REFERENCE DATA SOURCE DOCUMENTATION FOR PERFORMANCE ASSESSMENT STUDIES

BASALT WASTE ISOLATION PROJECT
HANFORD SITE, WASHINGTON

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EXECUTIVE SUMMARY

The National Waste Terminal Storage (NWTS) Program was initiated by the United States in the mid-1970's to investigate the feasibility of storing nuclear waste in deep geologic formations. The Basalt Waste Isolation Project (BWIP) is one of the major research and development projects under the direction of the NWTS program. Rockwell Hanford Operations is presently responsible for investigating the feasibility of siting a repository for terminal disposal of nuclear waste in the basalts underlying the Hanford Site.

Whether or not this site--or any site--is ultimately suitable for the purpose must be based on computer-generated predictions of long-term repository performance. Computer modeling requires the quantitative specification of a large number of parameters that characterize the properties of the three principal repository subsystems (Site, Repository Seals, and Waste Package). The acceptance of conclusions (drawn from predictive models) by the public, the scientific community at large, and the regulatory and review agencies depends in part on the existence of a well-documented performance assessment data base that they can scrutinize and review.

It is the purpose of this document to provide a single, up-to-date listing of the data inputs to the performance assessment models (i.e., the performance assessment source data). The parameter values compiled herein constitute a listing of pertinent data currently in use for performance assessment. The document will be updated periodically as additional information becomes available.

It is the intention of this document to achieve the following objectives:

- To satisfy preclosure and postclosure performance assessment models' data needs,
- To provide guidance for data collection and prioritization of data needs,
- To satisfy the BWIP's System Requirements Tree objectives,

- To be consistent with the BWIP's Mission Plan, Environmental Assessment Report, and Site Characterization Plan requirements and standards,

- To comply with the BWIP's Quality Assurance Standards.

Because modeling of repository performance will proceed by means of allocating the contributions of each of the three major repository subsystems to overall performance achieved, this reference document has accordingly been organized by subsystem. Following is a brief overview of the findings of this report, by subsystem.

Site Subsystem Data for Performance Assessment

Groundwater flow in the Site Subsystem is generally horizontal in flow tops and sedimentary interbeds between basalt flows, and vertical in basalt flow interiors. The results of numerous single-well tests are available to characterize horizontal hydraulic conductivity in the flow tops and interbeds, as well as in the overlying unconfined aquifer. However, very few multi-well tests have been conducted for determination of vertical hydraulic conductivity in the flow interiors and storage coefficient in flow tops, interbeds, and flow interiors. Vertical hydraulic conductivity and storage coefficient are important parameters, and there are effective multi-well testing methods in existence to determine them. Directional horizontal hydraulic conductivity and dispersion coefficient are also needed for complete hydrologic characterization of the Site Subsystem. Overall, there is a lack of three-dimensional areal representation of hydraulic parameters.

The hydrogeologic units of the Hanford Site are well defined in terms of thicknesses of units and effective intervals at locations throughout the Pasco Basin. The values reported herein for physical, mechanical, and thermal properties of the host rock are the result of analysis of numerous core samples from various basalt flows, major structural units within the flows, and interbeds between the flows. Fracture properties of basalt interiors have been determined by means of in-situ hydraulic fracture tests conducted in various intervals at several locations.

Applicable values for diffusion coefficient are lacking in the literature surveyed for the Site Subsystem. Some values are available for a limited number of species migrating through bentonite, but they are more representative of the Repository Seals Subsystem and the Waste Package Subsystem.

Numerous distribution coefficient values are available, covering a wide range of environmental parameters for the major radionuclides.

Hydraulic head and temperature measurements are available to determine initial conditions across the Hanford Site.

Repository Seals Subsystem Data Base for Performance Assessment

Groundwater flow in the Repository Seals Subsystem may be so slow that radionuclide transport through saturated backfill is diffusion-controlled. Hydraulic conductivity values for backfill and plug materials are generally less than 10^{-10} m/s. Compaction of the backfill materials determines the bulk density, which, in turn, influences other characteristics, such as hydraulic conductivity, porosity, and mechanical properties.

No quantitative determinations exist for effective porosity or dispersivity of backfill or plugs. Very few values for thermal properties have been published.

Although diffusion coefficient values have been determined for some radionuclide species in bentonite, the importance of the diffusion mechanism for radionuclide transport in the Repository Seals Subsystem suggests that a more thorough investigation of diffusion be conducted.

Distribution coefficient values exist for a wide range of conditions and a variety of backfill and plug materials. These values indicate the ability of a backfill or plug material to retard the migration of various radionuclides by sorption.

Waste Package Subsystem Data Base for Performance Assessment

The Waste Package Subsystem protects the waste form from interaction with groundwater and initially retards radionuclide transport in case of contact with groundwater due to container failure. Radionuclide solubility and sorption, along with thermal stress, are significant factors affecting radionuclide mobility in the very near field.

Waste Package Subsystem parameters are grouped into three categories: waste form, canister, and packing material. In the waste form category, radionuclide parameters include half-life, specific activity, solubility, and inventory. Radionuclides which share the characteristics of long half-lives, high solubilities, and abundant inventories include C14, I129, Np237, Se79, Sn126, and Tc99. These six radionuclides should be included in studies examining radionuclide transport parameters.

Several canister materials show potentially appropriate resistance to corrosion. Among them are 2.5% Cr/1% Mo and 1.25% Cr/0.5% Mo cast steels, 1025 cast steel, and Fe9/Cr1/Mo.

Limited data or no data were available for packing material parameters, including effective porosity, dispersivity, thermal diffusivity, thermal expansion coefficient, diffusion coefficient, and distribution coefficient.

Observations

Because of the large amount of information collected to date and the projected future availability of additional information, a computerized data storage and retrieval system is recommended for updating of the current performance assessment modeling data base. Additional data collection in areas for which current information is insufficient or lacking (see Table A) would improve the quality of the data base. Additional multi-well hydrologic test results would yield a clearer picture of horizontal anisotropy and storage coefficients in the basalts of the Hanford Site. The use of greater consistency in stratigraphic nomenclature and parameter measurement units would make the data base easier to use. Finally, well locations, as currently reported, should be checked for accuracy; discrepancies of up to 4000 ft were discovered between Hanford coordinates and State coordinates when well locations were converted to longitude and latitude for compilation of Site Subsystem data.

TABLE A
Areas of Current Data Base Deficiency

Site Subsystem	Repository Seals Subsystem	Waste Package Subsystem
Directional horizontal hydraulic conductivity Vertical hydraulic conductivity Storage coefficient Effective porosity Dispersivity Diffusion coefficient	Effective porosity Dispersivity Thermal properties Diffusion coefficient	Effective porosity Dispersivity Thermal properties Mechanical properties Diffusion coefficient

1.0 INTRODUCTION

1.1 Background

The National Waste Terminal Storage (NWTS) Program was initiated by the United States in the mid-1970's to investigate the feasibility of storing nuclear waste in deep geologic formations. Initially, several rock types (bedded salt, domal salt, granite, tuff, basalt) were studied on a non-site-specific basis to evaluate their general suitablity for a nuclear waste repository. The 1982 Nuclear Waste Policy Act provided a legislative directive and schedule for site characterization, repository design, licensing by regulatory agencies, construction, and operation of nuclear waste repositories in geologic media.

The Basalt Waste Isolation Project (BWIP) is one of three major research and development projects conducted under the direction of the NWTS Program. Rockwell Hanford Operations (Rockwell) is the prime contractor to the U.S. Department of Energy (DOE) for operation of the Hanford Site in south-central Washington State. As such, Rockwell is currently responsible for investigating the feasibility of siting a repository for terminal disposal of nuclear waste in the basalts underlying the Hanford Site. Should feasibility be demonstrated, detailed development and design of the associated facilities and technologies will be required for the permanent isolation of radioactive waste in basalt flows.

Field investigations completed to date at the Hanford Site have focused on the geologic and hydrologic characterization of the Columbia River Basalt Group, a thick accumulation of tholeitic plateau basalts. The accumulations of basalt are notable for their thicknesses, in excess of 1000 m. Individual basalt flows are commonly as thick as 70 m locally, and are laterally continuous over many miles.

During the past 38 years, the Hanford Site has been dedicated to nuclear waste management. The Hanford Site occupies a land area of 1,500 km^2, with the candidate repository site near the western boundary. Studies of the candidate site have identified four horizons that may be suitable as a repository host rock--the Rocky Coulee, Cohassett, McCoy Canyon, and Umtanum flows, at depths in excess of about 900 m in the candidate site area. These horizons were identified for further study based upon relative thickness of flow entablature, lateral continuity, and hydrologic and geologic properties that may enhance radionuclide isolation. Preliminary studies of the geochemical characteristics of these basalt flows suggest that they are amenable to low rates of canister corrosion and radionuclide solubility in groundwater.

1.2 Objective

It is the purpose of this document to provide a single, up-tp-date listing of performance-assessment source data. The aim of assessing long-term performance is to determine whether a nuclear waste repository sited in basalt of the Hanford Site will perform adequately and in conformance with regulatory criteria and standards. A basic objective of Rockwell's performance assessment studies is to assure that a reliable, complete, and accepted data base is assembled for eventual utilization in a licensing assessment of site suitability. The determination of site suitability must be based on predictions of long-term repository performance generated by computer models, which require the quantitative specification of a large number of parameters that characterize the properties of the repository subsystems (Site, Repository Seals, and Waste Package).

