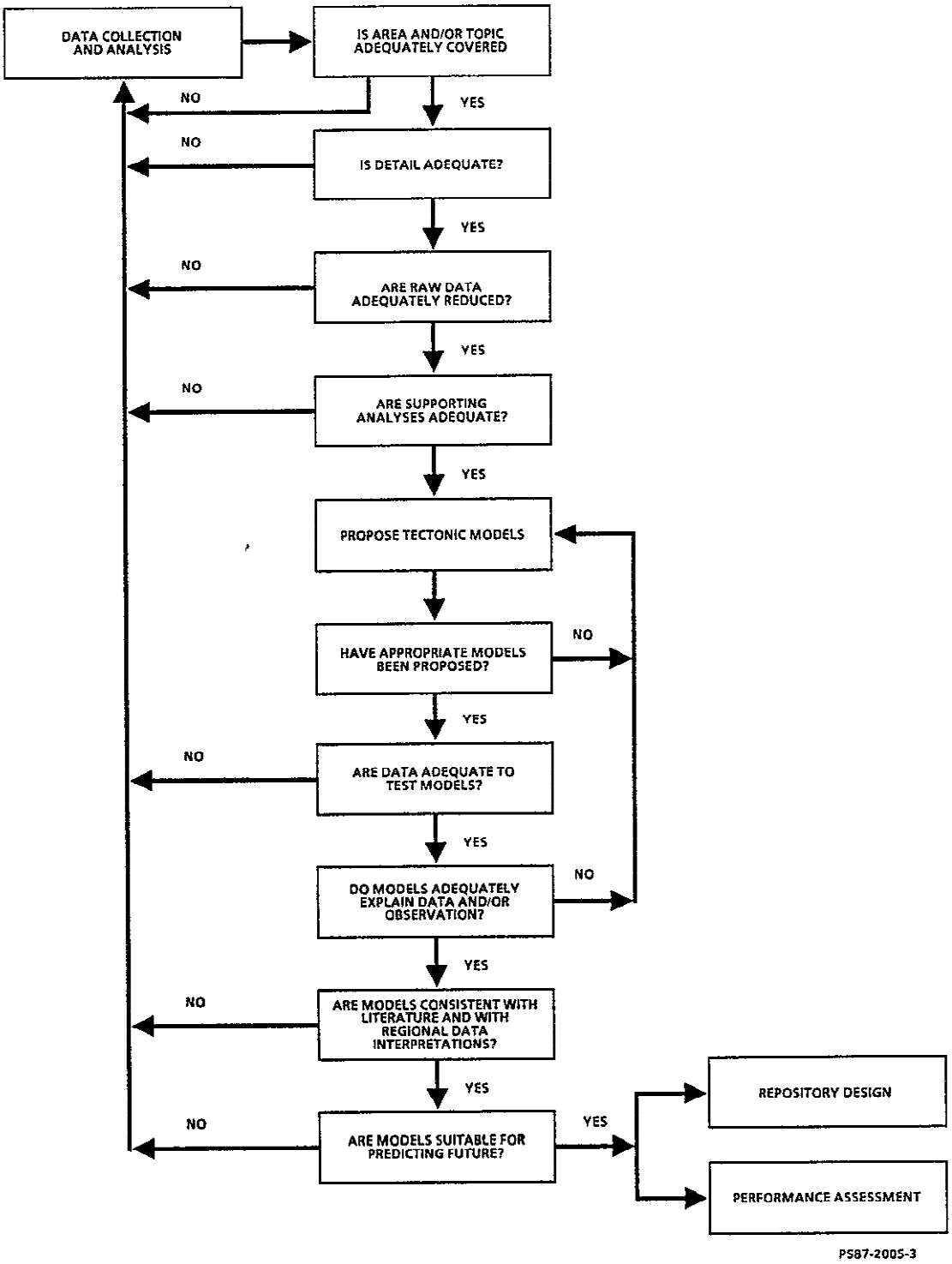

Figure 8.3.1.2-43. Flow chart for data integration and tectonic model development and (or) testing.

The steps that lead to a preferred model or group of alternative models include the following:

1. Review the available literature regarding the stratigraphy, structural geology, and tectonics for western North America, the Pacific Northwest, and the Columbia Plateau. Prepare a compilation of this information.

2. Compare the models proposed to explain the tectonic setting with available geologic, geophysical, seismologic, and geodetic data for the candidate area.

3. Identify models or elements of models that have the potential to affect the geologic stability of the candidate site.

4. Evaluate the potential impacts on the candidate site and repository of future tectonic activity that are suggested by models.

Step 1 has been completed (Caggiano and Duncan, 1983; Tolan, 1986), with the exception of updating the compilation with new ideas that are proposed in the literature or developed in this program. Table 1.5-1 presents a current compilation of models and a preliminary assessment of the impact that various classes of models might have on the stability of the reference repository location.

Step 2 is well underway as part of the initial stages of the site selection process. The progress to date in making these comparisons is reflected in the interpretations of the origin of structures described in Section 1.3.2.2.2. Reevaluation of current models will continue throughout the site characterization period as new data become available to test hypotheses. Indeed, it will continue throughout subsequent licensing activities if the site is selected for the first geologic repository.

Step 3 will be accomplished at several geographic scales and levels of detail. The screening of models for further use in evaluating the geologic stability of the site, and assessing the impacts to waste isolation, will consider the rates at which deformation is occurring, the distances from the site at which events are likely to occur, and the magnitude of structural changes that are possible. For example, the kinematics of folding and faulting within a Yakima fold will be analyzed in much greater detail than will the kinematics of subduction of the Juan de Fuca oceanic plate. An understanding of how both operate within the present tectonic regime, however, is important if the project is to instill confidence in future predictions of geologic stability.

Step 4 considers the impact that various aspects of future tectonic activity might have on the geologic stability of the candidate site. This is a two-step process in itself, since it will consist of identifying potential changes to the physical characteristics of the site, and of assessing the potential influence of those changes on the capability of the repository to isolate radioactive wastes.

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Analyses will be conducted to develop one or more tectonic models at several scales and levels of detail. The areas are (1) the repository site, (2) the controlled area study zone (3) the Cold Creek syncline, (4) the Pasco Basin, and (5) the region. These conceptual models will be illustrated on maps and cross sections at scales suitable for analysis.

A summary identifying the impact that tectonic activity might have on the geologic stability of the site can be found in the Environmental Assessment (DOE, 1986, pp. 6-158 to 7-172). Some discussion of the impact on waste isolation is also presented; however, most conclusions are pending the results of site characterization analyses. Part of this work will be to assign probabilities to the occurrence of particular events, such that a semi-quantifiable risk assessment can be made regarding the release and dispersion of radioactivity.

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8.3.1.2.4.3.3.2 Development of tectonic and volcanic disruptive scenarios from models and available data. Data to be used to bound analyses, to analyze radionuclide transport in the controlled area study zone, or to determine boundary conditions for analyses of radionuclide transport in the controlled area study zone are listed in Table 8.3.1.2-22. Fault and volcanism data are shown as to whether they are used for analyses of the preclosure or postclosure period.

Using the tested tectonic models, disruptive scenarios will be identified that could affect waste isolation. Potentially disruptive events will be identified for the repository near field and for the Pasco Basin and region if there is a potential for any of these events disrupting the flow of groundwater and (or) the travel time of radionuclides from the repository to the accessible environment. Scenarios involving disruptive events will be evaluated with data and interpretations contained in the open literature and in the BWIP data base. Sensitivity studies will be conducted to determine those scenarios that may have a significant impact on the route or rate of groundwater flow. For those which do impact groundwater flow and, thus, waste isolation, the characteristics of the event and probabilities of occurrence will be determined for computer model studies of long-term repository performance.

Parametric data will be supplied for sensitivity studies to determine the system and subsystem parameters important to long-term performance of the repository. These analyses will be followed by disruptive scenario analyses in which the probability of occurrence of initiating tectonic and volcanic events, and (or) processes and parameter values, will be provided to performance assessment personnel for analyses of system and subsystem performance. If parameter values adequate for analyses cannot be provided or the data provided are inadequate for analyses, the data needed for further analyses will be determined. These data needs will be transmitted to those conducting work under other study plans to allow incorporation of appropriate investigations into plans to acquire the needed data.

Analyses of system performance will be conducted as part of performance assessment with appropriate input from site and other programs that supply data obtained from various studies. Performance assessment system models will analyze radionuclide transport in the repository and controlled area, with data and information from surrounding areas as input to the boundary conditions governing the models for analysis. Probabilities and parametric data on tectonic and volcanic events and features will be supplied to the performance assessment program for input to computer models of system performance. Data will be used in sensitivity studies, nominal case analyses, and subsequently, disruptive scenario analyses determined to be significant to system performance.

For disruptive events and disruptive scenarios outside the controlled area, scenarios will be analyzed as part of the site program, and any changes in values for key parameters, different than those used in nominal case and sensitivity analyses, will be supplied to the performance assessment program for use in modifying boundary conditions of the system computer models. Analyses within the site group of disruptive events will be conducted in steps as follows:

1. Identify a disruptive event scenario.

2. Develop fault and (or) event trees to obtain the probability of the initiating event.

3. Develop fault and (or) event trees to obtain the probability of specific disruptive geologic consequences of the scenario. This may include developing values of other parameters for use in analyses (e.g., characteristics of geologic faults-geometry, extent, type, width, filling material).

4. Determine the consequences of the tectonic or volcanic process and (or) event on key system parameters or boundary conditions of computer models of radionuclide transport within the controlled area.

5. Determine whether the new values for a system variable significantly affect performance of the disposal system.

6. If the new parameter value exceeds that used in nominal case analyses, transmit new value(s) to performance assessment for further analyses of system performance.

Outside experts may be consulted in the preparation of fault and (or) event trees and in determining probabilities. Consultants may be used either to lead the preparation of such trees or to conduct peer reviews of fault and (or) event trees and derived probabilities determined by the BWIP.

Disruptive events for which scenario development and characterization may be required include the following:

- Renewal of Columbia River basalt volcanism.
- Cascade Range volcanism.
  - Airfall ash.
  - Volcanically induced damming of Columbia River.
- Displacement on a new or existing fault.
  - In the repository.
  - In the controlled area beyond the repository.
  - Beyond the controlled area.
- Vibratory ground motion from Pasco Basin and regional earthquakes and its effect on hydrologic properties.
- Vibratory ground motion (or displacement) from microearthquakes in the controlled area study zone.

For all scenarios involving faulting, the data needed for analyses include the location of the rupturing fault, the type and amount of displacement on the rupturing fault, the spatial orientation of the fault, the areal extent of the fault zone (plane), the recurrence rate for slip on the fault, the width of the fault zone, and the characteristics of the material filling the fault zone (e.g., compaction, transmissivity, sorption, chemical and (or) mineral composition). For preclosure safety analyses, any potential earthquake(s) that may be developed by slip on the fault, along with the spectrum of vibratory ground motion, also will be needed. Specific observations of these parameters will be made in other studies for use in evaluating tectonic models and in supplying parametric data to performance assessment.

For all scenarios involving volcanic (igneous) activity, the data needed for analyses include the location of the vent, the frequency of eruption, the volume and rate or eruption, the composition of the erupting lava, the duration of the eruption(s), the volume and composition of pyroclastic ejecta, the possible dispersal pattern of the ejecta, and the thermal effects in the surrounding rock (see Table 8.3.1.2-23).

<u>8.3.1.2.4.3.3.3 Preparation of engineering geology report</u>. An engineering geology report that will detail dynamic characteristics of the surface and subsurface environments of the reference repository location for a repository will be prepared. Data derived from studies of tectonic deformation and seismology will be compiled, integrated, and analyzed to provide information on ground motions, fault characteristics, and fault displacements

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for use in design and performance assessment. Elastic properties of units appropriate for modeling the effects of vibratory ground motion on surface and subsurface constructed facilities will be included. Data and information for use in preparing response spectra and engineering analyses of stability of surface and underground openings will be provided to those conducting analyses of scenarios and long-term performance. No analyses of the effects of these processes on preclosure safety or postclosure system performance will be conducted by the site program.

8.3.1.2.4.3.3.4 Uses of the study. The results of this study will be used chiefly for site subsystem performance assessment. Tectonic models also will provide a framework that will support ground-motion input to seismic design (see application of results) and will provide documentation as to whether favorable conditions relative to tectonics are met by the site.

8.3.1.2.4.4 Application of results

8.3.1.2.4.4.1 Deformation study.

The deformation history of the Pasco Basin and the controlled area study zone provides constraints on the construction and analysis of the geohydrologic model which will be used to assess the performance of the repository. For example, analysis of projected incision of the Grande Ronde Basalt will be used in groundwater travel-time estimates; study of deformation mechanisms will be used to model the rheological behavior of the rock layers; geodetic surveys provide information on contemporary magnitudes and rates of deformation; and the synthesis of styles, mechanisms, and rates of deformation will provide estimates and constraints on the rate of deformation processes and the ages of structures. In addition, information about past and present deformation styles and rates provides a basis for the identification of potentially disruptive volcanic and tectonic scenarios. These scenarios, in turn, provide information to assess the long-term performance of a repository at the reference repository location.

Geologic deformation data will provide direct support to determining surface and subsurface ground motion by identifying those faults and structures that cannot be shown to have ceased growth. Study of geologic deformation will also be used to predict the likelihood of new faulting at the repository site. Information about the orientation(s) of the past and present local and regional stress field(s) is an important consideration both in design and layout of the repository.

The study of geologic deformation is conducted in conjunction with other geologic, hydrologic, and rock mechanics studies. Information from the deformation study will be used in the construction and analysis of structural geology, tectonics, hydrology, and coupled tectonics-hydrology models. Knowledge of the rate and location of future deformation is important to the studies both of long-term opening stability and of retrievability.

8.3.1.2.4.4.2 Seismology study.

The information derived from this study has been planned for use in performance assessment and seismic design.

8.3.1.2.4.4.2.1 Performance assessment. Based primarily on the results of the seismic source parameter studies, fault parameters will be used to evaluate the hydrologic changes that would occur if an earthquake or earthquake swarm were to occur within the hydrologic environment on which long-term isolation depends. The following list gives representative input to performance assessment of potential future earthquake scenarios.

- Dimension of fault planes.
  - Length of hydrologic pathway.
- Fault displacement.
  - Amount of slip.
  - Proportion of slip on pre-existing fractures.
  - Proportion of slip creating new fractures.
  - Aperture of fault, gouge thickness.
- Stress drop.
  - Induced fluid flow due to stress changes.
  - Duration of readjustment period.

In addition to the relatively static changes listed above, changes in head levels may also be induced by seismic waves. Although the mechanism for this effect is not currently understood, earthquakes have been observed to affect well levels at the site.

8.3.1.2.4.4.2.2 Design. Seismic design of repository systems and components will be required at the time of issuance of the advanced conceptual design, and license application design. Seismic design will be applied on two significantly different time scales, the construction, operation, and decommissioning phases (about 100 yr), and for a 10,000-yr repository lifetime.

- 100-yr operation period.
  - Surface structures-ground motion design.
  - Ground motion from mine-induced seismic activity.

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- Shaft liner design.
  - o Misalignment due to earthquakes.
  - o Stresses and strains induced by ground motion.

- Tunnel Stability.
  - o Induced rockfall due to ground motion or due to static stress changes.

- 10,000-yr isolation period.
  - Potential for canister rupture due to fault intersection seal design for earthquake ground motion and displacement.

8.3.1.2.4.4.2.3 Characterization. Integration of earthquake seismology information with other studies will be done largely within the tectonic assessment study. Integration of other study data (especially in correlations of earthquakes with geological or geophysical features) occurs in the deformation and earthquake seismology study. Additional activities within this study include seismic risk estimation which will require input from the tectonic assessment study. All of these studies will be overlapping, and will require further definition of tie-in points.

Locations of earthquakes or earthquake swarms will be studied using geophysical surveys to detect any possible clues to evaluation of the association of geophysical measurements with areas susceptible to future earthquake swarm activity. Regional velocity models derived in this study may be further refined using geophysical techniques, and thus are used in planning of geophysical surveys, and as an aid in interpreting the results.

Potential seismic sources, determined to be significant to either performance or design based on ground motion estimates from this study, may require detailed geological study to determine fault slip rates, date of last movement, and fault length/width estimates.

The potential for seismicity induced by repository construction and operations, or by other human activity, will be evaluated. The effects of induced seismicity on the performance of the repository systems will be analyzed using methods similar to those applied to the naturally occurring earthquakes.

8.3.1.2.4.4.3 Tectonic assessment study.

The information derived from this study has been planned for use in performance assessment and seismic design, and in parallel development with other characterization activities.

8.3.1.2.4.4.3.1 Performance assessment. The evaluation of future repository performance can be accomplished using computer models replicating the present and past repository environment so that forward projection will allow a conceptual and numerical understanding of the future behavior of the disposal system. In assessing the safety of a repository, the possible effects of natural events and processes on the disposal system must be

evaluated probabilistically. For purposes of analyses of future repository performance, the NRC distinguishes anticipated and unanticipated events and processes. The EPA specifies that the events and processes considered are those having a 1 in 10,000 (or greater) chance of occurring over 10,000 yr; those with a lesser chance are not considered. Scenarios are then specific combinations of initiating events and (or) processes allowing calculation of consequences and risks for the repository. Analyses of scenarios thus constitute an integral part of performance assessment. Only those scenarios that may pose significant consequences for a waste repository will be analyzed. This approach will identify key system and subsystem variables:

- Assign technically reasonable limits on these variable parameters using available data and professional judgment.

- Conduct preliminary analyses (sensitivity analyses) to determine which variables are truly significant to system and subsystem performance.

Assessment of the disposal system performance can then be continued by postulating events and (or) processes resulting in extreme, but possibly significant, values of such parameters (i.e., postulating scenarios that could result in values of these parameters beyond those considered reasonable in the preliminary scoping (sensitivity analyses)). Only those events and processes that could significantly impact waste isolation and system performance would be investigated during site characterization with the intent to provide appropriate data on recurrence, probabilities, and consequences for scenarios allowing further analyses of system performance.

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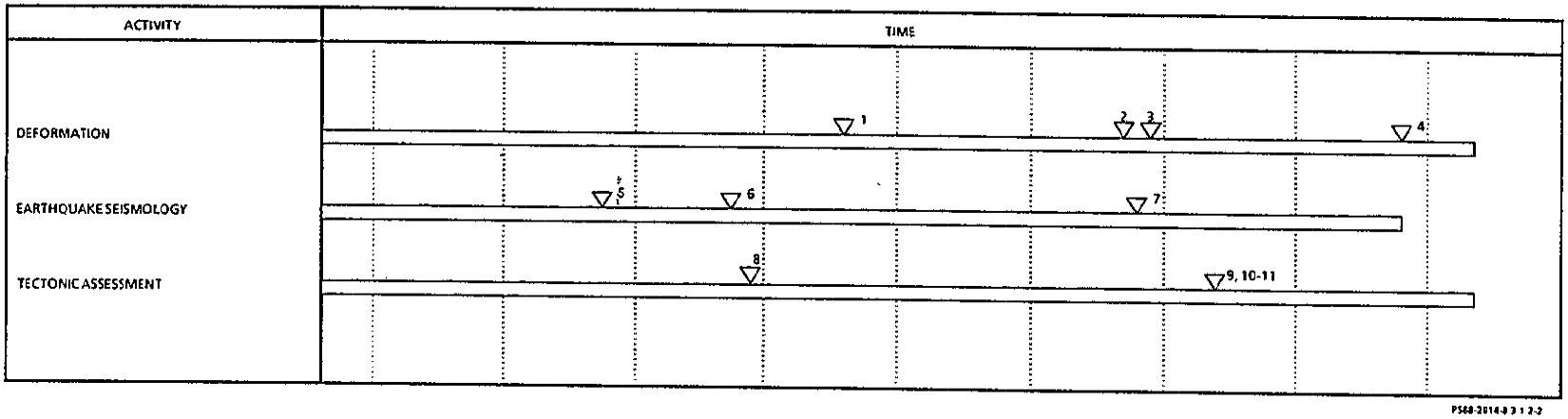
8.3.1.2.4.4.3.2 Design uses. The direction of in situ stress may be used in the design and stability analyses of tunnels and roof supports and may be a factor in retrievability of the waste. The potential for movement on existing structures and the potential for development of new structures will be considered in design of the waste package. Seismic design of repository facilities also will use the data from this investigation.

8.3.1.2.4.4.3.3 Characterization uses. Tectonic models will assist in evaluation of the site against favorable and potentially adverse unfavorable conditions relating to tectonics in Issues 1.8 and 1.9. Tectonic models may also be useful in evaluating the potential for geothermal and hydrocarbon resources in the Columbia Plateau.

8.3.1.2.4.5 Schedules and milestones

Generalized schedules and major milestones of the tectonic events and processes investigation, the deformation study, the earthquake seismology study, and the tectonic assessment study, are shown in Figure 8.3.1.2-44.



1 UPDATED STRUCTURE MODEL FOR LAD.
2 REPORT ON TIMING AND RATE OF MIOCENE DEFORMATION
3 REPORT ON PLIOCENE--QUATERNARY DEFORMATION
4 REPORT ON SYNTHESIS OF DEFORMATION DATA FOR THE DRAFT ENVIRONMENTAL IMPACT STATEMENT
5 PUBLISH BASALT WASTE ISOLATION PROJECT EARTHQUAKE CATALOG
6 GROUND MOTION ESTIMATES FOR ACD.
7 GROUND MOTION AND SEISMIC SOURCE PARAMETER REPORTS FOR LAD.
8 INPUT PART B ENGINEERING GEOLOGY REPORT TO ACD.
9 INPUT PART B ENGINEERING GEOLOGY REPORT TO LAD.
10 INPUT TECTONIC PARAMETER DATA TO PERFORMANCE ASSESSMENT SENSITIVITY STUDIES.
11 INPUT TECTONIC SCENARIOS AND DATA TO PERFORMANCE ASSESSMENT NOMINAL CASE AND DISRUPTIVE SCENARIO ANALYSES.

ACD = ADVANCED CONCEPTUAL DESIGN
LAD = LICENSE APPLICATION DESIGN

Figure 8.3.1.2-44. Schedules and milestones for the tectonic events and processes investigation.

CONSULTATION DRAFT

8.3.1.2.5 Mineralogy and petrology investigation

The mineralogy and petrology investigation comprises only one study, the mineralogy and petrology study. Therefore the purpose, objectives, and rational for the investigation are the same as those for, and apply to, the study.

8.3.1.2.5.1 Purpose and objective

Following are the objectives of the mineralogy and petrology investigation and study: (1) to characterize the rocks, minerals and mineral assemblages in the repository layout area, controlled area study zone and Cold Creek syncline, (2) to provide illustrations of the inferred distribution of the rocks, minerals, and mineral assemblages, and (3) to assess the chemical stability of individual phases and of the geochemical environment under natural and repository conditions.

The kinds of information to be obtained in the study are mineral abundances, petrographic features, compositions, ages, formation conditions (e.g., temperature, pressure, and composition), and spatial distributions of primary and secondary minerals in basalt, tectonic joints, faults, cooling joints, and interbeds.

The information obtained will be used in hydrochemistry, near-field geochemistry, geological characterization, and performance assessment. Hydrochemical models must account for the influence of the solids with which the groundwater is in contact. Waste package design must account for mineralogic properties in the near-field that are subject to change under repository operating conditions. Petrographic characterization is used extensively in geologic characterization activities which in turn supports repository layout and design. In support of performance assessment, spatial distributions of mineralogic and petrologic properties are used as a basis for estimating sorption coefficients along flowpaths. Mineralogic and geochemical stability also are factors in performance scenarios spanning the next 10,000 to 100,000 yr.

Justification for obtaining the information required by this investigation is based on performance measures and parameters derived from the issues in Section 8.2.2. Table 8.3.1.2-23 presents the issue identified parameters within the mineralogy and petrology investigation. These parameters deal with the mineralogy and geochemistry of primary and secondary minerals of the basalt and interbed stratigraphy and rock discontinuities.

The regulatory guidance addressed by the pertinent issues is of two general types: that which pertains to characterization, classification and inventory, of the rock materials constituting the site and that which pertains to an understanding of the chemical behavior of these materials under natural and repository induced conditions. The latter category includes processes and events that could result in changes in rock mass properties that could affect the ability of the rock mass to act as a barrier to the migration of radionuclides.

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Table 8.3.1.2-23. Parameters addressed by the mineralogy and petrology study (sheet 1 of 2)

Performance parameter	Issue	Scale/ location	Supporting parameter	Tentative parameter accuracy	Constraints on goal or accuracy
Cooling joint and fault infilling (e.g., grain)	1.1, 1.2, 1.3	CASZ	Secondary mineral modes	±5 modal %	Varies as a function of physical characteristics (size and abundance)
Postclosure--secondary minerals formed	1.4, 1.5	Host rock	Secondary mineral modes	±5 modal %	Varies as physical characteristics of sample
			Secondary mineral textures	Qualitative description	None major
			Chemical composition of secondary phases	±0.1 wt %	Varies as function of oxide measured
Postclosure environment--repository horizon bulk composition	1.4, 1.5		Ferrous/ferric ratio of secondary phases	0.1 to 1.0	Method dependent
			Structural, adsorbed, and total water content of secondary phases	±1 wt %	None major
			Paragenesis	Qualitative	Depends on test results used
Changes in mineral assemblages of secondary minerals	1.8 (PAC-9)	Host rock	Secondary mineral modes	±5 modal %	Varies as function of physical characteristics of samples
After hydrothermal treatment			Secondary mineral textures	Qualitative description	None major
			Chemical composition of secondary minerals	±0.1 wt %	Varies as function of oxide measured
			Ferrous/ferric ratio of secondary minerals	0.1 to 1.0	Method dependent
			Structural, adsorbed, and total water for secondary minerals	±1 wt %	None major
	1.8 (PAC-9)	RIS/CASZ	Structural, adsorbed and total water content of basalt	±1 wt %	None major
	1.8 (PAC-9)	RIS/CASZ	Distribution of secondary minerals	Distribution	Depends on accuracy of used test results
	1.8 (PAC-9)	RIS/CASZ	Paragenesis	Qualitative	Depends on test results used
	1.8 (PAC-9)	RIS/CASZ	Mineral stability	Qualitative and quantitative description	Depends on test results used
	1.8 (PAC-9)	RIS/CASZ	Isotopic age dates for secondary minerals	Absolute age	Varies as function of isotope measured and abundance

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Table 8.3.1.2-23. Parameters addressed by the mineralogy and petrology study (sheet 2 of 2)

Performance parameter	Issue	Scale/ location	Supporting parameter	Tentative parameter accuracy	Constraints on goal or accuracy
Redox potential of groundwater based on presence of redox sensitive secondary minerals	1.8 (PAC-9)	RIS/CASZ	Secondary mineral modes	±5 modal %	Varies as function of physical characteristics of samples
			Chemical composition of secondary minerals	±0.1 wt %	Varies as function of oxide measured
			Ferrous/ferric ratio of secondary phases	0.1 to 1.0	Method dependent
			Primary mineral modes	±5 modal %	Varies as function of physical characteristics of sample
			Chemical composition of primary minerals	±0.1 wt %	Varies as function of oxide measured
			Chemical composition of basalt	Chemical composition	Varies as function of element or oxide
			Ferrous/ferric ratio of basalt	0.1 to 1.0	Method dependent
			Interbed mineralogy	±5 modal %	Varies as function of physical characteristics of sample
Redox potential of groundwater based on isotopic ratios of sulfur or carbon species	1.8 (PAC-9)	RIS/CASZ	Stable isotope composition of secondary minerals	Isotopic composition	Varies as function of isotope measured
Alteration (joint alteration, weathering, and staining)	2.4, 4.2	Host rock	Primary mineral modes	±5 modal %	Varies as function of physical characteristics of sample
			Primary mineral textures	Qualitative description	None major
Alteration (joint alteration, weathering, and staining) (cont.)	2.4, 4.2	Host rock	Chemical composition of primary minerals	±0.1 wt %	Varies as function of oxide measured
			Chemical composition of basalt	Chemical composition	Varies as function of oxide or element
			Bulk and powder densities	±0.001 g/cm^3	None major
Infilling/minerals	2.4, 4.2	Host rock	Secondary mineral modes	±5 modal %	Varies as function of physical characteristics of sample
			Chemical composition of secondary minerals	±0.1 wt %	Varies as function of oxide measured

CASZ = Controlled area study zone.
PAC = Potentially adverse condition.
NA = Not applicable for analyses.
RIS = Repository isolation system.

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Mineralogy and petrology addresses issues 1.1, 1.2, 1.3, 1.4, 1.5, 1.8, 1.9, 2.4, 2.5, 4.1, 4.2.

8.3.1.2.5.2 Rationale

The mineralogy and petrology investigation and study derive from the need, as specified in the regulatory guidance, to understand the geochemical environment in terms of its chemical compatibility with the waste package, its capacity to act as a barrier to the migration of wastes escaping the waste package, and its potential to change over the lifetime of the repository.

Petrologic studies to date (summarized in Chapters 1 and 4) have initially emphasized characterization of flow interiors because of the need to develop stratigraphic discriminators and to understand textural/modal variations within and among flows. However, the current data are incomplete or uncertain with regard to some aspects of the mineralogic and petrologic environment of the site which are considered important in assessing the chemical stability.

Future work will emphasize the study of secondary mineralization within fractures, tectonic joints and faults, vesicles and flowtops, and the characterization of primary and secondary (detrital and authigenic) minerals in interbeds. Secondary minerals occupy potential groundwater flow paths, having precipitated from groundwater during and subsequent to subsidence of the basalts in the Pasco Basin. Thus, secondary minerals reflect the history of rock/water chemistry since emplacement of flows. Waste isolation capabilities are dependent, in some as yet unspecified degree, on the effectiveness of the secondary mineral assemblage in limiting radionuclide migration, either by restricting fluid flow or by sorption of radionuclides.

The conditions noted above pose two problems to the investigation and study. First, the rigorous characterization of rocks and mineral assemblages is made difficult by the lateral and vertical lithologic and mineralogic heterogeneity of the site and by the spatially restricted distributions of minerals in faults and fractures. The qualitative relations among secondary minerals, basalts, and interbeds are apparent, but no quantitative description yet exists of the rock package(s) containing the repository. Characterization in a quantitative context includes demonstrations of areal and stratigraphic variability of mineralogic properties. Quantitative demonstrations of spatial variations are difficult even in relatively homogeneous media such as granite; secondary minerals and interbed mineralogy pose especially difficult problems. Second, the assessment of trends and rates of chemical change is complicated by metastable phases in the ranges of pressure and temperature considered here, and by the paucity of datable materials.

The two problems, although interrelated, conveniently define a division to the investigation and study comprising two components. The first component (characterization of mineralogic properties) is designed primarily for data acquisition and presentation while the second (characterization of mineralogic stability) is designed primarily for interpretation of data.

8.3.1.2.5.2.1 Constraints on the investigation and study.

The following considerations constrain the investigation and study.

Reduction of uncertainty in models of spatial variability is required. Such requirements could form partial justification for new borehole placement.

1. The study will need to simulate repository conditions. Borehole samples from the repository location are required, and in situ conditions will need to be observed and evaluated in the exploratory shaft. No significant interference is expected between the activities of the study and exploratory shaft facility design and construction.

2. Several scales of compositional and mineralogic variation might conceivably exist, ranging from microscopic to megascopic scales. Analytical methods enable full characterization of variability within small samples, but at larger scales statistical and geostatistical techniques will be required.

8.3.1.2.5.3 Description of study

8.3.1.2.5.3.1 Mineralogy and petrology study.

The mineralogy and petrology study is divided into the following two components and associated tasks:

1. Characterization of mineralogic properties.

   - Characterization of primary mineralogy of basalt.
   - Characterization of secondary mineralogy of basalt.
   - Characterization of infilling mineralogy of faults and fractures.
   - Characterization of sedimentary interbeds.

2. Characterization of mineralogic stability.

   - Paragenesis of secondary minerals.
   - Stability of primary and secondary phases in basalt.
   - Stability of interbed mineralogy.
   - Stability of the geochemical environment.

The tasks of the first study component are concerned with collection and analysis of mineralogic data and the relationship of the data and uncertainty estimates to spatial position. The tasks of the second study component address the geochemical history and the projection of past rates of change into the future.

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8.3.1.2.5.3.1.1 Characterization of mineralogic properties. Each of the four tasks of the characterization of mineralogic properties involves essentially the same program of activities, differing mainly in the nature of the mineral assemblages to be characterized. Therefore, several of the parameters to be obtained are common to all four tasks: (1) whole rock chemical composition of basalt including major element concentrations, some trace element concentrations, and, for some samples, water content; (2) chemical composition of individual primary and secondary phases (major elements only); (3) primary and secondary mineralogy of basalt and detrital and authigenic mineralogy in interbeds; (4) quantitative or semi-quantitative mineral abundances; (5) petrographic textures; (6) potassium-argon (K/Ar) ages of potassium bearing secondary phases; (7) ferrous/ferric ratios for whole rock basalt and selected iron-bearing secondary phases; (8) structural, absorbed, and total water content for individual, hydrous secondary phases; and (9) bulk and powder densities of basalt.

Table 8.3.1.2-24 lists the methods to be used to obtain the parameters listed above. Most of the methods are standard analytical, petrologic tools. With the exceptions of x-ray fluorescense, K/Ar, and Mossbauer analyses that will be done by subcontractors, equipment for all of the methods are available within the BWIP.

All modern, analytical instruments used to determine rock and mineral composition and crystallographic parameters electronically collect and reduce data to produce either computer listings of the data, strip chart recordings, magnetic tapes or computer disks. Such instruments also provide quantitative estimates of analytical error. Further analysis of the data involves statistical manipulation to derive parameters for describing mineral and chemical populations.

Geochemical data, excepting textural descriptions, is amenable to graphic presentations. Kinds of graphs and plots include variation diagrams, activity diagrams, T-P diagrams, fugacity and Eh-pH diagrams, and plots of various parameters on maps and cross sections.

Current plans include incorporation of all data into the relational NOMAD data base. This will allow quick, easy comparisons of data. Computer programs are either available or will be developed to manipulate data into forms amenable for analysis. Such manipulations include calculation of norms, chemical modes, and structural formulas.

The following elements are also important in characterization of mineralogic properties:

- Samples--Part of the study is keyed to the development of structural/ stratigraphic models to show spatial variability. Samples are constrained by the locations of boreholes, outcrops, the Exploratory shaft, and boreholes drilled out from the shaft. Samples will be grouped areally and will be, therefore, spatially biased. Some samples will be highly restricted in occurrence (e.g., secondary minerals in faults). Statistical methods are required to demonstrate the spatial distribution of uncertainty in mineralogic properties.

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Table 8.3.1.2-24. Tasks/tests/analyses for the mineralogy and petrology study (sheet 1 of 3)

Tasks/tests/analyses	Methods	Location/ scale	Number of tests	Information for analyses	
				Data	Results
Characterization of mineralogic variability:		RIS/CASZ	160		
Primary mineralogy of basalt flows	Petrographic			Mineral abundances and textures	Spatial range of minerals
	Chemical analysis of phases			Elemental abundances	Variation in chemical composition
	Chemical analysis of bulk rock			Elemental abundances	Variation in chemical composition
				Ferrous/ferric ratio	Buffering capacity
				Water content	Effects of hydration and dehydration
				Bulk and powder densities	Elemental gains and losses due to alterations
	X-ray diffraction analysis			Mineral abundances	Spatial range of minerals
Characterization of mineralogic variability:		RIS/CASZ	320		
Secondary mineralogy of basalt flows					
	X-ray diffraction analysis			Mineral abundances	Spatial range of minerals
	Petrographic analysis			Mineral abundances and textures	Spatial range of minerals
	Chemical analysis and phases			Elemental abundances	Variation in chemical composition
	Age dating analysis			K/Ar and $^{14}C/^{12}C$ ratios	Absolute ages of minerals
Characterization of mineralogic variability:		RIS/CASZ	160		
Mineralogy of fault and tectonic joint infilling	X-ray diffraction analysis			Mineral abundances	Spatial range of minerals

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Table 8.3.1.2-24. Tasks/tests/analyses for the mineralogy and petrology study (sheet 2 of 3)

Tasks/tests/analyses	Methods	Location/ scale	Number of tests	Information for analyses	
				Data	Results
Mineralogy of fault and tectonic joint infilling (cont.)	Petrographic analysis			Mineral abundances and textures	Spatial range of minerals
	Chemical analysis of bulk-rock			Elemental abundances	Variation in chemical composition
				Ferrous/ferric ratio	Buffering capacity
				Water content, bulk, and powder density	Dehydration effects, elemental gains and losses due to alteration
	Chemical analysis of phases			Elemental abundances	Variation in chemical composition
Characterization of mineralogic variability:		RIS/CASZ	280		
Mineralogy of interbeds					
	Petrographic analysis			Mineral abundance and texture	Spatial range of minerals
	X-ray diffraction analysis			Mineral abundance	Spatial range of minerals
Characterization of mineralogical stability:[a]		(b) (a)	(b) (a)		
Paragenesis of secondary minerals	Use of determative mineralogic information and textural characteristics			Aspects of evolution of geochemical environments	Interpretation of past geochemical environments and prediction of future environments
Characterization of mineralogic stability:[a]		(b) (a)	(b) (a)		
• Stability of primary phases • Stability of secondary phases • Stability of interbeds	Use of determinative mineralogic information, petrographic characteristics, chemical compositions, and radiometric ages			Evaluation of mineral stabilities	Interpretation of past geochemical environments and prediction of future environments

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Table 8.3.1.2-24. Tasks/tests/analyses for the mineralogy and petrology study (sheet 3 of 3)

Tasks/tests/analyses	Methods	Location/ scale	Number of tests	Information for analyses	
				Data	Results
Characterization of mineralogic stability:[a] (cont.)	Use of published kinematic and thermochemical information and mineral assemblage stabilities				
Characterization of mineralogic stability:[a]		(b)	(b)		
Stability of the geochemical environment	Use of mineral stabilities, paragenesis, and age dates			Evaluation of stability of geochemical environment	Prediction of performance of repository

CASZ = Controlled area study zone
RIS = Repository isolation system.
[a]Analysis activity. All other activities are test activities.
[b]Not required for analysis activities.

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The location of 19 existing deep, cored boreholes from which samples can be obtained for mineralogic study are shown on Figure 8.3.1.2-45. There are, in addition, nine rotary holes (DC-1, DC-3, DC-5, DC-16C, DC-19C, DC-20, DC-22C, RRL-2B, and RRL-2C) from which chips can be obtained. Proposed boreholes include rotary holes DC-23CX, DC-24CX, DC-32CX, and DC-33CX to be drilled inside the controlled area study zone; DC-25CX to be drilled east of the controlled area study zone; six other boreholes, primarily for hydrochemical characterization, to be drilled outside the reference repository location; and two cored holes proposed for intraflow structure studies in the reference repository location. A deep borehole, to sub-basalt depths, is under consideration; its need will be assessed in a position paper. This borehole would be multidisciplinary in purpose and would also provide stratigraphic hydrologic, rock deformation, mineralogy and petrology, structural, and resource potential data. A deep borehole is of special geochemical significance because basalt samples with secondary minerals could be obtained from depths corresponding to 150 °C. This is the estimated maximum temperature expected in the host basalt (Yung et al., 1986).

The total number of samples required to meet the objectives of petrologic characterization depends on mineralogic and geochemical heterogeneities within and among samples. For these reasons, most aspects of petrologic studies are iterative, in that the acquisition and analysis of succeeding batches of samples depends on results obtained from preceding batches.

- Major element composition--Available major element compositions are mostly from samples from dense interiors. Approximately 11% of the analyses, however, represent portions of drill core which were logged as brecciated, vesicular, or vuggy and about half of these samples yield one or more oxide values lying outside the two sigma range of the reported means. Future work, to look specifically at the major element composition of flow tops to determine whether or not they are significantly different than dense interiors, may be useful. It is important also to group samples collected from brecciated, vesicular, and vuggy zones separately from dense interior samples during future manipulations of geochemical data. Work will emphasize rocks encountered in new boreholes and rocks from those portions of the rock packages from which little data are available.

  For stratigraphic purposes, two to three samples will be obtained from each flow interior encountered in new boreholes. These samples will be submitted for x-ray fluorescence analysis and the results used for correlation of rock units and delineation of any variations in chemical composition. For selected samples, bulk and powder densities will by obtained by pycnometer. The densities will be used in conjunction with the x-ray fluorescence data from fresh and altered basalt to determine absolute gains and losses in major elements due to alteration.

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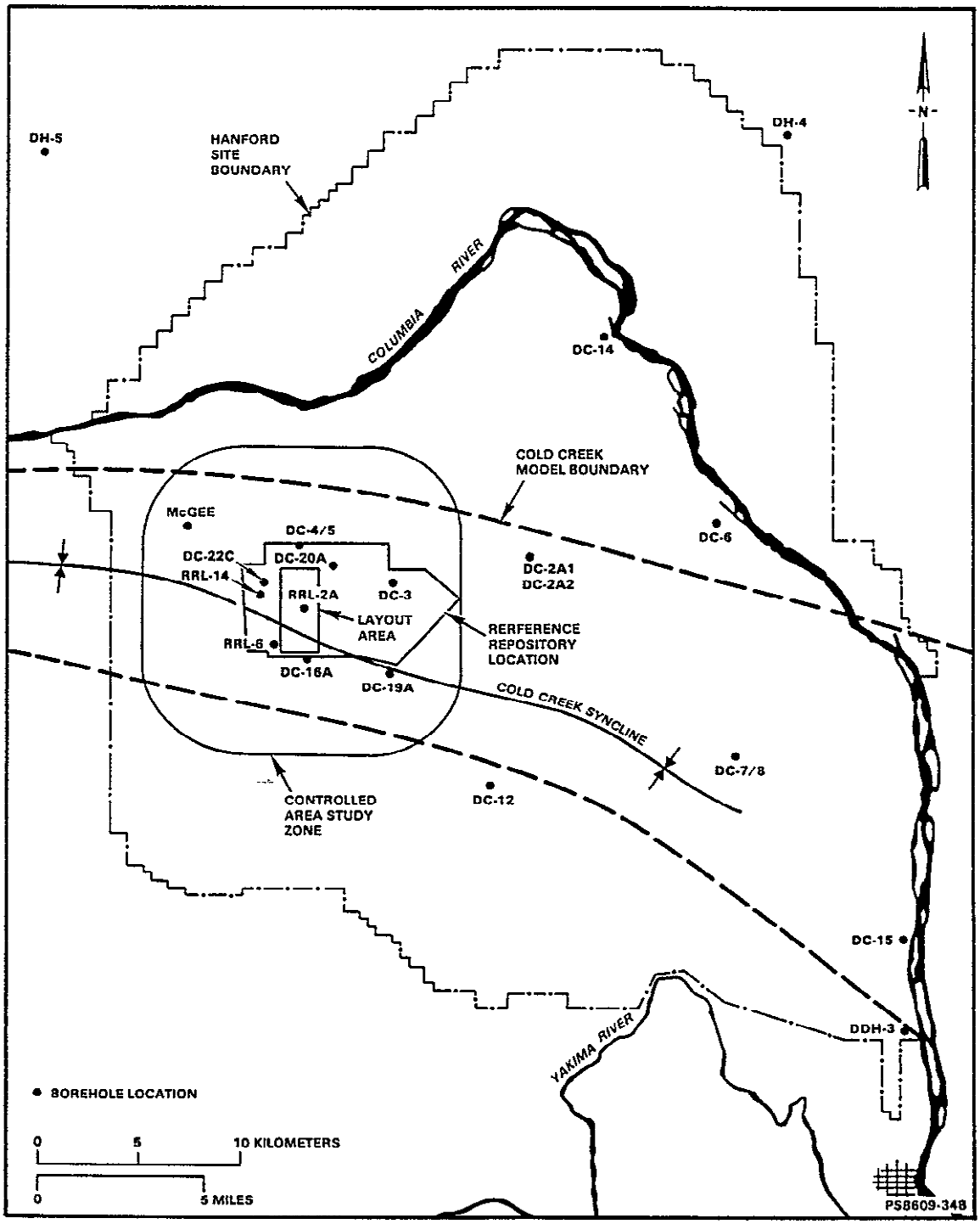

Figure 8.3.1.2-45. Location map of existing, cored boreholes available for sampling.

To date, little data exist for flow tops. Site characterization will include sampling each flow top in the repository isolation zone. At least two samples will be obtained from each flow top in the upper and lower isolation zones. Depending on the encountered variability in chemical composition, more than two samples may be taken from flow tops in the primary isolation zone. Variability is expected to be larger for flow tops than for flow interiors because of secondary mineralization. Samples from flow tops will be submitted for x-ray fluorescence analysis and the results used for determination of any variations in chemical composition.

In addition to flow tops in the repository isolation zone, some samples will be obtained from flow tops in the Saddle Mountains Basalt. Fewer samples will be taken from these flows than from the rocks within the repository isolation zone. The exact number of samples has not yet been determined and will depend on the compositional variability encountered and the quantity of information needed to understand the variability in ground water composition. As with other samples taken for major element concentrations, samples from the Saddle Mountains Basalt will be submitted for x-ray fluorescence analysis.

- Trace element composition--Site characterization will consist of obtaining minor and trace element concentrations for samples taken from new boreholes. Portions of the same samples taken for major element, x-ray fluorescence analysis will be submitted for instrumental neutron activation determination of minor and trace elements. In addition to samples from new boreholes, some samples will be obtained from existing core from flows in the upper secondary isolation zone for which no trace element data exist. These samples will be from boreholes within the controlled area study zone.

- Water content--Structural water, absorbed water, and total water have been measured on several samples from the flow interiors of specific flows within the primary isolation zone but none of the samples were collected within the controlled area study zone (Long and WCC, 1984). Also, data are only available for the basalt flows that were considered candidate repository horizons. Comparison of data from the four studied flows shows that there are no statistically significant differences in water content among the flow interiors of the studied flows (i.e., all flows have the same water content within two standard deviations).

  Site mineralogic characterization will consist of thermogravimetric measurement of water from whole rock samples. Analyzed samples will be portions of those samples obtained for x-ray fluorescence analysis. Not all samples submitted for x-ray fluorescence, however, will be analyzed for water content. Although whole-rock flow top samples will not be thermogravimetrically analyzed, the water content of individual secondary phases will be obtained. This is discussed under Section 3.1.4.1.

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- Ferrous/ferric ratio--The ferrous/ferric ratio has been determined for 34 samples of Rocky Coulee, Cohassett, McCoy Canyon, and Umtanum flow interiors (Long and WCC, 1984). Six of these samples are from drill core obtained within the controlled area study zone. The remainder of the samples are from drill core and outcrops from locations throughout and north of the Cold Creek syncline. Analysis of the available data shows that the ferrous/ferric ratio lies between 0.78 and 0.81 for the four studied flows.

  The ferrous/ferric ratio is essential in determining the redox characteristics of the rock/water system. Therefore, site characterization will include determination of the ferrous/ferric ratio from samples obtained within the controlled area study zone. Total iron will be determined by x-ray fluorescence and ferrous iron by ultraviolet/visable spectrophotometry.

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8.3.1.2.5.3.1.1.1 Characterization of primary basalt mineralogy. The mineralogy and petrography of Grande Ronde Basalt in the controlled area study zone have been described by Long and WCC (1984). The samples studied were from the interiors of the four flows in the primary isolation zone that were considered candidate horizons.

Characterization of primary minerals will involve obtaining mineralogic information by several techniques. Modes and textural descriptions will be obtained on samples of flow interiors by petrographic microscope. Flow interior samples will be of several kinds from several areas. Samples from outcrop in the Sentinel Gap area will be studied to develop a classification scheme for intraflow structures. Once the scheme is developed, it will be applied to core samples from the primary isolation zone with emphasis on the Cohassett flow. The total number of samples has yet to be determined.

Additional petrographic modes and descriptions will be obtained from samples of drill core from the interiors of flows in the upper and lower secondary isolation zones. Current plans are for no more than two samples from each flow interior, but the results of initial studies may dictate additional samples.

Modes and textural descriptions may be acquired for samples of flow top using a combination of petrographic microscopy and image analysis. Image analysis might also be a useful method for quantification of rock textures.

Finally, a combination of chemical analyses, x-ray diffraction, and thermogravimetric data will be developed to obtain chemical modes. Similar methods have been developed to obtain accurate modes by other workers (Hodgson and Dudeney, 1984; Pearson, 1978; Johnson et al., 1985). If successfully developed, this method will be applied to samples of flow interiors.

The chemical compositions of individual phases are to be determined by electron microprobe. The same thin sections used for petrographic analysis will be submitted for electron probe analysis. The specific number of thin sections for analysis is yet to be determined and will depend on the variability encountered.

8.3.1.2.5.3.1.1.2 Characterization of secondary basalt mineralogy. Characterization of secondary minerals is a program of analytical chemistry, modal analysis, and textural characterization of infilling minerals mainly within fractures and flow tops. The objective is to define the extent of vertical variability in the mineralogic makeup of the assemblage, which probably is not a function of individual flows. As above, the limited number of boreholes presents problems at the layout scale and large extrapolations between boreholes are required. Samples have a restricted occurrence in core. Thus far only one paragenetic sequence has been found. Potential variations in the secondary assemblage related to groundwater chemistry, temperature, or age are possible.

8.3.1.2.5.3.1.1.2.1 Secondary phases. The principal secondary minerals in Grande Ronde Basalt in the primary isolation zone are smectite clays, zeolites (clinoptilolite and mordenite), and silica. Celadonite, calcite, and pyrite are less common. Numerous other secondary minerals have been identified but are present in much lower abundances. The secondary minerals occur along fractures, in vugs, and in relatively porous, vesicular, and brecciated flow tops and flow bottoms.

The petrography and chemical composition of secondary minerals in the upper and lower secondary isolation zones have not been studied extensively.

Site characterization will include x-ray diffraction identification of secondary minerals, electron microprobe determination of secondary mineral compositions and petrographic microscopy to relate mineral textures with x-ray diffraction, and electron microprobe data.

Thin sections of each rock submitted for x-ray diffraction analysis will be examined by petrographic microscopy. This examination will aid mineral identification, will allow evaluation of mineral textures, and will be the basis for choosing which samples will be submitted for electron microprobe analysis. The chemical composition of individual secondary minerals will be determined by electron microprobe. Quantitative or semi-quantitative modal analysis of secondary minerals will be done using one or a combination of point count, image analysis, x-ray diffraction, and chemical techniques.

In addition to the above types of analyses, samples which yield sufficient quantity of monomineralic material will be submitted for further work. Monomineralic separates will be analyzed by inductively coupled plasma emission spectroscopy (ICP) to obtain chemical analyses as a check on electron microprobe data since microprobe analysis of hydrous clays and zeolites is difficult. These same samples will be submitted for thermogravimetric analysis to obtain H_2O+, H_2O-, and total water contents if sufficient sample is available. Finally, the ferrous/ferric ratio will be spectrophotometrically determined from portions of the same sample if sufficient quantity exists.

Some electron microprobe analyses of clays from the Hanford Site yield unreasonable structural formulas. One possible reason for this is that the sample may not be monomineralic under the electron beam. Appropriate samples of sufficient quantity will be submitted for Mossbauer spectrometry, scanning electron microscopy, and transmission electron microscopy to search for non-clay phases mixed with clay at the micrometer scale.

The stability of secondary minerals is a factor in establishing the nature and rates of geochemical processes operating in a geologic environment. One aspect in ascertaining the stability of minerals is to determine conditions of formation (e.g., temperature and pressure). Stable isotopic compositions will allow estimates of formation temperatures for secondary minerals. For the appropriate monomineralic samples, ^{18}O will be obtained for silica and zeolite phases, ^{18}O and deuterium for phyllosilicates, ^{13}C and ^{18}O for calcite, and ^{34}S for pyrite. In addition, appropriate samples of celadonite will be submitted for potassium-argon dating. The results will allow placing an absolute age, which is further evidence for mineral stability, on one member of the paragenetic sequence.

<u>8.3.1.2.5.3.1.1.2.2 Stratigraphic and lateral distribution of secondary minerals</u>. An understanding of the stratigraphic and geographic variations in secondary mineralogy is required to predict potential changes in groundwater composition and changes in rock/water/waste interactions with distance from a repository.

Based on the limited data, there may be differences in the relative abundances of secondary phases in the primary and lower secondary isolation zones. Quartz appears to be more abundant relative to opal and mordenite seems to be more common in the lower secondary isolation zone than in the primary isolation zone.

The only apparent lateral variation in secondary mineralization noted thus far is the distribution of celadonite. Rawson (1986) and Horton (1985) noted celadonite in most samples of Rocky Coulee and Cohassett flow tops from drill holes outside the controlled area study zone in the southwest portion of the Cold Creek syncline. They noted celadonite in only one sample obtained from drill holes within the controlled area study zone. More samples need to be studied in order to better understand and define this and other possible lateral distributions.

Site characterization will better define and quantify the stratigraphic and lateral variations in secondary mineral abundance. The locations of samples chosen for characterization of mineral properties (described above under secondary phases) will be such that they will add data in areas deemed critical for defining variations and trends in the secondary mineral assemblage.

<u>8.3.1.2.5.3.1.1.3 Characterization of tectonic joint and fault-infilling mineralogy</u>. Characterization of tectonic joint and fault-infilling minerals will involve analytical chemistry, modal analysis, and textural characterization with emphasis at the layout scale. Faults and tectonic joints

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interconnected with cooling joints and flow tops may form hydrologically integrated systems. The nature of the infilling mineral assemblage may be similar to secondary minerals in basalt.

The occurrence of infilling minerals is highly restricted and samples will not be found in all boreholes. The identification of structures in boreholes, and, therefore, the number and locations of samples, is accomplished as part of structural studies. To date, some possible tectonic zones have been identified (Landon, 1984).

No work has been done to determine the mineralogy and chemical composition of fault-infilling minerals.

Characterization of tectonic joint and fault-infilling mineral assemblages includes x-ray fluorescence, x-ray diffraction, bulk and powder densities, and thin section petrography. Electron microscopy will be done if deemed necessary from initial work.

X-ray fluorescence data coupled with density determinations when compared with similar data on unaltered basalt will yield elemental gains and losses to basalt breccia fragments due to tectonic and mineralization processes. X-ray diffraction data and petrographic data will identify the mineralogy of the infilling assemblage. Thin section petrography will relate mineralogy to texture.

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8.3.1.2.5.3.1.1.4 Characterization of sedimentary interbeds. Characterization of the interbeds (Chapter 8.3.1.4) is a program of analytical chemistry, modal analysis, and textural characterization of sedimentary layers within the basalt sequence. Some interbeds are transmissive aquifers which may be connected to repository depths by simple faults or by a system of faults, flow tops and fractures. There is a need to know the sorptive properties of interbeds in conjunction with similar information on fault-infilling minerals and secondary minerals in basalt. The objective is to define the occurrence and distribution of detrital and authigenic minerals within and among interbeds. Samples are limited in cores by poor recovery. Horizontal variability may be influenced by lateral facies changes.

8.3.1.2.5.3.1.1.4.1 Composition of interbeds in the Pasco Basin. Characterization of sedimentary interbeds includes petrographic and x-ray diffraction identification of minerals present. Techniques for quantitative mineral determination (modes) have been discussed under primary phases and secondary phases above and may be applied to interbeds. Petrographic examination will be used to describe textural characteristics of detrital grains (e.g. partial dissolution).

The number of samples to be studied will depend on lithologic variability, interbed thickness, and the number of drill holes in which a particular interbed is encountered. Generally, an interbed will be sampled at most major lithologic changes or approximately every two to three meters and at contacts with basalt. Those samples from contacts with basalt may exhibit different properties than samples from the center of interbeds due to baking of the contacts.

8.3.1.2.5.3.1.2 Characterization of mineralogic stability. Characterizing mineralogic stability involves an analysis of the chemical stability of the minerals and mineral assemblages characterized in the test described above. The analysis utilizes mineralogic/geochemical data from the test and from literature sources, and the results of thermal history modeling of the Pasco Basin (section 8.3.1.6, Resource Potential). The analysis will evaluate in-situ and current conditions, will evaluate indicated paragenetic trends in the evolution of the solids geochemistry, and will evaluate the potential for changes under natural and manmade conditions in the future.

The output of the analysis will be (1) a paragenesis of secondary minerals, (2) an assessment of the stability of primary and secondary phases in basalt, (3) an assessment of the stability of interbed mineralogy, and (4) an assessment of the stability of the geochemical environment. The analysis will encompass past, present and future conditions in the four rock/mineral assemblages at the three different scales and thus is a representative analytical approach with respect to spatial variability of existing conditions and uncertainties.

8.3.1.2.5.3.1.2.1 Paragenesis of secondary minerals. This task establishes the relative sequence of secondary mineral formation and demonstrates the stages and trends in the geochemical evolution of the assemblage. The paragenetic sequence is the basis for establishing the relative timing of mineral formation and rates of geochemical change.

Site characterization will establish the paragenetic sequence of secondary minerals in parts of the RIS for which a paragenesis has not been established already. This will be done using mineralogic, textural, and chemical information about the secondary minerals obtained in the above described test.

8.3.1.2.5.3.1.2.2 Stability of primary and secondary phases in basalt. This activity is an assessment of the thermodynamic stability of phases characterized in the test activities above. The analysis incorporates theory, experimental results, and comparisons with other natural occurrences, and forms the basis for predictions of mineral/water or rock/water reactions under natural and repository conditions.

Rock/water/waste reactions may change groundwater composition with time and, therefore, may affect radionuclide transport and release. For this reason, it is important to understand the stability of primary and secondary phases in the present and future geochemical environments.

The evaluation of stability of primary and secondary minerals in the repository isolation system will be accomplished by interpreting petrographic textures (e.g., dissolution features), by comparing the occurrence of the minerals found at the Hanford Site with the occurrence of the same and similar minerals in other geologic environments, by using potassium-argon ages (analyses described previously), and by incorporation of appropriate thermodynamic parameters derived from the technical literature into computer-modeled rock/water interactions. Computer modeling will primarily be done by the

hydrochemistry and engineered barrier groups. Mineralogy/petrology will supply these groups with information concerning the natural mineral assemblages to be used as input to the models. Mineral stability may be depicted by use of stability diagrams in pressure-temperature-composition space.

8.3.1.2.5.3.1.2.3 Stability of interbed mineralogy. This task is similar to stability of primary and secondary phases in basalt described above, with the emphasis on understanding the minerals in the interbeds and their interaction with groundwater.

Interbeds are important because they may behave as sorptive barriers above the Cohassett flow. Sorptive characteristics of interbeds may be very different from secondary minerals and basalt. Therefore, interbed studies will parallel the studies of basalt and secondary minerals.

8.3.1.2.5.3.1.2.4 Stability of the geochemical environment. This task is an integration of all other task and analysis activities of the characterization of mineralogic stability component. The results of this analysis are in effect predictions of the rate(s) and trend(s) of changes in the geochemical environment under natural conditions, and these results provide a basis for evaluating chemical compatibility with the waste package.

The stability of the geochemical environment will be assessed by integration of radiometric age dates, paragenesis, and mineral stabilities. Because the geochemical environment includes groundwater as well as rocks and minerals, appropriate aspects of hydrologic and hydrochemical work will be integrated with mineralogy and petrology, particularly results of computer modelled rock/water reactions.

8.3.1.2.5.4 Application of results

The information obtained will apply to performance assessment design and characterization.

In support of performance assessment, spatial distributions of mineralogic and petrologic properties are used as a basis for estimating sorption coefficients along flowpaths. Pathways for groundwater and radionuclide migration will likely be along systems of dominantly vertical cooling fractures, flow top layers, and steeply dipping faults which cross-cut multiple flows. The total sorptive capacities of these pathway systems can be estimated when the types and abundances of secondary minerals are known. Numerical model simulations of radionuclide releases to the accessible environment must account for these sorption effects. This application is dependent on the quantitative characterization of the mineral assemblages in and along the pathways.

Mineralogic and geochemical stability will be factors in performance scenarios spanning 10,000-100,000 yr. For example, the sorptive capacity of the secondary minerals and interbed minerals in the pathways will change with time as the concentration of radionuclides in the system changes, and the

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sorptive capacity will change, also, if the abundances of sorptive minerals changes with time. Gains and losses to the mineral assemblages over time are addressed by the analysis of stability.

The principal design use of mineralogy/petrology is in waste package design which must account for rock/water interactions within the rock which is thermally perturbed by the emplacement of waste. Mineralogic properties in the near-field may be subject to change under repository operating conditions. The starting point for deriving the specific reactions involved and calculating possible mass transfer are chemical compositions of the rocks and mineral assemblages. Such compositions are a product of quantitative characterization and must be representative of a specified portion of the rock mass or mineral assemblage and include estimates of spatial variability. Some chemical components may be mobile under repository conditions (e.g., H_2O) affecting bulk volume and, hence, the fundamental properties of the rock mass in the near-field environment. Moreover, chemical stability under repository conditions as dealt with in design requires a baseline understanding of the natural stability.

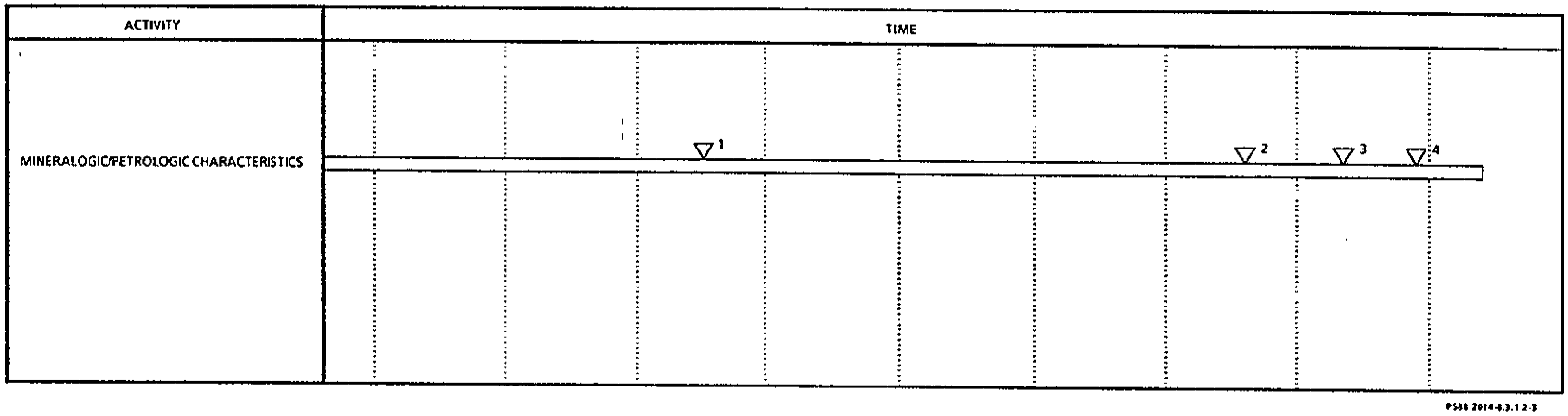
One role of the study in characterization is to support stratigraphic correlation and intraflow structure studies through petrographic analysis. Stratigraphic and intraflow structure studies are used extensively in geologic characterization activities which support repository layout and design. Another characterization role of the study is in hydrochemistry which must account for the influence of the solids with which the groundwater is in contact.

8.3.1.2.5.5 Schedules and milestones

Generalized schedules and major milestones of the mineralogy and petrology investigation are shown in Figure 8.3.1.2-46.

There are four major sequences of events shown on Figure 8.3.1.2-46 which represent work associated with the four rock/mineral assemblages comprising the study (primary phases, secondary phases, sedimentary interbeds, and tectonic joint and fault infillings). Each of the four major sequences is subdivided into three iterations of activities which consist of petrographic analysis, on which is based succeeding mineralogic and chemical analysis, and, finally, data synthesis and geochemical stability considerations based on all available analyses. Each iteration is designed to increase information, knowledge, and certainty in data for geographic and stratigraphic areas which the previous iteration shows data are lacking. Analyses from the third iteration can also be used to test predictions based on results of the first two iterations.

Inverted triangles on Figure 8.3.1.2-46 represent major milestones. Each milestone will be physically represented by a deliverable document and it is through these documents that links are made with, and mineralogy/petrology information is disseminated to other aspects of the project. Aspects of the project using mineralogy/petrology information include stratigraphy, intraflow structures, resource potential, hydrochemistry, waste package and, indirectly,



1 SUMMARIZE MINERALOGY AND PETROLOGY OF THE CONTROLLED AREA STUDY ZONE--INPUT TO ENGINEERING GEOLOGY REPORT FOR ADVANCED CONCEPTUAL DESIGN AND ISSUE 1.8 (REV. 1).

2 COMPLETE ANALYSIS OF TECTONIC JOINT AND FAULT INFILLING MINERALOGY--INPUT TO ENGINEERING GEOLOGY REPORT FOR LAD AND ISSUE 1.8, SORPTION (REV. 2)

3 COMPLETE ANALYSIS OF INTERBED MINERALOGY--INPUT TO ENGINEERING GEOLOGY REPORT FOR DEIS AND ISSUE 1.8 (REV. 2)

4 COMPLETE ANALYSIS OF GEOCHEMICAL STABILITY--INPUT TO ENGINEERING GEOLOGY REPORT FOR DEIS AND ISSUE 1.8, SORPTION (REV. 2)

DEIS = DRAFT ENVIRONMENTAL IMPACT STATEMENT.

Figure 8.3.1.2-46. Schedules and milestones, mineralogy/petrology study.

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performance assessment and design. In addition to the indicated major deliverables, there are other deliverables which are not shown. These consist of certified data transmittals, data packages, and letter reports which contain the data used to construct the major deliverables.

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SITE CHARACTERIZATION PLAN

Chapter 8 - SITE CHARACTERIZATION PROGRAM

Section 8.3.1.3

Hydrology

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8.3.1.3 Specific program for hydrology

The U.S. Department of Energy (DOE) hydrology investigative program for the Hanford Site collects and analyzes data concerning hydrologic factors influencing radionuclide containment. Hydrologic factors can influence radionuclide containment in the following ways:

- Interactions between the groundwater and the engineered systems can influence radionuclide containment in the engineered systems.
- Groundwater composition can influence the ability of the host rock to adsorb radionuclides and retard their migration.
- Groundwater flowpaths can provide a pathway for the migration of radionuclides to the accessible environment.

Section 8.3.1.3 of this Site Characterization Plan (SCP) describes the role of the hydrologic program in the site characterization program and plans for future hydrologic investigations and supporting studies.

Background

The hydrology of the Hanford Site is influenced by the surface and subsurface hydrologic components of the Columbia Plateau (Fig. 8.3.1.3-1). While the controlled area study zone is primarily within the Cold Creek drainage (Fig. 8.3.1.3-2), the nearby Columbia River dominates the regional surface water system. The subsurface hydrologic component of the Columbia Plateau comprises the near-surface groundwater system and the deep groundwater system. The near-surface groundwater system exists in the unconsolidated sediments above the basalt flows. The basalt flows' dense interiors and flow tops control water movement within the deep groundwater system (Fig. 8.3.1.3-3). Because the proposed repository would be located within the deep groundwater system, understanding water movement within this system is of primary importance.

A hydrology investigative program has existed at the Hanford Site since the early 1970s. The first formal hydrology investigative program studies followed the realization that groundwater would be the main transport mechanism for buried wastes. Both the surface and subsurface hydrologic regimes have been studied. Chapter 3 discusses the existing hydrologic data and their interpretations. Future studies will be directed toward satisfying the information needs set forth in the issue resolution strategies (Section 8.2.2) and responding to the data deficiencies described in Chapter 3. The planned studies will focus primarily on characterizing the surface water system (including the potential for flooding) and on characterizing the groundwater system within the controlled area study zone.

The site groundwater study is divided into pre-exploratory shaft testing activities and post-exploratory shaft testing activities. The pre-exploratory shaft testing is a critical part of early site characterization activities and

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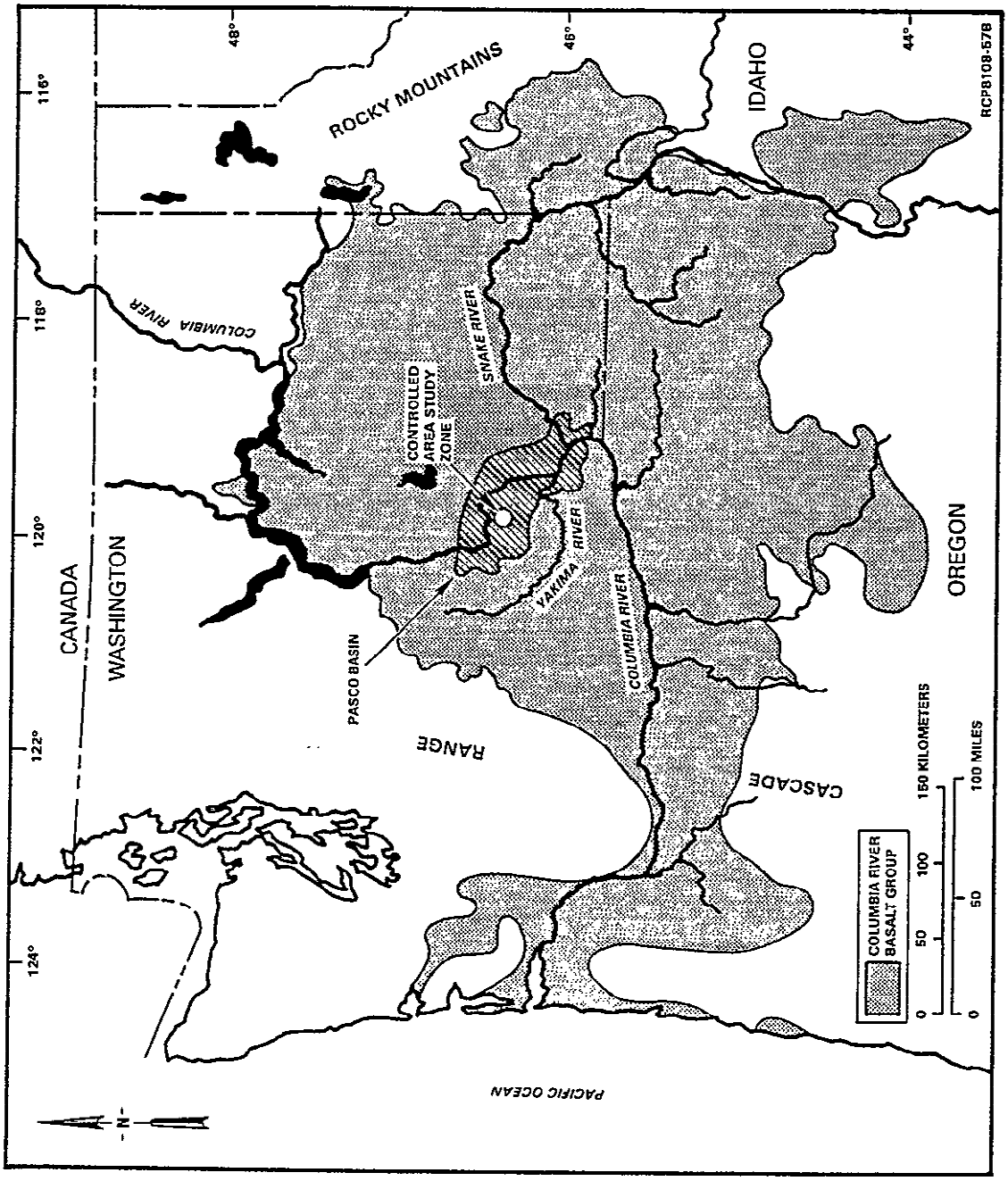

Figure 8.3.1.3-1. Location of the controlled area study zone within the Pasco Basin and Columbia Plateau.

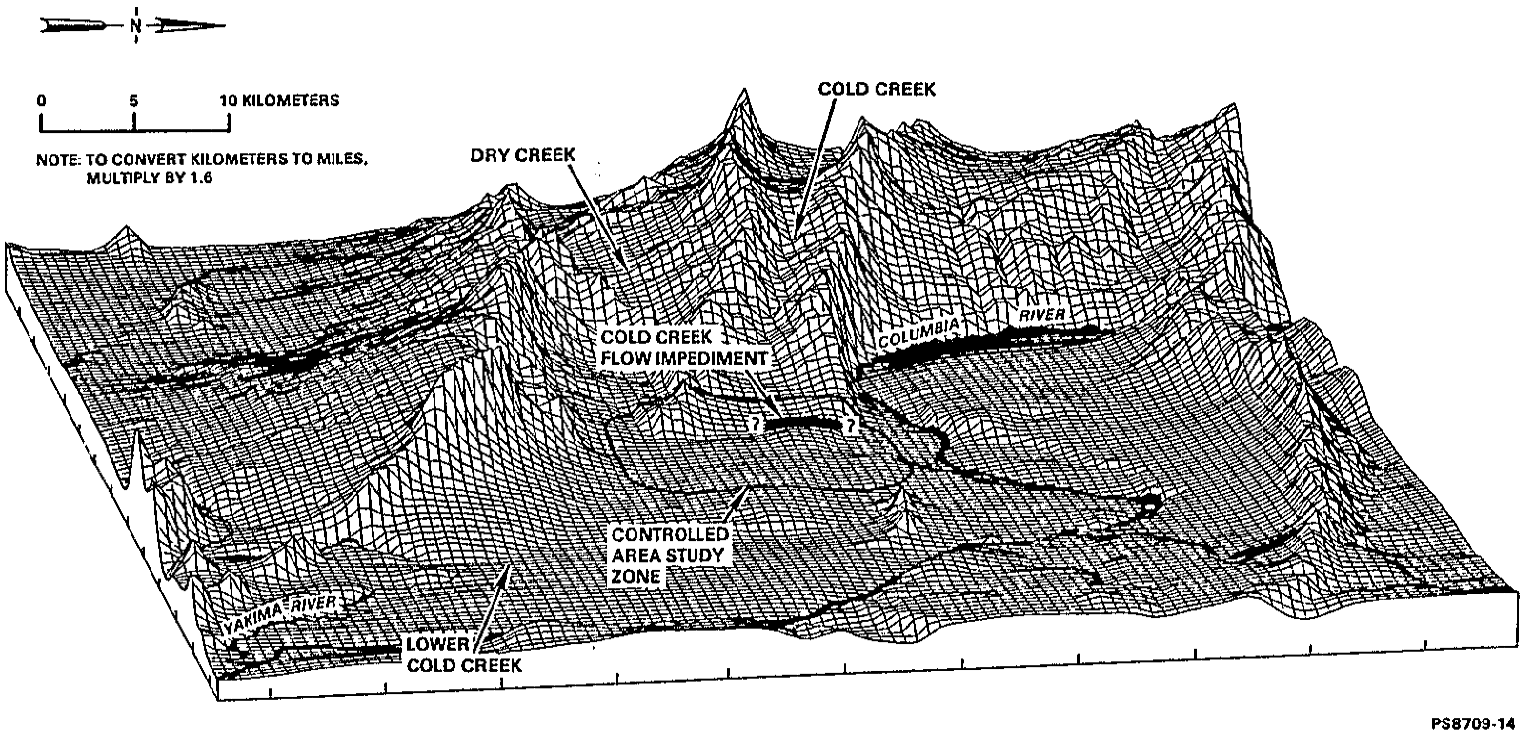

Figure 8.3.1.3-2. Cold Creek drainage dominates the surface water system in the immediate vicinity of the controlled area study zone.

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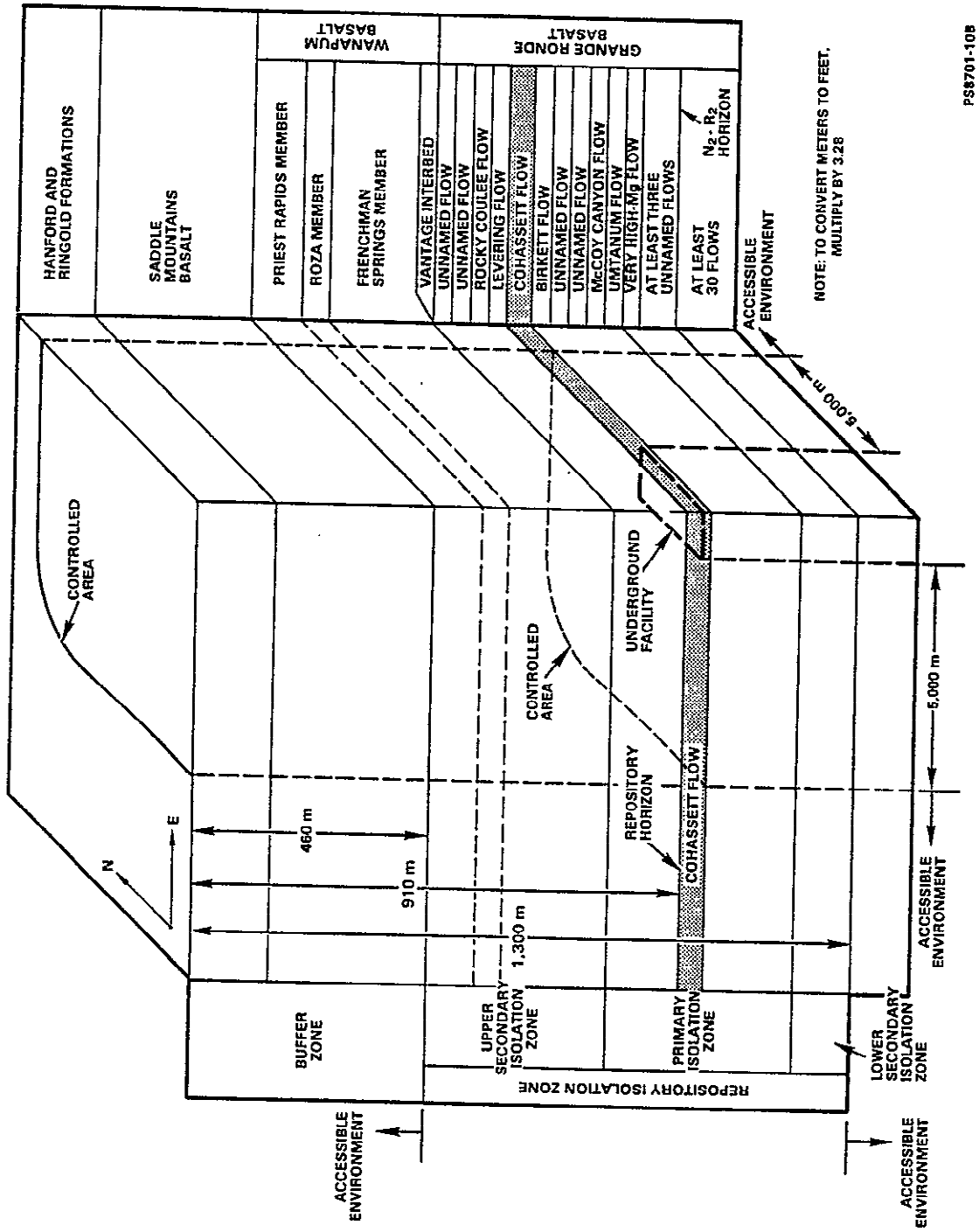

Figure 8.3.1.3-3. Stratigraphic position of the repository.

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is designed to collect hydrochemical and geohydrologic data that are considered unobtainable subsequent to construction of the exploratory shaft and underground facility.

Pre- and post-exploratory shaft hydrology testing programs will be conducted using a combination of data collection activities, including baseline monitoring of hydrualic heads, large- to small-scale hydraulic tests, and groundwater sampling, to provide a three-dimensional perspective of the site groundwter flow system. Primary attention will be devoted to understanding (1) the hydraulic and transport properties along likely flow paths from the repository to the accessible environment and (2) the hydraulic influence of nearby geologic structures. Regional studies are used to define the boundary conditions for the site groundwater flow system.

Summary of program

The hydrology investigative program is composed of the surface water and the groundwater investigations (Sections 8.3.1.3.3 and 8.3.1.3.4).

The Hanford Site investigators will use information from the surface water investigation when determining the flooding potential of the proposed site. The surface water investigation will also provide information for the groundwater investigation. The investigation of surface water comprises the surface water system study and the site flooding study.

The surface water system study (Section 8.3.1.3.3.3.1) is essentially a watershed study and will produce topographic flooding maps for use in the site flooding and regional groundwater studies. The surface water system study will determine the physical and hydrologic parameters of the Cold Creek watershed (the watershed controlling flooding at the proposed site). An inventory of water-control structures within the Pasco Basin will provide information on the potential for groundwater recharge from reservoirs and unlined ditches. Evapotranspiration data will be used in a watershed analysis, while streamflow data will be collected for use in the site flooding study.

The site flooding study (Section 8.3.1.3.3.3.2) will provide a description of both flooding history and flooding potential. The site flooding study will predict water surface elevations at the site caused by a probable maximum flood and lesser floods. The study will also predict the effects of windwave activity, sedimentation, erosion, and scouring on surface water elevations.

The Hanford Site investigators will use information from the groundwater investigation when determining groundwater flow directions, travel time, radionuclide release rates, and in designing the engineered systems (waste package and engineered barriers). Information from the groundwater investigation will help determine the presence or absence of favorable and adverse conditions for a nuclear repository in basalt at the Hanford Site. The investigation of groundwater is made up of the regional groundwater study and the site groundwater study.

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The regional groundwater study (Section 8.3.1.3.4.3.1) will provide the information needed to construct a groundwater flow model for the Pasco Basin and the Cold Creek syncline. The regional groundwater flow model is necessary for defining hydraulic boundaries for the controlled area study zone.

The regional groundwater study will (1) collect data to be used in predicting groundwater flow, recharge, and discharge; (2) integrate the collected data with existing data into a geographic information system type of data base; (3) use the integrated data to develop a conceptual model of the regional groundwater flow system; and (4) use the conceptual model as the basis for a numerical model of the regional groundwater flow system. The numerical model will then be used to predict the effects of man-induced, climatic, and tectonic stresses to the regional groundwater system and to predict the boundary conditions for the site model caused by these stresses.

The site groundwater study (Section 8.3.1.3.4.3.2) will produce conceptual models of the groundwater flow system within the controlled area study zone. To collect technically accurate data and predict the effect of repository construction, the study is divided into two parts. Surface-based tests conducted prior to the construction of the exploratory shaft will focus on baseline measurements. Surface-based tests, conducted after the construction of the exploratory shaft, will focus on measurements of hydraulic parameters in and near the controlled area study zone. Subsurface-based tests, conducted after the construction of the exploratory shaft, will be used to support predictions of the effects of repository construction on the hydraulic system and will provide smaller scale measures of hydraulic parameters within the controlled area study zone and within the exploratory shaft.

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Organization of Section 8.3.1.3

The DOE hydrology investigative program is divided into the following investigations and studies:

- Investigation of surface water (Section 8.3.1.3.3).
  - Surface water system study (Section 8.3.1.3.3.3.1).
  - Site flooding study (Section 8.3.1.3.3.3.2).
- Investigation of groundwater (Section 8.3.1.3.4).
  - Regional groundwater study (Section 8.3.1.3.4.3.1).
  - Site groundwater study (Section 8.3.1.3.4.3.2).

8.3.1.3.1 Purpose and objectives

The purpose of the hydrology investigative program is to provide data to (1) satisfy the site-selection requirements of 10 CFR 960 (DOE, 1987a), and (2) demonstrate compliance with the NRC licensing requirements presented in 10 CFR 60 (NRC, 1987). The DOE has developed a top-level licensing strategy for satisfying the requirements of 10 CFR 960 and 10 CFR 60 (Section 8.2.1).

The top-level strategy suggests the approach the hydrology investigative program should take to resolve the issues. The issues that impact the hydrology investigative program are summarized in Table 8.3.1.3-1.

By responding to the parameters associated with these issues, the hydrology investigative program should provide the support required for the resolution of those issues.

The program should increase the confidence in the following:

- The project data base.
- The assurance that the conceptual models represent the site.
- The adequacy of the proposed facility design.
- The capability of the proposed facility to meet all performance requirements.

A high confidence in these items should lead to a high probability that the site will meet the U.S. Nuclear Regulatory Commission (NRC) licensing requirements.

9 2 1 2 5 5 4 2 0 7 7

Specific objectives

Specific objectives for data collection will be described under the investigation of surface water (Section 8.3.1.3.3) and the investigation of groundwater (Section 8.3.1.3.4). The objectives include determining of the following:

- Surface water.
  - Potential for flooding.
  - Groundwater recharge.
- Groundwater.
  - Hydraulic properties and their spatial distribution.
  - Hydraulic heads and their spatial distribution.
  - Nature, extent, and location of hydraulic boundaries.
  - Conceptual and numerical models of the groundwater flow system.

The hydrology investigative program will meet these objectives by collecting data on the parameters resulting from the issue resolution strategies (Section 8.2.2, Table 8.2.2-1).

8.3.1.3.2 Rationale

The rationale behind the proposed investigations of surface water and groundwater lies primarily within the issues resolution and performance allocation process described in Section 8.2. Two additional concerns, design goals and non-nuclear regulatory requirements, are often referenced as part of

Table 8.3.1.3-1. Overview of the issues related to the hydrology investigative program

Key Issue 1. Isolation of radioactive waste from the accessible environment	Key Issue 2. Public and worker safety during operation and closure	Key Issue 3. Protection of the environment and public health	Key Issue 4. Ease and cost of construction, operation, and closure
1.1, Limiting radioactive release to the accessible environment 1.2, Individual dose 1.3, Protection of special sources of groundwater 1.6, Pre-emplacement groundwater travel time 1.8, NRC favorable and potentially adverse conditions 1.9, DOE guidelines 1.10, Waste package characteristics 1.12, Shaft and borehole seals characteristics	2.3, Accidental exposures to the public and the workers 2.4, Will the option of waste retrieval be preserved 2.7, Preclosure NRC criteria and repository characteristics	The issues will be identified after the environmental impact statement scoping meetings (Any hydrologic concerns will be addressed in the environmental and socioeconomic monitoring and mitigation plans)	4.2, Nonradiological health and safety of the workers
Postclosure performance	Preclosure radiological safety	Preclosure nonradiological environmental impacts	Preclosure feasibility and cost of facility development

DOE = U.S. Department of Energy.
NRC = U.S. Nuclear Regulatory Commission.

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the rationale for the collection of hydrologic information. But, they are also incorporated into the issues as Key Issues 2, 3, and 4 (Section 8.2), which include engineering design and regulatory compliance functions.

The performance allocation process entails deciding which of the system elements will be relied upon in resolving an issue, identifying and assigning quantitative goals to measures and parameters that represent the expected performance of each system element, and developing a testing program to obtain the information relevant to the identified parameters (DOE, 1987b). Figures 8.3.1.3-4 and 8.3.1.3-5 identify the parameters resulting from this process and illustrate the parallel data requirements of several issues.

Issue 1.1, releases to accessible environment, is the most critical issue relative to the site-selection and license-application objectives of the issues hierarchy described in Section 8.2.1. As illustrated by Figure 8.3.1.3-6, the resolution of Issue 1.8, NRC siting criteria, is critical to the resolution of Issue 1.1.

The hydrology investigative program is driven primarily by the need to satisfy Issue 1.1, limiting postclosure radioactive release to the accessible environment. The resolution of Issue 1.1 is supported by the resolution of the other issues under Key Issue 1 but most significantly by the resolution of Issue 1.8, the ability of the natural site to contain radioactive waste (see Table 8.3.1.3-1). Resolution of these issues depends on collecting accurate baseline hydrologic data. This will provide the basis for the analysis of the disturbances caused by the construction, operation, and closure of the repository and how the hydrologic system will react to these disturbances.

The resolution of Issues 1.4, 1.5, 1.10, and 1.11 will support resolution of Issue 1.8. The resolution of Issues 1.3 and 1.6 will be required for license application but will not play a critical support role to Issues 1.1 or 1.8. However, the groundwater data collected to support Issue 1.6 will parallel the data required to support Issue 1.1.

	ISSUES			
	1.8	2.3	2.7	4.2
SOIL/LAND COVER (RUNOFF CHARACTERISTICS)				X
PRECIPITATION INTENSITY (DESIGN RAINFALL)				X
TOPOGRAPHY (DRAINAGE PATTERNS)				X
INFILTRATION/RUNOFF RELATIONSHIPS	X			X
LESSER FLOODS (AS 100-YR FLOOD)		X	X	X
PROBABLE MAXIMUM FLOOD		X	X	X
CATASTROPHIC FLOODS	X			

X = SPECIFIED DIRECTLY BY THE ISSUES RESOLUTION STRATEGY (PERFORMANCE PARAMETERS)

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Figure 8.3.1.3-4. Surface water investigation parameter matrix.