The scope of performance assessment activities includes preclosure analysis of safety considerations in support of design, construction, and operation of the repository and analysis of post-closure long-term waste isolation potential subsequent to closure of the operating repository. For both pre- and post-closure analyses, performance assessment is a systematic process that evaluates the repository functions in terms of performance objectives and criteria as specified by the regulatory agencies. Performance assessment activities for a mined geologic repository, to culminate in a probabilistic risk assessment, will be supported by expert judgment in the form of peer review on such topics as the conceptual model of the geohydrology, model validation, scenario definition, and characterization.

The purpose of pre-closure performance assessment is to ensure that repository design and operation comply with radiological and non-radiological safety requirements. Pre-closure safety analysis will evaluate safety requirements as they relate to the construction and operations personnel.

The purpose of post-closure performance assessment is to evaluate the long-term radiological risk to future generations. Long-term waste isolation will be simulated on the computer through the use of mathematical models.

The performance assessment methodology is presently based on a probabilistic approach, which accounts for the uncertainty involved in data collection and interpretation, and a realistic distribution of the various input parameters. A detailed analysis of subsystem performance for the first 10,000 years will be conducted to obtain probabilistic predictions for five performance measures:

- Waste package containment time
- Radionuclide release rates from the waste package
- Groundwater travel times through the site
- Protection of major sources of groundwater for 1,000 years
- Cumulative radionuclide releases to the accessible environment.

It is the intention of this document to achieve the following objectives:

- To satisfy preclosure and postclosure performance assessment models' data needs,
- To provide guidance for data collection and prioritization of data needs,
- To satisfy the BWIP's System Requirements Tree objectives,
- To be consistent with the BWIP's Mission Plan, Environmental Assessment Report, and Site Characterization Plan requirements and standards,
- To comply with the BWIP's Quality Assurance Standards.

As the reference-source data bases grow and improve in quality (by incorporation of planned field testing and analysis activities), a more deterministic modeling approach will be utilized for assessing the performance of the repository subsystems. Table 1-1 shows the applicability of BWIP deterministic and probabilistic codes to the major subsystems.

Quantitative specifications of input parameter values and their associated uncertainties will be refined by means of on-going field testing, laboratory studies, and other research. The acceptance of conclusions (drawn from predictive models) by the public, the scientific community at large, and the regulatory and review agencies depends on the existence of a well-documented performance assessment data base that can be scrutinized and reviewed by the above parties.

TABLE 1-1
Applicability of Computer Codes for Performance Analysis

Computer Code*	Site Subsystem	Repository Seals Subsystem	Waste Package Subsystem
	System Performance Application		
Deterministic			
ADINA		X	X
ADINAT		X	X
MAGNUM 2D	X	X	X
CHAINT	X	X	X
PORFLO	X	X	X
PATH 2D	X	X	X
MAGNUM 3D	X		
PATH 3D	X		
FECTRA	X		
Probabilistic			
CHAINT-MC			X
MAGNUM-MC	X	X	
EPASTAT	X	X	X
REPSTAT	X	X	X
PORSTAT	X		

* Codes are described in Appendix D.

1.3 Guide to Usage

Because modeling of repository performance will proceed by means of allocating the contributions of each of the three major repository subsystems to overall performance achieved, this source-data reference document has accordingly been organized by subsystem.

The report comprises two volumes. Volume 1 consists of eight sections. Section 1 provides a brief introduction to the project and a brief overview of the reference document. Section 2 defines the input parameters applicable to performance assessment models. Section 3 describes testing methodologies which may best be applied to basalt media in the areas of formation hydraulic parameters, geochemical properties, thermal properties, mechanical properties, and fracture properties. Sections 4, 5, and 6 discuss the information collected for site, repository seals, and waste package subsystems with respect to adequacy, applicability, and statistical values of input parameters for performance assessment models. Section 7 describes the quality assurance program, and Section 8 contains observations on how the data base might be improved.

The compilation of performance assessment parameters is found in Volume 2, in Appendices A (Site Subsystem), B (Repository Seals Subsystem), and C (Waste Package Subsystem). The source-data summaries (value ranges, mean values, standard deviations) reflect all available pertinent field measurements, laboratory data, and assumptions or theoretical considerations upon which the listings are based.

Appendix D describes the probabilistic and deterministic BWIP performance assessment computer codes. Appendix E is a complete listing of all documents received from Rockwell by In-Situ Inc. Appendices F and G contain the credentials and comments of a panel of five peer reviewers (see below). At the submittal of this draft report, no peer reviewer comments were incorporated.

The method of approach of this investigative effort is summarized in the flow diagram of Figure 1-1. Technical verification and the quality assurance program is satisfied for each major deliverable effort.

This performance assessment source-data document has been reviewed by Rockwell Hanford Operations performance assessment staff members of various technical disciplines. As a further check on the quality and credibility of this document, a panel of five expert peer reviewers was selected to

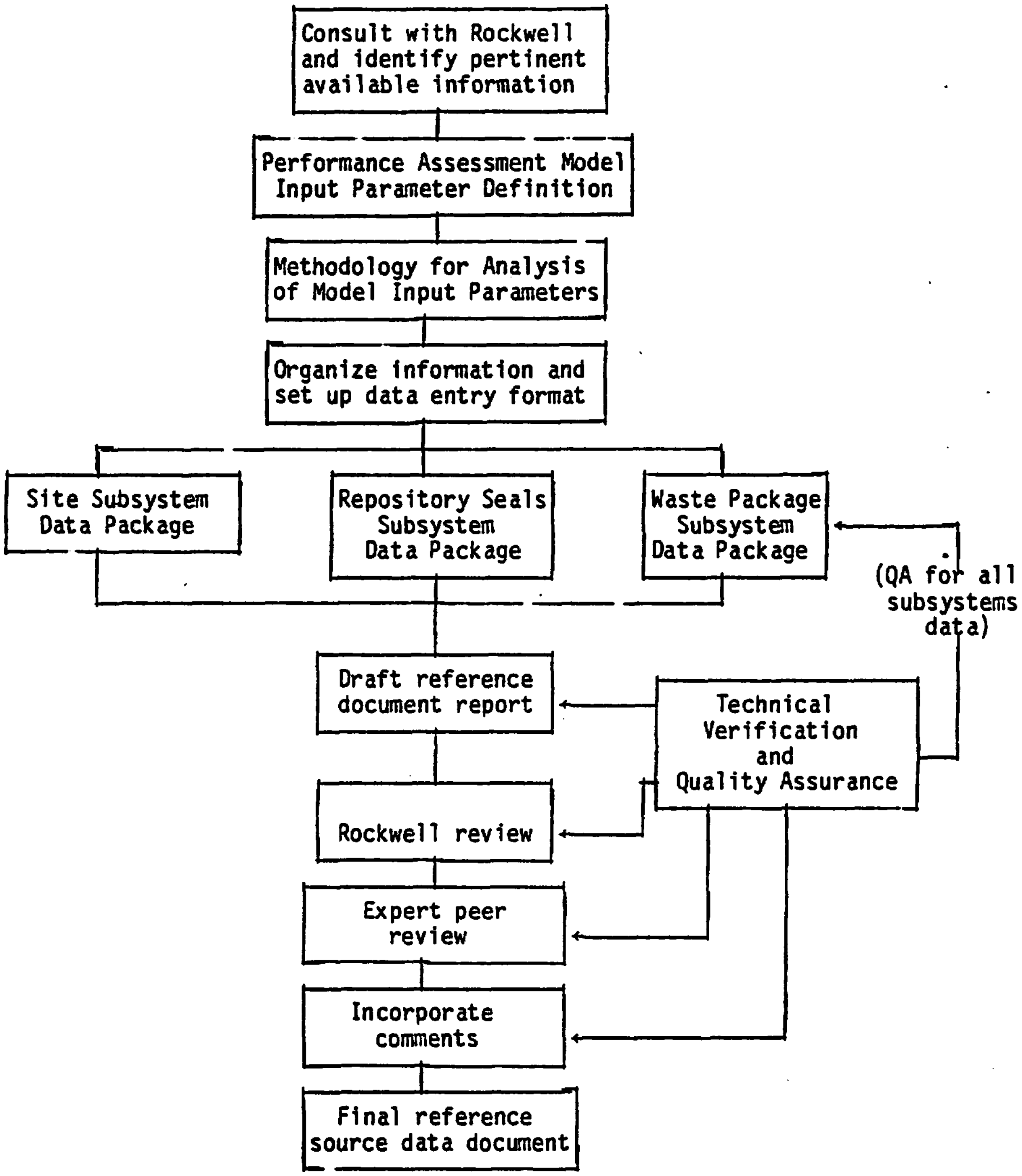

FIGURE 1-1
Project Approach

review it from the point of view of their respective areas of technical expertise. The selected peer reviewers are:

Name	Position	Organization	Expertise
Dr. James I. Drever	Professor	Univ. of Wyoming Laramie, WY	Geochemistry
Dr. Charles Fairhurst	Professor	Univ. of Minnesota Minneapolis	Rock Mechanics
Dr. Lynn W. Gelhar	Professor	Mass. Institute of Technology Cambridge, MA	Geohydrology
Dr. Jay Lehr	Executive Director	National Water Well Association Columbus, OH	Geohydrology
Dr. Stavros Papadopulos	President	S. S. Papadopulos & Associates, Inc. Rockville, MD	Geohydrology

At the completion of this draft report, there was no peer review activity. The peer review is planned to occur after this document is presented to the BWIP-NRC performance assessment workshop (early November 1984).

2.0 DEFINITIONS OF TERMS

2.1 Introduction

This section defines the source data input parameters for performance assessment studies. Table 2-1 presents a list of performance assessment modeling input parameters by subsystem. Section 2.2 defines parameters and related items, arranged alphabetically; Section 2.3 presents parameter units and sources of definitions; Section 2.4 lists the references used in compiling the definitions.

2.2 Definitions

ADSORPTION COEFFICIENT: see DISTRIBUTION COEFFICIENT.