9 2 1 2 5 5 4 2 0 7 9

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			ISSUES											
			1.1	1.2	1.3	1.6	1.8	1.9	1.10	1.12	2.3	2.4	2.7	4.2
DAMAGED ROCK ZONE	DRIFT OR SHAFT	HYDRAULIC CONDUCTIVITY	X		X		X			X		X		(a)
		STORATIVITY										X		(a)
		EFFECTIVE POROSITY	X		X					X		X		
		HYDRAULIC HEAD												(a)
	BORE-HOLES	HYDRAULIC CONDUCTIVITY	X		X		X			X		X		(a)
		STORATIVITY										X		(a)
		EFFECTIVE POROSITY	X		X					X		X		
		HYDRAULIC HEAD												(a)
COHASSETT FLOW INTERIOR		HYDRAULIC CONDUCTIVITY (HORIZONTAL)	X	X	X		X		(g)					(a)
		HYDRAULIC CONDUCTIVITY (VERTICAL)	X	X	X		X		(g)			X		(a)
		STORATIVITY										X		(a)
		EFFECTIVE POROSITY (HORIZONTAL)	X	X	X					X		X		
		HYDRAULIC HEAD							(g)					(a)
		HYDRAULIC GRADIENT (HORIZONTAL)	X	X	X									
		HYDRAULIC GRADIENT (VERTICAL)	X	X	X					X				
		WATER INFLOW TO DRIFTS									X		X	X
COHASSETT FLOW TOP		HYDRAULIC CONDUCTIVITY (HORIZONTAL)	X	X	X		X					X		
		TRANSMISSIVITY[b]	X	X	X	X								(a)
		EFFECTIVE THICKNESS[b]				X	(c)							
		STORATIVITY										X		(a)
		EFFECTIVE POROSITY	X	X	X					X		X		
		DISPERSIVITY[b]	X	X	X									
		WATER INFLOW TO SHAFT												X
		HYDRAULIC HEAD[b]				X	(c)							(a)
		HYDRAULIC GRADIENT (HORIZONTAL)	X	X	X					X				
BIRKETT FLOW TOP		HYDRAULIC CONDUCTIVITY (HORIZONTAL)								(d)				
		EFFECTIVE POROSITY								(d)				

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Figure 8.3.1.3-5. Groundwater investigation parameter matrix. (sheet 1 of 3)

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			ISSUES											
			1.1	1.2	1.3	1.6	1.8	1.9	1.10	1.12	2.3	2.4	2.7	4.2
PRIMARY ISOLATION ZONE (WITHIN CASZ)	FLOW INTERIORS	HYDRAULIC CONDUCTIVITY (VERTICAL)	x	x	x	x	x							
		HYDRAULIC HEAD[b]				x	(c)							
		EFFECTIVE POROSITY	x	x	x	x	(c)							
		HYDRAULIC GRADIENT (VERTICAL)	x	x	x									
	FLOW TOPS	HYDRAULIC CONDUCTIVITY (HORIZONTAL)	x	x	x		x			(f)				
		HYDRAULIC CONDUCTIVITY (VERTICAL)								(f)				
		TRANSMISSIVITY[b]	x	x	x	x								(a)
		EFFECTIVE THICKNESS[b]				x	(c)							
		STORATIVITY												(a)
		EFFECTIVE POROSITY	x	x	x									
		DISPERSIVITY[b]	x	x	x									
		HYDRAULIC HEAD[b]				x	(c)							(a)
		HYDRAULIC GRADIENT (HORIZONTAL)	x	x	x									
		HYDRAULIC HEAD AT CASZ BOUNDARY					x	x						
		HYDRAULIC FLUX AT CASZ BOUNDARY					x							
		WATER INFLOW INTO SHAFT												x
		HYDRAULIC CONDUCTIVITY (VERTICAL)	x	x	x		x							
SECONDARY ISOLATION ZONE (WITHIN CASZ)	FLOW INTERIORS	HYDRAULIC HEAD					(c)							
		EFFECTIVE POROSITY	x	x	x									
		HYDRAULIC GRADIENT (VERTICAL)	x	x	x									
	FLOW TOPS	HYDRAULIC CONDUCTIVITY (HORIZONTAL)	x	x	x		x							
		TRANSMISSIVITY[b]	x	x	x	x								(a)
		EFFECTIVE THICKNESS[b]				x	(c)							
		STORATIVITY												(a)
		DISPERSIVITY[b]	x	x	x									
		EFFECTIVE POROSITY	x	x	x									
		HYDRAULIC HEAD[b]				x	(c)							(a)
		HYDRAULIC GRADIENT (VERTICAL)	x	x	x									
		HYDRAULIC HEAD AT CASZ BOUNDARY				x	x							
		HYDRAULIC FLUX AT CASZ BOUNDARY				x								
		WATER INFLOW INTO SHAFT												x
UPPER BASALT FLOW TOPS (WITHIN CASZ)		TRANSMISSIVITY					(c)							(a)
		STORATIVITY												(a)
		HYDRAULIC HEAD					(c)							(a)
UPPER BASALT INTERIORS (WITHIN CASZ)		HYDRAULIC CONDUCTIVITY (VERTICAL)					(c)							
		HYDRAULIC HEAD					(c)							

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Figure 8.3.1.3-5. Groundwater investigation parameter matrix. (sheet 2 of 3)

		ISSUES											
		1.1	1.2	1.3	1.6	1.8	1.9	1.10	1.12	2.3	2.4	2.7	4.2
UNCONFINED AUQIFER (WITHIN CASZ)	TRANSMISSIVITY					(c)							(a)
	SPECIFIC STORAGE												(a)
	HYDRAULIC HEAD					(c)							(a)
PASCO BASIN (BASALT FORMATIONS)	HYDRAULIC CONDUCTIVITY				X	(c)							
	TRANSMISSIVITY				X	(c)							
	STORAGE COEFFICIENT				X	(c)							
	HYDRAULIC HEAD[b]				X	(c)							
	HYDRAULIC HEAD AT BASIN BOUNDARY				X	(c)							
	RECHARGE RATES				X	(c)							
FAULT ZONES	HYDRAULIC CONDUCTIVITY	X	X	X									
	EFFECTIVE POROSITY	X	X	X									
OTHER PARAMETERS	LEAKAGE VIA OLD BOREHOLES					X							

NOTE: DATA NEEDS MAY EVOLVE AS MORE IS KNOWN ABOUT THE SITE. THE CURRENT KNOWLEDGE OF THE SITE INDICATES A NEED TO COLLECT DATA RELATED TO THE PARAMETERS IN THIS FIGURE.

X = ITEMS SPECIFIED DIRECTLY BY THE ISSUES RESOLUTION PROCESS (PERFORMANCE PARAMETERS).

CASZ = CONTROLLED AREA STUDY ZONE.

[a]ISSUE 4.2 INCORPORATES BROAD TERMS, AS 'UNDERGROUND HYDROLOGIC PARAMETERS" AND "HYDROLOGY," TO DESCRIBE PARAMETERS. THESE SPECIFIC PARAMETERS ARE IMPORTANT COMPONENTS OF THESE BROAD TERMS.

[b]THE "SPATIAL DISTRIBUTION OF . . ." THE PARAMETER, AS OPPOSED TO A SPECIFIC POINT VALUE, IS REQUIRED BY SELECTED ISSUES.

[c]ISSUE 1.8 REQUIRES THE DEVELOPMENT OF SITE AND REGIONAL GROUNDWATER MODELS. THESE PARAMETERS SUPPORT MODEL DEVELOPMENT.

[d]ISSUE 1.12 CALLS FOR DATA ON THE COHASSETT FLOW BOTTOM. HYDROLOGICALLY, THIS IS EQUIVALENT TO THE BIRKETT FLOW TOP. THE BIRKETT FLOW TOP IS ALSO INCLUDED WITHIN THE BROADER DESIGNATION OF PRIMARY ISOLATION ZONE.

[e]THESE PARAMETERS MAY NOT BE MEASURED FOR ALL STRATIGRAPHIC INTERVALS.

[f]ISSUE 1.12 REQUIRES THE DETERMINATION OF HYDRAULIC CONDUCTIVITY ANISOTROPY.

[g]ISSUE 1.10 REQUIRES INFORMATION DESCRIBING THE HYDROLOGIC CONDITIONS OF THE COHASSETT FLOW AT THE EDGE OF THE ENGINEERED SYSTEM.

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Figure 8.3.1.3-5. Groundwater investigation parameter matrix. (sheet 3 of 3)

9 2 1 2 5 5 4 2 0 3 2

9 2 1 2 5 5 4 2 0 8 3

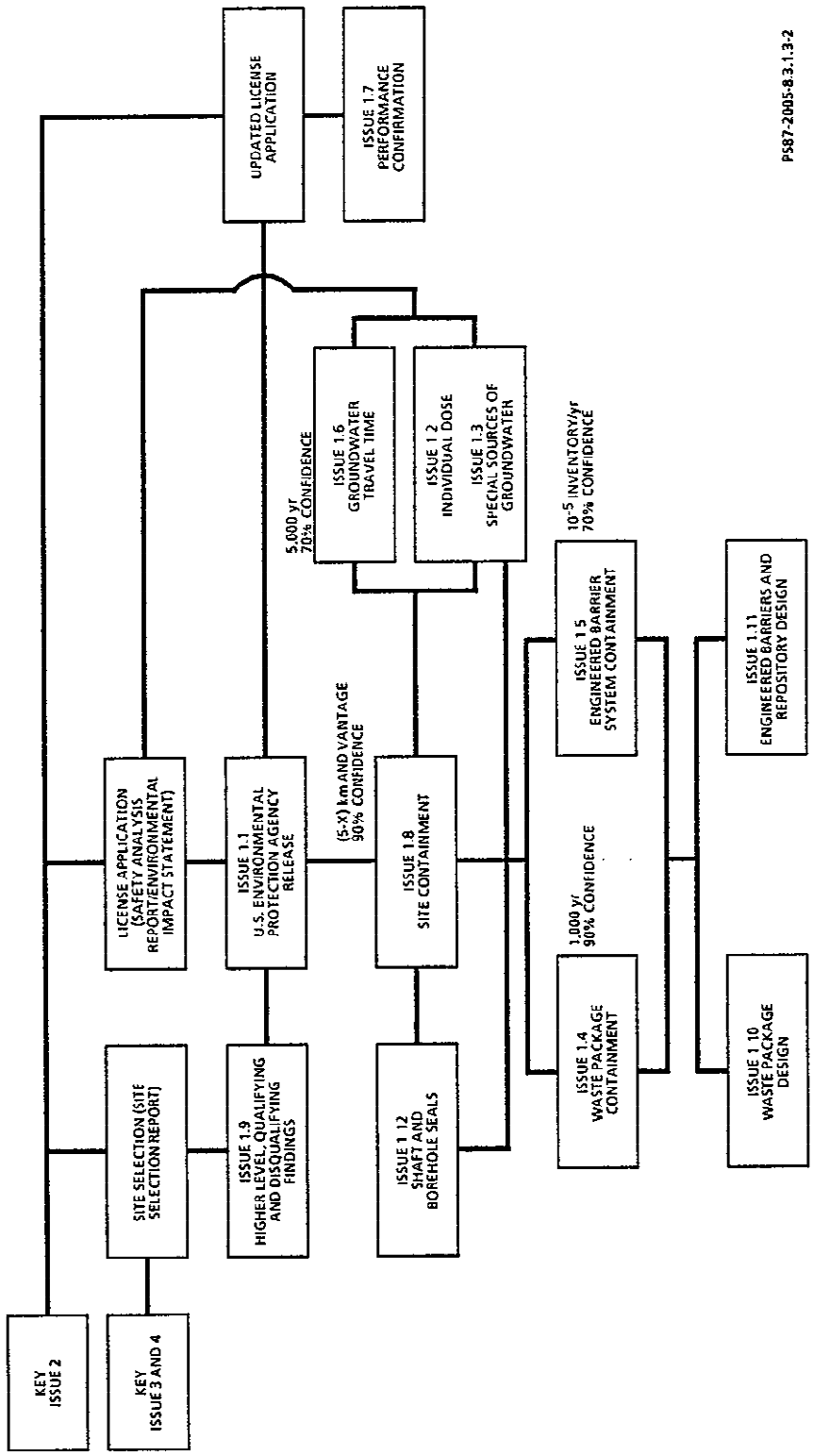

Figure 8.3.1.3-6. Issue hierarchy for Key Issue 1.

The postclosure issues (1.1 through 1.12) have a greater importance than the preclosure issues (Key Issues 2, 3, and 4).

The issue resolution strategies do not, at this time, directly address Key Issue 3, environmental quality and transportation. The environmental monitoring and mitigation plan will deal with the impact of hydrology on Key Issue 3.

The design goals are related to specific requirements for data to support facility design. The design goals are incorporated into the preclosure issues but are frequently of less visibility than those concerns of high importance to site selection or license application. Examples are the precipitation intensity data needed to calculate the runoff from the facilities area and the inflow data needed to calculate the methane levels within the underground facility. These calculations are necessary to design the facility to meet the NRC licensing guidelines. However, the calculations are of modest importance in comparison to the groundwater data needed in support of the question of cumulative release of radionuclides to the environment.

Compliance with state, local, and non-nuclear Federal regulations is described in Key Issue 3. This issue will be addressed by the environmental monitoring and mitigation and the socioeconomic monitoring and mitigation plans that will be published by Pacific Northwest Laboratories but not in this SCP. Data collected by the hydrologic investigations described in this section of the SCP will be used in response to other regulatory requirements when appropriate. Data, such as limnological and water quality information, not specified by the issues resolution process, but required by 10 CFR 960.5-2-5 (DOE, 1987a) or by state or local regulations, will be described in the monitoring and mitigation plans.

Data collected under the hydrology investigative program contribute to the data collection in other Hanford Site programs. Figure 8.3.1.3-7 represents the data cross-links between the hydrology investigative program and other Hanford Site programs. Figure 8.3.1.3-7 also demonstrates how data collected under the hydrology investigative program combines with data collected under the other programs to provide an adequate data base for performance assessment.

Four other parts of this Hanford Site SCP contain information essential for understanding the hydrology investigative program at the Hanford Site:

1. Chapter 3 provides a summary of the hydrologic studies previously conducted at the Hanford Site and a general description of the regional hydrologic setting of the Columbia Plateau. This information is summarized in Section 3.10.1.1, 3.10.1.2, and 3.10.1.3. Table 3.10-1 acts as a roadmap linking the data presented in Chapter 3 to the planned studies described in Section 8.3.1.3.

9 2 1 2 5 5 4 2 0 3 4

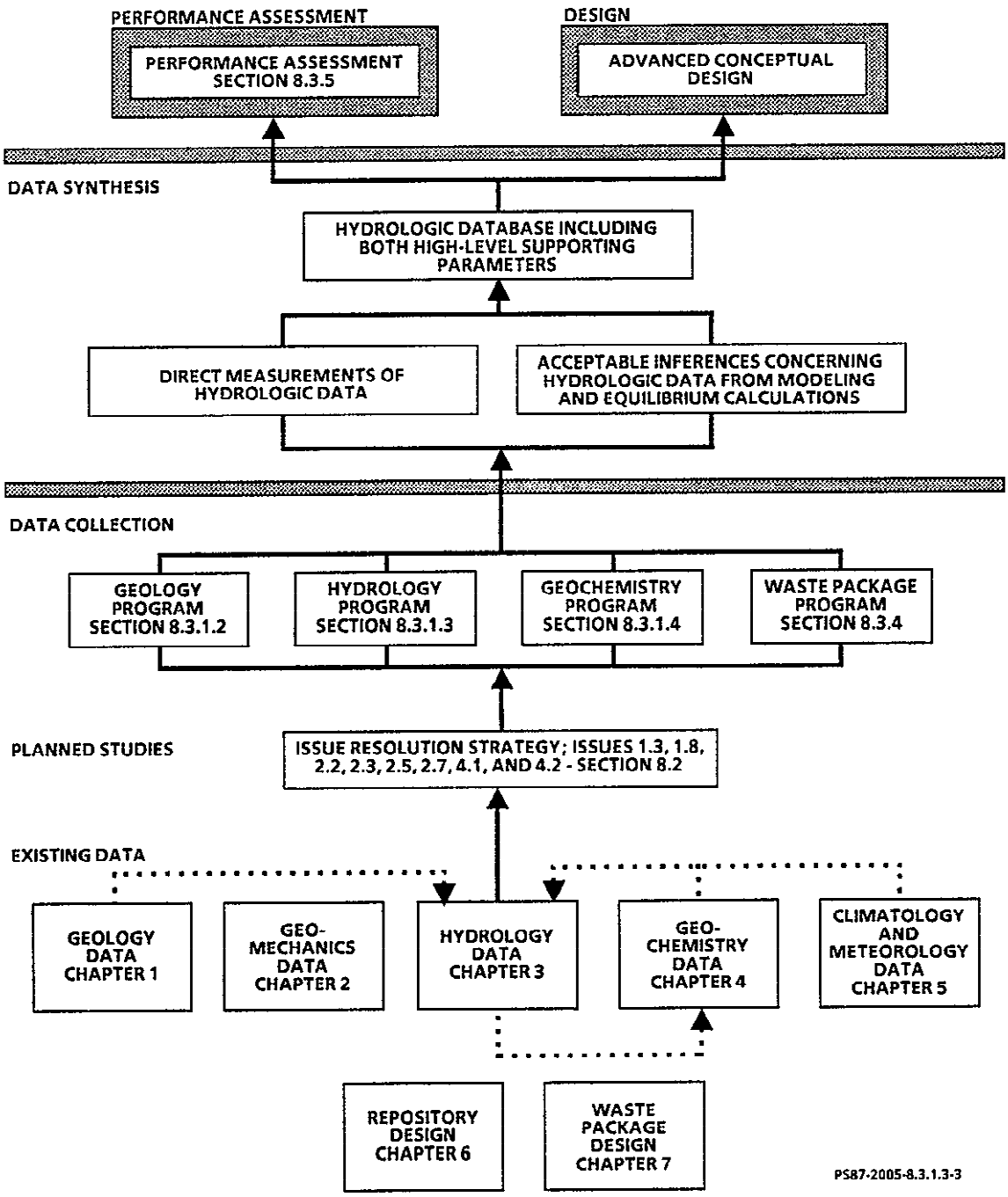

Figure 8.3.1.3-7. Links between the hydrology program and related activities.

9 2 1 2 5 5 4 2 0 3 5

2. Section 8.2 describes the issue resolution strategies, including the regulatory background, the licensing strategy, and the establishment of performance measures and parameter goals. These strategies are used to determine what hydrologic parameters must be measured to complete the site-characterization process. Sections 8.2.2.1 through 8.2.2.4 review each key issue and identify the hydrology information generated by each issue.

3. Section 8.3.5 discusses how the hydrologic data will be combined with other data to satisfy the data needs for performance assessment.

4. Chapter 1 provides a summary of the geologic studies previously conducted at the Hanford Site and a description of the geologic features of the site and the Columbia Plateau.

The issue resolution strategies (Section 8.2) provide the basis for the development of the hydrology investigative program. All work is focused on resolving an issue or providing information for design purposes. Broad hydrologic characterization studies will not be initiated to solely provide descriptive information not required by the issue resolution strategies.

9 2 1 2 5 5 4 2 0 8 6

8.3.1.3.3 Investigation of surface water

The surface water investigation is composed of two studies, the surface water system study and the site flooding study. The work will be concentrated on Cold Creek, in the vicinity of the controlled area study zone (Fig. 8.3.1.3-8).

The surface water system study is described in Judy (1987). It provides for the collection and analysis of the watershed characterization data (such as topography, soils, precipitation, and streamflow) that are needed to support the site flooding and groundwater recharge calculations.

The site flooding study is described in Wu (1987). The study focuses on preclosure events. Postclosure flooding, including the potential for flooding related to climate change, is discussed in Section 8.3.1.5. The study uses data from the surface water system study to provide estimates of the lesser (i.e., 100-yr return period) and probable maximum floods in the Cold Creek drainage. The site flooding study does not address the estimation of flood levels for the Columbia River; such data are already available from the power plant siting studies (WPPSS, 1981) and a U.S. Army Corps of Engineers report (COE, 1951). The Grand Coulee Dam break flood (COE, 1951) exceeds the probable maximum flood on the Columbia River. Neither the Grand Coulee Dam nor the probable maximum flood impacts the proposed repository site. Maps showing flood-prone areas are presented in Chapter 3.

9 2 1 2 5 5 4 2 0 3 7

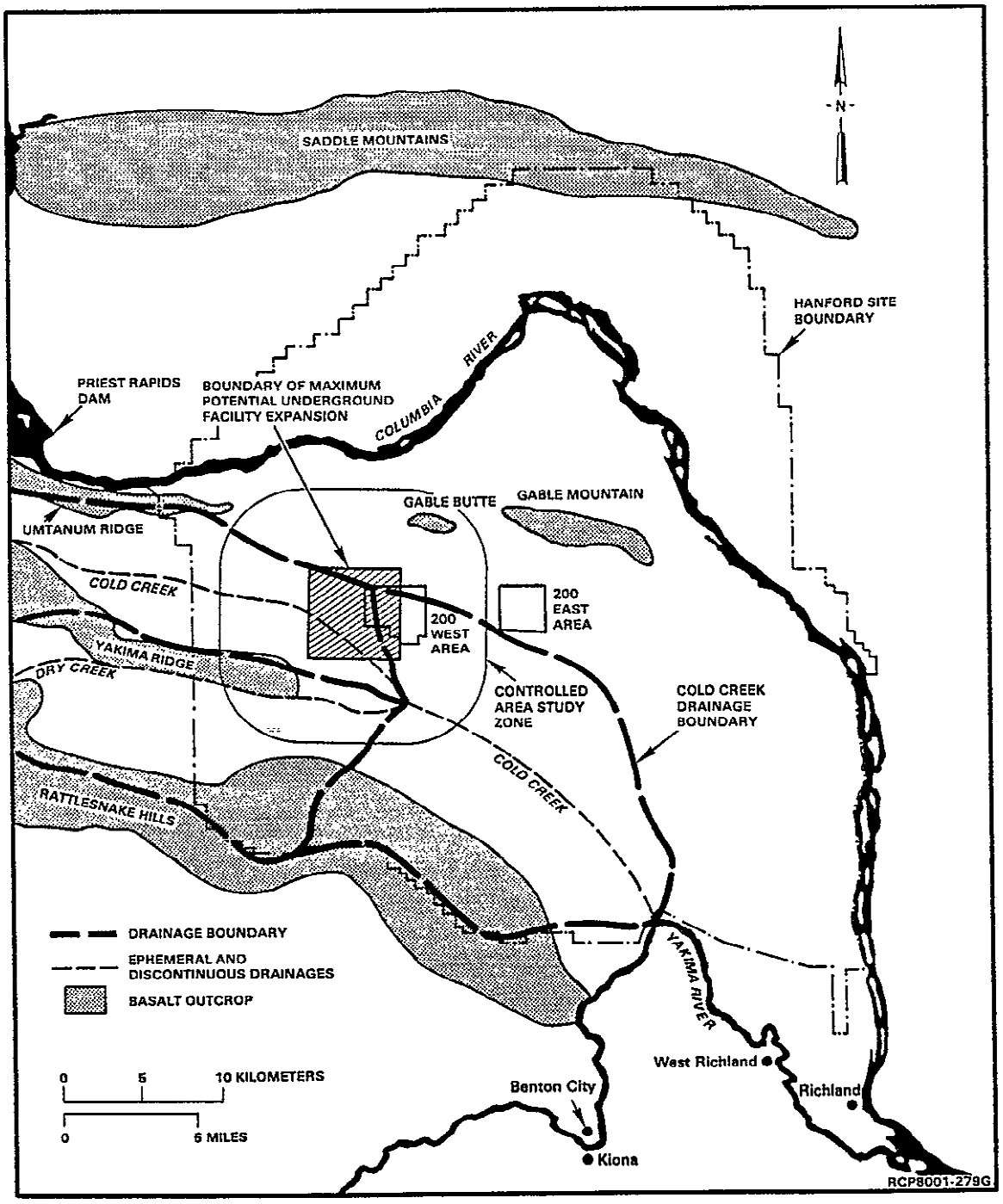

Figure 8.3.1.3-8. The relationships of the controlled area study zone to the surface water drainages.

8.3.1.3.3.1 Purpose and objectives

The purpose of the surface water investigation is to provide data for the calculation of flooding potential and the determination of groundwater recharge parameters. The potential for flooding is calculated as part of the surface water investigation. The recharge parameters are used in the regional groundwater study.

The specific objectives for data collection include the following:

- Determine the potential for flooding in the Cold Creek drainage.
- Determine the groundwater recharge parameters for use in the regional groundwater study.

The surface water system study provides data to support both of these objectives. The site flooding calculations are performed in the site flooding study, and the groundwater recharge calculations are performed in the regional groundwater study. Additional surface water studies related to baseline data for regulatory compliance requirements and the potential impact of the repository upon domestic and agricultural water rights are presented in the environmental monitoring and mitigation plan and the socioeconomic monitoring and mitigation plan, respectively.

8.3.1.3.3.2 Rationale

The surface water system and site flooding studies are required to support the design of the repository facilities and the development of the regional groundwater model. Figure 8.3.1.3-9 illustrates how the surface water system study provides the basic information required to meet the objectives related to both the potential for flooding and the groundwater recharge. Addressing these two areas of technical concern (i.e., potential for flooding and groundwater recharge) supports the issues related to surface water.

The surface water investigation will provide information required for the resolution of the issues described in Section 8.2. In contrast to the groundwater investigation that focuses on critical postclosure issues, such as Issue 1.1, the surface water investigation supports the preclosure issues related to the design and operation of the proposed repository. These issues (2.1, 2.2, 2.3, 4.1, and 4.2) require information related to the flood hazard on the proposed repository site. The relationships between the parameters to be addressed by the investigation and the issues requiring resolution are summarized in Tables 8.3.1.3-2 and 8.3.1.3-3. The performance parameters listed in Tables 8.3.1.3-2 and 8.3.1.3-3 are derived from the issues tables found in Section 8.2. The supporting parameters result from tests and analyses used in estimating the performance parameters. The SCP Glossary defines current confidence and needed confidence. Figure 8.3.1.3-10 is an illustration of the internal ties between the various supporting parameters.

9 2 1 2 5 5 4 2 0 3 8

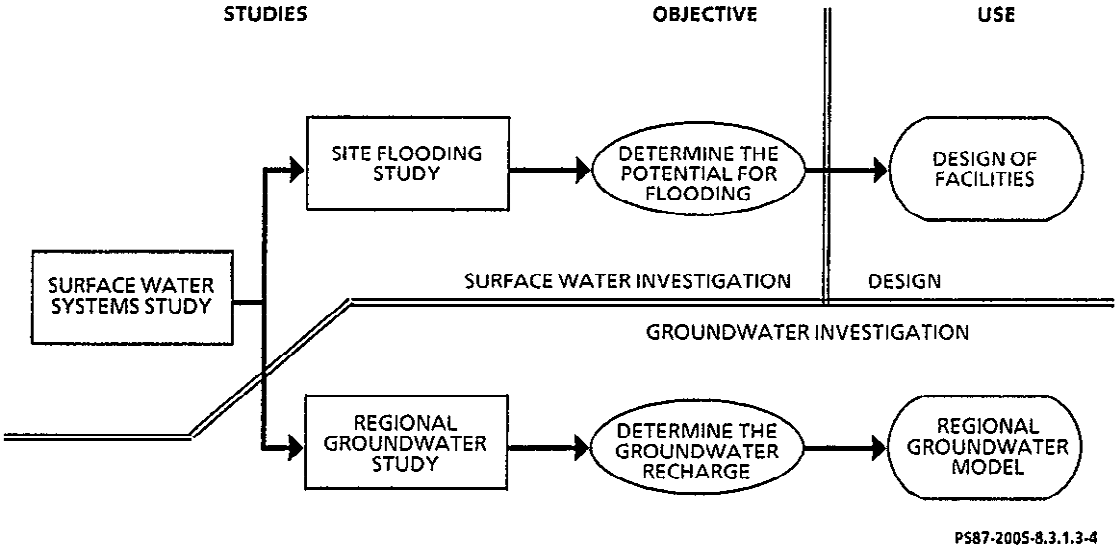

Figure 8.3.1.3-9. The surface water studies provide information to be used by other Basalt Waste Isolation Project activities.

The surface water investigation also provides support to the regional groundwater study (Section 8.3.1.3.4.3.1) of the groundwater investigation. The regional groundwater study will provide information needed for the resolution of Issue 1.8.

8.3.1.3.3.2.1 Technical concerns

The surface water investigation addresses the issues by collecting and analyzing information related to two areas of technical concern, the potential for flooding and groundwater recharge.

Potential for flooding

The potential for flooding within the Cold Creek drainage will be investigated to provide data for the design of the proposed repository facilities. The best available information (Skaggs and Walters, 1981) indicates that much of the proposed repository will be under the Cold Creek flood plain. The requirements set forth in Determining Design Basis Flooding at Power Reactor Sites ANSI/ANS 2.8 (1981) are being used to guide the site flooding study. It requires that flooding studies be done for any site that is not obviously flood dry, based on existing information.

The ANSI/ANS (1981) allows some flexibility in designing a site flooding study. The approach used in the site flooding study is centered on the use of the U.S. Corps of Engineer's computer models HEC-1 (COE, 1981a) and HEC-2 (COE, 1981b). These models have been used throughout the United States and most hydrologists recognize them as standard tools for flood estimation.

9 2 1 2 5 5 4 2 0 3 9

Table 8.3.1.3-2. Performance parameters and upper level supporting parameters for the surface water system study

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Soil/land cover (runoff characteristics)	4.2	CASZ	--	None[a]	Low	Medium
			Soil survey maps	(1:250,000)[a]	Low	Medium
			Land cover maps	(1:250,000)[a]	Low	Medium
Precipitation statistics (design rainfall)	4.2	CASZ	--	b	Low	High
			Precipitation time/ volume data	b	High	High
Topography (drainage patterns)	4.2	CASZ	--	1:24,000 (need 1:5,000)	Low	High
			Aerial photography	(c)	Low	High
			Horizontal and vertical survey control	3rd order	Medium	Medium
	4.2	Cold Creek watershed	--	1:24,000	High	High[d]
			(USGS 7½ min maps at 1:24,000)	1:24,000	High	High

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CASZ = Controlled area study zone.
USGS = U.S. Geological Survey.

[a]Number represents scale of existing maps. A scale of 1:25,000 (a larger numerical ratio equals a smaller scale) or larger is desirable. A minimum mapping unit (ability to detect variations in soils or land cover) of 5 acres is also desirable and is not met by current information.

[b]Precipitation data collection is currently funded by other programs. Design rainfall statistics not updated since 1969. Spatial distribution information is limited.

[c]Historic photos of varied scale and type available. Need current photos at a scale of approximately 1:10,000 and with control points adequate for preparing topographic maps.

[d]Basic map information is adquate but should be converted to digital format.

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Table 8.3.1.3-3. Performance parameters and upper level supporting parameters for the site flooding study

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Water level, lesser floods (as 10- or 100-yr floods)	2.3, 2.7, 4.2	Cold Creek watershed	--	0 - 1 m[a]	Low	High
			Flow, lesser floods	40 - 180 m^3/s	Medium	High
			Hydrologic parameters	(b)	Low	High
			Watershed physical parameters	(b)	Medium	High
Water level, probable maximum flood	2.3, 2.7, 4.2	Cold Creek watershed	--	0 - 7 m[a]	Low	High
			Flow, probable maximum flood	1,500 m^3/s	Low	High
			Hydrologic parameters	(b)	Low	High
			Watershed physical parameters	(b)	Medium	High
Catastrophic floods	1.8	Columbia River above Richland, Washington	--	2.0×10^4 to 2.3×10^5 m^3/s	Medium	Medium[c]
			Probable maximum flood	4.0×10^4 m^3/s	Medium	Medium[c]
			Dam break flood	2.3×10^5 m^3/s[d]	Medium	Medium[c]
Infiltration/runoff relationships	1.8	Columbia River above Richland, Washington	--	(b)	Low	Medium

NOTE: To convert meters to feet, multiply by 3.28.
CASZ = Controlled area study zone.
MSL = Mean sea level.

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[a]Highly dependent on specific location within the CASZ.

[b]Composed of many parameters, related to the analysis of the physical characteristics of the watershed and the anticipated hydrologic response based on these characteristics.

[c]Existing data may be adequate.

[d]Flow related to the failure of Grande Coulee Dam.

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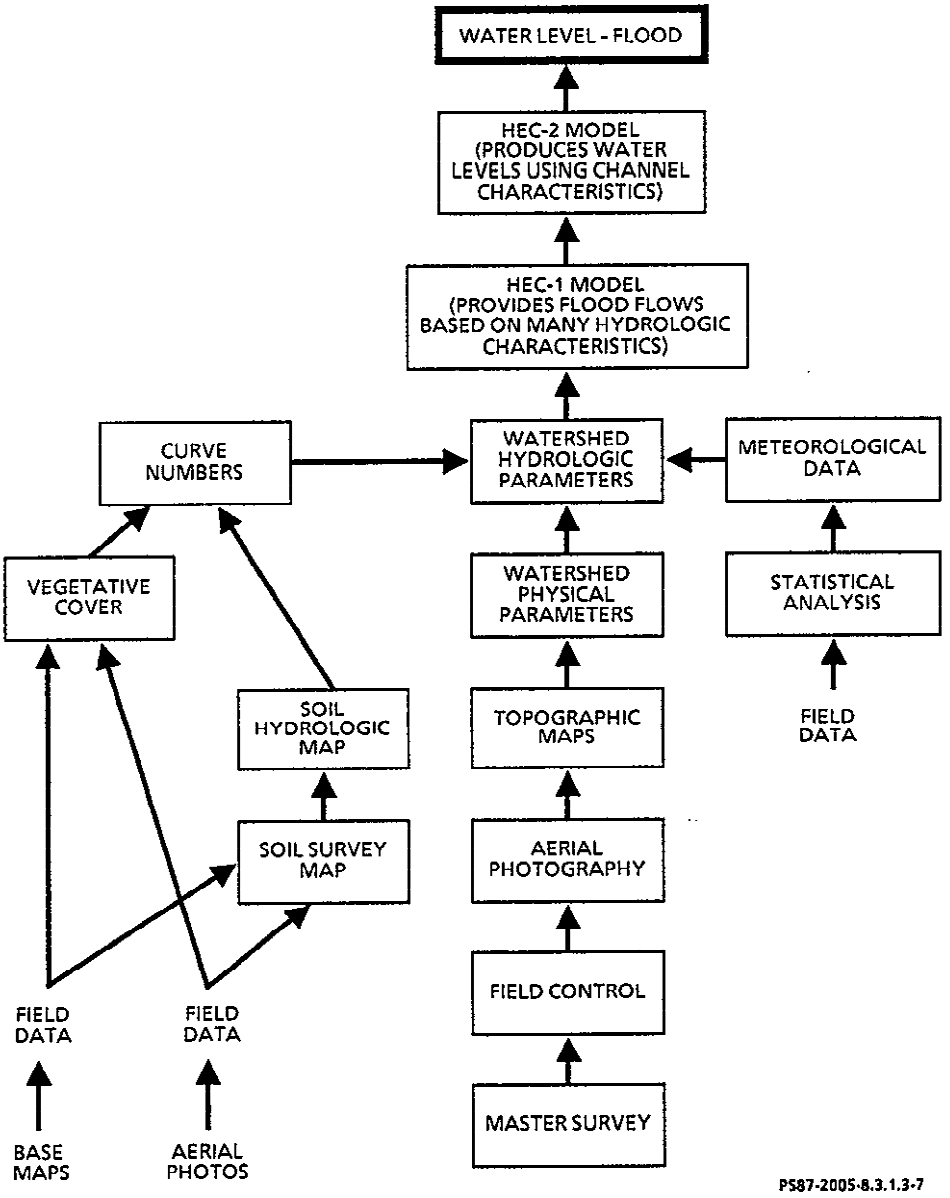

Figure 8.3.1.3-10. Supporting parameters for site flooding.

The hydrology investigative program will model two distinctly different types of flood events:

- Probable maximum flood, which represents the maximum flood that is possible due to the physical characteristics of the drainage and the transport of moisture into the basin.
- Lesser floods, which represent the floods that have calculated probabilities of occurrence and are developed by the statistical analysis of real streamflow and/or precipitation data.

The probable maximum flood is a rare event. It is typically used only for the design of a structure when the failure of that structure would have a catastrophic impact. The ANSI/ANS 2.8 (1981) requires that all repository facilities related to nuclear safety be designed to accommodate a probable maximum flood. Such a flood cannot be prevented or readily controlled by standard engineering practices. As a result, flood sensitive facilities such as ventilation shaft openings and emergency power supplies will have to be placed above the flood plain. Alternately, the structures will have to be designed to withstand the impact of the flood.

The occurrence of lesser floods, such as those having recurrence intervals of 10 to 100 yr, is routinely planned for in the design of buildings, highways, and other structures. The existing meteorologic (Stone et al., 1983) and soils data (Hajek, 1966) indicate that the rainfall intensity seldom exceeds the infiltration capacity of the soils in the vicinity of the proposed repository. Very little runoff will occur from undisturbed areas. As a result, the calculation of lesser floods will be most important for the following two distinctly different conditions:

1. Flooding originating in the steep topography of the upper Cold Creek drainage.
2. Localized flooding resulting from constructing buildings, paving parking lots, and other activities that reduce the infiltration capacity of the site.

Investigators will use models from the U.S. Army Corps of Engineers' (COE, 1981a; 1981b) to model the Cold Creek floods. The localized flooding will be estimated by the engineers responsible for the design of the facility, using one of the techniques described by Chow (1964) or the Soil Conservation Service (SCS, 1972).

The determination of the potential floods will be supported by the data collected under the surface water system study. Data collected under that study will include the following:

- Physical characteristics of the drainage.
  - Channel profile.
  - Channel cross sections.

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- Mean basin slope.
- Slope of channel segments.
- Sediment size distribution.

- Meteorologic data.
  - Probable maximum precipitation.
  - Local precipitation rates and totals.
  - Snowpack depth and distribution.

- Relief and ground cover.
  - Topography.
  - Soils.
  - Vegetative cover.
  - Land use.

- Hydrologic characteristics of the drainage.
  - Streamflow.
  - Time of concentration.
  - Time-lag curves.
  - Loss-rate parameters.
  - Peak discharge coefficients.
  - Curve numbers.

Much of these data will be obtained from existing sources such as Soil Conservation Service soil surveys and U.S. Geological Survey topographic maps.

The lack of historic streamflow records for Cold Creek places limits on the methods available for estimating flood frequencies. The period of record of the new gages will be too short for use in establishing statistically valid recurrence intervals for the measured-peak flows. As a result, calculations of the lesser floods will be based on the precipitation data (which has a long period of record) in models, and the resulting calculated floods will be used for design purposes. If any unusual runoff events occur, the related flood peaks will be correlated with the precipitation records and compared with the calculated floods.

The surface water data represent existing (preclosure) conditions. Postclosure conditions cannot be measured in the Cold Creek watershed. As a result, postclosure impacts can only be predicted through the use of existing data and modeling. The Future Climatic Change Study Plan (Underberg, 1987) will use modern climate data and physical-based models to predict the future climate of the Pacific Northwest. Predictions will include meteorologic conditions affecting the discharge of the Columbia River (i.e., long-term average precipitation, glaciation, glacial runoff, temperature). Underberg (1987) will provide the data necessary to calculate the extent of a probable maximum flood during postclosure conditions, although the final calculations for a probable maximum flood are not justified and will not be conducted. The occurrence of a probable maximum flood under any predictable environmental conditions would produce negligible damage to the Cold Creek watershed compared to the event of Grand Coulee Dam breaking or a catastrophic glacial flood. The potential for catastrophic glacial flooding is discussed in

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Section 8.3.1.5. The long-term (100-yr plus) potential for flooding related to future developments on the Columbia River is related to socioeconomic and political factors outside the scope of this investigation.

Groundwater recharge

Groundwater recharge will be studied under the regional groundwater study (Section 8.3.1.3.4.3.1). The surface water investigation will provide data, such as evapotranspiration rates, to support the analyses described in that section.

Existing data (Chapter 3) indicate that natural recharge to the unconfined groundwater system within the Hanford Site is small compared to the recharge resulting from waste water disposal by the Hanford Site defense-related facilities. Within the larger Pasco Basin, recharge caused by excess irrigation water exceeds the natural recharge.

The sensitivity of the confined aquifers within the deeper basalts to recharge from the unconfined aquifer is not clearly defined at this time. The low hydraulic conductivities of the interiors of the flows (Chapter 3) would appear to minimize the significance of any impacts of fluctuations in the unconfined aquifer upon the confined aquifers. The regional groundwater study (Section 8.3.1.3.4.3.1) incorporates the development of conceptual and numerical models of the groundwater system and the use of these models to explore the sensitivity of the confined aquifers to changes in recharge to the unconfined aquifer. The models will also be used to determine the sensitivity of the confined aquifers to changes in recharge resulting from long-term climatic change. The level of effort expended by the surface water investigation in collecting supportive data will be dependent upon the apparent sensitivity of the repository-level groundwater system to changes in recharge.

The sensitivity of the groundwater system to recharge could control both the extent and type of support provided by the surface water investigation. Initially, data collection would be limited to the Pasco Basin, but data collection could be expanded to that portion of the Columbia Plateau contributing to groundwater recharge. Also, the basic analyses resulting in the determination of potential evapotranspiration rates for typical land covers could be expanded to include developing computerized soil and vegetative cover maps for use in the water budget calculations done in the regional groundwater study (Section 8.3.1.3.4.3.1).

The data collected in support of the groundwater recharge analysis may include the following:

- Potential evapotranspiration.
  - Solar radiation.
  - Temperature.
  - Relative humidity.
  - Wind.
  - Pan evaporation.

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- Soils and ground cover.
  - Soil surveys.
  - Vegetative cover.
  - Land use patterns.

- Basin characteristics.
  - Reservoirs.
  - Unlined ditches.
  - Irrigation return flows.

Much of this data will be obtained from existing sources such as the Soil Conservation Service, the U.S. Bureau of Reclamation, and the U.S. Geological Survey. The precipitation inputs will be based on the climate studies discussed in Section 8.3.1.5.

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8.3.1.3.3.2.2 Constraints

The surface water investigation will not be adversely impacted by the construction of the exploratory shaft. The changes in land cover will be minimal and can be incorporated into the analyses. An example of these changes is the proposed construction of a site access road just south of the exploratory shaft. The road may modify the local topography enough to impact the level of floodwaters across part of the Hanford Site. But, the roadbed design can be incorporated into the cross sections used in the model to predict flood depth, and the impact of the road on the level of the floodwater can be predicted.

The collection of meteorologic and streamflow data will not be impacted by the construction of the exploratory shaft. No significant physical interferences with other field activities are anticipated. The only restrictive interrelationships between the tests and analyses are those related to the timing of data collection and the analysis of the data. Figure 8.3.1.3-11 is an illustration of the sequential flow of information through the investigative process.

The only apparent constraint on the surface water investigation will be the need to review existing data relative to the Basalt Waste Isolation Project (BWIP) quality assurance and quality control procedures. The ability to use historic (previous 30 yr) meteorologic data is critical to the development of precipitation information required for the calculation of lesser floods. The BWIP quality assurance and quality control procedures provide a vehicle for this review, and it is anticipated that data collected to well defined agency procedures (as National Weather Service or U.S. Geological Survey procedures) will be accepted by the project.

Relationship to other investigations

The surface water investigation will support the regional groundwater study by providing information required for water budget calculations. This relationship will be interactive as the sensitivity of the groundwater model to changes in recharge will determine the level of effort spent on acquiring

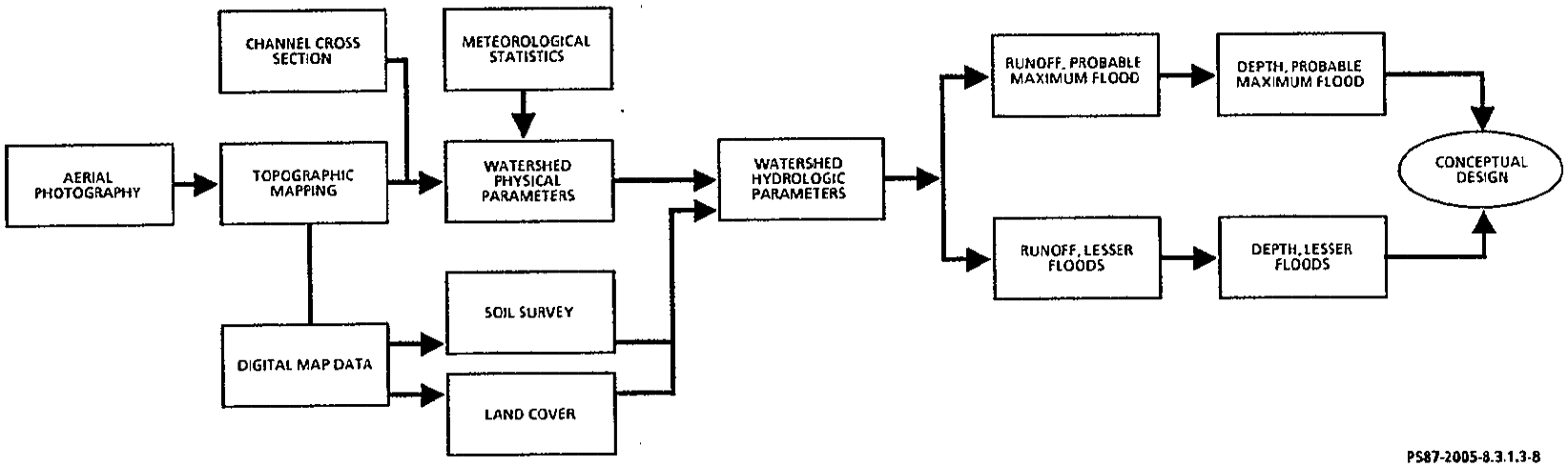

Figure 8.3.1.3-11. Tests and analyses within the surface water investigation are part of a sequence of tasks supporting the conceptual design of the proposed facility.

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supportive data. If the model indicates that the groundwater in the deeper basalts at the proposed repository site will respond to increased recharge rates resulting from a change in climate, additional land cover and soils data will be obtained to support the revised calculations.

Other repository studies, such as the conceptual design of the repository facilities, will be supported by the calculation of the probable maximum and lesser floods.

8.3.1.3.3.3 Description of studies

The surface water investigation comprises two studies, the surface water system study and the site flooding study. As illustrated by Figure 8.3.1.3-11, many of the tests and analyses included under the surface water system study will support the calculations done during the site flooding study.

8.3.1.3.3.3.1 Surface water system study.

The surface water system study is essentially a watershed characterization study except that no final, integrating report will be prepared. The study is designed to provide specific types of information to the site flooding study (Section 8.3.1.3.3.3.2) and the regional groundwater study (Section 8.3.1.3.4.3.1). This information will be transmitted to these studies by certified data base transmittal procedures and by computational briefs, not by descriptive reports on the Cold Creek and Pasco Basins. The Surface Water System Study Plan (Judy, 1987b) provides a detailed description of the proposed tests and analyses, the rationale behind them, and the strategy for completing them.

Study objectives

The surface water system study supports the design of the repository facilities and the development of the regional groundwater model. The immediate objective is the collection of data and the conversion of that data into information usable by others through such procedures as computational briefs and certified data transmittal packages. The broader objectives include supporting the determination of the potential for flooding and the determination of groundwater recharge as illustrated by Figure 8.3.1.3-8.

Support of conceptual model development

The surface water system study does not provide direct support to the development of the conceptual models of the geohydrologic system. But, the initial development and use of the regional groundwater model will impact the scope of the surface water system study. The sensitivity of the model to changes in recharge will determine the type and amount of soils, land cover, and evapotranspiration data collected for the Pasco Basin, and, if necessary, that data collection will be extended to other parts of the Columbia Plateau.

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Guidance to future activities

The surface water system study will provide information to be used in other studies. But these other studies are not dependent upon this information for determining type or scope of their activities.

8.3.1.3.3.3.1.1 Analyses. The surface water system study will include the analysis of new and existing data to convert the data into a format more usable in the site flooding and regional groundwater studies. Figure 8.3.1.3-9 provides a simplified illustration of how the information will flow through the study. The analyses to be conducted are summarized in Table 8.3.1.3-4.

Table 8.3.1.3-4. Summary of analyses performed during the surface water system study

Analysis	Area of influence	Performance parameter supported	Issue supported
Topographic map preparation	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
		Topography	4.2
Digital map information	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
		Soil/land cover	4.2
		Infiltration/runoff relationships	1.8
Watershed physical parameters	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
Water control structures	Watershed	*	
Meteorological statistics	Watershed	Lesser floods	2.3, 2.7, 4.2
		Precipitation intensity	4.2
Potential evapotranspiration	Watershed	*	
Streamflow statistics	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
Watershed hydrologic parameters	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2

*Supports regional groundwater studies.

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Topographic maps

Topographic maps will be produced, for the area overlaying the proposed repository, at a scale of 1:5,000 and with a 1-m (3.3-ft) contour interval to comply with ANSI/ANS 2.8 (1981) standards for maps for site flooding calculations. The maps will be based on aerial photographs and will be produced to the standards described by the U.S. Bureau of the Budget (1947) and Thompson (1979). They will be used to provide localized terrain details not available on the smaller scale U.S. Geological Survey 7 1/2-min (1:24,000) topographic maps and to provide a link between the flooding studies and engineering design. It is critical that the flood levels and the proposed structures use common horizontal and vertical reference systems.

Digital map information

Digital map information will be prepared from the existing U.S. Geological Survey 1:24,000 topographic maps to provide base maps of the controlled area study zone and the Cold Creek watershed for the hydrologic analyses. Accuracy standards are provided by the U.S. Bureau of the Budget (1947) and Thompson (1979). The working maps will be produced at a scale of 1:25,000 to comply with the BWIP procedures requiring metric scales. These maps will provide a standard base for use in compiling soils, land cover, and related data. The specification of digital locational data will allow the use of a geographical information system to create composite maps, calculate areas, and document these efforts for quality assurance and quality control purposes.

Watershed physical parameters

The watershed physical parameters (e.g., acreage, slope, channel length, mean basin elevation, and channel profile) will be determined for Cold Creek and the subbasins within the Cold Creek watershed using the digital map information described above. These data will be used in the site flooding study. The use of digital map information in determining these parameters will provide for the repeatability of measurements by different people. The measurements will be taken as specified in Chow (1964) and Strahler (1956; 1957).

Water control structures

Water control structures within the Pasco Basin will be inventoried to allow an assessment of man's impact on streamflow and to provide a basis for determining groundwater recharge from reservoirs and unlined ditches. Information will be obtained from maps and from government agency records. Any structures located within the controlled area study zone or the Cold Creek drainage will be checked against the water rights and claims for water use compiled by the regional groundwater study.

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Meteorologic data

Meteorologic data will be compiled, reviewed, and statistically analyzed for use in the site flooding and the regional groundwater recharge studies. The data types to be analyzed include precipitation, snowpack, wind, temperature, relative humidity, evaporation, and solar radiation. Widely accepted analytical methods, such as those described by the U.S. Weather Bureau (USWB, 1952; 1955a; 1955b; 1961), the World Meteorological Organization (WMO, 1969), Chow (1964), and Bruce and Clark (1966) will be used. The existing data from the Hanford Meteorology Station (Stone et al., 1983) will be used when practical. It will be supplemented by data from the Arid Lands Ecology Reserve, the Yakima Firing Center, and nearby meteorologic stations supervised by the National Weather Service.

Potential evapotranspiration

Potential evapotranspiration will be calculated by the procedure described by Penman (1948) for areas within the Pasco Basin. These theoretical values will be checked against pan evaporation data and the work done by Gutknecht et al. (1980). The resulting values will be used in the water budget analysis of the regional groundwater recharge study.

Streamflow data

Streamflow data will be compiled, reviewed, and analyzed statistically for use in the site flooding study, engineering design calculations, and for fulfilling regulatory compliance requirements. The analytical methods described by Chow (1964), Riggs (1968a, 1968b, 1973), and U.S. Bureau of Reclamation (USBR, 1977) will be used. The emphasis will be placed on the analysis of data from the gages to be installed on Cold Creek and the existing gages on the Yakima River and the Columbia River adjacent to the Hanford Site. The period of record for Cold Creek will be short, not adequate for some statistical analyses. If any unusually high runoff events occur, their approximate frequency will be determined by comparison to nearby drainages and precipitation data from stations with long periods of record.

Watershed hydrologic parameters

Watershed hydrologic parameters, such as time-lag curves, peak discharge coefficients, loss-rate parameters, time-of-concentration, and curve numbers, will be determined for the Cold Creek drainage for use in the site flooding study. These parameters will be determined from site-specific data using techniques such as those described by the U.S. Army Corps of Engineers (COE, 1981a) and the Soil Conservation Service (SCS, 1972).

8.3.1.3.3.3.1.2 Tests. The study will include tests (data collection tasks) that will support the analyses described in the preceding section. Table 8.3.1.3-5 summarizes the tests described below.

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Table 8.3.1.3-5. Summary of tests performed during the surface water system study

Test	Area of influence	Performance parameter supported	Issue supported
Aerial photography	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
		Topography	4.2
Channel cross sections	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
Precipitation data	Watershed	Lesser floods	2.3, 2.7, 4.2
		Precipitation intensity	4.2
Snowfall data	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
Streamflow, continuous	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
Streamflow, peak	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
Sediment samples	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
Soil survey	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
		Soil/land cover	4.2
		Infiltration/runoff relationships	1.8
Land cover	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
		Soil/land cover	4.2
		Infiltration/runoff relationships	1.8

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Aerial photography

Aerial photography, probably black and white stereo coverage at 1:10,000 will be obtained for the controlled area study zone. It will be used for the preparation of a large-scale (1:5,000) topographic map and as a visual model of the site. Technical procedures and accuracy standards are specified by Eckhardt et al. (1966).

Channel cross-sections

Channel cross sections will be surveyed, at 2-km (12-mi) intervals along Cold Creek and at specific features, including where Highways 24 and 240 cross the creek. They will include one cross section crossing the valley in the vicinity of the Exploratory Shaft Facility, to provide a surveyed tie to the site plans used by engineering design. These cross sections will provide the supplemental topographic detail for use in the site flooding water-level calculations. The U.S. Army Corps of Engineers' User's Manual (COE, 1981a) will be used as a guide in determining the location and width of the cross sections.

Precipitation data

Precipitation data will be collected in the upper Cold Creek drainage using 20-cm- (8-in.-) diameter recording precipitation gages. The data will be used to determine the spatial variations in watershed precipitation. The U.S. Weather Bureau (USWB, 1952) provides standards for measuring precipitation.

Snowfall data

Snowfall data will be collected at the precipitation monitoring stations using a simple staff gage (SCS, 1953). Two 10-point snow courses (SCS, 1953) may be installed in the upper Cold Creek drainage. The data will be used by future flood modeling and engineering studies.

Streamflow data

Streamflow data will be obtained for Dry Creek and upper Cold Creek. Wiers or flumes with recorders will be installed and operated in accordance with Buchanan and Sommers (1982) and Carter and Davidian (1968). The gages will be placed at the changes in channel slope on Dry Creek just above Cold Creek and on Cold Creek above the Hanford Site area boundary.

Peak flows

Peak flows will be measured with crest-stage gages (Carter and Davidian, 1968) at those segments of Cold Creek not being monitored continuously. These gages will provide supplemental information about any major runoff events that occur during the life of the project. Crest-stage gages were selected because

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they would provide some data on extreme flows at a modest cost. The lack of a well-defined channel in the lower portion of Cold Creek would make it difficult to install a wier or flume that would catch a representative runoff event.

Sediment samples

Sediment samples will be taken from selected cross sections of Cold Creek using the procedures described by Guy and Norman (1970). The data will be used in the evaluation of the scouring and deposition taking place during flood flows.

Soil data

The soil survey map (Hajek, 1966) for the Hanford Site will be reviewed and revised, as necessary, to bring it into compliance with current Soil Conservation Survey standards (SCS, 1951, 1983). The information will be used to assist in determining the hydrologic characteristics of the Cold Creek watershed to be used in the site flooding study. The soils map of the Hanford Site will be supplemented through the use of the published Soil Conservation Service Soil Survey for Benton County (SCS, 1971) for those areas outside the Hanford Site boundary.

Land cover data

The existing land cover and vegetation maps of the Cold Creek watershed will be reviewed and revised or remapped, as necessary, to provide the data required for determining the hydrologic characteristics to be used in the site flooding study. The mapping requirements would be based upon standard land cover mapping practices (Anderson et al., 1976) and modeling requirements (SCS, 1972).

8.3.1.3.3.3.2 Site flooding study.

The site flooding study will use the information on the Cold Creek drainage, collected and analyzed under the surface water system study (Section 8.3.1.3.3.3.1) to develop the floodwater elevations required for the design of the repository facilities. The Site Flooding Study Plan (Wu, 1987) provides a detailed description of the tests and analyses, the rationale behind them, and the strategy for completing them.

Study objectives

The site flooding study has a primary objective of providing a description of flooding history and potential. This objective has three components caused by the differences between the issues that require flood-related information:

1. Flooding related to worker safety.
2. Flooding related to nuclear safety concerns.
3. Flooding related to the ease and cost of construction.

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The calculation of the probable maximum flood will provide information for all of the above components of the primary objective. It will also be responsive to the standards provided by ANSI/ANS 2.8 (1981). In addition, lesser flood events will be described, and data will be provided for the engineering calculations required for localized flooding determinations related to the ease and cost of constructing the repository.

The site flooding study will incorporate two components, one to accommodate the early need for conventional design data for the construction of the exploratory shaft and another to address the later need for highly documented data to support the design of the repository facilities. The first component will be a preliminary calculation using the best available data and standard engineering practices. The second component will parallel the first, but will provide a refined estimate of flooding by using additional site-specific data collected by the surface water system study. Both components will incorporate the analyses for probable maximum floods and lesser floods described in the following section.

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Support of conceptual model development

The site flooding study will not contribute to the development of the conceptual geohydrologic model of the site.

Guidance to future activities

The site flooding study will provide information important to the design of the repository facilities. The type or scope of these studies will not depend upon the data unless these data are outside the currently estimated range. If the values for the flood elevations are higher than the existing study (Skaggs and Walters, 1981) indicates, additional design activities may be required to accommodate the potential impacts of the flooding.

8.3.1.3.3.3.2.1 Analyses. The study will be based on the analyses of information provided by the surface water system study. The analyses will be structured to take advantage of the HEC series of computer models developed by the U.S Army Corps of Engineers (COE, 1981a; 1981b). These models have received widespread use and acceptance in the United States. Figure 8.3.1.3-9 provides a simplified illustration of how the information will flow from the surface water system study, through the site flooding study, and will result in the provision of water-level data for the design of the repository facilities. Table 8.3.1.3-6 summarizes the analyses described below.

Probable maximum flood

The probable maximum flood for Cold Creek will be calculated using the U.S. Army Corps of Engineers' HEC-1 Flood Hydrograph Package (COE, 1981a). The determination of the probable maximum flood is required by ANSI/ANS 2.8 (1981) for those sites that are not flood dry. The best available information (Skaggs and Walters, 1981) indicates that a portion of the controlled area study zone may be inundated by a probable maximum flood on Cold Creek. As a

Table 8.3.1.3-6. Summary of analyses performed during the site flooding study

Analysis	Area of influence	Performance parameter supported	Issue supported
Probable maximum flood	Watershed	Probable maximum flood	2.3, 2.7, 4.2
Water surface elevation	Watershed	Probable maximum flood	2.3, 2.7, 4.2
		Lesser floods	2.3, 2.7, 4.2
Lesser flood event	Watershed	Lesser floods	2.3, 2.7, 4.2
Coincident wind wave activity	Watershed	Probable maximum flood	2.3, 2.7, 4.2
Sediment, erosion, and scouring effects	Watershed	Probable maximum flood	2.3, 2.7, 4.2

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result, new calculations done to the standards prescribed by ANSI/ANS 2.8 (1981) are required to refine the estimate of the peak flow during a probable maximum runoff event.

Lesser flood events

Lesser flood events (frequency-based floods) will be determined for the design of structures not required to withstand a probable maximum flood. As streamflow records are not available for Cold Creek, these floods will have to be determined by the application of regional flood equations (Cummans et al., 1975; Haushild, 1979) or precipitation (runoff approaches) (Chow, 1964). Supportive data for the precipitation (runoff calculations) are available from local data (Stone et al., 1983) and regional publications (NWS, 1974).

Flood flow elevations

The water surface elevation analysis will determine the water surface elevations along Cold Creek due to the probable maximum flood and lesser flood events. These elevations will provide the basis for designing nuclear safety-related structures, systems, and components (ANSI/ANS 2.8, 1981) and will also provide information for the design of other structures such as roads and ponds. The U.S. Army Corps of Engineers HEC-2 water surface profiles computer program (COE, 1981b) will be used to compute the water surface elevations relative to the actual terrain to place the flood flows in a useful perspective relative to the proposed repository facilities.

Wind wave activity

The coincident wind wave activity, related to the probable maximum flood on Cold Creek, will be analyzed as required by ANSI/ANS 2.8 (1981). The wave runup and wind setup will be determined using procedures described by the U.S. Army Corps of Engineers (COE, 1976; 1984). The wave runup and wind setup

values will be superimposed upon the flood levels (see water surface elevation analysis, above) to determine the design basis flood as prescribed by ANSI/ANS 2.8 (1981).

Sedimentation, erosion, and scour

Sedimentation, erosion, or scouring may modify the stream channel and impact the floodwater levels. These impacts will be evaluated using the procedures described by Vanoni (1977), and Pemberton and Lara (1982) and incorporated into the water-level calculations. Computer programs (i.e., HEC-6, Scour and Deposition on Rivers and Reservoirs (COE, 1977)) will be used if appropriate. Other techniques will be evaluated prior to the final calculations because the poorly defined channel of lower Cold Creek is not typical of the drainages normally evaluated by these procedures.

8.3.1.3.3.4 Application of results

The results of the surface water investigation will support the regional groundwater study and the design of the repository facilities. The primary applications of the results of the surface water system study will include the following:

- The internal integration of data and development of site hydrologic parameters to support the site flooding study.
- The compilation of data and calculation of potential evapotranspiration rates to support the water budget component of the regional groundwater study.
- The compilation of meteorologic, soils, topographic, and land cover data to support localized flooding calculations related to the design of the surface facilities.

The primary applications of the results of the site flooding study will include the following:

- Flood levels for the design of the Exploratory Shaft Facility.
  - Probable maximum flood.
  - Lesser, frequency-based floods.
- Flood levels for the design of the repository facilities.
  - Probable maximum flood.
  - Lesser, frequency-based floods.

Information from both studies will increase our knowledge of the site and contribute to the physical descriptions of the site presented in the license application and the environmental impact statement.

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Support of other investigations

The water budget component of the regional groundwater study of the groundwater investigation will use the results of the potential evapotranspiration calculations. Additional data on meteorology and land cover may be provided if the regional groundwater proves sensitive to recharge rates.

Performance assessment uses

Direct uses of the performance assessment data are not anticipated. Indirectly, as through facility design requirements and via the regional groundwater model, the data will influence the information used in performance assessment models.

Design uses

The primary application will be the determination of the design basis flooding at the repository site, as described by ANSI/ANS 2.8 (1981). The design-basis flood estimate will be required for the determination of the appropriate elevations of safety-related structures, systems, and components. The calculation of lesser flooding events will provide information for the design of structures that are not directly related to nuclear safety, such as the design of highway drainage and the sizing of runoff retention ponds.

Planning other activities

The surface water investigation will provide information required for the completion of other studies but will not control the content or scope of those studies.

8.3.1.3.3.5 Schedule and milestones

The schedule for the surface water investigation is summarized by Figures 8.3.1.3-12. Additional details showing the relationships of the tests and analyses and the intermediate milestones are presented in Figures 8.3.1.3-13 and 8.3.1.3-14.

The completion of the investigation will result in reaching several intermediate and one major milestone:

Intermediate milestones:

- Compilation of data related to the following:
  - Base maps.
  - Meteorologic data.
  - Channel cross sections.
  - Soils for Cold Creek drainage.
  - Land cover for Cold Creek drainage.
  - Curve number maps.
  - Hydrologic parameters.

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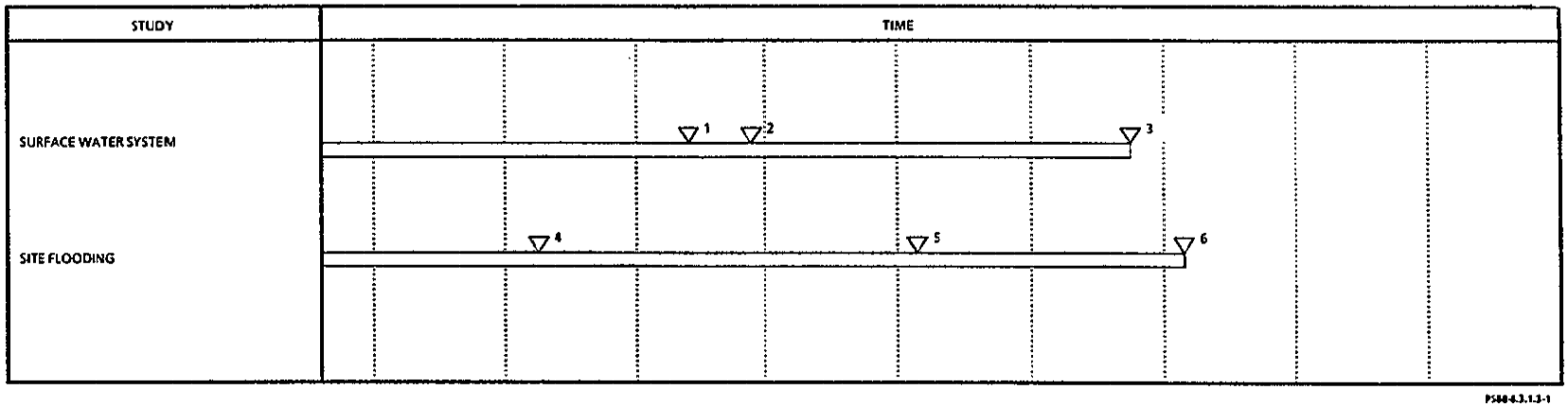

1 WATERSHED AND HYDROLOGIC DATA REQUIRED FOR SITE FLOODING STUDY.
2 RECHARGE INFORMATION REQUIRED FOR REGIONAL GROUNDWATER STUDY.
3 FINAL EVALUATION OF WATERSHED AND HYDROLOGIC DATA.
4 PRELIMINARY SITE FLOODING CALCULATIONS USED TO GUIDE ENGINEERING DESIGN.
5 FINAL SITE FLOODING CALCULATIONS FOR FACILITY DESIGN AND LICENSE APPLICATION SUPPORT.
6 CALCULATED FLOODS CHECKED AGAINST ACCUMULATED SITE-SPECIFIC HYDROLOGIC DATA.

Figure 8.3.1.3-12. Surface water investigation.

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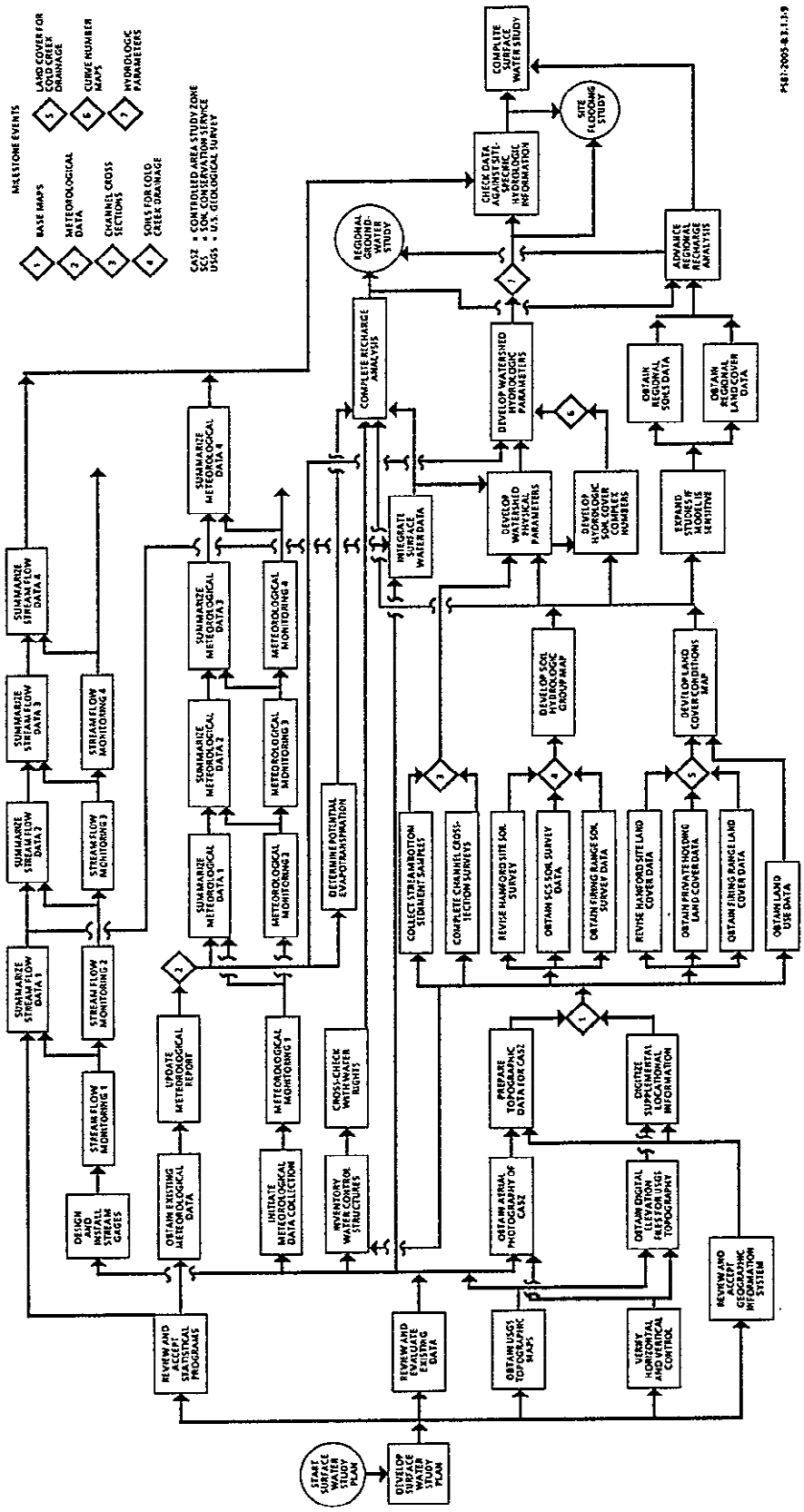

Figure 8.3.1.3-13. Surface water system study logic.

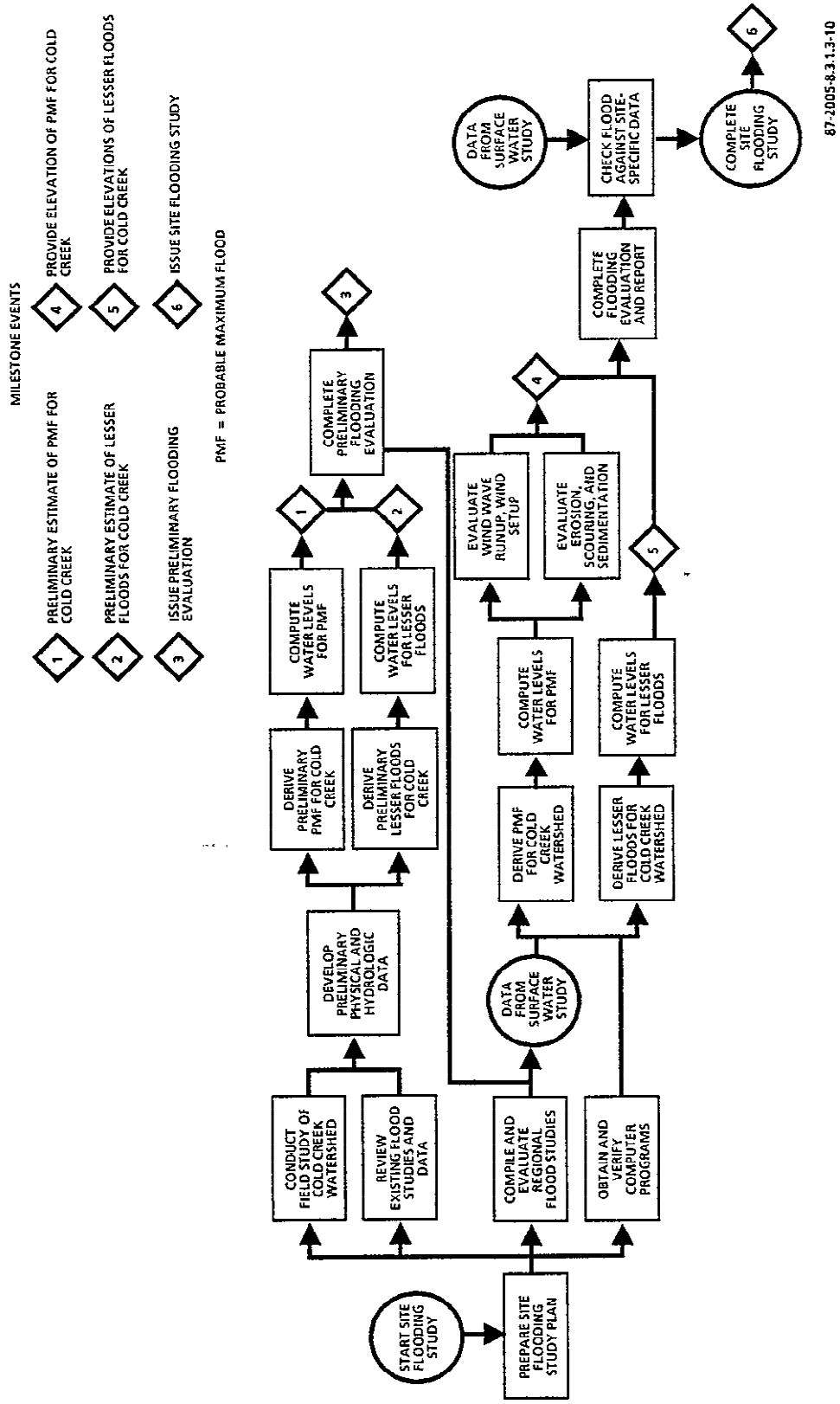

Figure 8.3.1.3-14. Site flooding study logic.

- Determination of the following:
  - Preliminary estimate of probable maximum flood elevation for Cold Creek.
  - Preliminary estimate of lesser flood elevations for Cold Creek.
  - Elevation of probable maximum flood for Cold Creek.
  - Elevations of lesser floods for Cold Creek.
- Issuance of the preliminary flooding evaluation.

Major milestone:

- Completion of site flooding study.

The major milestone, completion of the site flooding study, will incorporate the publication of a formal site flooding report. The intermediate milestones will be formalized by the transmittal of calculations, briefs, and certified data transmittal packages to the project data base. These intermediate milestones also include the results of preliminary calculations done to meet exploratory shaft design requirements. The publication of a formal watershed characterization report is not anticipated at this time.

The relationships between the surface water tests and analyses are illustrated by Figure 8.3.1.3-13. The meteorologic and surface water monitoring activities will continue for the duration of the project. Annual updates to the data base will provide the project with the best available information. The preparation of maps and the collection of field data, such as soils information, must proceed in a sequence (see Fig. 8.3.1.3-11) for the watershed hydrologic parameters to be determined and the site flooding study to proceed.

Ties between the investigation and other studies include the following:

- Data for the water budget calculation in the regional groundwater study.
- Data for the calculation of localized flooding during the design of the repository facilities.
- The elevations of the probable maximum and lesser floods required for the design of the repository facilities.

The data transferred to the BWIP data base at the intermediate milestones will also be useful for regulatory compliance and environmental impact statement preparation purposes.

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8.3.1.3.4 Investigation of groundwater

The groundwater investigation of the proposed repository site is composed of the regional groundwater study and the site groundwater study.

The regional groundwater study provides for the characterization of the regional groundwater flow system, which will assist in the definition of the hydrologic boundaries for the flow system in the controlled area study zone. This effort will include the development of conceptual and numerical models for the Pasco Basin and the Cold Creek syncline (Fig. 8.3.1.3-15). The impacts of possible future system stresses, such as resource development and climatic change, will also be evaluated.

The site groundwater study provides for the collection of the data required to describe the groundwater flow system within the controlled area study zone and to support the resolution of regulatory issues. The effort will include in situ testing, monitoring, conceptualization of the flow system, and numerical analysis of the flow in the site. The study is divided into pre-exploratory shaft and post-exploratory shaft construction phases to provide for the collection of data that may be sensitive to interference from construction and to be able to monitor the impacts of construction on the geohydrologic system.

8.3.1.3.4.1 Purpose and objectives

The purpose of the groundwater investigation is to accomplish the following:

- Collect and analyze data to provide the geohydrologic information required to resolve the issues in a timely fashion.
- Evaluate the boundary conditions that may influence the groundwater system within the controlled area study zone.
- Develop conceptual and numerical model(s) of the regional and site groundwater systems.
- Determine that the project has the level(s) of confidence in potential site suitability to justify major geohydrologic decisions.

The groundwater investigation is composed of two studies. The regional groundwater study will characterize the regional groundwater flow system and provide information on the boundary conditions that may influence the groundwater system within the controlled area study zone. The site groundwater study will describe the groundwater flow within the controlled area study zone and provide the site-specific geohydrologic information required to resolve the issues (see Table 8.3.1.3-1).

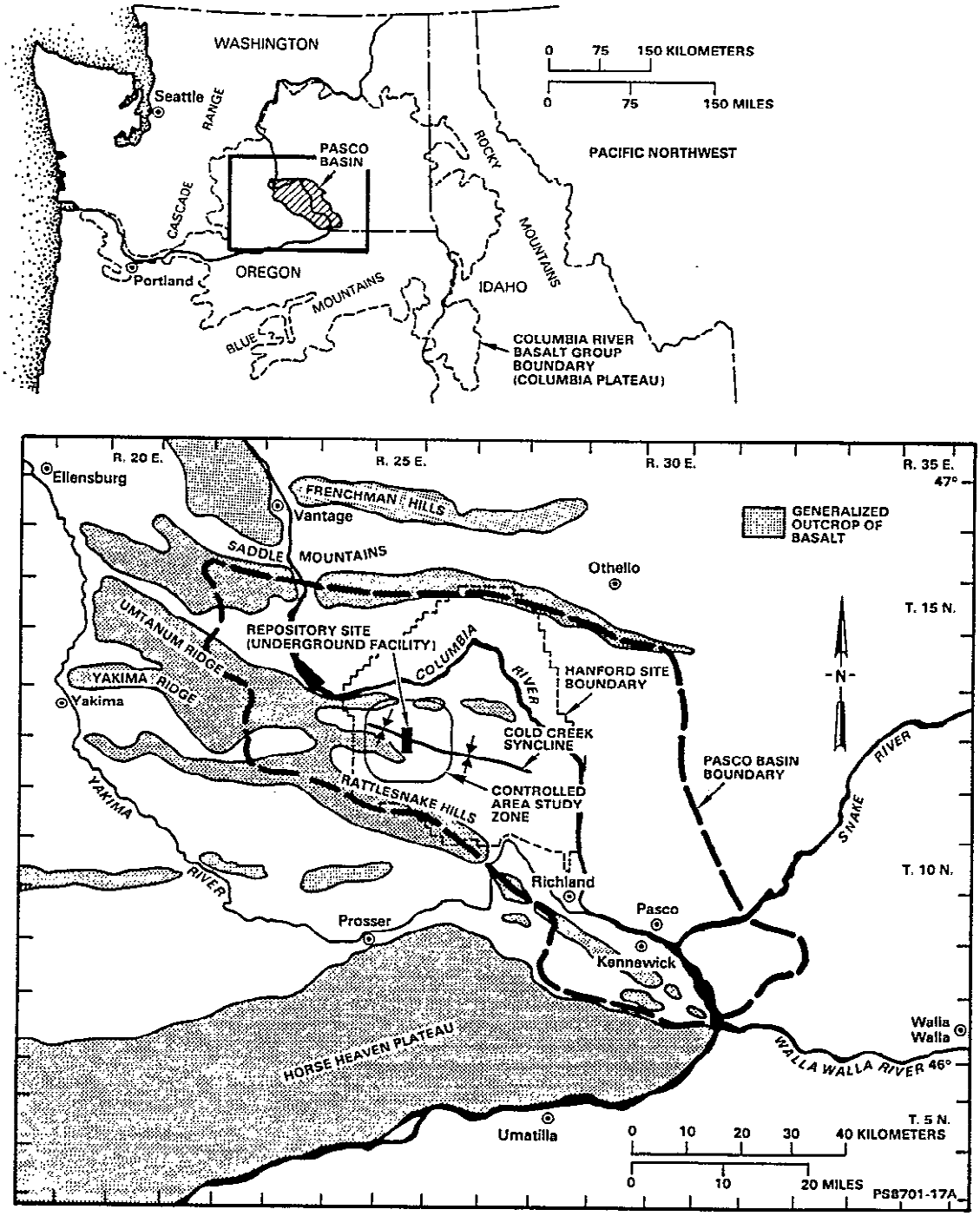

Figure 8.3.1.3-15. The groundwater investigation will focus on the Pasco Basin and the controlled area study zone.

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The specific objectives for the investigation include the determination of the following:

- Hydraulic properties and their spatial distribution.
- Spatial distribution of hydraulic heads.
- Nature, extent, and location of hydraulic boundaries.
- Character of the conceptual and numerical models of the groundwater flow system.

The following section on the rationale for the investigation will use these objectives as the basis for developing several technical concerns. These technical concerns will provide a vehicle for addressing the issues by integrating many tests and analyses into logical units for discussion.

8.3.1.3.4.2 Rationale

The groundwater investigation will provide information required for the resolution of the issues described in Section 8.2. Issue 1.1, a postclosure issue related to the cumulative release of radionuclides, is the most critical issue for both site selection and license application processes (see issues hierarchy, Section 8.2.1). Other postclosure issues requiring groundwater data are 1.5, 1.6, 1.8, 1.10, 1.11, and 1.12. Even though these issues concern future processes (typically 1,000 to 10,000 yr in the future), the present day groundwater system provides the baseline condition for these projections. As a result, the collection of current groundwater data is critical to answering questions regarding future conditions. Several preclosure issues also require information regarding groundwater in the vicinity of the proposed repository. This information, such as the anticipated rate of methane inflow, will assist in answering questions related to the safety (Issues 2.4 and 2.7) the ease and cost of constructing and operating (Issues 4.1 and 4.2) the proposed repository.

The relationships between the parameters to be addressed by the investigation and the issues requiring resolution are summarized in Tables 8.3.1.3-7 and 8.3.1.3-8. The performance parameters listed in these tables are derived from the issues tables found in Section 8.2. The supporting parameters result from tests and analyses used in estimating the performance parameters. The reader is referred to the SCP glossary for definitions of current confidence and needed confidence. Figures 8.3.1.3-16 through 8.3.1.3-18 illustrate the internal ties between the various parameters.

The rationale for the groundwater investigation uses the concept of "technical concerns," which reflects the objectives of the investigation to organize the geohydrologic parameter requirements from the issues into a format more appropriate for a technical discussion. The difficulty in discussing the specific geohydrologic parameters identified by the issues is illustrated by the need for a matrix with 11 rows and 72 columns (Tables 8.3.1.3-2 and 8.3.1.3-3) to summarize the primary relationships between the issues and the parameters. Responding to the following technical concerns will provide responses to the information requirements described in

Table 8.3.1.3-7. Performance parameters and upper level supporting parameters for the regional groundwater study

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Hydraulic conductivity	1.6	Pasco Basin	--	1×10^{-12} to 1×10^{-4} m/s	Low	Medium
			Transmissivity	1×10^{-10} to 1×10^{0} m^2/s	Low	Medium
			Aquifer thickness	*	TBD	Medium
Transmissivity	1.6	Pasco Basin	--	1×10^{-10} to 1×10^{0} m^2/s	Low	Medium
Storage coefficient	1.6	Pasco Basin	--	1×10^{-6} to 1×10^{-4}	Low	Medium
			Transmissivity	1×10^{-10} to 1×10^{0} m^2/s	Low	Medium
Hydraulic head	1.8	Pasco Basin	--	100 to 300 m above MSL	Low	Medium
Groundwater recharge rates	1.6	Pasco Basin	--	Less than 1×10^{5} m^3/yr	TBD	Medium

NOTE: To convert meters to feet, multiply by 3.28.
MSL = Mean sea level.
*Highly variable, dependent on stratigraphic unit and geographical position.

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Table 8.3.1.3-8. Performance parameters and upper level supporting parameters for the site groundwater study (sheet 1 of 9)

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Hydraulic conductivity	1.1, 1.3, 1.8, 1.12, 2.4, 4.2	Damaged rock zone (borehole, drift, and shaft)		1×10^{-12} to 1×10^{-7} m/s	Low	High
			Transmissivity	TBD	TBD	High
			Zone thickness	Borehole, 0-1 m drift/shaft, 0-5 m	Low	High
	1.1, 1.2, 1.3, 1.8, 4.2	Cohassett flow interior (horizontal)		1×10^{-10} to 1×10^{-14} m/s	Low	High
			Transmissivity	1×10^{-12} to 1×10^{-9} m^2/s	TBD	Medium
			Hydrogeologic unit thickness	43-76 m	Medium	Medium[a]
	1.1, 1.2, 1.3, 1.8, 2.4, 4.2	Cohassett flow interior (vertical)		1×10^{-10} to 1×10^{-14} m/s	Low	Medium
			Transmissivity	b	TBD	Medium
			Hydrogeologic unit thickness	43.76 m	Medium	Medium[a]
	1.1, 1.2, 1.3, 1.8, 2.4	Cohassett flow top (horizontal)		1×10^{-11} to 1×10^{-7} m/s	Low	High
			Transmissivity	1×10^{-10} to 1×10^{-3} m^2/s	TBD	High
			Aquifer thickness	4-23 m	Medium	High[a]
	1.1, 1.2, 1.3, 1.8, 1.12	Primary isolation zone flow tops[c] (horizontal)		1×10^{-11} to 1×10^{-7} m/s	Low	High
			Transmissivity	1×10^{-10} to 1×10^{-3} m^2/s	TBD	High
			Aquifer thickness	0-50 m	Low	High[a]

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Table 8.3.1.3-8. Performance parameters and upper level supporting parameters for the site groundwater study (sheet 2 of 9)

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Hydraulic conductivity (cont.)	1.1, 1.2, 1.3, 1.6. 1.8	Primary isolation zone flow interiors (vertical)		1×10^{-14} to 1×10^{-11} m/s	Low	High
			Transmissivity	(b)	TBD	High
			Aquifer thickness	0-76 m	Low	High[a]
	1.1, 1.2, 1.3, 1.8	Secondary isolation zone flow tops		1×10^{-11} to 1×10^{-7} m/s	Low	High
			Transmissivity	1×10^{-7} to 1×10^{-1} m^2/s	TBD	High
			Aquifer thickness	0-50 m	TBD	High[a]
	1.1, 1.2, 1.3, 1.8	Secondary isolation zone flow interiors (vertical)		1×10^{-14} to 1×10^{-11} m/s	Low	High
			Transmissivity	(b)	TBD	High
			Aquifer thickness	0-76 m	Low	High[a]
	1.1, 1.2, 1.3	Faults		1×10^{-11} to 1×10^{-6} m/s	Low	High
			Transmissivity	TBD	TBD	High
			Aquifer thickness	TBD	TBD	High
Storativity	2.4, 4.2	Damaged rock zone (borehole, drift, and shaft)		5 times storativ-ity of host rock	Low	Medium
			Transmissivity	TBD	TBD	Medium
	1.8, 2.4, 4.2	Cohassett flow interior		1×10^{-10} to 1×10^{-7} m/s	Low	Medium
			Transmissivity	1×10^{-12} to 1×10^{-9} m^2/s	Low	Medium

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Table 8.3.1.3-8. Performance parameters and upper level supporting parameters for the site groundwater study (sheet 3 of 9)

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Storativity (cont.)	2.4, 4.2	Cohassett flow top		1×10^{-5} to 1×10^{-3} m/s	Low	High
			Transmissivity	1×10^{-10} to 1×10^{-3} m^2/s	Low	High
	1.9	Primary isolation zone flow tops		1×10^{-6} to 1×10^{-3}	Low	High
			Transmissivity	1×10^{-10} to 1×10^{-3} m^2/s	Low	High
	1.8	Secondary isolation zone flow tops		1×10^{-6} to 1×10^{-3}	Low	Medium
			Transmissivity	1×10^{-7} to 1×10^{-1} m^2/s	Low	Medium
	4.2	Upper basalt flow tops		1×10^{-6} to 1×10^{-3}	Low	High
			Transmissivity	1×10^{-7} to 1×10^{-1} m^2/s	Low	Medium
Specific storage	4.2	Unconfined aquifer (within the CASZ)		TBD	TBD	Medium
Effective porosity	1.1, 1.3, 1.12, 2.4	Damaged rock zone (borehole, drift, and shaft)		1×10^{-4} to 1×10^{-2}	Low	High
			Darcy groundwater velocity	TBD	TBD	High
			Groundwater seepage velocity (tracer test)	TBD	TBD	High
	1.1, 1.2, 1.3, 1.12, 2.4, 2.7	Cohassett flow interior		1×10^{-4} to 0	Low	High
			Darcy groundwater velocity	TBD	TBD	High
			Groundwater seepage velocity (tracer test)	TBD	TBD	High

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Table 8.3.1.3-8. Performance parameters and upper level supporting parameters for the site groundwater study (sheet 4 of 9)

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Effective porosity (cont.)	1.1, 1.2, 1.3, 1.12, 2.4	Fault zone		1×10^{-4} to 1×10^{-1}	Low	High
			Darcy groundwater velocity	TBD	TBD	High
			Groundwater seepage velocity (tracer test)	TBD	TBD	High
	1.1, 1.2, 1.3	Primary isolation zone flow tops		1×10^{-4} to 1×10^{-1}	Low	High
			Darcy groundwater velocity	TBD	TBD	High
			Groundwater seepage velocity (tracer test)	TBD	TBD	High
	1.1, 1.2, 1.3, 1.6	Primary isolation zone interiors		1×10^{-6} to 1×10^{-2}	Low	Medium
			Darcy groundwater velocity	TBD	TBD	Medium
			Groundwater seepage velocity (tracer test)	TBD	TBD	Medium
	1.1, 1.2, 1.3	Secondary isolation zone flow tops		1×10^{-4} to 1×10^{-1}	Low	Medium
			Darcy groundwater velocity	TBD	TBD	Medium
			Groundwater seepage velocity (tracer test)	TBD	TBD	Medium
	1.1, 1.2, 1.3	Secondary isolation zone flow interiors		1×10^{-6} to 1×10^{-2}	Low	Medium
			Darcy groundwater velocity	TBD	TBD	Medium
			Groundwater seepage velocity (tracer test)	TBD	TBD	Medium

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Table 8.3.1.3-8. Performance parameters and upper level supporting parameters for the site groundwater study (sheet 5 of 9)

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Effective porosity (cont.)	1.1, 1.2, 1.3	Cohassett flow top		1×10^{-4} to 1	Low	High
			Darcy groundwater velocity	TBD	TBD	High
			Groundwater seepage velocity (tracer test)	TBD	TBD	High
Transmissivity	1.1, 1.2, 1.3, 1.6, 4.2	Cohassett flow top		1×10^{-4} to 1×10^{-2} m^2/s 1×10^{-10} to 1×10^{-3} m^2/s	Low	High
	1.1, 1.2, 1.3, 1.6, 4.2	Primary isolation zone flow tops		1×10^{-4} to 1×10^{-2} m^2/s 1×10^{-10} to 1×10^{-3} m^2/s	Low	High
	1.1, 1.2, 1.3, 1.6, 4.2	Secondary isolation zone flow tops		1×10^{-7} to 1×10^{-1} m^2/s 1×10^{-4} to 2×10^{-2} m^2/s	Low	High
	1.8, 4.2	Upper basalt flow tops		1×10^{-7} to 1×10^{-2} m^2/s	Low	Medium
	1.8, 4.2	Unconfined aquifer (within the CASZ)		TBD	TBD	Medium
Hydraulic gradient	1.1, 1.2, 1.3	Cohassett flow interior (horizontal)		1×10^{-5} to 1×10^{-3}	Low	High
			Hydraulic head		TBD	High
	1.2, 1.3, 1.12	Cohassett flow interior (vertical)		1×10^{-4} to 1×10^{-3}	Low	High
			Hydraulic head		TBD	High

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Table 8.3.1.3-8. Performance parameters and upper level supporting parameters for the site groundwater study (sheet 6 of 9)

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Hydraulic gradient (cont.)	1.1, 1.2, 1.3, 1.12	Cohassett flow top		1×10^{-5} to 1×10^{-3}	Low	High
			Hydraulic head	115-125 m above MSL	TBD	High
	1.1, 1.2, 1.3	Primary isolation zone flow tops (horizontal)		1×10^{-5} to 1×10^{-3}	Low	High
			Hydraulic head	115-125 m above MSL	TBD	High
	1.1, 1.2, 1.3	Primary isolation zone flow tops (vertical)		1×10^{-4} to 1×10^{-3}	Low	High
			Hydraulic head	115-125 m above MSL	TBD	High
	1.1, 1.2, 1.3	Secondary isolation zone flow tops (horizontal)		1×10^{-5} to 1×10^{-3}	Low	High
			Hydraulic head	115-125 m above MSL	TBD	High
	1.1, 1.2, 1.3	Secondary isolation zone flow tops (vertical)		1×10^{-4} to 1×10^{-3}	Low	High
			Hydraulic head	115-125 m above MSL	TBD	High
Hydraulic head	4.2	Damaged rock zone		115 to 125 m above MSL	Low	Medium
	1.10, 4.2	Cohassett flow interior		115 to 125 m above MSL	Medium	High
	1.6, 4.2	Cohassett flow top		115 to 125 m above MSL	Medium	High
	1.6, 1.8, 4.2	Primary isolation zone flow tops		115 to 125 m above MSL	Medium	High

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Table 8.3.1.3-8. Performance parameters and upper level supporting parameters for the site groundwater study (sheet 7 of 9)

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Hydraulic head (cont.)	1.6, 1.8, 4.2	Secondary isolation zone flow tops		115 to 125 m above MSL	Low	High
	1.8	Primary isolation zone flow interior		115 to 125 m above MSL	Low	Medium
	1.8	Secondary isolation zone flow interior		115 to 125 m above MSL	Low	Medium
	1.8, 4.2	Upper basalt flow tops		115 to 130 m above MSL	Low	Medium
	1.8	Upper basalt flow interiors		115 to 130 m above MSL	Low	Medium
	1.8, 4.2	Unconfined aquifer (within CASZ)		120 to 145 m above MSL	Low	Medium
Effective thickness	1.6	Cohassett flow top		1×10^{-3} to 1.0 m	Low	High
			Borehole geophysics	TBD[d]	TBD	High
			Geology/stratigraphy	TBD[d]	TBD	High
	1.6	Primary isolation zone flow tops		1×10^{-3} to 1.0 m	Low	High
			Borehole geophysics	TBD[d]	TBD	High
			Geology/stratigraphy	TBD[d]	TBD	High
	1.6	Secondary isolation zone flow tops		1×10^{-3} to 1.0 m	TBD	Medium
			Borehole geophysics	TBD[d]	TBD	Medium
			Geology/stratigraphy	TBD[d]	TBD	Medium
Dispersivity	1.1, 1.2, 1.3	Cohassett flow top		0.1 to 100 m	Low	High
			Groundwater seepage velocity (tracer test)	TBD	TBD	High
			Tracer concentration with time	TBD	TBD	High

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Table 8.3.1.3-8. Performance parameters and upper level supporting parameters for the site groundwater study (sheet 8 of 9)

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Dispersivity (cont.)	1.1, 1.2, 1.3	Primary isolation zone flow tops		0.1 to 100 m	Low	High
			Groundwater seepage velocity (tracer test)	TBD	TBD	High
			Tracer concentration with time	TBD	TBD	High
	1.1, 1.2, 1.3	Secondary isolation zone flow tops		0.1 to 100 m	Low	High
			Groundwater seepage velocity (tracer test)	TBD	TBD	High
			Tracer concentration with time	TBD	TBD	High
Hydraulic head at CASZ boundary	1.8, 1.9	Primary isolation zone flow tops		115 to 125 m above MSL	Low	High
	1.8, 1.9	Secondary isolation zone flow tops		115 to 125 m above MSL	Low	High
Hydraulic flux at the northern, western, and southern boundaries	1.8	Primary isolation zone flow tops		TBD	TBD	High
			Hydraulic gradient	TBD	TBD	High
			Hydraulic conductivity	TBD	TBD	High
			System geometry	TBD	TBD	High
	1.8	Secondary isolation zone flow tops		TBD	TBD	High
			Hydraulic gradient	TBD	TBD	High
			Hydraulic conductivity	TBD	TBD	High
			System geometry	TBD	TBD	High

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Table 8.3.1.3-8. Performance parameters and upper level supporting parameters for the site groundwater study (sheet 9 of 9)

Performance parameter	Issue	Scale/location	Supporting parameter	Test basis		
				Current estimate	Current confidence	Needed confidence
Water inflow into drifts	2.3, 2.7, 4.2	Cohassett flow interior		100 to 3,400 gal/min	Medium	High
			Hydraulic conductivity	--	TBD	TBD
			Storativity	--	TBD	TBD
			Hydraulic head	--	TBD	TBD
			Probability of faults/fractures	--	TBD	TBD
			Flow top/flow bottom intrusions	--	TBD	TBD
Water inflow into shafts	4.2	Cohassett flow top	--	100 to 10,000 gal/min[e]	Medium	High
			Hydraulic conductivity	--	TBD	TBD
			Storativity	--	TBD	TBD
			Hydraulic head	--	TBD	TBD
Water inflow into shafts	4.2	Primary and secondary isolation zone flow tops	--	10 to 10,000 gal/min[e]	TBD	Medium
			Hydraulic conductivity	--	TBD	TBD
			Storativity	--	TBD	TBD
			Hydraulic head	--	TBD	TBD

NOTE: To convert meters to feet, multiply by 3.28.
MSL = Mean sea level.
[a]The range of values is well known, but the actual thickness, as it varies geographically, may not be well known.
[b]Defined by borehole construction, not traditionally used relative to the vertical component of flow.
[c]Includes the Birkett flow top.
[d]Not normally expressed as simple value estimates.
[e]Highly variable, dependent on stratigraphic interval(s) and construction techniques.

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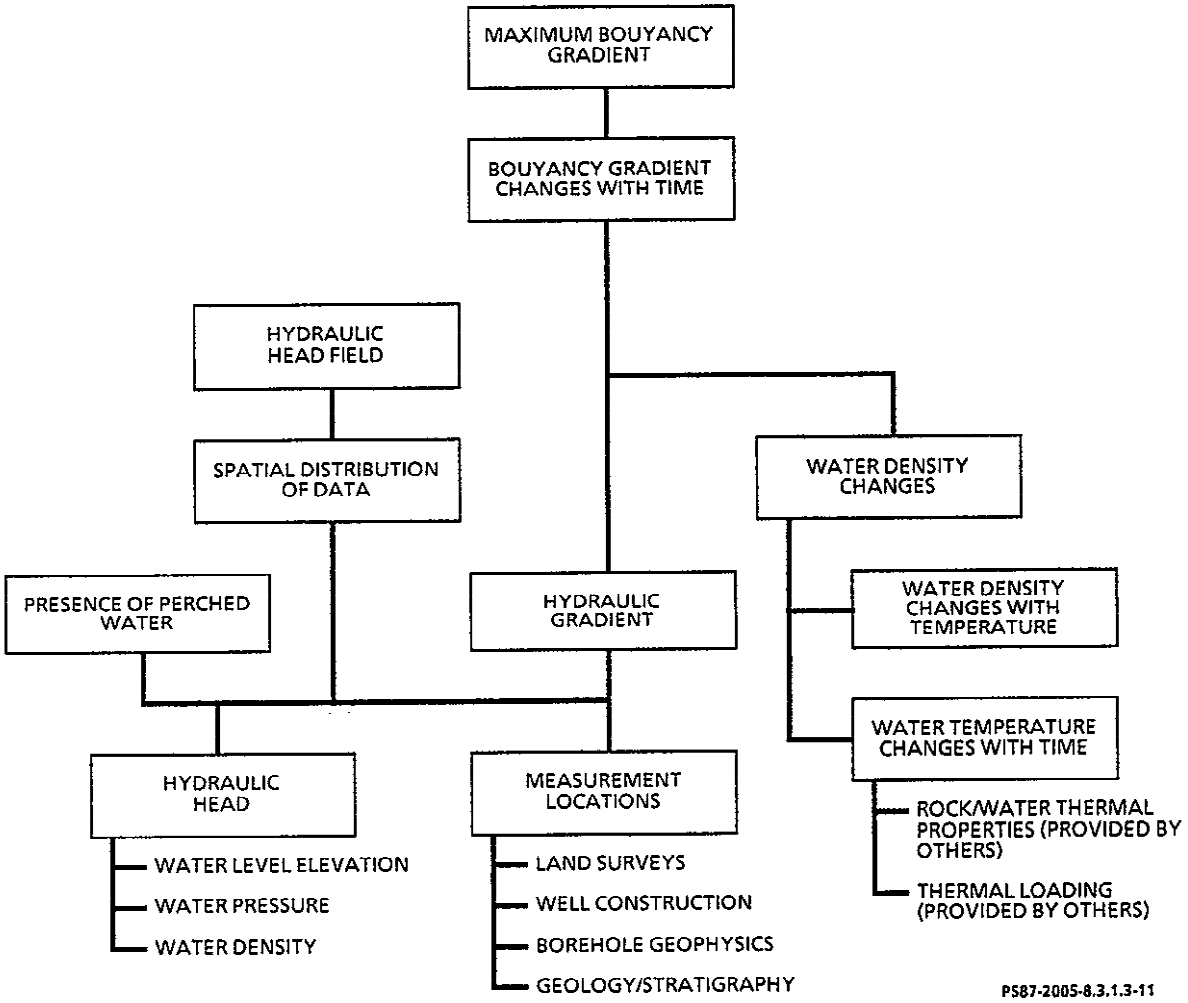

Figure 8.3.1.3-16. Relationship among hydraulic head and gradient parameters.

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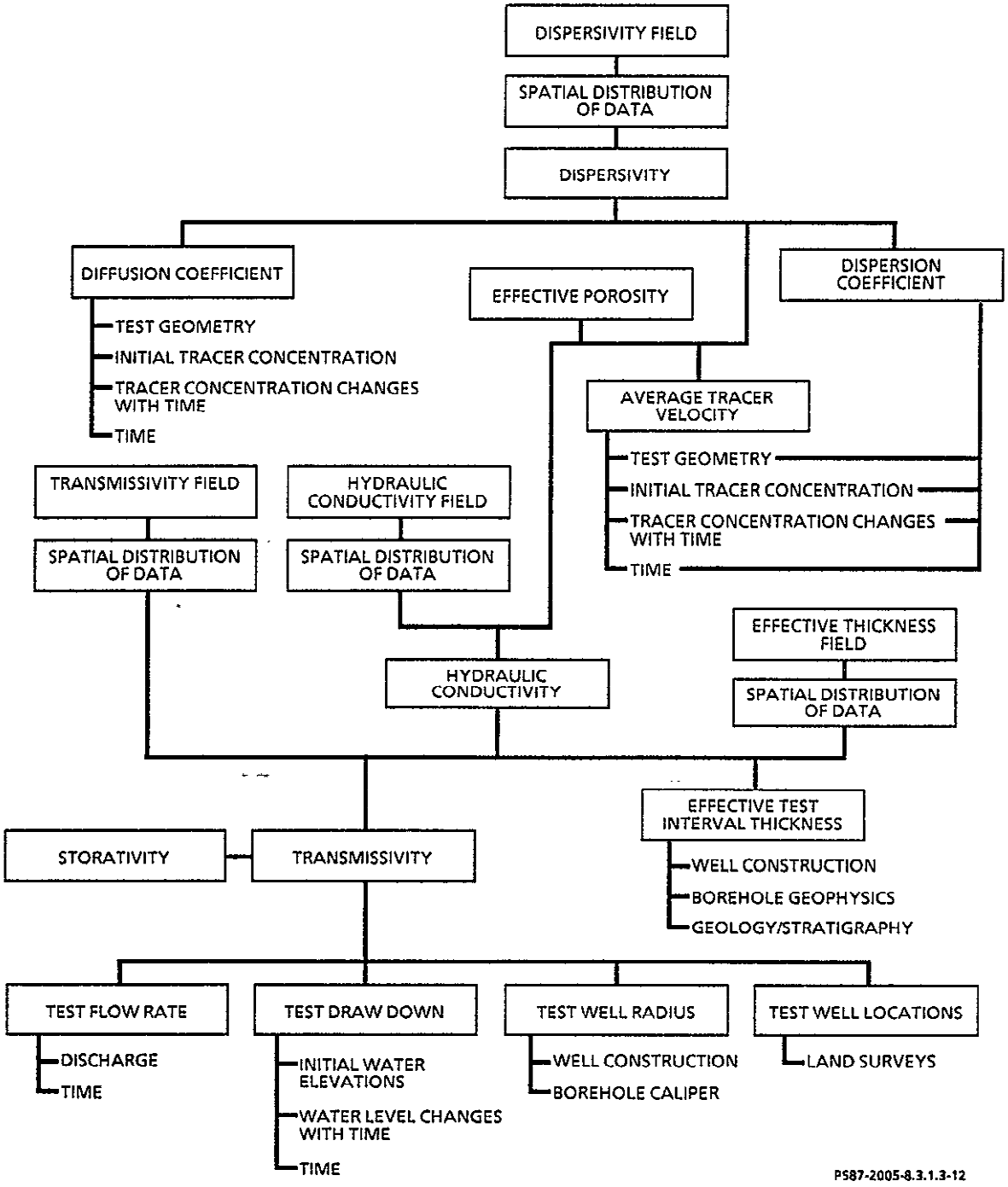

Figure 8.3.1.3-17. Relationship among hydraulic flow and transport parameters.

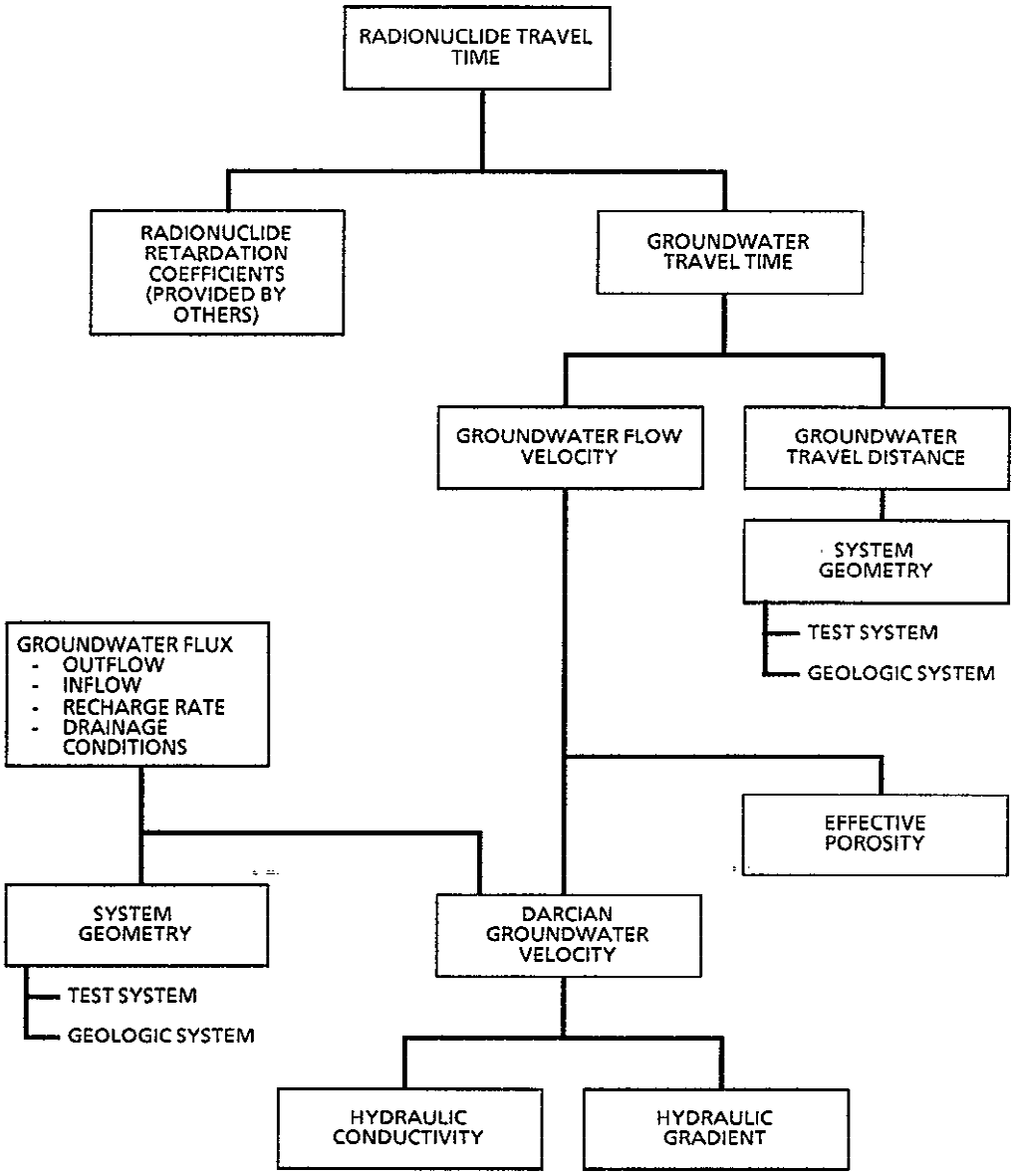

Figure 8.3.1.3-18. Relationship between radionuclide travel time and groundwater flow rate parameters.

the issues. These concerns are also structured to address the impact of the regional groundwater system (regional groundwater study) upon the groundwater system within the controlled area study zone (site groundwater study). Technical concerns include the following:

- The spatial distribution of hydraulic properties.
- The spatial distribution of hydraulic heads.
- The nature, extent, and location of the hydraulic boundaries impacting the flow system in the Cold Creek syncline.
- The determination of the appropriate conceptual model of the groundwater flow system.

The following section provides additional information regarding each technical concern. The decision to use this approach was based on the following considerations:

- Many issues require the same geohydrologic parameters for their resolution.
- There are technically logical clusters of parameters--several parameters must be used together to provide usable knowledge of the groundwater system.
- Many issues, though not explicitly specifying it, require the development of a basic conceptual geohydrologic model to determine what geohydrologic parameters are critical to resolving the issue.
- There is a cyclic process between parameter value determination, the development of the conceptual models, performance assessment analyses, and the redirection of testing programs.

It is important for the groundwater investigation to focus on the collection and analysis of data in a technically logical fashion, thus requiring a technical basis for the studies. Yet, the groundwater investigation must continually tie in with the format needs and strategies developed for the resolution of the regulatory issues, ensuring that (1) the issues will be resolved and (2) the program will not expend time and funds on irrelevant tests and analyses.

<u>8.3.1.3.4.2.1 Technical concerns</u>. The technical concerns will be addressed by both the regional groundwater study and the site groundwater study. The conceptual and numerical models of the groundwater system will provide a bridge between the studies. The analysis and interpretation of the ^{129}I data have not been included as a technical concern under the groundwater investigation. The ^{129}I material is discussed in Section 8.3.1.4.

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Hydraulic properties and their spatial distribution

In order to estimate pre-waste-emplacement and groundwater travel times and examine the impact of changes to the geohydrologic system on radionuclide release rates, the hydraulic and geochemical properties of the hydrostratigraphic units beneath the controlled area study zone and within the regional setting are required. Hydraulic properties within the controlled area study zone will be used in numerical models to assess impacts to repository performance, to determine groundwater travel times, and to produce groundwater inflow estimates into the repository.

The parameters under this information need are as follows:

- Basalt flow tops and interbeds.
  - Hydraulic conductivity.
  - Transmissivity.
  - Storativity.
  - Dispersivity
  - Effective porosity.
  - Effective thickness.

- Basalt flow interiors.
  - Hydraulic conductivity.
  - Specific storage.
  - Dispersivity.
  - Effective porosity.

The hydraulic properties will be determined using in situ field testing and laboratory testing. Because of the scale effects associated with some parameters, field testing at different scales will be necessary. Small-scale hydraulic stress tests, including single borehole tests, will obtain data representing the specific properties of an area a few meters to tens of meters across. Large-scale hydraulic stress tests will obtain data representing the typical properties of an area hundreds to thousands of meters across. Both hydraulic- and tracer-testing techniques will be used. It will be difficult to establish spatial distribution of properties in heterogeneous basalt. Stochastic and numerical modeling analyses will help determine the level of confidence necessary and bounding values. Techniques, such as geostatistics, will be used to determine model input parameters from field data. The location and number of the proposed tests may be modified after the initial data are reviewed.

Testing for the transverse dispersivity of the Cohassett flow interior and the vertical hydraulic conductivity of the flow tops may present special problems. The transverse and longitudinal components of dispersivity are not routinely characterized independently, as actual values are not considered important for modeling. Similarly, the vertical and horizontal components of hydraulic conductivity are seldom measured independently. If the models prove to be sensitive to these values, additional data will be collected.

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Some tests, such as those designed to measure effective porosity, may be sensitive to the scale of the test. The adequacy of the proposed test procedures will be reviewed as data are collected, and revised testing techniques are incorporated as necessary. Testing will proceed in an iterative manner. Data will be discussed with performance assessment and hydrochemistry groups. Based on these discussions, tests will be added to, deleted from, or modified for future testing activities.

Spatial distribution of hydraulic heads

In order to estimate pre-waste-emplacement groundwater travel times and to provide input to numerical models that predict repository performance, measurements of hydraulic head in three dimensions within the controlled area study zone and regional setting are necessary. Head measurements will also be used to support groundwater inflow predictions and the design of waste packaging.

A baseline of the three-dimensional head distributions will be established. Head distributions will be obtained from water-level measurements or down-hole pressure measurements at various depths and locations across the controlled area study zone and in the region. Baseline establishment includes documentation of temporal changes and fluctuations in heads resulting from seasonal variations, earth tides, and natural and man-induced stresses on the system. The resulting information will allow the determination of the temporal and spatial changes in water levels in the regional system on the local system.

The collection of head data will be accomplished through a head monitoring program that will be conducted at existing and proposed facilities within the controlled-area study zone and the regional setting.

Several new boreholes will be installed in the Pasco Basin to aid in conceptualizing the regional groundwater flow system and developing a numerical groundwater flow model of the Pasco Basin and Cold Creek syncline. Data from these boreholes will be used to obtain regional hydraulic heads, to delineate boundary conditions, and to assess vertical groundwater movement for determining recharge and discharge relationships.

Nature, extent, and location of hydraulic boundaries

A thorough understanding of the boundary conditions affecting both the local (site) and the regional (Pasco Basin) groundwater flow systems is an important part of the groundwater investigation. If initial data collection and modeling efforts indicate that the site system is sensitive to influences outside the Pasco Basin, the investigation will be modified.

Hydraulic boundaries are typically expressed as geologic features such as folds, faults, and relatively impervious layers of geologic material and hydrologic features such as beds of lakes, rivers, and other bodies of surface

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water (Walton, 1970, p. 485-487). In addition, groundwater drainage divides resulting from local groundwater recharge will be considered. To describe these hydraulic boundaries, data concerning two types of parameters are required. First, the locations and extents (vertical and horizontal) of the potential boundaries must be identified. Second, the type or character and overall hydraulic influence of the actual hydraulic boundaries must be understood. The first will be obtained from geologic and geophysical studies including mapping, core logs, and geophysical surveys. The second will be estimated from the response of water levels in the aquifer system to the withdrawal or injection of water. Numerical models will be used to guide the field studies and simulate the location, extent, and nature of boundary conditions as well as to assess their impact upon the groundwater flow system and the sensitivity of the system to those boundary conditions.

Determination of appropriate conceptual model

The development of a conceptual model of a groundwater flow system is fundamental to the mathematical analysis and simulation of that system. The conceptual model forms the basis from which the numerical codes are selected and initial conditions are determined. The term "conceptual model" embodies the minimum features of the real system that are needed to qualitatively determine the relevant behavior of the system. It incorporates a perception of the flow system and its dynamics as it fits within the geologic framework of the site. The conceptual model is a concept that implies that not everything in the model must be precisely known. However, relevant operational features of the real system must be described. It is a model or analog of the real system and should reproduce the behavior of the system when its input parameters and conditions are specified. The conceptual model is use-oriented. Finally, it will form the basis for analytical and numerical models in which numerical values are assigned to model parameters and quantitative results are obtained.

The conceptual models will evolve with time, depending on the information available. There may also be numerous conceptual models of an area at any one time, each model representing a different but feasible interpretation of the existing data. A geohydrologic test program must determine and reduce the uncertainty associated with quantitative values of parameters that are part of the model, but it must also include tests to determine which models are most representative of the area. As the nature of the conceptual models change, so does the test program that refines them.

The evaluation of alternative conceptual models must address the physical characteristics of the groundwater system. It will allow, through the understanding of the hydrologic system, the mathematical description of the

processes and the resultant ability to select or develop a mathematical model that represents the geohydrologic system. Thus, within the context of site characterization, the following steps are required:

- Develop conceptual model of the system.
  - Purpose.
  - Hypothesis.
  - Description.
  - Approach.
- Develop a mathematical model from the conceptual model.
- Select a particular type of solution.
  - Analytical.
  - Numerical.

An important question that must be resolved as part of this process is under what conditions a porous medium model can be substituted for a fracture flow model. The response to this question may be related to the geographical extent or scale of the area to be modeled. Fracture flow concepts may be more important in the immediate vicinity of the repository than on a regional basis.

The information required to define a transient boundary-valve problem for subsurface flow system (Freeze and Cherry, 1979, p. 67) includes the following:

- The size and shape of the region of flow.
- The equation of flow within the region.
- The hydraulic boundary conditions around the boundary margins of the region.
- The initial hydraulic conditions in the region.
- The spatial distribution of the hydrogeologic parameters that control flow.

In situ testing, laboratory testing, numerical modeling, and surveys of public records will be used to produce the above information. In situ testing includes large-scale hydraulic stress testing, small-scale hydraulic stress testing, and subsurface testing done from the exploratory shaft. Laboratory testing on selected cores will supplement in situ testing and provide parameters that (1) cannot be obtained from in situ testing or (2) are not affected by scale. Numerical models will be used to analyze data and to increase confidence in values assigned to parameters. Surveys of local, state, and Federal data bases and records pertaining to water rights, water use, and land use will represent the conditions occurring before site characterization and provide a basis for monitoring related activities during site characterization.

8.3.1.3.4.2.2 Constraints. There are several technical and schedule-related factors that may place constraints on the groundwater investigation. They include the following:

- Scale/time sensitive data.
- Geographic setting.
- Technical and logistic feasibility.
- Schedule.
- Cost.

The schedule and cost factors do not drive the investigation, but they must be considered, and any field work must present a balance between the usefulness of the data and the time and cost required to obtain it.

Scale/time sensitive data

The sensitivity of the values of some hydrologic parameters to the scale/time at which they are measured presents three potential problems:

- Technical and logistic difficulties in making the measurements at the appropriate scale.
- Difficulty in selecting the appropriate porous media or fracture flow model.
- Difficulty in establishing baseline or future conditions caused by possible man-related impacts.

The values of some parameters, such as dispersivity and effective porosity, may be dependent on the scale at which they are determined. The adequacy of the test procedures selected will be evaluated as test results are collected and model sensitivity is determined. Alternative test procedures will be reviewed as appropriate.

The choice of fracture flow theory or continuum theory to model a groundwater flow system is also scale dependent. It would not be feasible to conduct enough testing to completely defend the choice of theory. Modeling studies will be conducted to determine the amount, size, and distribution of fluid-bearing fractures necessary for a porous media approach to be valid at the scale of interest. The geologic data and hydraulic tests will be used to determine if the fracturing in the basalt is extensive enough to fall within the porous media range. If it does not, test plans will be modified to gather more data on fracture character and distribution. In addition, testing will be performed at different scales in an attempt to determine the applicability of the two theories at various scales and to provide estimates of hydrologic parameters at different scales.

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The defensibility of the model results depends, to a large extent, on the ability to demonstrate a compatibility between porous medium and fracture flow models. The use of a porous medium model is dependent on a demonstration that the inability to measure some scale-dependent parameters does not detract from the reliability of predicted fluxes at certain boundaries.

The magnitude of the impact of man on the deeper aquifers may be difficult to document. Since present-day measurements will be used to recreate an undisturbed (baseline) condition, any impact on the groundwater system related to changes in water use or water disposal practices could impact the establishment of a baseline condition. The Pasco Basin has undergone major changes in agricultural and industrial water uses during the past 50 yr, which is a very short time compared to the 1,000 to 10,000 yr time frame considered in this project. Present groundwater condition may represent a transient as opposed to a stable condition.

In a parallel sense, the future impacts of man will be difficult to predict. Changes in the regulation of the Columbia River and changes in irrigation practices could impact the local groundwater system. The prediction of socioeconomic impacts is beyond the scope of this document. It will be addressed in the environmental monitoring and mitigation plan.

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Geographic setting

The regional groundwater system, which includes the local groundwater system beneath the controlled area study zone, extends beyond the controlled area study zone boundary. Therefore, changes in the flow system in the regional setting may impact the flow system beneath the controlled area study zone (i.e., the site setting). Testing within the site setting will be more frequent and comprehensive than in the regional setting because of the expected greater sensitivity of the groundwater flow system within the controlled area study zone to local hydraulic conditions than to hydraulic conditions beyond the controlled area study zone boundaries.

Technical and logistic feasibility

The constraints related to technical and (or) logistic feasibility include the following:

- Unusual requirements for accuracy and precision, such as the possible need to measure groundwater gradients, as low as 1×10^{-5}.
- The need to measure parameters, such as effective porosity, that may be sensitive to scale.
- Working under unusual conditions, such as installing horizontal wells from inside a 1.8-m- (6-ft-) diameter shaft at a depth of 914 m (3,000 ft).

Schedule

There are two types of schedule-related constraints: coordinating the geochemical sampling and accommodating the impact of the construction of the exploratory shaft. The hydrochemical testing will be subject to varied schedule constraints (Section 8.3.1.4 and Long (1987)). The chemistry of the groundwaters is not perceived to be a "perishable" condition, so sampling during the drilling of DC-24 and DC-25 will not be required. Hydrochemical sampling during the pre-exploratory shaft phase must present a balance between avoiding disturbance of the hydrologic baseline and providing samples before any significant disturbance to the hydrologic system. The strategy for hydrochemical characterization under these constraints is to limit hydrochemical sampling within the controlled area study zone prior to the definition of the pre-exploratory shaft hydrologic baseline. Selected boreholes near the exploratory shaft will be sampled after the hydrologic baseline is measured but before the exploratory shaft is constructed. The chemistry of the groundwater system will be monitored during the construction of the exploratory shaft and during large-scale hydraulic stress testing.

The construction and operation of the Exploratory Shaft Facility is expected to create interference with the testing program of the site groundwater study. Interference may be classified as follows:

- Interference resulting from construction of the Exploratory Shaft Facility.
  - Disruption of baseline hydraulic heads from fluid loss and cross-formational flow.
  - Alteration of formation hydraulic characteristics from invasion of grout and (or) drilling fluid.
- Interference related to the creation of a hydraulic sink that acts as a long-term, uncontrolled pumping test.
  - Disruption of baseline hydraulic heads.
  - The introduction of a transient condition that would make interpretation of large-scale hydraulic stress tests in the vicinity of the Exploratory Shaft Facility difficult or impossible to interpret accurately.
- Alteration of hydrochemical conditions in the vicinity of the Exploratory Shaft Facility.

An analysis of these potential impacts, by using numerical modeling techniques using available data, will be performed before drilling the Exploratory Shaft Facility. Various scenarios will be simulated to determine the potential impact with respect to the distance and magnitude of the disturbance. The possibility of the impacts extending beyond the controlled area study zone

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will be investigated. Since the access and ventilation shafts associated with the Exploratory Shaft Facility will be lined and grouted into the rock, they will not function as open wells. Impacts may be restricted to the inflow into the test facility.

Data (e.g., groundwater-level baseline) that could be impacted by the Exploratory Shaft Facility will be collected before the construction of the Exploratory Shaft Facility. Data collected before the construction of the Exploratory Shaft Facility will not only define baseline conditions but can also be used to confirm the parts of the design basis for the repository that require geohydrologic data and parameters. The scheduling requirements therefore dictate that pre-exploratory shaft and post-exploratory shaft phases be accomplished for geohydrologic testing within the controlled area study zone.

One of the primary objectives of the pre-exploratory shaft phase is to collect those hydraulic head and hydraulic property data describing conditions that will otherwise be altered by exploratory shaft drilling and underground construction. Such data are considered perishable. The hydraulic tests conducted during the pre-exploratory shaft phase include constant discharge tests, pulse tests, and tracer tests. The constant discharge tests will be carried out in the basalt flow tops with higher transmissivities, while pulse tests are used within flow tops with lower transmissivities and the vesicular zone of the Cohassett flow. Convergent flow tracer tests, conducted during pump testing, will provide values on the effective thickness and dispersivity within the flow tops of higher transmissivity. As part of the pre-exploratory shaft testing program, hydrochemical samples will be collected during pump testing to analyze radiogenic (e.g., ^{129}I and tritium) inorganic, etc., constituents as described in Anttonen (1987a). Other objectives include the early collection of information addressing groundwater travel time and underground facility design issues.

The rationale and strategy supporting the decisions regarding the pre-exploratory shaft activities are provided in Long (1987).

<u>Pre-exploratory shaft tests</u>

The pre-exploratory shaft testing activities will be conducted from surface-based boreholes (Fig. 8.3.1.3-19). The testing activities include the following:

- Install nested piezometers DC-24 and DC-25 without collecting test and water sample information. Three monitoring points will be established in the Wanapum Basalt and four in the Grande Ronde Basalt flow tops at each hole site. These nested piezometers are required to support determination of the hydraulic head baseline and serve as observation points for post-exploratory shaft large-scale hydraulic stress tests.

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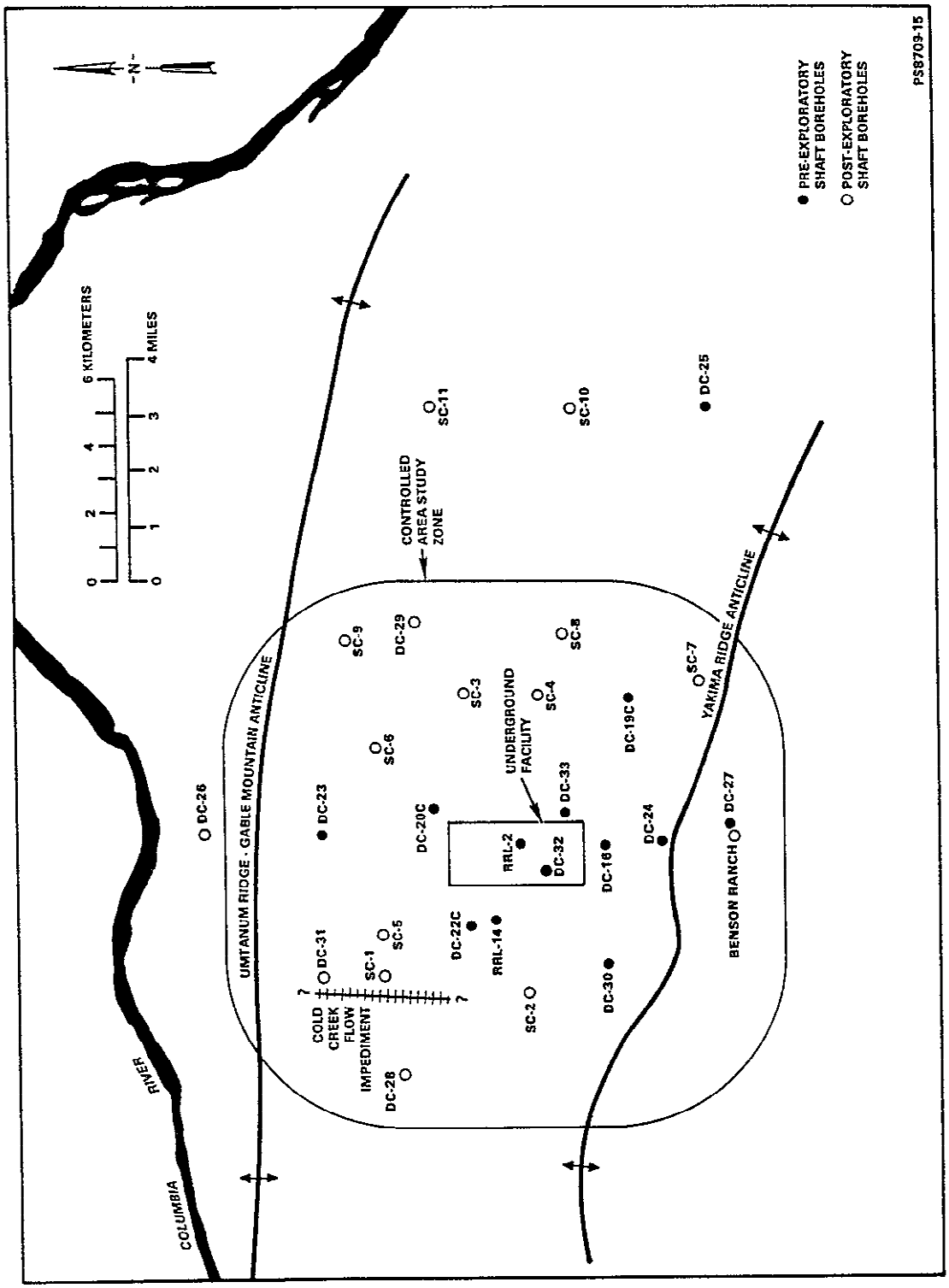

Figure 8.3.1.3-19. Pre-exploratory and post-exploratory shaft boreholes.

- Install nested piezometers at DC-32 and DC-33 as observation points for hydrologic testing. These facilities will be similar in construction to DC-24 and DC-25 and will serve as observation points. Data obtained during the construction of DC-32 and DC-33 will also provide additional information on the position and potential hydrologic importance of the Levering flow (see Fig 8.3.1.3-3 and Section 8.3.1.3.1).

- Install piezometers in DC-23GR. The nested piezometers at DC-23GR are required to support determination of the hydraulic head baseline and serve as observation points for post-exploratory shaft large-scale hydraulic stress tests.

- Reconfigure testing facilities at DC-16, RRL-14, RRL-17, RRL-2A, DC-4, DC-5, RRL-6, and McGee well for hydrologic testing. These facilities are required to support aquifer tests at RRL-2B. They will be reconfigured to monitor hydraulic head in the hydrostratigraphic units being pumped.

- Complete aquifer tests in Rocky Coulee flow top, Cohassett flow top, Cohassett flow vesicular zone, and Birkett flow top at RRL-2B. These aquifer tests are required to determine selected hydraulic and transport parameters at the RRL-2B location prior to potential hydraulic disturbance and (or) change in hydraulic properties associated with exploratory shaft construction.

The pre-exploratory shaft hydrology testing program, as defined in Option D of Long (1987), consists of one pumping center in the area expected to be significantly affected hydrologically by the sinking of the exploratory shafts and the excavation of the underground testing facility. The Site Groundwater Study Plan (Hiergesell, 1987) will identify tests to be conducted at this pumping center and other pumping centers areally distributed across the site. These other pumping centers should not be significantly affected by shaft sinking and excavation of the underground testing facility; accordingly, these other pumping centers will be drilled, installed, and tested after the start of construction of the two shafts. Groundwater samples and aquifer test data, except as may be defined by Antonnen (1987a), will not be obtained during drilling and equipping of DC-24, DC-25, DC-32, and DC-33 because such data collection will interfere with the establishment of the pre-exploratory shaft baseline.

Throughout the site groundwater studies, including during the pre-exploratory shaft hydrology testing program, the data gathered during drilling, installation, and testing for new and existing wells will be analyzed to (1) improve the understanding of the conceptual groundwater flow model(s), (2) refine and calibrate numerical site groundwater flow model(s), (3) evaluate postclosure and preclosure hydrology guidelines, (4) support performance assessment activities, and (5) reduce uncertainty related to site groundwater conditions. These analyses will be performed in an iterative process such that the analyses at one step will be used to predict the results of the next step, and those predictions will then be compared to the data

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collected and analyses performed in the next step. In this manner, the hydraulic heads, head responses across dense flow interiors, the vertical and horizontal hydraulic conductivities, the effective porosities and dispersivities, and the geochemistry (including radiogenic isotopes) will be periodically evaluated to determine whether there is consistency between the measurements, calculations, and modeling predictions; whether the level of uncertainty is being reduced; and whether modifications to the pre-exploratory shaft hydrology testing program or subsequent portions of the Site Groundwater Study Plan (Hiegersell, 1987) are needed.

Modeling is an integral part of the pre-exploratory shaft activities. The iterative process of evaluating data and modeling the site groundwater flow system, as described above and in Option D of Long (1987), will be a major contributor to the decision points described in Antonnen (1987b) for the workshop on the pre-exploratory shaft hydrology testing program, including the major decision point (after conclusion of the testing in the Birkett flow top) to terminate the pre-exploratory shaft hydrology testing program and proceed with the start of shaft sinking.

Post-exploratory shaft activities include all those performed during and after construction of the exploratory shaft and the Exploratory Shaft Facility. The objective of these activities will be to more fully characterize the repository isolation zone within the controlled area study zone and to search for the existance of hydrologic conditions that could potentially disqualify the site from further consideration. To accomplish these objectives, a series of surface- and subsurface-based tests will be conducted. These activities will be based on the following strategies:

- Preparation of defensible conceptual and numerical model(s) of controlled area study zone. This will be accomplished by obtaining initial, regional conditions as inferred from potentiometric surfaces, refining hydrogeologic geometry, and obtaining hydraulic parameters in and around the controlled area study zone.

- Obtaining the range of controlled area study zone boundary conditions that are likely to exist during the next 10,000-yr period using the Pasco Basin model results in conjuction with tectonic studies, water resource potential studies, paleoclimatic studies, and future climatic studies.

Post-exploratory shaft testing activities

Post-exploratory shaft tests include the following (see Fig. 8.3.1.3-20):

Surface-based activities

Post-exploratory shaft testing activities will be conducted during and after the drilling and excavation of the exploratory shaft and Exploratory

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Shaft Facility. Activities will consist of the installation of facilities and the testing of subsurface hydrologic conditions within the controlled area study zone using these facilities.

- Drill, borehole geophysical log, and install six additional multilevel nested piezometers (DC-26, DC-27, DC-28, DC-29, DC-30, and DC-31). Drilling will proceed on a drill-and-test basis. Each site will be completed with three piezometers finished in the Wanapum Basalt flow tops and with four finished in Grande Ronde Basalt flow tops.

- Drill, borehole geophysical log, and instrument six dual-site pumping centers and two single-site pumping centers in the vicinity of the multilevel piezometers. Dual-site pumping centers will be constructed with one completed in a Wanapum Basalt flow top and the other in a Grande Ronde Basalt flow top. The single-site pumping centers will be completed at sites where a pumping center already exists in either a Wanapum or Grande Ronde Basalt flow top. These pumping centers will eventually be used to conduct large-scale hydraulic stress tests.

- Conduct 16 large-scale hydraulic stress tests, each with an adjunct tracer test. The 16 large-scale hydraulic stress tests will be located to allow for the most complete characterization of the repository isolation zone within the controlled area study zone.

- Drill and borehole geophysical log five single-borehole facilities (SC-1, SC-7, SC-9, SC-10, and SC-11) on a drill-and-test basis to obtain hydrogeologic and hydrochemical data from the Wanapum and Grande Ronde Basalts at different points within the controlled area study zone. After testing and sampling, each borehole will be completed with one piezometer in the Wanapum Basalt and one piezometer in the Grande Ronde Basalt. Borehole facilities SC-10 and SC-11 will be installed just to the east of the controlled area study zone to obtain hydraulic head data in an area where little information exists.

- Drill and borehole geophysical log six dual-site boreholes (SC-2, SC-3, SC-4, SC-5, SC-6, and SC-8) for conducting small-scale hydraulic and tracer testing from selected Wanapum and Grande Ronde Basalts flow tops following borehole construction. Two piezometers (one per well) will be installed at each dual-site borehole following testing. One piezometer will be finished in a Wanapum Basalt flow top and one in a Grande Ronde Basalt flow top.

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Subsurface-based activities

- Core at least 13 boreholes and geophysical log through portholes in ES-1, and perform single-borehole tests using packers to isolate short lengths of these boreholes.

- Drill and borehole geophysical log four 304.8-m- (1,000-ft-) long exploratory boreholes from the Exploratory Shaft Facility. All four boreholes will be drilled at 90° to one another at different locations within the facility. Single-well hydraulic stress tests will be performed within each borehole utilizing straddle packers to isolate short lengths within them.

- Drill, borehole geophysical log, and instrument a series of boreholes for performance of cluster hydraulic and tracer testing in the Cohassett flow upper dense interior, lower dense interior, and internal vesicular zone.

- Drill and borehole geophysical log six boreholes within the chamber room of the Exploratory Shaft Facility. Hydraulic test each borehole, using straddle packers, and instrument each for conduct of the chamber test.

To conduct all of the itemized post-exploratory shaft activities in the most efficient manner, the installation of different facilities and subsequent testing must be conducted in concurrent testing must be conducted in concurrent or staggered sequences, which depend on many factors. The estimated sequence and timing of installation and testing activities are presented in Section 8.3.1.3.4.5.

The construction of the Exploratory Shaft Facility may also impact the geochemistry of the groundwater caused by pressure changes, mixing, and the introduction of contaminants. Geochemical sampling (Section 8.3.1.4) will be coordinated with the geohydrologic program.

Cost

Cost must be considered when designing a field program. An emphasis should be placed on collecting the information that is most important to describing the hydrologic characteristics of the site yet ensuring that all necessary information is acquired. The issues resolution process (Section 8.2) places the data requirements into a perspective that allows focusing on the tests and analyses that have the greatest probability of resolving the issues.

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8.3.1.3.4.3 Description of studies

The groundwater investigation is composed of (1) the regional groundwater study and the (2) site groundwater study. Figure 8.3.1.3-20 illustrates the ties between the studies.

The regional groundwater study will support the site groundwater study by providing a description of the regional groundwater flow system. This will establish the hydrologic setting for the more detailed site study. The site groundwater study is divided into two phases. Surface-based testing will be performed as part of the regional study and the pre-exploratory shaft phase of the site study. Both surface-based and subsurface-based testing will be performed during the post-exploratory shaft phase. Figure 8.3.1.3.3-21 illustrates the time-space relationship between the regional groundwater study and the site groundwater study, including the pre-exploratory shaft and post-exploratory shaft phases.

8.3.1.3.4.3.1 Regional groundwater study. The purpose of the regional groundwater study is to characterize the regional groundwater flow system. Information gained in this study is required to evaluate the performance of the Hanford Site as a geologic repository for nuclear waste. Knowledge of the regional pattern of groundwater movement will permit assessment of local groundwater flow systems around the controlled area study zone in the context of larger, regional (Pasco Basin) scale groundwater flow patterns. This study provides geohydrologic data and parameters to satisfy information needs for resolution of issues as shown in Table 8.3.1.3-5. The approach of the regional groundwater study can be summarized as follows:

- Collection, interpretation, and integration of existing information. The components of the hydrologic system are integrated into conceptual models of groundwater flow.
- Field testing and data collection. Additional field testing is conducted and data are collected to enhance the conceptual models.
- Numerical modeling. Numerical models are constructed to evaluate and refine the conceptual models and to evaluate the effects of system stresses.

A fundamental understanding of the groundwater flow system is developed from this methodology. Key questions regarding the dynamics of the regional flow system, the regional setting of the controlled area study zone, and questions regarding the adequacy of the data base can be addressed by following this methodology. By using an iterative process of analysis and testing in conjunction with the evaluation of the conceptual models, the site characterization program can be optimized. A detailed description of the regional groundwater study can be found within the regional groundwater study plan.

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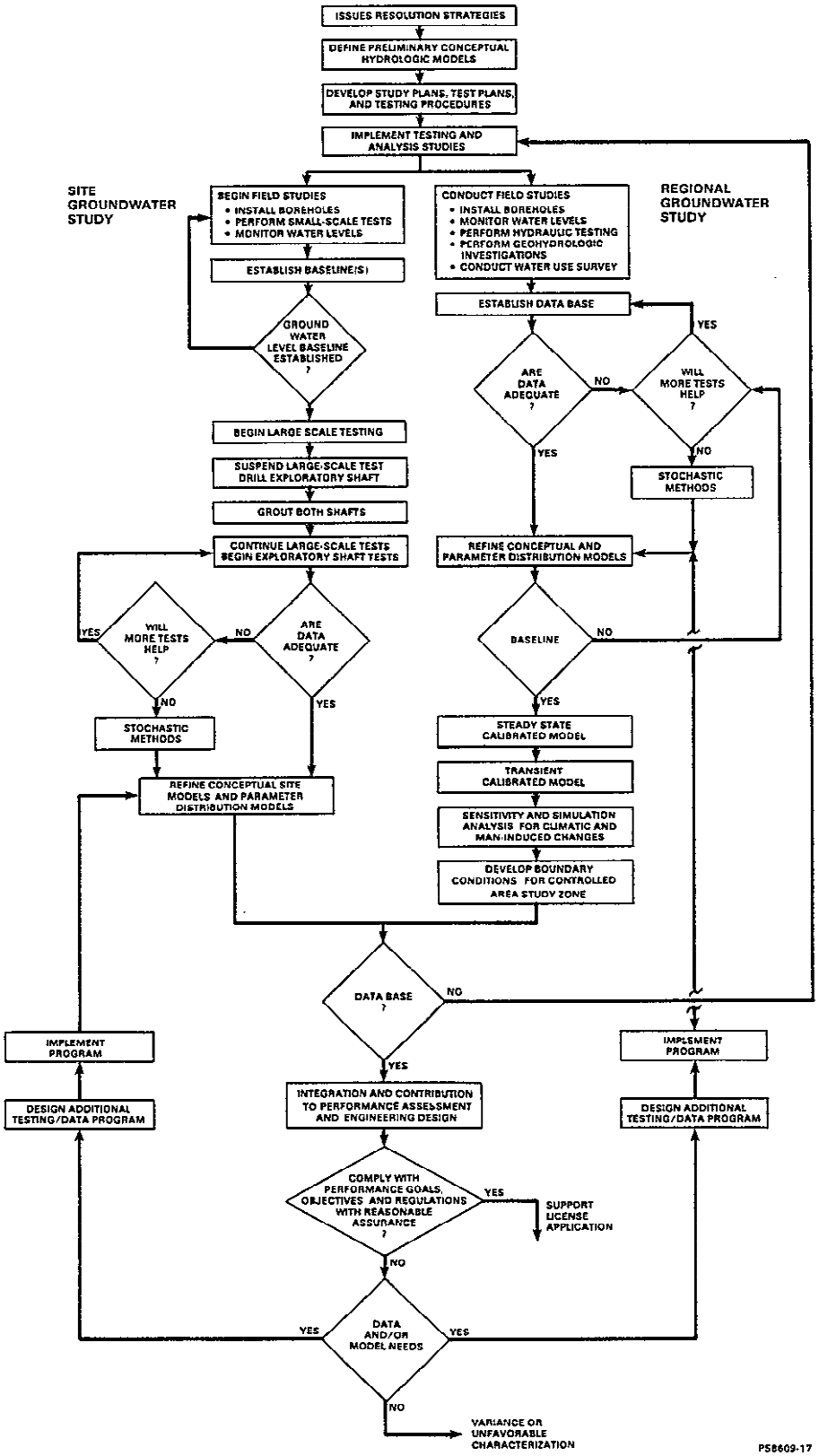

Figure 8.3.1.3-20. Linkages within the groundwater investigation.

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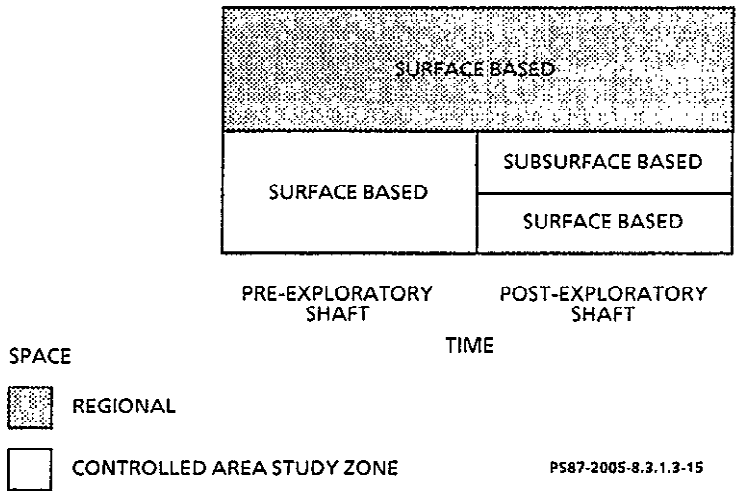

Figure 8.3.1.3-21. The time and space relationships of the groundwater studies.

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Study objectives

The regional groundwater study addresses several objectives related to the resolution of licensing issues. These objectives, generally stated, include the following:

- Provide a description of the physical characteristics of the regional groundwater flow system.
- Provide a description for the boundary conditions of the controlled area study zone.
- Provide a measure of the expected range of hydrologic conditions resulting from projected future stresses to the hydrologic regime from natural and man-induced causes.
- Provide an inventory of current water rights and groundwater withdrawals within the Pasco Basin.
- Provide information regarding recharge and discharge relationships and interbasin transfers of water.

Support of conceptual model development

The study of the regional groundwater flow system is intended to reduce the uncertainty associated with the choice of conceptual models used to describe the groundwater flow system within the Pasco Basin and Cold Creek syncline. This study is used to assist in the definition of hydrologic

boundaries for the local flow system around the controlled area study zone. This is necessary because the controlled area study zone is in an area of relatively low hydraulic gradient, where the differences among hydraulic head measurements are of the same order of magnitude as the accuracy limits of those measurements. While a low hydraulic gradient is a favorable condition for waste disposal, it is more difficult to establish hydrologic boundary conditions for the repository area. General predictions of groundwater movement and boundary conditions for the controlled area study zone are possible through conceptual and numerical models of the Pasco Basin and Cold Creek syncline.

Characterization of the regional system will also permit the assessment of the mechanisms and areas of recharge and discharge for groundwater moving through the repository area. This knowledge will provide the basis for identifying and evaluating the impacts of potential system stresses resulting from man-induced (resource development) and natural (climatic and tectonic) changes that may affect the present groundwater flow system near the controlled area study zone in the future. These stresses may potentially alter the rate and direction of groundwater movement and, hence, affect postclosure performance of the repository.

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Guidance to future activities

The regional groundwater study will provide guidance to future activities as well as providing data to support the site groundwater and performance assessment studies. This guidance will have two main components, providing direction relative to:

- The development of the appropriate conceptual model(s) of the groundwater system.
- The types and amounts of data to be collected.

The first component, conceptual model development, is discussed in the preceding subsection. The evaluation of the conceptual model(s) will provide guidance to the development of the site-specific numerical models in the site groundwater and performance assessment studies.

The second component, data collection, refers to the interactions within and between studies related to the adequacy of the data collected. The model(s) of the regional groundwater system will be tested for sensitivity to selected inputs and additional data collected as appropriate. An example of the resulting guidance to a future activity is the tie between the regional groundwater and surface-water system studies. If the regional groundwater system is sensitive to changes in recharge related to long-term variations in precipitation, the surface-water system study will be expanded to provide additional data for water budget calculations.

8.3.1.3.4.3.1.1 Analyses. The regional groundwater study includes the following analyses:

- Integration of data.
- Conceptualization of the groundwater flow system.
- Groundwater use survey.
- System stress analysis.
- Numerical simulation analysis.

These analyses are described on the following pages and summarized in Table 8.3.1.3-9.

Integration of data

The purpose of this analysis is to integrate data and information from other analyses and tests from this and other related studies. Through this procedure, a regional groundwater data base will be established.

The objectives of this analysis are as follows:

- Integrate data from published literature, other BWIP studies, and this study into a regional groundwater data base. The data base is to include every data set that will result from analyses and tests of this study. Numerical models shall use data contained in this data base.

- Provide data base functions that will be used to support the analyses and tests of this study.

Table 8.3.1.3-9. Summary of analyses performed during the regional groundwater system study

Analysis	Area of influence	Information provided	Issue supported
Integration of data	Groundwater flow system	Regional groundwater data base	1.6, 1.8
Conceptualization	Groundwater flow system	Conceptual models of groundwater flow system	1.6, 1.8
Groundwater use survey	Groundwater flow system	Groundwater use patterns in Pasco Basin	1.6, 1.8
Numerical simulation	Groundwater flow system	Numerical simulations of groundwater flow system of Pasco Basin and Cold Creek syncline based on conceptual models	1.6, 1.8
System stress	Groundwater flow system	Flow system sensitivity to man-induced and natural changes to the flow system	1.6, 1.8

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This analysis is composed of the following elements:

- Task 1--Identify the data sets that shall be incorporated into the data base. These data sets will be derived from tasks of the regional groundwater study and other related BWIP studies as identified in the Regional Groundwater Study Plan (Roley, 1987).

- Task 2--Collect the data sets from the appropriate task or study and perform a review on the data to characterize the quality of sources and completeness of the information. Finally, convert data sets to digital format and input data to the data base.

- Task 3--Document the contents of data base. The objective of this task is to provide documentation of the contents of the data base. This will provide the long-term retrievability and usability of data required by a project of this nature.

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Conceptualization of groundwater flow system

The purpose of this analysis is to collect, interpret, and integrate available data to establish conceptual models of groundwater flow within the Pasco Basin and Cold Creek syncline. Much information is currently available regarding concepts and data for the groundwater flow system within the Pasco Basin. This information is presented in Section 3.6 and 3.7. The analysis will evaluate and integrate currently available information with information and data collected during site characterization to develop detailed conceptual models of groundwater flow for the Pasco Basin and the Cold Creek syncline. Conceptual models will be used to form the basis for construction of numerical models.

This analysis is organized into seven tasks:

1. Determine geologic framework.
2. Determine hydraulic characteristics.
3. Determine hydraulic head distribution.
4. Determine groundwater recharge.
5. Define hydrochemical concepts.
6. Perform analog studies.
7. Define conceptual models.

Task 1 determines the geologic framework of the Pasco Basin to support the development of conceptual model(s) of the regional groundwater system. This task includes the following:

- Provide a three-dimensional geometry of the stratigraphic and structural framework of the Pasco Basin and Cold Creek syncline.

- Provide a lithological description of the Pasco Basin and Cold Creek syncline.

A structural and stratigraphic three-dimensional model will be produced for both the Pasco Basin and the Cold Creek syncline scales. The stratigraphy to be incorporated in this model will include the stratigraphy above and including the N2 Grande Ronde Basalt. The development of the structural and stratigraphic models is described in Section 8.3.1.2. These models will be used as the geometric framework required to conceptualize the regional groundwater flow system. The stratigraphic and structural models will provide the following information:

- Configuration, thickness, lateral variation, and internal characteristics of basalt and sedimentary layers.
- Location and dimensions of faults and folds.
- Graphic representations that include cross sections, block diagrams, structure contour maps, and isopach maps.

Lithologic descriptions within the Pasco Basin will be provided for basalt flows, interbeds, and suprabasalt sediment members and their internal features. Lithologic information can be used to correlate hydrologic properties to lithologic features.

Task 2 determines the hydraulic characteristics of hydrostratigraphic units of the Columbia River basalts and the sedimentary interbeds in the Pasco Basin. This task includes the following:

- Determine hydraulic parameter data for hydrostratigraphic units.
- Enhance the understanding of the controlling mechanisms of hydraulic properties through correlation of hydraulic data to discrete or composited stratigraphic units, features, and structures.

Hydraulic parameter data are available from numerous research activities of various local, state, Federal, and university-affiliated organizations for the Pasco Basin (see Section 3.8). Additional data are available from BWIP site-specific studies. A data search and collection program will be conducted for all available hydraulic parameter data representing the major hydrogeologic units, concentrating on the Pasco Basin and Cold Creek syncline. Data from other basins within the Columbia Plateau will be searched to support analog studies. These analog studies will be used to describe hydraulic characteristics of certain hydrogeologic features in which data are lacking for the Pasco Basin (e.g., fault and fold structures). Additional analyses to determine transmissivity distributions from specific capacity data may be required.

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This data collection program will focus on the following parameters:

- Transmissivity.
- Hydraulic conductivity.
- Specific capacity.
- Storativity.
- Vertical hydraulic conductivity and leakage coefficients.

Hydraulic parameter data will be screened and correlated to its source, method of analysis, quality, representativeness of a particular hydrostratigraphic unit, and areal coverage. Hydraulic parameter data will also be correlated to the flow or interflow feature that is associated with the particular parameter value.

Limited hydraulic testing (Section 8.3.1.3.4.3.2) is planned in association with the proposed regional piezometers. These field tests will be small-scale single-hole-type tests. These tests will provide a limited amount of data (only eight holes are planned), testing a small region around the well. While these data will be useful in filling some data gaps, they will not provide a statistically significant amount of data to accurately depict the hydraulic parameter values of the hydrogeologic units within the Pasco Basin. The initial evaluation of the Pasco Basin flow system will depend heavily on the use of existing data. The final determination of the extent of field testing will be based on the sensitivity of the flow model to the accuracy and precision of the data available.

Analysis of geophysical and driller logs will be performed to correlate a specific hydraulic parameter value to a specific stratigraphic unit or structural feature. Correlating the data according to geologic environment will facilitate the hydraulic characterization of the various geologic features by enhancing the understanding of the controlling mechanisms of hydraulic properties of aquifers and aquitards found within the Pasco Basin. Determination of the flow or interflow feature can then be used to provide an estimate of the hydraulic parameters in a given area or stratigraphic horizon where hydrologic data are lacking.

Task 3 determines the hydrualic head distribution for the Pasco Basin and Cold Creek syncline. Hydraulic head information will be used to provide interpretations of several key aspects of the groundwater flow system. Hydraulic head data will provide essential information for the following:

- Defining the hydraulic head distribution.
- Delineating groundwater flow paths.
- Determining horizontal and vertical hydraulic gradients.
- Interpreting hydraulic boundaries.
- Understanding groundwater recharge and discharge patterns.
- Providing information for model calibration exercises.

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CONTINUATION NOTICE

RECORD NO: 0009234

This record has been filmed in two parts. To view the beginning portion of this record, see the microfilm reel and frame number listed below.

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REEL NO: 12-12554

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The objectives for this activity are as follows:

- Construct hydraulic head distribution maps and cross sections for current conditions.
- Construct hydraulic head distribution maps and cross sections for predevelopment conditions as data permit.

Hydraulic head data for the Pasco Basin are maintained by Federal and state agencies that include the DOE, the U.S. Geological Survey's System hydrologic data base (WATSTORE), the U.S. Bureau of Reclamation, and the Washington State Department of Ecology. Hydraulic head data within the Pasco Basin outside the Hanford Site are derived primarily from water-supply wells (primarily irrigation). Data derived from selected water-supply wells represent composite water levels for the major hydrostratigraphic units of the Columbia Plateau. Data derived from wells within the Hanford Site represent water levels for discrete zones within the basalts. These data for both current and historic hydraulic head information will be compiled and input to a Pasco Basin wells data base within the groundwater use analysis of this regional groundwater study.

Wells within the Pasco Basin will be sorted to obtain an inventory of wells that contain hydraulic head information representative of the major hydrostratigraphic units. For Pasco Basin scale investigations, potentiometric information will be compiled for the four major hydrostratigraphic units: the suprabasalt sediments, the Saddle Mountains, Wanapum, and Grande Ronde Basalts. For Hanford Site wells, hydraulic head information from discrete zones that are representative of each regional scale hydrostratigraphic zone will be compiled.

An attempt will be made to construct maps that depict historic hydraulic head conditions through the 1950s. Present data are scant or nonexistent in the appropriate format to reconstruct hydraulic head conditions through time. A large data base exists within the files of the U.S. Geological Survey, which contains water-level data for current and historic conditions. At present, much of these data are not currently in the WATSTORE data base. An effort to input these data into WATSTORE will take place if it is established that these data could significantly improve the current and historic water-level data base for the Pasco Basin. Plans for these historical maps will be presented after the historic data availability is determined.

Task 4 determines the groundwater recharge within the Pasco Basin. Estimating groundwater recharge is considered essential to adequately describe the groundwater flow system and calibrate a numerical model. The calculation of recharge rates provide an additional means to verify that the numerical simulation results are reasonable. When recharge rates are used in conjunction with observed data on hydraulic properties to predict the hydraulic head distribution, the confidence in the accuracy of the groundwater model is

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enhanced. Definition of the flow volumes in and out of the hydrologic system, in conjunction with observed hydraulic head distributions, provides a tool that can be used to bound the transmissive properties of the groundwater system.

The groundwater recharge task will provide an estimate of groundwater recharge rates for both preirrigation (recharge from precipitation only) and for current conditions present (recharge including irrigation). Obtaining a preirrigation recharge rate allows groundwater model calibration to a "predevelopment" steady-state condition. A predevelopment steady-state calibration forms the base case from which transient analysis of the flow system can begin. Recharge incorporating current conditions allows for a transient model calibration.

Recharge models will be not only be used for model calibration purposes, but also as a base case for assessing the sensitivity of the groundwater flow system to changes in climate and land use changes.

Studies of predevelopment and current conditions of groundwater recharge within the Pasco Basin are in progress by the U.S. Geological Survey through their Regional Aquifer Systems Analysis program and have been developed by Battelle, Pacific Northwest Laboratories, as part of numerical simulation exercises of the Assessment of Effectiveness of Geologic Isolation Systems program (Dove et al., 1982). The results of the U.S. Geological Survey study are expected to be available to the BWIP during the first half of fiscal year 1988. These studies will be evaluated for their adequacy and applicability to Pasco Basin modeling studies. A data collection program will be initiated as part of the surface water investigation (Section 8.3.1.3.3) if it is determined that additional data collection and analysis are required to arrive at a defensible recharge distribution.

Task 5 defines the hydrochemical concepts and parameters. The purpose of this task is to collect and incorporate hydrochemical concepts and parameters to enhance and confirm conceptual models of groundwater flow.

The role of hydrochemistry in groundwater flow system evaluation is two-fold. First, the chemical evolution of the water is observed as the water progressively interacts with basalt along flow paths in the system. This is accomplished by analyzing water samples from wells penetrating the major aquifers in basalts of the plateau. Changes in water chemistry along any particular flow path are a function of mineralogy, temperature (and pressure), time, and aquifer conditions such as effective porosity. If flow paths are either not known or poorly known from hydraulic measurements, the chemical evolution of the water can be used to help indicate flow directions because the composition of dissolved constituents in groundwater tends to change systematically with increasing residence time. If flow paths have been inferred from hydraulic measurements, the chemical evolution of the water can be used to confirm the flow paths. The second role of hydrochemistry is in the estimation of residence time by analyzing radiogenic isotopic compositions such as ^{14}C abundance. The direction of increasing residence time determined by such measurements will generally coincide with flow-path directions.

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The hydrochemical and thermal parameters provide input to a conceptual flow model for groundwaters of the Columbia Plateau. Mapped contours of the ratio of major cation concentrations in solution define the distribution of hydrochemical facies. Definitions of these hydrochemical facies indicate zones where groundwater is young and outline areas where older, chemically evolved groundwaters occur. The following can be inferred through hydrochemical analysis:

- Areas of recharge and discharge.
- An indication of the vertical movement of groundwaters.
- Lengths and directions of groundwater flow paths.

Hydrochemical analysis of the groundwaters of the Columbia Plateau and Pasco Basin will be done within the groundwater flow system hydrochemistry study as described in Section 8.3.1.4.3.3.1. The regional groundwater study will incorporate the results of the hydrochemistry study into the regional groundwater data base and use the data to help develop conceptual models of groundwater flow.

Task 6 performs analog studies to provide conceptual information regarding the hydrologic role of geologic structures. It will be practical to design some analog studies to obtain supportive information regarding the basalt and sedimentary units, the distribution of recharge and discharge, estimation of hydraulic properties of hydrostratigraphic units, and the estimation of the impact of water use on deep basalt aquifers.

Analog studies will be conducted outside and (or) adjacent to the Pasco Basin in settings that exhibit hydrogeologic characteristics similar to the Pasco Basin. Areas currently identified for potential analog studies include Black Rock Valley, Horse Heaven Plateau, and other areas within the Yakima Fold Belt on the Columbia Plateau.

Task 7 defines conceptual models of groundwater flow in the Cold Creek syncline and the Pasco Basin. The overall objective of this task is to synthesize the data and information obtained within analysis and tasks of this study to formulate conceptual models of groundwater flow.

Conceptual models of groundwater movement within the Pasco Basin have been identified by several previous investigations including the DOE (DOE 1982; 1986), Arnett et al. (1981), and Dove et al. (1982). Differences in opinion exist among the above researchers regarding aspects of the behavior of groundwater flow within the Pasco Basin. The purpose of this task is to synthesize data generated in this study to develop quantitative and qualitative conceptual models of groundwater flow within the Pasco Basin and Cold Creek syncline. This task will result in the definition of conceptual models of groundwater flow for the Pasco Basin and identify uncertainties within the conceptual models. The conceptualizations developed within this task will be tested through numerical simulation exercises as in Section 3.6.4. It is anticipated that a defensible quantitative description of the Pasco Basin flow system will result through an iterative process of

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testing and modifying the conceptual model(s) and retesting through model calibration and sensitivity studies. The conceptual models will consider the following:

- Hydraulic gradients in horizontal and vertical directions.
- Direction of groundwater movement.
- Location and mechanism of recharge and discharge.
- Description of heterogeneities and anisotropies.
- Influence of geologic structures and stratigraphy.
- Location and nature of hydrologic boundaries.
- Information regarding aquifer intercommunication.
- Information regarding interbasin water transfer.
- Surface water and groundwater intercommunication.
- Time variant behavior from artificial and natural stresses.

To facilitate the development of conceptual models, hydrologic, geologic, and hydrochemical data will be integrated using computer graphic software to synthesize the large amount of data. Data will be stored and retrieved from the regional hydrologic data base. The basic form of the graphical representation will have the three-dimensional stratigraphic and structural geometry of the Pasco Basin and of the Cold Creek syncline. This will then be overlain by various combinations of hydrologic data such as hydraulic head information, hydrologic property data, recharge/discharge information, and hydrochemical properties and concepts to analyze for a particular concept. For example, hydraulic head and hydraulic property data can be overlain onto the geologic geometry maps to interpret hydrologic boundary conditions.

A three-dimensional graphic depiction of the groundwater flow system within the Pasco Basin and Cold Creek syncline will result from this task. Additionally, uncertainties regarding the dynamics of the flow system will be identified. Recommendations for numerical simulation exercises will be presented based on the uncertainties identified.

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Groundwater use survey

This analysis will provide an inventory of Pasco Basin wells, an inventory of current and historical groundwater use, a compilation of surface and subsurface water rights, and a description of available groundwater resources for the Pasco Basin. This analysis will provide information for the numerical simulation analysis, resource potential study, and surface-water system study.

The analysis is organized into the following tasks:

1. Water well inventory.

   - Determine locations and information regarding data availability of Pasco Basin wells.

   - Determine and document water use in the Pasco Basin.

   - Provide a basis for determining groundwater withdrawal rates.

2. Summation of water rights.

   - Provide a summary of groundwater and surface water rights to meet siting and permitting requirements.

   - Provide a tool to be used for quality control to validate the water well inventory for completeness.

3. Determination of groundwater withdrawal rates.

   - Provide an inventory of current and historic groundwater withdrawal rates to estimate groundwater stresses.

4. Incorporation of data collected by other studies.

Task 1 provides an inventory of all known wells in the Pasco Basin. This task will result in a complete inventory of all water wells in the Pasco Basin and will be the basis of the groundwater use survey. The inventory will result in the development of a Pasco Basin groundwater well data base, which will be used to determine groundwater use, water rights, and groundwater withdrawal. Groundwater use reports, maps, and modeling input information will be developed, based on combinations of qualifying parameters (attributes) that will be contained in the data base.

The development of the Pasco Basin well data base will include the collection and input of well information from various sources. The data will be reviewed for completeness. The primary source of well information will be the U.S. Geological Survey Groundwater Site Inventory data base. The Groundwater Site Inventory data base has been used to support previous BWIP work (Section 3.8; Bell and Leonhart, 1980). A complete, new listing of wells will be obtained to ensure that any new well information that has been recently added to the Groundwater Site Inventory is included in the Pasco Basin wells data base. The Groundwater Site Inventory will be queried annually to obtain any additional information that is added to the Groundwater Site Inventory during the conduct of the study.

Another source of well information is water rights information that is maintained by the State of Washington Department of Ecology. Groundwater rights and claims information will be used to augment and cross reference the groundwater site index data water rights records. This information will include well identification, location, place of use, type of use, water right priority data, and amount of use. Groundwater rights and claims information will be obtained for the entire Pasco Basin.

Well information will also be obtained from major water users in the Pasco Basin. The Bureau of Reclamation's Columbia Basin project provides irrigation water to the majority of irrigated lands in the Pasco Basin (see Section 3.8). Groundwater pumping is used to augment surface water supplies by the Columbia Basin project. Information concerning any wells operated or regulated by the project in the Pasco Basin will be added to the data base.

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Compilation of Columbia Basin project information will include a review of historic information to identify any wells that may have been in use and then abandoned as surface water supplies were developed.

The DOE, at the Hanford Site, is another major water user in the basin (Bell and Leonhart, 1980). The DOE well records and water use records will be obtained and added to the data base. A number of public supply and municipal water systems are also present in the basin. Records from the public water supply organizations will be reviewed and added to the data base.

Task 2 provides an inventory of all subsurface water rights in the Pasco Basin and surface water rights for the controlled area study zone and Cold Creek Basin. Both surface and subsurface water rights must be inventoried for the controlled area study zone and surrounding area as part of the siting and licensing requirements of the regulatory agencies. Water is a publicly owned resource in the State of Washington and is appropriated. Water rights records are maintained by the State of Washington Department of Ecology. These records document water appropriations and claims of water appropriations, including priority date, type of use, location of diversion, place of use, amount of use, and flow rate. The State of Washington Department of Ecology records will be obtained for all water rights for the controlled area study zone. In addition, since many water users on the Hanford Site have not filed for water rights with the state, local records will be checked for supplemental data. The groundwater records for the Pasco Basin will be used to meet information requirements and for cross-referencing to the groundwater well inventory.

A water rights data base component consisting of water rights information will be prepared and stored as a component of the overall wells data base. The following water rights information elements will be included:

- Water source.
- Place of diversion.
- Diversion rate.
- Annual diversion amount.
- Type of use.
- Place of use.
- Amount of land irrigated (for irrigation uses).
- Priority date.

The data base will facilitate comparison of water rights information with Groundwater Site Inventory data and preparation of specific water rights reports. Surface water rights information will be tabulated and prepared for reporting as a component of the surface water system study. Groundwater rights information will be tabulated and included as a section of the groundwater survey report.

Task 3 determines groundwater withdrawal rates for the Pasco Basin. Task 3 consists of the development of groundwater withdrawal information, which will be used to support regional numerical simulation and the water resource potential study. The water well data base will be the basis for

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defining groundwater withdrawal. A withdrawal amount will be determined for each well in the data base. The development of withdrawal information using the data base will support the reporting and application of withdrawal information based on hydrologic unit, x-y location, and time, all of which are attributes in the groundwater well data base. The withdrawal information will be developed on a well-by-well basis, based on recorded well use information. Withdrawal information will be developed for water years 1983 to 1986. Well-specific information will be developed for industrial, public supply, and irrigation wells. Basin-wide, average pumping values per well will be developed for other water use wells, including domestic and livestock wells.

A majority of groundwater use reported in the Pasco Basin is attributable to a relatively small number of wells. Section 3.8 lists the groundwater usage and number of wells for major water uses. Specific withdrawal rates will be developed for major wells such as irrigation, industrial, and public supply wells. It will not be necessary to develop different withdrawal rates for individual domestic and livestock wells. Domestic wells account for the majority of wells in the basin, but they account for a minimum of groundwater withdrawal. Groundwater withdrawal variations among individual domestic wells will not significantly affect overall groundwater withdrawal determinations. A per-well average withdrawal rate will be determined for the Pasco Basin. This average withdrawal rate will be applied to each domestic and livestock well. The recording of domestic and livestock withdrawal by well will support determination of the spatial distribution and cumulative effect of domestic and livestock groundwater withdrawal throughout the basin.

Groundwater withdrawal rates will be reported on a well-by-well basis. using the groundwater well data base. The recording of withdrawal rates on a well-by-well basis will allow for the maximum flexibility of data applications. Data base attributes such as well location and well depth can be used to generate pumping information for resource reporting and formodeling. The development of pumping information on a well-by-well basis will provide data for modeling that is independent of model grid characteristics. Withdrawal information can be developed for different model areas and grid sizes if detailed modeling is required.

Subtask 3.1 determines industrial and public supply use in the Pasco Basin. A total of 33 industrial wells have been identified in the Pasco Basin (Section 3.8). Ninety-nine percent of industrial groundwater use in the Pasco Basin is on the the Hanford Site (Bell and Leonhart, 1980). Groundwater use information is reported by DOE (ERDA, 1975) for the Hanford Site. Water use information concerning offsite industrial wells has been recorded by the State of Washington Department of Ecology.

The Groundwater Site Inventory data base lists a total of 76 public supply wells in the basin (Section 3.8). Groundwater use for these public supply wells can be determined based on the State of Washington Department of Ecology records and records maintained by municipal and public water supply agencies.

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Subtask 3.2 determines domestic water use in the Pasco Basin. Domestic wells account for the largest percentage of wells in the Pasco Basin and the smallest volume of groundwater use of the major water use classes (Section 3.8). A constant water use value will be developed for all domestic wells based on per-service unit water use reported by municipal and public water supply agencies in the basin. This constant value for domestic water use can be reported in the groundwater well data base for individual well locations. The well-by-well approach will also support the reporting of domestic groundwater use changes over time based on well construction dates.

Subtask 3.3 determines irrigation water use in the Pasco Basin. A total of 176 irrigation wells are reported in the Pasco Basin (Section 3.8). Irrigation well pumping volumes will be estimated on a per-well basis, based on irrigation water application rates and irrigated cropland acreages. Gutknecht et al. (1980) report irrigation application rates for the Pasco Basin for alfalfa, a high water-use crop, and small grains, a low-water use crop. In addition, the U.S. Geological Survey is estimating irrigation pumping rates on an area-specific basis for the Columbia Basin as part of the Regional Aquifer Systems Analysis program project. These estimates are based on LANDSAT satellite remote sensing data and power records. The LANDSAT image data are being used to determine contemporary pumping rates while power records are being used to determine pumping rates before 1985.

If U.S. Geological Survey procedures for determining pumping rates are published in a timely manner and review of these procedures indicates that the methodologies are suitable for the Pasco Basin, the methodologies will be used for the regional groundwater study. The U.S. Geological Survey methods for estimating pumping use have been selected because these methods address temporal and spatial variability resulting from rainfall variations, variations of crop type, and variation of soil conditions. If the U.S. Geological Survey methodologies have not been published or are found to be unsuitable, the application rates reported by Gutknecht et al. (1980) will be used. High and low pumping values based on requirements of high and low water-use crop types will be determined for each irrigation well.

Determination of irrigation groundwater use on a per-well basis will also require information on acreage of irrigated cropland served by each well. Cropland acreages will be determined using Landsat satellite imagery and compared with water rights information. The U.S. Geological Survey is mapping irrigated cropland distribution using Landsat multispectral scanner image data as part of the Columbia Plateau regional systems analysis program project. As with the pumping information, it is not known if the U.S. Geological Survey LANDSAT analysis results will be available for use in a timely manner. If available, the LANDSAT data will be reviewed for suitability for the groundwater use survey. If suitable, the data will be used to determine irrigated areas for each major irrigation well.

If Regional Aquifer Systems Analysis program LANDSAT data are not available, LANDSAT thematic mapper data will be used to map irrigated land use in the Pasco Basin. Mapping of irrigated land use will be based on digital processing of Landsat thematic mapper computer compatible data. Digital maps of the Pasco Basin and acreage summaries will be produced.

Surface water sources and groundwater sources must be differentiated in irrigated areas defined by LANDSAT data, in order for these data to be useful for the groundwater survey. Irrigation water source information has been developed as part of the regional systems analysis program project. If irrigated source information is available from regional systems analysis program, the data will be reviewed and used if suitable. If U.S. Geological Survey irrigation source data are not available or are unsuitable, source areas will be delineated for the following water source classes:

- Surface water (Columbia Basin and Yakima projects).
- Surface water (other).
- Groundwater (Columbia and Yakima projects).
- Groundwater (other).

Columbia Basin and Yakima project areas will be delineated from other areas so that the lands for which project water-use information exists can be identified. This will enable project water-use information (i.e., diversion rates) to be applied to specific areas. The irrigation water source delineation will be conducted using published information from Bell and Leonhart (1980), which includes maps or irrigation districts in the Pasco Basin, published and unpublished Columbia Basin and Yakima project data, and field mapping.

Task 4 provides for the incorporation of data collected by other studies. The groundwater use survey will use information developed as part of the surface water system study. The groundwater use survey and surface water system study occasionally require identical data, such as land use and (or) land cover and hydrometeorological data. To avoid duplication, specific data elements will be developed by each study. The groundwater use survey will obtain land resource, soils, and wells information. The conceptualization analysis of the regional groundwater study will develop geologic and recharge information. The surface water system study will develop hydrometeorological data, surface drainage within the Pasco Basin, and surface-water sources, including ponds, canals, and reservoirs.

The survey will incorporate data from the numerous groundwater resource investigations have been conducted in and around the Pasco Basin in support of the BWIP and as a function of regional groundwater management. The following data have been identified for use in the groundwater survey, either as direct information or as quality assurance data:

- Water use--Bell and Leonhart (1980)
- Regional hydrology--Leonhart (1979) and Dove et al. (1982)
- Hydrometeorology--Gutknecht et al. (1980)
- Land use--Stephan et al. (1979) and Wukelic et al. (1981)

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A major potential source of groundwater use information for the Pasco Basin is the Columbia Plateau Regional Aquifer Systems Analysis program project (Vacarro, 1986). Groundwater use information, including pumping rates, irrigated acreages, and groundwater well data, is being developed for the Columbia Plateau by the U.S. Geological Survey. The intent of the groundwater use survey is to make maximum use of U.S. Geological Survey Regional Aquifer Systems Analysis program data wherever they are appropriate. A significant limitation to the use of U.S. Geological Survey Regional Aquifer Systems Analysis program data is schedule and data availability. The groundwater survey must be completed in a timely manner to provide data for numerical simulation and the water resource potential study. The groundwater survey plan has identified where U.S. Geological Survey Regional Aquifer Systems Analysis program data may be used, if available. However, the plan also includes procedures for developing the required information if Regional Aquifer Systems Analysis program data are not available.

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Numerical simulation analysis

A groundwater model is used in this study as a tool to integrate the general concepts and data generated or collected within this study. These data will be used to formulate a three-dimensional depiction of the flow system within the Pasco Basin and Cold Creek syncline. The purpose of this test is to construct and use the groundwater flow model to (1) resolve conceptual uncertainties, (2) provide a defensible range in site-scale boundary conditions, (3) predict the effects of system stresses, and (4) guide further data collection.

The objectives of the numerical simulation analysis are the following:

- Assist in the definition, testing, and refinement of alternative conceptual models of groundwater flow for the Pasco Basin and Cold Creek syncline, including the influence of the Upper Cold Creek hydrologic impediemnt in the flow in the controlled area study zone and Cold Creek syncline.
- Provide supplemental and corroborative information in support of determining the possible range of pre-emplacement groundwater boundary conditions for the controlled area study zone.
- Determine the sensitivity of the groundwater flow system in and near the controlled area study zone to various system stresses (climatic, tectonic, and man-induced).
- Determine the nature and effects of hydraulic transients on the deep basalt groundwater flow systems.
- Determine the data weaknesses and prioritize data needs.

This analysis is organized into the following six tasks:

Task 1 determines a detailed strategy for development of calibrated Pasco Basin and Cold Creek syncline models, including the following activities:

- Based on the alternative conceptual models developed, determine which numerical code(s) will be used for Pasco Basin and Cold Creek syncline models.
- Describe the methods used to put the conceptual model into numerical format.
- Formulate a strategy for steady-state calibration.
- Design a strategy for an interactive development of the steady-state sensitivity studies and refinement of the conceptual models.
- Formulate a strategy for the needs and, if necessary, the approach for transient calibration and sensitivity analysis.
- Identify additional data needs.
- Determine the strategy for conducting future climate and resource potential sensitivity analyses.
- Determine needs and methods for transient calibration.
- Determine the types of simulations that will be used to estimate boundary conditions, validate hydraulic parameter estimates, and determine the effects of system stresses.

Task 2 results in the construction of numerical models by converting conceptual model(s) into numerical format. This task includes the following activities:

- Design model grids and define boundary conditions.
- Convert data contained in the conceptual models into a numerical data base for input to the numerical models.

Task 3 incorporates the performance of a steady-state calibration and sensitivity analysis of the models. This task includes the following activities:

- Calibrate a steady-state model to predict field-measured hydraulic heads.
- Perform sensitivity runs to reduce conceptual uncertainties and identify data weaknesses.

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- Determine the effects of current hydraulic transients on the deep basalt groundwater flow system.
- Determine the sensitivity of the groundwater flow system in and near the controlled area study zone to climatic, tectonic, and man-induced stresses.
- Determine the uncertainties in the data base and identify data needs.

Task 4 incorporates the performance of steady-state sensitivity analyses for future climate, tectonic, and resource development effects, including the following activities:

- Perform sensitivity runs to provide a preliminary assessment of the impacts of system stresses on the hydrologic regime.
- Provide information on system stresses to be used in planning future work.

Task 5 results in transient calibration and sensitivity exercises of numerical models, including the following activities:

- Perform transient history-matching exercises to calibrate a transient model.
- Perform transient sensitivity exercises to refine alternative conceptual models and to identify data needs.

Task 6 explores the practical applications of the model(s) by performing predictive studies, including the following activities:

- Assist in the definition, testing, and refinement of alternative conceptual models of groundwater flow for the Pasco Basin and Cold Creek syncline.
- Provide supplemental and corroborative information in support of determining the possible range of preemplacement groundwater boundary conditions for the controlled area study zone.

<u>System stress analysis</u>

Natural and man-induced stresses can impact the regional groundwater flow system significantly. The system stress test will evaluate the changes in the groundwater flow system caused by various stresses. Three types of system stresses are considered:

- Man-induced stresses.
- Climatic stresses.
- Tectonic stresses.

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The purpose of this analysis is to determine the effects of these stresses on the groundwater flow system.

Man-induced stresses to the groundwater flow system primarily consist of water resource development projects (e.g., major changes in irrigation practices or the construction of dams on the Columbia River) that could affect groundwater flow in the controlled area study zone.

Changes in the climate could also stress the groundwater flow system. Long-term variations in precipitation or evapotranspiration might alter recharge rates, thereby changing hydraulic heads. Another potential effect of climate on groundwater flow is glaciation. Glaciers have had a dynamic influence on precipitation, atmospheric circulation, and drainage in the Pacific Northwest during the Quaternary. Historic glacial-related events also imply the possibility of flooding by glacial meltwater. Similar events in the future could change the geohydrologic system in the vicinity of the repository.

Tectonic stresses are a third category of potential stress to the groundwater flow system. Tectonic stresses include changes in geostatic pressure, folding, faulting, and earthquake swarms.

Task 1 conducts sensitivity analyses to assess the need for further studies. The analyses will incorporate the following activities:

- Define groundwater flow parameters (e.g., recharge, hydraulic gradient) corresponding to various stress conditions (water resource development, climate, tectonics).
- Define the scope of related studies (e.g., water-resource potential, climatology, and tectonics).

These sensitivity studies will be conducted in the early phases of site characterization to provide direction regarding the scope and extent of data collection and evaluation activities of the future climate, water resource potential, and tectonics studies.

Task 2 conducts sensitivity analyses to determine impacts of significant stress scenarios. The analyses will incorporate the following activities:

- Evaluate each likely stress scenario developed in related studies.
- Quantify the impacts of various stress scenarios on groundwater flow in the controlled area study zone.

8.3.1.3.4.3.1.2 Tests. The purpose of the field work portion of this study is to provide information and parameter values that will reduce uncertainties in the existing data base. This information is necessary for construction of conceptual and numerical models.

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Field work that has been identified to date includes the following:

- Regional boreholes.
  - Installation of piezometers and testing facilities.
  - Hydraulic field testing.
  - Groundwater sampling.
  - Groundwater-level measurements.
- Geophysical logging.
- Hydraulic characterization of fault and fold features.

These tests are described below and summarized in Table 8.3.1.3-10.

Regional boreholes

Approximately eight boreholes beyond the controlled area study zone are planned to supplement the data base in locations where data are not available from other sources. Information obtained from these boreholes will aid in conceptualizing the regional groundwater flow system and developing a numerical groundwater flow model of the Pasco Basin and Cold Creek syncline. These boreholes are located in the Pasco Basin and along its periphery in the approximate locations as shown in Figure 8.3.1.3-22. The tentative locations of these boreholes have been selected based on the following criteria:

- The need for hydraulic head measurements near inferred hydrologic boundaries, geologic structures, and recharge and discharge areas. These hydrologic head measurements will assist in the definition of Pasco Basin boundary conditions for numerical modeling.

- Collect hydrochemistry data along inferred regional groundwater flow paths.

- Collect additional hydraulic parameter estimates of hydrogeologic units and structural features.

- Provide stratigraphic, lithologic, and structural definition of hydrologic units outside the Hanford Site.

It should be noted that additional analyses may be required before these borehole locations are finalized.

The following parameters will be gained from the regional boreholes:

- Hydraulic head.
- Hydraulic properties.
- Hydrochemical parameters.
- Stratigraphic, lithologic, and structural information.

Hydraulic head data from the regional boreholes, U.S. Geological Survey records, and Hanford Site monitoring locations will be used to delineate hydraulic boundary conditions and to provide calibration points for regional model calibration purposes.

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Table 8.3.1.3-10. Summary of tests performed during the regional groundwater study

Test	Area of influence	Parameter provided	Issue supported
Regional borehole testing	Groundwater flow system	Hydraulic boundaries Hydraulic heads Hydraulic properties Geologic information	1.6, 1.8
Geophysical logging of selected regional boreholes	Groundwater flow system	Hydraulic characteristics	1.6, 1.8
Hydraulic characterization of fault and fold features	Groundwater flow system	Hydraulic properties of faults and folds	1.6, 1.8

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Geophysical logging

Selected boreholes within and immediately adjacent to the Pasco Basin will be geophysically logged to provide the following hydrologic information: (1) identification of water-production zones; (2) porosity data; (3) water-level data; and (4) correlation of hydrologic information to stratigraphy, lithology, and discrete structures penetrated by the borehole. The selected boreholes will consist of water wells, hydrologic and geologic test boreholes, and, possibly, hydrocarbon exploration wells.

The selection of available and planned boreholes for logging will be coordinated between the geology and hydrology groups. In addition, cooperation with the State of Washington Department of Ecology and the U.S. Geological Survey will also be a means to identify strategic wells to be logged. The selection of these wells will be based on the following criteria:

- Wells located in areas where hydrologic information is lacking.
- Wells located in areas where stratigraphic and structural information is lacking.
- Access to wells in regard to property access and inactive pumping periods.

Interpretations of borehole geophysical logs will provide the following:

- Stratigraphic data.
- Lithologic data.
- Structural data.
- Water-level data.
- Porosity data.
- Aquifer and aquitard identification.
- Water-production zone identification.