BRAZILIAN TENSILE STRENGTH: see TENSILE STRENGTH.

BULK DENSITY: The mass of a unit bulk volume of geological medium.

COEFFICIENT OF VOLUME COMPRESSIBILITY: The decrease in volumetric strain per unit increase of pressure. It normally decreases with increasing stress.

COMPRESSIONAL WAVE, COMPRESSIONAL WAVE VELOCITY: A compressional wave is a traveling disturbance in an elastic medium characterized by volume changes (and hence density changes) and by partial motion in line with the direction of wave propagation. The velocity with which such a wave travels is the compressional wave velocity.

COMPRESSIVE STRENGTH: see TRIAXIAL COMPRESSIVE STRENGTH and UNIAXIAL COMPRESSIVE STRENGTH.

CORROSION RATE: The loss of weight or thickness of a corroding metal or alloy in a unit time period. Corrosion rate may also be expressed as the maximum or average depth of penetration from the surface of the corroding material in a unit time period.

DIFFUSION COEFFICIENT (D): A constant of proportionality representing the flux of diffusing ions or molecules per unit concentration gradient. Diffusion in solutions is a process in which ions or molecules move randomly from regions of higher concentration to regions of lower concentration.

TABLE 2-1
Performance Assessment Modeling Input Parameters, by Subsystem

Site Subsystem	Repository Seals Subsystem	Waste Package Subsystem
Hydraulic Conductivity	Hydraulic Conductivity	Waste Form
Vertical Hydraulic Conductivity	Effective Porosity	Radionuclide Half-Lives
Storage Coefficient	Bulk Density	Specific Activities
Effective Porosity	Dispersivities	Decay Heat Factors
Thickness	Geometry and Dimensions	Radionuclide Solubilities
Bulk Density	Thermal Properties	Radionuclide Inventory
Dispersivities	Diffusivity	Geometry and Dimensions
Thermal Properties	Conductivity	
Diffusivity	Specific Heat	Canister
Conductivity	Expansion Coefficient	Canister Lifetime
Specific Heat	Diffusion Coefficient	Corrosion Rate
Expansion Coefficient	Distribution Coefficient	Density
Mechanical Properties		Thermal Properties
Young's Modulus		Diffusivity
Poisson's Ratio		Conductivity
Uniaxial Compressive Strength		Specific Heat
Triaxial Compressive Strength		Expansion Coefficient
Compressional Wave Velocity		Geometry and Dimensions
Shear Wave Velocity		
Tensile Strength		Packing Material
Fracture Properties		Hydraulic Conductivity
Vertical Stress		Effective Porosity
Maximum Horizontal Stress		Bulk Density
Minimum Horizontal Stress		Dispersivity
Orientation		Thermal Properties
Density		Diffusivity
Aperture		Conductivity
Diffusion Coefficent		Specific Heat
Distribution Coefficient		Expansion Coefficient
Initial Conditions		Diffusion Coefficient
Hydraulic Head		Distribution Coefficient
Temperature		

DISPERSION COEFFICIENTS (D_L and D_T): As flow takes place in porous media, the solute (adsorbing as well as nonadsorbing) gradually spreads and occupies an ever increasing portion of the flow domain, beyond the region it is expected to occupy according to the average flow alone. The spreading phenomenon is called dispersion. This spreading and mixing is caused in part by molecular diffusion and microscopic variation in velocity within an individual pore.

The equation for dispersion in homogeneous and isotropic media for the two-dimensional case has the form

$$\frac{\partial c}{\partial t} = D_L \frac{\partial^2 c}{\partial x^2} + D_T \frac{\partial^2 c}{\partial y^2} - v \frac{\partial c}{\partial x},$$

where c is the relative tracer concentration, D_L and D_T are longitudinal and transverse dispersion coefficients, v is fluid velocity, x is the coordinate in the direction of flow, y is the coordinate normal to flow, and t is time.

D_L and D_T are constant parameters determined experimentally. They represent the tendency of the solute particle to spread relative to the direction of flow and normal to it.

DISPERSIVITIES: see DISPERSION COEFFICIENTS.

DISTRIBUTION COEFFICIENT (K_d): In solute transport involving adsorption/desorption processes, the distribution coefficient is the ratio of mass of solute per unit mass of solid phase to the mass of solute in solution per unit mass of solution. The distribution coefficient depends on several factors, including the solute species and the nature of the porous medium. The distribution coefficient is determined experimentally for specific conditions for each species.

EFFECTIVE POROSITY: The ratio of interconnected pore space available for fluid flow to the total volume. The dead-end pores and the portion of the pores in which fluid is immobile due to large surface tension effects are not considered in determining effective porosity.

EFFECTIVE STRESS (σ_e), TOTAL STRESS (σ), and PORE PRESSURE (p): The stress carried by the formation skeleton is called the effective stress, σ_e, and the stress carried by the pore water is called the pore pressure, p. The total stress is the sum of the effective stress and the pore pressure.

FRACTURE PROPERTIES:

Stresses: In reservoir conditions, an elementary rock volume is in a state of stress provoked by overburden (geostatic) pressure, confining pressure, and fluid (pore) pressure. Tectonic forces are an additional stress. These stresses are usually represented by three normal vectors designated as the principal stresses. The vertical stress is typically the overburden pressure due to the overlying rock, while the horizontal stresses (maximum and minimum) may act as compressional or tensional stresses.

Fracture aperture is the distance between the fracture walls.

Fracture density is the number of fractures in the rock per unit volume, area, or length of the rock. If the ratio refers to the bulk volume, the fracture density is called "volumetric fracture density"; if the ratio refers to an area or to a length, the fracture density is called "areal" or "linear fracture density."

Fracture orientation is the direction of a fracture plane relative to a specified coordinate system.

HALF-LIFE ($t_{1/2}$): The half-life of a radionuclide is the time at which the number of radioactive atoms remaining is one-half the original number.

HYDRAULIC CONDUCTIVITY (K): A medium has a hydraulic conductivity of unit length per unit time if it will transmit in unit time a unit volume of groundwater at the prevailing viscosity through a cross-section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head through unit length of flow.

HYDRAULIC HEAD (h): The potential energy per unit weight of the solution, composed of a gravitational head and a pressure head. For a homogeneous fluid, hydraulic head is measured with a piezometer and is defined as the elevation at which the free fluid (water) surface stands in an open piezometer tube terminating at a given point in the porous medium. The reference level for measuring hydraulic head is arbitrary.

POISSON'S RATIO (ν): The ratio of lateral expansion, ε_x, to axial compression, ε_z, resulting from a uniaxial stress applied to the flat ends of an elastic prismatic cylinder:

$$\nu = -\frac{\varepsilon_x}{\varepsilon_z} .$$

POROSITY (ϕ): Porosity is the ratio of the volume of the interstices (or pore spaces) to the total (gross) volume. Pore spaces are volumes in a rock or soil not occupied by solid matter. See also EFFECTIVE POROSITY.

SHEAR MODULUS (G): If shear stress, τ_{zx}, is applied to an elastic cube, there will be a shear distortion, γ_{zx}, such that

$$G = \frac{\tau_{zx}}{\gamma_{zx}} ,$$

where G is the shear modulus. Shear modulus is related to Young's modulus, E, and Poisson's ratio, ν, by

$$G = \frac{E}{2(1+\nu)} .$$

SHEAR STRENGTH: The shear stress at which a material fails by shear fracturing.

SHEAR WAVE VELOCITY: A shear wave is a body seismic wave advancing by shearing displacements, i.e. displacements (strain) normal to the wave movement. The shear wave velocity is the velocity at which such a wave propagates.

SOLUBILITY: The solubility is the maximum amount of a species (the solute) that can be dissolved in a unit mass (or volume) and composition of solvent at a specified temperature and pressure. The solvent of interest in repository studies is groundwater containing dissolved minerals.

SORPTION COEFFICIENT: see DISTRIBUTION COEFFICIENT.

SPECIFIC ACTIVITY: The rate of decay of atoms by radioactivity, measured in curies.

SPECIFIC HEAT: The specific heat of a substance at a given temperature is the quantity of heat necessary to raise the temperature of a unit mass of substance by unit temperature.

STORAGE COEFFICIENT (S): The storage coefficient or storativity is the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface.

STRESS: see EFFECTIVE STRESS and FRACTURE PROPERTIES.

TENSILE STRENGTH: The maximum tensile stress that a material under nominal conditions can withstand without failing. For soils and rocks, indirect methods are used to obtain tensile strength because of difficulty associated with performing a direct tensile test. The tensile strength obtained using the "Brazilian" test is known as Brazilian tensile strength. The Brazilian method is to compress a cylinder of material across its diameter. Such loading creates a uniaxial tensile stress in the material normal to the compressed diameter, and the cylinder fails when this stress equals the tensile strength of the material.

THERMAL CONDUCTIVITY: The ratio of heat transfer through an area to the temperature gradient, measured normal to the heat flow. Thermal conductivity is a constant for a specific material and depends on chemical composition and physical structure.

THERMAL DIFFUSIVITY: Thermal conductivity divided by the product of specific heat times density. It is an index of the facility with which a material changes temperature.

THERMAL EXPANSION COEFFICIENT: The change in length of a unit length of material in response to a unit change in temperature.

TOTAL POROSITY: see POROSITY.

TOTAL STRESS: see EFFECTIVE STRESS.

TRIAXIAL COMPRESSIVE STRENGTH: The load per unit area (stress) at which a cylindrical specimen of soil or rock fails when compressed uniaxially under a constant confining pressure.

UNIAXIAL COMPRESSIVE STRENGTH: The load per unit area (stress) at which a cylindrical specimen of soil or rock fails in a simple uniaxial compression test. It is also the stress at which material behavior changes from ductile to brittle.

YOUNG'S MODULUS (E): The ratio of uniaxial stress, σ_z, applied to the flat ends of an elastic prismatic cylinder, to the resulting axial strain, ε_z.

2.3 Dimensions and References

Table 2-2 shows the dimensions of the source-data input parameters for performance assessment studies and the sources of the definitions of terms.

TABLE 2-2.
Dimensions and References for Thermal, Mechanical, and Fracture Properties

Term	Dimensions*	Source†
Brazilian Tensile Strength	$ML^{-1}T^{-2}$	Thrush et al., 1968
Bulk Density	ML^{-3}	Mercer et al., 1982
Coefficient of Compressibility	$M^{-1}LT^{2}$	Mercer et al., 1982
Compressional Wave Velocity	LT^{-1}	Thrush et al., 1968
Compressive Strength	$ML^{-1}T^{-2}$	Jaeger and Cook, 1979
Corrosion Rate	MT^{-1} or LT^{-1}	Thrush et al., 1968
Diffusion Coefficient	$L^{2}T^{-1}$	Bird et al., 1960
Dispersion Coefficient	$L^{2}T^{-1}$	Todd, 1980
Distribution Coefficient	$L^{3}M^{-1}$	Mercer et al., 1982
Effective Porosity	Dimensionless	Todd, 1980
Effective Stress	$ML^{-1}T^{-2}$	Mercer et al., 1982
Fracture Stress	$ML^{-1}T^{-2}$	Golf-Racht, 1982
Fracture Aperture	L	Golf-Racht, 1982
Fracture Density	L^{-1}	Golf-Racht, 1982
Fracture Orientation	Degree	Golf-Racht, 1982
Half-Life	T	Mercer et al., 1982
Hydraulic Conductivity	LT^{-1}	Lohman, 1979
Hydraulic Head	L	Mercer et al., 1982
Poisson's Ratio	Dimensionless	Mercer et al., 1982
Shear Modulus	$ML^{-1}T^{-2}$	Mercer et al., 1982
Shear Strength	$ML^{-1}T^{-2}$	Thrush et al., 1968
Shear Wave Velocity	LT^{-1}	Thrush et al., 1968
Solubility	ML^{-3}	Mercer et al., 1982
Specific Activity	T^{-1}	Thrush et al., 1968
Specific Heat	$L^{2}T^{-2}\,{}^{\circ}C^{-2}$	Thrush et al., 1968
Storage Coefficient	Dimensionless	Mercer et al., 1982
Tensile Strength	$ML^{-1}T^{-2}$	Thrush et al., 1968
Thermal Conductivity	$MLT^{-2}\,{}^{\circ}C^{-1}$	Bird et al., 1960
Thermal Diffusivity	$L^{2}T^{-1}$	Thrush et al., 1968
Thermal Expansion Coefficient	${}^{\circ}C^{-1}$	Mercer et al., 1982
Total Stress	$ML^{-1}T^{-2}$	Mercer et al., 1982
Triaxial Compressive Strength	$ML^{-1}T^{-2}$	Jaeger and Cook, 1979
Uniaxial Compressive Strength	$ML^{-1}T^{-2}$	Jaeger and Cook, 1979
Young's Modulus	$ML^{-1}T^{-2}$	Mercer et al., 1982

* M denotes mass, L denotes length, T denotes time, °C denotes temperature.

† Refer to references cited in section 2.4.

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3.0 METHODOLOGIES FOR PARAMETER TESTING AND ANALYSIS

3.1 Introduction

This section contains brief descriptions of the testing methodologies for determination of formation hydraulic parameters, geochemical properties, thermal properties, mechanical properties, and fracture characteristics. Its purpose is not to provide a complete listing of methods, or to describe them in detail. Rather, it is intended to serve as an overview of testing methods which, because of their suitability to the basalt and interbed environment, have been used in the literature surveyed.

3.2 Hydraulic Parameter Tests

Hydraulic parameters include three-dimensional hydraulic conductivity, storage coefficient, dispersivities, and effective porosity. (See Section 2.2, above, for brief definitions of these terms).

Hydraulic parameter values are determined by means of two types of tests: single-well tests and multi-well tests. In general, single-well tests are more economical because they involve less drilling expense and require shorter test durations. Test duration is a significant factor in testing Columbia River basalts due to their typically wide variability in hydraulic conductivities. The lower the hydraulic conductivity, the longer the test required to achieve meaningful results. Single-well methods permit determination of hydraulic conductivity, well efficiency, and storage coefficient in some cases.

Multi-well tests are more expensive and require longer test durations; however, they yield more precise information in many cases, in addition to permitting the testing of a larger areal extent of the formation than do single-well tests. Moreover, multi-well tests are necessary to determine leakage from adjacent formations, boundary effects, and horizontal directional properties in anisotropic formations.

The anisotropic nature or directional permeabilities of basalt flow tops and interbeds has been documented by Davis (1969). The potential hydraulic discontinuities and directional permeabilities are important input parameters to radionuclide transport performance assessment studies.

The highly variable hydraulic properties of basalts impose certain constraints on standard methods of formation testing and data analysis.

The hydrologic constraints can be divided into two broad groups. The first group consists of factors (such as change in pressure and flow rate) which affect only measurement accuracy and instrumentation design and have no effect on test duration and radius of influence. The second group (hydraulic test conditions such as well spacing, well size, well efficiency, hydraulic conductivity, and well orientation) has a significant effect on test duration, test requirements, radius of influence, and instrumentation design. It is important to understand each of these hydrologic constraints and to know the kind of information to be obtained before a formation test can be prepared, performed, and analyzed properly and professionally. Tests designed and analyzed with these constraints in mind will yield valid results.

Group 1

Change in Pressure. The amount of pressure change is directly proportional to flow rate and has no effect on test duration or radius of influence. If other hydrologic parameters are the same, the well with the highest column of water in it should have the highest productivity. The static water level and pump depth or injection horizon will determine the maxmium well productivity or injectivity, which is one of the major design factors for formation testing.

Flow Rate. A well's flow rate (pumping rate or injection rate) has little or no effect on its radius of influence or on test duration. A higher flow rate results in greater change in pressure and better measurement accuracy. Most analytical solutions for formation test analysis require a constant flow rate to yield accurate values. Keeping flow constant during testing, therefore, is crucial to obtaining good results.

Group 2

Well Spacing. This is one of the most critical determining factors for the duration of a well test. In any of the methods, the test duration required to obtain a unique value for hydraulic conductivity is proportional to the square of the distance between the pumping or injection well and the observation wells (large spacing for flow tops and permeable interbeds; small spacing for relatively impermeable zones).

Well Size. Well size has the same impact on test duration as spacing. In other words, the test duration is proportional to the square of the internal well diameter. Generally, pumped wells require a larger diameter than do injection wells.

Well Efficiency. The wellbore storage effect and well efficiency are significant for single-well tests. Minimizing drilling damage to the formation during well completion is an important consideration in holding testing duration to a reasonable length, particularly for relatively impermeable zones.

Hydraulic Conductivity. The low hydraulic conductivity typical of Columbia River basalt-flow interiors influences well testing procedures. In any method, the test duration required to obtain a unique, reliable value for a parameter is inversely proportional to the hydraulic conductivity of the unit tested.

Well Orientation. Proper well orientation is essential in calculating the horizontal directional hydraulic conductivity. A number of wells are required to find the components of hydraulic conductivity, and the observation wells must lie in different directions from the pumping (or injection) well. Proper well orientation is particularly important in determining hydraulic parameters of highly permeable anisotropic interbeds and flow tops.

A survey of the major petroleum engineering and hydrologic technical journals was conducted to identify recent developments in well testing analysis appropriate for determining hydrologic properties of basalts. Table 3-1 summarizes the applicability of these hydraulic testing methodologies to the Basalt Waste Isolation Project. Theoretically, it makes no difference whether a pump test or an injection test is run. If the well has large available drawdown allowed for pumping, as is generally the case for this project, a pump test should provide accurate results.

For determining the hydraulic conductivity of backfill or packing material in the Repository Seals and Waste Package subsystems, a test utilizing a permeameter (Wood, 1983) may be appropriate.

3.3 Geochemical Parameter Tests

Geochemical parameters of principal concern to this study are related to the distribution coefficients (adsorption coefficients) of pertinent radionuclides.