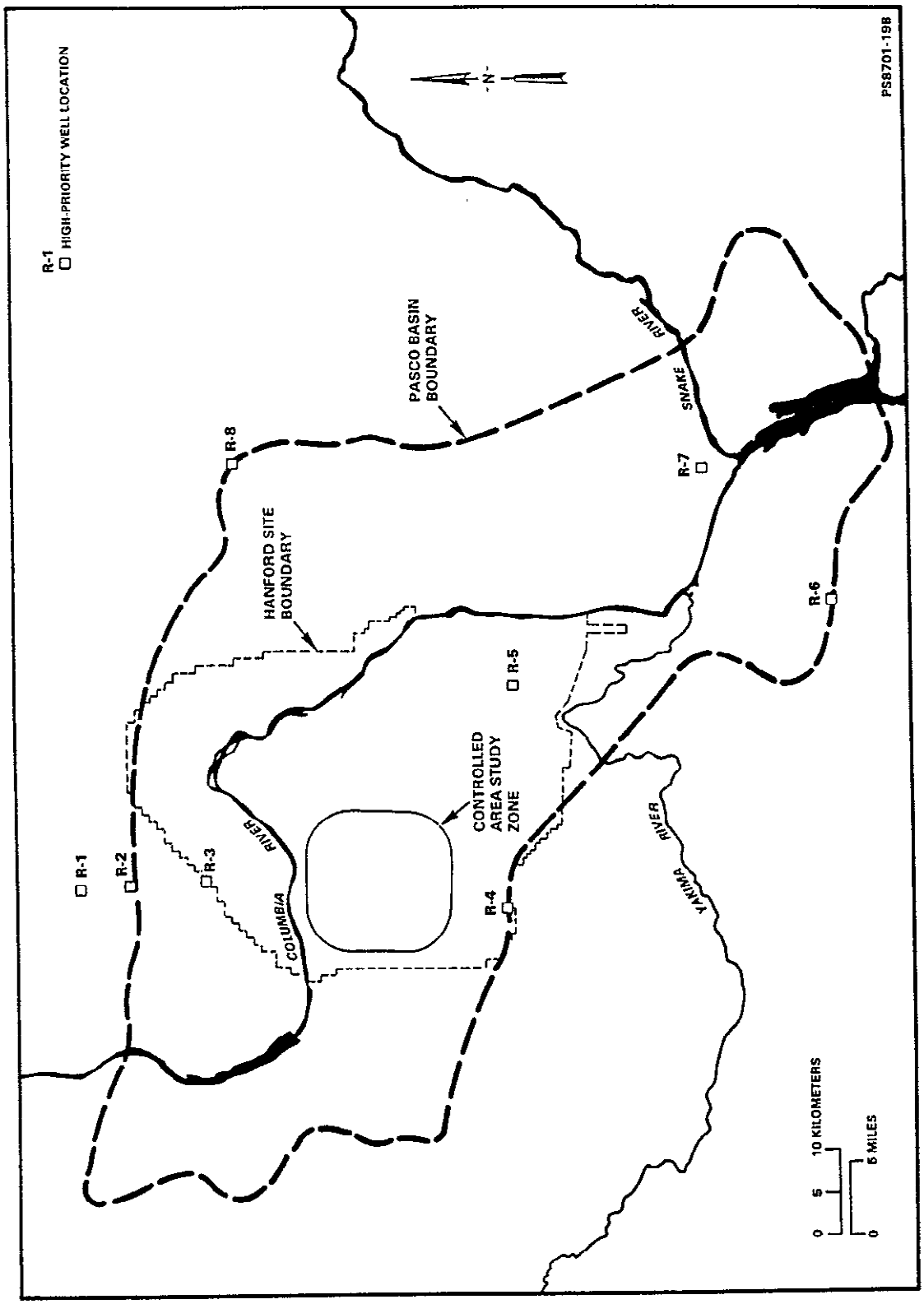

Figure 8.3.1.3-22. Approximate regional borehole locations.

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Hydraulic characterization of fault and fold features

The objective of field testing faults is to (1) aid in defining the properties of faults that provide boundary conditions surrounding the proposed repository site (e.g., Umtanum Ridge-Gable Mountain anticline, Yakima Ridge anticline, Cold Creek impediment) and (2) define the properties of faults and tectonic joints that lie within the controlled area study zone. Hydrologic testing on analogs (similar features at another location) of the faults in the controlled area study zone has been preliminarily proposed. This work may provide a marked improvement in site numerical modeling and testing in the absence of, or in corroboration with, results derived from pumping tests conducted in the controlled area study zone vicinity specifically designed to determine the hydrologic influence of the above-mentioned structures.

The proposed repository site is bordered by the Umtanum Ridge-Gable Mountain anticline and the Yakima Ridge anticline to the north and south, respectively, and bordered to the west by the Upper Cold Creek hydrologic impediment. In addition, structural features may exist within these potential boundaries that affect the flow field in the syncline. Groundwater models in the controlled area study zone will include suppositions concerning the nature of the three potential boundaries alluded to above and any structures found within the syncline. Drilling and testing activities will provide data on the above-mentioned structures within the controlled area study zone. Field testing at selected regional borehole locations will support characterization of strucutral features outside the controlled area study zone. Analog testing would also provide important information for modeling the influence of these structures on the groundwater flow system. In relation to deep borehole pumping tests, analog studies can provide more measurements for a given expenditure of money and effort where fault features are exposed or accessible to shallow, small-diameter drill holes.

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8.3.1.3.4.3.2 Site groundwater study. The site groundwater study responds to the objectives and rationale discussed in Sections 8.3.1.3.4.1 and 8.3.1.3.4.2. The tests described in the study are surface-based tests located within and near the controlled area study zone and subsurface-based tests located at the Exploratory Shaft Facility near the center of the controlled area study zone.

Study objectives

The following objectives of the site groundwater study support repository design and resolution of licensing issues through the collection, evaluation, and analysis of data:

- To describe the controlled area study zone groundwater flow system.
- To provide data about that groundwater flow system in support of the resolution of regulatory issues.

Several types of surface- and subsurface-based hydraulic tests are needed to collect the required data. As described in the rationale, the site groundwater study is divided into two phases, pre-exploratory shaft and post-exploratory shaft. Pre-exploratory shaft activities are based on the following guidelines:

- Collection of data on geohydrologic conditions that will be changed by surface-based tests and construction and operation of the exploratory shaft.
- Collection of data needed for indicating the potential for the presence of disqualifying conditions.
- Collection of geohydrologic data that may affect the design of the exploratory shafts and underground testing facility.

The first large-scale pump tests are important for several reasons, including the following:

- Examine basic test design adequacy.
- Calculate large-scale flow top hydraulic conductivities.
- Calculate flow interior hydraulic conductivities.
- Detect hydraulic responses from known and yet unidentified geologic structures and basalt heterogeneities.
- Identify any additional data needs.

The above information will address the performance and design issues raised in Section 8.2.2. Specific interpretative calculations and models will focus on questions of groundwater travel time and groundwater/methane inflow into underground facilities.

Post-exploratory activities include all those performed during and after construction of the exploratory shaft. These activities involve the collection of data required to develop a defensible conceptual model of the controlled area study zone and Pasco Basin and to form the basis for input to predictive models.

Support of conceptual model development

The primary purpose of this activity is to collect and interpret available data to establish the conceptual model(s) of the groundwater flow within and around the controlled area study zone. The conceptual model(s) will then be used to form a basis for the selection of numerical codes and will qualitatively address the relative behavior of the hydrologic system. This will be accomplished by defining initial regional conditions as inferred from potentiometric surfaces, refining hydrogeologic geometry, and obtaining hydraulic parameter values in and around the controlled area study zone.

Information regarding the following factors will be collected as needed for conceptual modeling:

- Geometries of hydrostratigraphic units.
- Geometries of structural features.
- Hydraulic parameters of hydrostratigraphic units and structural features.
- Groundwater potential distribution.
- Refinement of the identification of hydrostratigraphic units.
- Direction and magnitude of groundwater movement in horizontal and vertical directions.
- Location and nature of hydrologic boundaries (influence of stratigraphy and structure on flow system).
- Location and mechanisms of groundwater recharge and discharge.
- Description of hydraulic transients.

This information will be used to select and refine the conceptual model(s) of the site groundwater system. These conceptual models may contain fracture-flow, porous-media, and double-porosity concepts (Chapter 3). They will also reflect the geologic structure and the probable hydrologic boundaries.

Guidance to future activities

The data base generated will serve as a central reservoir of data that will be used by subsequent investigations. These include the regional groundwater, water resource potential, and performance assessment studies. The information and results of the investigation will also be used in engineering design and continued site characterization activities.

Performance assessment studies will use data generated by the groundwater investigation to assist in the following activities:

- Model validation.
- Assessment of groundwater travel time.
- Assessment of cumulative release to the accessible environment.

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Design uses of data from the groundwater investigation will include the following:

- Water inflow characterization during repository development.
- Performance modeling, repository engineered barriers.
- Support of calculations of methane and heat inflow.
- Seals evaluation, disturbed rock zone of the shaft and boreholes.

8.3.1.3.4.3.2.1 Analyses. The analyses to be performed as part of the Site Groundwater Study Plan (Hiergesell, 1987) are listed in Table 8.3.1.3-11. These analyses are described in detail in the site groundwater study and summarized in the following text.

To satisfy data needs for technical concerns presented in Section 8.3.1.3.4.2, it is necessary to (1) develop a method to ensure existing and new hydrogeologic, geologic, hydrochemical, water use, climatological, surface water, and geomechanical data are integrated; (2) formulate alternative conceptual models of the groundwater flow system based on integrated data; (3) formulate numerical simulations based on the conceptual models and utilize these simulations to rank the conceptual models, obtain a better understanding of the hydrologic system, refine parameter values, and evaluate predictive scenarios; and (4) perform sensitivity studies to understand the relative importance of different parameters in governing the groundwater flow system behavior.

Integration

The purpose of the integration of data is to provide an assessment of all data that describe any feature of the hydrologic system in the controlled area study zone. The data will be gathered in a central location so it can be made available for other analyses that may follow this activity. The objective of

Table 8.3.1.3-11. Summary of analyses performed during site groundwater study

Analysis	Area of influence	Information provided	Issue supported
Data integration	Groundwater flow system	Compiled geologic, geomechanical, geohydrologic, and geochemical data	1.1, 1.6, 1.8, 1.12, 2.4, 2.7, and 4.2
Conceptualization	Groundwater flow system	Alternative conceptual models Ranked conceptual models	1.1, 1.6, 1.8, 1.12, 2.4, 2.7, and 4.2
Numerical modeling	Groundwater flow system	Numerical simulations of groundwater flow system in controlled area study zone based on conceptual models	1.1, 1.6, 1.8, 1.12, 2.4, 2.7, and 4.2
Sensitivity analysis	Groundwater flow system	Significance of components of models to groundwater flow system behavior	1.1, 1.6, 1.8, 1.12, 2.4, 2.7, and 4.2

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integration is to assemble the information into a data base that can be used within the site characterization program for the assessment of the repository performance and for design of the exploratory shaft facility and repository. Key categories of data to be considered for integration include the following:

- Hydrogeologic data including hydraulic head, hydraulic conductivity, storativity, effective porosity, effective thickness, and dispersivity.
- Geologic data including borehole logs, stratigraphy, structural mapping, surface and borehole geophysics.
- Hydrochemical data including water chemistry and rock chemistry with emphasis on temperature, pressure, dissolved gas, trace elements, radioactivity, organic content, and particulates and colloids in the water.
- Water-use data including well location, well design, pumping estimates, irrigation diversions, and surface and groundwater irrigation permits and usage.
- Climatological data including precipitation, temperature, solar radiation, and paleoclimatic information.
- Surface water hydrology data including stream flow records, diversion records, flood studies, water quality and temperature, and site disposal records.
- Geomechanical data including measurements of in situ stresses and other rock properties.

To support pre-test analyses, these geohydrologic data from the controlled area study zone and vicinity will be used to develop a range of conceptual models. Known and estimated hydraulic information to be assembled includes hydraulic conductivity, specific storage, effective porosity, and dispersivity values for basalt flow tops, flow interiors, and sedimentary interbeds. Known and interpreted hydraulic head distributions will be combined with hydraulic, hydrochemical, and geologic data to define flow fields and boundary conditions. This information will support the development of numerical models used to examine a range of likely flow system responses to the first pump tests. A variety of scenarios will be examined ranging from homogeneous to heterogeneous flow top hydraulic properties to isotropic and anistropic flow interiors. The hydraulic responses of possible structural and stratigraphic features complicating test analyses will also be evaluated and factored into test performances. Examples of known structural features include the anticlines along the northern and southern boundaries of the controlled area study zone and the Cold Creek flow impediment to the west. Examples of unknown or yet unverified geologic structures include faults along the axis of the Cold Creek syncline or along the eastern boundary of the controlled area study zone.

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The above numerical models will be calibrated using waater level fluctuations monitored during past borehole drilling or development activities. These calibrated models will be used to help develop acceptance criteria for identifying when a hydraulic head baseline has been established and when pump tests are initiated or terminated.

Conceptualization

The purpose of conceptualization is to develop an understanding of the physical system and the physical processes that work within it. Comprehensive evaluation of all data is involved to develop a spatial distribution of material properties for conceptual model development that is consistent with the data. The conceptual models developed will form a basis for assessment of site performance and guide data collection during further site characterization. The formulation of conceptual models will help to prove existing hypotheses or will be useful in developing alternative hypotheses about the groundwater flow system. The conceptual models will then be used to formulate and establish conditions for numerical model simulation.

Numerical simulation

Numerical simulation of the groundwater system will include finite difference and finite element techniques that can incorporate complex boundary conditions, heterogenous and anisotropic conditions, complex geometry and three-dimensional flow. Numerical models will be used for the following purposes:

- Integration of hydrologic data.
- Guidance of data collection efforts.
- Pretest and post-test analyses of hydraulic stress and tracer testing.
- Refinement and evaluation of conceptual models.
- Analysis of flow system transient behavior as a result of the large-scale hydraulic stress tests.
- Analysis of aquifer parameter sensitivity.
- Prediction of effects of potential disruptive events to the groundwater flow system.

Sensitivity analyses

Sensitivity analyses will be conducted to identify the relative sensitivities of the flow system to individual flow system parameters that are critical in numerical modeling of the observed hydraulic head data. Sensitivity analyses will also help to refine conceptual models that adequately account for the existing data. They are conducted as part of calibration of

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steady state and verification of transient numerical models. Parameter sensitivity serves as a guide in the adjustment of input data sets to achieve a match of simulated hydraulic heads with field measurements. The basic approach will be to vary a selected independent variable (parameter) while leaving all other independent variables in the model domain constant. A series of simulations are conducted, each having the selected variable adjusted by a different amount.

8.3.1.3.4.3.2.2 Tests. The tests relate to hydrogeology and transport of radionuclides and are conducted both at the ground surface and within the exploratory shaft and the Exploratory Shaft Facility depending on the specific test. The tests are summarized in Table 8.3.1.3-12 and are described below.

The tests have been divided into two categories to emphasize the physical location of their support facilities. The two categories are surface- and subsurface-based testing. The former refers to testing that is conducted from support facilities on the land surface (i.e., wells, boreholes, and piezometers). The latter refers to testing from support facilities within the Exploratory Shaft Facility (i.e., piezometers, boreholes, chamber room), which is located within the candidate horizon (Cohassett flow).

The testing plan also incorporates tests to be completed prior to and after the construction of the exploratory shaft. This sequence of testing is described at the end of Section 8.3.1.3.4.2, rationale.

Surface-based tests

The surface-based tests refer to testing using conventional borehole drilling techniques from the surface of the ground.

Hydraulic head baseline tests. The hydraulic head baseline is used to determine the temporal and spatial distribution of hydraulic head prior to activities that may cause long-term disruption of the hydraulic head. Data from this activity are used for the following:

- Input into the development of conceptual groundwater flow models.
- Calibration of numerical groundwater flow models.
- Determination of the dynamics of the natural flow system.
- Antecedent data for analysis of hydraulic stress tests.

The locations of existing and proposed monitoring points within the controlled area study zone and the Hanford Site are provided in Figure 8.3.1.3-23.

Large-scale hydraulic stress tests. These multiple-well tests are constant rate discharge tests used to estimate hydraulic parameters of flow tops and flow interiors on scales from hundreds to thousands of meters. These hydraulic parameters include areal estimates of transmissivity and storativity of flow tops and several estimates of vertical hydraulic conductivity and specific storage of flow interiors. Test data are also expected to assist in

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Table 8.3.1.3-12. Summary of tests performed during the site groundwater study

Test	Area of influence	Parameter provided	Issue supported
Surface-based tests			
Hydraulic head baseline	Controlled area study zone	Hydraulic gradient	1.1, 1.2, 1.3, 1.12, 2.7, 4.2
Large-scale hydraulic stress (multiple-well test)	Represents an area with radius in scale of hundreds to thousands of meters	Hydraulic conductivity Transmissivity Storativity k'_v (flow interior) s'_s (flow interior) Effective thickness Delineation of suspected boundaries	1.1, 1.2, 1.3, 1.8, 1.11, 4.2 1.1, 1.2, 1.3, 1.6 4.2 1.6 1.8
Small-scale hydraulic stress (a multiple-well test)	Represents an area with radius in scale of tens to hundreds of meters	Hydraulic conductivity Transmissivity Storativity k'_v	1.1, 1.2, 1.3, 1.8, 2.4 1.1, 1.2, 1.3, 1.6, 4.2 2.4
Large-scale hydraulic stress tracer	Distances of 76 and 152 m	Dispersivity Effective porosity	1.1, 1.2, 1.3 1.1, 1.2, 1.3, 1.8, 1.12, 2.4
Single-well hydraulic stress	Represents an area with radius in scale of a few meters to a few hundred meters	Hydraulic conductivity Transmissivity	1.1, 1.2, 1.3, 1.8, 2.4 1.1, 1.2, 1.3, 1.6, 4.2
Drillling fluid invasion	Vicinity of exploratory shaft	Check of previously determined hydraulic conductivity and storativity	
Geophysical logging	All horizons at borehole location scale of up to a few meters	Borehole fluid temperature Borehole fluid movement	To be determined
Subsurface-based tests			
Single boreholes (portholes, exploratory boreholes, cluster boreholes, chamber piezometers)	Vicinity of borehole	Hydraulic conductivity	1.1, 1.2, 1.3, 1.8, 2.4, 4.2
Cluster hydraulic	Vicinity of boreholes	Hydraulic conductivity Storativity	1.1, 1.2, 1.3, 1.8, 2.4,
Cluster tracer	Vicinity of boreholes	Effective porosity Dispersivity Hydraulic conductivity	1.1, 1.2, 1.3, 1.12, 2.4 1.1, 1.2, 1.3 1.1, 1.2, 1.3, 1.8, 2.4
Chamber	Vicinity of chamber	Hydraulic conductivity Storativity	1.1, 1.2, 1.3, 1.8 2.4, 4.2

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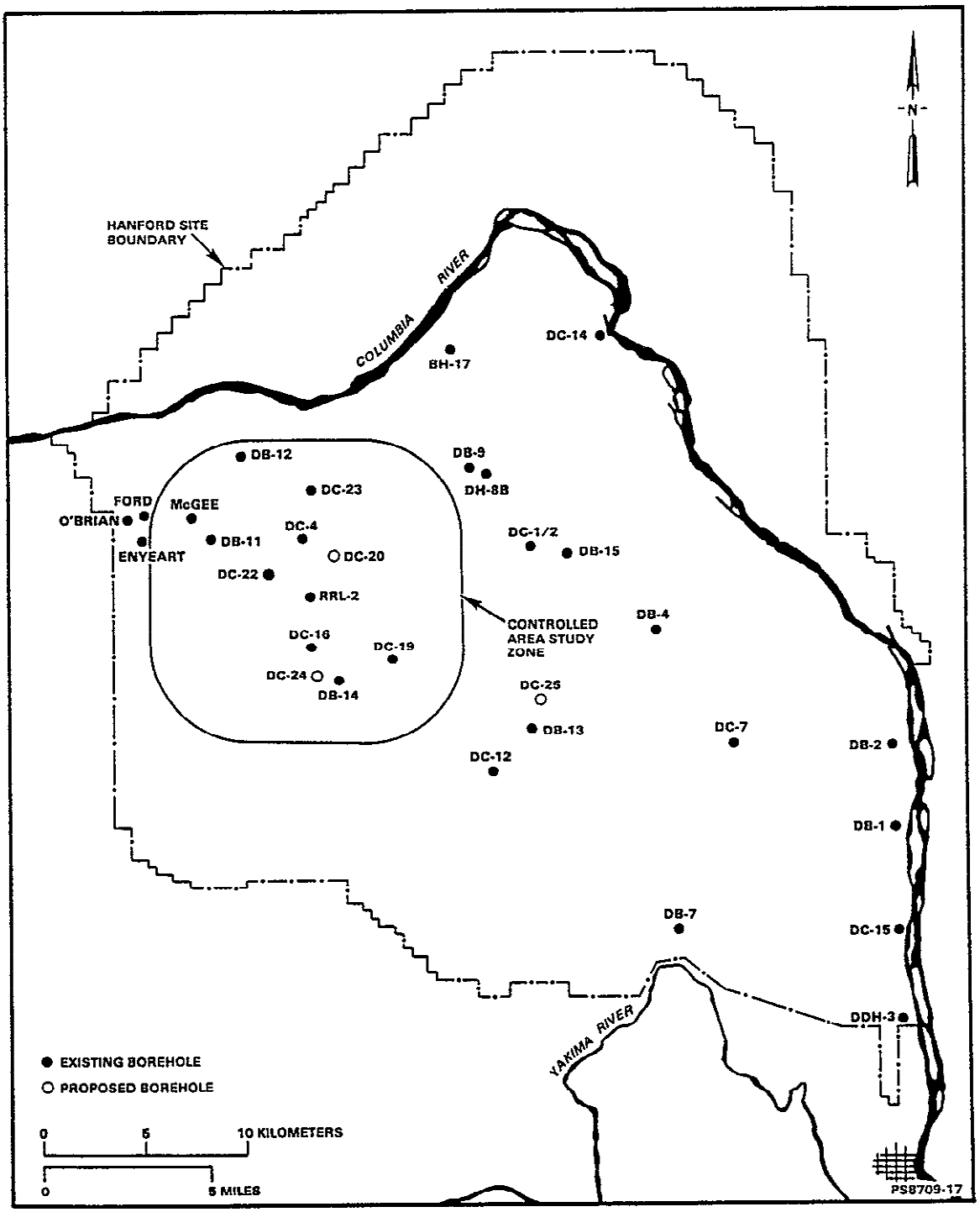

Figure 8.3.1.3-23. Monitoring locations on the Hanford Site.

the determination of boundary conditions within the controlled area study zone as well as obtaining hydraulic characterization throughout the controlled area study zone.

In the pre-exploratory shaft timeframe at least two large-scale hydraulic stress tests will be conducted. At the RRL-2B site, these tests will be conducted within the Rocky Coulee and Birkett flow tops. Additional large-scale hydraulic stress tests will be conducted within the Cohassett flow top and (or) the Cohassett flow internal vesicular zone, should the single-well tests in those horizons indicate that their transmissivities are high enough to successfully conduct a large-scale stress test.

The objectives of the large-scale hydraulic stress tests conducted during the pre-exploratory shaft program are discussed in Section 8.3.1.3.4.2.2 and include the following:

- Collect data on geohydrologic conditions of horizons adjacent to the Exploratory Shaft Facility that may change because of construction and operation of the Exploratory Shaft Facility.
- Evaluate the existence of pervasive features within the Cohassett flow and adjacent flows that would allow cross-formational hydraulic communication.
- Evaluate the pre-exploratory shaft hydrologic conditions to determine the effect of the Exploratory Shaft Facility on post-exploratory shaft geohydrologic tests.
- Collect data on geohydrologic conditions that will affect the design of the Exploratory Shaft Facility or the repository.

In the post-exploratory shaft timeframe 16 additional large-scale hydraulic stress tests will be conducted at different locations within the controlled area study zone. Eight of these tests will be conducted at a horizon located within the Wanapum Basalt and eight within a horizon located within the Grande Ronde Basalt. Multiple-well tests will also be conducted at the six dual-site borehole locations (SC-2, SC-3, SC-4, SC-5, SC-6, and SC-8). (These are discussed under Section 8.3.1.3.4.2.2, Post-exploratory shaft testing activities, and the location of these sites is illustrated in Fig. 8.3.1.3-19.)

The data generated from large-scale hydraulic stress tests will be analyzed using analytical solutions, when possible. When the inherent assumptions of the analytical approaches cannot be satisfied, numerical techniques will be utilized. These techniques can incorporate complex boundary conditions, heterogeneity, anisotropy, complex stratigraphy, and three-dimensional flow.

Test duration is on the order of several tens of days. Preliminary pumping center locations for large-scale hydraulic stress tests are provided in Figure 8.3.1.3-24. Details on expected test results, acceptance criteria,

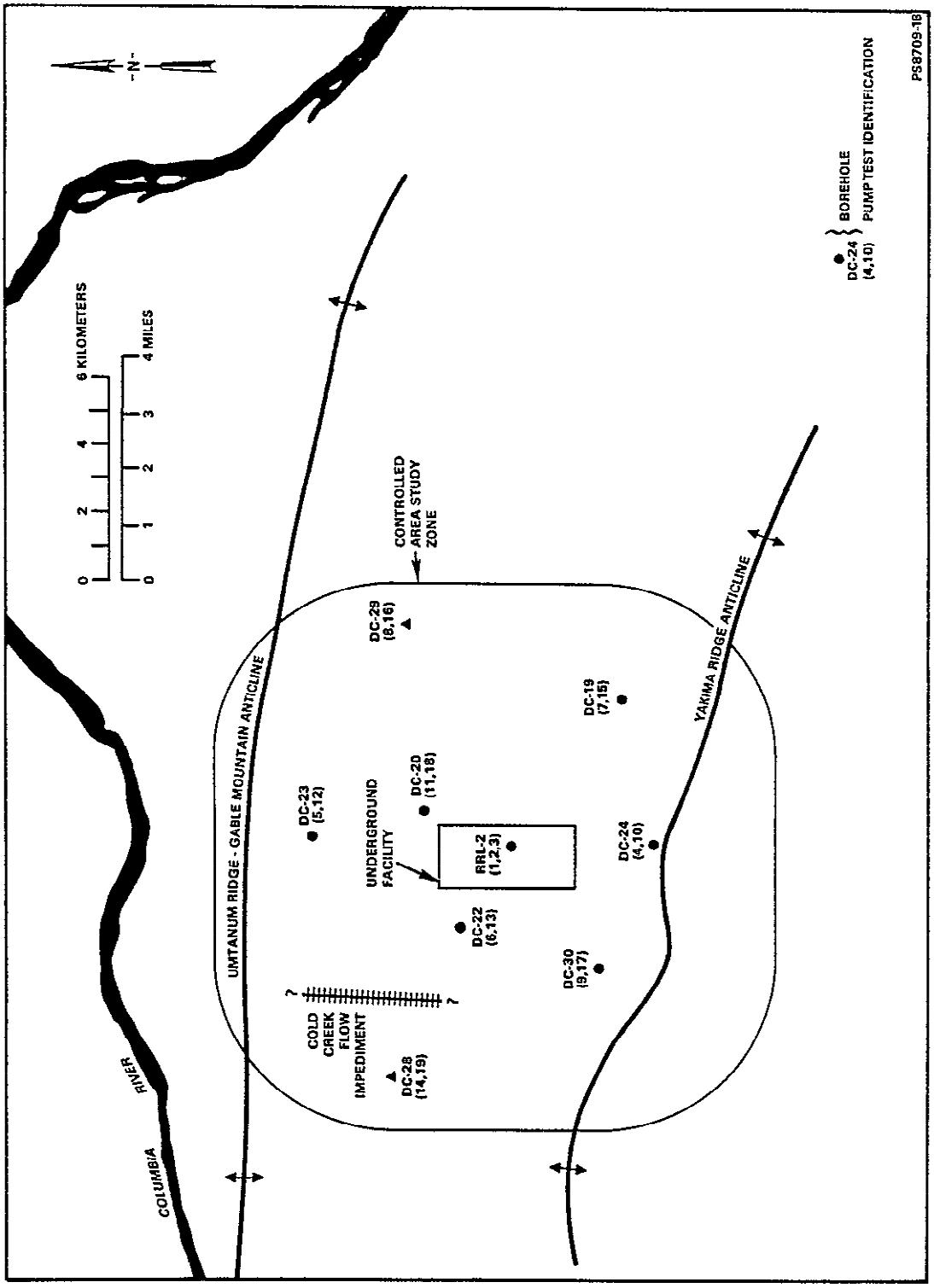

Figure 8.3.1.3-24. Proposed locations of large-scale hydraulic pump tests.

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and data analysis are found in the site groundwater study. Equipment selection, test design, and test procedures are found in the test plans (Stone et al., 1985).

Small-scale hydraulic stress tests. These multiple-well tests are constant head or constant discharge rate or injection tests used to estimate hydraulic parameters of flow tops at scales of tens to hundreds of meters. Test duration is in the order of days. Preliminary pumping center locations for small-scale hydraulic stress tests are provided in Figure 8.3.1.3-25. Hydraulic parameters provided by these tests are transmissivity and storativity. The tests will also provide an indication of hydraulic boundaries or cross-cutting features present within the area of influence of the test.

Tracer tests. Tracer tests are performed (1) as adjuncts to large-scale hydraulic stress tests using the large-scale hydraulic stress pumping well as the sink and nearby piezometer(s) as tracer injection points (source) and (2) from specially designed dedicated borehole pairs where radial convergent and (or) recirculating techniques may be used. Preliminary tracer test locations are provided in Figure 8.3.1.3.3-26. Tracer test duration ranges from a few days to several months. The tracer tests produce data that are used to estimate effective thickness, effective porosity, average flow velocity, and longitudinal dispersivity of flow tops based on the movement of a conservative (nonreactive) tracer from a point of injection to a point of withdrawal. Tracer testing is planned as an adjunct part of large-scale hydraulic stress testing with tracers released from monitoring wells in the vicinity of the pumping well. Techniques for introducing tracers include either (1) introduction of tracer into monitoring wells prior to initiation of pumping or (2) introduction of tracer during pumping. The first technique would not cause a hydraulic perturbation to the drawdown field during the large-scale hydraulic stress test but would result in a more dispersed breakthrough curve. If the second technique is used, it would be conducted after sufficient data have been collected to meet the objectives of the large-scale hydraulic stress test and would result in a more clearly defined breakthrough curve. In addition, the use of nonconservative tracers in association with conservative tracers will yield information on chemical processes that promote the removal of mass from the liquid to the solid materials. Numerous tracers are available for use in these tests. Several being considered include ammonium, thiocyanate, lithium bromide, metatrifluoromethylberyonate, pentafluorobenzonate, and deuterium. The analysis of data from tracer testing will include both numerical and analytical methods. Analytical curve matching methods and numerical methods will be used to estimate values for the previously mentioned parameters. Testing applications and theory are contained in Gelhar (1982), Bakr et al. (1980), and Leonhart et al. (1985).

Single-well hydraulic stress tests. Single-well hydraulic stress tests refer to hydraulic tests that will be performed within a single borehole in both the pre- and post-exploratory shaft hydrology programs. The pre-exploratory shaft program will involve two single-well tests within the

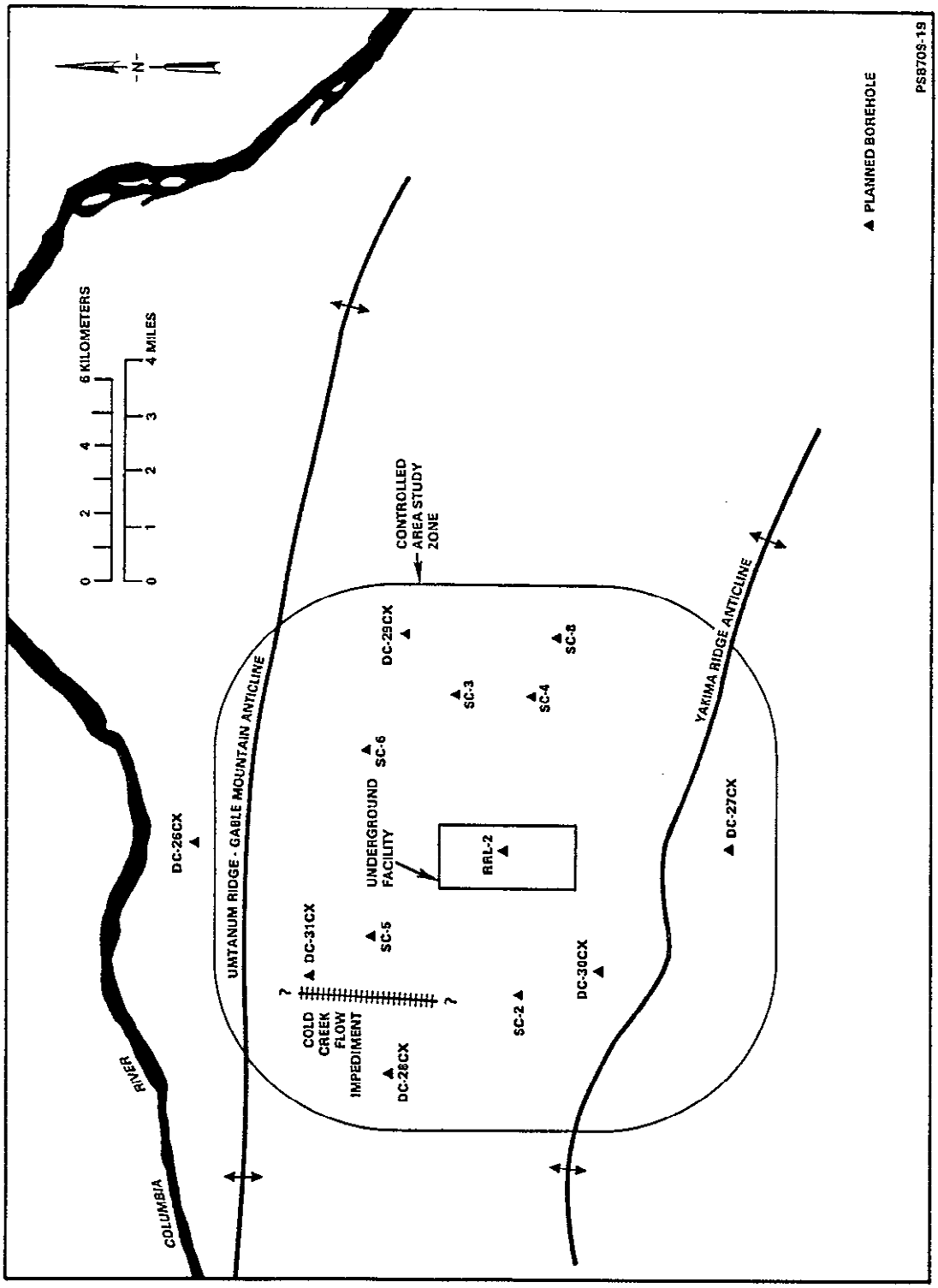

Figure 8.3.1.3-25. Proposed small-scale hydraulic stress test locations.

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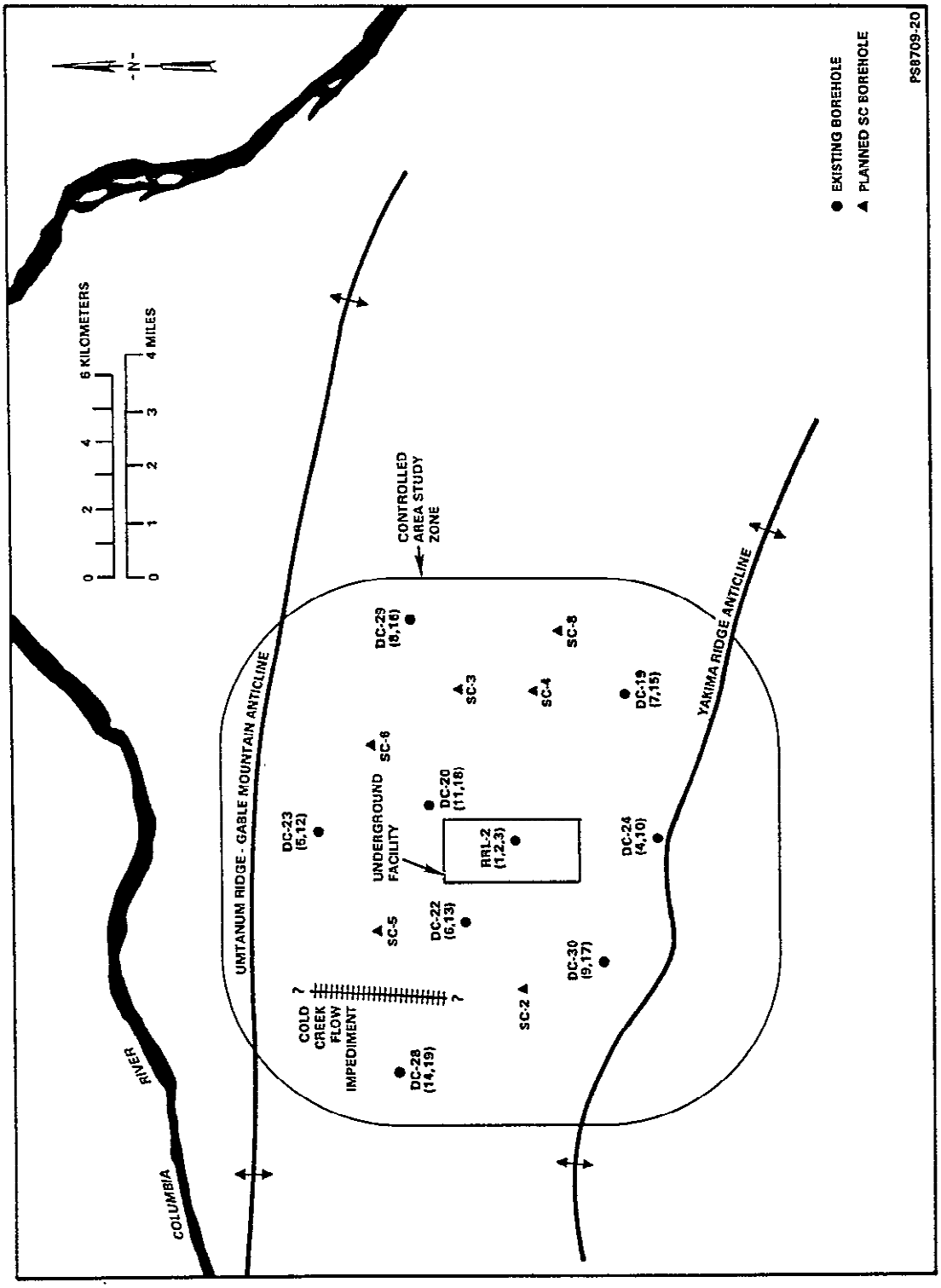

Figure 8.3.1.3-26. Proposed tracer test locations.

Cohassett flow top and internal vesicular zone at the RRL-2B site. Post-exploratory shaft testing involves single-borehole tests in boreholes DC-26 through 31 and SC-1, 7, 9, 10, and 11. The purpose of the single-well hydraulic stress tests are to obtain information on local scale (from a few meters to a few hundred meters) hydraulic conductivity of each tested horizon. Post-exploratory shaft test horizons and specific test methods will be based on pretest analysis conducted before testing is initiated. Pressure-pulse tests and multiple-constant pressure-head injection tests will be performed during the pre-exploratory shaft program. The methods used for pressure-pulse and constant-pressure head tests have been described in Spane and Thorne (1985). The technique involves a rapid pressurization of the test horizon using a pressure-regulated argon cylinder and monitoring recovery for the pressure-pulse test. The constant head injection test will be designed so that a selected pressure will be maintained on the fluid in the boreholes. Numerical and analytical techniques will be used in the analyses. Numerical modeling will be used to simulate ranges and possible distribution of pressure responses. Analytical techniques will be used to estimate formation responses and involve curve-matching techniques. These techniques are described by Spane and Thorne (1985). The type curves to be used have been developed by Cooper et al. (1967) and Papadopulos et al. (1973).

Drilling fluid invasion tests. Drilling fluid invasion tests will be performed to examine the effects of drilling fluid invasion into the tested formation on the estimates of hydraulic properties of those formations. Details of the test are still under development. Conceptually, the test will compare calculated hydraulic properties from a borehole drilled without drilling fluid to those properties from the same borehole after the introduction of a drilling fluid (under simulated drilling conditions). Laboratory testing of geologic cores may be used to corroborate field testing.

Borehole geophysical logging. The borehole geophysical logging that will be conducted in new boreholes as part of the hydrology investigative program is limited to downhole continuous flow meter, downhole fluid temperature, and borehole tracer movement logging. A more complete suite of geophysical logging that will be conducted is described in Section 8.3.1.2.

These geophysical logging techniques will be conducted only in the boreholes that are drilled in the post-exploratory shaft timeframe.

Subsurface-based tests

All subsurface-based tests will be performed within the shafts and underground facilities of the Exploratory Shaft Facility. Test locations, except for exploratory boreholes, are shown in Figure 8.3.1.3-27. The locations of exploratory boreholes will be chosen based upon final design criteria to ensure that their locations are compatible with other facilities in the Exploratory Shaft Facility.

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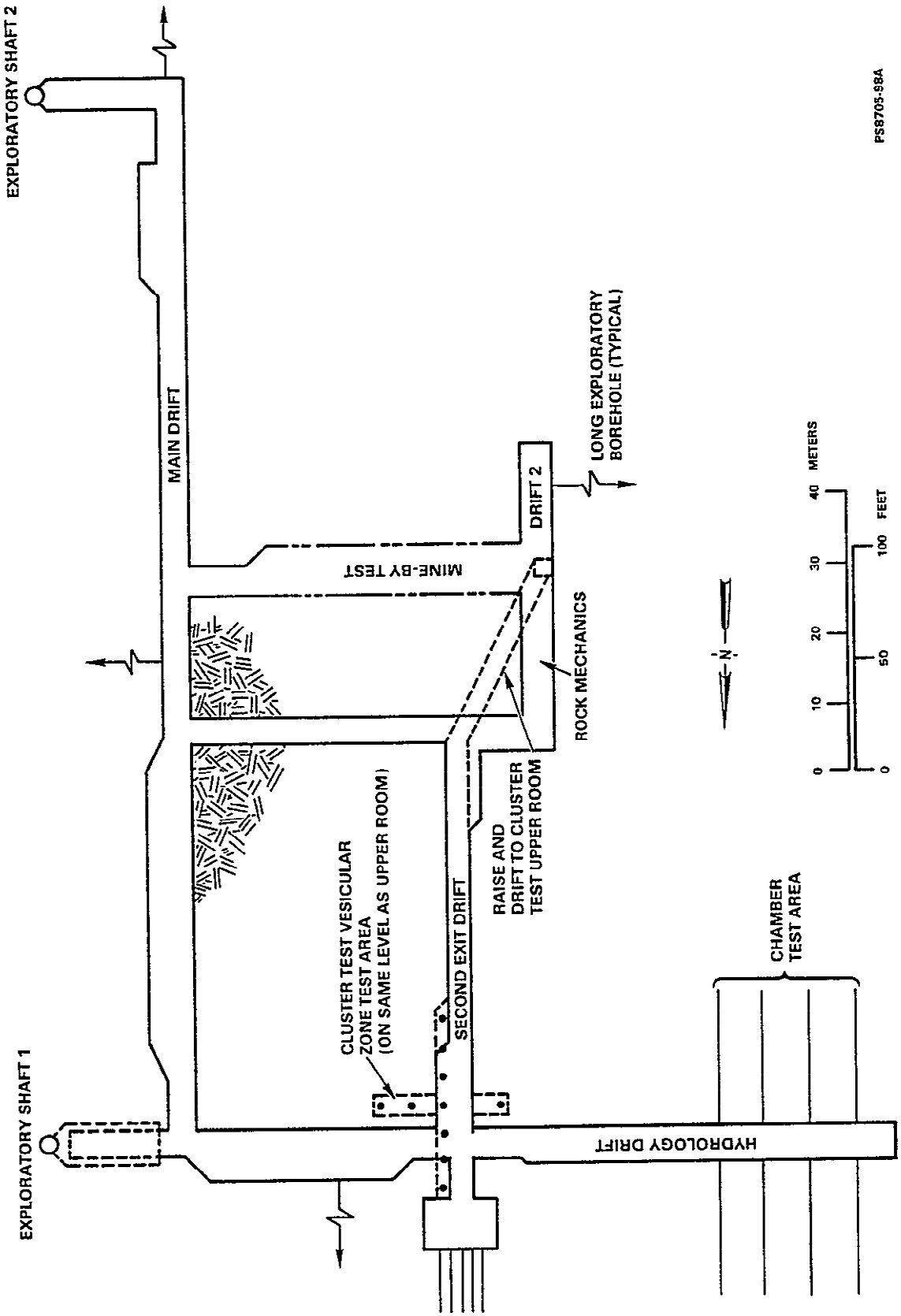

Figure 8.3.1.3-27. View of subsurface-test facilities plan.

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Single-borehole tests. Single-borehole tests are performed in the shaft portholes, cluster boreholes, long exploratory boreholes, chamber room boreholes, and single-rock mechanics boreholes. There are three major purposes for conducting single borehole testing:

1. To locate potentially hazardous hydrologic conditions before construction.

2. To provide specific hydrologic property values in the Cohassett flow and other key stratigraphic units.

3. To provide hydrologic information to aid in the design of other subsurface-based tests.

Testing procedures include constant head injection, pressure pulse, constant-rate injection, discharge, and constant drawdown. Straddle packers or a single-packer method may be used. Qualitative information will be obtained concerning the relationship of hydrologic properties to specific geologic features. Special techniques such as borehole orientation will increase the likelihood of intersecting specific geologic features such as a vertical fracture for testing. Testing of single boreholes will be conducted as follows:

- Test over entire length of the borehole.
- Test discrete sections of the borehole using packers.
- Test multiple zones of the borehole using packers.

Test duration will range from hours to several days. Analysis of test data will support water-inflow estimates and estimates of the hydraulic conductivity of the disturbed rock zone and the Cohassett dense interior. Constant head-injection tests and withdrawal tests will be analyzed using the transient-flow methods as defined by Jacob and Lohman (1952) and Ehlig-Economides (1979). Steady flow analysis (Ziegler, 1976) will be used as necessary. Nonlinear and deformation effects will be assessed using techniques described by Elsworth and Doe (1986) and Noorishad and Doe (1982). Pulse-test analysis will use methods described by Bredehoeft and Papadopulos (1980) and Neuzil (1982). Wang et al. (1977) and Barker and Black (1983) describe techniques for analysis of fracture effects. Thermal- and well-pressure effects will be dealt with using numerical analysis methods (Grisak et al., 1985).

Single-borehole testing is usually conducted in formations having relatively low hydraulic conductivities. Consequently, they only yield hydraulic properties representative of a very limited radial distance from the well. This scale is expected to range from 1 to 100 m (3.3 to 328 ft), depending on the hydraulic conditions encountered. Testing of the Cohassett flow top, vesicular zone, and the other flow tops will be performed. Water samples will be taken if sufficient water can be obtained.

Cluster hydraulic tests. The cluster hydraulic test will be performed in facilities located in the lower dense zone, vesicular zone, and upper dense zone of the Cohassett flow interior. The objectives of the cluster hydraulic test include assessing the hydraulic properties of the Cohassett flow interior and vesicular zone, determining scale effects, interpreting other tests, validating numerical models, refining of test methods, and evaluating the disturbed rock zone. The test will provide cluster-scale estimates (approximately 1 to 10 m (3.3 to 32.8 ft) of vertical and horizontal hydraulic conductivity and specific storage. The test will also examine hydraulic boundaries. Constant head-injection procedures will be used during this cross-hole testing. Packers will be used to isolate individual sections of observation boreholes surrounding the injection borehole. One test will be performed at each testing facility (three total). Each test is expected to last approximately 12 mo, including setup, and two tests will be run simultaneously.

Data analysis will employ well-established techniques, although more complex numerical models will be employed to refine the analyses and reduce parameter uncertainty. Possible analytical methods range from an equivalent porous-media approach to discrete fracture-flow approach. Methods being considered include an equivalent porous-media analysis considering radial flow to a well with constant head-injection/drawdown (Reed, 1980) and transient flow methods (Jacob and Lohman, 1952; Hantush, 1964). Various numerical models may also be used to evaluate nonideal aquifer conditions. Numerical codes that appear capable of modeling the cluster test are the MODFLOW code (McDonald and Harbaugh, 1984) and the FPM code (Golder, 1983). These codes are capable of incorporating anisotropy, heterogeneity, and complex boundary conditions.

Fracture-flow methods using an analytical approach are available (Ziegler, 1976). Also, stochastic fracture-flow numerical codes are available, but the level of development and documentation is inadequate at this time to determine their possible use with the cluster hydraulic test.

Cluster tracer tests. The cluster tracer test will be performed in the same facilities in the Cohassett flow upper and lower dense zones and vesicular zones that are used to perform the cluster hydraulic test. Objectives of the cluster tracer test include estimating the hydraulic and transport parameters of the Cohassett interior and vesicular zone, determining scale effects, zone characteristics, validating numerical models, refining test methods, and evaluating the disturbed rock zone. The test will provide estimates of effective porosity and retardation factors in the vicinity of the boreholes. Information acquired on transport mechanisms in the Cohassett flow upper and lower dense zones will have transfer value to other flow interiors of the Grande Ronde and Wanapum Basalts.

The test method will be a two-well, injection-withdrawal test. The tracer will be injected over the entire open interval of the injection hole. The withdrawal hole will be subdivided into up to five separate sampling intervals isolated by packers. One test will be performed at each testing location (three total). Each test is expected to last approximately

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nine months, including setup. Two tests (upper and lower dense zones) will be run simultaneously. Analytical techniques available for the cluster tracer test are based on either equivalent porous-media or fracture dominated flow assumptions. The porous-media approach uses a mathematical solution to estimate longitudinal dispersivity and effective porosity from measured breakthrough curve data. This technique has been described by Gelhar and Collins (1971) and adapted for a two-well tracer test with a solute pulse input by Gelhar (1982). Stochastic fracture-flow and solute transport numerical codes are not at an adequate level of development and documentation to use at this time, but may be available in the future.

Chamber test. The chamber (ventilation) test will be performed in a sealed room at the end of the hydrology drift in the Exploratory Shaft Facility. The chamber test will provide room-scale estimates of vertical and horizontal hydraulic conductivity and specific storage (if conditions permit) within the lower dense zone of the Cohassett flow. Estimates within the vesicular zone and upper dense zone may be possible if the interference effects from Exploratory Shaft Facility openings are minimal. The test will help to evaluate the hydraulic properties of the disturbed rock zone and the groundwater inflow rates to a drift. The test will also provide information for evaluating the importance of size effects in the basalt-interior hydrologic tests by comparing data from the single- and multiple-borehole tests.

The test method will be a ventilation test (constant head withdrawal test) in which the water inflow into the sealed interval is monitored at the same time that pressure measurements are made in piezometers arranged radially around the sealed interval. Packers will be used to isolate individual sections of the piezometers. A second design option would require a pressure chamber filled with water. These tests could be the constant pressure or constant rate type. They could be run as injection or withdrawal tests by controlling the fluid pressure. A number of advantages favor the ventilation test over the pressure chamber test. The chamber test is expected to last approximately 21 mo.

Test analysis will be equivalent to a constant drawdown borehole test but on a larger scale. The analyses will use radial flow solutions assuming porous-media behavior similar to that presented by Ehlig-Economides (1979) and Earlougher (1977). Numerical modeling will be used to analyze the more complex issues such as anisotropic flow, complex boundary conditions, and hetergeneous properties. Fracture-flow conditions that appear most useful have been described by Wilson et al. (1983), Long et al. (1982), and Dershowitz (1985). Long and Dershowitz use computer generation of fracture networks based on the statistics of fracture density, area, and transmissivity.

Data that will form the basis for this modeling approach will be collected in the cooling joint and structural geology studies, Sections 8.3.1.2.3.3.3 and 8.3.1.2.3.3.4, respectively.

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8.3.1.3.4.4 Application of results

The results of the groundwater investigation will support the performance assessment, repository design functions, and other planning activities of the BWIP.

Support of other investigations

The regional groundwater study will provide the description of the boundary conditions required for the development of the groundwater flow model of the controlled area study zone. This description comes from developing conceptual and numerical models of the regional flow system. The conceptual model is primarily intended for integrating and interpreting existing geohydrologic data. The analysis goals are to establish the following:

- Geologic framework for Pasco Basin and Cold Creek syncline.
- Hydraulic characteristics of hydrostratigraphic units and structure features.
- Groundwater potentiometric surface maps for current and predevelopment conditions.
- Groundwater recharge and discharge rates.
- Hydrochemical delineation of groundwater systems.

Numerical models are used to develop and enhance conceptual models of the Pasco Basin and Cold Creek syncline and to evaluate the effects of flow system stresses on the regional groundwater flow system. The analysis goals are as follows:

- Assist in the definition, testing, and refinement of alternative conceptual models.
- Provide supplemental and corroborative information for determining the possible range of pre-waste-emplacement groundwater boundary conditions to the controlled area study zone.
- Determine the sensitivity and effects of future changes to the groundwater flow system due to climatic, tectonic, and man-induced factors.

Performance assessment uses

Performance assessment is defined in Section 8.3.5, as those analyses conducted to assess the suitability of a site for disposing high-level nuclear wastes. This task generally encompasses quantitative evaluations that are required in the issue resolution and licensing strategies; i.e., those evaluations that require a model result. One of the tasks of performance assessment is to identify, for each performance issue, the barriers that can

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contribute to closing that issue. In broad terms, four barriers may be identified: (1) the waste package; (2) the engineered barriers system (which includes the waste package); (3) the repository seals; and (4) the site. The task of the hydrology testing program is to provide the conceptual model framework on which the numerical models of performance assessment will be based, boundary conditions affecting the flow or transport field, and values for the physical parameters required in the model format.

The site groundwater study will provide data for the performance assessment studies and the repository design effort. The primary types of data provided will include the following:

- Hydraulic properties.
  - Basalt flow tops (transmissivity, specific storage, dispersivity, effective porosity).
  - Basalt flow interiors (horizontal and vertical hydraulic conductivity, specific storage, dispersivity, effective porosity).
  - Structural features (horizontal and vertical hydraulic conductivity).
- Hydraulic heads.
  - Three-dimensional head distributions.
  - Baseline establishment (temporal, natural, or man-induced changes that may be cyclic or represent trends).
- Hydraulic boundaries.
  - Locations and extent (vertical and horizontal).
  - Type and overall hydraulic influence.
  - Changes due to natural and man-induced stresses.

<u>Design uses</u>

Information acquired by the site groundwater study will be used in the design of the Exploratory Shaft Facility and the repository. Specific examples of these uses include the following:

- Shaft and drift excavation.
- Underground service and utility systems.
- Underground facility dewatering and ventilation systems.
- Seals and engineered barriers.

Planning other activities

As groundwater studies reveal the significance of various features and parameters to the resolution of regulatory issues, other investigations can redirect or reprioritize their studies to collect the pertinent data, refrain from collecting extraneous data, and hence, optimize the characterization process. Examples of these interactions might include the following:

- The range of suspected boundary conditions created by geologic structures and the influences these conditions may have on repository performance will direct future geologic mapping, hydrochemical sampling, hydraulic testing and (or) hydraulic head definition in and around these structures.

- The discovery of fractures or fracture sets that could significantly influence groundwater flow near the proposed repository will direct future borehole drilling and testing needs. Discovery of such fractures within the underground facility of the exploratory shaft could impact hydraulic test designs, underground drilling, and facility construction.

- The similarity or dissimilarity of Cohassett flow interior hydraulic properties to other basalt flows will influence the extent to which direct flow comparisons can be made. The greater the diversity of basalt flow to flow composition, the more hydraulic testing will be required.

- The sensitivity of the regional groundwater model to changes in recharge will control the amount and type of water-budget-related information collected under the surface water systems study.

The regional groundwater study will provide data to the site groundwater and other studies via computational briefs, certified data transmittal packages, and formal reports. The primary types of information will include the following:

- Integration of data provides a data base for use by subsequent analyses within the regional groundwater study and by the site groundwater, water resource potential, surface water system, and performance assessment studies.

- Conceptual model development forms the basis for the development of conceptual and numerical models of the Pasco Basin and the Cold Creek syncline and will influence the development of the model for the controlled area study zone.

- Groundwater use survey provides water use and water rights data for use within the regional groundwater study and by the water resource potential and surface water system studies.

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- Data synthesis provides information to enhance and corroborate conceptual models, provides a range in controlled area study zone boundary conditions for performance assessment modeling of the controlled area study zone, and provides a measure of the sensitivity of the groundwater flow system to changes in system stresses.

- Numerical simulation of system stresses determines the effects of natural and man-induced stresses on the groundwater flow system in and around the controlled area study zone. This provides the range of conditions impacting the groundwater flow model of the controlled area study zone used by performance assessment.

8.3.1.3.4.5 Schedule and milestones

The schedule for the groundwater investigation is summarized in Figure 8.3.1.3-28.

The completion of the investigation will result in the following:

- Regional groundwater study milestones.

  - Preliminary regional groundwater data base completed.
  - Preliminary conceptual model completed.
  - Preliminary Pasco Basin calibrated model.
  - Sensitivity of groundwater system-to-system stresses assessed.
  - Regional groundwater data base updated.
  - Conceptual models defined.
  - Regional models calibrated.
  - Range in controlled area study zone boundary conditions.
  - Complete regional groundwater study.

- Site groundwater study milestones.

  - Pre-exploratory shaft testing program.

    - Large-scale hydraulic stress test plan at DOE Headquarters for approval.

    - Hydraulic head baseline established.

    - Data on perishable hydrologic conditions collected.

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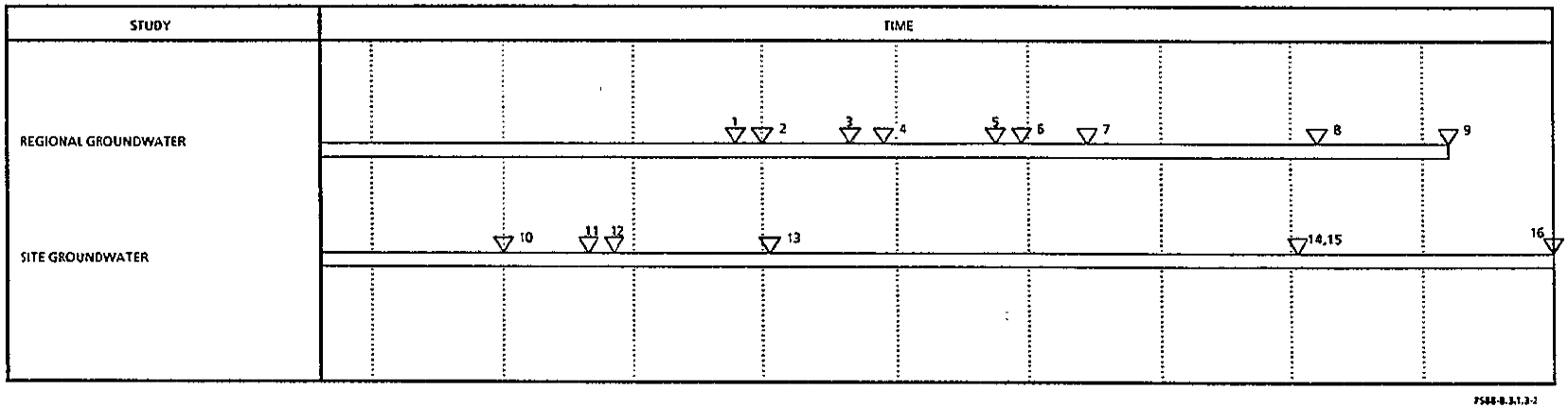

1 PRELIMINARY REGIONAL GROUNDWATER DATA BASE COMPLETED.

2 PRELIMINARY CONCEPTUAL MODELS DEFINED

3 PRELIMINARY PASCO BASIN MODEL CALIBRATED.

4 SENSITIVITY STUDIES COMPLETED USE TO SCOPE CLIMATE, TECTONICS, AND WATER RESOURCE POTENTIAL STUDIES.

5 UPDATED DATA BASE COMPLETED.

6 COMPLETED MODEL FINALIZED.

7 FINAL CALIBRATION OF REGIONAL MODELS COMPLETED (BOTH PASCO BASIN AND COLD CREEK SYNCLINE).

8 RANGE OF CONTROLLED AREA STUDY ZONE BOUNDARY CONDITIONS DETERMINED FOR CLIMATE, TECTONICS, AND WATER RESOURCE POTENTIAL STUDIES.

9 REGIONAL GROUNDWATER STUDY COMPLETED.

10 ISSUE SITE GROUNDWATER STUDY PLAN.

11 ESTABLISH HYDRAULIC HEAD BASELINE.

12 CONDUCT ROCKY COULEE LARGE-SCALE HYDRAULIC STRESS TEST.

13 DATA ON PERISHABLE HYDROGEOLOGIC CONDITIONS COLLECTED.

14 CHAMBER TESTS COMPLETED.

15 SURFACE-BASED TESTING COMPLETED.

16 CHARACTERIZATION OF GROUNDWATER FLOW SYSTEM COMPLETE.

Figure 8.3.1.3-28. Groundwater investigation schedule.

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- Post-exploratory shaft testing program.
    - Collection of hydrologic data from controlled area study zone completed.
    - Hydrologic characterization of repository horizon complete.
    - Characterization of controlled area study zone groundwater flow system complete.
    - Complete site groundwater study.

As noted under Section 8.3.1.3.4.2, rationale, the schedule for the site groundwater study incorporates consideration of the impacts of the construction of the exploratory shaft on the groundwater baseline conditions.

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8.3.1.3.5 References

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SITE CHARACTERIZATION PLAN

Chapter 8 - SITE CHARACTERIZATION PROGRAM

Section 8.3.1.4

Specific Program for Geochemical Characterization

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8.3.1.4 Specific program for geochemical characterization

Geochemistry plays a central role in demonstrating compliance with regulatory criteria for postclosure radionuclide containment. Additionally, geochemical information is required for design issues involving rock and mineral stability, corrosion, and mine safety as it relates to flammable and toxic gases.

Geochemical processes or interactions of primary concern for radionuclide containment at the Hanford Site include the following:

- Hydrochemical and thermal interactions among the groundwater, the waste package, and the engineered barrier system that will affect containment within the waste package.
- Hydrochemical and thermal interactions between the groundwater and the engineered barrier system that will control the rate of release from the engineered system to the controlled area natural system.
- Groundwater flow path, hydrochemical, and host rock/porous media/secondary mineral interactions within the controlled area natural system that will determine radionuclide sorption and desorption and, therefore, the ability of the natural system to retard and contain radionuclides.

Section 8.3.1.4 describes (1) the role of the geochemistry program in evaluating the above processes, and (2) plans for future geochemical investigations and studies designed to provide the geochemical parameters identified from the performance allocation process (see Section 8.2).

Background

Geochemical studies of the hydrogeologic environment at the Hanford Site have been conducted in the past (since 1960) in association with defense waste management programs as well as more recently (since 1977) for the Basalt Waste Isolation Project (BWIP). The defense waste studies concentrated on radioactive waste behavior in the unsaturated zone and the unconfined and uppermost confined aquifers. The relationship of the Hanford Site stratigraphy to zones of interest for defense and commercial waste programs is illustrated in Figure 8.3.1.4-1. The BWIP-related work concentrated on site geochemical conditions, including isotopic and solute distribution and general chemical characteristics of surface waters, springs, and unconfined and confined aquifers on and contiguous with the Hanford Site.

Interpretations of existing data provide our current understanding of the groundwater flow regime and general geochemical conditions in the vicinity of the proposed repository location. Existing data and their interpretations are summarized in the hydrology chapter (Chapter 3, Sections 3.4, 3.7, and 3.9) and geochemistry chapter (Chapter 4) of the Site Characterization Plan (SCP).

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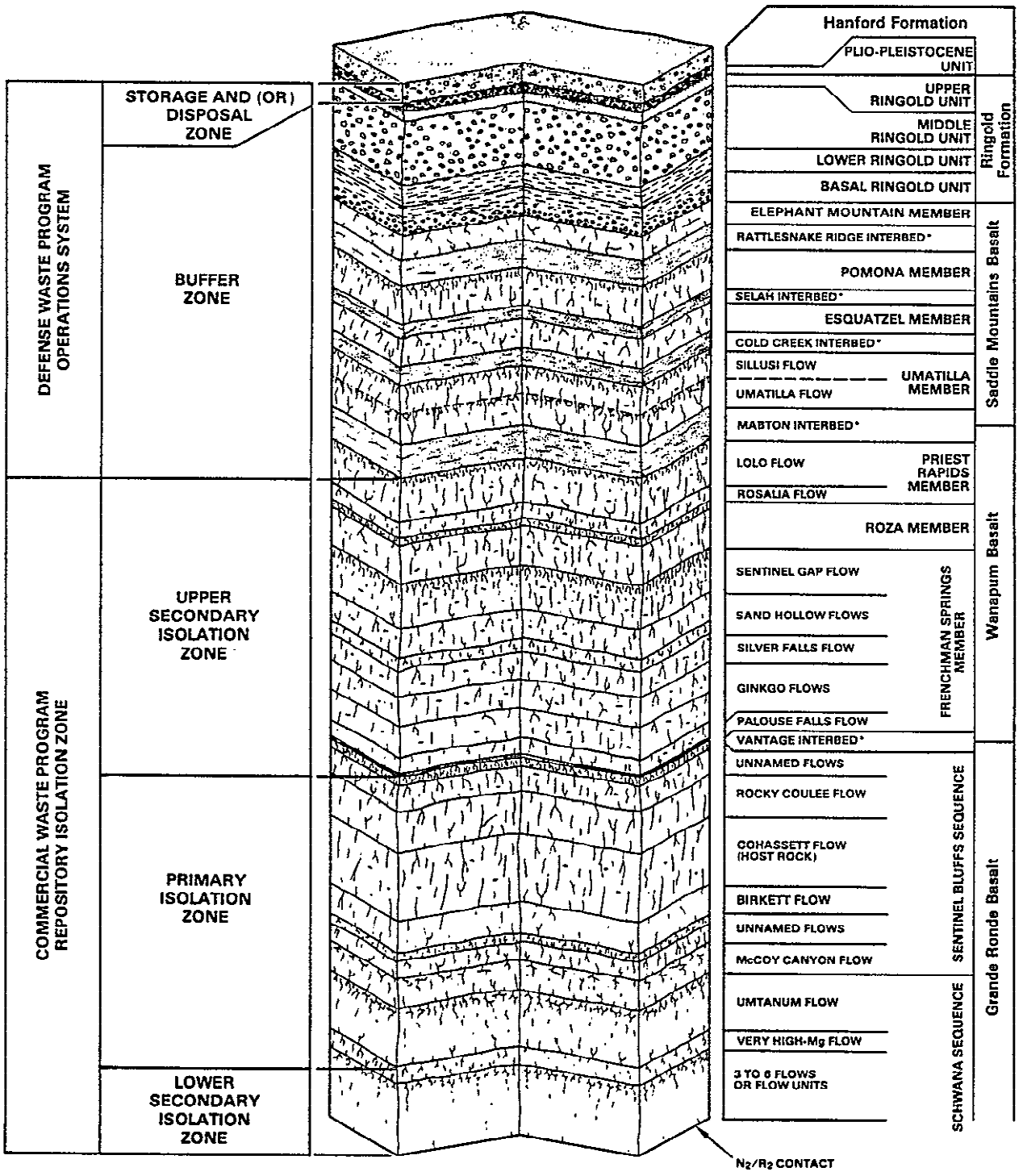

Figure 8.3.1.4-1. Hanford Site stratigraphy in relation to zones of interest for defense and commercial waste programs.

Waste package and engineered barriers geochemical studies (see Chapter 7) have been conducted primarily in the BWIP and other Hanford Site laboratories since 1978. Information from these studies form the basis of our current knowledge about hydrothermal and radiation effects, corrosion, sorption, and radionuclide solubility under disturbed or postemplacement conditions.

Summary of program

Chapter 8 of this SCP separates discussions of geochemical investigations according to whether the investigations apply to natural, undisturbed site conditions or to postemplacement, disturbed conditions. Postemplacement, disturbed conditions involve the following:

- Hydrothermal effects within the waste package.
- Hydrothermal effects of waste emplacement on the engineered system and disturbed rock zone.
- Radiation effects and geochemical interactions within the engineered barrier system.

This section discusses the portion of the BWIP geochemistry program pertaining to natural, undisturbed conditions, hereafter referred to as the site geochemistry program. Section 8.3.4.2 discusses the portion of the BWIP geochemistry program pertaining to postemplacement, disturbed conditions.

As Table 8.3.1.4-1 and Section 8.2 show, the issues resolution process has generated several geochemistry information needs. This section of the SCP describes the studies designed to satisfy the first three information needs from Table 8.3.1.4-1. The program to address these information needs is divided into three studies (one for each information need) clustered under two investigations:

- Hydrochemical characterization investigation (8.3.1.4.3).
  - Groundwater flow system hydrochemistry study (8.3.1.4.3.3.1).
  - Groundwater redox characteristics study (8.3.1.4.3.3.2).
- Radionuclide retardation behavior investigation (8.3.1.4.4).
  - Radionuclide reactivity study (8.3.1.4.4.3).

The BWIP investigators will use information from the hydrochemical characterization investigation to help define groundwater flow paths in the confined basalt aquifers, estimate groundwater travel times in the confined aquifers, and evaluate the groundwater redox environment. The hydrochemical characterization investigation will also produce information on in situ organic constituents and natural particulate matter in groundwater, both of which influence radionuclide reactivity.

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Table 8.3.1.4-1. Correspondence of geochemistry information needs to planned site characterization investigations

Information need	Relevant data chapter sections	Investigation where addressed	Section number of corresponding study
Natural or undisturbed site conditions			
Groundwater flow system hydrochemistry	3.4.1, 3.7.3, 3.9.3, 3.9.5, 4.1.2, 4.5.3.2	Hydrochemical characterization	8.3.1.4.3.3.1
Groundwater redox characteristics	4.1.3.4.1, 4.5.3.2	Hydrochemical characterization	8.3.1.4.3.3.2
Radionuclide reactivity	4.1.3, 4.5.3.3	Radionuclide retardation behavior	8.3.1.4.4.3
Mineralogic and petrologic characteristics	1.2.1.2.4, 1.7, 4.1	Mineralogic and petrologic characteristics	8.3.1.2.5.3
Postemplacement/disturbed conditions			
Basalt/groundwater interactions	7.4.1.1	Postemplacement waste package environment	8.3.4.2.3.3.1
Geochemical environment	4.5.1.2, 4.5.1.3, 4.5.1.4, 4.5.1.6	Postemplacement waste package environment	8.3.4.2.3.3.2
Radionuclide solubility/ sorption and speciation behavior	7.4.5.2, 7.4.5.4.1.7, 7.4.5.4.2.7	Waste package radionuclide behavior	8.3.4.3.6.3.1
Waste/barrier/rock interactions: spent fuel release	7.4.5.4.1	Waste package radionuclide behavior	8.3.4.3.6.3.2
Waste/barrier/rock interactions: borosilicate glass release	7.4.5.4.2	Waste package radionuclide behavior	8.3.4.3.6.3.3
Waste/barrier/rock interactions: other waste forms	7.4.2.2	Waste package radionuclide behavior	8.3.4.3.6.3.4

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Finally, the hydrochemical characterization investigation will provide data on rock and groundwater composition for the radionuclide retardation behavior investigation.

The groundwater flow system hydrochemistry study (part of the hydrochemical investigation) will provide data by which BWIP investigators can estimate paleo groundwater flow paths and travel times. This study involves characterization of groundwater samples, secondary mineral phases, bulk rock, mesostasis, and geochemical modeling. The characterization data will allow BWIP investigators to design appropriate laboratory tests of basalt/ground-water interactions. The results of the characterization and interaction tests will then be used in geochemical models to predict flow paths and travel times in the natural system. Characterization information on colloids and organic components will also help evaluate transport mechanisms and rates.

The groundwater redox characteristics study (also part of the hydrochemical characterization investigation) will provide data from which BWIP investigators can assess the redox status of the fluid and porous media. In this study, BWIP investigators will measure the ratios of selected redox pairs and the concentration of certain isotopes in the natural system.

The BWIP investigators will use data from the radionuclide behavior investigation to determine radionuclide retention characteristics of flow tops, flow interiors and interbeds. This information will provide bounding estimates for radionuclide retardation and distribution. The radionuclide behavior investigation will be conducted simultaneously with the hydrochemical characterization investigation and will depend on input from that investigation.

The radionuclide reactivity study is the only study under the radionuclide retardation investigation. This study will provide data on geochemical processes that retard or promote the transport of key radionuclides through flow tops, fracture zones, and sedimentary interbeds. The radionuclide reactivity study involves laboratory tests of the sorption properties of core samples, tests on naturally occurring radionuclides and tracer tests. The laboratory tests will involve batch sorption/desorption experiments to quantify the steady-state distribution of key radionuclides between aquiferous solids and groundwater. By determining the concentrations of radioactive daughters in the uranium and thorium decay chains, the test of naturally occurring radionuclides will help BWIP investigators estimate the in situ retardation capability of flow top solids. The tracer tests will be used to help transfer the results of the laboratory tests to the scale of the repository setting.

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8.3.1.4.1 Purpose and objectives

The primary purpose of the site geochemistry program is to measure the geochemical parameters that influence radionuclide containment and migration. Figure 8.3.1.4-2 lists high-level parameters for the natural, undisturbed setting and shows which issues mandate measurement of each parameter. (Supporting parameters are developed in appropriate study sections.) The following are objectives of the geochemistry program:

- To provide the necessary parameter measurements at the necessary level of detail.
- To determine whether the site geochemical parameters meet the favorable or potentially adverse conditions.

8.3.1.4.2 Rationale

The top-level strategy (Section 8.2.1) suggests the general approach the site geochemistry program should take to resolve SCP issues. The geochemistry program is derived primarily from Issue 1.1 (radionuclide containment) and Issue 1.8 (demonstrations for favorable and potentially adverse conditions). Because of hydrochemical interactions with the waste package, the site geochemistry program contributes to Issue 1.4, waste package performance. The measurement of solute and isotopic distributions, and chemical evolution in the groundwater flow system, provide an independent check for Issue 1.6, groundwater travel time. The top-level strategy and issue resolution process provide the programmatic rationale for the geochemistry program.

8.3.1.4.2.1 Technical rationale

The site average containment equation provides the scientific rationale (10 CFR 60 (NRC, 1987)) for the geochemistry program. The following discussion and development of this equation show why the planned geochemical studies are needed for Key Issue 1, the containment issue.

Key Issue 1 requires for each radionuclide in the repository:

> The cumulative amount of radionuclides released from the repository or engineered barrier system less the amount contained within the geologic setting (controlled area) will not exceed the permissible cumulative release limits to the accessible environment specified in 10 CFR 60.115 (Table 1) and at a level of uncertainty as stipulated in 10 CFR 60.112(a).

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Issues / Information needs and parameters	Scale (or system element)	Hydrochemical characterization investigation										Radionuclide retardation investigation					
		Flow system hydrochemistry study (8.3.1.4.3.3.1)				Redox characteristics study (8.3.1.4.3.3.2)						Radionuclide reactivity study (8.3.1.4.4.3)					
		Spatial distribution of groundwater age	Spatial distribution of inorganic solutes	Spatial distribution of dissolved gases	pH (and alkalinity)	General redox conditions	Dissolved oxygen	Major redox couples	Redox capacity	Analog redox state	Carbon and sulfur isotopic ratios	Sorption coefficients	Inorganic complexants	Organic complexants	Particulates/colloids	^{14}C molecular* diffusion coefficient	Natural radionuclides in groundwater
Geochemical process-related issues																	
1.1 (Radionuclide containment)	CASZ		●		●	●						X				X	X
1.11 (Repository seals performance/radionuclide transport)	LA		●		●	●						●					
1.6 (Groundwater travel time)	CASZ, PB	X	X	X													
1.8, FC 3 (Conditions that promote radionuclide containment)	CASZ		X		X	X	X	X	X	X	X		X	X	X		
1.8, PAC 7 (Effect of mixed groundwaters; related to issues 1.4 and 1.5)	CASZ		X		X	X	X						X	X			
1.8, PAC 8 (Desorption or reduced sorption on secondary minerals)	CASZ											X					
1.8, PAC 9 (Reducing conditions in host rock)	CASZ, PIZ					X	X	X	X	X	X	X					
Design-related issues																	
1.8, PAC 20 (Methane gas explosion hazard)	CASZ, PIZ			●													
1.8, PAC 24 (Gaseous radionuclide transport potential)	LA, PIZ			●													
2.4 (Personnel protection/gas emission)	LA, PIZ			●													
2.7 (Toxic and flammable gases; mine water contaminants)	LA, PIZ			●													●
4.2 (Grout stability and corrosion potential)	LA, PIZ		●		●	●											

*For engineered barrier subsystem only.
● Indicates information to be used in other studies to address indicated issue.
X Primary parameter(s) to satisfy issue.

CASZ = Controlled area study zone.
FC = Favorable condition.
LA = Layout area.

PAC = Potentially adverse condition.
PB = Pasco Basin.
PIZ = Primary isolation zone.

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Figure 8.3.1.4-2. Site geochemistry program issues and parameters matrix diagram. (Related performance parameters, shown as column headings are grouped under the three studies or information needs comprising the site geochemistry program. The general scale over which the issue and parameter apply is shown in the far left column. The design-related issues generally apply to the primary isolation zone in the immediate vicinity of the repository layout area.)

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The preceding statement is represented by the following general equation and the conceptual model illustrated in Figures 8.3.1.4-3 and 8.3.1.4-4:

$$\int_{T_o}^{10^4-T_o} R_{i,EB}(t) - \int_{V_{CA}} C_{i,CA}(V, t)\, dV \quad dt \leq N_{i,AE} \qquad (8.3.1.4\text{-}1)$$

where

i = Radionuclide species

EB = Engineered barriers system boundary

CA = Controlled area

AE = Accessible environment boundary

$R_{i,EB}(t)$ = Input flux of radionuclide i from the barriers system boundary EB to CA

t = Time

T_o = First time of release from the EB to the CA

V = Volume of space (both rock and pore space) within the CA that lies between the EB and the EA; $0 \leq V \leq V_{CA}$

V_{CA} = Volume (V) of the CA

$C_{i,CA}$ = Mass of radionuclide i contained in a unit volume of the CA space V

$N_{i,AE}$ = Cumulative release of radionuclide i to the AE, as allowed by the limiting U.S. Nuclear Regulatory Commission (NRC) rules.

The top-level strategy (Section 8.2.1) sets the goals controlling the term $R_{i,EB}(t)$. The strategy calls for a 1,000-yr containment within the waste package with a probability of 90% and a 10,000-yr release rate from the engineered barriers of 1×10^{-5} of inventory per year with a probability of 70%. The waste package and repository design programs incorporate these goals. The location of the proposed repository area and the controlled area study zone are shown in Figure 8.3.1.4-4.

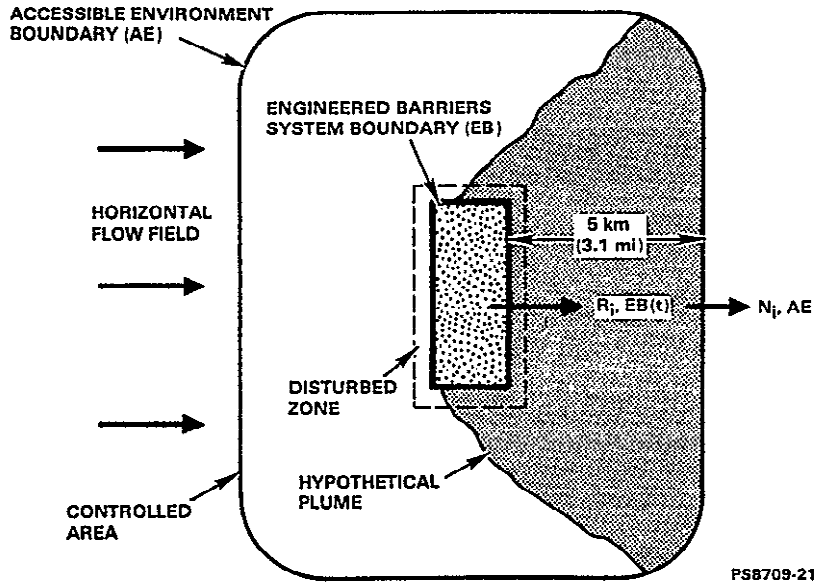

Figure 8.3.1.4-3. Conceptual model for the site containment equation. (The conditions depicted are based on a flow model that involves steady-state, horizontal flow from west to east in the first basalt flow top above the candidate horizon (Cohassett flow dense interior). The conceptual model for potential radionuclide transport from the repository assumes instantaneous movement through the disturbed rock zone into the first flow top above the repository horizon. Thereafter, groundwater movement is envisioned to occur through fracture networks lined with secondary minerals and through interconnected pore space (flow tops) partially filled with secondary minerals (clays, zeolites).)

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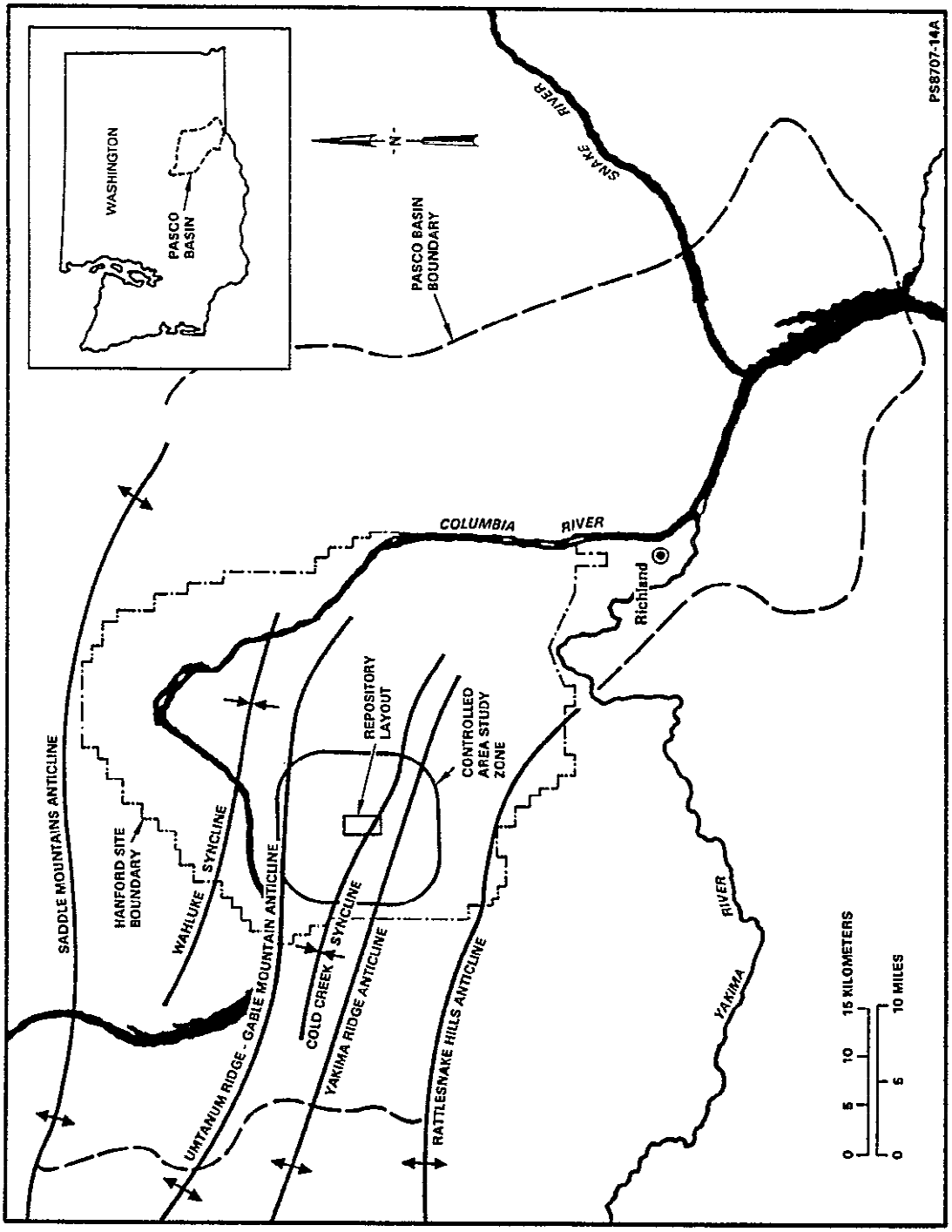

Figure 8.3.1.4-4. Location of proposed repository layout and controlled area study zone.

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The site geochemistry program is responsible for measuring the site's ability to meet the goals for the term $C_{i,CA}(V,t)$--the amount of each radionuclide contained within the controlled area as a function of space and time. The BWIP investigators will use the geochemical parameters associated with the hydrochemical studies of groundwaters, basalt/water interactions, radionuclide sorption, and other radionuclide reactions with primary and secondary minerals (see Fig. 8.3.1.4-2 and 8.3.1.4-5) to evaluate $C_{i,CA}(V,t)$.

The combined ability of the controlled area to contain radionuclides over space and time is represented by the following equation:

$$\int_t \int_{V_{CA}} C_{i,CA}(V, t)\, dV\, dt. \qquad (8.3.1.4\text{-}2)$$

Evaluation of this term will be based on the geochemical reaction and transport models that will be developed through the cross-links between the geochemistry program and the performance assessment program (Section 8.3.5). Groundwater travel time, likely travel paths, and identification and abundance of mineral phases along the groundwater travel paths also enter in the contained mass term, $C_{i,CA}$.

In addition to the site containment rationale that addresses most of the parameters listed in Figure 8.3.1.4-2, some technical questions associated with the Hanford Site must be addressed. These include the following:

- What is the origin of and controls on the distribution of methane in the reference repository location?
- Is there hydrochemical and (or) isotopic evidence (^{129}I, ^{99}Tc, ^{3}H, and NO_3^-) of vertical exchange or leakage between near-surface aquifers and deeper aquifers in the controlled area study zone?
- Is there evidence of two-phase conditions (noncondensed gas phase) in the controlled area study zone?
- What is the redox capacity of the major aquifers within the controlled area study zone?

These questions will be addressed in the hydrochemical characterization investigation (Section 8.3.1.4.3) as an adjunct to opportunistic sampling from planned hydrologic testing boreholes (Section 8.3.1.3) and planned sampling associated with hypothesis testing for vertical mixing and flow direction (Section 8.3.1.4.3).

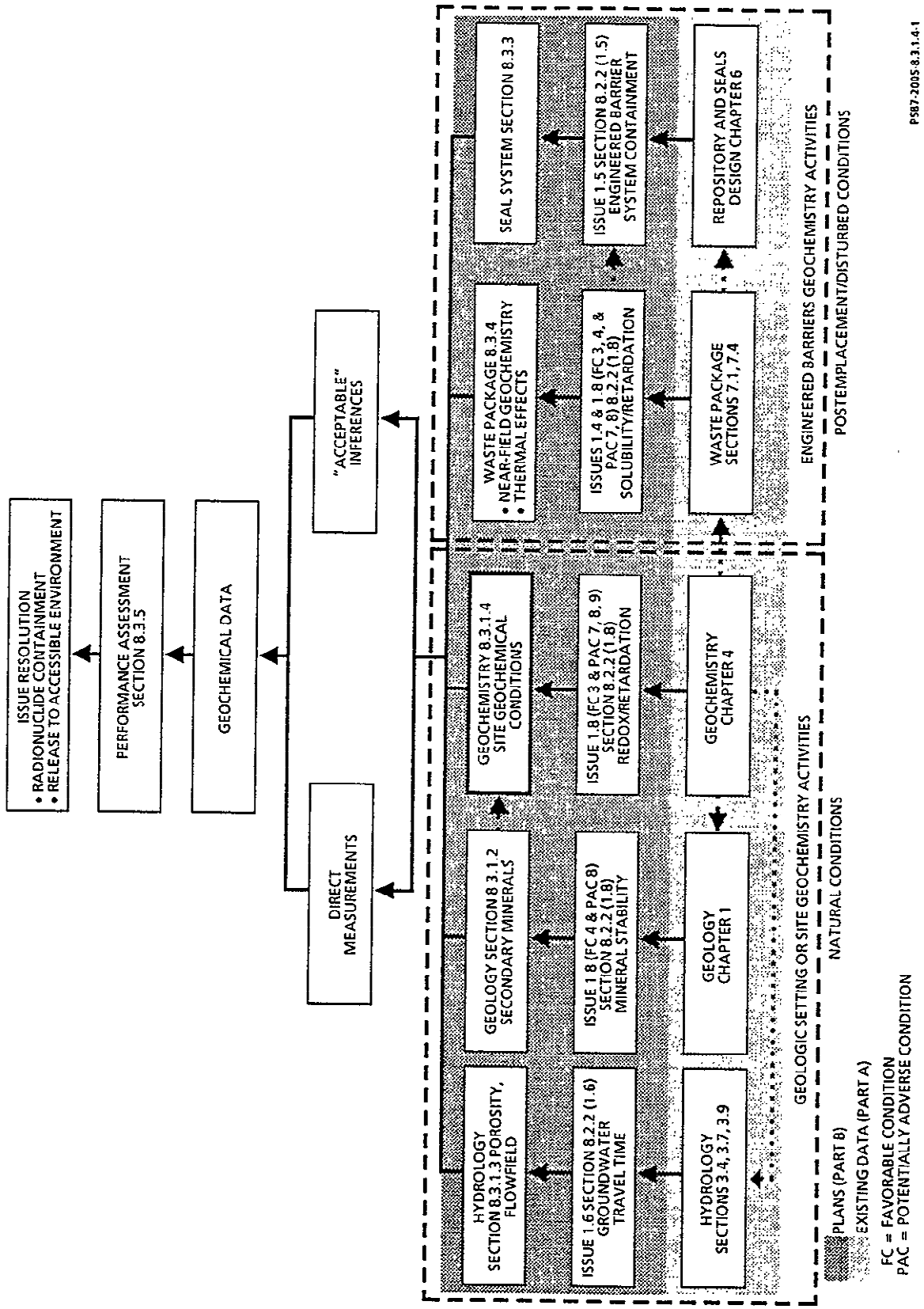

Figure 8.3.1.4-5. Geochemistry cross-links and issue resolution process.

8.3.1.4.2.2 Description of geochemistry program cross-links

The geochemistry program does not function independently in contributing to the overall SCP goal of satisfying the requirements of 10 CFR 60 (NRC, 1987) and 10 CFR 960 (DOE, 1987). Figure 8.3.1.4-5 illustrates how information from other programs merge to address geochemical information needs. In particular, geochemical studies both contribute to and draw from the hydrology, waste package design, and seals design programs. The programs together then contribute to the performance assessment program goal of demonstrating whether the proposed site would meet the performance criteria for a nuclear waste repository in basalt.