Adsorption can be determined in the laboratory by batch or column methods (Isherwood, 1979). The major problem in applying laboratory methods to field conditions concerns scaling the effect of particle size and obtaining representative samples. The push-pull test (Bumb, Drever,

TABLE 3-1
Summary of Applicability of Hydraulic Testing and Analysis Methodologies to the Basalt Waste Isolation Project

Aquifer type	Media type[1]	Method	Parameter[2]	Formation type[3]	Test type[4]	Min. well requirement[5]	Comments[6]
Confined	Ho-Is	Agarwal et al. (1970)	k,skin	B,I	Single-well	1	a,f
"	"	Bredehoeft & Papadopulos (1980)	k	B	Slug	1	a,f
"	"	Cooper et al. (1967)	k	B,I	Slug	1	a,f
"	"	Cooper & Jacob (1946)	k,s	B,I	Multi-well	1+1	f
"	"	Jacob & Lohman (1952)	k	B,I	Single-well	1	a,f
"	"	Neuzil (1982)	k	B	Slug	1	a,f
"	"	Papadopulos & Cooper (1967)	k	B,I	Single-well	1	a,f
"	"	Ramey et al. (1975)	k	B,I	Single-well	1	a,f
"	"	Theis (1935)	k,s	B,I	Multi-well	1+1	f
"	"	Van der Kamp (1976)	k	B	Single-well	1	a,f
"	"	Walter & Thompson (1982)	k,s	B	Multi-well	1+1	f
"	Ho-An	Hantush (1966)	k_x,k_y,s	B,I	Multi-well	1+3	f
"	"	Hantush & Thomas (1966)	k_x,k_y,s	B,I	Multi-well	1+3	f
"	"	Neuman et al. (1984)	k_x,k_y,s	B,I	Multi-well	1+2	f
"	"	Papadopulos (1965)	k_x,k_y,s	B,I	Multi-well	1+3	f
"	"	Ramey (1975)	k_x,k_y,s	B,I	Multi-well	1+3	f
"	"	Way & McKee (1982)	k_x,k_y,k_z,s	B,I	Multi-well	1+3	b,f
"	"	Weeks (1969)	k_z	B,I	Multi-well	1+1	b,f
"	He-An	Kamal (1979)	Numerical solution	B,I	Multi-well	Several	g
"	"	Ponzini & Losej (1982)	Inverse problem	B,I	Multi-well	Several	g
Leaky	Ho-Is	Hantush (1956)	k,s,k_a	B,I	Multi-well	1+1	c,f
"	"	Hantush (1959)	k,s,k_a	B,I	Multi-well	1+1	c,d,f
"	"	Neuman & Witherspoon (1972)	k,s,k_a	B,I	Multi-well	1+2	d,e,f
"	Ho-An	Way & McKee (1982)	k_x,k_y,k_z,s,k_a	B,I	Multi-well	1+3	b,c,f

[1] Media type: Ho-Is = Homogeneous-Isotropic
Ho-An = Homogeneous-Anisotropic
He-An = Heterogeneous-Anisotropic

[2] Parameters: k = mean hydraulic conductivity
s = storage coefficient
k_x = maximum horizontal hydraulic conductivity
k_y = minimum horizontal hydraulic conductivity
k_z = vertical hydraulic conductivity
k_a = vertical hydraulic conductivity of the aquitard

[3] Formation type: B = basalts
I = interbeds

[4] Test type: Single well can be pumping or injection
Mulitple wells can be pumping or injection

[5] 1+3 = one pumpirg or injection well and three observation wells

[6] a Storage coefficient cannot be determined accurately.
b One partially penetrating pumping (or injection) well and at least one partially penetrating observation well.
c The source of leakage cannot be distinguished without the aid of geologic information.
d Calculate the vertical hydraulic diffusivity (hydraulic conductivity divided by specific storage) of the aquitard.
e At least one aquitard observation well.
f Assume radial flow, infinite boundary, unsteady state.
g Two dimensional, unsteady state.

and McKee, 1984), which is a simple injection-and-pumping sequence of groundwater spiked with solutes of interest, may be a better way to study adsorption under representative field conditions than batch or column methods.

The same kinds of scaling problems exist in applying laboratory-derived results to field conditions when measuring effective porosity and dispersivity. Field determinations of effective porosity and dispersivity are therefore preferable.

Table 3-2 summarizes methodologies for determining contaminant migration parameters.

TABLE 3-2
Summary of Testing Methodologies for Determination of
Contaminant Migration Parameters

Parameter	Method	Reference
Effective porosity	Tracer test	Gelhar & Callins (1971)
	Pump test	McKee et al. (1984)
Adsorption	Laboratory test	Isherwood (1979)
	Push-pull test	Bumb et al. (1984)
Dispersivity	Tracer test	Gelhar & Collins (1971)
	Push-pull test	Bumb et al. (1984)
	Pump test	Way & McKee (1981)

3.4 Thermal, Mechanical, and Fracture Parameter Tests

Thermal properties consist of thermal diffusivity, thermal conductivity, specific heat, and thermal expansion coefficient.

Mechanical properties are Young's modulus, Poisson's ratio, shear strength, compressive strength (uniaxial and triaxial), tensile strength (and Brazilian tensile strength), compressional wave velocity, shear wave velocity, and total porosity.

Fracture properties include vertical stress, minimum horizontal stress, maximum horizontal stress, orientation, fracture density, and fracture aperture.

See Section 2.2, above, for brief definitions of these terms.

Table 3-3 summarizes standard testing methodologies for thermal, mechanical, and fracture properties which are applicable to each of the subsystem environments.

TABLE 3-3
Summary of Testing Methodologies for Thermal, Mechanical, and Fracture Properties

	Property	Reference
THERMAL	Diffusivity	Bescanon (1956), p. 316 Boley & Weiner (1960), p. 140
	Conductivity	Bescanon (1956), pp. 316, 508, 662 Boley & Weiner (1960), pp. 30, 137
	Specific Heat	Bescanon (1956), pp. 240, 250, 291, 312, 313, 508 Boley & Weiner (1960), pp. 31, 42, 139
	Expansion Coefficient	Bescanon (1956), pp. 244, 314 Boley & Weiner (1960), pp. 30, 37, 244
MECHANICAL	Young's Modulus	ASTM (1979), Part 19, D2845-69 Dreyer (1972), Part I, p. 88 Jaeger & Cook (1979), pp. 78, 110, 185
	Poisson's Ratio	ASTM (1979), Part 19, D2845-69 Dreyer (1972), Part I, p. 185 Jaeger & Cook (1979), pp. 82, 110, 185
	Shear Strength	Jaeger & Cook (1979), p. 398 Vutukuri et al. (1974), Vol I., pp. 141, 144, 147, 154, 166, 231, 243
	Uniaxial Compressive Strength	ASTM (1979), Part 19, D2938-71A Jaeger & Cook (1979), p. 80 Vutukuri et al. (1974), Vol. I, p. 13
	Triaxial Compressive Strength	ASTM (1979), Part 19, D2664-67 Goodman (1980), pp. 55-60 Jaeger & Cook (1979), p. 147 Vutukuri et al. (1974), Vol. I, pp. 105, 176, 183, 189
	Brazilian Tensile Strength	ASTM (1973), C496-71 Jaeger & Cook (1979), pp. 167, 169, 175 Vutukuri et al. (1974), Vol. I, p. 105
	Compressional Wave Velocity	ASTM (1979), Part 19, D2845-69 Jaeger & Cook (1979), pp. 352, 354
	Shear Wave Velocity	ASTM (1979), Part 19, D2845-69 Jaeger & Cook (1979), p. 354
	Total Porosity	Jaeger & Cook (1979), p. 312 Vutukuri et al. (1974), Vol. IV, p. 328
FRACTURE	Vertical Stress	Howard & Fast (1970), pp. 14, 19, 20
	Minimum Horizontal Stress	Howard & Fast (1970), pp. 19, 20
	Maximum Horizontal Stress	Howard & Fast (1970), pp. 19-20
	Fracture Orientation	Howard & Fast (1970), pp. 1, 16, 17, 21, 139, 145
	Fracture Density	Howard & Fast (1970), pp. 32-49 Jaeger & Cook (1979), p. 92
	Fracture Aperture	Vutukuri et al. (1974), Vol. IV, p. 264

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4.0 SITE SUBSYSTEM PARAMETERS

4.1 Introduction

The repository isolation system consists of both engineered and natural barriers to radionuclide migration. From a systems analysis standpoint, it is useful to represent these barriers as three major subsystems: (1) site, (2) repository seals, and (3) waste package. The nature and function of each subsystem and its components have been described in detail elsewhere (Rockwell, 1984). In this section, the site subsystem and the model input parameters characterizing it are briefly reviewed. Data tables of values for these parameters are found in Appendix A (Volume 2) of this report.

4.2 The Site Subsystem*

The "site subsystem" is that natural geologic barrier that extends from the boundaries of the waste package and repository seals subsystem to the accessible environment. (Figure 4-1 depicts a proposed definition of the accessible environment boundary.) The site subsystem consists of: (1) the emplacement horizon (i.e., dense basalt flow interior in which the waste containers are emplaced), (2) the overlying basalt flow top, and (3) the sequence of dense basalt, interbedded sediments, and flow tops along the predominant groundwater flow path(s) to the accessible environment. (See Figure 4-2 for a conceptual model of groundwater flow paths.) The repository could be located in the dense interior of one of four candidate basalt flows: Rocky Coulee, Cohassett, McCoy Canyon, and Umtanum. Figure 4-3 shows the stratigraphy of the Pasco Basin underlying the reference repository location.

After closure of the repository, potential radionuclide flow paths from the emplacement horizon to the accessible environment must traverse two distinct hydrologic zones. The first zone is the thermally affected area around the repository. In this zone, water flow paths and travel times are controlled by a combination of natural hydraulic gradients and buoyancy forces induced by heat generated by the waste. This thermally influenced zone may extend several hundred meters vertically and horizontally from the edge of the repository. Groundwater flow in the second hydrologic zone, beyond the thermally affected zone, is controlled only by natural hydraulic gradients.

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* This section is taken from the BWIP's Environmental Assessment report (Rockwell, 1984).

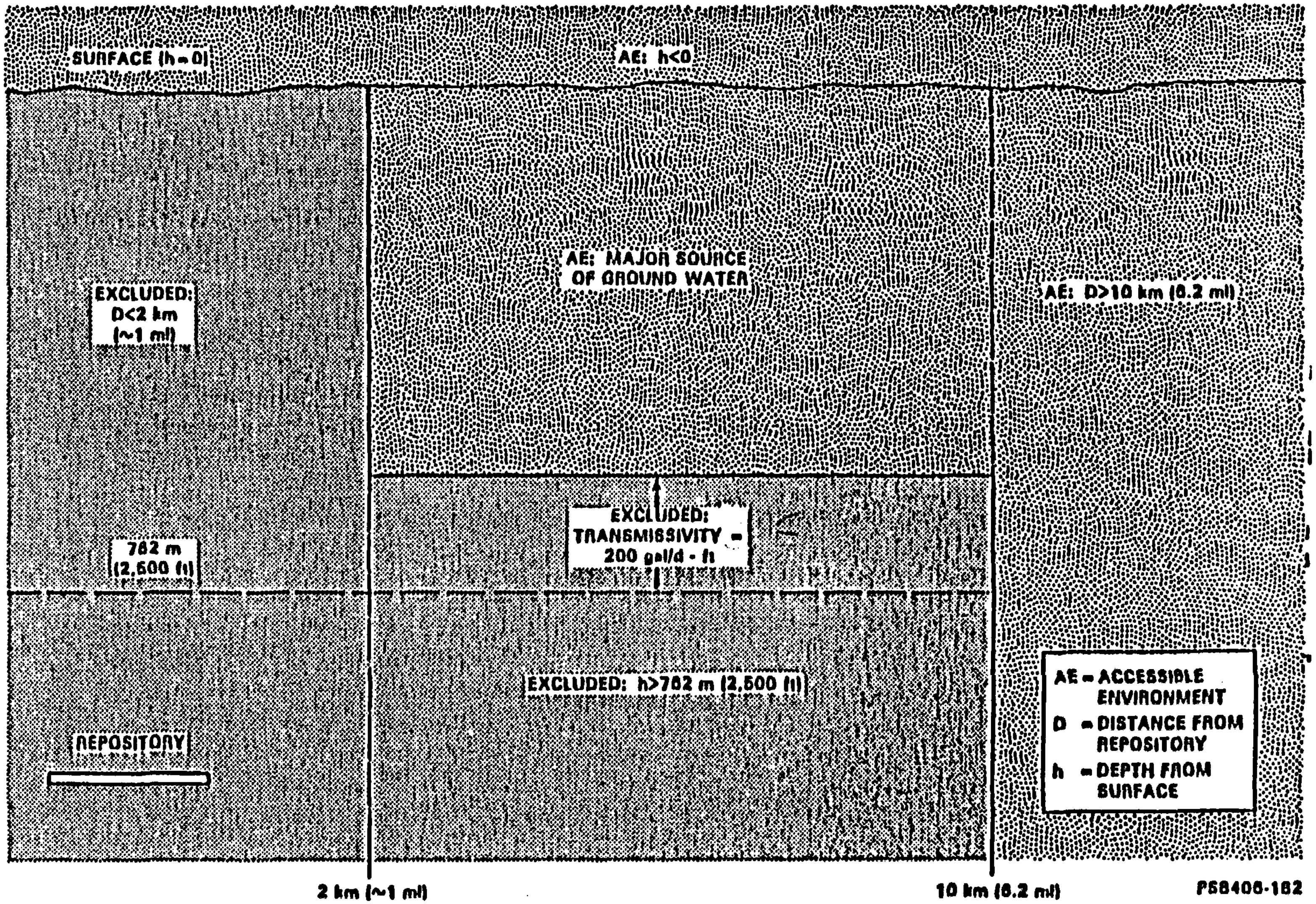

FIGURE 4-1. Proposed definition of accessible environment boundary. From Rockwell (1984).

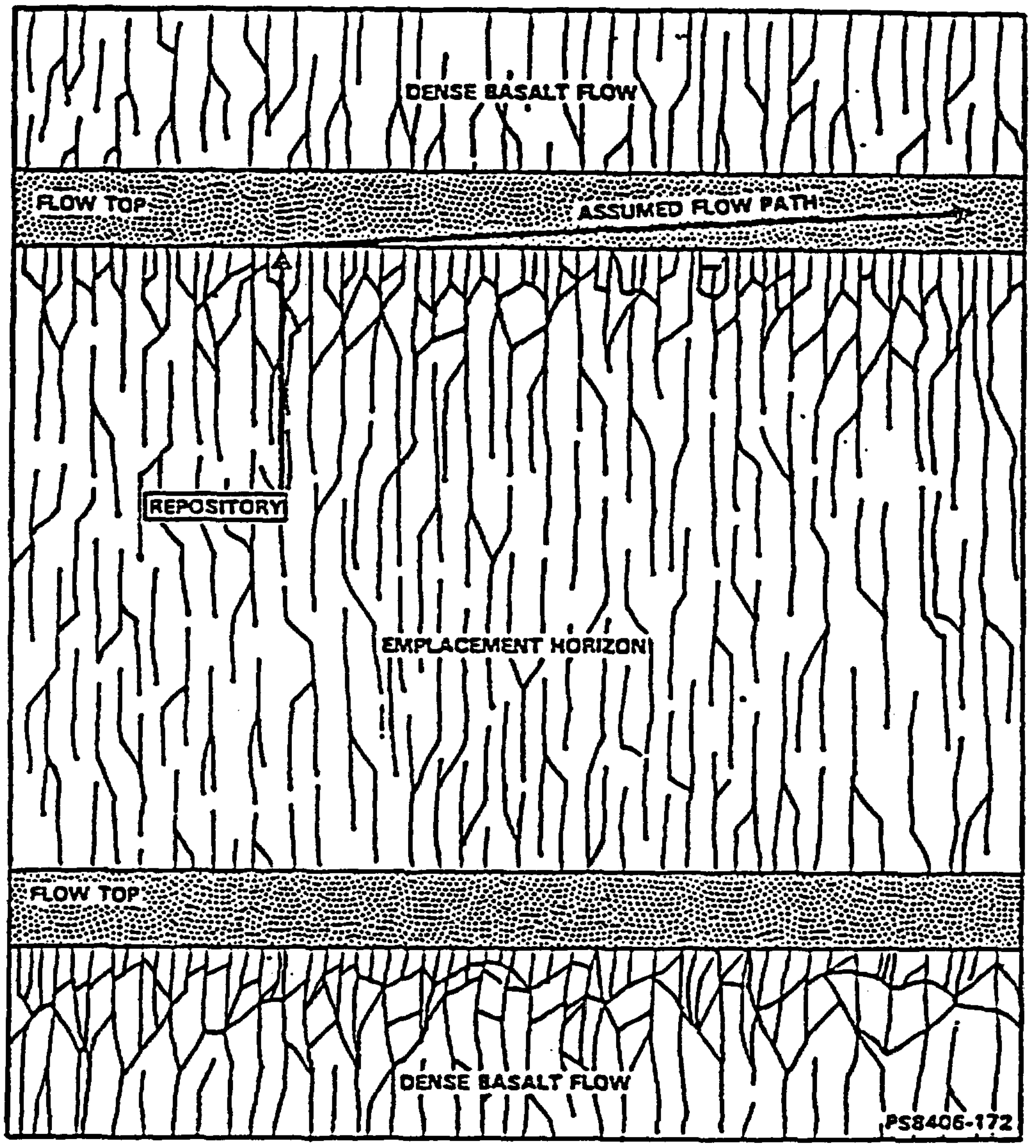

FIGURE 4-2. Conceptual model of groundwater flow paths used in site subsystem performance analysis (no scale). From Rockwell (1984).

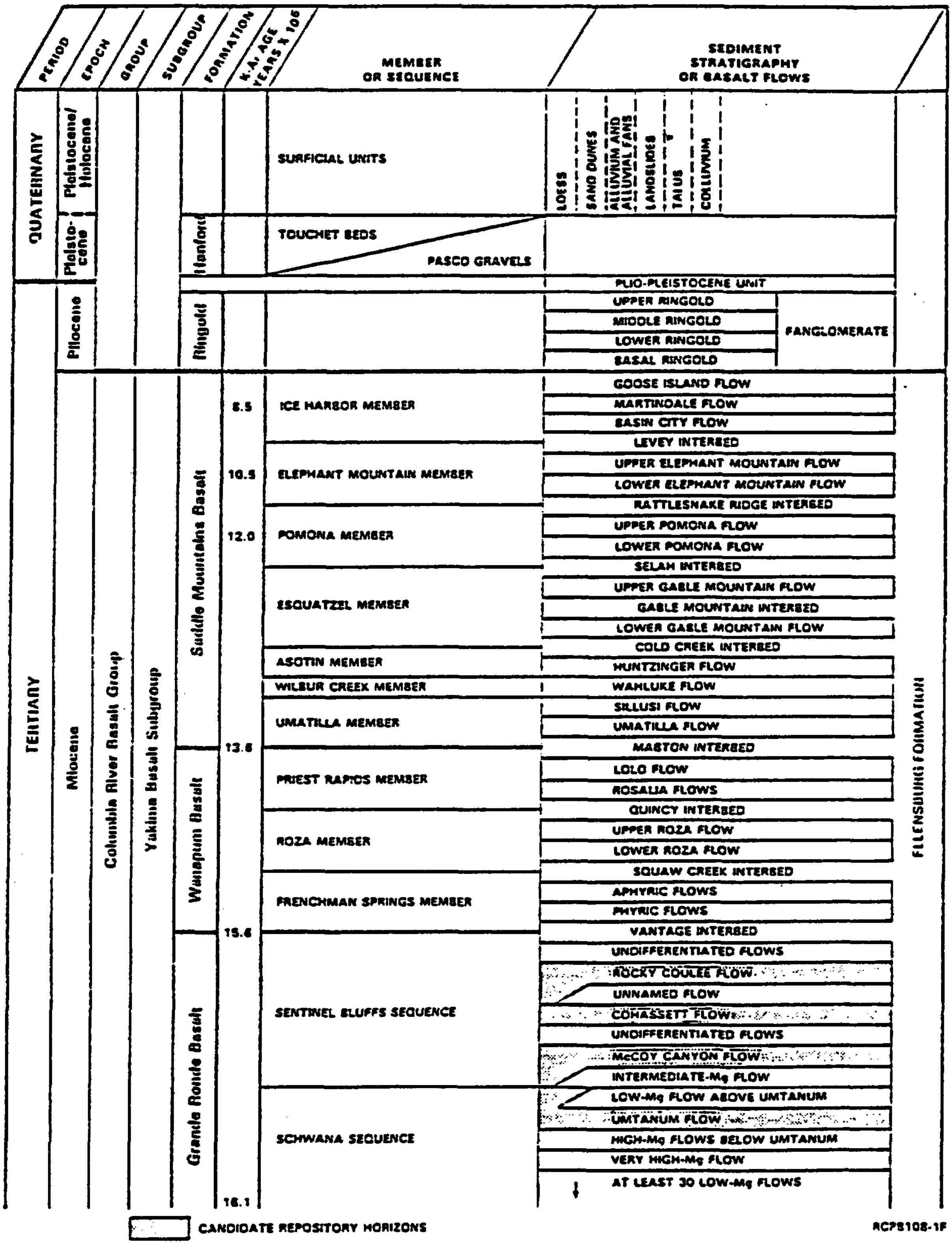

FIGURE 4-3. Stratigraphy of the Pasco Basin.