The BWIP geochemistry program is described schematically in Figure 8.3.1.4-5; all of the SCP sections identified are required for a comprehensive description of the geochemistry program. The data chapters (Part A), shown as the bottom row of boxes, contain summaries of existing data relevant to geochemical considerations. This information was used to develop geochemical parameters in response to the various issue requirements (Part B, Section 8.2) shown in the second row from the bottom. The primary subject area or geochemical process important to repository performance is indicated at the bottom of each issue box. The various issues and associated favorable and adverse conditions (Issue 1.8) identified contain considerable rationale and discussion related to geochemical considerations.

The top row in the Part B section of Figure 8.3.1.4-5 represents the data acquisition activity. These chapters contain the descriptions of plans for new data. The primary type of data to be obtained is indicated at the bottom of each box. The information from all of the relevant data collection activities (top row, Part B) provide either direct measurements or information from which acceptable inferences are derived. The latter involves calculation of a data-need based on theoretical considerations (equations) and other information obtained by direct measurements. An example is the computation of bicarbonate ion concentration based on alkalinity and pH measurements and appropriate equilibrium constants.

Direct measurements and acceptable inferences, based on existing and new data, collectively form the geochemical data base for performance assessment modeling and analysis that will be used to resolve the issue of radionuclide containment and release to the accessible environment. The geochemical uncertainty in these analyses will be assessed by using alternate models and assumptions as well as alternative measurement approaches. It is reemphasized that the SCP sections indicated in Figure 8.3.1.4-5 must be reviewed for a complete understanding of the BWIP geochemistry program.

8.3.1.4.3 Hydrochemical characterization investigation

The hydrochemical characterization investigation provides data with which to evaluate groundwater flow paths and redox conditions in the natural system. Groundwater flow paths are important because they provide the most likely route for radionuclide migration from the proposed repository to the

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accessible environment. Redox conditions in the natural system are important because they are a major factor controlling radionuclide mobility.

8.3.1.4.3.1 Purpose and objectives

The purpose of the hydrochemical characterization investigation is to characterize surface and groundwater within the controlled area study zone, the Hanford Site, and the subregional basin. The Basalt Waste Isolation Project investigators will use the information obtained from this effort to (1) evaluate site-specific technical issues for the Hanford Site (origin of methane and occurrence of defense waste ^{129}I), (2) evaluate groundwater flow paths and travel time (Section 8.2.2, Issue 1.6), and (3) evaluate the contribution of redox environment to the presence of favorable and adverse geochemical conditions (Section 8.2.2, Issue 1.8). Information from this investigation is also needed to evaluate mine safety and design issues involving corrosion and flammable and toxic gases in aquifers adjacent to the candidate horizon.

The objectives of the groundwater flow system characterization investigation are as follows:

- Determine pathways for radionuclide migration from the proposed repository site to the accessible environment.
- Determine the preemplacement rate of groundwater flow along such pathways.
- Establish the composition of groundwater within the vicinity of the proposed repository and along probable flow paths in order to:
  - Establish a groundwater hydrochemical baseline.
  - Aid in design of the shaft liner, ventilation system, waste package, and other engineered systems.
  - Quantify prevailing redox conditions, including the rates of certain redox reactions along groundwater flow paths.

8.3.1.4.3.2 Rationale

The BWIP investigators need the information that will be collected in the hydrochemical characterization investigation to evaluate radionuclide containment by the geologic setting (see Section 8.3.1.4.4) and groundwater travel time (Section 8.3.1.3.4).

To satisfy the objectives, groundwater samples must be collected at strategic locations and depths under ultraclean conditions. Special drilling and sampling procedures are required to provide analytical results that are representative of formation conditions. The investigation consists of two studies that have in common the need for ultraclean sampling conditions from locations along likely or hypothesized groundwater flow paths in the vicinity of the controlled area study zone.

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The principal constraints for this investigation involve timing of the studies relative to construction of the exploratory shaft and accurate measurement of the predisturbance water-level baseline. The timing of studies relative to exploratory shaft construction is a concern because dewatering may disturb the preexisting hydrochemical conditions near the shaft. The investigation is further constrained by the need for minimal disturbance in the controlled area study zone when the hydrologic baseline is being measured. The strategy for hydrochemical characterization under these competing constraints is to limit sampling before exploratory shaft construction in the controlled area study zone to avoid disturbance of the hydrologic baseline (Section 8.3.1.3.4). Boreholes near the exploratory shaft will be tested after the hydrologic baseline is measured but before exploratory shaft construction. Locations further removed from the exploratory shaft site will be tested at later dates.

The hydrochemical and groundwater investigations (Sections 8.3.1.4.3 and 8.3.1.3.4) share the goals of providing data for groundwater travel time and radionuclide transport parameters (Fig. 8.3.1.4-6). Testing facilities for the groundwater investigation also provide opportunities for hydrochemical sampling when interferences can be avoided.

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8.3.1.4.3.3 Description of studies

The hydrochemical characterization investigation consists of the following two studies:

- Groundwater flow system hydrochemistry study (Section 8.3.1.4.3.3.1).
- Groundwater redox characterization study (Section 8.3.1.4.3.3.2).

8.3.1.4.3.3.1 Groundwater flow system hydrochemistry study.

The groundwater flow system hydrochemistry study encompasses the following four objectives:

1. Determine historical pathways for groundwater migration to and from the proposed repository site.
2. Determine the rate of groundwater flow along such pathways.
3. Establish a groundwater composition baseline for the repository site for the purpose of future performance monitoring.
4. Measure the repository's geochemical environment for design of the shaft, liner, ventilation system, waste package, and other engineered systems.

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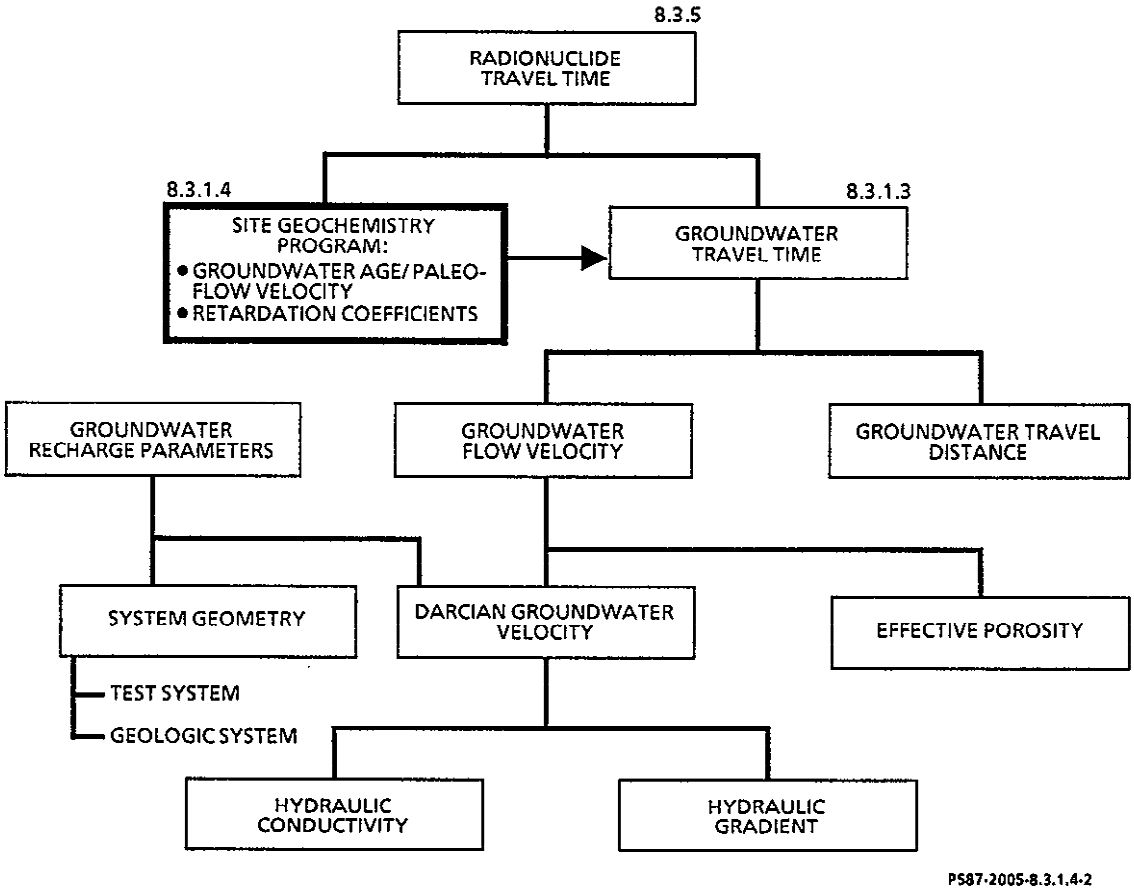

Figure 8.3.1.4-6. Relationship among groundwater velocity, flow rate, and hydrochemical parameters.

Each of these objectives requires that the groundwater hydrochemical regime be measured under predisturbance conditions. The groundwater flow system hydrochemistry study will involve the following measurements:

- Spatial distribution of major and trace solutes, including dissolved gases and organics in the groundwater.
- Spatial distribution of age-dating parameters such as ^{14}C, ^{36}Cl, and ^{4}He in the groundwater.
- Spatial distribution of primary and secondary minerals and certain chemical attributes of the solid phase system (e.g., the progenitor radionuclides of ^{4}He).
- Spatial distribution of stable isotope ratios in the groundwater and mineral systems.

These measurements, given suitable vertical and horizontal resolution, constitute a geochemical description of the groundwater/mineral system. This description itself satisfies the study objectives of establishing design factors and a chemical baseline. Determining flow paths and flow rates requires further interpretation. The interpretation must account for the following natural processes:

- Effect of rock/water interactions on chemical maturation of groundwater along flow paths.
- Possible interaction of groundwaters from different sources.
- Radionuclide decay and helium accumulation (both of which are time-dependent phenomena) along natural flow paths.

This study will establish the net groundwater flow pattern over geologic time. For example, preliminary studies using ^{36}Cl indicate Grande Ronde Basalt groundwaters may take several hundred thousand years to travel along the Cold Creek syncline from the reference repository location to the Columbia River. Because the flow-rate estimates are averaged over geologic time, they are not subject to short-term perturbations caused by periodic shifts in the hydrologic cycle.

The performance parameters and upper level supporting parameters for this study are shown in Table 8.3.1.4-2.

8.3.1.4.3.3.1.1 <u>Spatial distribution of test facilities (rationale and description)</u>. The three-dimensional hydrochemical, hydrologic, and geologic models being developed for the site characterization stage of the BWIP need vertical and horizontal resolution. The number and size of natural features encompassed by such models, complexity of each feature, and degree to which features must be resolved determine the sampling point density necessary for model development.

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Table 8.3.1.4-2. Performance parameters and upper level supporting parameters for the groundwater flow system hydrochemistry study

Performance parameter	Issue	Tentative goal	Scale	Test basis			Supporting or subparameters[a]
				Expected value	Current confidence	Needed confidence	
Spatial distribution of groundwater age	1.6	Paleoflow rates <1 m/yr	CASZ	NA	Low	High	Natural radionuclides (^{14}C, ^{36}Cl, ^{81}Kr) Helium in groundwater and core; porosity Natural gamma logs of boreholes sampled (potassium, thorium, uranium) Recharge area locations and distances
			Region	NA	Low	Medium	
Spatial distribution of inorganic solutes	1.6 (1.11, 1.8, 4.2)	Map of paleoflow directions and evidence of vertical mixing	CASZ	NA	Medium	High	Major inorganic constituents Field (hydrochemical) parameters Stable isotopes Trace level fission products (^{129}I, ^{99}Tc, ^{3}H) Trace elements
			Region	NA	Low	Medium	Major inorganic constituents Field (hydrochemical) parameters Stable isotopes
Spatial distribution of dissolved gases	1.6, (1.8, 2.7, 4.2)	Establish quantitative distribution of methane, major gases and noble gas composition (supports groundwater age and mine safety information needs)	CASZ/LA	NA	Low	High	"Excess"[b] methane (evidence of in situ noncondensed gas phase) In situ groundwater temperature and pressure
	1.6	Establish major and noble gas compositions (supports groundwater age)	Region	NA	Low	Medium	Recharge temperature calculation

NOTE: CASZ = Controlled area study zone.
LA = Repository layout area.
NA = Not applicable.

[a]Subparameter groups and measurement methods are described in Tables 8.3.1.4-3 and 8.3.1.4-4, respectively.
[b]In excess of methane solubility at sampling depth/pressure and temperature.

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Hydrochemical models focus on such features as concentration gradients, plumes, and compositional discontinuities. The BWIP investigators will use such features to deduce the migration patterns of solutes. Additional changes to groundwater composition along flow paths are caused by the mixing and reaction of different water types, the chemical evolution of water as it reacts with the host rock, and the decay of natural radionuclides with time. The results of BWIP hydrochemical investigations will be based on the three-dimensional hydrochemical patterns that emerge from the surface water and groundwater sampling activities.

Sampling facilities should be placed to best define hydrochemical features. These features are illustrated with a conceptual groundwater flow model for the Columbia Plateau in Figure 8.3.1.4-7. According to this model, deep water originating on the margins of the plateau in sub-basalt sediments, is believed to upwell in the center of the Pasco Basin in the vicinity of the reference repository location. Groundwater flow in the reference repository location is thought to be controlled by anticlines bordering the Cold Creek syncline and by a hydrologic barrier immediately to the west of the reference repository location. Upwelling, chloride-rich waters are thought to pass through laterally discontinuous carbonaceous beds, similar to lignite beds that occur in the Rattlesnake Hills region along the western border of the Hanford Site, and entrain methane. When this upward-migrating groundwater encounters the Wanapum Formation, greater transmissivities result in lateral spreading down the syncline controlled by the local flow regime. Hydrochemical plumes, elongated in the direction of flow and roughly symmetrical and perpendicular to the flow, exemplify this pattern.

At least one upwelling center is believed to exist in the Cold Creek syncline. Chloride concentration data for the Wanapum formation were interpreted as evidence for either a single center, as illustrated in Figure 8.3.1.4-8, or possibly multiple ones. If the data represent a single upwelling, the plume is thought to originate east of the hydrologic barrier (to the west of the reference repository location) and extend southeast along the synclinal axis. Alternatively, it has been suggested that the same data could represent multiple centers with at least one near the hydrologic barrier and another at the lower end of the syncline. At present, the distribution of sample locations and limited hydrochemical data do not allow discrimination between the two possibilities.

Similar uncertainties arise when the distribution of other solutes are considered. For example, sulfate-rich waters occur only on the eastern margin of the Hanford Site and appear to be confined to the Grande Ronde Basalt. A deep source is hypothesized that originates in the sub-basalt sediments to the east and upwells, once again, in the center of the basin (see Fig. 8.3.1.4-7; see also Section 3.9.5.2 for interpretation of existing data related to this topic). Alternatively, the absence of high sulfate in the deep groundwaters over most of the Hanford Site may be a result of sulfate reduction/sulfide precipitation in the hypothesized sub-basalt coal deposits.

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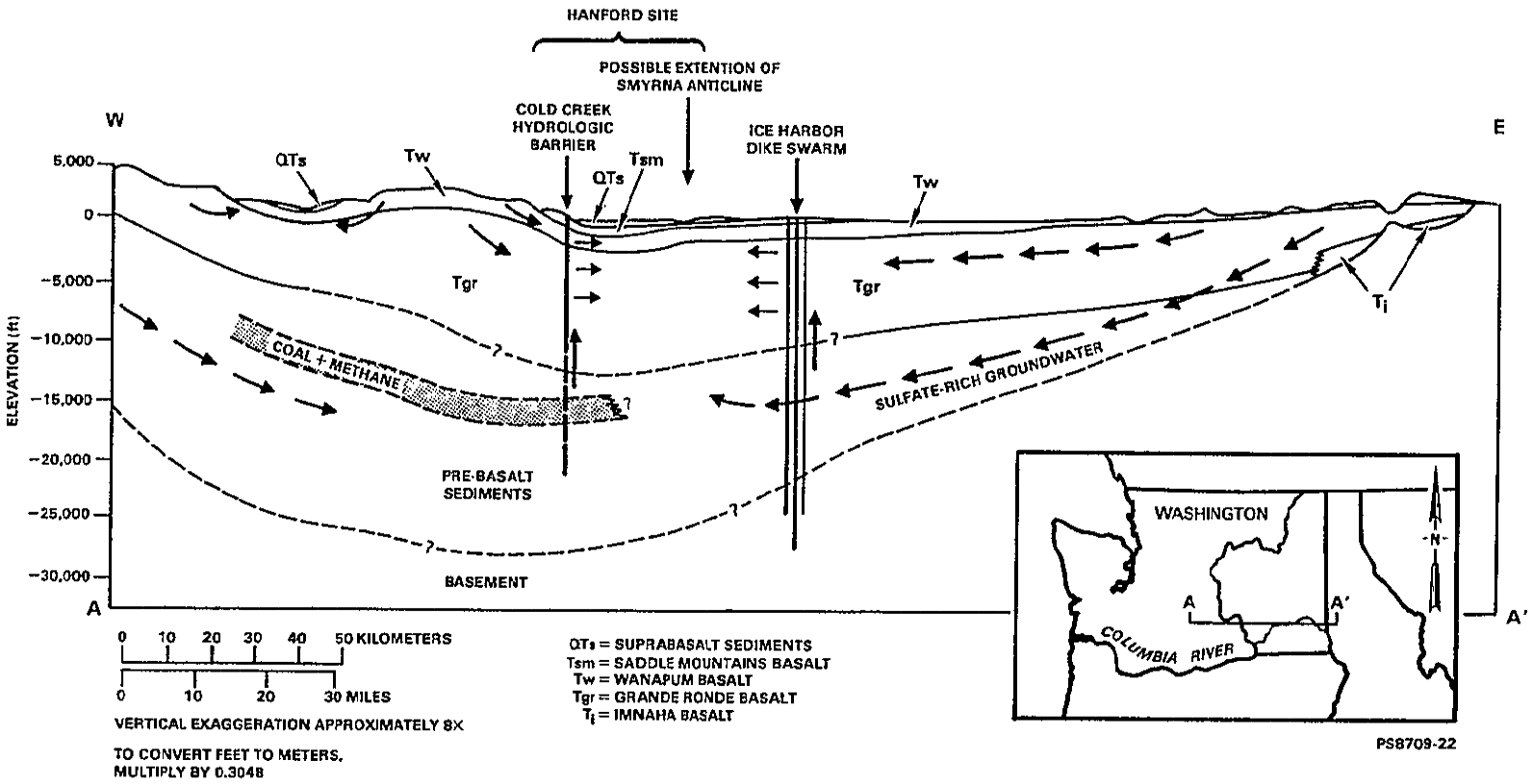

Figure 8.3.1.4-7. Conceptual flow model of the Columbia Plateau. (Based on interpretations of hydrochemical data presented in Section 3.9.5.2).

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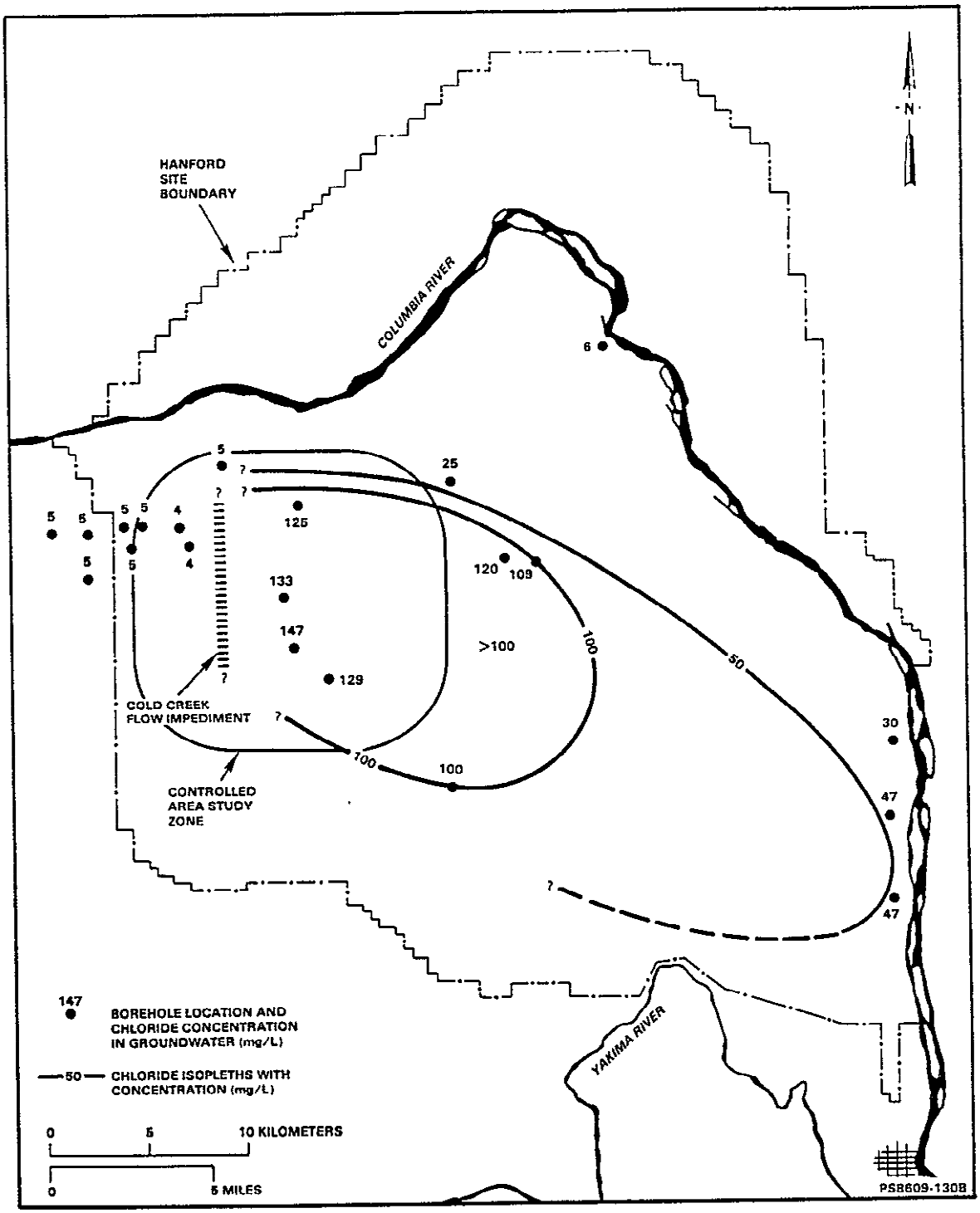

Figure 8.3.1.4-8. Chloride in upper Wanapum Basalt groundwaters.

If this is the case, methane from the coal would be expected to occur with the chloride-rich groundwaters (i.e., high-sulfate, high-chloride groundwaters would be converted to high chloride, methane-containing groundwaters). However, methane in the Grande Ronde Basalt is highly localized in the vicinity of the reference repository location while the low sulfate/high chloride water type in this formation is widely distributed over the Hanford Site. If the distribution of chloride and methane results from steady-state groundwater flow, some mechanism to consume methane must be invoked to explain the discrepancy. In this latter case, the geochemical controls involved are of primary concern as a technical issue. Additional spatial resolution, isotopic data, and geochemical modeling are needed to resolve this issue.

A useful pattern of sampling points for elucidating the hydrochemical pattern exemplified by the chloride plume (see Fig. 8.3.1.4-7) is one that will yield hydrochemical cross sections, some coincident with and some transverse to the synclinal axis. The number of sampling points within each cross section should reflect the broad and diffuse nature of hydrochemical features, which tend to exist on a scale similar to that of the geologic structures in which they occur (Fig. 8.3.1.4-9).

Figure 8.3.1.4-10 illustrates major structural features, existing sampling points (boreholes), and proposed locations for nine additional sampling points. Existing sampling points shown are those that have yielded hydrochemical data for the Grande Ronde Basalt. New borehole locations will be based on the sampling density and pattern of existing Grande Ronde Basalt data for the following two reasons.

1. At the Hanford Site, Grande Ronde Basalt aquifers have the lowest sampling point density of the basalt formations (Early et al., 1986).

2. The Grande Ronde Basalt contains the basalt horizon intended for the repository.

Figure 8.3.1.4-10 also shows the three principal cross sections that can be completed with data from the nine locations. Sections A-A' and B-B' intersect at borehole RRL-2, and will maximize hydrochemical detail at the reference repository location. Section C-C' (in addition to the axial Section B-B') will help define: (1) the extent of solute plumes extending eastward from the reference repository location and (2) the degree of mixing of reference repository location groundwaters with sulfate-rich Grande Ronde Basalt east waters. Note that boreholes HC-6 and HC-7 are appropriately located only if predominant flow in the Grande Ronde Basalt follows the synclinal axis. These boreholes will be the last two drilled in the hydrochemistry sampling campaign, and will be located to intercept and confirm principal flow regimes for Grande Ronde Basalt aquifers.

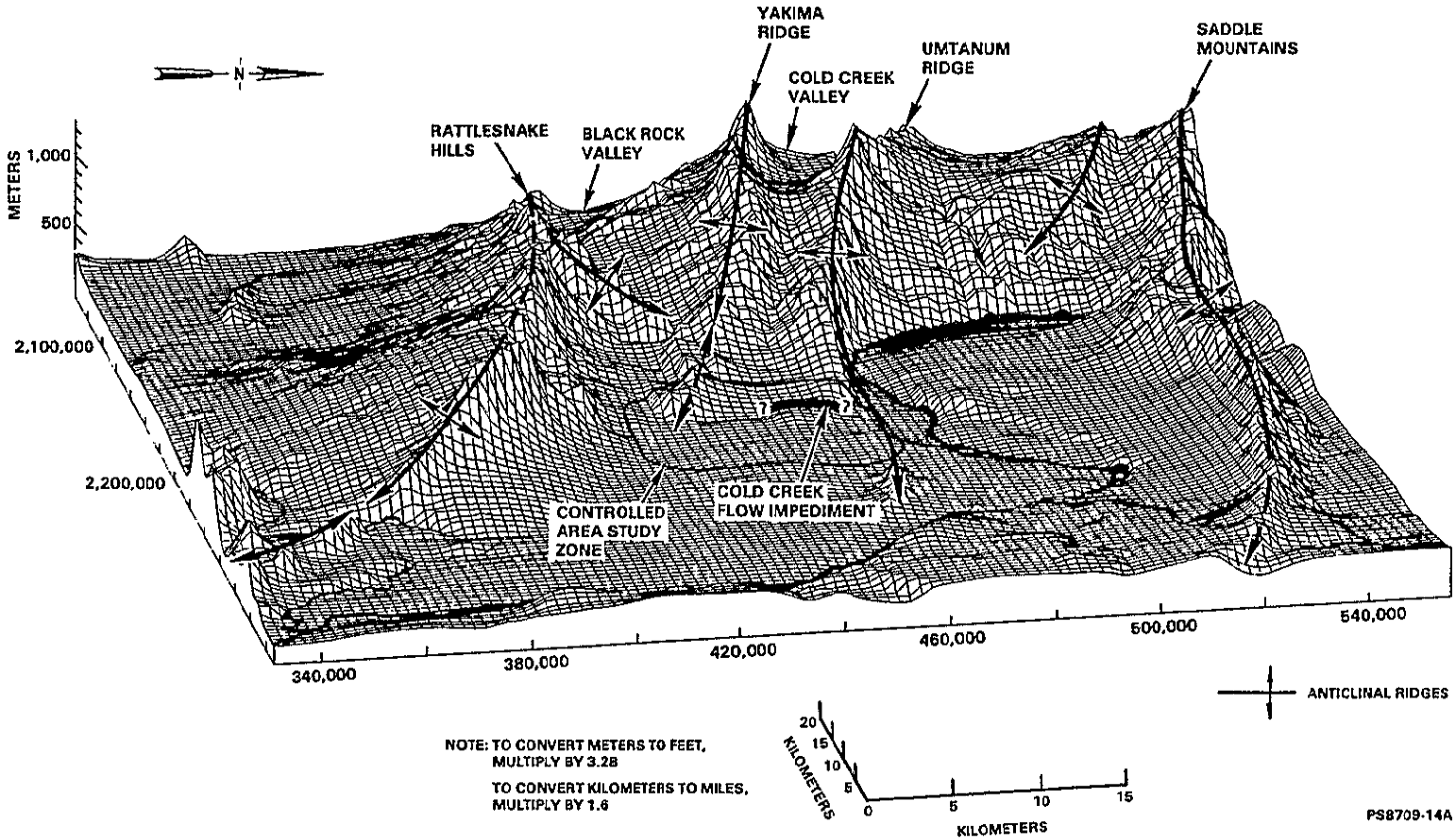

Figure 8.3.1.4-9. Land surface perspective map of the Hanford Site showing location of major geologic structures. (The Umtanum Ridge and Yakima Ridge anticlines are thought to confine horizontal flow to the Cold Creek syncline across the Hanford Site. The depths to which these structures influence lateral groundwater movement is unknown but are presumed to extend to the candidate horizon depth. The Cold Creek hydr-ologic barrier, located immediately west of the proposed repository location, is thought to restrict horizontal flow in the controlled area study zone. Hydrologic and geologic data suggest this feature is a transverse fault.)

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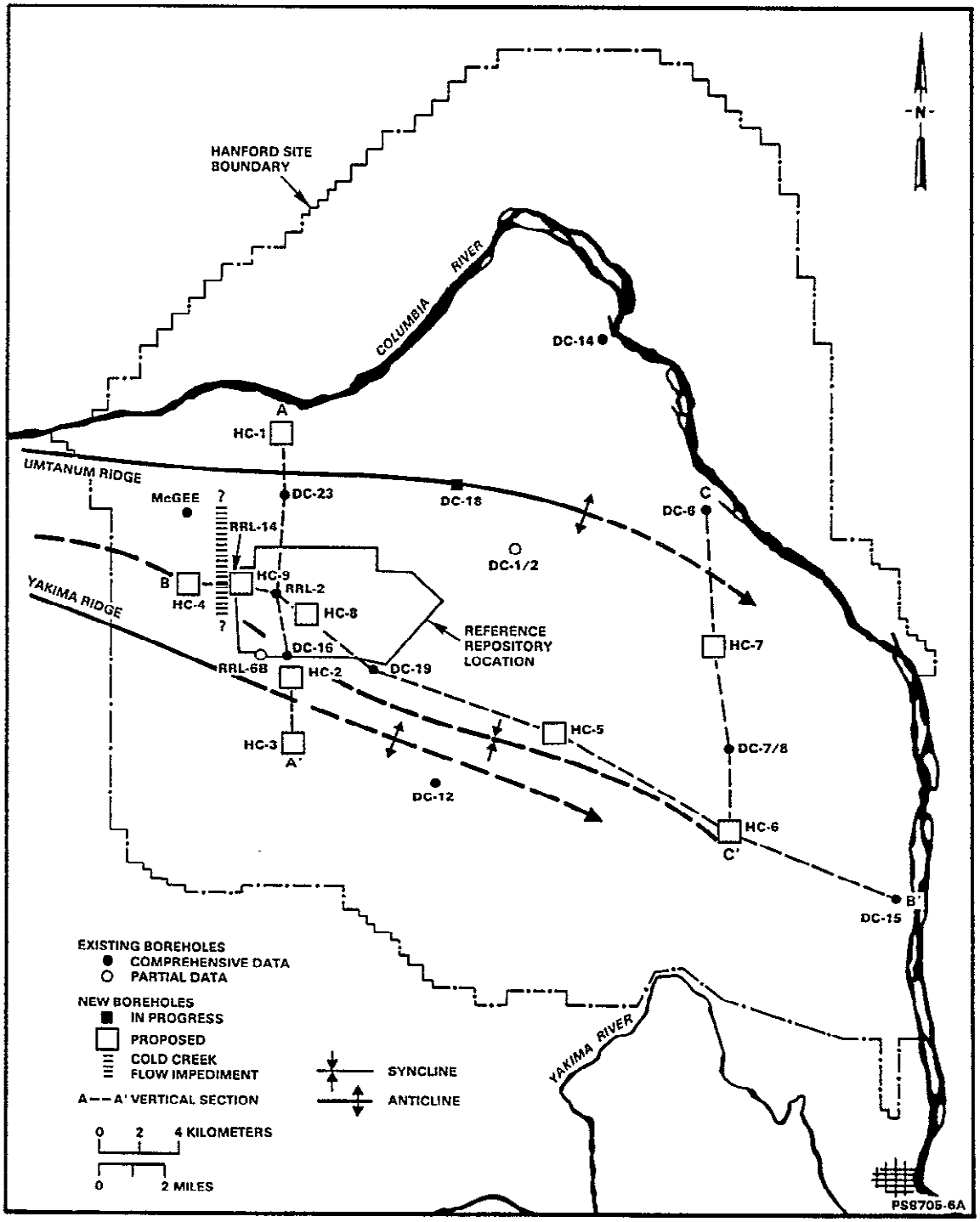

Figure 8.3.1.4-10. Proposed hydrochemistry (HC) borehole locations in relation to existing boreholes that have yielded Grande Ronde Basalt hydrochemical data at the Hanford Site. ("Comprehensive data" includes analysis of major and trace inorganics, stable and radioactive isotopes, dissolved gases, and total organic carbon, but does not imply the degree of vertical resolution.)

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The HC-series boreholes* will be the foundation of the hydrochemistry sampling campaign, and will be supplemented by construction of the DC-series boreholes (for the site groundwater study), the PB-series boreholes (for the regional groundwater study), and the SC-series boreholes (for hydrologic testing). In addition, source terms for recharge waters will come from the sampling of regional surface water, local springs, and the unconfined aquifer. Figure 8.3.1.4-11 shows regional and Pasco Basin surface-water sampling stations. Figure 8.3.1.4-12 shows locations of spring and unconfined aquifer sampling sites. Figure 8.3.1.4-13 shows the locations of planned DC- and SC-series boreholes. Figure 8.3.1.4-14 shows the locations of planned PB-series boreholes.

The principal aquifers to be tested for the SC- and DC-series boreholes (see Fig. 8.3.1.4-13) include the seven identified for piezometer installations in the hydrology program (Section 8.1.3.3.4). These represent four principal Grande Ronde Basalt aquifers in the primary isolation zone (two above and two below the candidate horizon (Cohassett flow interior) and three aquifers in the secondary isolation zone (Wanapum Basalt)). Up to four zones will be tested in the Saddle Mountains Basalt at the HC-series borehole locations only. The basic seven aquifers noted above will be included in all tests to maintain spatial continuity and comparability for both hydrologic and hydrochemical parameters. Three of the seven common test zones for hydrologic and hydrochemical programs as well as additional zones for hydrochemical profiles are listed below and shown schematically in Figure 8.3.1.4-15.

Zone	Formation	Aquifer
Buffer zone	Saddle Mountains Basalt	Rattlesnake Ridge interbed Selah interbed Umatilla flow top Mabton interbed
Secondary isolation zone	Wanapum Basalt	Priest Rapids flow top** Roza flow top** Ginkgo flow top** Vantage interbed
Primary isolation zone	Grande Ronde Basalt	Rocky Coulee flow top** Cohassett flow top** Birkett flow top** Umtanum flow top**

*The letter prefixes for boreholes stand for the following: HC = hydrochemical, PB = Pasco Basin, SC = small-scale test boreholes, DC = piezometer boreholes.

**Test zones monitored for piezometric baseline.

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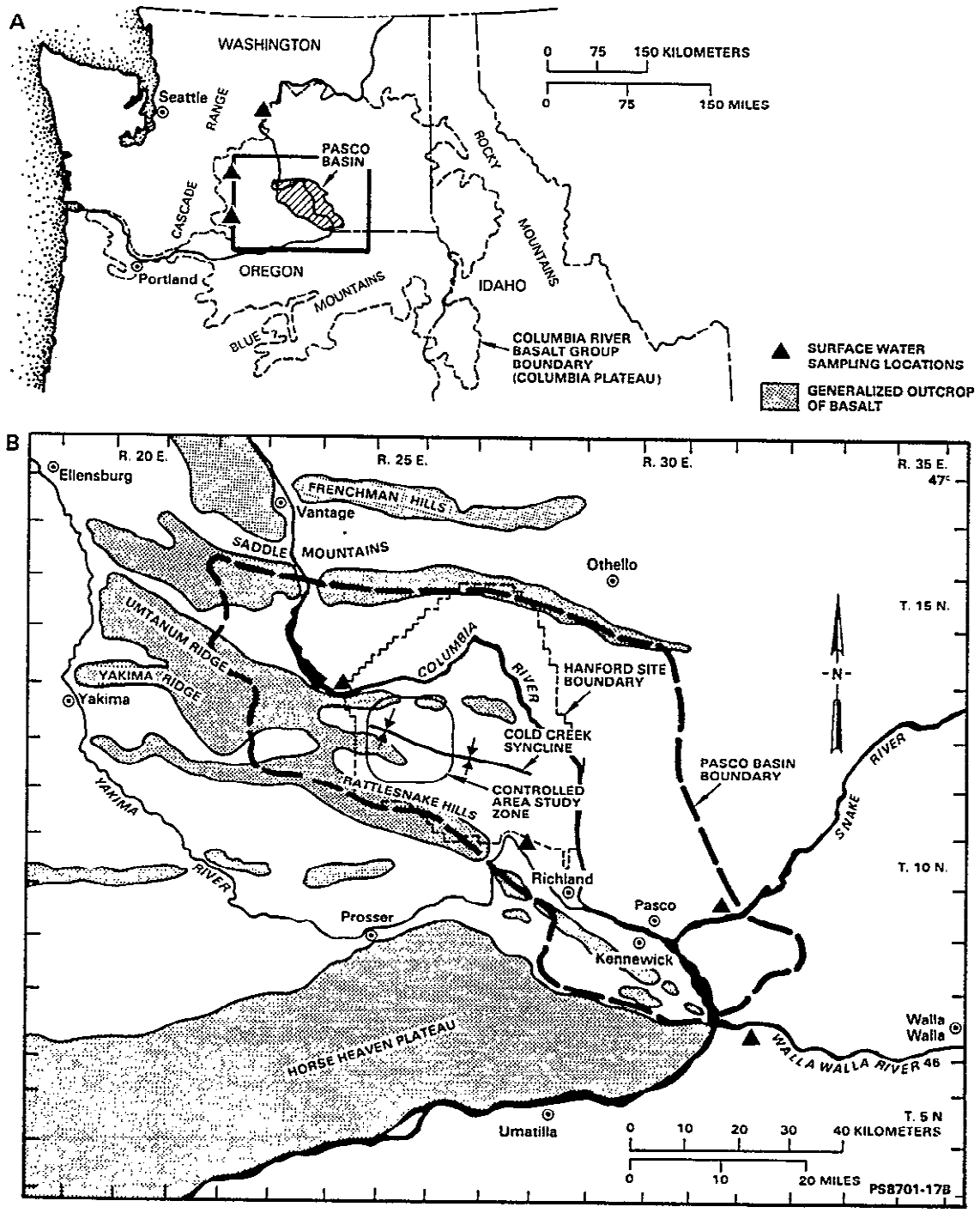

Figure 8.3.1.4-11. Surface water sampling locations. (Seasonal water samples for oxygen and hydrogen isotopic composition will be taken at selected regional (A) and Pasco Basin (B) locations to aid in identification of likely recharge locations for deep basalt and subbasalt acquifers. Very limited data exist at the regional scale. See Sections 3.4 and 3.9 for discussion of existing data and additional needs. General recharge location for the deep system is important in estimating paleoflow rate based on groundwater age and distance to recharge area.)

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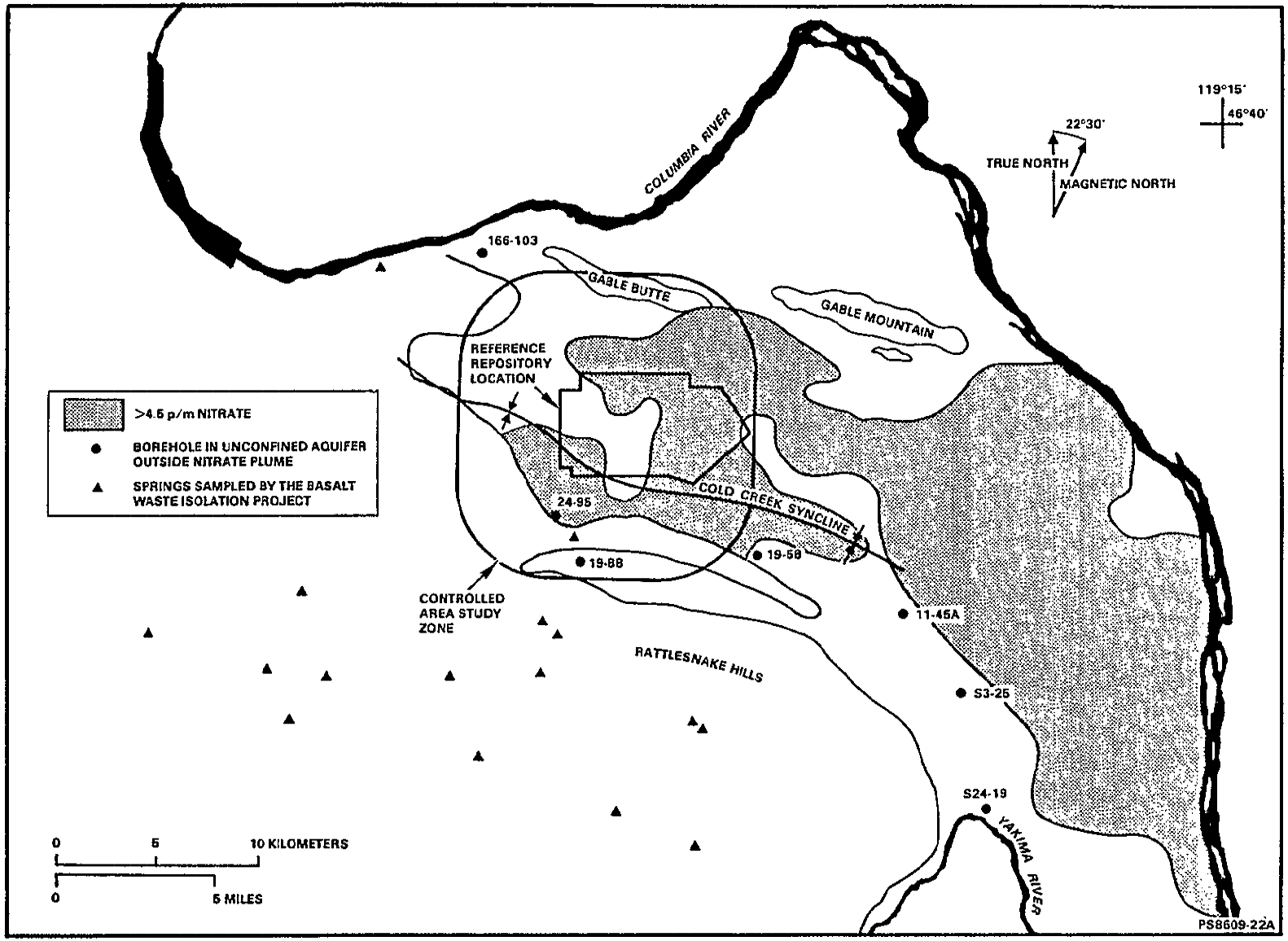

Figure 8.3.1.4-12. Basalt Waste Isolation Project sampling locations for springs and unconfined aquifer monitoring wells. (Monitoring wells were purposely selected at locations upgradient of contaminant plumes. The hydrochemical data base is nearly adequate for these locations. Additional sample collections will be initiated if a review of existing data reveals deficiencies.)

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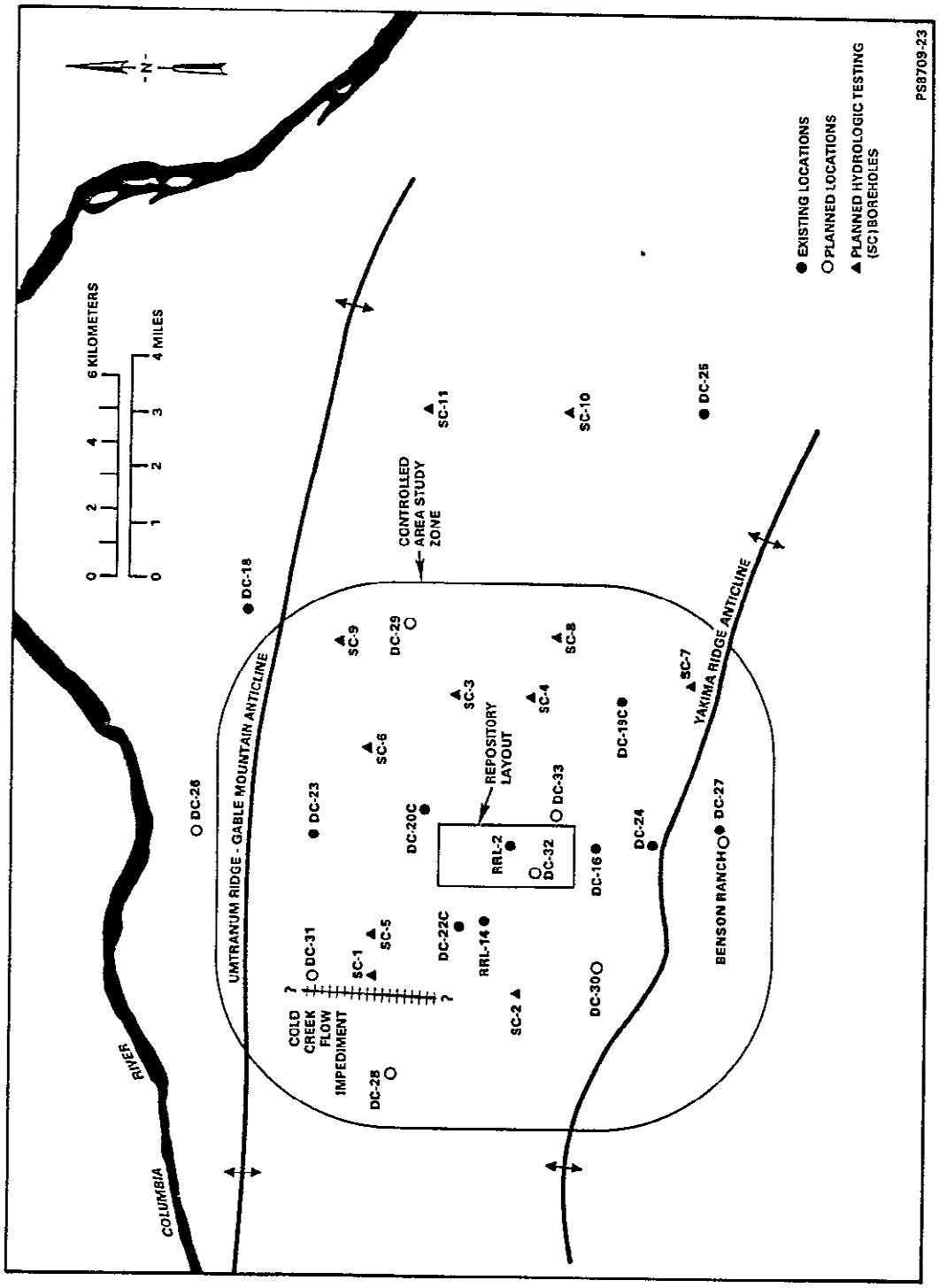

Figure 8.3.1.4-13. Piezometer (DC) and hydrologic testing (SC) facilities. (The DC-series boreholes will be sampled following piezometric baseline and hydrologic testing. The SC-series boreholes will be sampled in conjunction with the hydraulic testing activities (hydraulic properties and tracer tests) described in the groundwater study (Section 8.3.1.3.4).)

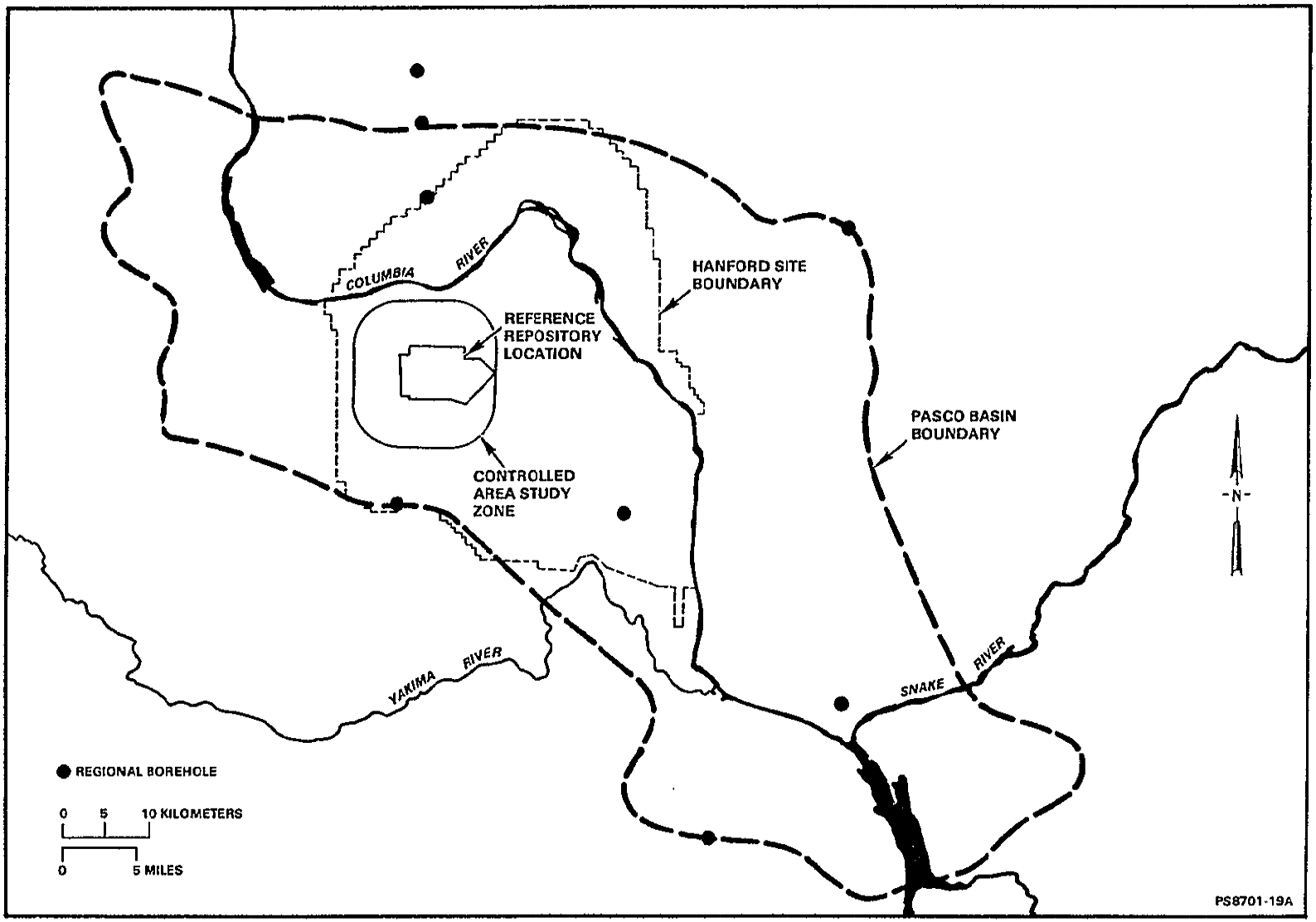

Figure 8.3.1.4-14. Planned regional borehole locations. (The regional boreholes are needed to complete areal gaps in data between the regional USGS hydrochemical data base and the Hanford Site. Sampling and testing these boreholes will be a joint effort with the hydrology program.)

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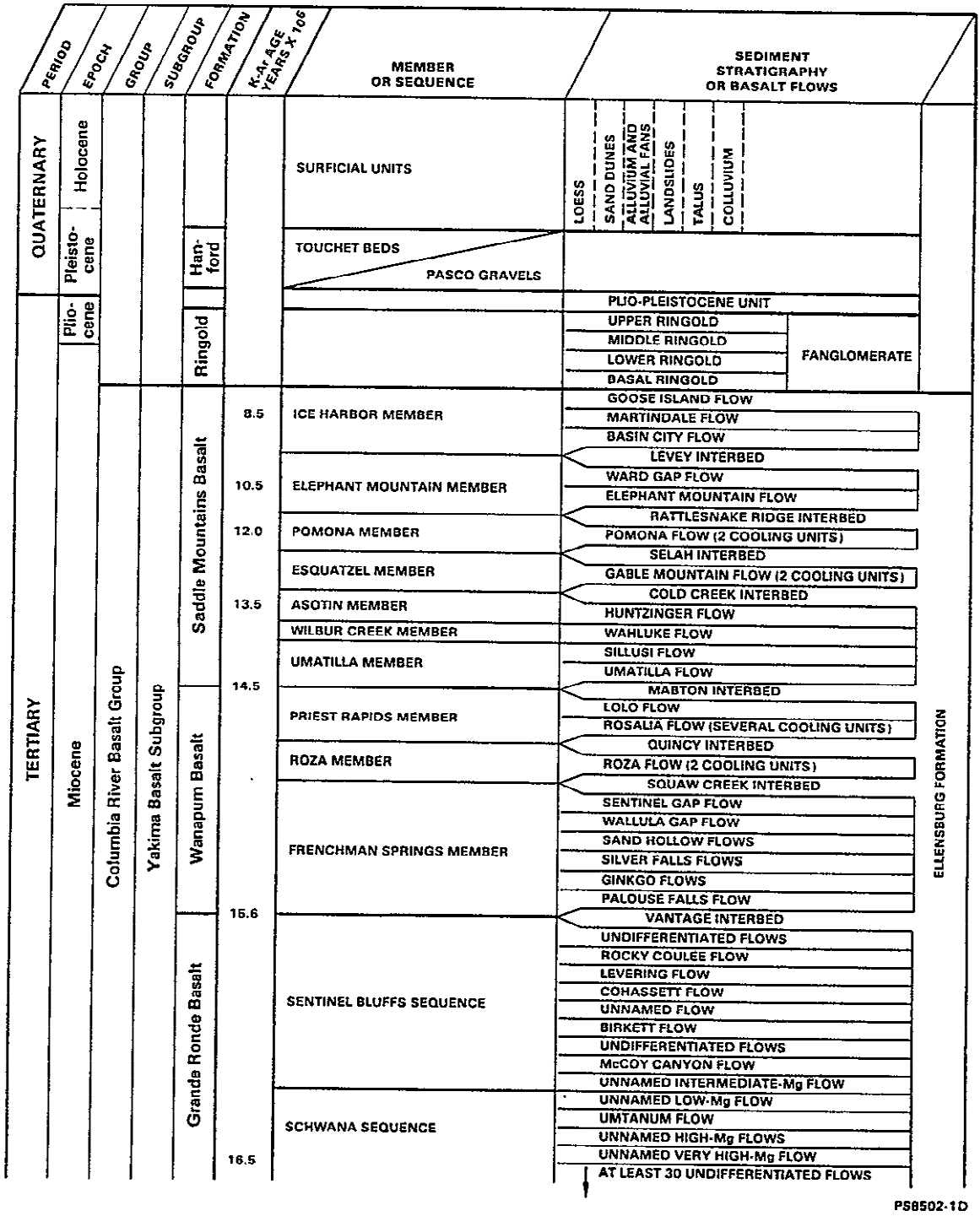

Figure 8.3.1.4-15. Generalized stratigraphy for the Pasco Basin.

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Sampling from DC-series boreholes may involve postpiezometer installation development and testing following completion of the hydrologic baseline. It is yet to be demonstrated that adequate cleanup can be accomplished from piezometer installations for all desired hydrochemical parameters.

8.3.1.4.3.3.1.2 Number of tests, test methods, data to be collected, and procedures. For the purpose of the groundwater flow system hydrochemistry study, a test is equivalent to sampling a single formation at a single borehole location (or surface-water sampling site). Table 8.3.1.4-3 lists the number of samples analyzed for each hydrochemical parameter within each test. A total of 303 planned or possible tests (test zones) are shown in Table 8.3.1.4-3. The hydrochemistry (HC) borehole tests, representing a total of 118 test zones, are first priority. The non-HC-series tests are considered opportunistic and will depend on satisfactory resolution of constraints between hydrologic testing needs and sampling requirements. One strategy for the DC-series boreholes (piezometer installations) is to sample from the piezometer risers after hydrologic testing needs have been met. This will involve potentially long cleanup pumping periods to achieve acceptable conditions for hydrochemical sampling purposes. (Cleanup pumping or development and sampling requirements are discussed in the Section 8.3.1.4.3.3.1.3.) Resampling of existing boreholes is also planned to correct deficiencies in the data base at selected locations. Table 8.3.1.4-4 provides a tabulation of locations and measurements of interest. Figure 8.3.1.4-15 is a generalized stratigraphic column and includes the formations proposed in this study. Figure 8.3.1.4-16 shows the borehole locations for wells identified for resampling in Table 8.3.1.4-4. Table 8.3.1.4-5 lists the analytical procedures for each parameter within each type of measurement. The following discussion give the rationale for selecting the specific analyses listed in Table 8.3.1.4-3.

Excess methane

"Excess" methane is defined as the amount in excess of its solubility at the temperature and pressure at which the water sample was obtained. The measurement of excess methane addresses the question of whether gas pockets exist in the vicinity of the repository horizon. One method for assessing the presence of excess methane is to measure gas flow rate in relation to fluid flow rate during borehole development (pumping). Another method is to monitor off-gases in the drilling fluid returns. Monitoring gas flow from the top of the borehole immediately after penetration of the test zone could also provide information on excess methane (i.e., if significant excess methane exists at depth, the evolving gas should be easily detectable at the well head). Only Grande Ronde Basalt test zones above and below the candidate horizon and at borehole locations near the reference repository location will be examined for excess methane.

Table 8.3.1.4-3. Number of tests, location, and hydrochemical parameter matrix table (includes geologic formations and expected number of zones to be sampled for each borehole) (sheet 1 of 3)

Area	Boreholes[a]	Number of zones[b]	Formations[c]	Excess methane[d]	Field parameters[e]	Major inorganic constituents[f]	Trace elements[g]	Dissolved gases[h]	Stable isotopes	Trace level fission products[i]	Natural radionuclides[j]	Porous media mineralogy and geochemistry[k]	Redox couples[l]	Redox analog[m]	Particulates	Trace organics[n]
Hydrochemistry (HC) boreholes plus borehole DC-18	HC-1	12	GR W SM		4 4 4	4 4 4	4 4 4	4 4 4	4 4 4		4 4 4	4 4 4	2 1 1	2 1 1	3 4 4	2 1 0
	HC-2	12	GR W SM		4 4 4	4 4 4	4 4 4	4 4 4	4 4 4		4 4 4	4 4 4	2 1 1	2 1 1	4 4 4	2 1 0
	HC-3	12	GR W SM		4 4 4	4 4 4	4 4 4	4 4 4	4 4 4		4 4 4	4 4 4	2 1 1	2 1 1	4 4 4	2 1 0
	HC-4	12	GR W SM		4 4 4	4 4 4	4 4 4	4 4 4	4 4 4		4 4 4	4 4 4	2 1 1	2 1 1	4 4 4	2 1 0
	HC-5	12	GR W SM		4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	2 1 1	2 1 1	4 4 4	2 1 0
	HC-6	12	GR W SM		4 4 4	4 4 4	4 4 4	4 4 4	4 4 4		4 4 4	4 4 4	2 1 1	2 1 1	4 4 4	2 1 0
	HC-7	12	GR W SM		4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	2 1 1	2 1 1	4 4 4	2 1 0
	HC-8	12	GR W SM	4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	2 1 1	2 1 1	4 4 4	2 1 0
	HC-9	12	GR W SM	4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	2 1 1	2 1 1	4 4 4	2 1 0
	DC-18	10	GR W		5 5	5 5	5 5	5 5	5 5	5 5	5 5	5 5	3 0	5 0	5 0	3 0
Pasco Basin	PB-1	10	GR W		5 5	5 5	5 5	5 5	5 5		5	5 5				
	PB-2	10	GR W		5 5	5 5	5 5	5 5	5 5		5	5 5				

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Table 8.3.1.4-3. Number of tests, location, and hydrochemical parameter matrix table (includes geologic formations and expected number of zones to be sampled for each borehole) (sheet 2 of 3)

Area	Boreholes[a]	Number of zones[b]	Formations[c]	Excess methane[d]	Field parameters[e]	Major inorganic constituents[f]	Trace elements[g]	Dissolved gases[h]	Stable isotopes	Trace level fission products[i]	Natural radionuclides[j]	Porous media mineralogy and geochemistry[k]	Redox couples[l]	Redox analog[m]	Particulates	Trace organics[n]
Pasco Basin (cont.)	PB-3	10	GR W		5 5	5 5	5 5	5 5	5 5		5	5 5				
	PB-4	10	GR W		5 5	5 5	5 5	5 5	5 5		5	5 5				
	PB-5	10	GR W		5 5	5 5	5 5	5 5	5 5		5	5 5				
	PB-6	10	GR W		5 5	5 5	5 5	5 5	5 5		5	5 5				
	PB-7	10	GR W		5 5	5 5	5 5	5 5	5 5		5	5 5				
Controlled area study zone 1	DC-26	7	GR W		4 3	4 3	4 3	4 3	4 3	0 0	4 3	4 3	2 1	2 1	4 3	2 1
	DC-27	7	GR W		4 3	4 3	4 3	4 3	4 3	0 0	4 3	4 3	2 1	2 1	4 3	2 1
	DC-28	7	GR W	4	4 3	4 3	4 3	4 3	4 3	0 0	4 3	4 3	2 1	2 1	4 3	2 1
	DC-29	7	GR W	4	4 3	4 3	4 3	4 3	4 3	4 3	4 3	4 3	2 1	2 1	4 3	2 1
	DC-30	7	GR W	4	4 3	4 3	4 3	4 3	4 3	4 3	4 3	4 3	2 1	2 1	4 3	2 1
	DC-31	7	GR W	4	4 3	4 3	4 3	4 3	4 3	0 0	4 3	4 3	2 1	2 1	4 3	2 1
	DC-32	7	GR W	4	4 3	4 3	4 3	4 3	4 3	0 0	4 3	4 3	2 1	2 1	4 3	2 1
	DC-33	7	GR W	4	4 3	4 3	4 3	4 3	4 3	0 0	4 3	4 3	2 1	2 1	4 3	2 1
	RRL-2B	4	GR	4	4	4	4	4	4	4	4	4	4	4	4	4

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CONSULTATION DRAFT

Table 8.3.1.4-3. Number of tests, location, and hydrochemical parameter matrix table (includes geologic formations and expected number of zones to be sampled for each borehole) (sheet 3 of 3)

Area	Boreholes[a]	Number of zones[b]	Formations[c]	Excess methane[d]	Field parameters[e]	Major inorganic constituents[f]	Trace elements[g]	Dissolved gases[h]	Stable isotopes	Trace level fission products[i]	Natural radionuclides[j]	Porous media mineralogy and geochemistry[k]	Major redox couples[l]	Major redox analogs[m]	Particulates	Trace organics[n]
Controlled area study zone 2	SC-1	5	GR W	3	3 2	3 2	0 0	3 2	3 2	0 0		3 2				
	SC-2	5	GR W	3	3 2	3 2	0 0	3 2	3 2	0 0		3 2				
	SC-3	5	GR W	3	3 2	3 2	3 2	3 2	3 2	3 2	3 2	3 2	2 1	2 1	3 2	2 1
	SC-4	5	GR W	3	3 2	3 2	3 2	3 2	3 2	3 2		3 2	2 1	2 1	3 2	2 1
	SC-5	5	GR W	3	3 2	3 2	0 0	3 2	3 2	0 0		3 2				
	SC-6	5	GR W	3	3 2	3 2	3 2	3 2	3 2	3 2	3 2	3 2	2 1	2 1	3 2	2 1
	SC-7	5	GR W	3	3 2	3 2	3 2	3 2	3 2	3 2	3 2	3 2	2 1	2 1	3 2	2 1
	SC-8	5	GR W	3	3 2	3 2	3 2	3 2	3 2	3 2	3 2	3 2	2 1	2 1	3 2	2 1
	SC-9	5	GR W	3	3 2	3 2	3 2	3 2	3 2	3 2	3 2	3 2	2 1	2 1	3 2	2 1
	SC-10	5	GR W	3	3 2	3 2	0 0	3 2	3 2	0 0		3 2				
	SC-11	5	GR W	3	3 2	3 2	0 0	3 2	3 2	0 0		3 2				

[a]The HC-1, HC-3, HC-4, and HC-7 boreholes are at the same locations as DC-26, DC-27, and DC-28 and a planned regional borehole, respectively. These boreholes may be constructed as joint hydrologic testing may be constructed as joint hydrologic testing and hydrochemical sampling facilities provided both sampling requirements and hydrologic testing needs can be accommodated from the same borehole.

[b]Total number of zones within formations analyzed for each sampling parameter.

[c]GR = Grande Ronde Basalt.
W = Wanapum Basalt.
SM = Saddle Mountains Basalt.

[d]Ratio of observed to maximum concentration that could occur at the temperature and pressure of the sampling depth. Excess methane will be measured only in Grande Ronde Basalt test zones above and below the candidate horizon in boreholes near the reference repository location.

[e]Field parameters are pH, dissolved oxygen, oxidation/reduction conditions, alkalinity, and conductivity.

[f]Major inorganic constituents include sodium, calcium, magnesium, potassium, SO_4^{2-}, chloride and HCO_3^-.

[g]Trace elements include the rare earth elements, selenium, nickel, uranium, arsenic, iodine, iron, thorium, and molybdenum.

[h]Dissolved gases include CH_4, C_nH_x, N_2, CO, H_2S, and the noble gases (helium, neon, argon, kypton, xenon, and radon).

[i]Trace level fission products include ^{129}I, ^{99}Tc, and ^3H.

[j]Natural radionuclides are uranium, thorium, ^{40}K, ^{14}C, and ^{36}Cl.

[k]Porous media mineralogy and geochemical parameters include stable isotopes, trace elements, noble gases, and natural radionuclides.

[l]Major redox couples include Fe(II/III), S(-II/VI), N(-III/V), and Mn(II).

[m]Redox analogs of radioactive waste components include Se(-II/IV), Sn(II/IV), U(IV/VI), I(-I/V), and Re(III/VII).

[n]Trace organics include total organic carbon, total carbon, fulvic acid, humic acid, and aliphatic acids.

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Table 8.3.1.4-4. Data needs from existing boreholes (sheet 1 of 4)

Borehole	Zone	Data needs
DB-1	Priest Rapids Member	(1) Nutrients[a] (2) Dissolved gases[b] (3) ^{36}Cl (5) ^{129}I
DB-2	Roza Member	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl
DB-4	Mabton interbed	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{13}C, ^{34}S
DB-5	Mabton interbed	(2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{13}C, ^{34}S, D/H (5) ^{129}I
DB-7	Mabton interbed	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{34}S (5) ^{129}I
DB-9	Mabton interbed	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{34}S (5) ^{129}I
DB-10	Mabton interbed	(1) Nutrients (2) Dissolved gases (3) ^{14}C, ^{36}Cl, uranium (4) ^{13}C, ^{34}S
DB-11	Priest Rapids Member	(1) Nutrients (2) Dissolved gases (3) ^{14}C, tritium (3) ^{36}Cl, uranium (4) ^{34}S, ^{13}C, ^{18}O, D/H
DB-12	Priest Rapids Member	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl (4) ^{34}S

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Table 8.3.1.4-4. Data needs from existing boreholes (sheet 2 of 4)

Borehole	Zone	Data needs
DB-13	Mabton interbed	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{34}S
DB-14	Priest Rapids Member	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{34}S
DB-15	Frenchman Springs Member	(3) ^{36}Cl (5) ^{129}I
DC-1	Grande Ronde Basalt	(1) Nutrients (2) Dissolved gases (3) ^{14}C, ^{36}Cl, uranium (4) ^{34}S (5) ^{129}I
DC-2A	Grande Ronde Basalt	(1) Nutrients (2) Dissolved gases (3) ^{14}C, ^{36}Cl, uranium (5) ^{129}I
DC-3	Umtanum flow	(1) Nutrients (2) Dissolved gases (3) ^{14}C, tritium (3) ^{36}Cl, uranium (4) ^{34}S, ^{13}C, ^{18}O, D/H
DC-5	Vantage interbed	(2) Dissolved gases (3) ^{14}C, ^{36}Cl (4) ^{34}S, ^{13}C (CH_4)
DC-6	Grande Ronde Basalt	(1) Nutrients (2) Dissolved gases (3) ^{14}C, ^{36}Cl (4) ^{13}C, D/H (CH_4) (5) ^{129}I
DC-7	Grande Ronde Basalt	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl (4) ^{13}C, D/H (CH_4)
DC-12	Grande Ronde Basalt	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl (4) ^{13}C, D/H (CH_4)
DC-14	Grande Ronde Basalt	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl

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Table 8.3.1.4-4. Data needs from existing boreholes (sheet 3 of 4)

Borehole	Zone	Data needs
DC-15	Grande Ronde Basalt	(1) Nutrients
DC-16A	Rocky Coulee flow	(1) Nutrients (2) Dissolved gases (3) ^{14}C, ^{36}Cl (4) D/H (CH_4) (5) ^{129}I
DC-16B	Mabton interbed	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{13}C, ^{34}S (5) ^{129}I
DC-16C	McCoy Canyon flow	(1) Nutrients (2) Dissolved gases (3) ^{14}C, ^{36}Cl, uranium
DC-19C	Umtanum flow	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{13}C, D/H (CH_4) (5) ^{129}I
DC-20C	Wanapum Basalt/ Grande Ronde Basalt	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{13}C, D/H (CH_4)
DC-22C	Wanapum Basalt/ Grande Ronde Basalt	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{13}C, D/H (CH_4)
RRL-2	Umtanum flow	(1) Nutrients (2) Dissolved gases (4) D/H (CH_4)
RRL-6B	Umtanum flow	(5) Anions (5) Cations (2) Dissolved gases (3) ^{14}C, ^{36}Cl, uranium (4) ^{34}S, ^{13}C, ^{18}O, D/H (3) Tritium
RRL-14	Umtanum flow	(1) Nutrients (2) Dissolved gases (3) ^{14}C, ^{36}Cl, uranium (4) ^{13}C, D/H, ^{18}O (4) ^{34}S, D/H (CH_4) (3) Tritium

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Table 8.3.1.4-4. Data needs from existing boreholes (sheet 4 of 4)

Borehole	Zone	Data needs
S11-E12A	Levey interbed	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium
Enyeart	Priest Rapids Member	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{13}C, D/H (CH_4) (4) ^{34}S
Ford	Priest Rapids Member	(1) PO_4^{3-} (2) Dissolved gases (3) ^{36}Cl, uranium (4) ^{13}C, D/H (CH_4)
McGee	Grand Ronde Basalt	(3) ^{36}Cl (2) Dissolved gases (4) ^{13}C, D/H (CH_4) (4) ^{34}S (5) ^{129}I
O'Brian	Priest Rapids Member	(1) Nutrients (2) Dissolved gases (3) ^{36}Cl, uranium

NOTE: Present hydrochemical data from these boreholes are considered inadequate because either (1) inappropriate sampling procedures were used, (2) certain measurements were never made (i.e., noble gases, quantitative major gas analyses, nutrients), (3) residual contaminant (tritium or nitrate) present indicates insufficient cleanup pumping, or (4) reported occurrences of ^{129}I in certain locations need to be validated (IWG, 1987). Additional cleanup pumping would be needed prior to resampling these wells; for locations in or near the controlled area study zone, this would be done after the piezometric baseline period.)

Nutrients: SO_4^{-2}, NO_3^{-1}, PO_4^{-3}.

Dissolved gases: CH_4, N_2, CO_2, O_2, NH_3, noble gases, ethane, propane, butane.

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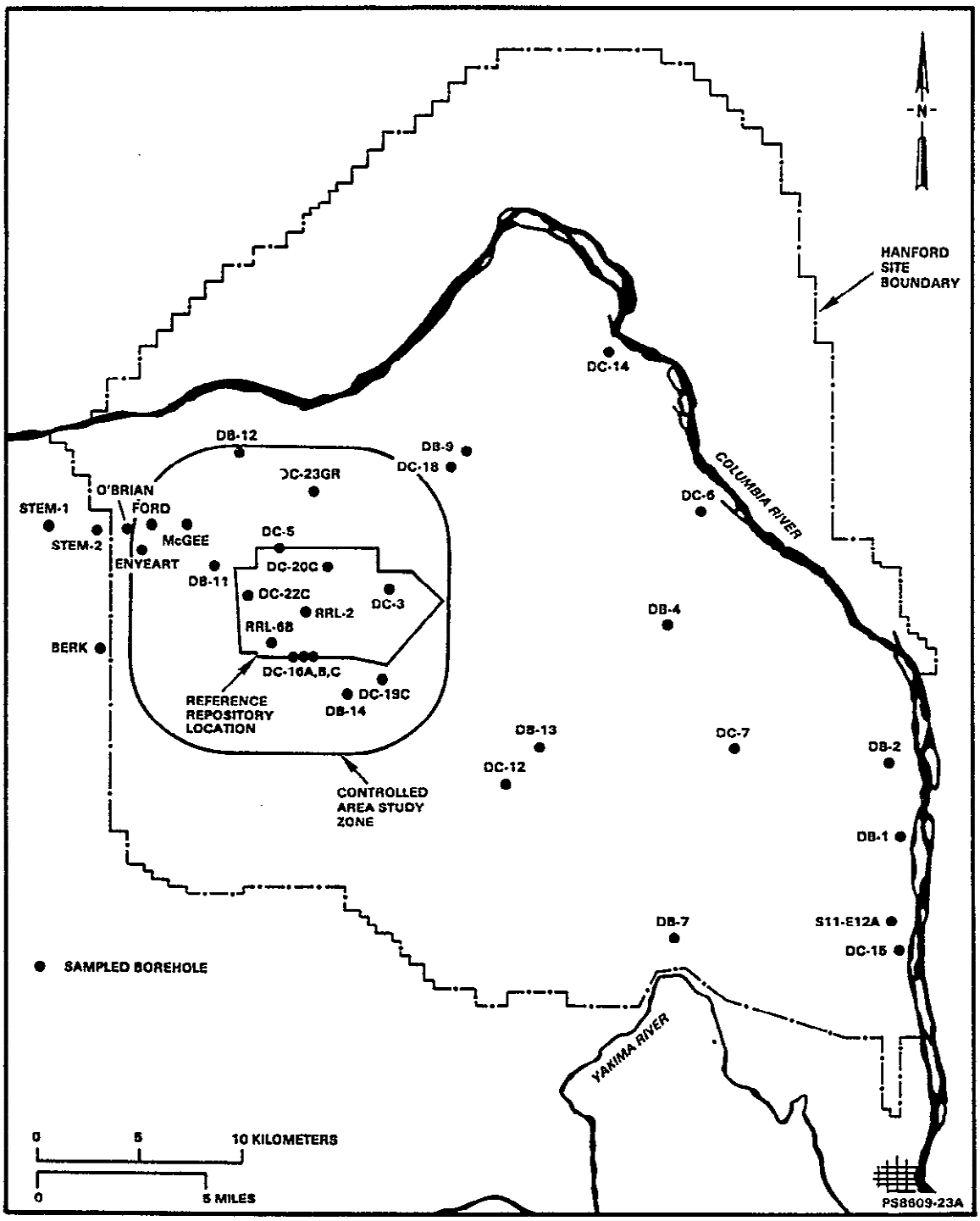

Figure 8.3.1.4-16. Borehole locations for wells identified for resampling (see Table 8.3.1.4-4).

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Table 8.3.1.4-5. Flow system hydrochemistry study: description of test measurements and procedures (sheet 1 of 3)

Type of measurement	Key parameters measured	Applicable procedures (date available)	Accuracy/ precision[a]	Range of expected results	Required equipment	Data reduction/ analysis techniques
Field measurements	pH	BOP	±5%	7 to 10.5	pH meter and electrodes	Direct readout
	Platinum electrode potential	BOP	±15%	-300 to +300 mV	Platinum electrode/pH meter	Direct readout
	Alkalinity	BOP	±5%	25 to 200 mg/L	Titration apparatus	Direct readout
	Conductivity	BOP	±5%		Conductivity meter	Direct readout
	Temperature	BOP	±5%	20 to 60 °C	Temperature probe	Direct readout
Laboratory measurements	Major cations[b]	BOP	±5%	1 to 400 mg/L	ICP, AA	Instruments
	Anions[c]	BOP	±5%	1 to 500 mg/L	Ion chromatograph	Instruments
	Trace elements[d]	BOP/PNL (1/87)	±5%	ng/L to mg/L	ICP, ICP-MS, AA	Instruments/ computer
	Rare earth elements[e]	RSD-51-DIS-9, 14	±5%	1 to 100 µg/L	INAA, ICP-MS	Instruments/ computer
	Major gases[f]	BOP	±5%	0.1 to 1,000 mg/L	Gas chromatograph	Instruments/ computer
	Noble gases[g]	Allied-Bendix	±5%	10^{-8} to 10^{-4} cm^3 STP/cm^3	Mass spectrometer	Instruments/ computer
	Stable isotopes[h]	Offsite vendors (Geochron and University of Miami)	0.2% to 2%			
	^{14}C	Offsite vendors (Geochron and University of Miami)	±0.5	1.5% to 100% modern carbon		
	^{36}Cl	Offsite vendors (University of Rochester)	±10%	1 to 30 x 10^7 atm/L	Accelerator mass spectrometer	Instruments/ computer
	Tritium	Offsite vendors (University of Miami)	±5% (at 1 TU)	0.1 to 100 TU		

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Table 8.3.1.4-5. Flow system hydrochemistry study: description of test measurements and procedures (sheet 2 of 3)

Type of measurement	Key parameters measured	Applicable procedures (date available)	Accuracy/ precision[a]	Range of expected results	Required equipment	Data reduction/ analysis techniques
Laboratory measurements (cont.)	Low-level fission products[i]	PNL/RSD-51-DIS-15, 16,17,18,19 (in preparation/available 1/87)	±10%	10^{-6} to 10 pCi/L	Radiochemistry separations and counting equipment	Hand data reduction RSD-51-DIS-19
	Natural radionuclides[j]	RSD-51-DIS-2,3,4,5,6, 7,8,10,11, and 12	±5% to 10%	10^{-3} to 1 pCi/L (^{222}Rn 30 to 1,000 pCi/L)	Radiochemistry separations and counting equipment	Hand data reduction RSD-51-DIS-19
	Organics		±10%	0.05 to 2 mg/L	GC-MS; total organic carbon analyzer	Hand data reduction RSD-51-DIS-19
	Particulates		±15%	0.01 to 0.1 mg/L	Gravimetric	Hand data reduction RSD-51-DIS-19
Key flow-top secondary mineral phases	Stable isotopes	Vendor supplied	0.2% to 2%		Vendor supplied	
	Rare earth elements	RSD-51-DIS-14	±10%	0.1 to 20 µg/g	INAA/RNAA; ICP-MS; laser ablation	
	Trace elements[a]	PNL (1/87)	±10%	0.1 to 1,000 µg/g	INAA/RNAA; ICP-MS; laser ablation	
	Natural radionuclides[k]	RSD-51-DIS-213, 4,13	±10%	~ 1 pCi/g		Uranium, thorium, and radon only
	Noble gases (^{4}He)	Allied-Bendix	±5%	10^{-6} to 10^{-7} cm^3 STP/cm^3	Furnace and mass spectrometer	
Bulk rock composition	Stable isotopes	Vendor supplied	0.2% to 2%		Vendor supplied	
	Rare earth elements	RSD-51-DIS-14	±10%	0.1 to 20 µg/g	INAA/RNAA; ICP-MS; laser ablation	
	Trace elements[a]	PNL (1/87)	±10%	0.1 to 1,000 µg/g	INAA/RNAA; ICP-MS; laser ablation	

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Table 8.3.1.4-5. Flow system hydrochemistry study: description of test measurements and procedures (sheet 3 of 3)

Type of measurement	Key parameters measured	Applicable procedures (date available)	Accuracy/ precision[a]	Range of expected results	Required equipment	Data reduction/ analysis techniques
Bulk rock composition (cont.)	Natural radionuclides[k]	RSD-51-DIS-213, 4,13	±10%	~ 1 pCi/g		Uranium, thorium, and radon only
	Noble gases (^4He)	Allied-Bendix	±5%	10^{-6} to 10^{-7} cm^3 STP/cm^3	Furnace and mass spectrometer	
Mesostasis	Trace element abundance/ isotopic ratios		Abundances ± 10% to 15% Ratios: ± 10%		ICP-MS/laser ablation	Instrumental/ computer codes

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NOTE: AA = Atomic absorption.
BOP = Basalt operating procedure.
ICP = Inductively coupled plasma emission.
ICP-MS = Inductively coupled plasma emission-mass spectrometer.
INAA = Instrumental neutron activation analysis.
PNL = Pacific Northwest Laboratory (Battelle).
RNAA = Radiochemical neutron activation analysis.
STP = Standard temperature and pressure.
TU = Tritium unit.

[a]Isotopic ratios are also available from ICP-MS instrumentation to be acquired in FY 87 and procedures established for both elemental abundance and isotope ratio analysis of selected elements ($^{87/86}Sr$, $^{37/35}Cl$).

[b]Sodium, potassium, magnesium, calcium, aluminum (silicon).

[c]Chloride, SO_4^{2-}, HCO_3^-, fluoride, bromide, NO_3^-.

[d]Tin, palladium, selenium, zircon, nickel, strontium, cesium, barium, iodine (isotopic ratios also available with ICP-MS).

[e]Lanthanum, cesium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, holmium, thulium, ytterbium, lutetium.

[f]CH_4, N_2, argon, O_2, H_2, (C_nH_x, NH_3, H_2S).

[g]Helium, neon, argon, krypton, xenon, $^3He/^4He$, $^{40}Ar/^{36}Ar$.

[h]$\delta^{34}S$, $\delta^{13}C$, δD, $\delta^{18}O$, (δD, $\delta^{13}C$) methane.

[i]^{129}I, ^{99}Tc, ^{90}Sr, ^{137}Cs.

[j]^{238}U, ^{235}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{222}Rn, ^{210}Pb, ^{232}Th, ^{228}Th, ^{228}Ra, ^{224}Ra, ^{210}Po, ^{210}Bi.

[k]Radioisotopes of uranium, thorium, and radon only.

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Field parameters

Many reaction mechanisms involve hydrolysis by silicates, and the stability of the silicates is directly related to pH. The pH will also affect the mobility of radionuclides released from a repository. Many of the key radionuclides form hydrolysis products whose stabilities are directly related to groundwater pH. Furthermore, in geochemical modeling, pH is an important variable in evaluating the plausible sets of reactions that result in changes of groundwater composition. Thus, alkalinity and pH must be measured in the field to avoid changes that can occur during storage and transfer to the laboratory.

Major inorganic constituents

As groundwater moves through an aquifer from regions of recharge to discharge, the concentrations of major anions and cations (e.g., sodium, potassium, calcium, magnesium, chloride, HCO_3^-, SO_4^{2-}) change in response to physical and chemical processes such as ion exchange, dissolution-precipitation and mixing of waters from different sources. In principle, through interpretative techniques such as geochemical modeling, it may be possible to relate the observed chemistry of groundwaters to a set of mechanisms that control their composition. The proposed mechanisms can be integrated with hydrologic and geologic information to arrive at a conceptual groundwater flow model consistent with all available data (Kerrisk, 1983; Plummer et al., 1983).

Trace elements

Some trace elements (arsenic, iron, selenium) are potentially useful indicators of the site redox environment. Others are key constituents in rock-forming minerals and must be considered in geochemical models and other rock/water reaction studies. Certain elements (e.g., molybdenum) are useful indicators of pipe joint lubricant contamination in groundwater samples (DOE, 1982, p. 5.1-129). Other trace elements (uranium, thorium, iodine, tin, etc.) are stable counterparts of long-lived radioactive waste; their distribution across hydrochemical regimes may provide clues to the expected behavior of radioactive wastes. The rare earth elements can provide similar information about the expected behavior of the actinides.

Dissolved gases

The composition of dissolved gases in groundwater can reveal significant information on geochemical processes in the aquifers. For example, methane is present in many Hanford Site groundwater samples. The BWIP investigators will study the origin of the methane because of the potential commercial value of methane and because of its implications for mine safety. The isotopic composition of carbon and hydrogen provide evidence about the origin of methane.

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Dissolved noble gases (helium, neon, argon, krypton, and xenon) provide some information about recharge temperature (Sugisaki, 1961; Mazor, 1972; Andrews and Lee, 1979; Herzberg and Mazor, 1979). Data about dissolved noble gases may help define the areas of recharge and therefore might help elucidate groundwater flow paths. Reconstruction of the relative ages of different groundwaters from helium content and (or) isotopic compositions may also help clarify direction of groundwater flow and lead to semiquantification of flow rates (Phillips, 1981; Davis and Murphy, 1987).

Stable isotopes

Groundwater ratios of $^{18}O/^{16}O$ and $^{2}H/^{1}H$ are well suited for the study of groundwater movement because they are incorporated as part of the water molecule. Provided that groundwaters are not subjected to temperatures in excess of 60 to 80 °C, these isotopes are generally conservative within a flow system. These isotopes provide information regarding origin and elevation of recharge and secondary processes such as evaporation and mixing of various waters. (See Sections 3.4, 3.7, and 3.9 for additional discussion.)

The stable carbon isotopic composition can reveal information about redox conditions in the system (e.g., redox equilibrium versus disequilibrium). Determination of carbon isotopic ratios in secondary minerals in the basalt flow tops and in the water may help show oxidizing or reducing trends along flow paths. However, if the kinetics of the redox reactions between solids and water are sluggish compared with fluid flow rates, the redox-related fractionations are not observed. Investigators will evaluate this possibility by comparing calculated travel times with data collected from the literature and from in situ field sorption tests. Possible disequilibrium fractionations can be modeled and compared with the field data.

Groundwater sulfate can come from several sources. Most commonly, sulfate is the result of either evaporite-mineral dissolution and (or) the oxidation of sulfide minerals (e.g., pyrite). Temperature and redox conditions are the most common factors affecting sulfur isotopic changes in groundwater regimes. Of particular interest is the relationship between $^{13}C/^{12}C$ and $^{34}S/^{32}S$ in waters where methane and sulfate could have interacted.

Trace-level fission products

The trace-level fission products, ^{129}I, ^{99}Tc, ^{3}H, and nitrate are present in certain portions of the unconfined aquifer as contaminants from defense wastes. The BWIP investigators will use these isotopes to evaluate the extent of communication between the unconfined aquifer and the deeper, confined basalt aquifers. Iodine-129 is particularly well-suited for this purpose because it does not occur naturally at the levels found in the unconfined aquifer. Thus, levels above the practical detection limit of approximately 10^{-6} pCi/L in basalt groundwaters may indicate aquifer intercommunication. Aquifer intercommunication, if it exists, has important implications for postclosure monitoring and for evaluation of potential vertical pathways between the repository and the accessible environment. These measurements

will be made at borehole locations that intersect the near-surface defense waste contaminant plume (see Fig. 8.3.1.4-12). (See also Section 3.9.5.5 for a review of existing ^{129}I data and implications for vertical groundwater movement.)

Natural radionuclides

The naturally occurring radionuclides (^{14}C, ^{36}Cl, ^{81}Kr) enter the groundwater through normal recharge. The groundwater concentrations equilibrate with the atmospheric concentrations at the recharge areas. Once the radionuclides become isolated from the atmosphere, their concentrations decrease exponentially with time caused by radioactive decay. If the half-life of the radionuclide is comparable to the groundwater residence time, then the amount of decay is a measure of the time since recharge. This method of groundwater dating assumes no isotopic exchange with the solids along the groundwater flow path; an age correction may be applied if exchange is suspected. Constraints and methods of analysis that will be applied are as described in Davis and Murphy (1987).

Porous media mineralogy and geochemistry

The BWIP investigators will analyze the stable isotopic compositions of porous media to evaluate the degree of isotopic fractionation between secondary minerals and water and the extent of equilibrium (or disequilibrium) in the hydrologic system. These data may provide insight into the paleoclimatic conditions occurring at the time of recharge. They may also provide insight into the isotopic variations related to redox conditions along a flow path. The identity of secondary alteration minerals formed by basalt and (or) water interactions will be determined by x-ray diffraction, scanning electron microscopy, and scanning transmission electron microscopy. The secondary phases can be used as input to geochemical models if the identity and abundances of the minerals are known.

Major redox couples

The concentration ratios of redox couples provide empirical evidence about groundwater and flow path redox conditions. The BWIP investigators will evaluate the natural site redox conditions from the concentration ratio of each redox couple. By comparing the calculated redox conditions, investigators can evaluate whether or not the couples are in equilibrium and whether or not the site redox conditions can be estimated within a narrow range of values. Assumptions about equilibrium are critical in interpreting existing data simulation results. The estimated site redox environment is a critical parameter in the modeling of radionuclide migration through the natural system. (These data will be used in the redox characteristics study, Section 8.3.1.4.3.3.2.)

Redox analogs

The behavior of redox analogs of the radioactive waste components provides empirical evidence for how the radioactive waste will behave in the natural system. The natural analogs are tin (an analog of ^{126}Sn), selenium

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(an analog of ^{79}Se), uranium (an analog of $^{234}U/^{238}U$), iodine (an analog of ^{129}I), rhenium (an analog of ^{99}Tc). Detectable amounts of selenium (II/IV) have already been measured in Hanford Site groundwater (Wong, 1986). The analog studies provide a check on the validity of theoretical models. Only selected test zones in the vicinity of the candidate horizon within the controlled area study zone will be examined (see Table 8.3.1.4-3). These data will be used in the redox characteristics study (see Section 8.3.1.4.3.3.2).

Particulates

Investigators will use the data on groundwater particulate matter in the radionuclide retardation behavior investigation. Natural particulates consist mostly of clay minerals, zeolites, and hydrated oxides or hydroxides of silicon, iron, and aluminum. Particulate stability is a function of sodium and calcium concentrations in the groundwater as well as the flow rate, density of particles, and pore size distribution. Two studies (Neretnieks, 1978; Barnes, 1976) in areas other than at the Hanford Site show particulate concentrations in natural groundwaters may be as low as one part per billion. At this concentration, the likelihood of significant radionuclide migration by particulate transport is small. However, further work is necessary because particulate concentrations in Hanford Site groundwaters are unknown.

The measurement of particulate concentrations depends on the availability of boreholes drilled without clay-based drilling fluids. The boreholes should either have already been developed for extensive time periods or should be capable of being developed for extensive time periods.

Trace organics

Because certain organic species can form complexes that promote radionuclide transport, investigators will determine the nature and concentration of organic constituents in groundwater samples. These data will provide input to the radionuclide retardation behavior investigation. The total organic carbon content of Hanford Site groundwaters is available in the BWIP hydrochemical data base (Early et al., 1986). However, essentially no data exist on the structure, complexing properties, and concentration of specific naturally occurring organic compounds in these groundwaters.