Potential radionuclide releases to the accessible environment during the time of interest (i.e., a 10,000-year period after closure) are a function of the release rate from the waste package and the rate of radionuclide migration through the site to the accessible environment. Based on current knowledge, the emplacement horizon is expected to contribute significantly to the isolation performance of the overall repository system. The dominant mechanism that could potentially transport radionuclides from the waste package to the accessible environment is groundwater flow within the basalt. For radionuclides that are adsorbed by minerals in the projected flow path, the effective transport velocities are much slower than the groundwater velocity. As a result, for most radionuclides, travel times to the accessible environment are generally much longer than groundwater travel times.

Groundwater travel times through the dense basalt of flow interiors vary because of the variability of rock transport-path properties. Local changes in site subsystem hydraulic properties during the period of peak thermal output from emplaced waste may arise from thermal-induced stresses around the underground facility. The heat may also affect site subsystem performance by changing (increasing or decreasing) the hydraulic conductivity of microfractures in the rock. Geochemical properties, such as host rock alteration rates and radionuclide adsorption, could also change because of the effect of elevated temperature on pH, Eh, and ionic and colloidal properties.

The basalt flow top of the emplacement horizon is a likely lateral groundwater flow path because of the existence of: (1) a slightly upward hydraulic head gradient (natural and thermal-induced) across the emplacement horizon; (2) expected low vertical conductivity of the basalt flow interior above the flow top of the emplacement horizon; and (3) greater hydraulic conductivity of the emplacement horizon flow top relative to that of the emplacement horizon flow interior. (Refer to Figure 4-4 for a representation of the primary structures of a typical basalt flow.)

The sequence of dense basalt flow interiors, interbedded sediments, and relatively porous flow tops surrounding the emplacement flow comprises the remainder of the geologic barrier of the site subsystem. Sources of data uncertainties are similar to those of the emplacement horizon and flow top, but are of decreasing significance to performance predictions as their distance from the repository increases.

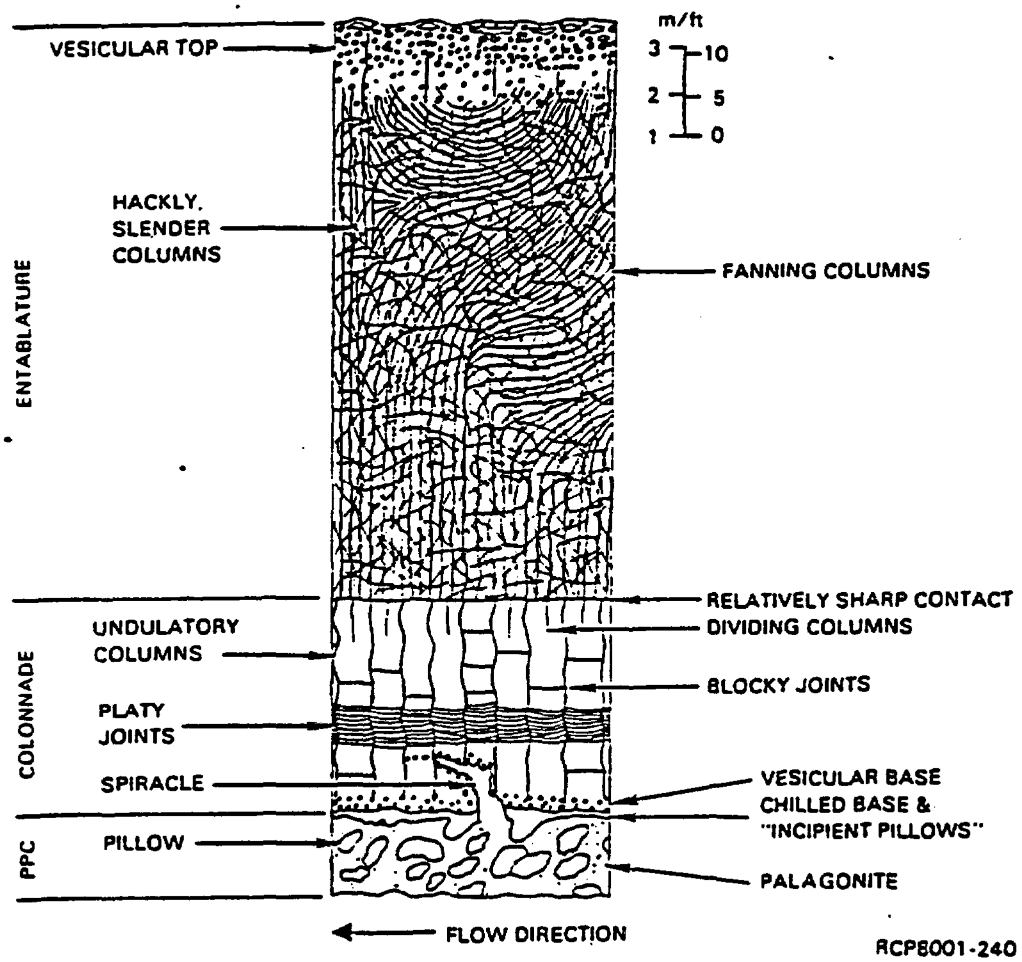

FIGURE 4-4. Primary structures of a typical basalt flow.

4.3 Site Subsystem Parameters

Parameters required for the hydrogeologic characterization of the site subsystem are the following:

- Hydraulic Conductivity
- Vertical Hydraulic Conductivity
- Storage Coefficient
- Effective Porosity
- Thickness
- Bulk Density
- Dispersivities
- Thermal Properties
    - Diffusivity
    - Conductivity
    - Specific Heat
    - Expansion Coefficient
- Mechanical Properties
    - Young's Modulus
    - Poisson's Ratio
    - Uniaxial Compressive Strength
    - Triaxial Compressive Strength
    - Compressional Wave Velocity
    - Shear Wave Velocity
    - Tensile Strength
- Fracture Properties
    - Vertical Stress
    - Maximum Horizontal Stress
    - Minimum Horizontal Stress
    - Orientation
    - Density
    - Aperture
- Diffusion Coefficent
- Distribution Coefficient (Sorption Coefficient)
- Initial Conditions
    - Hydraulic Head
    - Temperature

The performance-assessment source data compiled for the site subsystem are tabulated in Appendix A (Volume 2) of this report. For each parameter listed above, the data are arranged by formation, member, flow, and well where appropriate. In converting well locations to longitude and latitude In-Situ Inc. found discrepancies of as much as 4000 ft between Hanford coordinates and State coordinates. Well locations as currently reported should be checked for accuracy.

References are provided in each data table in Appendix A, citing the source of each value reported. Concise definitions of the parameters are given in Section 2 (Definitions of Terms) of this report. Information about the methodologies for measuring or calculating the various parameters is in Section 3 (Methodologies for Parameter Testing and Analysis) of this report.

Brief remarks on the scope, quality, or significant implications of the data are listed in Table 4-1 for each parameter.

Tables 4-2, 4-3, and 4-4 summarize the data found in Appendix A for the candidate emplacement horizons, for the flow tops of candidate emplacement horizons, and for other basalt flows or sedimentary interbeds. These tables include a ranking (on a scale of 1 to 10) of the relative importance of each parameter to subsystem performance calculations. They also include a rating (on a scale of 1 to 5) of the performance assessment data quality.

The performance assessment data quality/sufficiency definitions are as follows:

1. High confidence data base

   - Sufficient sample size to support high confidence
   - Sample distribution fully representative of area/volume of interest
   - Comprehensive data analysis
   - Confirming measurements

2. Moderate confidence data base and sample size

   - Sample distribution significant over area/volume of interest
   - Comprehensive data analysis

3. Data base sufficient for range or bounding values

   - Limited sample size relative to area or volume of interest
   - Low expected performance sensitivity to parameter range of final quality; demonstration of insensitivity needed

TABLE 4-1
Summary of Parameters Characterizing the Site Subsystem

Parameter	Remarks
Hydraulic Conductivity, Horizontal	Numerous values are reported from tests using 8 methods in about 35 boreholes; test intervals range from the Pomona Member to the Schwana Sequence, and for basalt flow-tops, basalt flow interiors, and sedimentary interbeds. Data show variability both within a horizon and between horizons. Flow tops may be 6-8 orders of magnitude more permeable than flow interiors in some cases. Although directional hydraulic conductivity of flow tops and interbeds may be significant for the Hanford Site, no values were reported.
Hydraulic Conductivity, Vertical	Field data were obtained from only one two-well tracer test. Flow tops and interbeds in some instances are aquifers, with horizontal flow; flow interiors act as confining layers, with vertical flow.
Storage Coefficient	Data from only one multi-well field test were found. (Single-well tests often give unreliable values.)
Effective Porosity	Values were found from only one tracer test, although many tests for apparent porosity and total porosity have been conducted on core samples used to determine mechanical and thermal properties. Effective porosity determined by in-situ tracer tests may vary significantly from these.
Thickness	Thicknesses of the various geohydrologic units and intraflow structures have been determined from data collected from boreholes penetrating them within and without the Hanford Site.
Bulk Density	Numerous laboratory tests conducted on core samples from Hanford Site basalts give values for bulk density for the various geohydrologic units, intraflow structures and interbeds.