Means (1982, pp. 1-22) characterized the organic compounds found in one sample of Grande Ronde Basalt groundwater from the Hanford Site. A wide variety of organic constituents was found in the sample and fulvic acids seemed to predominate. Considering the known complexing ability of fulvic acids for radionuclides (Means, 1982) these studies will be expanded to include analyses of total organic carbon on all groundwater samples and detailed analyses of other organic species on selected samples. Consequently, this portion of the investigation will constitute a more comprehensive characterization of organic constituents in Hanford Site groundwaters.

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The occurrence of aliphatic acids may also provide clues concerning the origin of and controls on methane in the reference repository location. Beds of lignite may underlie the reference repository location and could serve as a source of methane and other trace organics. Selected test zones for drilling that have undergone extensive cleanup pumping will be used for these measurements.

8.3.1.4.3.3.1.3 Borehole development and sampling strategy. Before groundwater samples are collected from a water-producing zone, the zone must be developed by pumping to flush contaminants from the aquifer, the borehole itself, and the pump and riser pipe system. The drilling fluid used during borehole construction is the main source of contaminants. Part of the drilling fluid is effectively injected into the aquifer when the hydraulic head of fluid in the borehole is greater than the static head of the aquifer.

Hydraulic communication between aquifers via the borehole is a secondary source of contamination. Under such circumstances, a difference in static head between the aquifers can result in flow from the aquifer(s) with higher head(s) to the aquifer(s) with lower head(s). Contamination by aquifer cross-communication can be prevented by aquifer isolation.

The pump and riser pipe system is a third source of contamination. Lubricants and rust can bias results of sample analysis for iron, organic carbon, and carbon isotopes. Contamination from the pump and riser pipe system can be extremely difficult to assess. A mitigating factor is that such contaminants are largely flushed from the hardware system during the pumping campaign. (See Section 8.3.1.4.4.3.3.2 for additional discussion of procedures to avoid sample contamination.)

Contamination in groundwater samples alters the apparent concentration of dissolved species, including ionic species, gases, stable and radioactive isotopes, and organic solutes. In some cases, a contaminating fluid may completely mask the true in situ concentration of trace species. This masking is of particular concern for species such as ^{36}Cl or ^{14}C, which are used in determining groundwater age and whose abundance in young water sources (e.g., surface water or shallow unconfined aquifers) is normally very much greater than in deep groundwaters.

Contamination also introduces species that are foreign to in situ groundwaters. Principal examples are nitrate and dissolved oxygen, both common to surface sources. In both cases, any detectable concentration in groundwater samples, if considered "real" rather than simple contamination, has a profound effect on redox calculations.

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The extent to which a contaminant fluid alters apparent groundwater chemistry depends on the composition of the contaminant fluid compared to the groundwater and on the volumetric ratio of groundwater to contaminant fluid in collected samples.* The ratio can be determined by monitoring chemical tracers during the development campaign. The following discussion assumes that contamination is due to drilling fluid loss and that samples of the drilling fluid will themselves be generally subjected to the same analysis as the formal suite of samples collected near the end of the pumping campaign.

Borehole development data and data for contaminant evaluation come from three sources: (1) field analysis, (2) quantitative interpretation of tracer results, and (3) aquifer isolation. Each of these data sources and contaminant problems for each source are discussed below.

Field analysis

Determination of key chemical parameters in samples collected during borehole development is the only effective means of judging the degree of restoration of in situ hydrochemical conditions. Key chemicals should be measured immediately in the field in order to avoid time delays caused by laboratory turnaround time. A further advantage to performing analyses immediately upon collection is to avoid sample preservation for chemically unstable species.

In theory, any dissolved species that might change as a result of changes in the groundwater-to-contaminant fluid ratio can be used to monitor cleanup. Historically, investigators have used the stabilization of hydrochemical parameters to indicate that a collected sample represents in situ chemistry. Figure 8.3.1.4-17 illustrates this approach and shows that the approach defies precise quantification, because the progression towards stabilization is asymptotic.

Experience at boreholes DC-18 and DC-23, historical review of data from borehole DC-14 (Graham et al., 1985), and corroboration using data from the Raft River Geothermal Field in Idaho (Koslow and Hull, 1984), show that development data, especially for conservative species, can be plotted as a straight line when log [concentration] is plotted against log [pumped volume] for attenuating species. Figures 8.3.1.4-18 through 8.3.1.4-20 illustrate the behavior of attenuating tracer species. Table 8.3.1.4-6 lists properties of species that have been studied for possible use as tracers at Hanford. The BWIP strategy will be to use both tracers added to the drilling fluid and "natural" tracer in the drilling fluid makeup water. Bromide is the tracer of choice for field monitoring of cleanup or removal of drilling fluid from BWIP boreholes (see Table 8.3.1.4-6).

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*This approach neglects nonconservative behavior of certain analytes (like total organic carbon and O_2). Such analytes therefore cannot be used as tracers. However, their nonconservative behavior provides information about site redox conditions (oxygen removal rate under actual aquifer conditions).

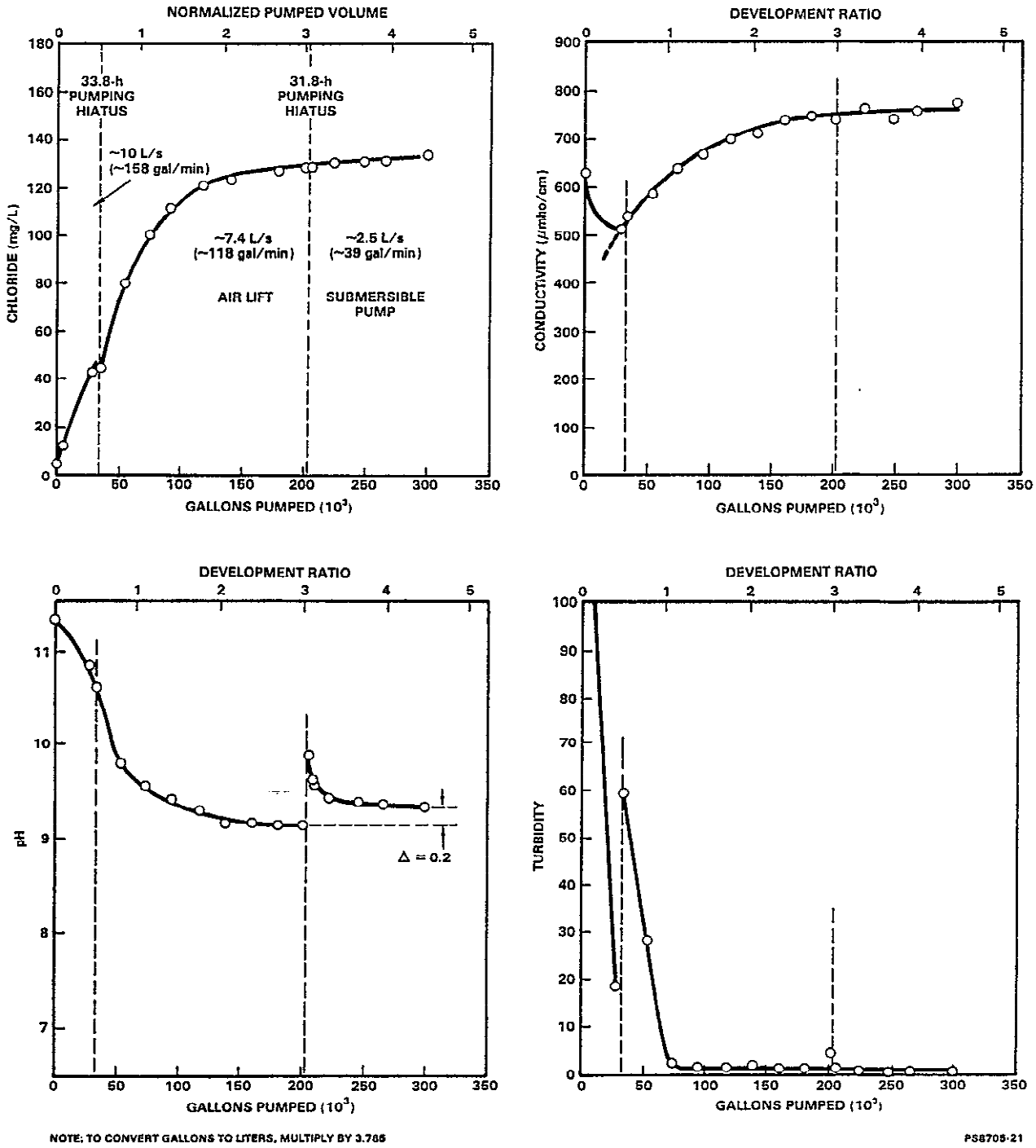

Figure 8.3.1.4-17. Conventionally plotted field analysis results from borehole DC-23GR, Rosalia flow top. (Pumping was performed in three stages. Note the effect of air-lift pumping on sampling pH. The development ratio is the volume pump divided by the volume of drilling fluid injected into the aquifer during borehole construction.)

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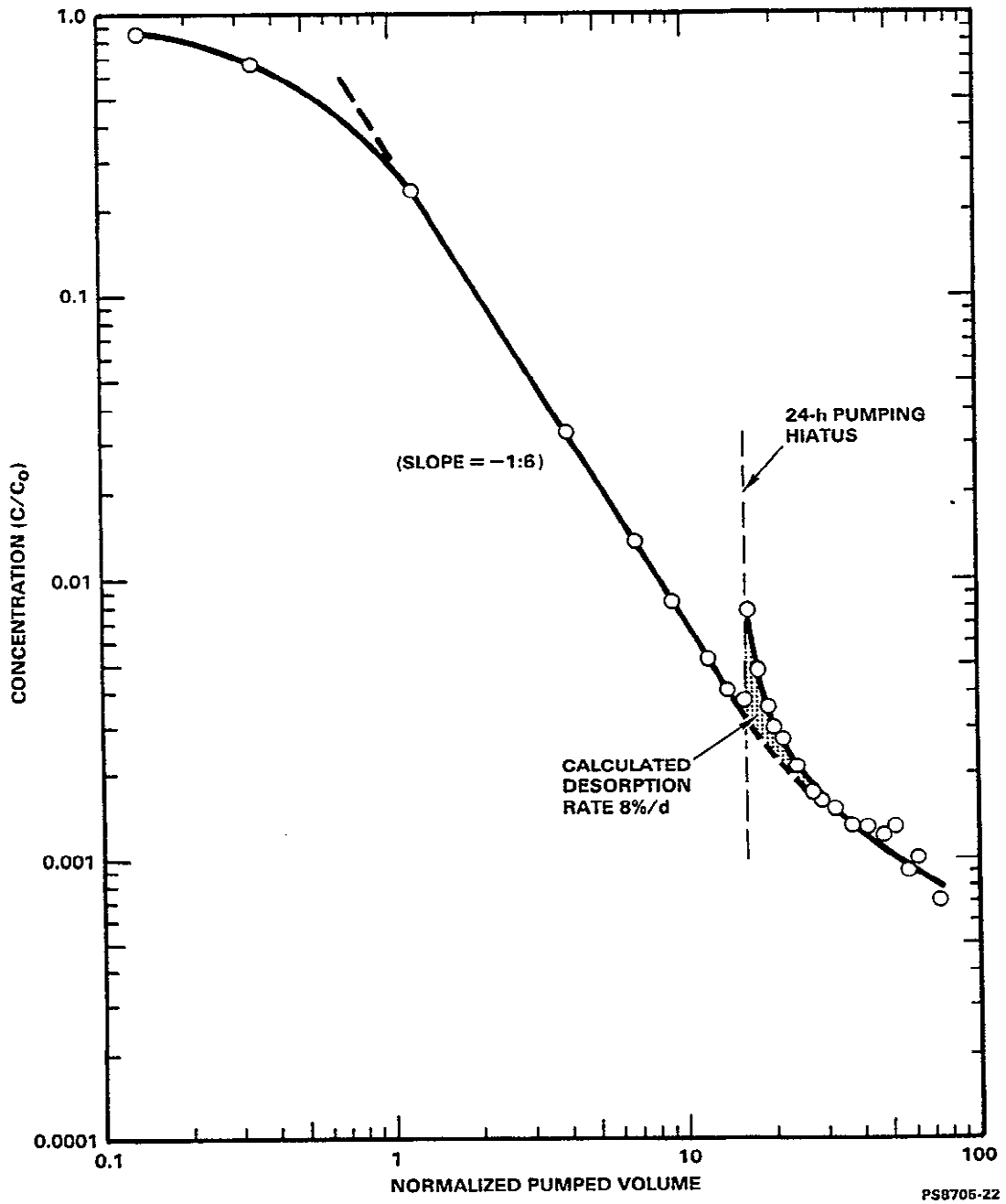

Figure 8.3.1.4-18. Fluorescein attenuation at borehole DC-18, Roza flow top. (The concentration spike following the soak period and the curve toe are both due to desorption of dye from mineral phases.)

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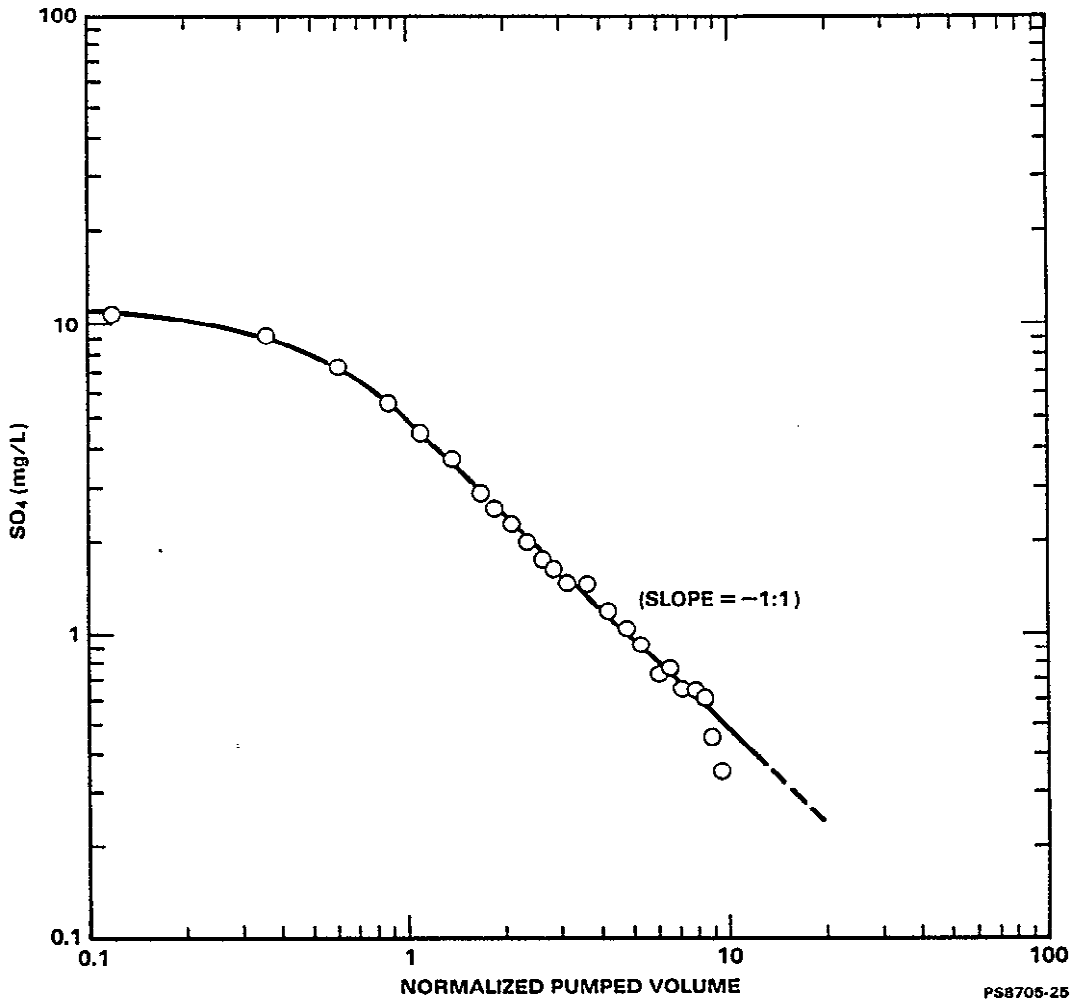

Figure 8.3.1.4-19. Sulfate attenuation at borehole DC-18, Sentinel Gap flow top. (The -1:1 slope shows that sulfate behaves conservatively in the Hanford Site basalts.)

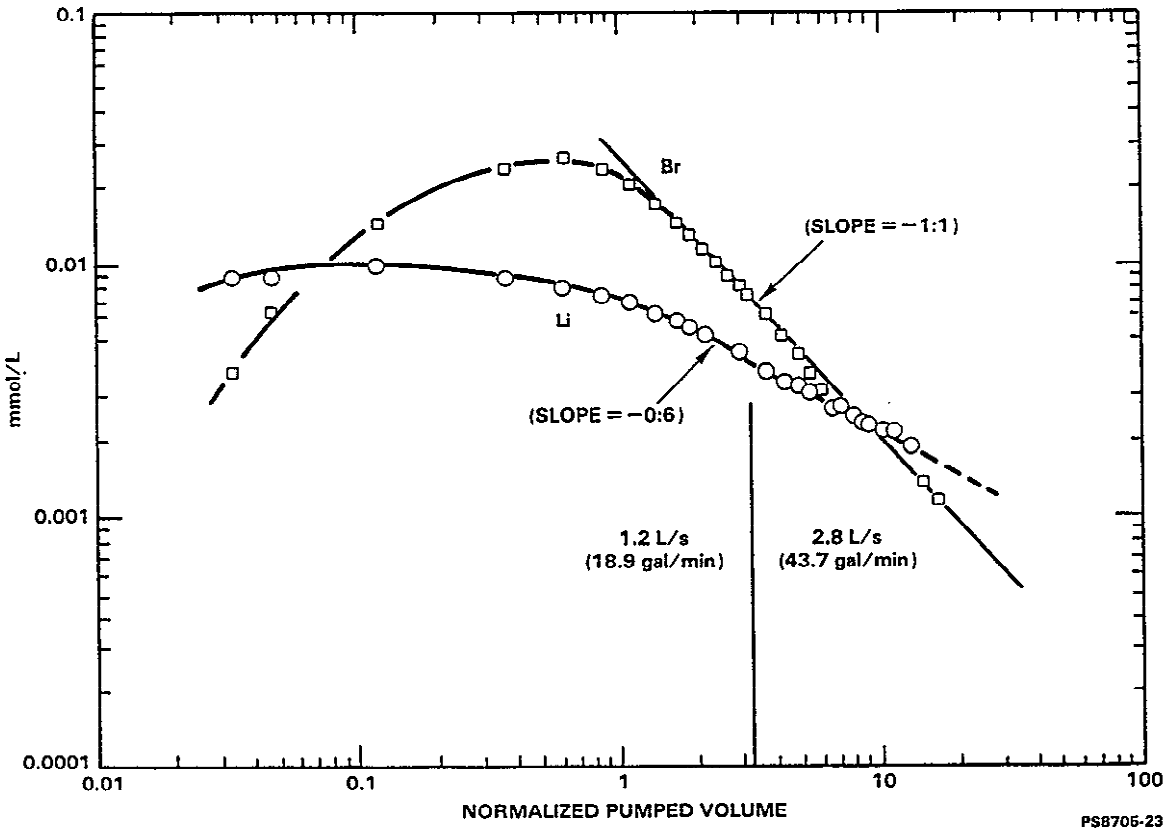

Figure 8.3.1.4-20. Attenuation of lithium and bromide at borehole DC-18, Sentinel Gap flow top. (These species were added as lithium bromide in a tracer pulse. Note that bromide behaves conservatively, with a -1:1 slope, and that lithium is attenuating at a rate lower than that of bromide, due to reversible sorption by mineral phases.)

Table 8.3.1.4-6. Groundwater development tracer properties as applied to Hanford Site basalts

Species	Reactivity	Analytical	Comments
Bromide*	Conservative	Good field methods available	Absent in groundwater, best tracer identified to date
Sulfate	Conservative	Poor field precision, moderate to good laboratory precision	Only used for retrospective confirmation of cleanup data, due to poor precision of field methods
Tritium*	Conservative	Poor precision, no field method	May be used as confirmatory data using time-series analysis
Fluorescein*	Sorbs to mineral phase	Ultraviolet-fluorescence. Excellent field method, with high sensitivity	Desorbs sluggishly, which may exaggerate apparent degree of cleanup
Chloride	Conservative	± 1% or 2 mg/L, whichever is greater, using field titration method	At the Hanford Site, Cl^- recovers rather than attenuates, useful for retrospective confirmation of cleanup date
Oxygen*	May be reactive	Extremely sensitive field determination, but precision and accuracy affected by sampling	Not suited as cleanup tracer due to strong sorption or reaction, difficult to quantify, injected O_2 concentration
Sodium	Sorbs to mineral phase	Analytical precision ± 1%	Recovers, rather than attenuates, and sorbs, poor tracer choice
Lithium*	Sorbs to mineral phase	No available field method. Laboratory precision ± 1%	High retention factor, poor cleanup tracer, apparent rapid solid/liquid equilibrium

*Natural abundance extremely low or undetectable in Wanapum and Grande Ronde Basalt groundwaters.

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Quantitative interpretation of tracer results

Data collected while monitoring either a recovering or an attenuating tracer can be used to quantitatively estimate the residual percentage of drilling fluid in groundwater samples provided that (1) the concentrations of the tracers injected with the drilling fluid into the formation are known, (2) the tracer behaves conservatively, (3) the aquifer is isolated during injection and withdrawal, and (4) the natural groundwater concentration of an attenuating tracer species is very low compared to the injected concentration.

Evaluation procedure. For an attenuating tracer, plot log (C/C_0) as a function of log (pumped volume) where C_0 = injected concentration and C = sample concentration. Note that (C/C_0) x 100 equals the volume percent of contaminant fluid in the sample. Extrapolate the straight-line portion of the resulting curve to any desired C/C_0 and the required pumped volume may be read from the abscissa. If the plot flattens, indicating either a natural groundwater concentration of the species or slightly nonconservative behavior, such flattening should be ignored for the purpose of extrapolating the straight-line segment of the curve.

The BWIP has established the following rules for development pumping in order to maximize useful information from tracers added to drilling fluid:

- Choose a conservative drilling fluid tracer, such as bromide, that exists in very low or undetectable levels in the groundwater and that can be precisely and sensitively determined in the laboratory.
- Use a concentration of tracer in the drilling fluid be great enough to allow precise determination of the tracer in samples, even after significant dilution by groundwater. Tracer concentration in the drilling fluid should be at least 1,000 times greater than the practical analytical detection limit.
- During development, sample frequently to ensure the establishment of accurate trends. Twenty or thirty data points are a reasonable goal for a total pumping withdrawal of about ten times the volume lost to the test zone during drilling.

Aquifer isolation

The most meaningful interpretation of drilling fluid tracer data can be made when the concentration of the tracer in the injected fluid and the volume of drilling fluid introduced into the aquifer of interest are both known. The former is relatively easy to control at the surface. The latter presupposes that, during penetration of the aquifers of interest, no other aquifer will be contributing to drilling fluid losses.

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The simplest way to ensure this kind of volumetric control is to use a "drill-and-sample" approach. Each water-producing zone is penetrated, developed, sampled, and then cased or cemented before proceeding to the next producing zone. The drill-and-sample approach has two main advantages:

- The bottom of the hole serves to isolate the zone of interest from lower aquifers, eliminating the need for a lower packer. Also, because all water-producing zones above the target zone are sealed by either cement or well casing, it is possible (though not desirable) to develop the aquifer without an upper packer. This becomes necessary when a good packer seat cannot be obtained and when the hole is an oblate or large-diameter hole.

- Fluid losses during drilling are confined to the single aquifer being penetrated. This enhances the ability to quantify relative tracer mass recovery, and it facilitates an estimate of the total mass of host rock encountered by the tracer solution.

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8.3.1.4.3.3.1.4 Sampling methods. Groundwater samples will be obtained at the Hanford Site by three means: air lifting, submersible pumping, and downhole sampling.

Air lifting

Surface air is injected downhole and the rising bubbles effectively lift water, which may be collected at the surface. However, the injecting of air causes exsolution ("scrubbing") of dissolved gases from the groundwater; changes carbonate/bicarbonate alkalinity, pH, and mineral solubilities (see Fig. 8.3.1.4-17); affects the redox-sensitive solutes by air contact; and subjects natural radionuclide content (e.g., ^{14}C and ^{3}H) of the groundwater to contamination.

Submersible pumping

Submersible pumping includes all pumping methods that deliver groundwater samples to the well-head via a riser pipe. In this study, a sample may be routed through filters and collected under inert gas to avoid atmospheric contamination. Where reduction in pressure is sufficient to cause gas exsolution as the sample is raised to the surface, the off-gas can be collected separately (HT-ES-214, Gas Separator Barrel Sampling).

Loss of hydrochemical information is minimal, and such losses are directly related to pressure (and sometimes temperature) effects. Many of the losses can be corrected mathematically. However, pressure reduction, especially when combined with gas exsolution, can result in mineral precipitation. Mineral precipitation may be unnoticed and it may actually occur in the pump riser tubing. Further, the pump tubing, pump impellers, and pipe lubricants must be viewed as possible sources of contaminants.

Downhole sampling

Downhole sampling includes sampling probes that are lowered into the well to collect an uncontaminated sample at aquifer depth. The probes will return the sample to the surface under pressure. The BWIP is currently using such a device (Fig. 8.3.1.4-21). (An improved, narrow-diameter device is also under development and is shown in Fig. 8.3.1.4-22.)

Pressure-sensitive geochemical information is not lost with downhole sampling (barring temperatures extremes) as described above. Teflon and stainless steel components are used to minimize container contamination for trace element sampling (i.e., without the copper tube attachment for dissolved gases). The disadvantage of this sampler is that it yields a small sample size (less than 1 L (0.26 gal)pressurized). Therefore, it will be used where necessary to supplement or validate results from submersible pump sampling and to obtain dissolved gas data at in situ pressures. See Section 8.3.1.4.4.3.3.2 for additional discussion of downhole sampling methods for trace constituents (e.g., selenium, arsenic, etc.).

8.3.1.4.3.3.1.5 Origin of high chloride groundwater. The origin of the high chloride groundwaters beneath the Hanford Site is currently unknown. An understanding of the evolution of this water is needed to assess the rate and extent of postclosure geochemical changes that might occur in the vicinity of the proposed repository.

Current evidence and considerations (Section 4.1.2.9) suggest that high chloride (greater than 50 mg/L) groundwater cannot arise by basalt/water reactions. If this is true the deep groundwaters (up to 600 mg/L) beneath the Hanford Site must have been in contact with source rocks other than basalt at some point in their history. Possible explanations include the following:

- Leaching of sub-basalt marine sedimentary deposits.
- Injection of volcanic emanations into groundwater near areas of recharge (east side of the Cascade range).
- Leaching of high chloride inclusions from past volcanic activity.

Mineralogic and petrographic analysis of sub-basalt strata and vesicular basalts may shed some light on the sources involving past volcanic activity. Some sub-basalt core will be available from nearby exploration wells. These as well as other core can be examined for evidence of chloride containing inclusions (leaching of fracture/vesicle linings).

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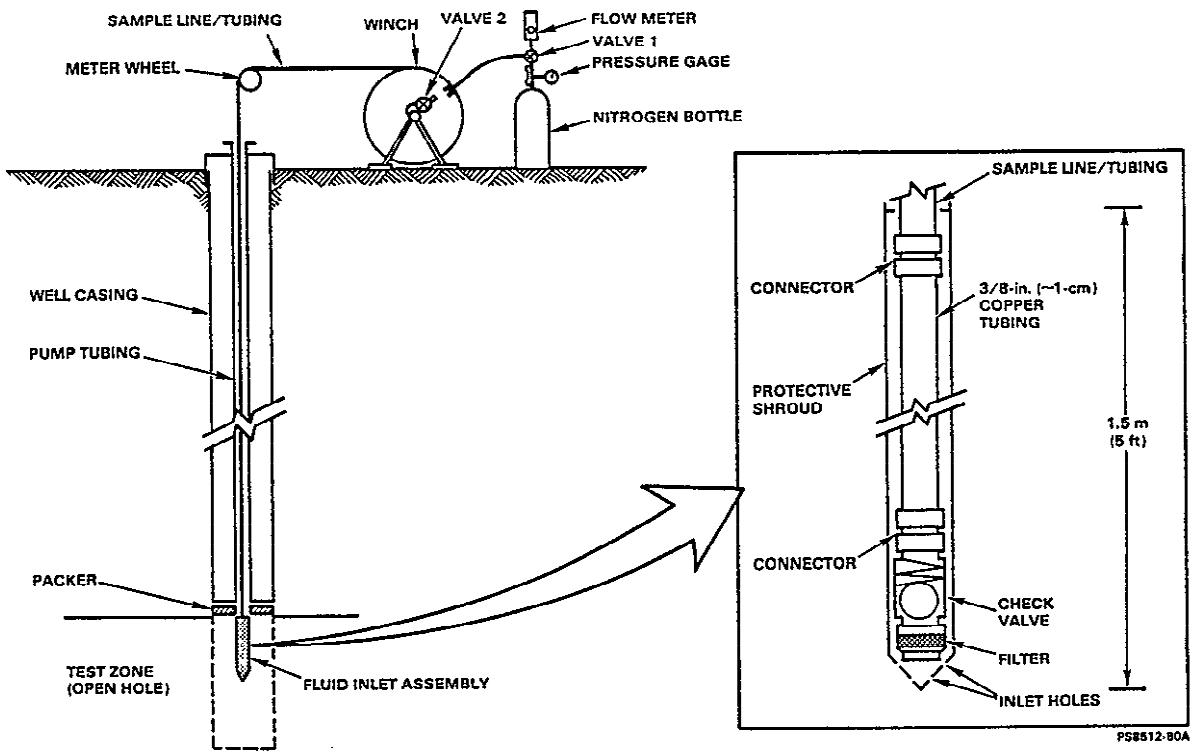

Figure 8.3.1.4-21. Narrow-diameter, downhole grab-sampling device. (In use, the entire flexible line is pressurized with inert gas to keep the terminal check valve closed at formation pressure. When the probe is at depth, pressure is released at Valve 2. Then the line is repressurized and retrieved, and the copper tubing is crimped, thereby isolating a small sample in situ pressure. Variations on the copper tube sampler are under development that will replace the pressurized nitrogen valve closure with electrically actuated inlet and outlet valves on the downhole probe (see Fig. 8.3.1.4-21). The copper tube is replaced with a container made of an inert material (teflon, etc.) for trace element and reactive constituent sampling.)

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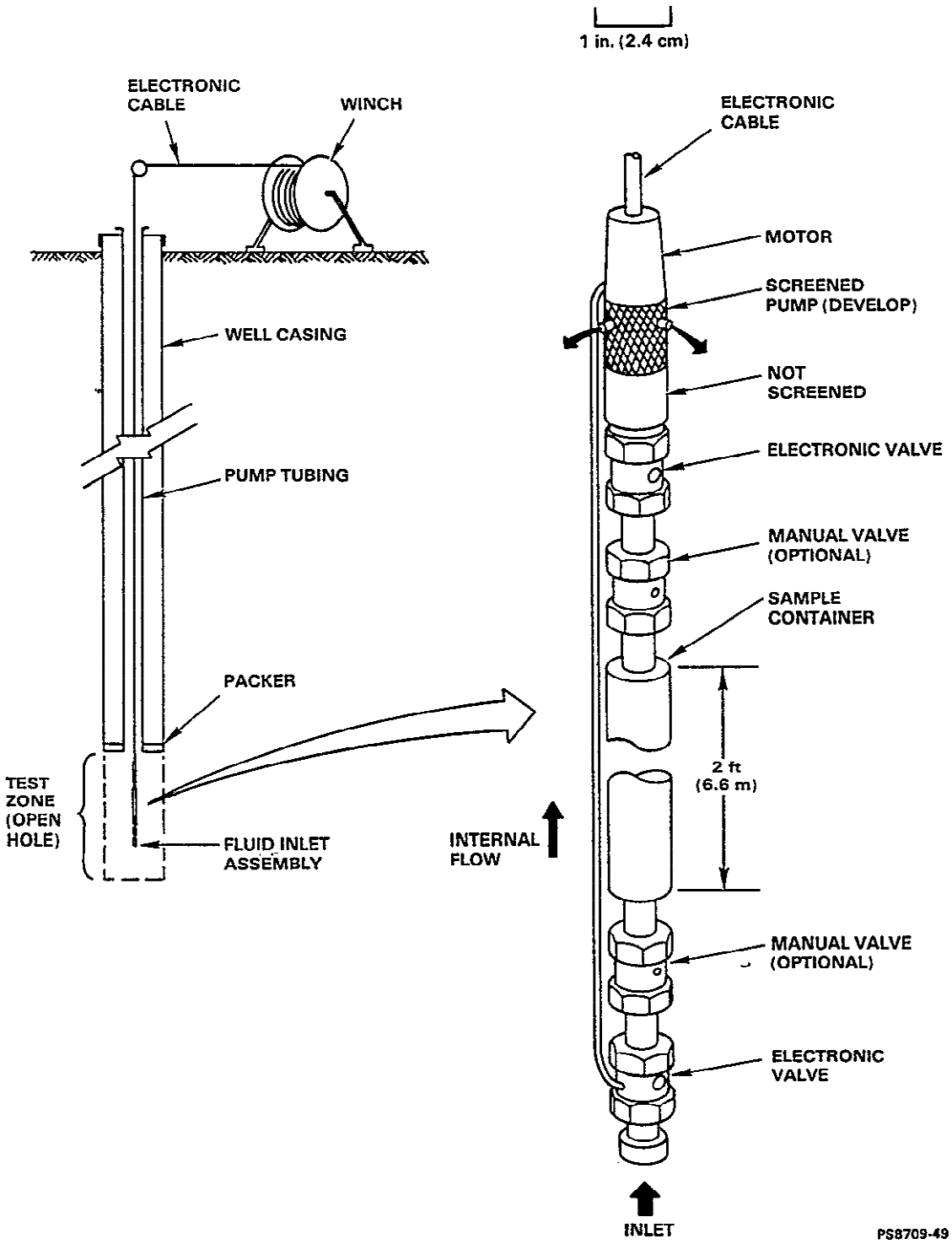

Figure 8.3.1.4-22. Conceptual design of a narrow-diameter downhole probe for the collection of dissolved gases. (The sample container can be either copper tubing for dissolved gas sampling or an inert material for trace constituent sampling.)

Results of the above investigation will be combined with geochemical modeling results to evaluate the general question of groundwater evolution as well as the origin of the chloride-rich deep groundwaters (see Section 8.3.1.4.5 for additional discussions of geochemical modeling).

8.3.1.4.3.3.1.6 Evaluation of gas-filled pore space. Release of radionuclides from the waste package in a gaseous form (for example, ^{14}C as methane or acetylene and ^{129}I as molecular iodine) could result in more rapid transport than expected for solute transport in fluids. This situation could result if radioactive gases from the waste package were to partition into a gas phase ("gas pockets") within or in the vicinity of the repository. Gas-filled pore space in the rock, or structural defects in seals or disruptive events could then provide a direct pathway for gas phase migration to the accessible environment.

The following data are needed to evaluate potential radionuclide transport in a gas phase:

- Reliable dissolved and noncondensed gas concentrations in the vicinity of the proposed repository location.
- Thermochemical and transport data that are generally available in the literature.

While existing qualitative and semiquantitative gas data suggest methane concentrations may exist up to the limit of solubility at the temperature and pressure near the reference repository location, additional data using improved methods for quantitative gas sampling are needed to confirm previous observations. In addition, evidence for a gas phase in the candidate horizon near the repository layout has not been systematically explored. If naturally occurring, two-phase conditions or gas concentrations at the solubility limit are discovered near the repository layout area, a formal study will be initiated to address this condition.

The sampling plans, described in Table 8.3.1.4-3, include sampling to evaluate the existence of gas-filled pore space.

8.3.1.4.3.3.1.7 Solids characterization. The BWIP will acquire core samples for each producing zone tested for the hydrochemical characterization investigation. Isotopic and elemental abundances (see Tables 8.3.1.4-3 and 8.3.1.4-5) are needed as supporting parameters for groundwater age, natural and analog radionuclide behavior assessment (Sections 8.3.1.4.4.3 and 8.3.1.4.3.3.2).

The BWIP investigators will determine secondary mineral abundance patterns (at selected locations) in the above samples as part of the mineralogic and petrographic characterization study, and for the radionuclide reactivity study (Section 8.3.1.4.4.3). The solids characterization efforts will emphasize the controlled area study zone. The additional mineralogic data for the principal water-bearing zones will extend the mineralogic data

base for the likely flow paths beyond the disturbed zone in the controlled area study zone. These data combined with mineralogic characterization of the emplacement horizon (Cohassett flow interior) and engineered barrier materials will provide an estimate of location, volume distribution, and accessibility of minerals along likely flow paths with which to evaluate the following:

- Radionuclide migration and retardation.
- Mineral stability.
- Flow path geochemical history.
- Evidence of reducing conditions.
- Spatial variability of mineral assemblages that are important to retardation.

The BWIP will model and apply the above data during performance assessment (Section 8.3.5). These data will help resolve the geochemical aspects of Issue 1.1 for both disturbed (disruptive scenarios) and undisturbed conditions.

8.3.1.4.3.3.1.8 Iodine-129 and other defense waste tracers. A review of existing waste tracer data and a discussion of its significance to the BWIP are provided in Section 3.9.5.5 and in Early et al. (1987). The occurrence and distribution of ^{129}I and other potential traders raise questions about (1) possible vertical pathways in the vicinity of the controlled area study zone and (2) horizontal movement in the Saddle Mountains Basalt at rates much faster than currently thought possible (see Section 3.9.5.5).

The vertical distribution of ^{129}I and other defense waste tracers in and around the controlled area study zone can be indicative of vertical hydraulic communication and may be useful as an indicator of a potentially disqualifying condition. A strategy to assess the viability of this application recently has been implemented (Anttonen, 1987; see also Section 8.3.1.3.4.2.2). Fundamental questions that must be resolved are (1) what is the natural background level of ^{129}I in Grande Ronde Basalt groundwaters, and (2) can sampling facilities be installed to provide reliable analytical results? These questions will be addressed by sampling flowing artesian wells completed in the Grande Ronde Basalt (boreholes DC-6 and DC-14) to establish "natural background" and by monitoring ^{129}I and other tracers in drilling fluids during borehole construction at boreholes DC-24, DC-25, DC-32, and DC-33. The latter will provide information with which to assess theoretical constraints on application of evaluation criteria in the option paper (Long, 1987) that sets indicator threshhold concentrations at natural background levels for tritium and ^{19}C as well as ^{129}I. Additional details of the overall sampling strategy for this purpose are described in Anttonen (1987).

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The apparent occurrence of ^{129}I in the Saddle Mountains Basalt across the Hanford Site and in nearby offsite irrigation wells (see Section 3.9.5.5) noted above must first be confirmed because of potential borehole and (or) sample contamination problems (IWG, 1987). Resampling using ultraclean techniques at locations noted in Table 8.3.1.4-4 and the possible installation of new boreholes at certain locations (boreholes DB-7 and DB-15) may be needed to resolve questions about the origin of ^{129}I at these locations. Resampling results will first be reviewed and then the need for any new boreholes will be evaluated.

8.3.1.4.3.3.2 Groundwater redox characteristics study.

The principal objective of the groundwater redox characteristics study is to investigate prevailing redox conditions, including the redox behavior of key radionuclides or their analogs, within the basalt geologic setting. Determining the rates of certain redox reactions is an important component of these testing activities. The BWIP investigators can use rate data to factor kinetic considerations into estimates of radionuclide mobility from the proposed repository.

This study also includes tests that will use the redox behavior of carbon and sulfur, as ascertained from examination of their respective stable isotopes, to provide constraints on possible groundwater flow pathways from regions of recharge. The BWIP investigators will also use the test results in developing a conceptual flow model for the Hanford Site.

Performance parameters and supporting parameters from the issue resolution process (Section 8.2) that will be addressed by this study are shown in Table 8.3.1.4-7.

The groundwater redox characteristics study consists of the following two tests designed to provide the issue-derived parameter needs (see Table 8.3.1.4-7) and to meet the above technical objectives:

- Redox couples in groundwater test.
- Stable isotopes test.

A flowchart showing the time sequence and task interrelationships for the study is shown in Figure 8.3.1.4-23.

As shown in the flowchart, the study consists of three major phases or activities associated with the above tests:

- Initial planning activities.
- Passive characterization of redox conditions.
  - Analysis of naturally occuring redox couples at analog sites and along the Cold Creek syncline.

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Table 8.3.1.4-7. Performance parameters and upper level supporting parameters for the groundwater redox characteristics study

Performance parameter	Issue	Tentative goal	Scale	Test basis			Supporting or subparameters[a]
				Expected value	Current confidence	Needed confidence	
Redox conditions	1.8 FC 3, PAC 7, PAC 9, 1.4, 1.5, 4.2[b]	Demonstrate reducing conditions and assess redox capacity	Controlled area study zone/repository layout area	Not applicable	Low	High	Major redox couples in groundwater Radionuclide and analog redox states Dissolved oxygen Dissolved gas composition Ferrous iron content of aquifer solids pH and ORP (field measurements) Carbon and sulfur isotopic ratios in groundwater and secondary minerals
			Analog study site in upper Cold Creek syncline	Not applicable	Not applicable	Not applicable	Redox states of radionuclide analogs Groundwater age parameters Major redox couples

NOTE: FC = Favorable condition.
ORP = Oxidation reduction potential.
PAC = Potentially adverse condition.

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[a]Subparameter groups and associated measurement methods are described in Tables 8.3.1.4-8 and 8.3.1.4-9.

[b]Oxygen consumption capacity of aquifer solids based on theoretical calculations requiring estimates of iron content, porosity and surface area of reactive solids (Wallick and Ford, 1987).

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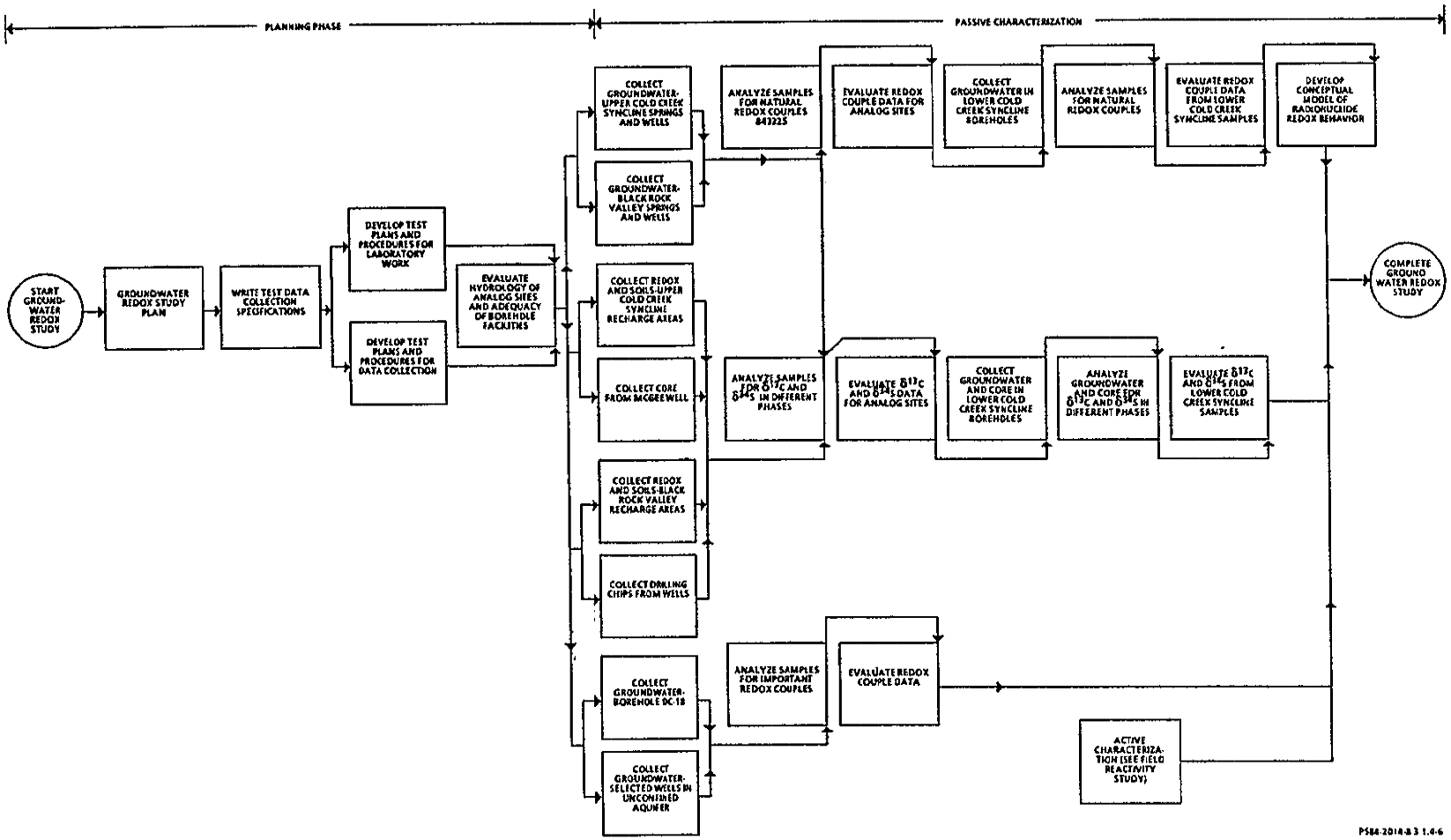

Figure 8.3.1.4-23. Flowchart for the groundwater redox study. (See Fig. 8.3.1.4-9 for locations).

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- Analysis of elemental concentrations and isotopic compositions of carbon and sulfur in water and rock.
- Analysis of redox couples in unconfined aquifers and at borehole DC-18.

- Active characterization of redox conditions.
  - Data to be obtained during swish tests in the field radionuclide reactivity study.

Initial planning activities consist of preparation of the study plans and the test data collection specifications. Test plans will be prepared both for the collection of field samples and for obtaining in situ oxidation and reduction potential measurements. Test plans will also be prepared for laboratory analyses to be conducted on groundwater, soil, and core samples. It will also be necessary to determine the nature of the groundwater flow systems in the analog sites in order to assess whether present borehole facilities are adequate to obtain samples along flow paths where groundwater is evolving chemically.

Passive characterization activities consist of the collection and analysis for redox constituents of representative groundwater samples from springs and wells in the upper Cold Creek syncline and from analog sites in Black Rock Valley and the lower Cold Creek syncline. Inasmuch as data for redox couples will be available for the flow path that parallels the Cold Creek syncline, it will be possible to assess the validity of the model for redox systematics behavior. Should the model prove valid, information will be available concerning the redox sensitivity of the basalt geochemical system (e.g., the depth to which oxidized redox species persist in basalt groundwaters).

Analyses of elemental and isotopic composition of sulfur and carbon will be performed on samples of groundwater and core. Samples will be collected in boreholes in analog recharge areas and along the Cold Creek syncline. The distribution of sulfur and carbon concentrations in the basalt rock, together with the distribution of isotopic ratios will be useful for determination of large-scale bulk redox conditions. Furthermore, the isotopic data may clarify the origin of sulfur and carbon in basaltic groundwaters.

The third (lowest) branch of the flowchart (see Fig. 8.3.1.4-23) shows the collection and analysis of redox couples in groundwaters from selected wells in the unconfined aquifer as well as the confined aquifers at borehole DC-18.

Swish tests (Section 8.3.1.4.4.3.2.1) will be used to determine short-term (days) redox kinetics and to assess whether redox equilibrium exists in a deep flow top environment. Data will be acquired in the field radionuclide reactivity study and supplied as input to the groundwater redox study.

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All of the data acquired for the redox study will be incorporated into a conceptual model that describes the manner in which redox conditions develop in the basalt geochemical environment and how sulfur and carbon (two redox sensitive elements) are transported by groundwater flow and precipitated in response to variable redox conditions.

Details of the two tests comprising the redox study are described in the following sections.

8.3.1.4.3.3.2.1 Test of redox couples in groundwater. The test of redox couples in groundwater will have as its focus the determination of the redox conditions in the basalt groundwater by measuring the concentrations of both oxidized and reduced species that are either (1) naturally occurring in the system (passive method) or (2) actively injected into the system in oxidized states and allowed to interact with the in situ redox conditions (active method). The passive method will measure concentrations of dissolved oxygen and manganese (II) and the distributions among oxidation states of the elements nitrogen, sulfur, iron, arsenic, selenium, tin, iodine, rhenium, uranium, and defense waste transuranics. Total concentrations of arsenic, selenium, rhenium, and uranium will also be measured. Methods of measurement will include ultraviolet/visible spectrophotometry (for nitrogen, oxygen, sulfur, manganese, and iron), atomic absorption spectrophotometry (for arsenic), fluorimetry (for selenium), differential pulse polarography (for iodine), gamma-ray spectrometry (for rhenium), and alpha counting and laser fluorescence spectrometry (for uranium). The active method will measure the distributions among oxidation states of reactive tracers that will be injected as oxidized species and allowed to react and speciate. The specific tracers that will be employed will be determined in laboratory reactivity experiments but may include dissolved oxygen, nitrate, sulfate, arsenic (as $HAsO_4^{2-}$), selenite, and pertechnetate (or a surrogate thereof).

The passive method consists of three activities:

- Determination of redox speciation of fission products and transuranic elements in the suprabasalt, the unconfined aquifer, and the aquifers in hydraulic communication with the unconfined aquifer. (Activity 1)

- Determination of redox speciation of a range of naturally occurring redox-sensitive elements, including key radionuclides or their analogs, in the upper Cold Creek syncline. (Activity 2)

- Determination of redox speciation of a range of naturally occurring redox-sensitive elements, including key radionuclides or their analogs, in the controlled area study zone and vicinity. (Activity 3)

Since 1943, significant quantities of water containing a variety of radioactive constituents from the waste streams of Hanford Site processing plants have been released to numerous ponds and cribs. Zimmerman et al.

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(1986) summarized the locations of major disposal areas and the volumes of water involved. In order to assess the rate of transport of these contaminants and their potential environmental impact, the DOE has monitored the groundwater in the unconfined aquifer for key constituents such as tritium, nitrate, and gross beta producing components (e.g., see PNL, 1985). Figures 8.3.1.4-24 and 8.3.1.4-25 show the location of nitrate tritium plumes emanating from the major disposal sites in the vicinity of the 200 East and 200 West Areas at the Hanford Site.

Activity 1 will attempt to examine groundwaters collected from boreholes along the approximate centerlines of these contaminant plumes for the presence of redox-sensitive key radionuclides. Because the wastewater contained a blend of fission products and transuranic components similar to that found in spent reactor fuel, the possibility exists that this large tracer experiment will permit the DOE to perform redox characterization on elements not found in measurable quantities in the natural system. Selenium, technetium, tin, uranium, plutonium, and neptunium are among the key species that will be studied. Table 8.3.1.4-8 summarizes information about the redox species and analytical techniques to be employed. Investigators will also attempt to determine if any changes occur in the relative abundances of the redox species of a specific element along the groundwater flow path, and if these changes can be related to the rates of redox reactions.

The major uncertainties associated with the test of transuranic (and other) redox couples in groundwater include the following questions:

- Are the geochemical conditions of the unconfined groundwaters oxidizing and, thus, not representative of the basalt environment?
- Is the substrate environment for the unconfined aquifer sufficiently similar to that of basalt aquifers so that solid/water redox controls are similar also?
- Is the composition of the wastewater such that it contains unusual quantities of potential complexants that may interfere with the approach to redox equilibrium?
- Did the initial composition (including redox species) in the waste-water change significantly over time?

The BWIP will answer these questions by (1) performing preliminary analyses on groundwaters and evaluation of substrate materials from the boreholes and (2) consulting available information on disposal volumes and compositional inventories for the disposal sites contributing to the plumes. More detailed redox analyses will not proceed unless preliminary results are favorable.

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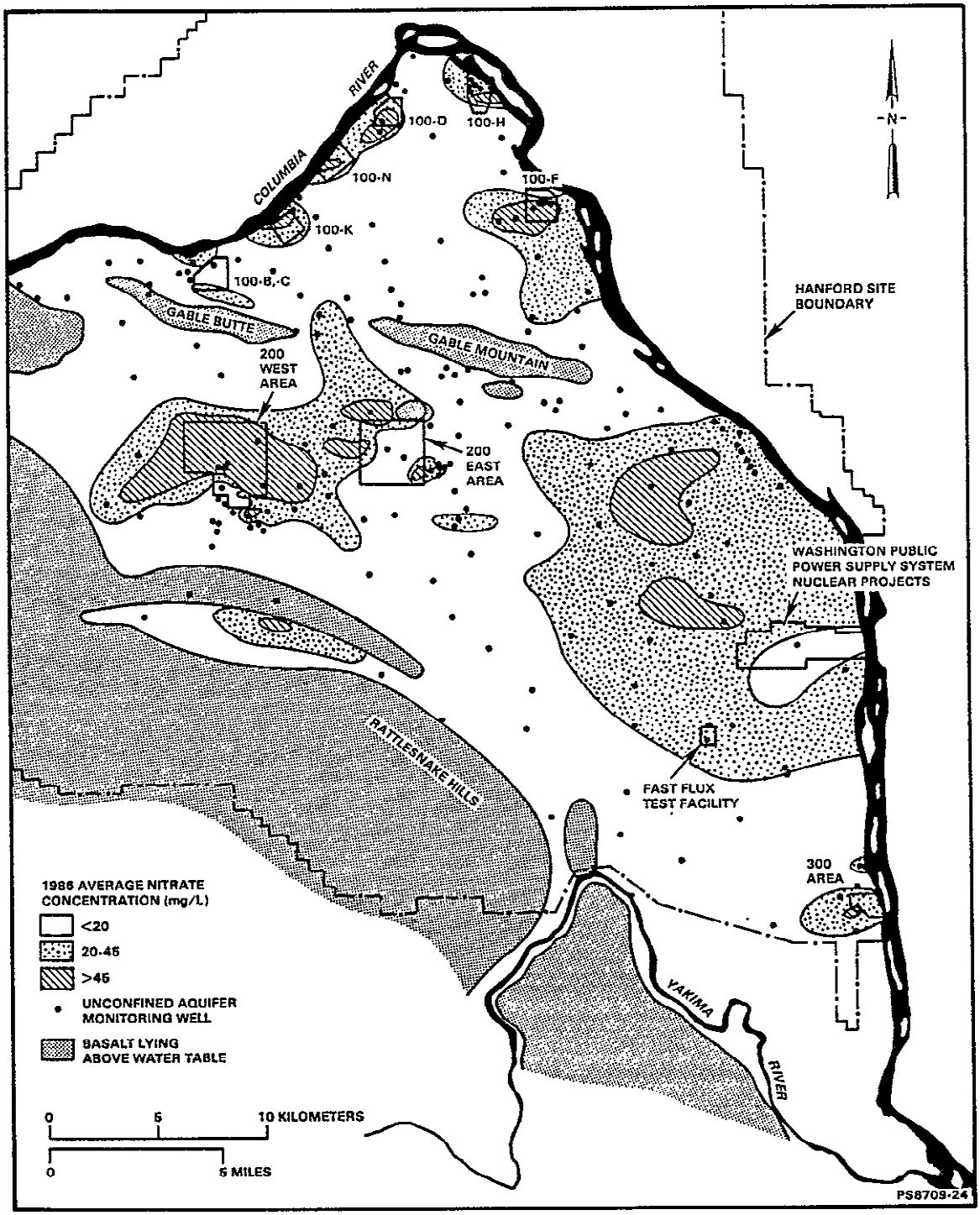

Figure 8.3.1.4-24. Average nitrate distribution in unconfined groundwater (1986).

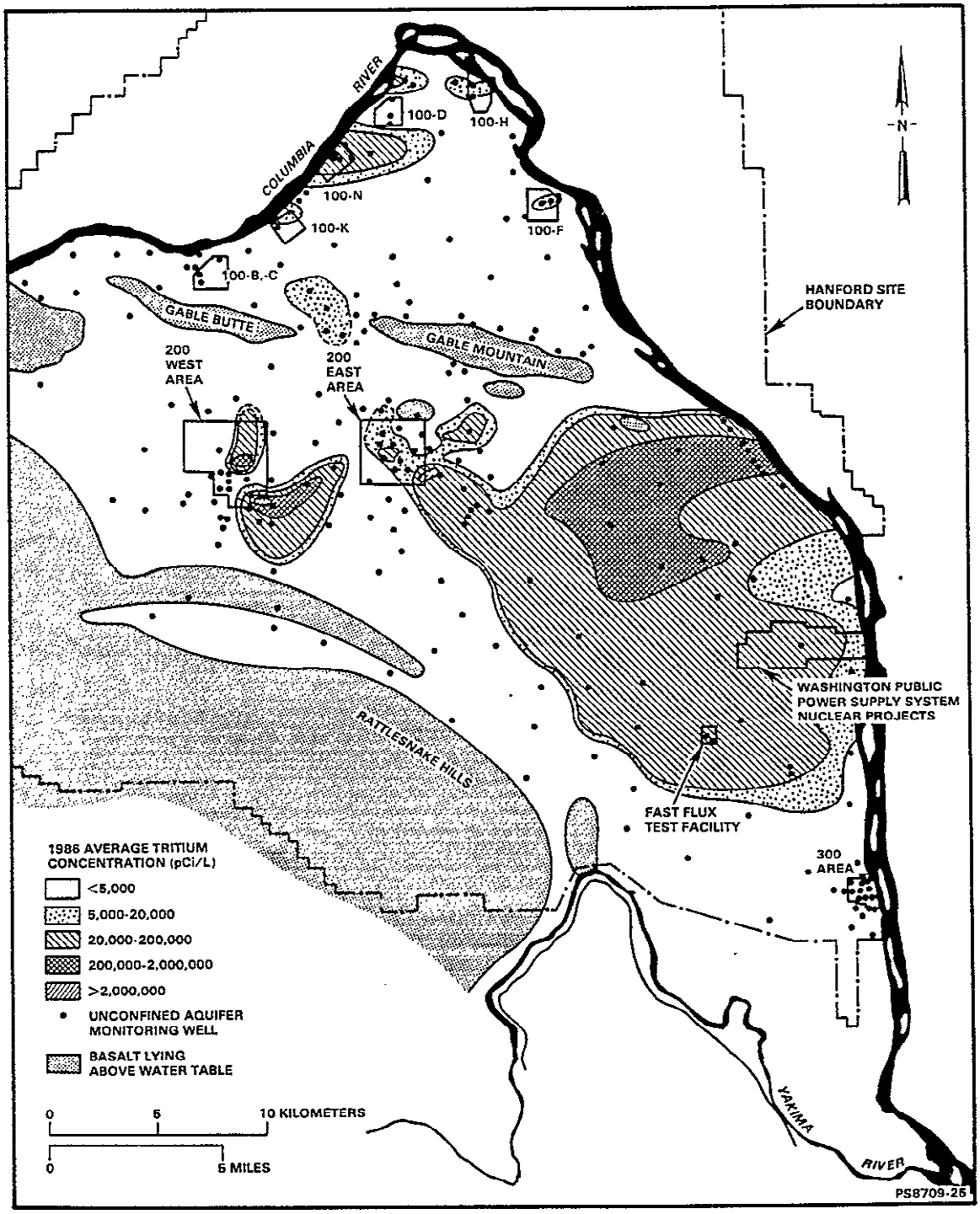

Figure 8.3.1.4-25. Average tritium distribution in unconfined groundwater (1986).

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Table 8.3.1.4-8. Groundwater redox study: description of test measurements for redox couples in groundwater (sheet 1 of 2)

Key measurements	Applicable procedures/date available	Level of QA	Accuracy/ precision	Range of expected results	Required equipment	Data reduction/analysis techniques
Nitrogen NH_3: N(III) NO_2^{-1}: N(III) NO_3^{-1}: N(V)	In preparation	TBD	TBD	<5 mg/L (total nitrogen*	Ultraviolet/visible spectrophotometer	Data will be reduced by comparison of instrument response for sample to that for standards and by standard addition techniques
Dissolved oxygen O_2 (aq)	In preparation	TBD	TBD	<10 mg/L	Ultraviolet/visible spectrophotometer	
Sulfur HS^{-1}: S(-II) SO_4^{-2}: S(VI)	In preparation	TBD	TBD	<250 mg/L (SO_4^{-2})	Ultraviolet/visible spectrophotometer	
Manganese Mn(II)	Available 10/86	TBD	TBD	TBD	Ultraviolet/visible spectrophotometer	
Iron Fe (II) Fe (III)	In preparation	TBD	TBD	<1 mg/L (total iron)	Ultraviolet/visible spectrophotometer	
Arsenic As (III) As (V) Total arsenic	Available 10/86	1	TBD	TBD	Atomic absorption	
Selenium Se (IV) Total selenium Organic selenium	Available 10/86	1	TBD	TBD	Fluorimeter	

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Table 8.3.1.4-8. Groundwater redox study: description of test measurements for redox couples in groundwater (sheet 2 of 2)

Key measurements	Applicable procedures/date available	Level of QA	Accuracy/ precision	Range of expected results	Required equipment	Data reduction/analysis techniques
Tin Sn (II) Sn(IV)	Scoping studies in progress	TBD	TBD	TBD	TBD	
Iodine IO_3^{-1}: I(V) I^{-1}: I(-I) Organic iodine	Available 10/86	1	TBD	<1 mg/L (Total iodine)	Differential pulse polarography	
Rhenium Re (IV) Total rhenium Organic rhenium	Scoping studies in progress	TBD	TBD	<1 mg/L (Total rhenium)	γ-ray spectrometer	
Uranium U (IV) Total uranium Organic uranium	Development procedure available 10/86	TBD	TBD	<1 mg/L (Total uranium)	α-counter, laser fluorescence	
Others Np(III), Np(V) Pu(IV), Pu(VI) Tc(IV), Tc(VII) Se(IV), Se(VII)	TBD	TBD	TBD	TBD	α/γ spectrometers	
Oxidation reduction potential	TBD	TBD	TBD	−500 to +600 mV	Downhole assembly with platinum, gold, glassy carbon sensing electrodes	

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NOTE: QA = Quality assurance.
TBD = To be determined.

*Nitrate concentrations >5 mg/L occur in the unconfined aquifer due to defense waste disposal activities; concentrations in the confined aquifers are expected to be <5 mg/L.

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Evidence exists that in the vicinity of borehole DC-18 (see Fig. 8.3.1.4-10) hydraulic communication exists between the suprabasalt sediments and aquifers of the Saddle Mountains Basalt (Early et al., 1987). Furthermore, evaluation of hydrologic and hydrochemical data at borehole DC-18 suggests that this communication probably extends at least to the lower Wanapum Basalt and has led to the downward migration of groundwater from the contaminated suprabasalt aquifer near borehole DC-18. The amount of mixing probably is relatively small, so redox controls imposed by the basalt geochemical system are dominant. Any redox-sensitive radionuclide associated with the shallow end member becomes a potential redox probe for the basalt aquifers. Consequently, Activity 1 will include the characterization of fission product (^{99}Tc) and transuranic species that may have migrated downward in this region.

Activity 2 will focus on the characterization of naturally occurring redox-sensitive elements in one or two analog study sites close to the controlled area study zone. Figure 8.3.1.4-26 shows a schematic illustration of the conceptual flow model/natural redox regime of the analog sites. Figure 8.3.1.4-27 is a map of the upper Cold Creek syncline, the primary analog site chosen for evaluation. The upper Cold Creek syncline is part of the same structural entity as the proposed repository location and, due to the presence of a number of irrigation wells that withdraw water from the Priest Rapids/Roza aquifer, this region has undergone rather extensive hydrologic and hydrochemical investigations by the BWIP (Livesay, 1986; Early et al., 1986). In general, investigators believe that these aquifers are recharged in the vicinity of surface outcroppings and that the predominant groundwater flow is eastward along the trend of the synclinal axis. Hydrochemical evidence suggests that the groundwaters systematically increase in age from west to east in the sampled boreholes. In order to complete this activity, several additional boreholes must be drilled that are closer to suspected areas of recharge than existing wells (see Fig. 8.3.1.4-27 for proposed locations).

This analog site presents the possibility of conducting two complementing redox investigations that are pertinent to repository studies. First, investigators will examine naturally occurring redox couples to evaluate the redox conditions prevalent in the aquifers. This work will include a variety of common constituents such as carbon, sulfur, and nitrogen, as well as radionuclides or analogs to radionuclides (rhenium (technetium)). The intent is to determine, either directly or by inference, how the key radionuclides associated with the repository will behave in the basalt geochemical system. Second, investigators will analyze redox maturation as a function of time along a groundwater flow path. Because each redox couple will approach chemical equilibrium at different rates, it is important not only to establish what that equilibrium point is, but also how fast equilibrium is achieved relative to groundwater flow rates.

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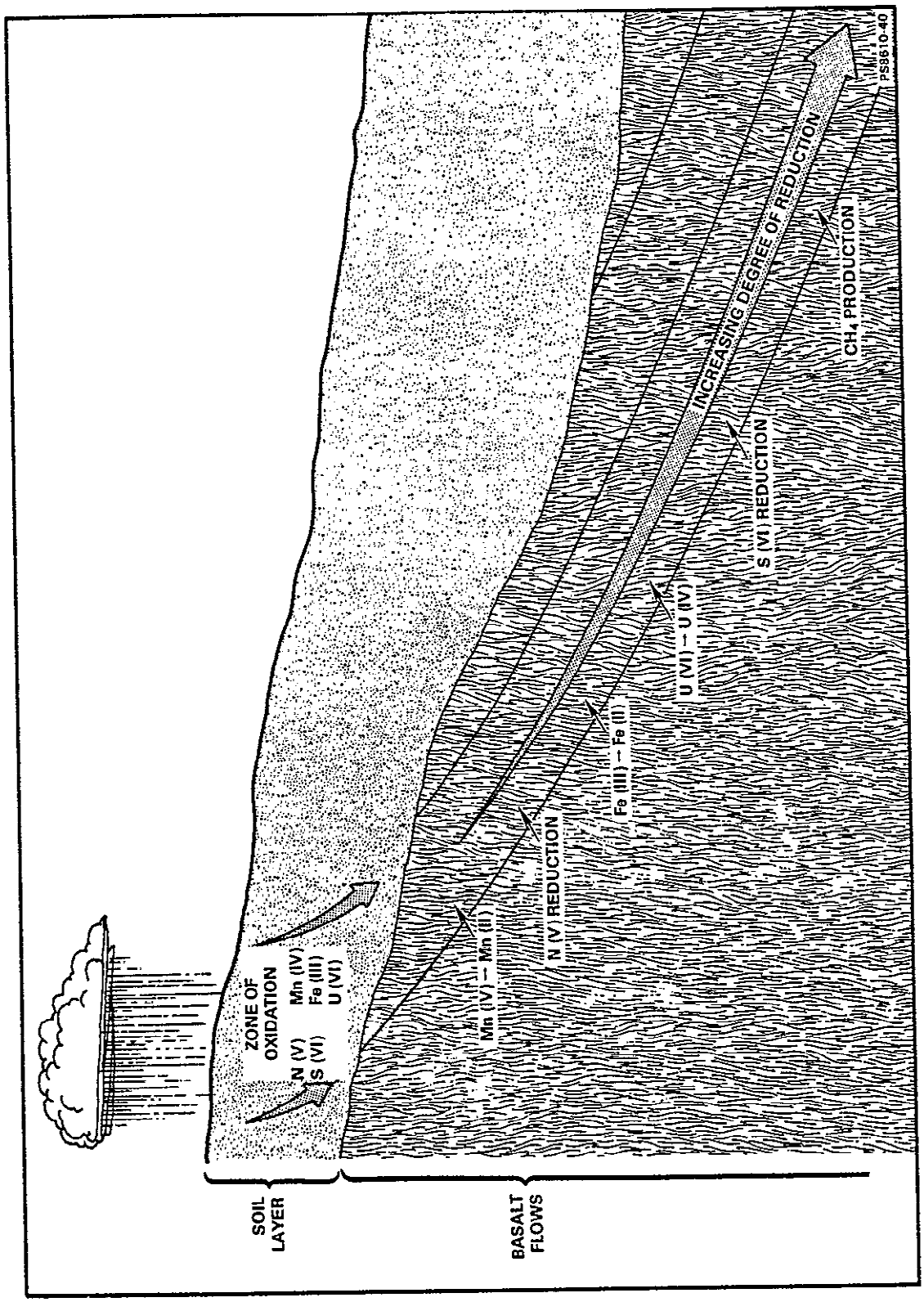

Figure 8.3.1.4-26. Schematic cross section showing redox systematics.

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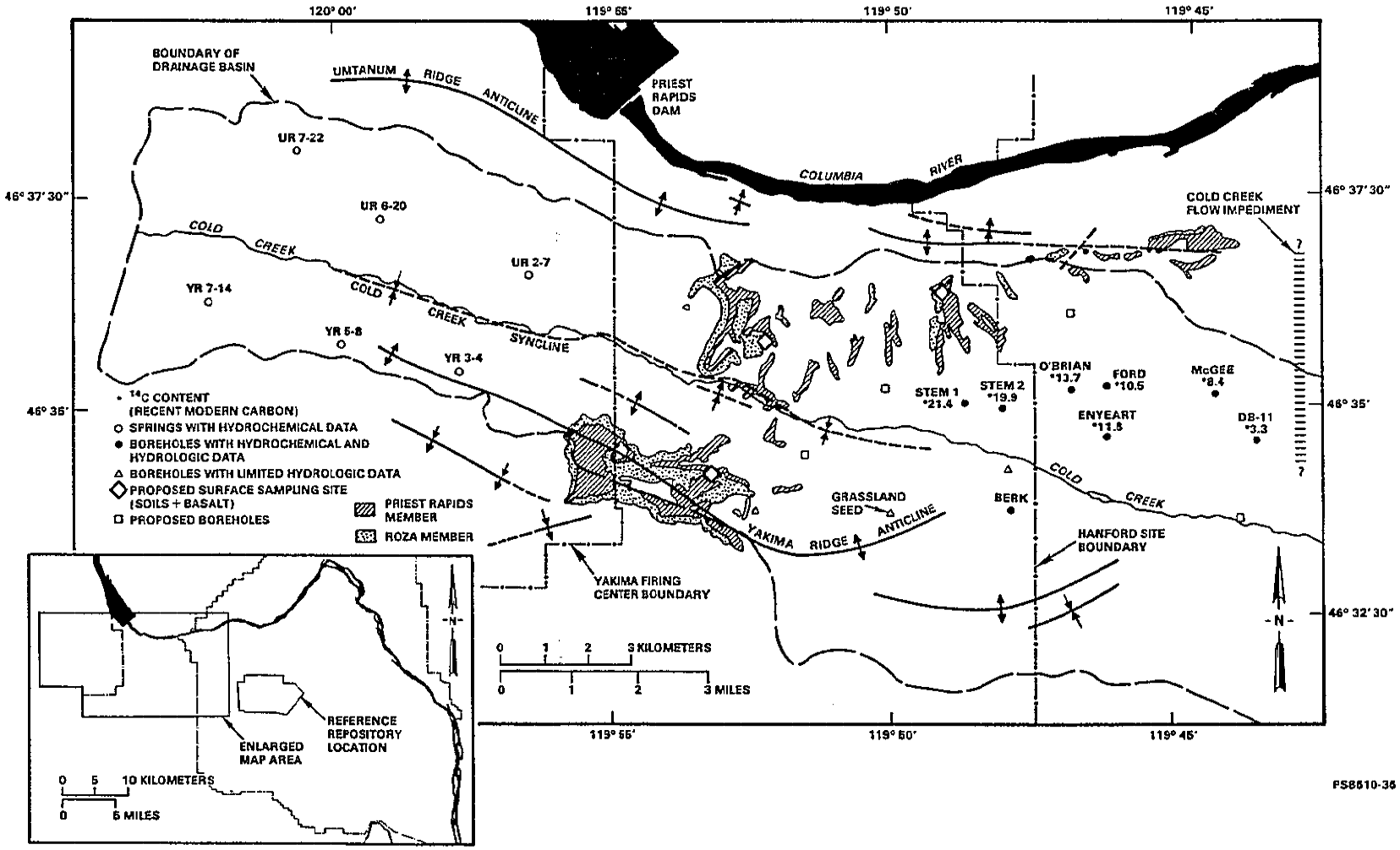

Figure 8.3.1.4-27. Proposed sampling locations in Upper Cold Creek syncline. Shaded areas are suspected recharge locations for the aquifer (Priest Rapids).

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Activity 3 represents an extension of the work done in the analog study site (Activity 2) into the controlled area study zone and environs. Figure 8.3.1.4-10 is a map showing the planned sampling sites (also see Table 8.3.1.4-3) and Table 8.3.1.4-8 identifies the species and technical data that applies. Activity 3 will focus on characterizing redox conditions in the Grande Ronde Basalt and, to a lesser extent, Wanapum Basalt aquifers.

Lindberg and Runnels (1984) showed that a variety of redox couples from groundwaters in the U.S. Geological Survey WATSTORE data base indicate the lack of redox equilibrium. This observation probably is due in part to sluggish kinetics for redox reactions requiring the transfer of many electrons. For example, Ohmoto and Lasaga (1982) report that the HS^-/SO_4^{2-} couple will not achieve redox equilibrium in geologically relevant times at relatively low temperatures (less than 100 °C) in the absence of catalysts. Giggenbach (1982) reaches similar conclusions for the CO_2-CH_4 couple. Because of these concerns, the main thrust of Activity 3 is to obtain direct information (ratio of oxidation states) on the redox behavior of naturally occurring analogs or key radionuclides (or those disposed of by man during the existence of the Hanford Site) in the basalt geochemical system.

The active method of testing redox conditions in the basalt system involves the injection of oxidized reactive tracer species into a flow top that is then sampled and analyzed to determine concentrations of oxidized and reduced species as a function of time. This is a system stimulus-response type of testing that will be a gage of the redox capacity of the basalt groundwater system. Passive methods for determining the basalt flow system redox potential are generally limited to making only qualitative assessments because of experimental limitations in measurements of redox species concentrations or poorly controlled probe response. Oxidized species will be injected in sufficient concentration to allow accurate analytical determination of the degree of reduction that occurs. Expected results from this method are a more precise estimate of the in situ redox potential of the basalt system and kinetic information that can be used to determine the extent to which redox equilibrium is approached in the natural system.

The active testing program will be run on the same schedule and in conjunction with the field reactive tracer test (Section 8.3.1.4.4.3.2). The flowchart for the field reactive tracer tests is included in Section 8.3.1.4.4.3.2.3. Single-well injection-withdrawal testing is the primary method proposed for the active determination of redox conditions. Test methodologies are described in detail in Section 8.3.1.4.4.3.2.1 and include opportunistic injection-withdrawal tests during drilling and development of piezometers, formal single borehole injection-withdrawal testing, and swish testing. The optimum method for the determination of in situ redox conditions is the swish test. This test is designed to allow injection and sampling of reactive species with the least possible disruption of the natural system. The other two tests mentioned allow dissolved oxygen to enter the test zone, which may interfere with the kinetics of other redox-sensitive tracers. Suitability of oxidized species in terms of their interaction with other tracers will be evaluated in advance of field testing during the laboratory component of the radionuclide reactivity study.

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8.3.1.4.3.3.2.2 Test of stable isotopes. The test of stable isotopes focuses on understanding how carbon and sulfur behave in the basalt groundwater system. Activities will involve tracing the movement of different redox species of these elements along groundwater flow paths from regions of recharge. The BWIP will reconstruct important reactions by considering carbon and sulfur isotopic fractionation effects that accompany both heterogeneous (precipitation and dissolution) and homogeneous (involving only dissolved species) reactions occurring along the flow paths. Investigators will use a geochemical model that has been modified to permit theoretical calculation of isotopic fractionation effects to evaluate the importance of specific reactions. One or more analog study sites will be investigated prior to starting investigations in the vicinity of the proposed repository. Table 8.3.1.4-9 lists the key measurements, procedures and equipment measurements.

Test 2 will measure deviations from standard values of abundances of deuterium, ^{13}C, and ^{34}S in various oxidation states in both solid and liquid (water) samples. Soil, outcrop basalt, and basalt core samples will be analyzed for ^{34}S in pyrite, ^{13}C in calcite, and ^{34}S as S(-II) and S(VI) and ^{13}C in matrix materials. Spring and groundwater samples will be analyzed for deuterium and ^{13}C in methane, ^{13}C in dissolved inorganic carbon, and ^{34}S in the aqueous species HS^- and SO_4^{2-}. All analyses will be performed by mass spectrometry.

Testing will involve sampling and analysis of carbon- and sulfur-bearing phases in host basalt and soil material in recharge areas. Initially, three sampling sites in upper Cold Creek Valley will be chosen. In addition, investigators will subject core material from McGee well to carbon and sulfur extraction and isotopic analysis. Adequate carbon and sulfate-sulfur isotopic data for spring and groundwaters from this area currently exist (Early et al., 1986). If bisulfide-sulfur is to be characterized, additional samples must be collected. Furthermore, if the new boreholes are drilled, full hydrochemical characterization of the water must be completed as specified in the groundwater sampling and chemical characterization study plan.

A similar strategy will be followed in the Dry Creek-Black Rock Valley area. Investigators will collect and analyze soils and basalt outcropping in recharge areas from at least three sites. Only limited hydrochemical data exist from this area, and detailed characterization must be completed.

Following the analog site studies, the emphasis will shift to the lower Cold Creek syncline. Investigators will subject core material from selected boreholes to carbon and sulfur extraction techniques and will isotopically analyze the material. Cores will be either continuous (from standard rotary coring procedures) or obtained by a sidewall coring device in flow tops of selected hydrostratigraphic units. Groundwater samples from large-scale hydraulic stress tests and sampling events in proposed and existing boreholes identified in Figure 8.3.1.4-13 will be analyzed. Investigators will begin these testing activities at the startup date of large-scale hydraulic stress testing.

Table 8.3.1.4-9. Groundwater redox study: description of stable isotopes test measurements

Key measurements	Applicable procedures/ date available	Level of QA	Accuracy/ precision	Range of expected results	Required equipment	Data reduction/analysis techniques
Soil, outcrop basalt, basalt core • pyrite: $\delta^{34}S$ • calcite: $\delta^{13}C$ • matrix - S(-II): $\delta^{34}S$ - S(VI): $\delta^{34}S$ - Carbon: $\delta^{13}C$	Vendor procedures currently available	1 1 1 1 1	$\delta^{34}S$ = ± 0.2 ‰ $\delta^{13}C$ = ± 0.2‰ δD = ~2‰	TBD	Mass spectrometer	Comparison of sample ratio of isotopes in comparison to that for standards
Spring and groundwater samples • δD (CH_4) • $\delta^{13}C$ (CH_4) • $\delta^{13}C$ (DIC) • $\delta^{34}S$ (HS^-) • $\delta^{34}S$ (SO_4^{-2}) • $\delta^{18}O$ (SO_4^{-2})	Vendor procedures currently available	1 1 1 1 1 1	$\delta^{34}S$ = ± 0.2 ‰ $\delta^{13}C$ = ± 0.2‰ δD = ± 2‰	TBD	Mass spectrometer	Comparison of sample ratio of isotopes in comparison to that for standards

NOTE: QA = Quality assurance.
TBD = To be determined.

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8.3.1.4.3.4 Application of results

The groundwater flow system hydrochemistry study provides data for a conceptual model of groundwater flow paths and travel times. The conceptual model, in turn, acts as independent estimate of flow paths and travel times for resolution of Issues 1.1 and 1.6.

The spatial hydrochemical data will be used to develop conceptual flow models that will be integrated with hydrologic flow models. Flow paths will be assessed as being likely or unlikely based on agreement with all the observed hydrochemical and hydrological data and inferred mechanisms for the geochemical processes that operate in the basalt aquifers. Travel times based on spatial distribution of age-dating parameters will be determined along the likely flow paths, and thus an independent means of validating numerically calculated travel times will be available. Data obtained by this study will also be used to supply inorganic and organic chemical information necessary to evaluate radionuclide reactivity, including the nature of particulate matter in the groundwater.

Groundwater sampling, as described through the end of the large-scale hydraulic stress testing period, address Issue 1.6 and effectively provides an early search for the following unfavorable conditions:

- Methane resource potential.
- High dissolved gas concentrations that could cause problems associated with two-phase flow and with excess toxic and (or) flammable gases in the exploratory shaft.
- Vertical interaquifer communication.

Hydrochemical characterization of preemplacement groundwaters also establishes a baseline composition. The BWIP will use the baseline data to monitor groundwater changes during proposed repository construction and operation.

The results of the redox couples test are most directly applicable to radionuclide reactivity assessment and indirectly to performance assessment modeling. For example, investigators should be able, in principle, to use the time-dependent redox behavior information for key radionuclides (e.g., selenium, uranium, tin) or their close analogs (e.g., rhenium (technetium)) derived from this test to model the expected behavior of key radionuclides when released from a nuclear waste repository. Redox behavior directly influences radionuclide solubilities and sorption characteristics. Consequently, the results of this test will permit estimates of time-dependent solubility and sorption-limiting concentrations of selected radionuclides in the basalt environment.

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An additional benefit of the redox couples test relates to performance assessment. Investigators will use the redox kinetics results to establish the appropriateness of conducting laboratory experiments under oxidizing or reducing conditions.

The principal value of the stable isotope test is that it should provide refinement in defining groundwater flow paths and in developing conceptual flow models. These results will be integrated with analysis efforts described in the groundwater sampling and chemical characterization study plan. If these test activities are successful, investigators should be able to integrate refinements with performance assessment models.

Information developed in the stable isotopes test should support development of conceptual flow models for the Hanford Site. Information developed in both tests will provide field redox parameters applicable to the tracer tests and laboratory simulations in support of the radionuclide reactivity study.

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8.3.1.4.3.4.1 Design uses.

Methane inflow, an adjunct to the shaft dewatering problem, is a mine safety and ventilation issue. Accurate dissolved gas measurements will provide data needed to quantify probable CH_4 exsolution as well as the H_2S that may be released with the methane. This information is needed for repository design and safety.

Methane is known to occur in groundwaters associated with the candidate horizon in the vicinity of the controlled area study zone. Unfortunately, past dissolved gas sampling efforts were inadequate (Early, 1986a). Consequently, large uncertainties exist in the possible methane concentrations for groundwaters. Inflow of CH_4-bearing water and (or) direct diffusion/outgassing into the mined spaces from this source due to lowering of adjacent hydrostatic pressures, may result in elevated CH_4 as well as other major gases in the vicinity of the controlled area study zone.

Improved downhole pressurized fluid sampling methods and dissolved gas sampling procedures previously described will rectify some of these deficiencies. Resampling from boreholes in the vicinity of the controlled area study zone will be critical for this purpose. Key locations include boreholes RRL-2, RRL-14, etc. It is important, however, to acquire this new information as early as possible in the program so that appropriate changes can be made if necessary.

Estimates of corrosion rates must be made, based on such factors as pH, dissolved O_2, and salinity. A recent attempt at estimating the 100-yr corrosion rate of the steel shaft liner (Becker and Graber, 1986) cited oxygen-controlled galvanic protection of the exposed metal from the slightly saline groundwaters. Because there appears to be no detectable oxygen in deep groundwaters at the Hanford Site (Hall, 1986), this mechanism cannot predict how the exposed metal will fare when exposed to chloride at elevated

temperatures. Becker and Graber (1986) also concluded that stress-corrosion cracking from H_2S and NH_3 will not occur, although Hall reports both of these species in measurable quantities.

8.3.1.4.3.4.2 Characterization uses.

The results of this investigation will support several other studies in site characterization. The chemical analyses obtained from the groundwater flow system hydrochemical characterization tests provide constraints for conceptual flow modeling, which is proposed for the regional groundwater and site groundwater study plans. These results will also be used as bounding conditions in tracer tests specified in the radionuclide reactivity study plan. In addition, geochemical modeling analyses will be applied to chemical analyses obtained in the radionuclide reactivity and the redox characterization of groundwater studies.

8.3.1.4.3.5 Schedule and milestones

The schedule information provided for investigations in this program includes the sequencing, interrelationships, and relative durations of the studies in the investigation. Specific durations and start/finish dates for the studies are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

Figure 8.3.1.4-28 illustrates the schedule for the groundwater flow system hydrochemical characterization investigation. Boreholes DC-18 (currently completed to the top of Grande Ronde Basalt), HC-3, HC-1, and HC-4 will be drilled and sampled concurrently with the large-scale hydraulic stress tests at borehole RRL-2. The large-scale hydraulic stress tests are part of the hydrology program's proposed site groundwater study. Distance and the presence of flow barriers will prevent interference with the hydrologic testing.

Completing these boreholes early in the hydrochemistry sampling program has several advantages:

- The effect of structural features in controlling groundwater flow at Grande Ronde Basalt depths can be evaluated by comparative hydrochemistry.
- The areal extent of methane distribution and absolute concentrations can be evaluated. (The methane resource potential must also be considered in evaluating the Hanford Site for a repository.)
- The HC-series boreholes are needed in constructing cross sections shown in Figure 8.3.1.4-10.

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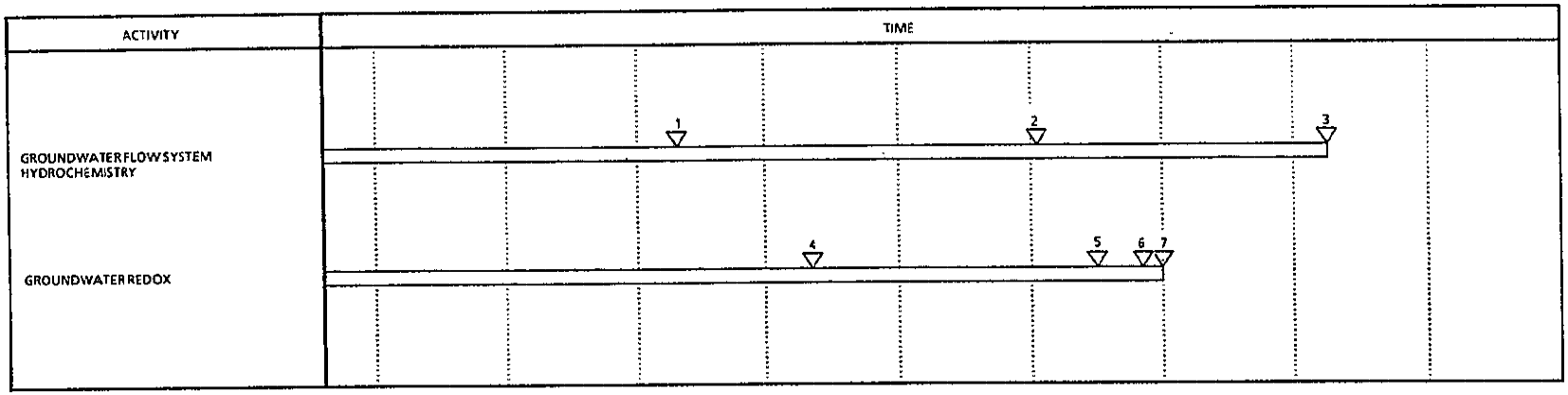

▽ 1 HYDROCHEMISTRY STATUS REPORT

- INDICATIONS OF DISQUALIFYING CONDITIONS
  - EXCESS TOXIC OR FLAMMABLE GASES (H_2S, CH_4)
  - RAPID VERTICAL TRANSPORT OF GROUNDWATER
  - ECONOMIC RESOURCE POTENTIAL.
- GEOCHEMICAL ENVIRONMENT FOR DESIGN/PERFORMANCE FACTORS
  - EXPLORATORY SHAFT/EXPLORATORY SHAFT FACILITY VENTILATION, CORROSION, ETC.
  - NECESSARY DATA FOR LABORATORY STUDIES OF WASTE FORM, SEALS, WASTE PACKAGE, ETC.
  - REDOX INDICATORS (FOR WASTE FORM STABILITY/MATRIX DISSOLUTION TESTING AND EVALUATION).

▽ 2 INTERMEDIATE DETERMINATION OF FLOW VECTORS

- REPORT APPARENT FLOW PATHS AND VELOCITIES WITHIN A RADIUS OF 8 km (5 mi) AROUND BOREHOLE RRL-2 (THE PURPOSE OF THIS REPORT IS TO LOCATE CONFIRMATORY/FOLLOW-UP BOREHOLES HC-6 AND HC-7.)

▽ 3 FINAL REPORT OF FLOW VECTORS

- REPORT FLOW DIRECTIONS AND VELOCITIES FROM THE PROPOSED REPOSITORY TO THE ENVIRONMENT
- REPORT COMPLETED GEOCHEMICAL/RADIONUCLIDE BASELINE
- COMPARE RESULTS TO THE HYDROLOGIC DETERMINATION OF FLOW VECTORS, REGIONAL FLOW, AND REGIONAL GEOCHEMISTRY.

▽ 4 COMPLETE EVALUATION OF REDOX COUPLE DATA.

▽ 5 COMPLETE EVALUATION OF REDOX DATA FOR COLD CREEK SYNCLINE

▽ 6 COMPLETE CONCEPTUAL MODEL OF RADIONUCLIDE REDOX BEHAVIOR AND REDOX CAPACITY

▽ 7 COMPLETE GROUNDWATER REDOX STUDY

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Figure 8.3.1.4-28. Schedule and milestones for the hydrochemical characterization investigation.

CONSULTATION DRAFT

- Early et al. (1987) demonstrated vertical groundwater migration from the unconfined aquifer through the Wanapum Basalt at the location for borehole DC-18. Continuing borehole construction to a total depth of at least the Birkett flow top will provide an analog site for examining vertical interaquifer communication. Analog data will be important in evaluating data from boreholes in the reference repository location for similar vertical communication. Evidence of vertical communication could be an unfavorable condition for the proposed repository.

In addition, producing zones pumped during large-scale hydraulic stress testing at borehole RRL-2 will be sampled. Investigators will examine these samples to determine if these wells can be used for detailed hydrochemical analysis. Investigators will also quantify toxic and flammable dissolved gases (principally methane and hydrogen sulfide) at the locations for the large-scale hydraulic stress tests.

Construction of the exploratory shaft and, later on, the Exploratory Shaft Facility, may result in induced flow and drilling contamination in boreholes HC-8 and HC-9. Therefore, drilling and sampling at boreholes HC-8 and HC-9 will begin as soon as the large-scale hydraulic stress tests are completed. Boreholes HC-2 and HC-5 are progressively more distant from the exploratory shaft site and may be started later.

Boreholes DC-18, HC-1 through HC-5, HC-8, and HC-9 will provide hydrochemical cross sections that describe a radius of about 8 km (5.0 mi) from the exploratory shaft site. When these boreholes are completed, an interim report will describe principal flow within that radius. Also, locations for boreholes HC-6 and HC-7 will be determined. The locations will be chosen to intercept and confirm net flow within the Grande Ronde Basalt (especially the Cohassett and Birkett flow tops).

The final report on flow system hydrochemical characterization will include confirmatory and supplemental data from the DC- and SC-series boreholes, as well as an evaluation of regional flow based on the U.S. Geological Survey WATSTORE data base and the PB-series boreholes.

Figure 8.3.1.4-28 also illustrates the schedule for the groundwater redox characteristics study. The first task is to evaluate the analog site and facilities. Once that task is completed, data collection and analysis will begin for all three activities associated with this study. The study plan for the groundwater redox study contains further details.

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8.3.1.4.4 Radionuclide retardation behavior investigation

The radionuclide retardation behavior investigation quantitatively assesses the kind and degree of geochemical interaction between radionuclides and the in situ water/rock environment that can be expected in a flow path between a repository and the accessible environment. As the investigation name implies, radionuclide behavior is a major factor controlling release of radionuclides from the natural site to the accessible environment.

The investigation contains one formal study: the description of radionuclide reactivity. The study, however, contains three components: (1) laboratory reactivity, (2) field reactivity, and (3) natural radionuclide reactivity. The reactivity study yields a sorption/desorption isotherm data base that is derived from both actual in situ field measurements of radionuclide reactivity and from laboratory reactivity measurements that have been obtained under simulated site-specific conditions.

8.3.1.4.4.1 Purpose and objectives

The purpose of the radionuclide retardation behavior investigation is to describe and quantify geochemical processes controlling radionuclide migration between a 55 °C isotherm and the accessible environment. Figure 8.3.1.4-29 shows the apportionment of responsibility for characterization of the geologic setting. The diagram shows overlap of responsibility between the waste package and geochemistry programs in the region between the 100 and 55 °C isotherms. This means that some laboratory sorption testing will be conducted at higher temperatures than the mean temperature of groundwater in the Grande Ronde Basalt.

Five basic geochemical processes generally control the migration of solutes in porous media:

- Advection--Solutes are transported with groundwater as they move through a porous medium in response to a hydraulic gradient.
- Mechanical dispersion--Variations of flow velocity promote mixing of water from one layer with another, thus smearing out the distribution of the solute in the vertical plane and diluting the solute along the horizontal plane.
- Molecular diffusion--Mixing also occurs on the microscopic level. In a fractured aquifer system or in a dual porosity system where a low permeability porous matrix exists, molecular diffusion can occur in both the water-filled fractures and in the matrix. Inasmuch as flow in the matrix occurs much more slowly than flow in the fractures, diffusion of solutes into the matrix may be a dominant process affecting solute transport.

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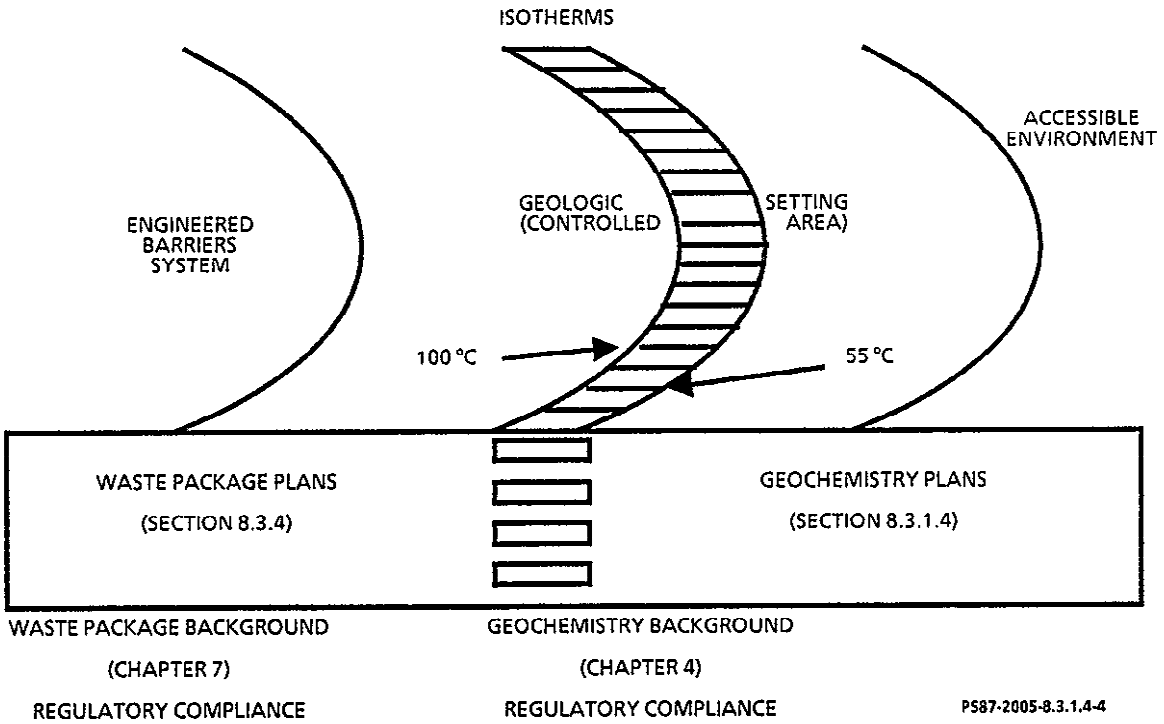

Figure 8.3.1.4-29. Schematic illustration of engineered barriers and site geochemistry program responsibilities (55 °C is the preemplacement ambient temperature at the planned repository depth).

- Geochemical retardation--Transfer across phase boundaries due to precipitation, chemisorption, and ion-exchange will retard advective and dispersive solute movement.

- Complexation--Solute solubility and transport may be enhanced by the formation of soluble complexes between a solute and inorganic and organic ligands dissolved in the groundwater, and solute sorption onto stable, mobile particulates (e.g., colloidal clays and alumina).

In order to quantify the effects of the above processes in the proposed site, the BWIP will collect the data under actual or simulated conditions for the following parameters:

- Radionuclide sorption.
- Diffusion coefficients.
- Radionuclide complex formation and stability.
- Mobility of colloids.
- Isotope exchange.
- Redox reactions.

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The objective of the radionuclide retardation behavior investigation is to quantify the above parameters with enough precision and confidence to meet the performance assessment goals of the SCP (Section 8.3.5).

8.3.1.4.4.2 Rationale

The radionuclide reactivity investigation includes experiments designed to quantify all of the parameters above. The approach is primarily empirical rather than theoretical. An empirical approach is warranted because direct measurements have a lower level of uncertainty than model calculations, which may be based on sparse data and yet unverified assumptions. The BWIP will characterize sorption by determining the effects of various physical and chemical parameters on radionuclide sorption under increasingly complex site-specific conditions.

The laboratory reactivity component of the radionuclide reactivity study consists of two types of tests: batch and column.

Laboratory batch tests constitute a closed static system in which radionuclide-free solids are exposed to a radionuclide-bearing solution for a set time, followed by analytical determination of the solid/solution distribution ratio, R_s. These experiments will evaluate various retardation mechanisms and kinetics under controlled conditions and quantify retardation effects for all key radionuclides under likely site subsystem geochemical conditions. This includes comprehensive laboratory sorption evaluations of key radionuclides (Table 8.3.1.4-10) on geologic samples from selected groundwater flow zones.

Closed, static system experiments are a rapid, efficient means of deriving solubility estimates, sorption/desorption isotherms, and distribution ratios between solid and solution phases. Groundwater composition will be varied to investigate inorganic and organic complexation effects on distribution ratios and sorption/desorption isotherms. Batch tests reflect conditions dominated by chemical diffusion in the fractures of the Cohassett flow interior. Sorption/desorption isotherms will be generated for the larger of either the solubility limit or the DOE maximum permissible concentration for drinking water (see Table 8.3.1.4-10 and DOE, 1981).

Column experiments are more complex. By analyzing the time-dependent concentrations of reactive and nonreactive tracers in the eluted fluid, investigators obtain differential flow velocities, thus yielding the retardation factor. Column experiments may better represent radionuclide migration. They provide a direct measure of retardation and an evaluation of speciation effects and colloid transport. Column experiments also permit less alteration of the adsorbent phase and, thus, may be more representative of in situ conditions. The column experiments simulate conditions in the flow tops where significant advection may occur.

Table 8.3.1.4-10. Preliminary list of key radionuclides for a nuclear waste repository in basalt (based on 1,000-yr-old commercial spent fuel)

Element	Isotope[a]	1,000-yr inventory[b] (Ci/MTHM)	EPA limit[c] (Ci/MTHM)	Inventory / EPA limit
Americium	^{241}Am	1,430	0.1	14,300
Plutonium	^{240}Pu	649	0.1	6,490
Uranium	^{234}U	4.08	0.1	40.8
Carbon	^{14}C	2.16	0.1	21.6
Neptunium	^{237}Np	1.74	0.1	17.4
Curium	^{245}Cm	1.74	0.1	17.4
Nickel	^{59}Ni	6.34	1	6.34
Zirconium	^{93}Zr	3.32	1	3.32
Thorium	^{230}Th	0.0331	0.01	3.31
Niobium	^{94}Nb	2.18	1	2.18
Technetium	^{99}Tc	21.0	10	2.10
Tin	^{126}Sn	1.46	1	1.46
Cesium	^{135}Cs	0.765	1	0.765
Selenium	^{79}Se	0.710	1	0.710
Iodine	^{129}I	0.0568	0.1	0.568

NOTE: Information based on pressurized-water reactor spent fuel with a burnup of 60,000 MWd/MTHM.

EPA = U.S. Environmental Protection Agency.

[a]When more than one isotope of an element met the screening criteria (e.g., ^{241}Am, ^{242}Am, ^{243}Am), the one with the highest inventory is shown.

[b]From Roddy et al. (1985).

[c]From EPA (1986, p. 38087).

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The field reactivity component also consists of two types of experiments: active and passive. The first is labeled "active" because the system is perturbed by the addition of radionuclide analogs in the form of foreign solutions and solutes, and the second is labeled "passive" because it describes the abundance and distribution of naturally occurring radionuclides.

Active field tests include injection-withdrawal experiments and flow-through tracer experiments such as recirculating tracer tests. Injection-withdrawal experiments are static in nature because there is no net translational flow through the basalt. The recirculating tracer experiments are dynamic in nature. These active field reactivity experiments are analogous to static and dynamic laboratory experiments and yield estimates of radionuclide reactivity within relatively small in situ water/rock volumes.

Passive field experiments, on the other hand, entail the collection and analysis of representative samples of groundwater and aquifer materials to describe the abundance and distribution of natural radionuclides of the uranium and thorium decay series. This method yields radionuclide reactivity over geological time for large-scale groundwater flow systems.

The types of sorption information generated by each experiment differ in format, representativeness, and comprehensiveness. Although laboratory methods allow for the examination of more species than either active or passive field tests, there is considerable uncertainty as to whether the laboratory sorption values are transferable to the field due to scale effects and possible contamination. Field methods restrict the number of radionuclides that can be studied due to solubility and environmental considerations. Therefore, any rationale for characterization of radionuclide reactivity must be a combined approach applying the several methods toward a common goal.

The BWIP position for field sorption testing (Grisak et al., 1985) established that data obtained for radionuclide sorption in the laboratory be transferable to the field. To achieve this, scaling factors must be obtained to adjust laboratory sorption determinations to field conditions. Field and laboratory conditions differ significantly in terms of specific surface area exposed to solution, water/rock ratio, and the possible existence of particulates that can further radionuclide mobility. Inasmuch as it is difficult to measure these quantities directly, the BWIP approach is to incorporate them into laboratory-field-scaling factors and use these factors to adjust laboratory-derived sorption isotherms and retardation factors to field conditions (Wallick, 1986).

Scaling Factors

Scaling factors are proportionality factors that relate analogous field and laboratory sorption tests. Laboratory batch testing and field injection-withdrawal testing are analogous because there is no net displacement of fluids within the porous medium. Laboratory column testing and field recirculating tracer testing are also analogous because there is a net

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displacement of fluid through a porous medium, and breakthrough curves can be measured for reactive and conservative tracers. Scaling factors are computed by plotting field versus laboratory sorption parameters. The appropriate field and laboratory sorption parameters that will be compared to produce scaling factors are listed below:

Field	Laboratory
• Field retention factor obtained by injection-withdrawal testing	Laboratory batch K_d
-	Selenium
-	Technetium-95 m
-	Strontium
-	Dissolved oxygen
-	Niobium-91 m
-	Nitrate
-	Lithium
-	Particulates
• Field retardation factor by recirculating tracer testing	Laboratory retardation factor based on column tests
-	Lithium
-	Particulates
-	Selenium
-	Technetium
-	Dissolved oxygen
• Natural radionuclide behavior test	Laboratory batch and column
-	^{234}U, ^{238}U
-	^{230}Th, ^{232}Th
-	^{226}Ra, ^{228}Ra
-	^{210}Pb

The laboratory approach to characterization of sorption parameters has the advantage of providing relative (between radionuclides) reactivity estimates for all radionuclides of interest. The disadvantage of the approach is that conditions in the laboratory may not accurately reflect in situ conditions, and quantifying the amount and distribution of reactive surface along a flow path is difficult, thus limiting the use of such data to bounding calculations and qualitative applications. The main advantages of the field approach are that test conditions are as representative of the natural system as possible and that behavior of key radionuclides (or analogs) can be tested in actual flow paths through which radionuclide transport must be predicted.

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The major disadvantages of field testing are that radiological controls effectively limit the number of radionuclides that can be tested and that only a small number of tests can be conducted.

Extrapolation of laboratory results to the field requires an assessment of scaling factors. These scaling factors can be obtained by (1) determining relationships between analogous field and laboratory data, and (2) laboratory analysis of core samples collected from a test zone after injection-withdrawal testing that contain radionuclides sorbed under in situ conditions.

Comparison of breakthrough curves for laboratory and field flowthrough tests using the same tracers is a direct means of approximating scaling factors. The retardation factors can be plotted against one another to arrive at a relationship that gives the field retardation factor in terms of the laboratory values. In addition, the shapes of the breakthrough curves can be examined to obtain information about the retardation process under field and laboratory conditions.

The laboratory samples will consist of crushed and intact flow-top materials that are representative of a particular hydrostratigraphic zone. Although samples for laboratory sorption work will mainly consist of anoxic core collected during borehole drilling, sidewall core samples will be collected after injection and withdrawal tests that contain sorbed tracer. These sidewall core samples will be mounted in a column setup and backflushed with a solution that will dissolve the sorbed tracer(s). The mass of tracer desorbed from the rock will be determined and will be considered to reflect sorption under in situ conditions.

The same column setup will be used to perform a column test under laboratory conditions using the same tracer. The amount of tracer sorbed by the rock will be determined and will be considered to reflect sorption under laboratory conditions.

A scaling factor will be computed as the ratio of the mass of tracer sorbed under in situ conditions to the mass of tracer sorbed under laboratory conditions.

In the case of the natural radionuclide test, retardation factors will be available for large-scale groundwater flow paths for selected isotopes of uranium, thorium, radium, and lead. These retardation factors will be computed based on the ratio of the latter reactive tracers and ^{222}Rn, an inert gas.

These field retardation factors will be compared with values for retardation of the above isotopes, based on laboratory column and batch tests. Scaling factors computed for the natural radionuclide test will be relevant to bulk properties of the basalt geochemical flow system and not to individual flow tops.

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Scaling factors will be used to adjust laboratory sorption data to field conditions. This will permit the field extrapolation of laboratory sorption measurements for a suite of key radionuclides. It would not be possible to perform field tests with the majority of these radionuclides because of radiological health and safety problems.

A flowchart for characterization of site subsystem radionuclide reactivity is shown in Figure 8.3.1.4-30. At the most basic level, the diagram shows laboratory and active and passive field experiments converging to produce a site subsystem sorption/desorption isotherm data base. The three components are linked by both common radionuclides and common samples of preserved solids for analysis so that scaling factors can be computed for several radionuclides. This approach will be validated by demonstrating a relationship between field and laboratory retardation factors.

The radionuclide retardation behavior investigation carries a major part of the SCP responsibility to demonstrate that the site meets the regulatory criteria of a favorable condition for containment.

The following discussion develops a conceptual model and a simple mathematical relationship for sorption parameters K_d, R_s, and K_f (R_s is a parameter similar to K_d) that are presented in terms of generic equations. Minimum values for sorption parameters are given that would demonstrate existence of a favorable condition. The model further develops the ideas presented in the site average containment equation in Section 8.3.1.4.2.

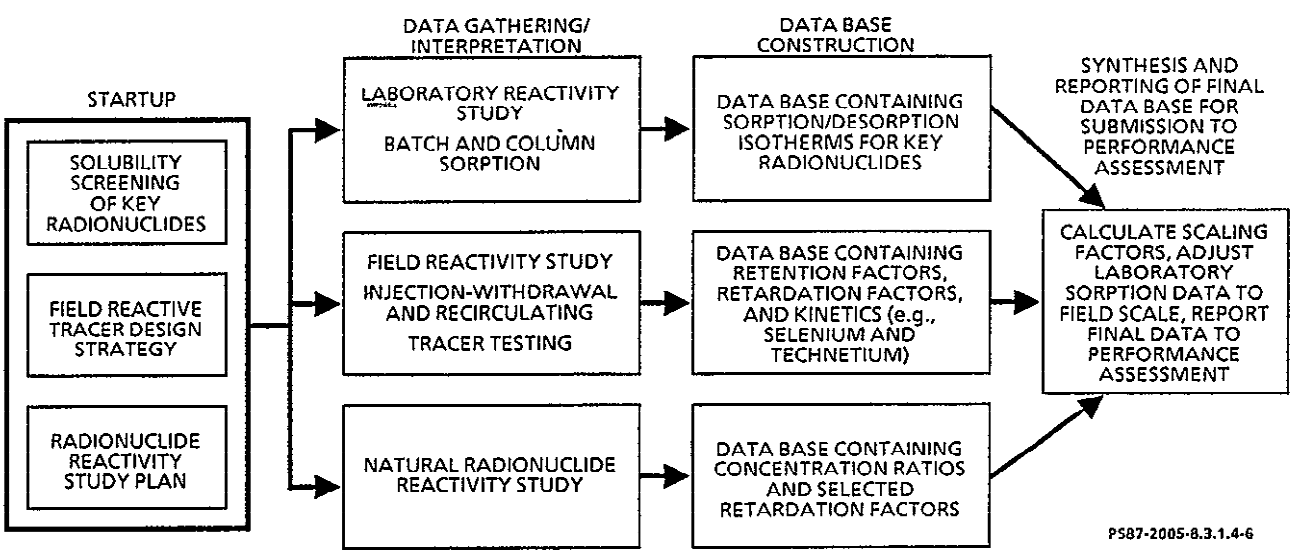

Figure 8.3.1.4-30. Generalized flowchart showing interrelationships among components of the radionuclide reactivity study.

Implicit in the definition of the sorption ratio R_s (NRC, 1987), the ratio of the concentration of solute bound on the solid to that dissolved in the water (C_s/C_w), is the assumption that the system is at equilibrium. Both K_d and R_s assume chemical equilibrium and reversibility of adsorption/desorption isotherms. The equilibrium assumption requires that the solute sorb and desorb reversibly.

Another concept dealing specifically with sorption of radionuclides that have escaped the engineered system and entered the controlled water/rock volume is the containment factor, K_f. The containment factor does not depend on any exchange equilibria, but simply describes the fraction of radionuclides that is sorbed onto aquifer solids.

The containment factor is called the retention factor (R_{tf}) in later discussions pertaining to field reactive tracer testing. The retention factor is a relative measure of the fraction of sorbing tracer that is present in the groundwater versus that sorbed on the solids after a given contact time. The controlled water/rock volume is defined by the volume of an injected tracer slug (see Section 8.3.1.4.4.3.2.1). The retention factor is analogous to the containment factor but differs in two major respects:

1. In an injection-withdrawal test, fluid moves out and back from the formation, whereas the definition of containment factor assumes unidirection flow.

2. Reaction times and volumes are significantly smaller for field tests as opposed to the bulk system defined in Section 8.3.1.4.4.2.1.

The containment factor, K_f, is derived on the basis of the following conceptual model for release of radionuclides from the repository over a 10,000-yr period.

<u>8.3.1.4.4.2.1 Conceptual model</u>.

Figure 8.3.1.4-31 illustrates the factors influencing the mass or activity of a radionuclide contained within the engineered barriers subsystem 1,000 yr after repository closure. Each radionuclide (i) is released across the engineered barriers system boundary to the controlled area then across the boundary to the accessible environment. Within the controlled area, radionuclides are transported by groundwater and taken up from solution by some fraction of the rock-mineral mass. The activity remaining in groundwater is carried to the accessible environment boundary. Over a period of 10,000 yr, the cumulative amount of radionuclide that has escaped retention by the adsorbing minerals in the controlled area and has reached the accessible environment boundary must not exceed the regulatory limits for cumulative release, (NRC, 1986, Part 60.115, Table 1).

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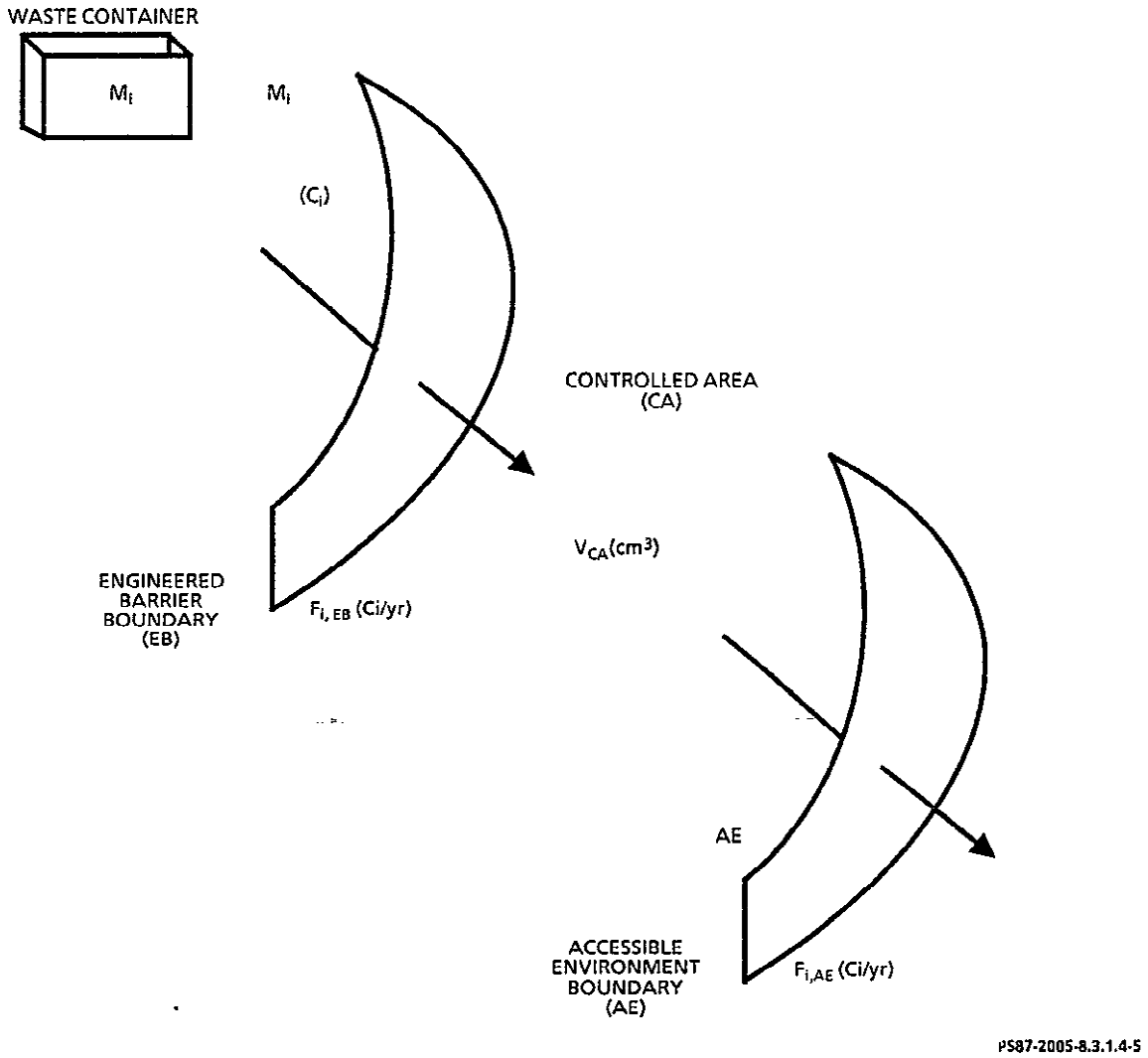

Figure 8.3.1.4-31. Schematic illustration of the conceptual model for radionuclide containment in the controlled area.

Derivation of the containment factor, K_f

Let

a = Ratio of release rates of radionuclides at boundaries AE ($F_{i,AE}$) and EB ($F_{i,EB}$), or $a = F_{i,AE}/F_{i,EB}$ (8.3.1.4-3)

ϕ = Volume fraction of CA space that is available for groundwater transport (porosity + cracks + ...)

ρ = Mean density of rock in CA (g/cm^3)

b = Fraction of the CA rock mass that sorbs radionuclides

τ = Mean travel or residence time of groundwater in the CA (yr)

T = Regulatory time period for cumulative release (yr).

Expressions may be written for the following quantities:

(i) Radionuclide release rate at EB boundary: $F_{i,EB}$ (Ci/yr)

(ii) Mean groundwater flow rate through CA: $\phi V_{CA}/T$ (cm^3/yr)

ϕ = Effective porosity

V_{CA} = Rock volume

τ = Mean water travel or residence time

(iii) Mean radionuclide i concentration in groundwater:

$$C'_w = \frac{F_{i,EB}}{\phi V_{CA}/\tau} \ (Ci/cm^3)$$

(iv) Mass of rock (minerals) in the CA: $(1 - \phi)V_{CA}\rho$ (g)

(v) Mass of minerals sorbing radionuclide i is a fraction b of the rock mass, M_m: $M_m = (1 - \phi)V_{CA}\rho b$ (g)

(vi) Amount of radionuclide i that is to be retained within the CA in T yr, M_{ret}: $M_{ret} = (F_{i,EB} - F_{i,AE})T$ (Ci)

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(vii) Mean concentration of radionuclide i sorbed on minerals in CA, C_s: a defined in Equation 8.3.4.1-3

$$C'_s = \frac{M_{ret}}{M_m} = \frac{F_{i,EB}(1 - a)T}{(1 - \phi)V_{CA}\rho b} \text{ (Ci/g)}$$

Recall that the equilibrium sorption ratio R_s was defined as C_s/C_w. The containment factor, K_f, is defined in a similar manner for the nonequilibrium case as described by the conceptual model as C'_s/C'_w, where the superscript prime denotes a time-dependent property. Substituting for C'_s from (vii) and for C'_w from (iii) yields the expression:

$$K_f = \frac{(1-a)\ \phi T}{(1-\phi)\rho b \tau} \qquad (8.3.1.4\text{-}4)$$

Estimation of K_f needed to meet cumulative release requirement

K_f is the minimum value that satisfies the following condition for retention in the controlled area (see Fig. 8.3.1.4-31):

$$\text{Amount retained in CA} = (F_{i,EB} - F_{i,AE})T \qquad (8.3.1.4\text{-}5)$$

An estimate of the value of K_f needed to meet the cumulative release requirement at the accessible environment boundary will be based on the following numerical values of the parameters:

a = 0 (this is consistent with a strategy of having a <<1, Equation 8.3.1.4-3)

ϕ = 0.03 or 3% of the controlled area volume available for groundwater flow and transport

ρ = 3 g/cm^3

b = 0.01 or 1% of the rock mass available for effective sorption

τ = 1,000 yr (mean groundwater travel time, equated to mean water residence time)

T = 10,000 yr.

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Substitution of the above numerical values for the parameters in Equation 8.3.1.4-4 gives:

$$K_f = \frac{1 \times 3 \times 10^{-2} \times 10^4}{0.97 \times 3 \times 0.01 \times 10^3} = 10 \ (cm^3/g) \qquad (8.3.1.4\text{-}6)$$

It should be noted that Equation 8.3.1.4-4 and the computed result in Equation 8.3.1.4-6 are independent of the release rates (flux values) at the EB and AE boundaries, but they depend on the ratio value of the latter.

The value of K_f in Equation 8.3.1.4-6 is sensitive to the effective rock porosity and fraction of the mineral mass adsorbing. It also depends on the estimates of mean groundwater travel time and the length of the regulatory containment period. An increase in T and shortening of the mean groundwater travel time would require high values of K_f to meet the containment criterion.

Lower porosities and longer travel times than used in the above example would lower the K_f estimate. For example, a K_f of 1 would be obtained by using either a 10,000-yr travel time or by decreasing the porosity to 0.3% (both of the latter hydrologic parameters are considered highly probable for Grande Ronde Basalt flow tops).

The above considerations suggest a tentative performance parameter goal of 1 to 10 cm^3/g for demonstrating radionuclide containment by the site subsystem. This general guidance was used in assignment of the sorption parameter goals presented in the following description of the radionuclide reactivity study.

8.3.1.4.4.3 Description of radionuclide reactivity study

The radionuclide reactivity study is divided into three major components that, in turn, are subdivided into tests and analyses to quantify the transport behavior of radionuclides in the site subsystem. The components are as follows:

- Laboratory reactivity component.
  - Batch tests.
  - Column tests.
- Field reactivity component.
  - Injection-withdrawal field tracer tests.
  - Flowthrough field tracer tests.
- Natural radionuclide reactivity component.
  - Laboratory validation tests.
  - Field tests.

The radionuclide reactivity study will collect data on many high-level and supporting parameters. Information about these parameters are presented in Table 8.3.1.4-11 and are discussed in the following component and test descriptions.

8.3.1.4.4.3.1 Laboratory reactivity component.

The laboratory reactivity component focuses on measuring sorption parameters. Sorption is the net accumulation of a substance at the common boundary of two contiguous phases (Everett, 1972). The study of sorption in aqueous systems generally involves reaction of a solid with a solution of particular composition, isolation of the solid from the reactant solution phase, and chemical analysis of the solid and (or) solution phases. The reaction step can involve either a batch (static) analysis or a dynamic (flow-through) analysis.

This section discusses the equations used in adsorption analysis, techniques to distinguish between adsorption and precipitation, techniques to measure sorption kinetics, types of tests, the various batch tests planned for the laboratory reactivity component, and the various column tests planned for the laboratory reactivity component.

8.3.1.4.4.3.1.1 Equations used in adsorption analysis. The interpretation of sorption data requires the use of a sorption equation. The three sorption equations most commonly used to describe sorption data are the following:

- Langmuir equation.
- Freundlich equation.
- Brunauer-Emmett-Teller (BET) equation.

The Langmuir equation was originally derived for the sorption of gases by solids. It is of the form

$$x/m = \frac{KCb}{1+KC} \qquad (8.3.2.4\text{-}7)$$

where

C = Equilibrium concentration of adsorbate in question

x/m = Weight of adsorbate per unit weight of adsorbent

K = Constant related to binding strength

b = Sorption capacity (monomolecular layer).

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Table 8.3.1.4-11. Performance parameters and upper level supporting parameters for the radionuclide reactivity study (sheet 1 of 6)

Performance parameter	Issue	Scale/ location	Tentative parameter goal/needed accuracy	Test basis			Supporting parameter list*
Sorption coefficients				Needed confidence	Current estimate of goal/accuracy	Current confidence	
R_s Curium, cesium, zirconium, americium	1.1, 1.8	Laboratory/ Cohassett flow top	>10/±1	High	>100	High	A
R_s Carbon, iodine	1.1, 1.8	Laboratory/ Cohassett flow top	>0	High	0-1	High	A
R_s Nickel, tin	1.1, 1.8	Laboratory/ Cohassett flow top	>10/±1	High	>50	Medium	A
R_s Selenium, rhenium, technetium, niobium	1.1, 1.8	Laboratory/ Cohassett flow top	>10/±1	High	>10	Low	A
R_s Radium, thorium	1.1, 1.8	Laboratory/ Cohassett flow top	>10/±1	High	>100	Medium	A
R_s Uranium, bismuth, neptunium	1.1, 1.8	Laboratory/ Cohassett flow top	>10/±1	High	>100	Medium	A
R_s Curium, cesium, zirconium, americium	1.1, 1.8	Laboratory/ Cohassett flow top	>10/±1	High	>100	High	A
R_s Carbon, iodine	1.1, 1.8	Laboratory/ Rocky Coulee flow top	>0	High	0-1	High	A
R_s Nickel, tin	1.1, 1.8	Laboratory/ Rocky Coulee flow top	>10/±1	High	>50	Medium	A
R_s Selenium, technetium, niobium	1.1, 1.8	Laboratory/ Rocky Coulee flow top	>10/±1	High	>10	Low	A
R_s Radium, thorium	1.1, 1.8	Laboratory/ Rocky Coulee flow top	>10/±1	High	>100	Medium	A
R_s Uranium, neptunium, plutonium	1.1, 1.8	Laboratory/ Rocky Coulee flow top	>10/±1	High	>100	Medium	A
R_s Curium, cesium, zirconium, americium	1.1, 1.8	Laboratory/Gingko flow top	>10/±1	High	>100	High	A
R_s Carbon, iodine	1.1, 1.8	Laboratory/Gingko flow top	>0	High	0-1	High	A

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Table 8.3.1.4-11. Performance parameters and upper level supporting parameters for the radionuclide reactivity study (sheet 2 of 6)

Performance parameter	Issue	Scale/ location	Tentative parameter goal/needed accuracy	Test basis			Supporting parameter list*
Sorption coefficients				Needed confidence	Current estimate of goal/accuracy	Current confidence	
R_s Nickel, tin	1.1, 1.8	Laboratory/Gingko flow top	>10/±1	High	>50	Medium	A
R_s Selenium, technetium, niobium	1.1, 1.8	Laboratory/Gingko flow top	>10/±1	High	>10	Low	A
R_s Radium, thorium	1.1, 1.8	Laboratory/Gingko flow top	>10/±1	High	>100	Medium	A
R_s Uranium, neptunium, plutonium	1.1, 1.8	Laboratory/Gingko flow top	>10/±1	High	>100	Medium	A
R_s Curium, cesium, zirconium, americium	1.1, 1.8	Laboratory/ Vantage interbed	>10/±1	High	>100	High	B
R_s Carbon, iodine	1.1, 1.8	Laboratory/ Vantage interbed	>0	High	0-1	High	B
R_s Nickel, tin	1.1, 1.8	Laboratory/ Vantage interbed	>10/±1	High	>50	Medium	B
R_s Selenium, technetium, niobium	1.1, 1.8	Laboratory/ Vantage interbed	>10/±1	High	>10	Low	B
R_s Radium, thorium	1.1, 1.8	Laboratory/ Vantage interbed	>10/±1	High	>100	Medium	B
R_s Uranium, plutonium, neptunium	1.1, 1.8	Laboratory/ Vantage interbed	>10/±1	High	>100	Medium	B
R_s Curium, cesium, zirconium, americium	1.1, 1.8	Laboratory/ fracture infilling	>10/±1	High	>100	High	B
R_s Carbon, iodine	1.1, 1.8	Laboratory/ fracture infilling	>0	High	0-1	High	B
R_s Nickel, tin	1.1, 1.8	Laboratory/ fracture infilling	>10/±1	High	>50	Medium	B
R_s Radium, thorium	1.1, 1.8	Laboratory/ fracture infilling	>10/±1	High	>100	Medium	B
R_s Selenium, technetium, niobium	1.1, 1.8	Laboratory/ fracture infilling	>10/±1	High	>10	Low	B

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Table 8.3.1.4-11. Performance parameters and upper level supporting parameters for the radionuclide reactivity study (sheet 3 of 6)

Performance parameter	Issue	Scale/ location	Tentative parameter goal/needed accuracy	Test basis			Supporting parameter list*
Sorption coefficients				Needed confidence	Current estimate of goal/accuracy	Current confidence	
R_s Uranium, plutonium, neptunium	1.1, 1.8	Laboratory/fracture infilling	>10/±1	High	>100	Medium	B
R_s Radium, thorium	1.1, 1.8	Field/Cohassett flow top	>10/±1	High	>100	Medium	C
R_s Radium, thorium	1.1, 1.8	Field/Rocky Coulee flow top	>10/±1	High	>100	Medium	C
R_s Radium, thorium	1.1, 1.8	Field/Gingko flow top	>10/±1	High	>100	Medium	C
R_s Radium, thorium	1.1, 1.8	Field/Vantage interbed	>10/±1	High	>100	Medium	C
R_s Radium, thorium	1 1, 1.8	Field/Vantage inberbed	>10/±1	High	>100	Medium	C
R_s Selenium, technetium, niobium	1.1, 1.8	Field/McCoy Canyon flow top	>10/±1	High	>10	Low	D
Ndes Curium, cesium, zirconium, americium	1.1, 1.8	Laboratory/Cohassett flow top	<1	High	<1	High	A
Ndes Carbon, iodine	1.1, 1.8	Laboratory/Cohassett flow top	<1	High	<1	Medium	A
Ndes Nickel, tin	1.1, 1.8	Laboratory/Cohassett flow top	<1	High	<1	Medium	A
Ndes Radium, thorium	1.1, 1.8	Laboratory/Cohassett flow top	<1	High	<0 1	High	A
Ndes Selenium, technetium, niobium	1.1, 1.8	Laboratory/Cohassett flow top	<1	High	<1	Medium	A
Ndes Carbon, iodine	1.1, 1.8	Laboratory/Rocky Coulee flow top	<1	High	<1	Medium	A
Ndes Uranium, plutonium, neptunium	1.1, 1.8	Laboratory/Cohassett flow top	<1	High	<1	Medium	A

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Table 8.3.1.4-11. Performance parameters and upper level supporting parameters for the radionuclide reactivity study (sheet 4 of 6)

Performance parameter	Issue	Scale/location	Tentative parameter goal/needed accuracy	Test basis			Supporting parameter list*
Sorption coefficients				Needed confidence	Current estimate of goal/accuracy	Current confidence	
Ndes Curium, cesium, zirconium	1.1, 1.8	Laboratory/Rocky Coulee flow top	<1	High	<1	High	A
Ndes Nickel, tin	1.1, 1.8	Laboratory/Rocky Coulee flow top	<1	High	<1	Medium	A
Ndes Selenium, technetium, niobium	1.1, 1.8	Laboratory/Rocky Coulee flow top	<1	High	<1	Medium	A
Ndes Radium, thorium	1.1, 1.8	Laboratory/Rocky Coulee flow top	<1	High	<0.1	High	A
Ndes Uranium, neptunium, plutonium	1.1, 1.8	Laboratory/ Coulee flow top	<1	High	<1	Medium	A
Ndes Curium, cesium, zirconium, americium	1.1, 1.8	Laboratory/Gingko flow top	<1	High	<1	High	A
Ndes Carbon, iodine	1.1, 1.8	Laboratory/Gingko flow top	<1	High	<1	Medium	A
Ndes Nickel, tin	1.1, 1.8	Laboratory/Gingko flow top	<1	High	<1	Medium	A
Ndes Selenium, technetium, niobium	1.1, 1.8	Laboratory/Gingko flow top	<1	High	<1	Medium	A
Ndes Radium, thorium	1.1, 1.8	Laboratory/Gingko flow top	<1	High	<0.1	High	A
Ndes Uranium, neptunium, plutonium	1.1, 1.8	Laboratory/Gingko flow top	<1	High	<0.1	High	A
Ndes Curium, cesium, zirconium, americium	1.1, 1.8	Laboratory/ Vantage interbed	<1	High	<1	High	B
Ndes Carbon, iodine	1.1, 1.8	Laboratory/ Vantage interbed	<1	High	<1	Medium	B
Ndes Nickel, tin	1.1, 1.8	Laboratory/ Vantage interbed	<1	High	<1	Medium	B
Ndes Selenium, technetium, niobium	1.1, 1.8	Laboratory/ Vantage interbed	<1	High	<1	Medium	B

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Table 8.3.1.4-11. Performance parameters and upper level supporting parameters for the radionuclide reactivity study (sheet 5 of 6)

Performance parameter	Issue	Scale/ location	Tentative parameter goal/needed accuracy	Test basis			Supporting parameter list*
Sorption coefficients				Needed confidence	Current estimate of goal/accuracy	Current confidence	
Ndes Radium, thorium	1.1, 1.8	Laboratory/Vantage interbed	<1	High	<0 1	High	B
Ndes Uranium, plutonium, neptunium	1.1, 1.8	Laboratory/Vantage interbed	<1	High	<1	Medium	B
Ndes Curium, cesium, zirconium, americium	1.1, 1.8	Laboratory/fracture infilling	<1	High	<1	High	B
Ndes Carbon. iodine	1.1, 1.8	Laboratory/fracture infilling	<1	High	<1	Medium	B
Ndes Nickel, tin	1.1, 1.8	Laboratory/fracture infilling	<1	High	<1	Medium	B
Ndes Selenium, technetium, niobium	1.1, 1 8	Laboratory/fracture infilling	<1	High	<1	Medium	B
Ndes Radium, thorium	1.1, 1.8	Laboratory/fracture infilling	<1	High	<1	Medium	B
Ndes Uranium, plutonium, neptunium	1.1, 1.8	Laboratory/fracture infilling	<1	High	<1	Medium	B
Ndes Radium, thorium	1.1, 1 8	Field/Cohassett flow top	<1	High	<0.1	High	C
Ndes Radium, thorium	1 1, 1 8	Field/Rocky Coulee flow top	<1	High	<0.1	High	C
Ndes Radium, thorium	1.1, 1.8	Field/Gingko flow top	<1	High	<0.1	High	C
Ndes Radium, thorium	1.1, 1.8	Field/Vantage interbed	<1	High	<0.1	High	C
Ndes Selenium, technetium, niobium	1.1, 1.8	Field/Cohassett flow top	<1	High	<1	Medium	D
Ndes Selenium, technetium, niobium	1.1, 1.8	Field/Rocky Coulee flow top	<1	High	<1	Medium	D

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Table 8.3.1.4-11. Performance parameters and upper level supporting parameters for the radionuclide reactivity study (sheet 6 of 6)

Performance parameter	Issue	Scale/location	Tentative parameter goal/needed accuracy	Test basis			Supporting parameter list*
				Needed confidence	Current estimate of goal/accuracy	Current confidence	
Ndes Selenium, technetium, niobium	1.1, 1.8	Field/McCoy Canyon flow top	<1	High	<1	Medium	D
R_{tf} Selenium, technetium, niobium	1.1, 1.8	Field/McCoy Canyon flow/ Cohassett flow/ Rocky Coulee flow	R_{tf}>1/10%	High	>1/low	Low	E
K_f Selenium, technetium, niobium	1.1, 1.8	Field/McCoy Canyon flow/ Cohassett flow/ Rocky Coulee flow	K_f>10/10%	High	>10/low	Low	E

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*Supporting parameter lists:

A
- Sorption isotherm
- Bulk density
- Porosity
- Ferrous/ferric ratio-secondary minerals and glass
- Chemical composition-secondary minerals
- Distribution-secondary minerals
- Paragenesis
- Mineral stability
- Groundwater composition
- Temperature
- Redox
- Solid/solution ratio
- Surface area (flow top)
- Cation exchange capacity
- pH
- R_f (column)

B
- Sorption isotherm
- Bulk density
- Porosity
- Ferrous/ferric ratio-secondary minerals and glass
- Interbed mineralogy
- Groundwater composition
- Temperature
- Redox
- Solid/solution ratio
- Surface area
- Cation exchange capacity
- pH
- R_f (column)

C
- R_f (field)
- Bulk density
- Porosity
- Groundwater composition
- pH
- Temperature
- Surface area (in situ)
- Stable isotope composition-secondary phases
- Isotopic age dates-secondary minerals

D
- R_f (field)
- Bulk density
- Porosity
- Groundwater composition
- pH
- Temperature
- Surface area (in situ)

E
- Chemical parameters
  - Masses of various tracers (iodine, ^{95}Tc m, selenium, and others) added to injection water
  - Concentrations of tracers in withdrawn tracer slug as a function of volume
  - Background concentrations of tracers in formation water
  - Major chemical constituents (sodium, potassium, calcium, magnesium, chloride, bicarbonate, carbonate, sulfate, nitrate, silica, iron, pH, Eh) of formation water
  - Major chemical constituents of tracer slug
- Distance, depth parameters
  - Distance between injection and monitoring/pumping borehole for flowthrough tracer testing
  - Thickness of test interval
  - Depth to top of test interval
- Volumes, volume/time
  - Volume of borehole in test interval
  - Volumes of tracer solution injected and withdrawn for injection-withdrawal testing
  - Volumes of formation water withdrawn, injected, and withdrawn for swish testing
  - Pumping rates for all types of tests
- Time
  - For injection-withdrawal and swish testing, the residence time of the tracer slug in the formation
  - For flow through tracer testing, the arrival time of various tracer pulses (breakthrough)
- Temperature
  - Injected water
  - Withdrawn water as a function of time
  - Borehole fluid as a function of depth (dynamic temperature profile) to locate producing zones
- Pressure
  - In annulus just above packers
  - In shut-in interval
  - As a function of time during injection and withdrawal

R_s = Sorption ratio (equivalent to Kd).
Ndes = Desorption coefficient (derived from sorption/desorption isotherms).
R_{tf} = Retention factor.
K_f = Containment factor.

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The Langmuir equation depends on the assumptions that (1) the energy of sorption is constant, (2) adsorption is independent of the extent of surface coverage, (3) adsorbate species do not interact, and (4) maximum adsorption is represented by a complete monomolecular layer on all sorbent surfaces.

An advantage of the Langmuir isotherm is that it defines an adsorption capacity for the adsorbent. A disadvantage is that it assumes constant free energy of adsorption, which is rarely the case. Energy of adsorption tends to decrease with increasing surface coverage.

The Freundlich equation is an empirically derived equation of the form

$$\frac{x}{m} = KC^{n} \qquad (8.3.1.4\text{-}8)$$

where

K and n = Empirically derived constants

C = Equilibrium concentration of adsorbate in question

x/m = Weight of adsorbate per unit weight of adsorbent.

The Freundlich equation can be derived theoretically by assuming that the decrease in energy of adsorption with increasing surface coverage is due to surface heterogeneity.

The Freundlich equation is limited because it does not predict adsorption capacity. Despite this, the Freundlich equation is the most commonly used adsorption equation and has been used to successfully model trace inorganic and organic sorption behavior in soils and geologic media.

The Brunauer-Emmett-Teller (BET) equation takes into account multilayer adsorption, which is characteristic of physical and van der Waals attraction. The BET equation has the form of

$$A = (V_m/V_o)\ [(N_a)(A_m)] \qquad (8.3.1.4\text{-}9)$$

where

A = Surface area of the adsorbent

V_m = Volume of gas required to form a molecular monolayer

V_o = Molar volume of adsorbate gas

N_a = Avogadro's number.

A_m = Cross-sectional area of the sorbate molecule.

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The BET equation has been applied to ion adsorption from soil solutions and pesticide adsorption in soils.

Previous work (Ames and McGarrah (1980, 1981a, 1981b); Ames et al. (1981, 1984); Salter et al. (1981a, 1981b); Salter and Jacobs 1982; Barney (1981a, 1981b, 1982, 1983, 1984); Barney et al. (1983, 1985); and Puls et al. (1987)) has shown that the Freundlich fits most radionuclide-basaltic data. However, BWIP investigators will use all three of the above equations and possibly others to determine which equation best models laboratory adsorption data obtained with updated procedures.

Adsorption experiments conducted on a mass basis can be transformed to a surface area basis from measurements of specific surface area of solids used in analyses. This is the current and proposed experimental practice. The BWIP investigators will evaluate the need and (or) practicality of determining adsorption capacities of solids. The expected low solubility of most radionuclides and relatively large (almost infinite) available surface area along projected flow paths would seem to make such determinations unnecessary under normal site conditions. In the case of disruptive scenarios (e.g., earthquake, seals, failure) however, such data may be necessary. If transport models requiring radionuclide specific adsorption capacities are employed, the adsorption capacities will be determined from the Langmuir isotherm (or others) or from specific experimental laboratory tests.

<u>8.3.1.4.4.3.1.2 Techniques to distinguish between adsorption and precipitation</u>. The distinction between adsorption and precipitation is important in the interpretation of adsorption data. Precipitation can be defined as an accumulation of a substance to form a new bulk solid phase, whereas adsorption involves the net accumulation at an interface. Both involve a loss of material from the solution phase. The distinction becomes less clear because the chemical bonds formed in either are very similar.

Adsorption is a two-dimensional process, while precipitation is three-dimensional. In soils and geologic environments, new solid phases can precipitate homogeneously onto existing solid surfaces, and weathering solids may provide host surfaces for more stable new solid phases. The heterogenous nucleation of a new solid phase can occur when a critical supersaturation of adsorbate is exceeded. Below that critical concentration, adsorption controls the activity of the adsorbate.

Kinetics can be used to distinguish between adsorption and precipitation (Sposito, 1984). Typically, metal adsorption data follows an L shaped curve (Fig. 8.3.1.4-32). The L-shaped curve reflects an initial relatively rapid removal of material from solution followed by a slow or a steady-state removal. Such data alone do not suggest a particular mechanism, but the rapid initial stage may correspond principally to adsorption if the initial concentrations in solution are below supersaturation levels. Adsorption mechanisms can be elucidated by taking a kinetic approach with subsequent chemical and optical analyses of solids and solutions. The kinetic approach uses a large range of initial radionuclide concentrations, variable solution compositions (e.g., varying important liquid concentrations), and in situ solids and pure mineral phases of those solids.

9 2 1 2 5 5 0 1 6 1

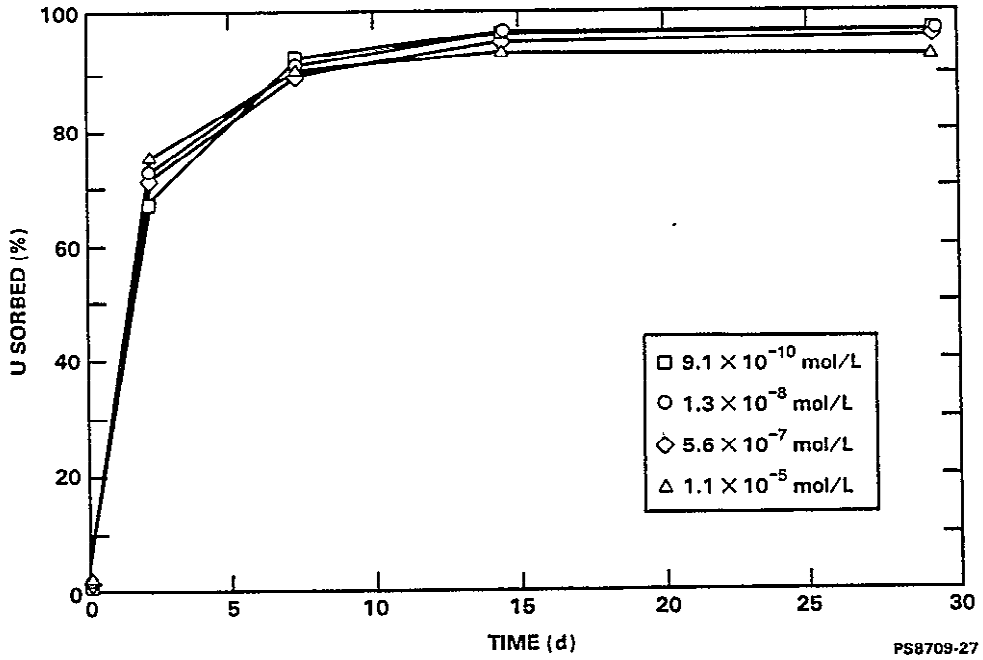

Figure 8.3.1.4-32. Kinetics of uranium adsorption on Cohassett flow basalt (flow-top disaggregates; 55°C).

8.3.1.4.4.3.1.3 Equations for adsorption and desorption. Investigators have used numerous mathematical expressions to describe the rate of metal adsorption from aqueous solution. There is growing acceptance of the following Elovich equation to represent the rapid initial stage:

$$dq/dt = K_1 \exp(-K_2 q) \qquad (8.3.1.4\text{-}10)$$

where

q = Amount adsorbed per unit mass solid

K_1 and K_2 = Constants.

A classical kinetic model approach for adsorption/desorption in a closed system requires information on forward and reverse rates and initial concentrations. Assuming first-order kinetics, adsorption/desorption can be described by the following equation:

$$\begin{aligned} \frac{dC}{dt} &= kaC + kd\ (C_o - C) \\ &= kdC_o - (ka\ \ kd)C \end{aligned} \qquad (8.3.1.4\text{-}11)$$

where

C = Current solution concentration

C_0 = Initial solution concentration

ka = Adsorption rate

kd = Desorption rate.

Integration of the above equation results in the following expression for adsorption and desorption reactions:

$$C = kdC_0e^{-(ka + kd)t} \qquad (8.3.1.4\text{-}12)$$

Typically, ka/kd >>1. This approach is applicable if reactions in both directions approach equilibrium rapidly.

Sorption as used in this report refers to surface processes including ion exchange, chemisorption or selective adsorption/complexation, co-precipitation in amorphous coatings, and redox mediated precipitation/sorption whereby a radionuclide is removed from solution by interactions with solid adsorbents.

Previous sorption experiments with radionuclides in basalt geochemical experiments indicate that many sorption reactions are slower than typical solute sorption reactions; and desorption is extremely slow, making desorption rate measurements impractical. Refinement of existing experimental methodology as detailed in the radionuclide reactivity study plan may make such assessment possible. If so, the geochemistry program will use the above approach to analyze kinetic data. Field studies, involving injection of reactive tracers into basalt formations, and natural radionuclide analyses will provide additional data to assess sorption/desorption mechanisms and rates of reaction.

8.3.1.4.4.3.1.4 Types of tests. The BWIP approach to determining radionuclide reactivity in the site subsystem is primarily empirical. The laboratory tests are designed to determine the effects of various physical and chemical parameters on sorption under complex site-specific conditions.

Batch tests are the simplest and most numerous of the laboratory tests. Batch tests will be performed to generate sorption/desorption isotherms, solubility estimates, and sorption ratios (or distribution coefficients) for radionuclides and for elements of interest for field studies (e.g., lead) under different physical and chemical conditions. The results of batch tests will have some bearing on the number and type of column tests to be performed.

9 2 1 2 5 5 0 1 6 3

Investigators will run variations of column tests to examine speciation effects for elements such as uranium, neptunium, and plutonium and colloid formation and the effect of colloid-size particle transport on radionuclide mobility. The extent of latter efforts is dependent upon groundwater sampling analyses in the hydrochemical investigation as discussed in Section 8.3.1.4.3. Column tests will generate breakthrough curves from which sorption ratios and reaction kinetics can be determined.

The laboratory component will include evaluation of the geochemical code MINTEQ. Investigators will run solubility/speciation simulations to help in designing laboratory testing matrices. Laboratory sorption data will be used as input to MINTEQ adsorption algorithms. Such efforts will serve as checks on laboratory approaches and will assess the usefulness of the MINTEQ code for modeling sorption in a basalt geochemical environment. Current deficiencies in the MINTEQ data base will have to be corrected if the data base and program are going to be more useful.

Radionuclides of importance are listed in Table 8.3.1.4-10 based on 1,000-yr inventory of commercial spent fuel and U.S. Environmental Protection Agency release limits (Roddy et al., 1985). Current data on the retardation behavior of these elements are discussed in Section 4.1.3. Much of the previous work was for engineered barriers materials and did not adequately simulate natural site subsystem geochemical conditions. Additional work is particularly needed for solids from major flow zones in the Wanapum and Grande Ronde Basalts (mainly flow-top samples) and for varying groundwater compositions.

Flow-top, fracture, and interbed material will be collected from the BWIP core library, planned hydrochemistry boreholes, and porthole drilling operations during exploratory shaft construction. The laboratory tests will use both crushed and intact core material. The cores will be retrieved, crushed, stored, and tested under an argon or nitrogen environment.

Laboratory studies will focus on the sorption/desorption behavior of uranium, plutonium, neptunium, technetium, selenium, niobium, and iodine. Uranium, plutonium, and neptunium have large projected inventories and need additional work on redox reactions, complexation, and colloid transport. Selenium, niobium, and technetium behave as anions in the basalt groundwaters and need considerable work to understand their behavior in the natural system. Selenium is removed to a significant extent, but additional work is needed to define the removal mechanism for flow top solids. Technetium redox behavior is poorly understood in this geochemical environment. Previous work indicates that carbonate complexation may decrease sorption. Very little information is presently available on niobium behavior for the site subsystem. Iodine is not expected to sorb to any detectable extent, but it will be included in both batch and column developmental work to verify this and to assess its usefulness as a nonconservative tracer in column and field studies. Carbon sorption is not expected under natural site conditions, and no work is planned with respect to its retardation.

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Nickel and tin will receive additional study. The current data are scant but indicate that these elements are very sorptive in a basalt geochemical environment. Additional testing will focus on complexation and specific adsorbent effects on sorption.

Extensive current data on americium, curium, and zirconium indicate high sorption/low mobility. Additional work is not planned at this time. Previous work with basalt and flow top solids show these elements have very large sorption ratios. Some limited work will be done with lead, radium, thorium, and strontium in support of field reactivity studies.

The laboratory tests will use solids from likely pathways for radionuclide movement. The most credible pathways away from the repository include flow tops, fractures filled or lined with secondary minerals, and interbeds in the primary and lower secondary isolation zones (the Grande Ronde and Wanapum Basalts strata, respectively) (see Section 3.9.3.1). The laboratory tests will therefore use flow-top solids from the Cohassett, Rocky Coulee, and Ginkgo flows; secondary minerals lining interior fractures; and interbed material from the Vantage interbed (see Fig. 8.3.1.4-1 or 8.3.1.4-15 to locate these strata). Most previous sorption work has been on other solids such as crushed entablature basalt, Mabton interbed material, and Umtanum flow-top solids.

The synthetic groundwater formulations have been selected to ensure a stable, consistent composition that can be used as a reference for the evaluation of sorption reactions. Section 4.5.1.2 discusses groundwater compositions of Grande Ronde and Wanapum Basalts in detail. Investigators can obtain information on complex formation by varying synthetic groundwater compositions and measuring the sorption effects. Previous work by Barney (1981a, 1982, 1984) and thermodynamic data compiled by Apps et al. (1982) and Allard (1982) show that hydroxide and carbonate/bicarbonate complexes may affect sorption of some radionuclides.

As indicated in Section 4.1.2.4, additional characterization of organics in the basalt groundwaters is needed to determine what contribution organic complexation may have on radionuclide mobility. This characterization effort is planned as part of the hydrochemical characterization investigation (Section 8.3.1.4.3). Should significant quantities of organic complexants be identified, detailed sorption/desorption studies will be initiated.

A flow chart showing the sequencing of and relationship between various laboratory testing activities is presented in Figure 8.3.1.4-33. The various activities shown are discussed in the following test descriptions.

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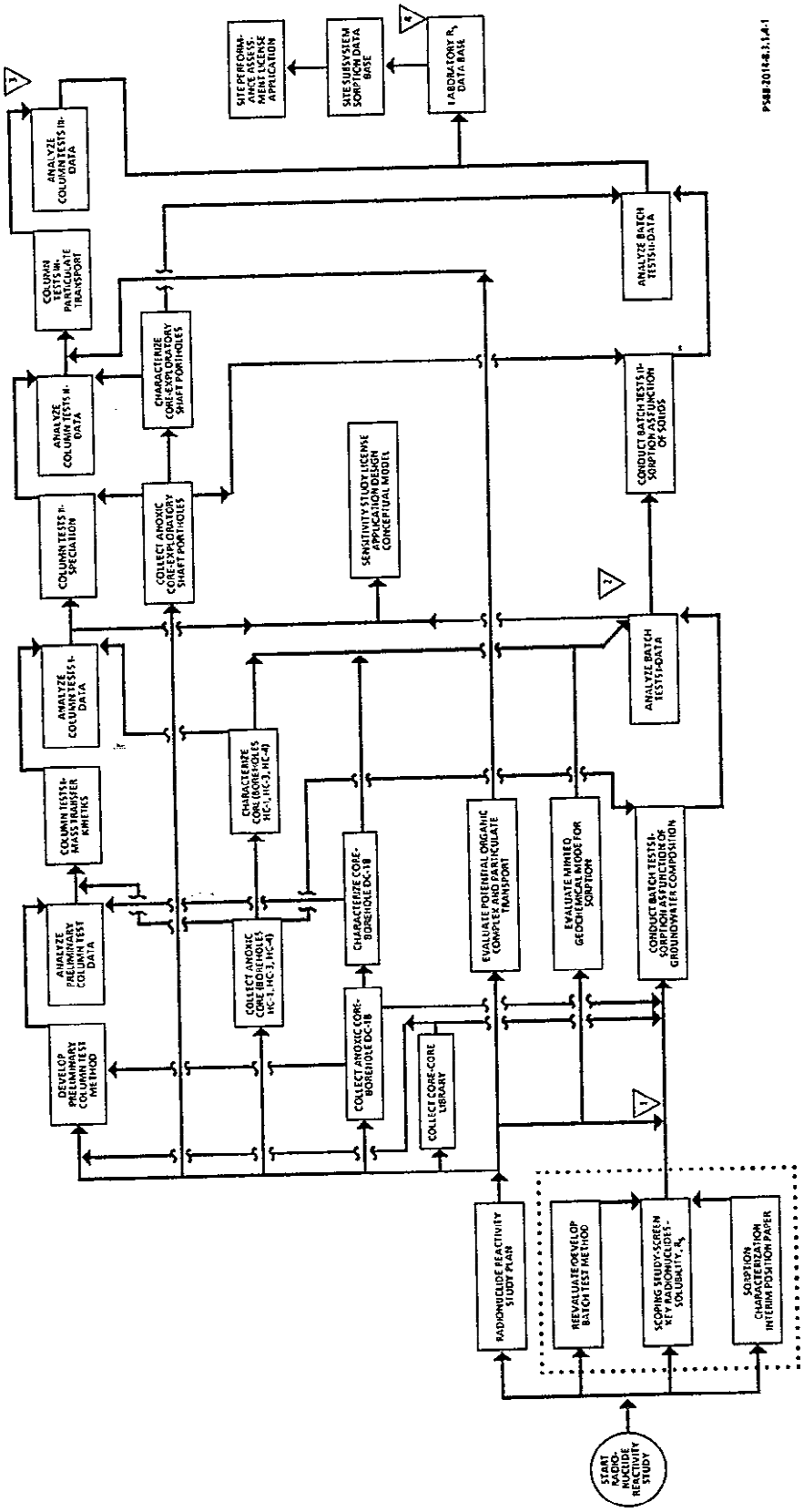

Figure 8.3.1.4-33. Flowchart for the laboratory component of the radionuclide reactivity study.

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Batch tests

The purpose of the batch experiments is to quantify the steady-state distribution of radionuclides between solid phases and solution. The objective is to provide a comprehensive radionuclide sorption/desorption data base for key radionuclides for important groundwater flow zones. These data needs are required by Issue 1.1 (see Section 8.2).

The basic technique used in static sorption experiments consists of contacting a measured quantity of solid with a specific volume of solution containing a spike of the radionuclide of interest. The steady-state radionuclide concentration in solution is determined by analysis, and the steady-state radionuclide concentration on the solid phase is determined by the difference between the initial and steady-state solution concentrations. Static desorption experiments are conducted in the same manner except that the solid phase begins with a known quantity of sorbed radionuclide and the contacting solution is radionuclide-free.

The experiments will be conducted under a variety of conditions involving different sorbents*, variable groundwater composition, and slight variations in Eh and pH conditions of the ambient site environment. The Eh or redox test conditions will be allowed to reach whatever level the solids can impose on the system under low-oxygen conditions using either nitrogen or argon atmospheres. This value of Eh will define anoxic conditions. Investigators will determine radionuclide sorption as a function of radionuclide concentration, time, solid, groundwater composition, Eh, and temperature. The batch tests will consist of three types of tests:

- Scoping tests.
- Groundwater composition tests.
- Solid tests.

Scoping tests. BWIP will use the results of preliminary scoping tests to verify the prioritization of radionuclides and reevaluate and, if necessary, improve existing technical procedures. The results of some of these tests are detailed in Puls et al. (1987). A test matrix with important parameters governing the analyses is delineated in Table 8.3.1.4-12.

*Preliminary sorption tests on solids collected with anoxic core sampling and handling procedures will be used to assess the effects of solids pretreatment (e.g., crushing or grinding core samples in an oxic environment may result in an underestimate of sorption of radionuclides subject to reduction). This potential effect will be assessed early in the program so that test conditions can be modified if needed (see Fig. 8.3.1.4-33, anoxic core activity boxes).

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Table 8.3.1.4-12. Scoping tests: radionuclide solubility and sorption/desorption kinetics

Radionuclide	Solid phase	Groundwater	Concentrations*
Iodine, niobium, nickel, lead, radium, selenium, tin, strontium, technetium, uranium	Cohassett flow top, Rocky Coulee flow top	GR-4	10^{-4} to 10^{-12} M

*Approximate (depends on specific radionuclide).

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The synthetic groundwater GR-4 will be used for all of the scoping tests, (Section 4.1, Table 4.1-22, describes GR-4). The scoping tests represent approximately 15 tests, where a test is defined as 1 radionuclide (4 concentrations), 2 solids, and a particular groundwater composition, performed in triplicate. Some of the radionuclides will be tested more than once for procedural assessment purposes. The test matrix is tentative and may be changed based on other testing results. Tests last from 10 to 90 d depending on the radionuclide. The entire scoping activity will last 2 yr (see Section 8.3.1.4.4.5).

Methods and technical procedures for the scoping tests are listed in Table 8.3.1.4-13. Additional test conditions such as grain size distribution, test durations, rock/water ratios, temperature ranges, and amount of sorbent material will be established for the batch tests during the screening or scoping test period (see the chemical speciation section below).

Table 8.3.1.4-13. Batch test methods/technical procedures

Test method	Governing technical procedures	
	Number	Title
Batch--to generate sorption/desorption isotherms, R_s*, solubility	ECS 6S	Radionuclide sorption/desorption kinetics experiments
	ECS 8S	Operation of low-oxygen atmosphere chamber and accessories
	ECS 13S	Operation of the incubator shaker as a low-oxygen chamber
	ECS 31S	Radioanalysis of alpha, beta, and gamma emitting radioisotopes
	ECS 34S	Preparation of Grande Ronde No. 4 (GR-4) synthetic groundwater
	ECS 39S	Preparation of radionuclide stock solutions

*R_s = sorption or desorption ratio--the ratio of the concentration of radionuclide on or within the solid to that in the liquid (units are L/kg).

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Sorption/desorption as a function of groundwater composition. The objective of this work is to determine the effect inorganic and organic complexation may have on sorption and desorption reactions. In general, complexation tends to decrease sorption. Significant inorganic and organic species are identified in Section 4.1.3.4.4 and in Table 4.1-41. Carbonate/bicarbonate, hydroxide, fluoride, and fulvic and humic acids are known to be important complexing agents for key radionuclides. Previous work has also demonstrated that calcium and chloride are important complexing agents. Investigators will obtain information on complexation by varying the concentrations of significant complexing species and quantifying their effect on sorption. Table 8.3.1.4-14 gives a test matrix for the complexation tests.

The synthetic groundwater will be used for all of the complexation tests. Table 8.3.1.4-14 represents approximately 100 individual tests, where a test is defined as one radionuclide (two concentrations), one solid, and a particular complexant (at two concentrations), performed in triplicate. The test matrix in Table 8.3.1.4-14 is tentative and may change based on other testing results. Each test will last from 30 to 60 d depending on the radionuclide, with the entire testing activity to last approximately 2 yr (see Section 8.3.1.4.4.5).

Investigators will use methods and technical procedures similar to those of the batch tests (see Table 8.3.1.4-13) with some modifications as a result of developmental work. Additional technical procedures will be developed for collection, handling, storage, and processing of geologic core material under an argon (or nitrogen) atmosphere.

Table 8.3.1.4-14. Sorption/desorption as a function of groundwater composition

Radionuclide	Solid phase	Groundwater variable
Niobium, nickel, plutonium, tin, uranium	Cohassett flow top[a], VI, SM/F	CO_3^{2-}/HCO_3^-, F^-, OH-Cl^-, humic and fulvic acids[b]
Neptunium, technetium	Cohassett flow top, VI, SM/F	CO_3^{2-}/HCO_3^-, humic and fulvic acids
Selenium	Cohassett flow top, VI, SM/F	Ca^{2+}, humic and fulvic acids

[a]Additional flow tops may be used depending on results from previous testing.

[b]If the humic and fulvic acids are determined to be present in significant concentrations in natural groundwaters.

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Sorption/desorption as a function of solids. The objective of this work is to develop a sorption/desorption data base as a function of different solids likely to be encountered by radionuclides migrating from the waste repository horizon. Investigators will use solids from the Cohassett flow-top, the Rocky Coulee flow-top, and Ginkgo flow-top horizons as well as Vantage interbed solids and secondary minerals lining interior fractures. Some limited analyses with pure secondary minerals are also proposed to identify sorption contributions of specific mineral phases. Table 8.3.1.4-15 gives a test matrix for the solids tests.

The solids tests will use synthetic groundwaters that are compatible with the solids as determined by hydrochemical sampling of the deep aquifers (Section 4.5.1.2). Additional testing in support of field studies may include nickel, tin, radium, thorium, and lead but not in a comprehensive matrix as above.

The testing matrix in Table 8.3.1.4-15 will use a wide concentration range, with GR-4 and W-1 the reference groundwater compositions. Detailed procedures will be developed for sample collection, characterization, and pretreatment.

Investigators will characterize the mineralogy of the solids in detail to correlate sorption with mineralogy (Section 8.3.1.2.5). Section 4.1.1.3 contains a discussion of mineralogic characterization efforts to date for the primary and secondary isolation zones.

The radionuclide concentrations in Table 8.3.1.4-15 range from an apparent solubility limit to near analytical detection limits. The solids tests consists of approximately 12 individual tests, where a test is defined as 1 radionuclide, 5 solids, 1 groundwater composition, and a wide concentration range (4 to 5 concentrations), performed in triplicate. Individual tests will last from 10 to 90 d depending on the radionuclide, with the entire testing activity lasting approximately 2 yr (see Section 8.3.1.4.4.5).

Table 8.3.1.4-15. Sorption/desorption as a function of solid composition

Radionuclide	Solid phase	Groundwater	Concentration range[a]
Niobium, neptunium, plutonium, selenium, technetium, uranium	Cohassett flow top	GR-4	10^{-12} to 10^{-4} M
	Rocky Coulee flow top	GR-4	10^{-12} to 10^{-4} M
	Ginkgo flow top		
	Vantage interbed	W-1[b]	10^{-12} to 10^{-4} M
	Saddle Mountains Basalt	GR-4	10^{-12} to 10^{-4} M
		GR-4	10^{-12} to 10^{-4} M

[a]Approximate-varies with radionuclide.
[b]Yet to be formulated groundwater for Ginkgo flow in Frenchman Springs Basalts.

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Investigators will use methods and technical procedures similar to those used in the batch tests (see Table 8.3.1.4-13), with some modifications as a result of developmental work.

Column tests

The purpose of the column tests is to quantify the relative migration rates of radionuclides through flow-top packed columns and columns constructed with fractured dense interior basalt. The latter is important from the standpoint of a fissure flow scenario and will include cracks with and without secondary mineral infilling. The objective is to support batch test results, help identify multiple chemical species of radionuclides, model possible fast channel transport, and investigate colloid mobility. Limited use of pure secondary minerals in these tests can help identify important minerals responsible for specific sorption. These data are required by Issues 1.1 and 1.8 (see Section 8.2).

Column or flowthrough laboratory sorption/desorption tests involve the passage of a radionuclide traced solution through a column of solid-phase sample or the passage of a radionuclide-free solution through spiked solid phase material. In the absence of sorption, a radionuclide will move with the groundwater and be affected only by dispersion. Where some sorption is evident, the retardation factor for a given radionuclide in a particular solid/solution system is mathematically described by the following equation:

$$R_f = 1 + (\rho * R_s)/e \qquad (8.3.1.4\text{-}13)$$

where

R_f = Retardation factor

R_s = Distribution between the solid and solution phases (L/kg)

ρ = Bulk density (kg/m^3)

e = Porosity (m^3/m^3).

An R_s of zero yields a retardation factor of one (i.e., the radionuclide migration velocity (Vr) equals the average water velocity (Vw; $R_f = V_w/V_r$).

Elution and breakthrough curves are the major products of column tests. Investigators can determine sorption/desorption ratios from these curves and can estimate sorption reaction kinetics and sorption related to speciation of the radionuclides (Barney et al., 1983).

Investigators will choose groundwater composition, pH, and temperature equal to those found in the strata from which the solids are obtained. The column tests will be run under anoxic redox conditions.

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The solid-phase samples will include both crushed and intact core maintained in an argon or nitrogen atmosphere following removal from a borehole. Samples for crushed and cracked core columns will be from the same sources as described above. Fresh intact sidewall cores obtained within the Cohassett and Rocky Coulee flow-top zones will also be used in column construction.

Investigators will evaluate breakthrough curves with respect to sorption/desorption reactions, mass transfer kinetics, radionuclide speciation, and colloid mobility. No determinations of dispersion will be calculated from laboratory tests. Field tests will address dispersion, effective porosity, and field retardation estimates.

Preliminary column studies will be performed to develop adequate technical procedures and provide correlation for field reactivity studies (lithium, strontium, ^{2}H). Studies will also be performed to evaluate analytical instrumentation for aqueous speciation identification and oxidation states of sorbed species.

The column test work will be subdivided into work on the following:

- Sorption/desorption mass transfer kinetics.
- Chemical speciation.
- Particulate transport.

Sorption/desorption mass transfer kinetics. The objective of this work is to determine elution rates as a function of flow velocity. From the results, investigators will determine the flow volume for optimum column operation.

Kinetics are a controlling factor in sorption reactions, particularly redox-mediated sorption reactions. These kinetic tests will delineate mass transfer kinetic limitations with respect to the various radionuclides used in column analyses. These tests will also provide useful kinetic data for fracture flow/retardation assessments.

Radionuclides to be tested include niobium, neptunium, plutonium, selenium, technetium, and uranium (and lead for natural radionuclide retardation). Kinetic rate constants, optimum column flow velocities, and retardation factors will be obtained. The tests will use flow-top solids from the Cohassett, Rocky Coulee, and Ginkgo flow horizons in crushed and intact form. Some limited analyses with pure secondary minerals are also proposed to identify sorption contributions of specific mineral phases. A test matrix for the kinetics tests is given in Table 8.3.1.4-16.

Investigators will develop the detailed procedures for sample collection, treatment, storage, and column tests. The number of tests and their duration and other variables (e.g., column size, flow rate, rock/water ratio and grain size) will be determined at that time for the various subsequent column testing activities. Column testing activities will run concurrently with batch testing activities (see Section 8.3.1.4.4.5).

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Table 8.3.1.4-16. Mass transfer kinetic evaluation

Radionuclide	Solid phase	Groundwater	Concentration range*
Niobium, neptunium, lead, plutonium, selenium, technetium, uranium	Cohassett flow top	GR-4	10^{-12} to 10^{-4} M
	Rocky Coulee flow top	GR-4	10^{-12} to 10^{-4} M
	Ginkgo flow top	W-1	10^{-12} to 10^{-4} M

*Approximate (varies with radionuclide).

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Chemical speciation. Investigators will generate solubility estimates with flow top present as part of the laboratory batch sorption tests. Solubility estimates will come from the analyses of solutions that have reached a steady state from oversaturation (Fig. 8.3.1.4-34). The waste package program will conduct the majority of solubility analyses. These analyses are discussed in Section 8.3.4 and in the radionuclide solubility/sorption and speciation study plan.

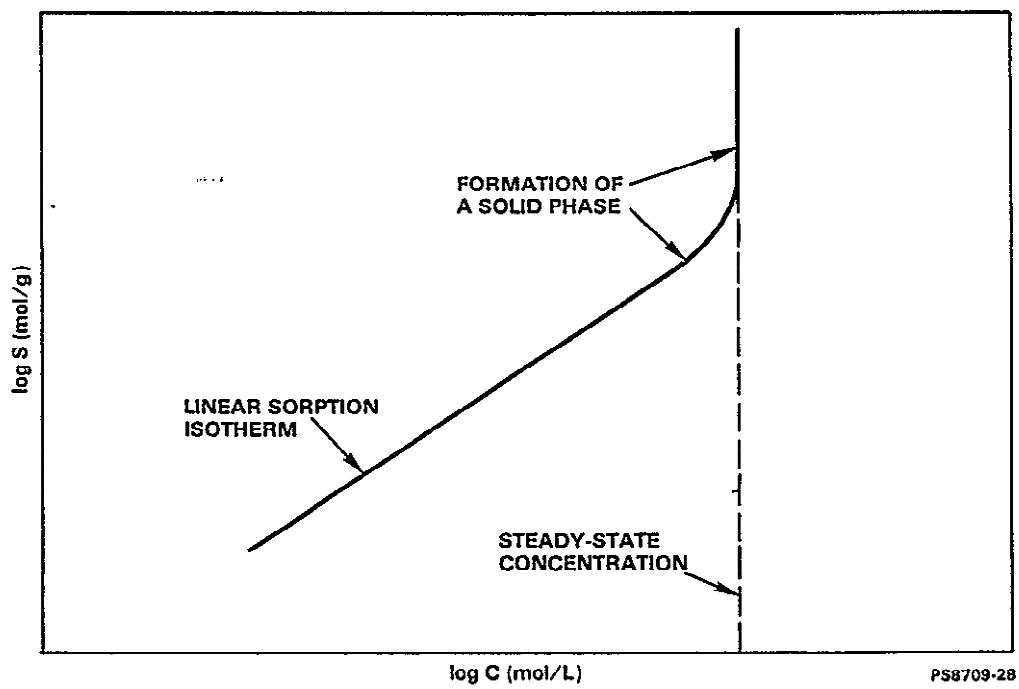

Figure 8.3.1.4-34. Sorption isotherm schematic with formation of solid phase.

Investigators will identify multiple ionic species in solutions and sorbed on solids for site subsystem studies by using various analytical techniques and column studies. Photoacoustic spectroscopy and laser Raman spectroscopy are proposed for identification of aqueous species, and x-ray photoelectron spectroscopy and Fourier transform infrared analysis are proposed for identification of surface species.

Verification and correlation of identified species will be accomplished with column tests where multiple species may elute at different rates, depending on sorptive properties of individual species. In addition to flow-top material, pure secondary minerals present in flow tops will be used. Retardation factors can then be compared and estimates on specific mineral contributions to sorption determined. Differences in retardation of a radionuclide due to multiple speciation is hidden in typical batch methods. These tests are thus a refinement of batch tests for radionuclides with multiple reactive species. Investigators may calculate new retardation estimates for a particular radionuclide based on sorption differences between species. The new estimates will more adequately reflect reality.

The testing matrix and accompanying procedures for this activity will be based on the kinetic work mentioned above. Those key radionuclides that exist in multiple aqueous forms in basalt groundwaters will be studied. The chemical speciation tests are expected to last 1 yr and will be performed concurrently with batch analyses (see Section 8.3.1.4.4.5).

Particulate transport. Particulate transport of radionuclides as colloidal-size particles may enhance radionuclide mobility. Colloids are stable suspensions of very small particles and range in size from approximately 1 to 500 nm. (However, other conditions such as filtration and gravitational settling may act as retardation mechanisms for radionuclide-colloid associations.)

The stability of a colloidal system depends upon its ability to remain dispersed. The presence of a predominately univalent electrolytic system also promotes colloidal stability. Deep Grande Ronde Basalt groundwaters represent such a system (see Table 4.1-22).

Radionuclides form two types of colloids: true radiocolloids and pseudocolloids. True radiocolloids are formed from a supersaturated solution of a radioisotope. Pseudocolloids are formed from adsorption of the radionuclide on colloidal size mineral particles in suspension. Americium and plutonium are known to form true radiocolloids. Because of the significant inventory of radionuclides in high-level wastes, the BWIP is planning to study radionuclide formation and stability. The study techniques include column and batch tests and autocorrelated photo spectroscopy.

Work by Ames et al. (1984) using crushed basalt with GR-3 groundwater (see Table 4.1-21 for composition) and silica colloids indicated the presence of stable colloidal systems even at the elevated temperatures of repository depth. Recent site subsystem laboratory testing has indicated that silica, alumina, and ferrous colloidal materials are generated in batch tests using

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synthetic groundwater and basalt flow tops. These colloids were detected by filtration/centrifugation separation techniques. Investigators have shown that the colloids are reactive sorption sites. Additional laboratory testing is currently under way to investigate the contributions of such colloidal material to radionuclide mobility.

Testing of a limited nature with respect to particulate transport will continue, but comprehensive tests on particulate transport will not begin until later in the study (see Section 8.3.1.4.4.5). Colloid testing is expected to last about 9 mo, but the exact scope and length of the tests depends on preliminary laboratory and field analyses. Investigators will attempt to analyze "clean" groundwater samples to determine if significant concentrations of pseudocolloids are present and stable in the site subsystem environment.

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8.3.1.4.4.3.2 Field reactivity component.

The field reactivity component focuses on field scale or in situ measurement of sorption parameters. The general approach is to model the behavior of selected reactive tracers injected into key flow top aquifers. In situ field tests are important to site characterization because they can provide empirical evidence for confirming laboratory results and because they provide scaling factors for extrapolating laboratory sorption data for key radionuclides to the natural system. The field reactivity tests involve two types of active tests: injection-withdrawal tests and recirculating tests. Both of these types of tests are active tests because they involve a stimulus and response rather than passive monitoring (see Section 8.3.1.4.4.2). Because the methods for the field reactivity tests are largely unproven, a considerable amount of early effort will involve development testing. This section discusses the planned injection-withdrawal tests, the planned recirculating tracer tests, the logistics for the field reactivity component, and development testing.

8.3.1.4.4.3.2.1 Injection-withdrawal testing. Injection-withdrawal testing represents the field equivalent of laboratory batch testing. In both laboratory batch tests and field injection-withdrawal tests, fluid is reacted with solid in an essentially closed system for a known amount of time. In both the laboratory and field tests, there is no net translational flow of the fluid. Since the tests are analogous, results from the field injection-withdrawal tests can be used to scale results from the laboratory batch tests.

Single borehole injection-withdrawal tests have been used to study the dispersion and sorption characteristics of porous media (Sternau et al., 1966; Drever and McKee, 1980; Pickens et al., 1981; Fuginawa, 1983). The reactive tracer version of this test consists of the injection of a solution containing at least one reactive and one conservative tracer into the zone of interest and then the withdrawal of the diluted fluid to determine the amount of tracer remaining on the liquid versus the amount sorbed onto the solid. Injection-withdrawal tests are more useful for obtaining basic geochemical data than for obtaining hydrological data. Table 8.3.1.4-17 shows the types of data that may be collected during injection-withdrawal tests. These tests are especially useful for studying highly reactive tracers in porous media.

Table 8.3.1.4-17. Types of data that may be collected during injection-withdrawal tests

Dimensional mass	Length (L)	Time	Temperature	Pressure
Various tracers added to injection water Various tracers in withdrawn tracer slug as function of volume Background concentrations of tracers in formation water Major chemical constituents of injection water Major chemical constituents of formation water Major chemical constituents of tracer slug	Volume (L^3) of formation water withdrawn and injected Volume (L^3) of water withdrawn/injected as function of time Thickness (L) of test interval Depth (L) to top of test interval Volume (L^3) of borehole in test interval	Quiescent period (interval between injection and withdrawal)	Injected water Withdrawn water as function of time Dynamic temperature profile	In annulus In shut-in interval As function of time during injection-withdrawal

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The following types of injection-withdrawal tests will be used to obtain radionuclide reactivity data:

- Opportunistic injection-withdrawal tests during drilling and development of piezometers.
- Formal single borehole injection-withdrawal testing (with or without a monitoring borehole).
- Swish testing (recovery/injection reaction period/withdrawal).

Opportunistic injection-withdrawal tests will be conducted during drilling and development of boreholes and piezometers. The geochemistry program will have minimal control over the location and timing of these tests. The performance of various tracers in basalt field tests are summarized in Table 8.3.1.4-6. These tracers have been used in reconnaissance tests as indicators of the extent to which drilling fluid contamination has been purged from a test zone. Other reactive tracers that are under consideration are strontium, nitrate, and selenium (selenate, selenite).

The lithium and bromide data in Figure 8.3.1.4-20 demonstrates how injection-withdrawal tests will provide information about sorption in the natural system. The attenuation of lithium and bromide at borehole DC-18 in the Sentinel Gap flow top is shown in Figure 8.3.1.4-20. Bromide behaves conservatively, and the trailing edge of the tracer pulse has a negative 1:1 slope. Lithium behaves as a reactive tracer and attenuates at about half the molar rate of the bromide as a result of reversible sorption, presumably because of cation exchange on smectites. The retention factor is a measure of

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the degree to which the reactive tracer is purged from the test zone in comparison to the nonreactive tracer at a given time. In the case shown in Figure 8.3.1.4-20, the retention factor is approximately three (antilog of the ratio of the slopes of lithium to bromide attenuation curves). Scale dependency of the retention factor for various combinations of reactive and nonreactive tracers remains to be investigated as well as its variability between locations and from one hydrostratigraphic unit to another.

The equipment requirements for this type of test are modest: a surface tank to mix up the tracer slug and field analytical equipment for detection of a working tracer (e.g., fluorescein). Tracer solution is mixed with the system water prior to drilling into the flow top. Tracer solutions penetrate the flow top during drilling because the borehole pressure exceeds the formation pressure. Because dissolved oxygen is introduced along with the tracer slug, opportunistic tests are not suitable for work with redox-sensitive reactive tracers such as selenium and technetium. Contamination of formation fluids with even trace amounts of oxygen can result in very slow kinetics of reduction-precipitation, essentially unnoticeable within the context of a field experiment. Rapid withdrawal of fluids is not possible because the drill stem must be withdrawn from the borehole before a pump can be installed. Also, there is little control over the rate of injection of tracer solutions into the test zone since this is a function of drilling equipment and borehole conditions.

Formal, single borehole injection-withdrawal tests involve installing the equipment shown in Figure 8.3.1.4-35 and controlling the rates of fluid injection and withdrawal. Sufficient time is available for fluids to remain in the test interval to ensure equilibrium conditions for fast sorption reactions. The BWIP proposes three types of formal injection-withdrawal tests. The first type of test involves injection of the tracer at a constant concentration followed by immediate withdrawal. The second type of test involves injection of the tracer at a constant concentration followed by a reaction period and then withdrawal. The third type of test involves injection of a tracer as a pulse followed by an optional reaction period and withdrawal. Investigators will use the results of development testing to determine which of these three types of tests to use in the deep basalts.

Formal, single borehole injection-withdrawal tests are particularly amenable to low permeability zones because of the relatively small quantities of water that must be displaced through porous media. The reactive tracer version of this test consists of the injection of a solution containing at least one reactive and one nonreactive tracer into the zone of interest. The diluted fluid is then withdrawn to determine the partitioning of the tracer between formation solids and groundwater as a function of pumped volume (retention factor). Injection and immediate withdrawal tests are primarily used to determine aquifer dispersivity (extent of mixing within the aquifer), to study fast sorption reactions, and to approximate surface area to volume relationships.

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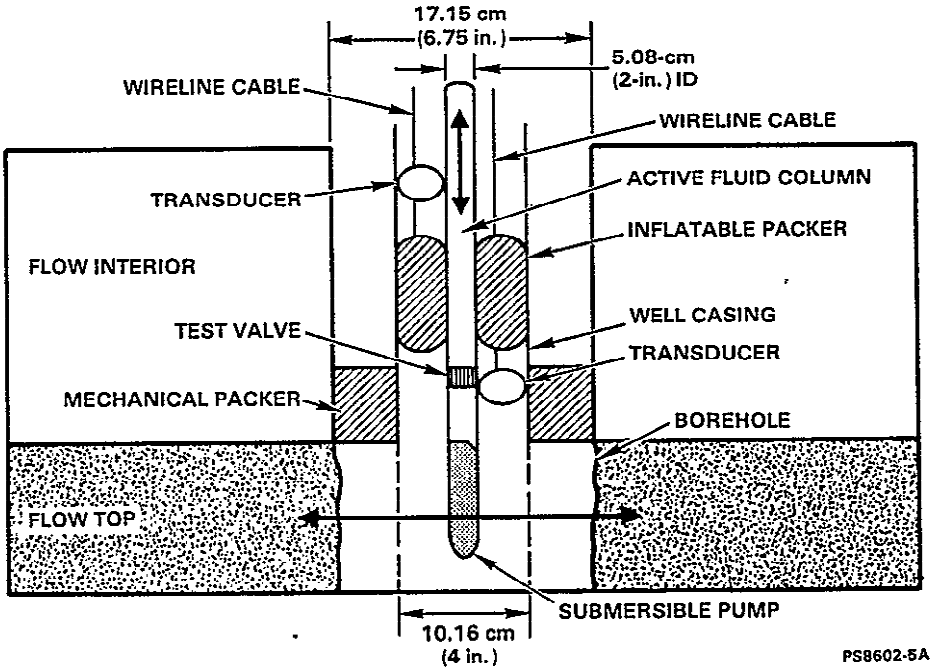

Figure 8.3.1.4-35. Equipment for injection/withdrawal testing.

If a second borehole is located sufficiently close by so that the dispersed tracer slug may be monitored, then the effective radius of a hypothetical cylindrical slug may be determined (Pickens et al., 1981, Guven et al., 1984). Immediate withdrawal allows minimum mixing to occur and preserves the axial symmetry of the slug. Investigators can monitor the water composition in the monitoring borehole and determine breakthrough curves for the reactive and conservative tracers. Investigators can then use the breakthrough curves to determine dispersivity and retardation factors using methods developed by Ogata and Banks (1961) and Gelhar and Collins (1971). The method solves the advection-dispersion equation in one dimension.

By conducting these tests using increasing volumes of injected fluid in the same test zone, it is possible to evaluate the scale dependency of dispersion and sorption data. One of the most important assumptions in the field reactivity study is that a certain degree of sorption homogeneity exists within a given flow top. Tests for scale dependency will determine whether this assumption is valid. Should this assumption be valid, then greater confidence can be placed in the assignment of retardation factors for specific radionuclides to given basalt flow tops.

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Injection-withdrawal tests assume little or no lateral flow components. Lateral flow gradients are very low in the Hanford region (see Section 3.9.1.2). Incorporation of a reaction period in the injection-withdrawal test allows for the study of slow sorption (redox-precipitation reactions) and for determination of tracer slug displacement in cases where there is a small lateral flow component in the test zone. This type of test places the reactive tracer into an environment that is similar to the natural quasi-stagnant flow condition. The fluid will be essentially static in the test zone for the majority of the reaction time. These types of tests are used primarily for the measurement of dissolved oxygen uptake by the basalt geochemical system and evaluation of kinetically sluggish sorption reactions.

Swish testing allows reactive tracer testing with the least possible disruption of natural ambient geochemical conditions. A preliminary design for swish testing is shown in Figure 8.3.1.4-36. The procedure is given below:

1. The test pipe and packer assembly are run down the hole with the test valve closed. The packers are pressurized. The test pipe is blown out with compressed nitrogen.

2. Nitrogen is circulated in the test pipe to displace atmospheric oxygen. The test valve is opened, and the formation water is allowed to rise up in the borehole under natural formation pressure, displacing nitrogen from the test pipe. The rate of recovery is monitored. When recovery is essentially complete, the valve is closed.

3. The tracer is injected into the standing-water column using a wireline tool. The tracer is contained in a submersible tank that releases tracer to the water in response to the movement of the impeller.

4. The test valve is opened, and the tracer is displaced into the formation using compressed nitrogen or by means of a swabbing tool with a weighted piston suspended from a wire line. The tracer is left to react in the formation for the given quiescent period.

5. The pump and packer assembly are run down the test pipe. The tracer slug is withdrawn, analyzed in real time for fluorescein, and sampled for laboratory analysis.

Swish testing is only possible in zones where the lateral hydraulic gradient is effectively zero because with the extended times (on the order of weeks to months) required to attain equilibrium under natural conditions significant lateral flow could result in migration and loss of the tracer slug. The BWIP will monitor hydrochemical composition and redox speciation of tracers in withdrawn solutions. Investigators will perform mass balance analyses on input tracer concentrations versus tracer concentrations in withdrawn fluids. The mass balance analyses will provide information on the kinetics of reduction-precipitation reactions and sorption in the natural system. The tracers of most interest for swish testing are selenium and technetium because of their solubility and sorption dependence on redox conditions.

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(a) PURGING OF ATMOSPHERIC CONTAMINATION FROM TEST PIPE

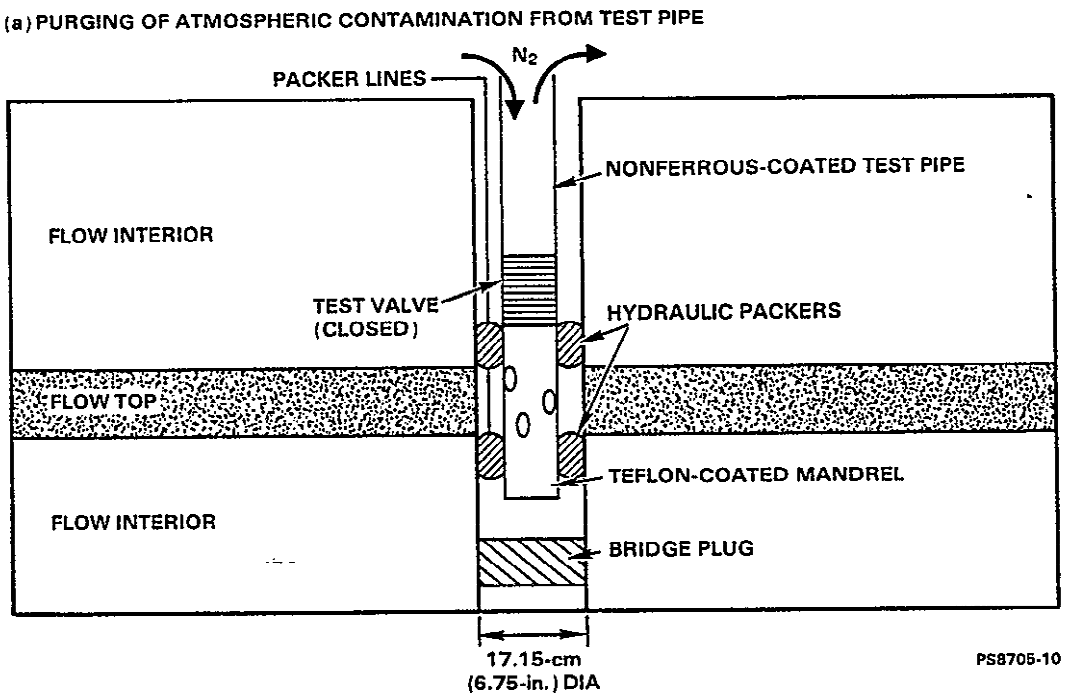


Figure 8.3.1.4-36. Equipment for swish testing. (sheet 1 of 5)

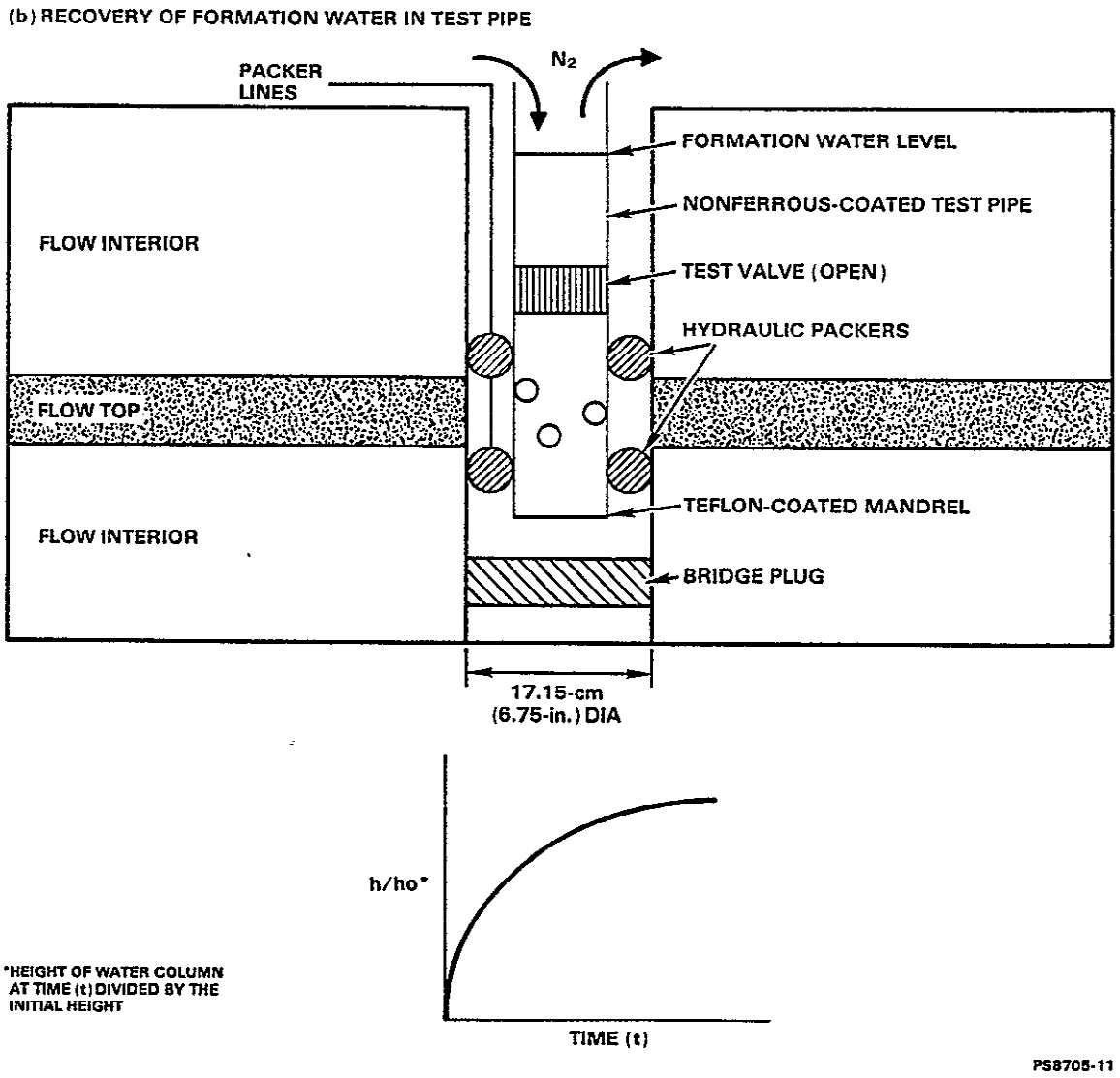
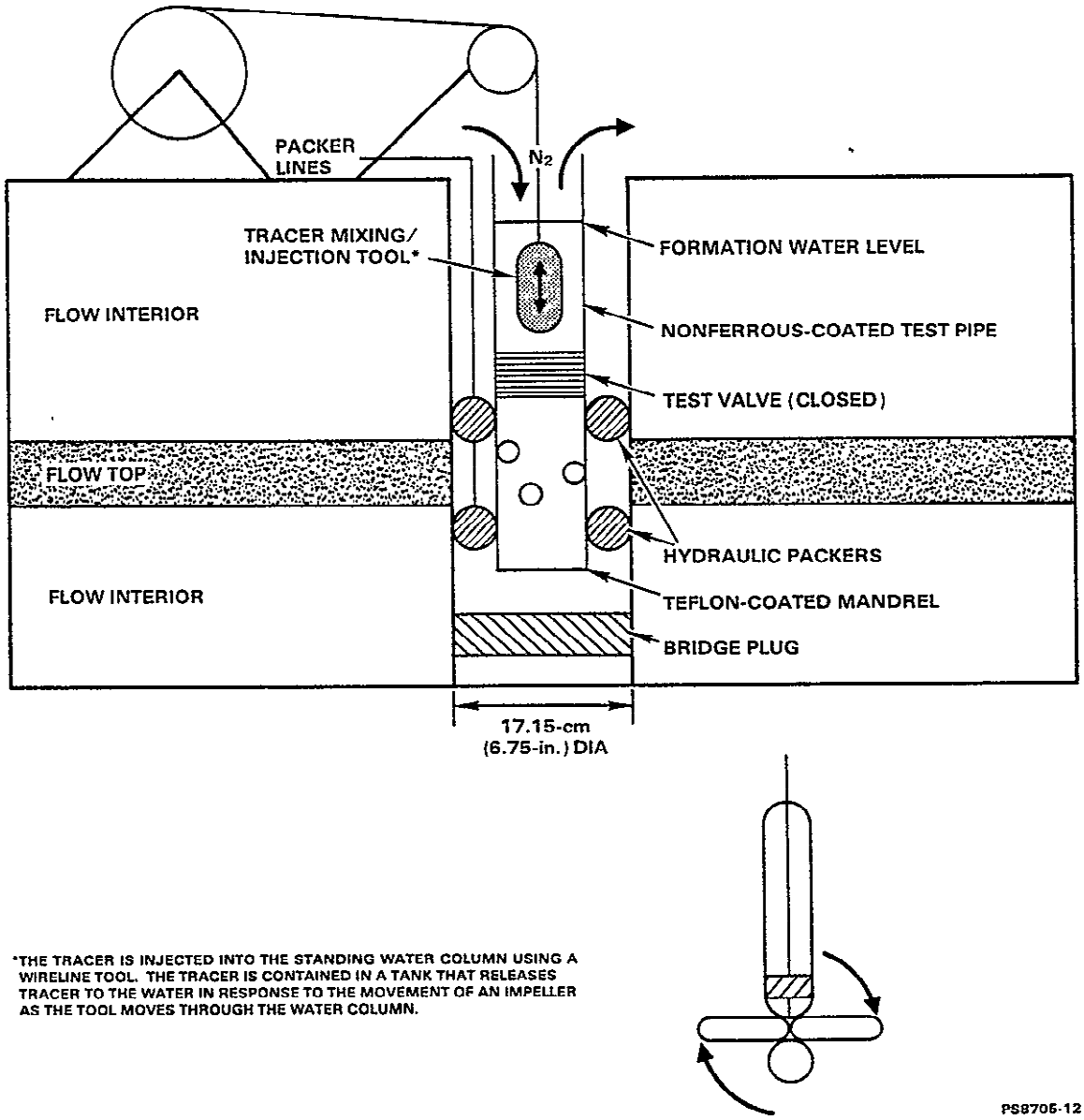


Figure 8.3.1.4-36. Equipment for swish testing. (sheet 2 of 5)

(c) INJECTION AND MIXING OF TRACERS IN WATER COLUMN



*THE TRACER IS INJECTED INTO THE STANDING WATER COLUMN USING A WIRELINE TOOL. THE TRACER IS CONTAINED IN A TANK THAT RELEASES TRACER TO THE WATER IN RESPONSE TO THE MOVEMENT OF AN IMPELLER AS THE TOOL MOVES THROUGH THE WATER COLUMN.

Figure 8.3.1.4-36. Equipment for swish testing. (sheet 3 of 5)

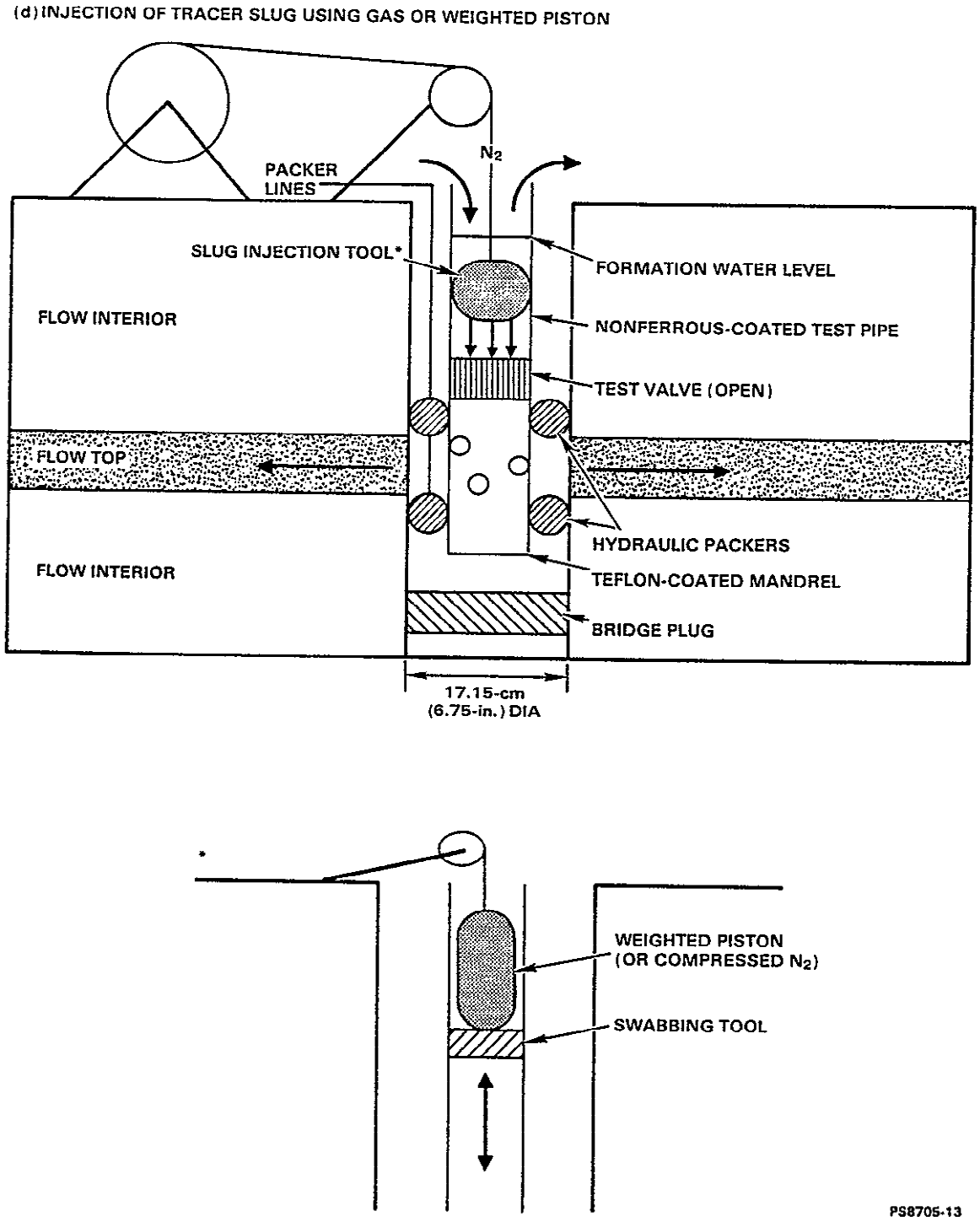


Figure 8.3.1.4-36. Equipment for swish testing. (sheet 4 of 5)

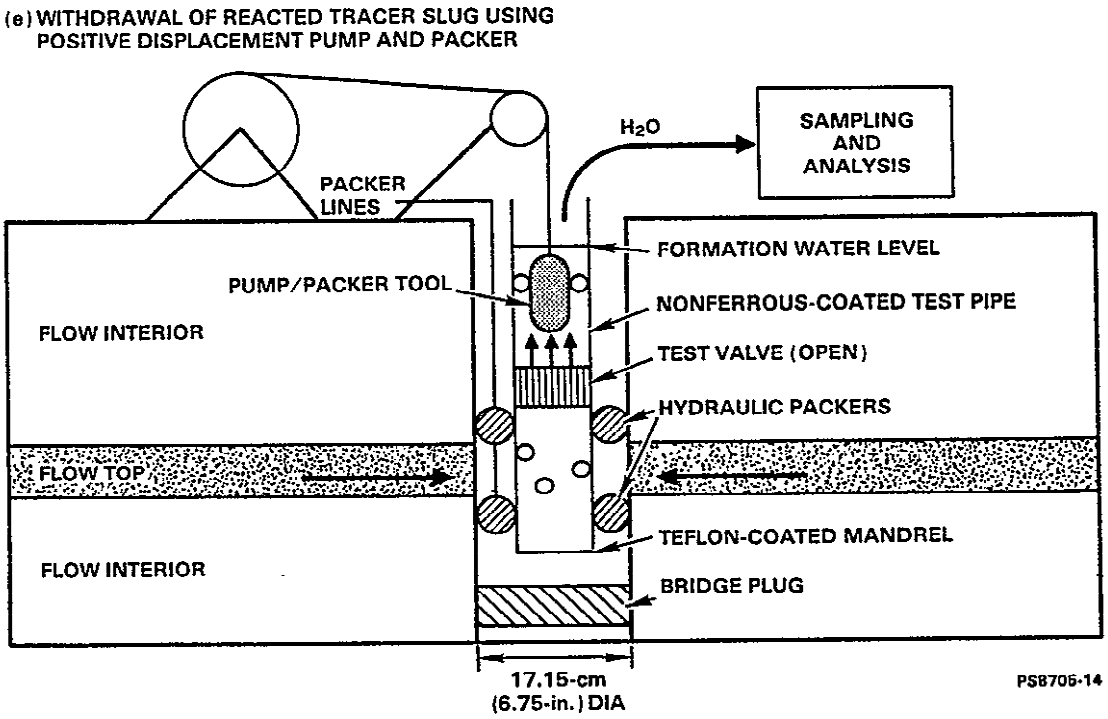


Figure 8.3.1.4-36. Equipment for swish testing. (sheet 5 of 5)

8.3.1.4.4.3.2.2 Recirculating tracer tests. Recirculating tracer tests are the field analogy to laboratory column tests; both involve a net translation of fluid through the test zone. In the paired-borehole recirculating tracer test (Fig. 8.3.1.4-37), water is withdrawn from one borehole and injected at an equal rate into a second borehole. The test maximizes the hydraulic gradient between recharge and discharge boreholes. The tracer is added to the injection borehole once water levels equilibrate. Leonhart et al. (1985) provided estimates of longitudinal dispersivity and effective thickness for the McCoy Canyon flow top based on data from the recirculating tracer test at boreholes DC-7/8. Retardation factors are computed based on the relative velocities of reactive and conservative tracers as determined from the breakthrough curves.

Very reactive tracers may not move far enough along the flow path during the test to break through at the pumping borehole. In this case, if the test is carried out well beyond the time that it takes for the conservative tracer to appear, minimal values may be stated for the retardation factor based on the velocity of the conservative tracer and the time over which the test is carried out. For example, if the conservative tracer breaks through in 10 h, and after 100 h of recirculation the reactive tracer has not appeared, the retardation factor can be estimated as greater than 10. This is the approach that has been used by Swedish researchers to study the retardation of strontium and cesium in granite (Landstrom et al., 1983).

8.3.1.4.4.3.2.3 Logistics for the Field Reactivity Component. The logistics for conducting the field reactive tracer tests are illustrated schematically in Figure 8.3.1.4-38. The effort is separated into two phases: a development phase and an applications phase. Greater detail is available for the development phase than for the applications phase because the field testing during the applications phase depends on the successful outcome of the development phase.

Phase I: development phase

Predevelopment testing feasibility studies and design of development tests at the borehole DC-7/8 site are the principal tasks during the first year of the project (after the date of study plan approval).

Year 1 involves four parallel activities:

- Design and development of field tracer testing tools.
- Preparation of the borehole DC-7/8 site for tracer testing, feasibility testing of the sidewall coring device, and development of laboratory procedures for sorption testing on sidewall core plugs.
- Design of development tracer tests at borehole DC-7/8.
- Opportunistic tracer testing at boreholes HC-1, HC-3, and HC-4.

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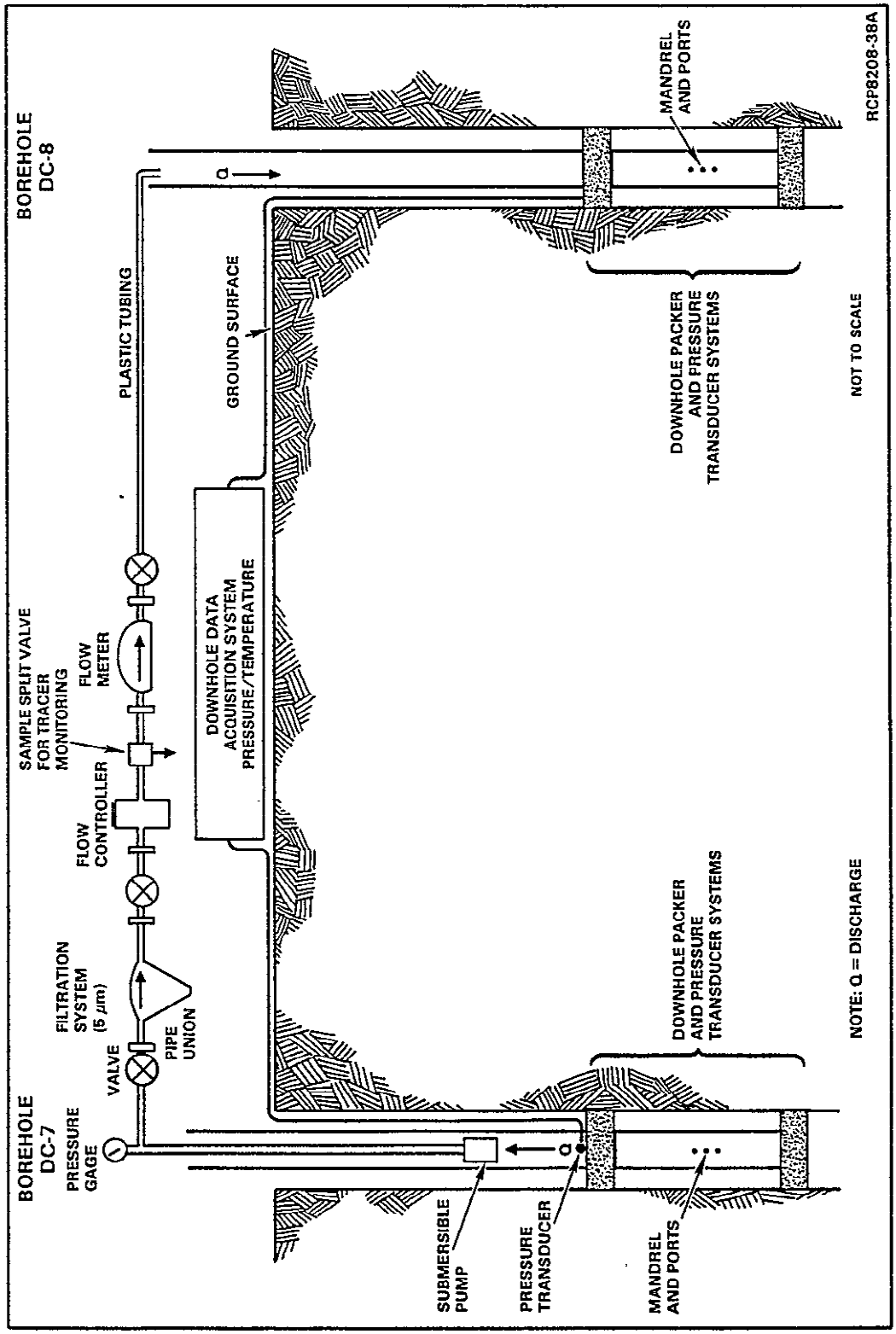

Figure 8.3.1.4-37. Equipment for recirculating tracer test (after Leonhart et al., 1985).

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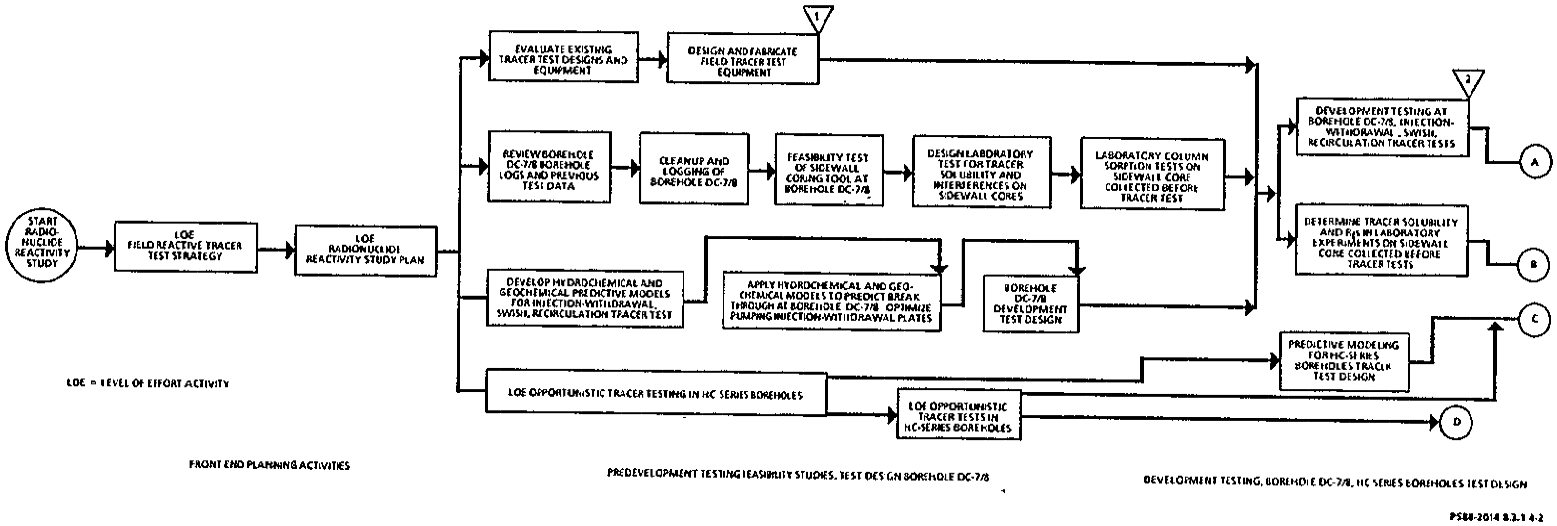

Figure 8.3.1.4-38. Flowchart for field-reactive tracer tests. (sheet 1 of 2)

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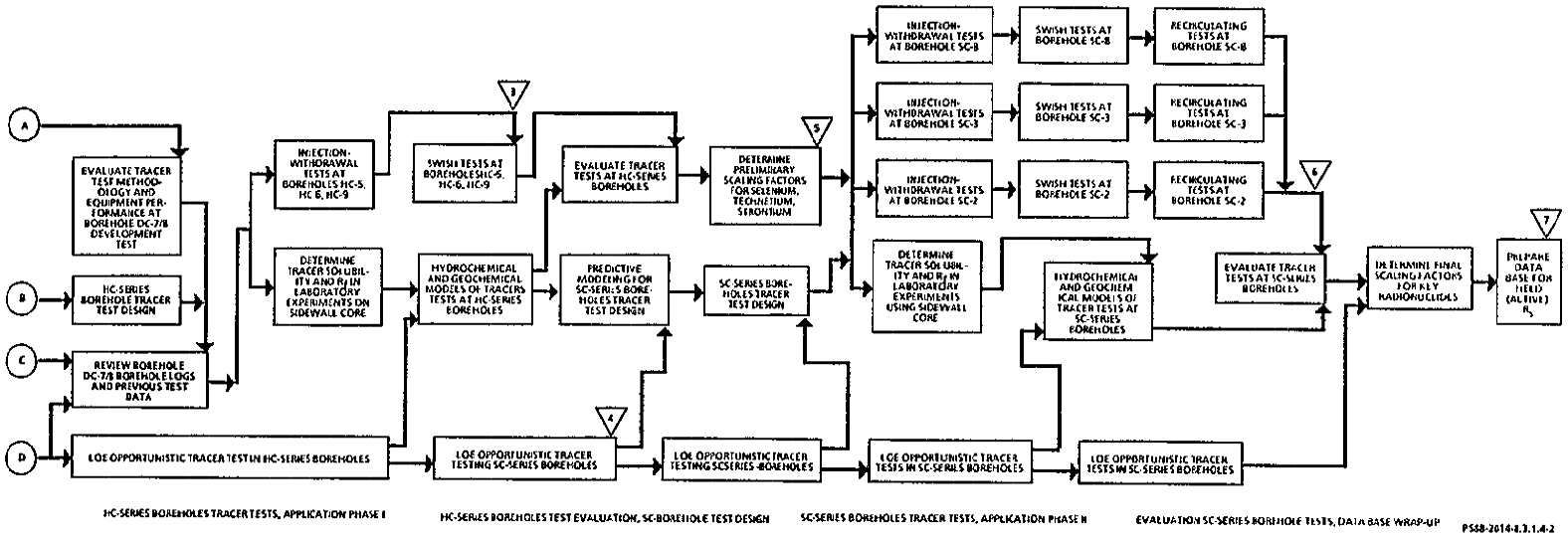

Figure 8.3.1.4-38. Flowchart for field-reactive tracer tests. (sheet 2 of 2)

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Field tracer testing tools will consist of single and dual strings of test pipe and several wireline tools for tracer mixing, injection, and pumping. The BWIP will build a prototype, and it will be available for development tracer testing at borehole DC-7/8 (see Fig. 8.3.1.4-10 for locations).

Borehole DC-7/8 is contaminated with drilling fluid and require cleanup prior to tracer testing so that the sorption values obtained from these boreholes will be representative of the natural site conditions. The sidewall coring device has not been previously applied in the Hanford Site basalts and must be feasibility tested. The most likely place for testing the coring tool is at borehole DC-7. This will also provide early samples for laboratory column testing. Laboratory procedures for performing column testing on sidewall core plugs (2.5 cm (1 in.) in diameter by 5.0 cm (2 in.)) must be developed so that sorption/desorption can be studied on samples that have been collected from the test zone before and after field tracer testing.

Design of tracer tests at the paired borehole DC-7/8 site entails the scheduling of injection-withdrawal tests, swish testing, and recirculating tests. Important elements of the design include determinations of injection and withdrawal rates, durations of tests, times required for recovery between individual tests, concentrations of tracers required, volumes required for given effective porosity values, and predictive modeling of tracer recovery and breakthrough curves.

The level of effort in opportunistic tracer testing at boreholes HC-2, HC-4, HC-5, HC-6, HC-7 HC-8, and HC-9, will start in Year 1 and extend over a 2-yr period (see Fig. 8.3.1.4-10 for locations).

During the second year of the project, investigators will conduct development tests at the borehole DC-7/8 location and will design tracer tests in the HC-series boreholes. Investigators will evaluate the methodology applied in the development tests at borehole DC-7/8 and will determine whether that methodology is justified at other borehole locations. Investigators will also write procedures for further testing.

Phase 2: applications phase

Year 3, the first year of the applications phase, will involve tracer testing at three hydrochemistry borehole locations: HC-5, HC-6, and HC-9. Injection-withdrawal testing will be carried out in parallel at three borehole locations. Three zones (Cohassett, Rocky Coulee, and McCoy Canyon flows) will be tested in succession within each borehole. Injection-withdrawal tests will be carried out prior to swish tests.

The injection-withdrawal tests will include a fast, cold water injection-withdrawal test using a relatively small amount of fluid and two short injection-withdrawal tests using successively larger volumes of injected fluid in order to evaluate surface area to volume relationships and the effect of scale on retention factors, respectively. A total of 27 injection-withdrawal tests are to be conducted.

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Swish tests will be carried out in only two zones due to the 6-mo period required for each test and the fact that only three sets of testing tools will be available. This work will be carried out in parallel with laboratory column studies on core collected before and after tracer testing, hydrological and geochemical modeling of tracer test and laboratory column test data, and predictive modeling of SC-series borehole tracer testing (see Fig. 8.3.1.4-13 for borehole locations).

Opportunistic tracer testing will be carried out in paired boreholes SC-8 and SC-9 in parallel with the latter activities. The rationale behind the development of the opportunistic tracer testing method is to establish a working correlation between retention factors computed from the log-log plots of tracer distribution curves and formal field and laboratory retardation estimates. In order to accomplish this, investigators will follow these steps:

1. Within a given test zone, and with the same suite of conservative and nonconservative tracers, complete three injection-withdrawal tests using several different volumes.

2. Compare retention factors (ratio of slopes of reactive to conservative tracers on a log-log plot of tracer recovery curves) at various scales to determine whether they are independent of scale.

3. Compare retention factors for appropriate tracers with laboratory retardation factors and batch K_d to determine if linear relationship exists.

Year 4 of the project is a period of evaluation of tracer test data from the HC-series boreholes; predictive modeling; design of tracer tests in the SC-series boreholes; and the production of preliminary scaling factors for selenium, technetium, strontium, neodymium, and dissolved oxygen. During this period, level of effort work continues for opportunistic tracer testing at boreholes SC-2, SC-3, and SC-8. Drilling and testing of these boreholes is controlled principally by the site groundwater study plan.

Year 5 of the project is the second application phase in which injection-withdrawal tests, swish tests, and recirculating tracer tests are run at paired boreholes SC-2, SC-3, and SC-8. The tests will be run in parallel at three borehole locations using three sets of testing tools. Three testing zones (Cohassett, Rocky Coulee, and McCoy Canyon flow tops) will be considered in each borehole. Investigators will conduct the injection-withdrawal tests before the swish tests to determine surface area to volume relations and scale effects on retention and retardation factors.

A total of 27 injection-withdrawal tests will be conducted. One borehole will be an injection-withdrawal hole, while the other will be a monitoring borehole. Investigators will conduct swish tests in the same zone at all three borehole locations (a total of three tests). Following swish tests, investigators will conduct recirculating tracer tests between the paired boreholes in the same zone at all three borehole locations (a total of three

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tests). In parallel with field testing, investigators will conduct laboratory column tests of sidewall core samples collected before and after tracer testing and hydrologic and geochemical modeling of tracer tests and laboratory column test data.

Year 6 of the study is a period for evaluating the tracer test data from SC-series boreholes and combining data from opportunistic tracer tests, formal tracer tests, and laboratory tracer tests to produce a final table of scaling factors. Investigators will also prepare a data base for field R_S values and ranges for radionuclides and analogs that have been used as tracers in the study. These data will be entered in the radionuclide reactivity data base so field-scale R_S values and isotherms can be computed for key radionuclides.

Development testing

Development of the field reactive tracer testing methodology necessitates further testing at the paired borehole DC-7/8. The borehole DC-7/8 site is ideal for this purpose because of the closely situated (13.8 m (45.3 ft) apart) boreholes completed into the Grande Ronde Basalt and because hydrologic parameters are known from previous testing.

The following activities pertaining to the borehole DC-7/8 site will be conducted during the first year:

- A review of borehole logs and previous test data.
- Cleanup and logging of boreholes.
- Feasibility testing of the sidewall coring tool.
- Development of laboratory column sorption tests using sidewall core collected from borehole DC-7 and preliminary sorption testing.
- Application of hydrologic and geochemical predictive models for tracer tests.
- Design of development tests.

Investigators will review borehole logs in order to choose suitable intervals for packer testing zones for sidewall coring. Deficiencies in the existing logs will be noted and recommendations will be made for repeating such logs if necessary. Investigators will obtain and examine televideo and tube wave logs in order to evaluate the relative importance of fractures within and between the zones chosen for tracer testing.

The program will review previous hydrologic test data in order to select appropriate equipment and cleanup procedures. A work overrig will be used to carry out the cleanup and logging activities at the site. After completing this work, investigators will use the sidewall coring tool to retrieve cores from the Cohassett, Rocky Coulee, and McCoy Canyon flow tops. This will constitute a feasibility test for the tool and will also provide anoxic core for laboratory column studies.

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The BWIP must develop methods for mounting the cores in columns and excluding oxygen from the system. If the hydraulic conductivity proves to be too low to complete the experiment within the time allotted, techniques for enhancing fluid flow through the cores will need to be developed. Such techniques may include pressurized columns and fracturing of the core material. Investigators will use these column experiments to obtain retardation factors for tracers in the same combinations and concentrations as in the field. This information is important for designing the field tracer tests.

Geochemical and hydrologic modeling of the various tests to be conducted at the borehole DC-7/8 site are also important for design. The program will conduct the following types of modeling efforts:

1. Use of a geochemical model such as MINTEQ to compute the chemical effects of mixing the injection water into the flow top and serve as a check on whether precipitation is likely at input tracer concentrations.

2. Use of a hydrologic model such as FRACSL (Clemo, 1984) to predict tracer concentration curves at various injection volumes within a given flow top.

3. Use of a hydrologic model such as the one developed by Gelhar (1982) to calculate breakthrough curves for the recirculating test using tracer concentrations and retardation estimates from the laboratory column tests as a starting point for interaction.

Investigators will model test interference to predict water level recovery time between the various tests. Since three injection-withdrawal tests are planned, each with an approximate 1-wk duration, the program will allow maximum recovery of formation pressure between tests to ensure a minimum of interference between tests.

The BWIP plans the following development test sequence at the borehole DC-7/8 site:

- Injection-withdrawal testing will be carried out over a 3-mo period in each of three flow tops. Altogether, three tests will be run in each zone; borehole DC-7 will be used as an injection-withdrawal borehole and borehole DC-8 will serve as a monitoring borehole.

Each of the three tests will consist of two parts. The first part involves a fast, cold-water injection-withdrawal test in which the fluids will be withdrawn very shortly after injection. This test will be used to approximate the surface area to volume ratio by considering the heat transfer from warm rock surfaces to the injected cold-water tracer slug. The test will be successful if the injected water can be withdrawn from the test zone before reaching thermal equilibrium (i.e., if temperature variations are preserved in the tracer distribution curves from the withdrawn fluids). This test will take approximately 5 d to complete. The actual time for injection and withdrawal will depend on the hydraulic conductivity of the test zone and on the amount of fluid displaced. The second part of the test consists of two

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medium and large-scale injection-withdrawal tests in which successively larger volumes of water will be injected to interrogate greater portions of the test zone. These tests are expected to take about 5 to 10 d each to complete. Investigators will use the test results to assess possible scale effects on values of retention factors computed from the tracer distribution curves.

Based on the time estimates indicated above, the injection-withdrawal testing will take about 75 d to complete.

The next step will be to conduct a swish test in borehole DC-7 in a single flow top. The program will choose the flow top with the highest hydraulic conductivity in order to achieve maximum recovery of formation water into the test tubing. The swish will take approximately 4 mo to complete. This duration includes: (1) the reaction period and an estimated 3 wk to deploy and recover test equipment, (2) time to purge the system of oxygen, (3) time for formation water to approach static level in the test tubing, (4) mixing of tracer into the formation water, (5) injection of the tracer solution into the flow top, (6) withdrawal of the tracer solution, and (7) time to obtain sidewall core samples from the borehole walls in the test zone.

The core samples will be collected and preserved under anoxic conditions and will be analyzed to determine the depth of penetration of the reactive tracers and the concentration of the reactive tracers in the solid phase. The core samples will be mounted in columns so that column retardation tests can be run under laboratory conditions using the same tracer composition used in the field.

The final component of the development testing sequence at the borehole DC-7/8 site will be a recirculating tracer test between boreholes DC-7 and DC-8 using borehole DC-7 as the pumping borehole and DC-8 as the injection borehole. Investigators will conduct two recirculating tracer tests in the two highest permeability zones (McCoy Canyon and Umtanum flow tops). Recirculating tests will take about 25 d each to complete. This duration includes the time required to set up and dismantle the test equipment (4 d), pump to establish steady-state flow conditions (3 d), inject the tracer (4 d), and induce transport (14 d) of all mobile tracers to the pumping borehole.

The selection of tracers in the field tests is based on the following factors:

1. The need for the tracers to be related in some way to certain key radionuclides (e.g., stable selenium for ^{79}Se, ^{95m}Tc for ^{99}Tc, ^{95}Nb for ^{94}Nb).

2. The requirement that tracers be sufficiently mobile that they can migrate to the test zone in a reasonable time.

The recommended conservative tracers are bromide, chloride, iodide, tritium, deuterated water, thiocyanate, and organic acids such as pentafluorobenzoate. Although fluorescein dye has been demonstrated to be somewhat nonconservative in the basalt, it will be used because of its potential for real-time monitoring in the field.

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The recommended reactive tracers are lithium, strontium, dissolved oxygen, nitrate, selenite/selenate, ^{95m}Tc, and ^{95}Nb. Lithium and strontium are useful indicators of cation exchange equilibria. Natural ^{87}Sr will be determined as an independent check on strontium exchange. Dissolved oxygen* and nitrate are useful indicators of redox conditions. The remaining three are important redox sensitive radionuclide analogs.

8.3.1.4.4.3.3 Natural radionuclide reactivity component.

Naturally occurring radionuclides of the uranium and thorium decay series include radionuclides present in high-level waste (i.e., radioisotopes of uranium, radium, thorium, lead). Understanding the behavior of these radionuclides under actual or pre-emplacement environmental conditions will help validate model predictions of radionuclide behavior in the natural system based on laboratory sorption data and transport model calculations. The natural radionuclide reactivity component consists of both laboratory and field passive tests of radionuclide reactivity. A significant difference between this approach and the other tests in the radionuclide reactivity study is the length of time (thousands of years) for solute/solid phase equilibration and the minimal disturbance of test zone chemistry since the test involves only withdrawal of formation water (or analysis of solid phases).

The distribution and abundance of the uranium and thorium decay series (Fig. 8.3.1.4-39 and 8.3.1.4-40, respectively) radionuclides in rock matrices and secondary minerals will be used as long-term indicators of mobility. Enrichment of uranium and thorium in secondary mineral phases relative to the rock matrix provide indirect evidence of sorption (or precipitation) from circulating waters (LBL, 1983). In addition, the degree of secular equilibrium in the uranium and thorium decay chains in the secondary minerals reveals the varying mobility of members in the series and also provides depositional age information of mineral phases. Thus, a complete evaluation of natural radionuclide behavior requires analysis of core samples and secondary mineral-separates as well as formation fluids.

The natural radionuclide reactivity component of this study consists of two tests:

- Laboratory validation tests.
- Field measurement tests.

A flowchart showing the time sequence and task interrelationships for the two tests is shown in Figure 8.3.1.4-41 and discussed in the following test descriptions.

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*Rapid removal of oxygen from drilling fluid (Columbia River water) injected into basalt flow-top aquifers has been observed by BWIP investigators. Additionally, nitrate in the drilling fluid was rapidly converted to ammonia, suggesting reducing conditions of less than -400 mV.

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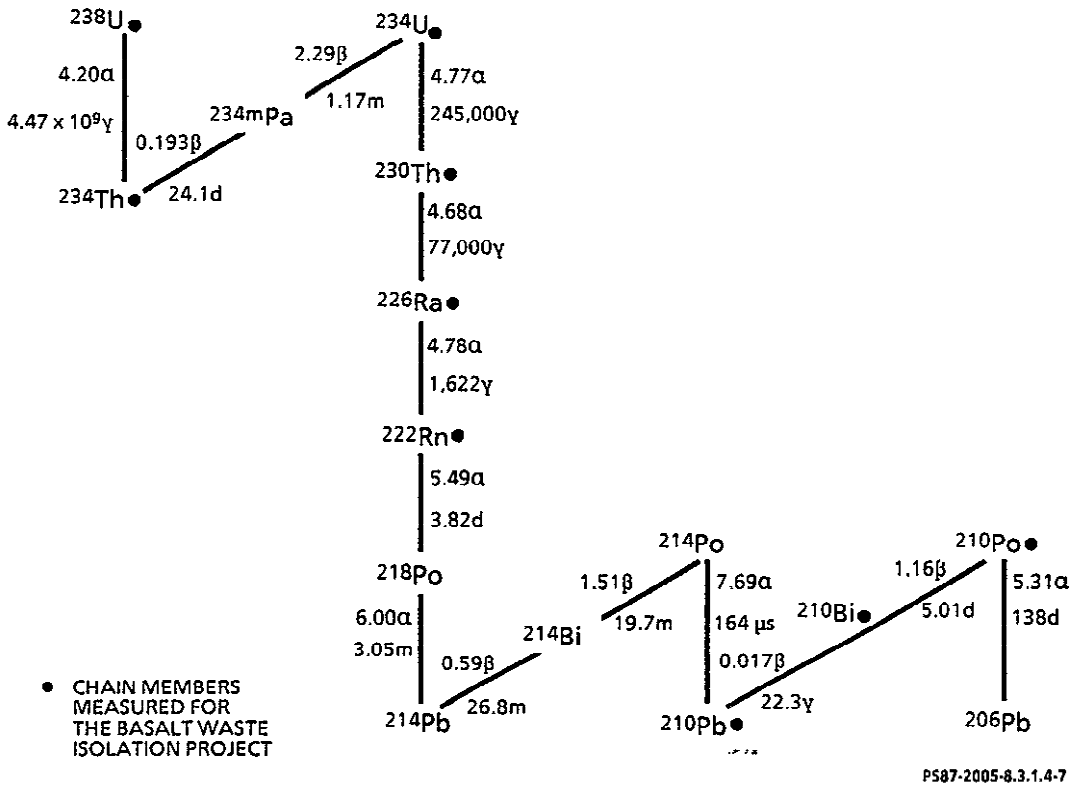

Figure 8.3.1.4-39. Uranium-238 decay series. (When secular equilibrium exists, the decay rate (activity) of each member in the chain is the same. Deviation from this condition occurs in response to differences in chemical behavior of the chain members.)

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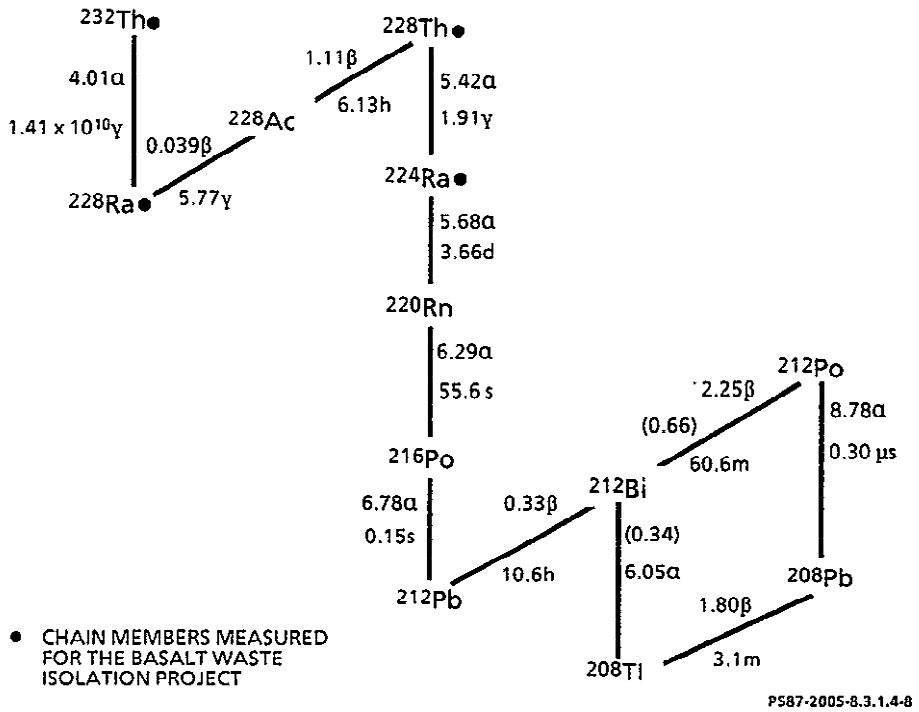

Figure 8.3.1.4-40. Thorium-232 decay series.

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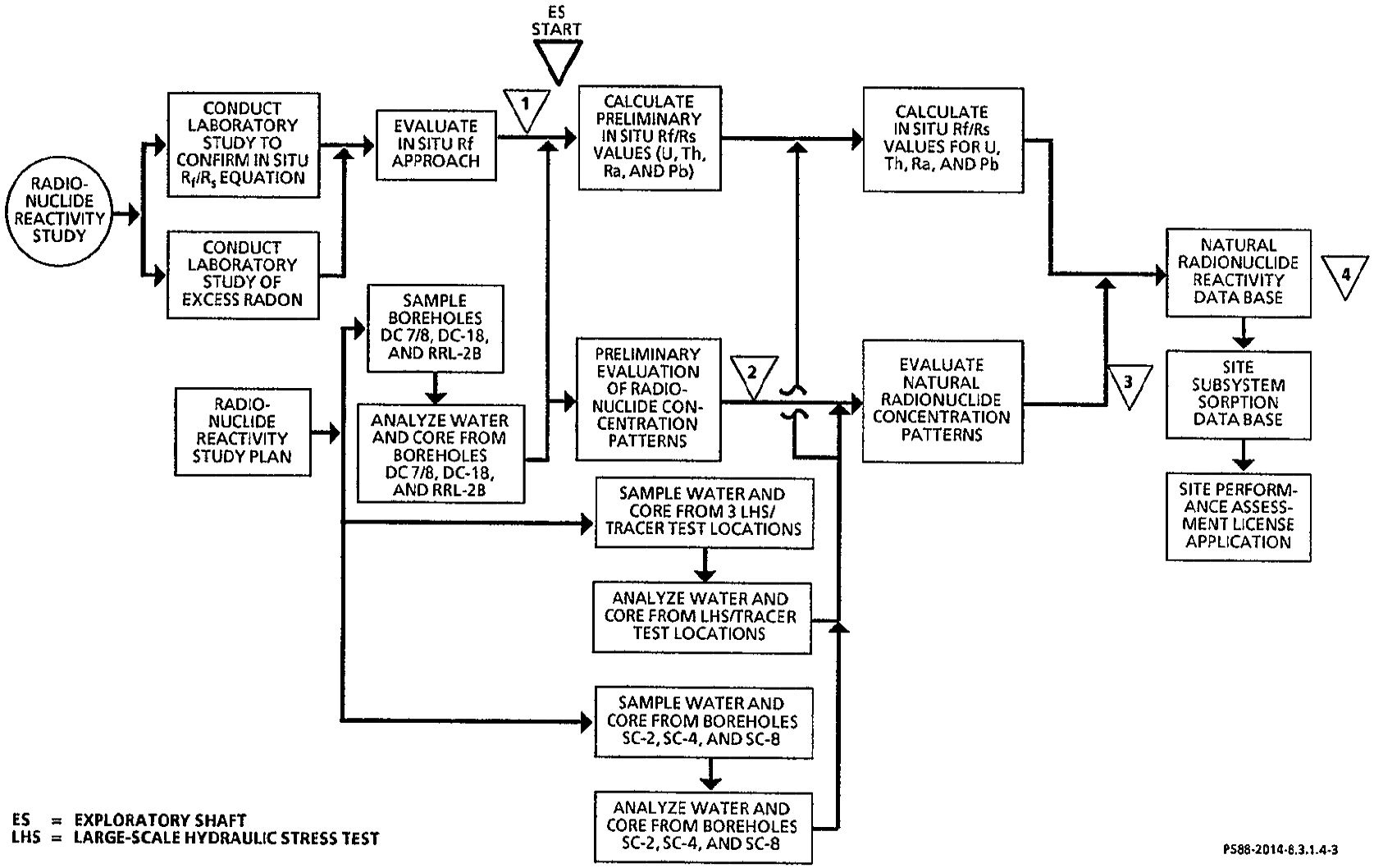

Figure 8.3.1.4-41. Flowchart for the natural radionuclide component.

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8.3.1.4.4.3.3.1 Laboratory validation tests. The primary objective of the laboratory studies is to examine the validity of a fundamental assumption in calculating in situ retardation factors from natural radionuclide data.

Krishnaswami et al. (1984) set forth the theoretical basis for calculating in situ retardation factors from natural radionuclide data. The fundamental assumption is that all members in the decay series (see Fig. 8.3.1.4-39 and 8.3.1.4-40) are initially supplied to the solution phase as a result of recoil from solid surfaces directly into the pore fluid. The recoil supply mechanism arises as a result of the radioactive decay process.

According to this model, radiochemical species that are injected into the pore fluid by recoil from solid surfaces will either remain in solution or will be partitioned between solid and solution in accordance with the in situ chemical conditions and the radionuclide reactivity. This can be thought of as a "continuous" tracer experiment (i.e., the radioactive tracer is continuously added to solution under actual environmental conditions). The advantage of this natural experiment is that sorptive properties are not influenced by the experimental conditions. However, a disadvantage is that conditions are fixed; hypothetical changes in pH, oxygen fugacity, etc., cannot be altered as in a laboratory experiment (unless chemicals are injected into a test zone to purposely simulate hypothetical perturbations such as heat, oxidizers, acid, salt, organics, etc.).

If the fundamental assumption noted above is correct, it can be shown that the retardation factor (R_f) is related to the activity ratio of a chain member divided by a conservative (nonadsorbing) chain member such as radon in the following way:

$$R_f = \frac{V_w}{V_r} = \frac{1}{AR} = 1 + \frac{R_s \rho}{n_e} \qquad (8.3.1.4\text{-}14)$$

where

V_w = Velocity of fluid phase

V_r = Velocity of radionuclide

AR = Activity (disintegrations/min) of radionuclide of interest divided by ^{222}Rn activity

R_s = Distribution coefficient (mL/g)

ρ = Density of host rock (g/cm^3)

n_e = Effective porosity, a dimensionless expression for the fraction of connected pore space relative to a unit volume of rock.

If the effective porosity is known for a sample site, the equation can be solved for in situ R_s. This will be possible at those sites for which tracer tests will be conducted to determine effective porosity. Solving for

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in situ R_S in Equation 8.3.1.4-12 permits comparison of field and laboratory results and, thus, provides a measure of geochemical uncertainty.

Recently the fundamental assumption for the above approach was challenged on the basis of laboratory observations of radon release from a granitic (saprolite) test material (Rama and Moore, 1984). This study showed that "excess" radon was supplied to solution. The explanation proposed was that microfractures may allow differential diffusion of radon from the interior of the solid phase in excess of that supplied by recoil from mineral surfaces. The consequence is that the retardation factor would be over estimated in proportion to the excess radon. Because of this possibility, the BWIP will repeat the Rama and Moore (1984) laboratory study using solid phases relevant to the Hanford Site basalts.

The BWIP will also demonstrate that the activity ratio (AR) can predict the correct retardation factor and (or) distribution coefficient under laboratory or known conditions. This would permit relating laboratory R_S measurements to in situ retardation factors for at least selected elements.

The following discussion first addresses tests directed toward resolving the "excess" radon question and then the approach to demonstrating the validity of the calculational method.

Tests to evaluate excess radon

Two experimental approaches will be used to evaluate the excess radon in basalt flow top solids: the ^{220}Rn method and the excess radon laboratory test. The ^{220}Rn method will make use of the difference in radioactive half-life between ^{222}Rn from the ^{238}U series and ^{220}Rn from the ^{232}Th series. The excess radon laboratory test will involve repeating the Rama and Moore (1984) experiment using basalt flow-top solid phases.

Radon-220 method. The ^{220}Rn is a short-lived (half-life of 1 min) daughter of ^{228}Ra from the ^{232}Th decay chain. On the other hand, ^{222}Rn has a 3.8-d half-life and is supplied by decay of ^{226}Ra from the ^{238}U chain. If there is diffusion of radon from nanopores or microfractures into pore fluid, the $^{228}Ra/^{220}Rn$ and $^{226}Ra/^{222}Rn$ ratios are expected to be significantly different due to decay of the short-lived ^{220}Rn during diffusion/transport out of the microfracture network. If recoil is the predominant supply mechanism to pore fluid, the radium/radon ratios from the uranium and thorium decay chains should be substantially the same.

This test will be conducted on a laboratory spiked system as well as direct sampling of formation fluids. In the latter case, the BWIP proposes to determine the ^{220}Rn via collection of the ^{212}Pb on MnO-impregnated fibers and back calculate the original ^{220}Rn. Procedures have not yet been established for this analytical step. For the laboratory spike experiment, ^{226}Ra and ^{228}Ra will be added to a crushed basalt flow-top column (i.e., the radium allowed to adsorb from solution onto the solid surfaces). This will permit testing of the concept for a known case of mineral surface supply only.

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Excess radon laboratory test. This test is essentially a duplication of the Rama and Moore (1984) experiment using representative flow-top solids.

A 250-cm^3 (15.3-in^3) glass column will be filled with the same flow-top solids used in the laboratory or batch R_s work. An ethylenediaminetetraacetic acid (EDTA) solution will be added to just fill the pore space in the column, the column will be sealed, and the ^{220}Rn allowed to "grow" in for approximately 3 wk. The EDTA will remove the surface-adsorbed radium and will thus represent the total surface supply of radon.

At the end of the equilibration period, the solution will be analyzed for radon and radium. The radon to radium ratio in the EDTA solution will be an indication of excess radon. If the ratio is near one, the conclusion will be that most of the radon supply is due to surface recoil from adsorbed radium. If the radon is substantially greater than the radium in the EDTA solution, the activity ratio will be an indication of the magnitude to which the in situ retardation factors can be overestimated. Variables in conducting the above experiment will include matrix type, porosity, and test solution (Table 8.3.1.4-18).

Validation of the calculation for retardation factor

This test will involve a variation of the test procedure described above but using identical solids and solution conditions as used in the batch R_s experiments. The procedure involves adding a radium spike to the column and allowing the short-lived radon and radon daughters to come to equilibrium (2 to 3 wk). Investigators will then measure the amount of ^{214}Pb and ^{222}Rn in the fluid. Since the porosity will be known for the solids in the column, the R_s can be back calculated from the ^{214}Pb:^{222}Rn activity ratio using the relationship noted in Equation 8.3.1.4-12. Thus, rearranging the expression, the R_s for lead should be:

$$R_s = \frac{n_e((1/AR) - 1)}{\rho}; \quad AR = {}^{214}Pb:{}^{222}Rn \text{ in fluid phase} \qquad (8.3.1.4\text{-}15)$$

If the equation relating activity ratio and retardation factor is correct, the R_s calculated as in Equation 8.3.1.4-18 should agree with the batch R_s from the laboratory sorption experiments using identical solids/solution conditions.

8.3.1.4.4.3.3.2 Field measurements test. This test involves measurement of the abundance patterns of the decay series radionuclides in aquifer host rock, formation fluids, and colloidal phases. Test zones and locations include those specified in Figure 8.3.1.4-41 (see Fig. 8.3.1.4-10 for location) as well as special study sites for the reactive tracer injection tests. The principal requirements are clean drilling methods, representative formation water, clean sampling techniques, and availability of representative core samples and secondary minerals.

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Table 8.3.1.4-18. Laboratory test matrix for natural radionuclide tests (first year)

Test type	Test conditions	Absorbent material	Replications
Excess radon evaluation	Sealed, glass 250-cm^3 column (30 d) Solid/solution ratio: 10:1 GR-4 test solution with and without EDTA/anoxic Test temperature: 50 °C Measure natural ^{222}Rn and ^{226}Ra in fluid from column	Cohassett and Rocky Coulee flow tops Crushed basalt from the Cohassett and Rocky Coulee flow interiors Intact core (when available)	In triplicate for each solid and test condition variable (3 x 4 x 2 = 24)
Comparison of batch sorption and activity ratio/R_s for Pb	Same as above and in Table 3.1-1 without EDTA ^{226}Ra spike Measure $^{222}Rn/^{214}Pb$ in solution after 30-d equilibration	Cohassett and Rocky Coulee flow tops	In triplicate (3 x 2 = 6)

NOTE: EDTA = Ethylenediaminetetraacetic acid.

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Investigators will use the radiochemical methods summarized in Tables 8.3.1.4-19 and 8.3.1.4-20 to analyze water, core, and secondary minerals. Table 8.3.1.4-20 references the detailed analytical methods. The analytical methods are available as supporting documents to the study plan.

Water

Investigators will filter water samples in the field immediately upon collection under closed-system conditions (exclusion of air). A 0.4-μm pore membrane filter will be used for all routine filtrations while a series of filters with pore sizes ranging from 0.01 to 1 μm will be used on selected test zones to evaluate the occurrence of submicron particulate phases or radiocolloids. Due to the extremely low concentrations, some water samples may have to be preconcentrated. The BWIP will use the Battelle large-volume sampler, configured as shown in Figure 8.3.1.4-42, to preconcentrate water samples. Analytical procedures dictate other sampling requirements that may be performed on up to 50 L (13 gal) of water. The BWIP will preserve such water samples by adding either ultrapure nitric acid or hydrochloric acid immediately after filtration. Details of these procedures are included in the referenced procedures (see Table 8.3.1.4-20).

The first year of this study plan emphasizes completion of analytical work for previously collected water samples and refinement of some analytical procedures. The emphasized analytical procedures include application of new, state-of-the-art instrumentation (e.g., the inductively coupled plasma emission-mass spectrometer (ICP-MS) for selected analyses to improve detection limits and reduce analytical blanks for uranium, thorium, and analog elements.

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Table 8.3.1.4-19. Radiochemical analysis of groundwater

Radionuclides	Method	Tracer
^{238}U, ^{235}U, ^{234}U	Mass spectrometry	^{233}U
^{234}Th, ^{232}Th, ^{230}Th, ^{228}Th	Beta and alpha spectrometry	With and without ^{230}Th
^{228}Ra, ^{226}Ra, ^{224}Ra	Large volume sampler--Al_2O_3-$BaSO_4$ adsorption beds and gamma counting	Isotopic ratios only
^{222}Rn (^{226}Ra)	Alpha scintillation	--
^{210}Pb via ^{210}Po	Alpha spectrometry	^{208}Po
^{210}Bi	Beta counting and alpha spectrometry via ^{210}Po	^{208}Po
^{210}Po	Alpha spectrometry	^{208}Po

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Solid phases

The BWIP will use core and drill cuttings for analysis of bulk composition of aquifer host rock for uranium and thorium and selected daughters. The BWIP core library contains sufficient core sample for this type of analysis for relevant flow tops. This work will use flow top samples that correspond to formation fluid sampling zones. Analytical methods for the various decay series will include gamma-ray spectrometry, neutron activation analysis, ICP-MS, and alpha-beta spectroscopy.

Analysis of secondary minerals may prove to be sample-limited for some decay-chain members since the mass of material available is small. It may be necessary to composite several locations to obtain sufficient material for analysis. The geochemistry program will establish sampling procedures for this purpose during periods when water sampling is precluded due to possible hydraulic interferences with the hydrologic baseline.

Investigators will use fission track, delayed neutron, and neutron activation methods to determine the microscopic distribution of uranium and thorium in the rock matrix. The laser-surface ablation method combined with the recently developed ICP-MS method may also be used for microscopic elemental distribution analysis (Gray, 1985). This type of analysis is important for determining whether uranium or thorium occurs at mineral grain boundaries or whether they are uniformly distributed in secondary minerals or the rock matrix. Uniform distribution in secondary minerals would be consistent with sorption from solution. Accumulation along grain boundaries is characteristic of primary emplacement (i.e., associated with segregation from the original magma).

Table 8.3.1.4-20. Description of key measurements for the natural radionuclide field test

Test phase	Key parameters measured	Applicable procedures[a]	Accuracy and precision	Range of expected results	Required equipment	Data reduction analysis techniques
Water	^{234}U ^{235}U ^{238}U ^{232}Th, ^{230}Th ^{224}Ra, ^{226}Ra ^{228}Ra $^{222}Rn^{b}$ ^{210}Pb ^{210}Po ^{210}Bi	RSD-51-DIS-2 RSD-51-DIS-2 RSD-51-DIS-3 RSD-51-DIS-4 RSD-51-DIS-4 RSD-51-DIS-5 RSD-51-DIS-6 RSD-51-DIS-8	±5% ±5% ±5% ±5% ±5% ±5% ±5% ±5% ±5% ±5%	0.001 to 1 dpm/L 0.001 to 1 dpm/L 0.001 to 1 dpm/L 0.001 to 1 dpm/L 0.001 to 1 dpm/L 0.001 to 1 dpm/L 1 to 10,000 dpm/L 0.001 to 1 dpm/L 0.001 to 1 dpm/L 0.01 to 1 dpm/L	Radiochemical separations in conjunction with mass spectrometry alpha-, beta-, gamma-based counting equipment	Simple reduction by hand and computer
Core (bulk)	U, Th, K series	RSD-51-DIS-13	±5%	U 0.5 to 1.5 dpm/g Th 0.5 to 1.5 dpm/g	Radiochemical separations in conjunction with mass spectrometry alpha-, beta-, gamma-based counting equipment	Simple reduction by hand and computer
Secondary minerals	^{234}U, ^{238}U ^{226}Ra/REE	RSD-51-DIS-2 RSD-51-DIS-4 and 5 RSD-51-DIS-9	±5% ±5%	1 dpm/g	Radiochemical separations in conjunction with mass spectrometry alpha-, beta-, gamma-based counting equipment	Simple reduction by hand and computer

NOTE: Locations and aquifers to be sampled for this test will be from selected new boreholes to be drilled within the controlled area study zone (see Section 8.3.1.4.3.3.1).

[a]Pacific Northwest Laboratory reports - author J. C. Laul.

[b]^{222}Rn is also to be used in helium/radon age-dating alternative.

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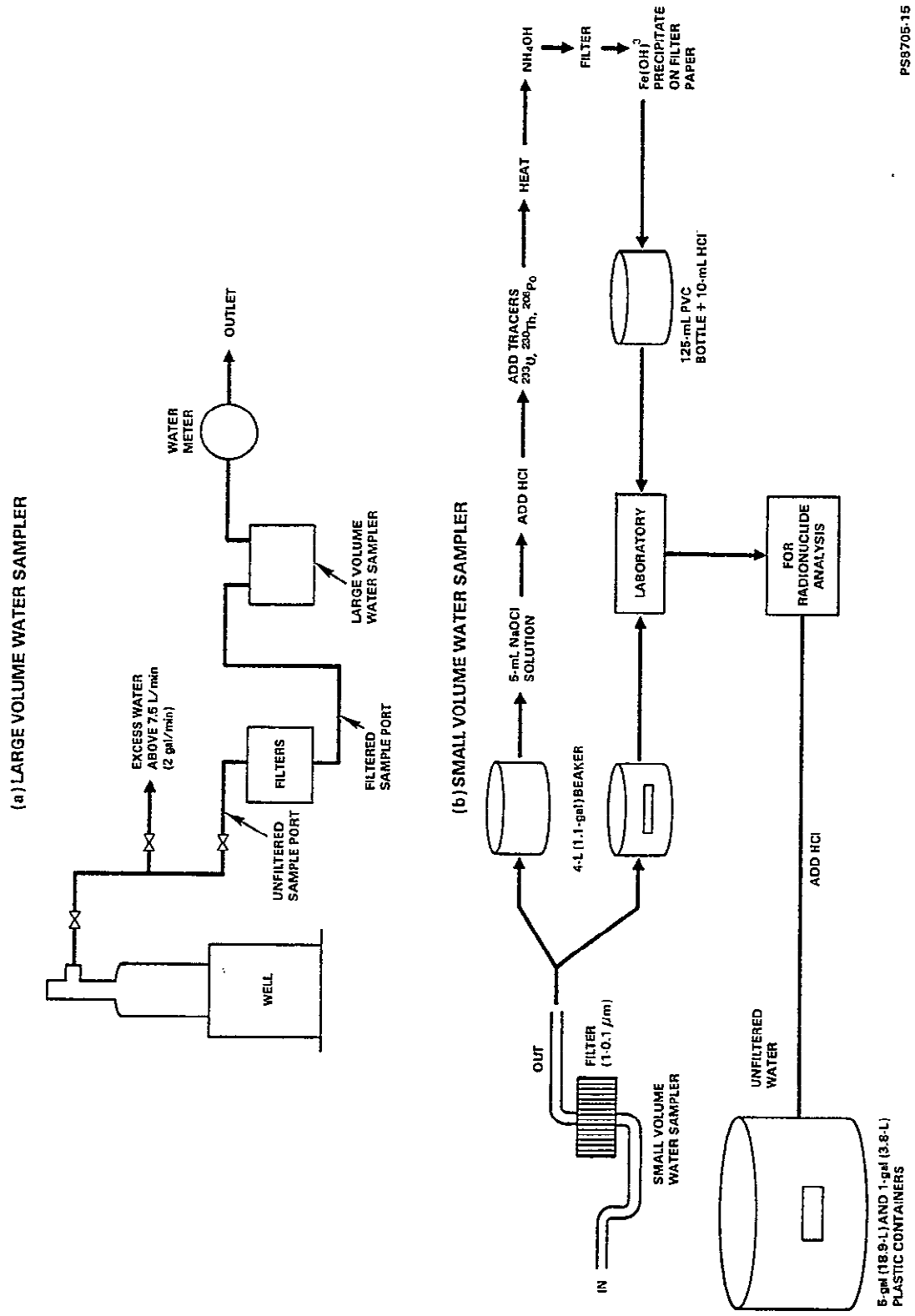

Figure 8.3.1.4-42. Groundwater sampling setups.

Work during the first year will emphasize establishing the analytical methods and procedures as well as sampling for solid phases. However, some bulk rock abundances of uranium and thorium will be determined during the first year by conventional methods (i.e., gamma spectrometry and (or) chemical analysis). The BWIP will use the abundances to evaluate radon and helium source terms for selected test zones for which fluid samples have already been analyzed.

Sample representativeness

Borehole cleanup and spatial distribution of test zones are the primary considerations in sample representativeness.

Cleanup conditions related to borehole development prior to sampling are discussed in Section 8.3.1.4.3.3.1.3. Since the natural abundances of uranium/thorium decay series radionuclides are so low in basalt groundwaters, cleanup requirements are stringent. For example, drilling fluid involving Columbia River water typically contains dissolved uranium at approximately 1 μg/L as compared to deep confined aquifer concentrations of 0.001 to 0.01 μg/L. Thus, a test zone should be restored to 99% to 99.9% formation water (i.e., attenuation of a drilling fluid tracer by a factor of 100 to 1,000). The BWIP can achieve this degree of cleanup provided drilling fluid losses are controlled and sufficient pumping time is allotted for cleanup prior to sampling. Factors controlling cleanup and related constraints are discussed in Section 8.3.1.4.3.3.1.3. Existing drilling technology is adequate for cleanup provided sufficient precautions are taken. Representativeness of natural radionuclide concentrations in Hanford Site basalt groundwaters may be severely constrained by the extent of borehole cleanup. Other sensitive hydrochemical parameters (ultratrace level measurements, age-dating parameters, etc.) require the same degree of cleanup.

Compromises to accommodate hydrologic testing can preclude successful data acquisition. For example, the objective of the hydrologic testing program requires minimizing disturbances due to extended pumping; but the objectives of the hydrochemical sampling program requires extended pumping. These objectives are nearly always incompatible with obtaining clean samples. Thus, the most reliable data will be obtained from "dedicated" hydrochemistry boreholes (i.e., the HC-series boreholes shown in Fig. 8.3.1.4-10).

Sample acquisition using the standard pump tubing associated with submersible pumps and well-head fixtures have been shown to be acceptable at the BWIP site provided sufficient flushing has occurred. Additional checks of this assumption are needed using ultraclean downhole sampling and packer assemblies (Fig. 8.3.1.4-43). The BWIP will accomplish this by using a stainless steel inlet screen in the test zone combined with a downhole sampling bottle with inert materials or linings (teflon coated). Sample analyses requiring large volumes cannot be checked in this manner. However, based on experience thus far, these sampling constraints are not expected to be limiting.

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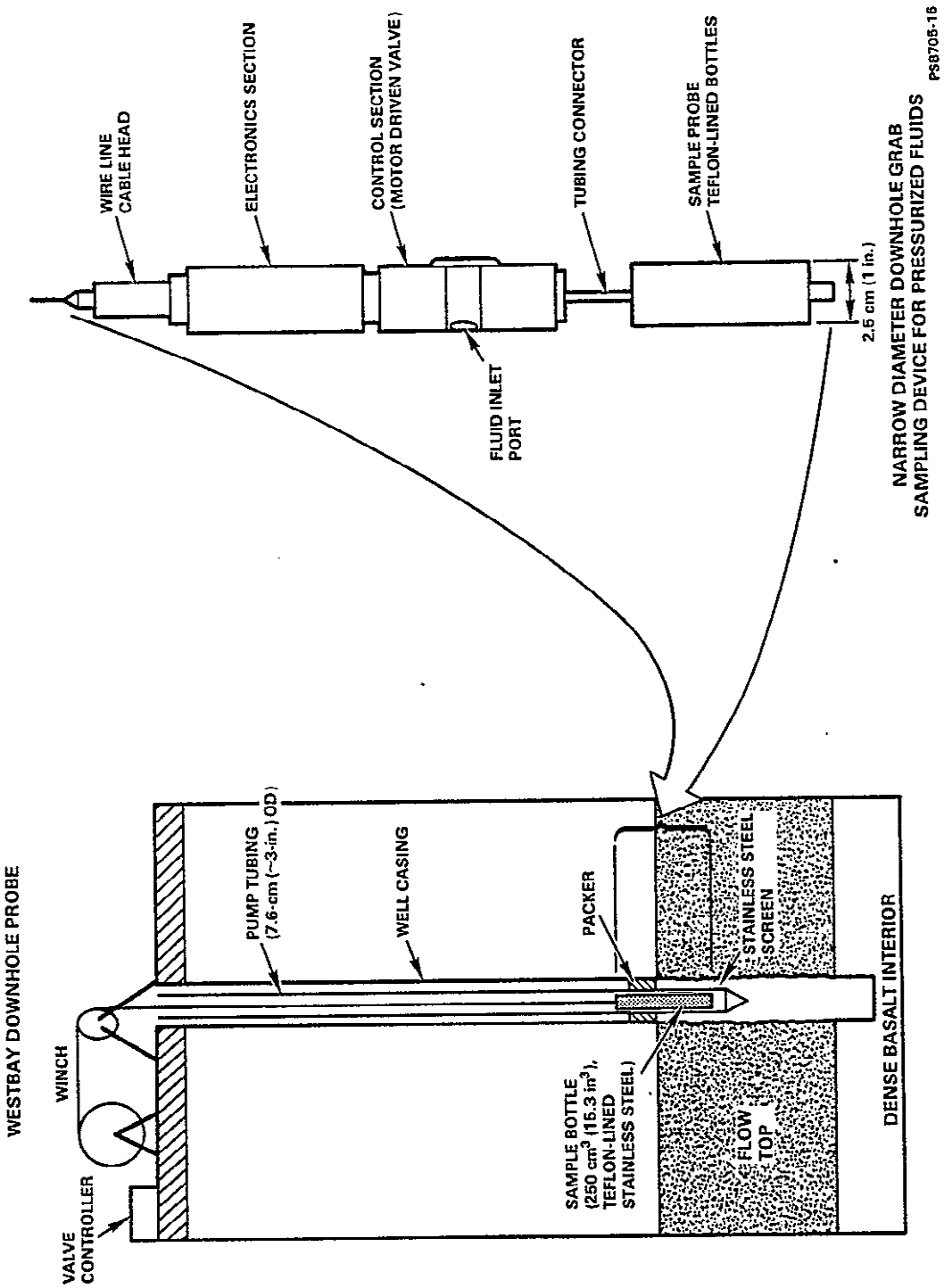

Figure 8.3.1.4-43. Equipment for downhole sampling.

Spatial variability

The test zones and locations discussed in Section 8.3.1.4.3.3.1 are expected to provide a sufficient data base with which to assess spatial variability for the key flow tops and (or) along hypothesized flow paths (i.e., at least four test zones in the Grande Ronde Basalt and three zones in the Wanapum Basalt at seven test sites located in the Cold Creek syncline, including selected resampling opportunities discussed elsewhere). These planned test zones will be the only ones for which natural radionuclide data will be available since this type of information was not acquired for previous sampling efforts at the BWIP. The borehole testing and sampling program are the minimum that may be required. Results of the initial phase will determine the need for additional data.

8.3.1.4.4.4 Application of results

The results of this investigation will be used for performance assessments, site characterization analyses, and design development. This section discusses these applications.

8.3.1.4.4.4.1 Performance assessment uses.

Site performance assessment models will use the results of the radionuclide retardation behavior investigation to predict cumulative release to the accessible environment. These models require distribution coefficients for key radionuclides under natural conditions. In practical terms, if the retardation factor for a radionuclide is significantly greater than one, it can be omitted from the matrix that must be solved in order to model far-field radionuclide transport in the natural system. Therefore, the first order application of results will be to simplify performance assessment calculations by omitting terms that are insignificant within the performance requirements for a nuclear waste repository in basalt.

Results from the natural radionuclide behavior test will serve as a partial validation check of performance assessment model predictions of radionuclide behavior in the natural system. The BWIP will compare in situ R_s; retardation factors; and solute/colloid occurrence for lead, radium, thorium, and uranium under natural or "undisturbed" conditions with performance assessment model predictions at key flow-top aquifer locations. Observed behavior of the naturally occurring radioactive waste radionuclides will be compared with model predictions based on laboratory results. These comparisons will provide estimates of "geochemical uncertainty."

8.3.1.4.4.4.2 Characterization uses.

Data will consist of laboratory and field retardation factors, sorption/desorption isotherms, effective porosity x thickness products, coefficients of hydrodynamic dispersion, redox rate constants, and sorption kinetics. Graphical data will consist of reduced tracer concentration plots for single borehole tests, breakthrough curves for laboratory tests and paired borehole tests, and redox-precipitation kinetics. Investigators will also

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interpret graphical data to show whether or not matrix diffusion and aqueous complex formation and colloid transport are significant processes affecting ion mobility. These data will be organized according to the flow top that was tested.

The program will statistically evaluate field sorption data to determine whether values for given flow tops are from the same population regardless of position. Should this be the situation, data will be reported as population means and standard deviations. If this is not the case, interpolation will be necessary to report distributed values for each flow top along the Cold Creek syncline. The geochemistry program will supply performance assessment with an algorithm that will permit the calculation of retardation factors for key radionuclides within a flow system that parallels the axis of the Cold Creek syncline. Performance assessment will incorporate this algorithm with mass transport codes in site performance assessment models.

An understanding of the processes that govern sorption is necessary in order to support the extrapolation of laboratory sorption data to field conditions and to lend additional credence to the data. It is important to verify that the sorption processes that operate in the laboratory are the same in kind and degree as those that operate in the field. For example, the sorption hysteresis observed for lithium in laboratory batch tests may not be operative under field conditions. Sorption may strictly involve a concentration of the sorbed substance at a solid surface (adsorption) or its penetration into the interior of the solid (absorption). Chemisorption is a process considered limited to adsorption on a single surface layer, whereas physical adsorption may include the surface accumulation of multiple layers of the sorbing species on the solid. Laboratory batch tests use different mineral surfaces, specific surface areas for reaction, contact times, and water rock ratios than are normally found in field tests. Different sorption processes may occur in field and laboratory tests, and simple scaling factors may not be adequate for extrapolating laboratory results to the field.

Surface ionization and complexation are probably the most important process for sorption of radionuclides. Models describing these processes (Davis et al., 1978; Davis and Leckie, 1979, 1980; Westall and Hohl, 1980; and Hsi and Langmuir, 1985) deal with ion exchange and specific adsorption of anions and cations, variations in both surface charge and potential (related to pH), the effects of ionic strength, and the simultaneous adsorption behavior of several complexed and uncomplexed metal and nonmetal species. Before these models can be applied, the BWIP must perform a great many measurements on the solution and sorbents to adequately characterize the adsorption process. Some of the most important parameters that must be measured are surface site density, specific surface area, and intrinsic equilibrium constants for the surface reactions. At the present state of development of this project, it is not possible to say with certainty that meaningful estimates of these parameters can be obtained from laboratory tests, let alone field tests. The requisite data base for such models would be extensive due to the numerous adsorbents and adsorbates of the system.

Chemical kinetics defines how long a chemical system takes to reach equilibrium and by what reaction pathways equilibrium is reached. Kinetic models describe the reaction pathways towards equilibrium and the reaction position and times along those pathways. Langmuir and Mahoney (1984) summarized the essence of equilibrium versus kinetics in the following discussion.

> When reactions are fast and reversible ($T_R >> T_{1/2}$), equilibrium models may be used to describe the state of those reactions. On the other hand, when reactions are slow and irreversible ($T_{1/2} < T_R$) kinetic models are needed to describe the state of those reactions. In most groundwater systems, reaction half times range on the order from 10^{-10} s to 10^6 yr or longer, so that both kinetic and equilibrium models are necessary to understand the chemistry of the total rock/water system.

In the swish tests using redox-sensitive tracers (e.g., dissolved oxygen, selenium, and technetium), retrieval of tracer solutions at various times during the test will permit an estimation of the rate at which oxidized anions are reduced. In the case of sluggish reactions such as the reduction of Se(IV) to Se(II) to Se(0) and Tc(VII) to Tc(IV) to Tc(0), laboratory reaction times have been on the order of days to weeks (Cherry et al., 1979; Vandergraaf et al., 1984). It is not presently known whether rates in the field will be faster or slower than rates in the laboratory. Unless rapid and total sorption of selenium and technetium is observed, field sorption data will not be credible until the redox kinetic factor is addressed. Further discussion of the aqueous geochemistry and sorption of selenium and technetium may be found in Wallick (1986).

In addition to the above application, the natural radionuclide study will support the groundwater age-dating test associated with the groundwater flow system hydrochemistry study plan. For example, the hydrochemistry program will use uranium and thorium abundances in aquifer host rock as the source term for helium in groundwater residence time in age calculations. The ^{222}Rn in pore fluid from test zones will also be used in alternative groundwater age calculation methodology combining both radon and helium. The $^{234}U/^{230}Th$ ratios derived from the decay series measurements in pore fluids will also provide additional evidence for the redox state of uranium and thus will support the groundwater redox study plan.

8.3.1.4.4.4.3 Design applications.

The buildup of radon daughters is a well-known problem in some subsurface excavations. Radon may contaminate the underground workings as a result of direct diffusion from the solid rock wall and indirectly as a gaseous constituent in groundwater inflow. Because of the relatively low uranium content of basalt, the BWIP does not expect the buildup of radon daughters to be a serious problem. However, virtually no data exist with which to assess the validity of this assumption.

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Radon concentrations in groundwater for key basalt flow tops will be available from the natural radionuclide study. These data are useful for assessing the groundwater inflow source. In addition, the laboratory studies planned for the first year of this study plan include radon emanation tests on the Cohassett and Rocky Coulee flow interior basalt samples. This information can be used to calculate a radon flux term for representative basalt surfaces. When the above source terms are combined with mine ventilation rates, investigators can assess the adequacy of the test shaft and repository heating, ventilation, and air conditioning design to control radon daughter concentrations. Appropriate changes, if any, can be included early in the project.

8.3.1.4.4.5 Schedule and Milestones

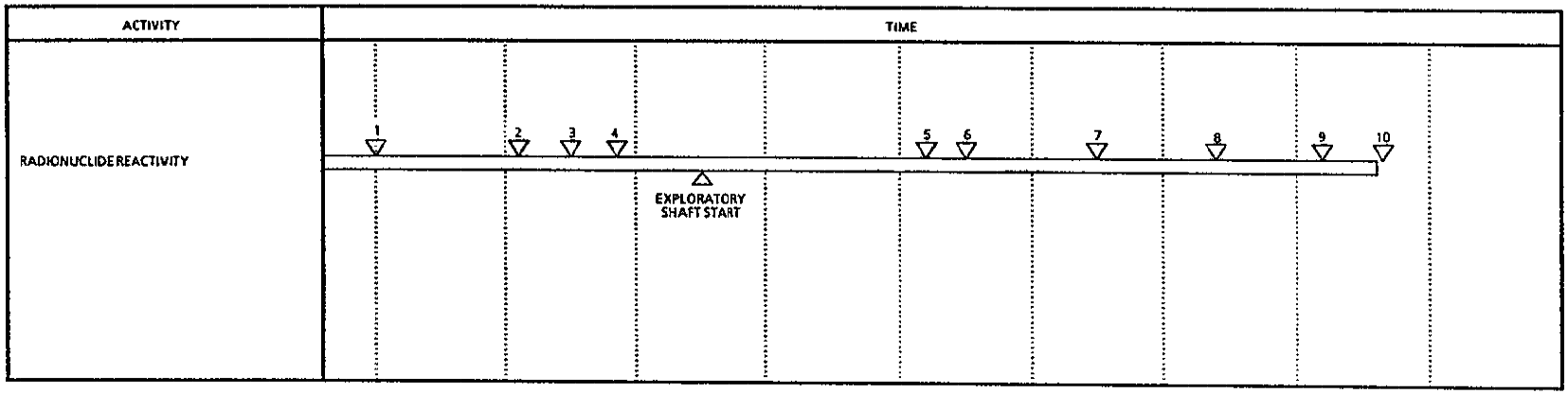
The schedule information provided for investigations in this program includes the sequencing, interrelationships, and relative durations of the studies in the investigation. Specific durations and start/finish dates for the studies are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress report.

An abbreviated schedule and milestones chart for the radionuclide retardation investigation is shown in Figure 8.3.1.4-44.

8.3.1.4.5 Geochemical modeling

Geochemical modeling is an integral part of the geochemistry program because of its value for understanding geochemical processes and for developing a predictive capacity for evaluating repository performance over geologic time scales. Geochemical modeling is an intrinsic part of all studies. Table 8.3.1.4-21 is a generalized summary of the modeling concerns that have been identified for the various studies in the Site Geochemistry Program along with the applicable code(s) that may be employed in their solution. Each of the concerns are discussed in greater detail below.

Knowledge of the geochemical controls on fluid composition is fundamental to the interpretation of the three-dimensional distribution of solutes. Characterization of the chemical evolution of groundwaters beneath the Hanford Site as well as determination of potential mixing of groundwaters are therefore listed as modeling concerns. Characterizing the redox conditions that exist in the basalt groundwater system is necessary for radionuclide solubility and mobility calculations. Modeling codes such as EQ3/6 (Wolery, 1983), PHREEQE (Parkhurst et al., 1980) and BALANCE (Parkhurst et al., 1980) can simulate the chemical evolution of groundwater as it reacts with major basalt flow tops.



1 COMPLETE STUDY PLANS.
2 COMPLETE RADIONUCLIDE SOLUBILITY SCREENING OF KEY RADIONUCLIDES.
3 COMPLETE EVALUATION OF NATURAL RADIONUCLIDE/IN SITU R_f APPROACH
4 COMPLETE INITIAL LABORATORY SORPTION TESTING AND EVALUATION OF ANOXIC CORE SAMPLES.
5 COMPLETE SINGLE BOREHOLE FIELD REACTIVE TESTING.
6 COMPLETE PRELIMINARY SORPTION PARAMETER DATA BASE FOR PERFORMANCE ASSESSMENT MODELING.
7 COMPLETE LABORATORY SORPTION/DESORPTION ISOTHERMS FOR KEY RADIONUCLIDES.
8 COMPLETE EVALUATION OF NATURAL RADIONUCLIDE CONCENTRATION PATTERNS.
9 COMPLETE MULTIBOREHOLE FIELD REACTIVE TRACER TESTS.
10 COMPLETE FIELD AND LABORATORY SORPTION DATA BASE FOR PERFORMANCE ASSESSMENT MODELING OF RADIONUCLIDE TRANSPORT.

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Figure 8.3.1.4-44. Schedule and milestones for the radionuclide retardation investigation.

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Table 8.3.1.4-21. Geochemical modeling matrix for the site geochemistry program

Site geochemical study	Modeling concern	Modeling code
Groundwater flow system hydrochemistry study	Chemical characterization of water along regional flow paths and in the vicinity of the repository site	EQ3/NR, PHREEQE
	Chemical evolution of water along regional flow paths	EQ3/NR/EQ6, PHREEQE, BALANCE
	Mixing of waters from different sources	EQ3/NR/EQ6, PHREEQE, BALANCE
Groundwater redox characteristics study	Redox characterization of water along regional flow paths (from active/passive determinations of redox couple concentrations)	EQ3/NR
	Redox maturation of water along regional flow paths	EQ3/NR/EQ6
	Determination of kinetic data from field sampling	EQ3/NR/EQ6, PHREEQE, BALANCE
Radionuclide reactivity study	Verification of laboratory-derived sorption parameters with field data	MINTEQ

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Characterizing the redox conditions that exist in the basalt groundwater system is necessary for radionuclide solubility and mobility calculations. The EQ3/NR code (Wolery, 1983) will be used to determine individual redox couple Eh values as measured by both passive and active field testing methods. Convergency of Eh determinations on a unique value reflecting a system Eh is an unreasonable expectation; however, a narrowly delimited range of values is possible based on alternate lines of evidence as discussed in Section 4.1.3.4.1. In addition, kinetic information for actively injected redox-sensitive tracer species can be derived by plotting EQ3/NR-computed Eh values as a function of time (for time-series samples collected during the withdrawal phase of an injection-withdrawal test). This information can be used to evaluate the rate and extent to which redox equilibrium is approached under in situ conditions.

The radionuclide reactivity study will use the MINTEQ (Felmy et al., 1984) code for verification of the applicability of laboratory-derived R_s values as predictive measures of in situ conditions. The code employs aqueous speciation-solubility-adsorption modeling techniques to solve for the equilibrium composition of water in contact with mineral solids. The relative importance of specific adsorption reactions can be tested by modifying the basic input file to reflect different solid phase distributions.

8.3.1.4.6 Impact of planning assumptions on proposed site geochemistry program

The geochemical characterization plans presented in this chapter are designed to address both licensing requirements, as interpreted in Section 8.2 for the BWIP site, as well as site-specific technical issues or concerns of the State, Indian tribes, and the U.S. Nuclear Regulatory Commission. Changes in the existing laws, the Nuclear Waste Policy Act (NWPA, 1983), state and

Federal regulations, and (or) early findings in other parts of the BWIP program could significantly alter the extent and priorities of the planned studies presented in this chapter. Thus, the planned activities are "baseline" plans of which part or all may be implemented. For example, the current program is based on the assumption that the fission product inventory in spent fuel is sufficiently soluble in basalt groundwaters that radionuclide migration can occur from the waste package to the accessible environment. However, there is growing evidence that the solubility of the source-controlling waste form (UO_2) and the thermodynamic stability of the canister may preclude release from the engineered barrier system. If this condition is established with reasonable assurance, much of the proposed sorption testing to characterize radionuclide containment in the site geologic setting would be unnecessary. This would result in a significant down scoping of the proposed site geochemistry program. An essentially insoluble waste form would also diminish the importance of groundwater travel time and associated tests to confirm this preemplacement performance parameter.

At present there are too many uncertainties to rule out worst cases or disruptive scenarios. Thus, evaluation of the full complement of site geochemical parameters for the BWIP site are deemed necessary at this stage in the planning process. As the program matures it may be possible to narrow the scope of the planned activities.

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8.3.1.4.7 References

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