Table 4-1 (continued)

Parameter	Remarks
Dispersivities	Only one two-well tracer test was found.
Thermal Properties	Thermal property tests have been conducted on basalt samples from a variety of flows and horizons at the Hanford Site.
Mechanical Properties	Mechanical property tests on numerous intact core samples from the various basalt flows and major structural units found in each flow give values for the various mechanical properties contributing to the understanding of observed in-situ rock behavior.
Fracture Properties	In-situ state-of-stress tests have been conducted in 3 boreholes over several test intervals.
Diffusion Coefficient	The only values found were for HS, H_2, and various heavy anions, with molecular weights of 290 to 30,000, migrating through bentonite.
Distribution Coefficient	Values were found for major radionuclides under a wide range of temperatures, Eh, pH, and groundwater compositions. (See Table 4-5 for the two principal groundwater compositions used in most of the sorption experiments.) Distribution coefficients for secondary minerals are generally greater than for basalts under similar experimental conditions.
Initial Conditions	Hydraulic head measurements from 36 boreholes were found, mostly for flowtops and interbeds. Temperature readings in 15 boreholes at various depths and for virtually all geohydrologic units were found. Fluid temperature generally increases with depth and reflects the local geothermal gradient.

TABLE 4-2

Summary of Properties of Candidate Emplacement Horizons at the Hanford Site

Parameter, unit	Rank*	ROCKY COULEE EMPLACEMENT HORIZON		COHASSETT EMPLACEMENT HORIZON		McCOY CANYON EMPLACEMENT HORIZON		UMTANUM EMPLACEMENT HORIZON	
		Value	Qual.†	Value	Qual.†	Value	Qual.†	Value	Qual.†
Hydraulic Conductivity, m/s	10	5.6E-14 - 1.4E-13	3	1E-16 - 3E-10	3	E-11 - E-9	3	1E-16 - 1E-4	3
Vertical Hyd. Conductivity, m/s	10	< 3.5E-11	4	--	--	--	--	--	--
Storage Coefficient	4	E-5	5	E-5	5	E-5	5	E-5	5
Effective Porosity, %	10	E-2 - 1	5	E-2 - 1	5	--	5	E-2 - 1	5
Thickness, m	8	27.1 - 46.6	2	39.6 - 78.3	2	31.4 - 54.5	2	19.7 - 75	2
Bulk Density, g/cm^3	4	2.71 - 2.81	2	2.64 - 2.89	2	2.55 - 2.88	2	2.73 - 3.01	2
Dispersivity, m									
Longitudinal/Transverse	6	30/18	5	30/18	5	30/18	5	30/18	5
Thermal Properties									
Diffusivity, m^2/s	9	0.6E-6	5	0.6E-6	5	0.6E-6	5	0.33E-6 -0.80E-6	3
Conductivity, W/m·°K	9	1.5	5	1.32 - 1.74	3	1.5	5	0.84 - 2.46	3
Specific Heat, kJ/kg·°K	9	0.9	5	0.80 - 1.0	3	0.9	5	0.80 - 1.0	3
Expansion Coefficient, /°K	9	6E-6	5	5.7E-6 - 6.3E-6	3	6E-6	5	6E-6 - 1.2E-5	3
Fracture Properties									
Vertical Stress, MPa	8	23	5	23.1	3	24	5	27.6 - 38	3
Max. Horiz. Stress, MPa	8	57	5	53 - 63	3	58	5	54 - 68	3
Min. Horiz. Stress, MPa	8	35	5	30 - 37	3	36	5	32 - 39	3
Orientation	8	--	--	N3°W	4	--	--	N15°E	4
Density, fractures/m	8	2 - 25	3	0 - 27	3	1 - 21	3	0 - 29	3
Aperture, mm	8	0.07 - 0.29	3	0 - 0.45	3	0 - 0.61	3	0 - 0.27	3
Mechanical Properties									
Young's Modulus, MPa	5	75,800 - 94,900	2	51,800 - 86,000	2	32,900 - 84,300	2	20,000 - 102,000	2
Poisson's Ratio	5	0.21 - 0.29	2	0.15 - 0.31	2	0.13 - 0.31	2	0.17 - 0.29	2
Uniaxial Comp. Strength, MPa	5	170 - 380	2	70 - 408	2	84 - 404	2	18 - 871	2
Triaxial Comp. Strength, MPa	5	350	5	350	5	350	5	81 - 671	4
Compress. Wave Velocity, m/s	5	6,000	5	6,000	5	6,000	5	5,360 - 6,430	4
Shear Wave Velocity, m/s	5	3,400	5	3,400	5	3,400	5	3,080 - 3,900	4
Tensile Strength, MPa	5	9 - 11.6	2	6.3 - 20.6	2	7.2 - 26.8	2	1.4 - 28.9	2
Diffusion Coefficient, m^2/s	7	--	--	--	--	--	--	--	--
Distribution Coefficient, ml/g (reducing conditions)	10								
C		0	5	0	5	0	5	0	5
Ni		--	--	--	--	--	--	--	--
Se		15	5	15	5	15	5	15	5
Rb		--	--	--	--	--	--	--	--
Sr		100	5	100	5	100	5	100	5
Zr		100	5	100	5	100	5	100	5
Tc		50	5	50	5	50	5	50	5
Pd		100	5	100	5	100	5	100	5
Cd		--	--	--	--	--	--	--	--
Sn		--	--	--	--	--	--	--	--
I		0	5	0	5	0	5	0	5
Cs		200	5	200	5	200	5	200	5
Sm		100	5	100	5	100	5	100	5
Sb		--	--	--	--	--	--	--	--
Eu		--	--	--	--	--	--	--	--
Ho		--	--	--	--	--	--	--	--
Pb		100	5	100	5	100	5	100	5
Ra		100	5	100	5	100	5	100	5
Ac		100	5	100	5	100	5	100	5
Th		100	5	100	5	100	5	100	5
Pa		100	5	100	5	100	5	100	5
U		50	5	50	5	50	5	17 - 170	3
Np		100	5	100	5	100	5	10 - 1015	3
Pu		200	5	200	5	200	5	150 - 2000	3
Am		100	5	100	5	100	5	100	5
Cm		100	5	100	5	100	5	100	5
INITIAL CONDITIONS									
Hydraulic Head, m > msl	6	--	--	--	--	--	--	--	--
Temperature, °C	4	--	--	--	--	--	--	--	--

* Relative importance to subsystem performance calculation (increasing from 1 to 10).

† Performance assessment data quality definitions: 1 = high confidence data base.
2 = moderate confidence data base and sample size.
3 = data base sufficient for bounding value or range.
4 = limited confidence data base.
5 = literature values.

TABLE 4-3
Summary of Properties of Flow Tops at the Hanford Site

Parameter, unit	Rank*	ROCKY COULEE FLOW TOPS		COHASSETT FLOW TOPS		McCOY CANYON FLOW TOPS		UMTANUM FLOW TOPS	
		Value	Qual.†	Value	Qual.†	Value	Qual.†	Value	Qual.†
Hydraulic Conductivity, m/s	10	1E-7 - 1E-5	3	3.5E-12 - 3.5E-5	3	6.4E-11 - E-8	3	3.5E-9 - E-5	3
Storage Coefficient	4	E-5	5	E-5	5	E-5	5	E-5	5
Effective Porosity, %	10	E-2 - 1	5	E-2 - 1	5	E-4 - E-2	3	E-2 - 1	5
Thickness, m	5	5.2 - 24.7	3	5.2 - 25.6	3	6.4 - 20.1	3	4.9 - 32.9	3
Bulk Density, g/cm^3	4	2.2	5	1.92 - 2.47	3	1.88 - 2.42	3	1.79 - 2.84	3
Dispersivity, m									
Longitudinal/Transverse	6	0.8	5	0.8	5	0.8	4	0.8	5
Thermal Properties									
Diffusivity, m^2/s	4	0.6E-6	5	0.6E-6	5	0.6E-6	5	0.6E-6	5
Conductivity, W/m·°K	4	1.5	5	1.5	5	1.5	5	1.5	5
Specific Heat, kJ/kg·°K	4	0.9	5	0.9	5	0.9	5	0.9	5
Expansion Coefficient, /°K	4	6E-6	5	6E-6	5	6E-6	5	6E-6	5
Fracture Properties									
Vertical Stress, MPa	--	23	5	23	5	24	5	26	5
Max. Horiz. Stress, MPa	--	57	5	57	5	58	5	60	5
Min. Horiz. Stress, MPa	--	35	5	35	5	36	5	36	5
Orientation	--	--	--	--	--	--	--	--	--
Density, fractures/m	--	20	5	20	5	20	5	20	5
Aperture, mm	--	0.1	5	0.1	5	0.1	5	0.1	5
Mechanical Properties									
Young's Modulus, MPa	--	30,000	5	28,400 - 64,000	2	14,000-75,700	2	11,500 - 50,000	2
Poisson's Ratio	--	0.26	5	0.13 - 0.33	2	0.16 - 0.38	2	0.11 - 0.32	2
Uniaxial Comp. Strength, MPa	--	60	5	19 - 98	2	38	2	14 - 202	2
Triaxial Comp. Strength, MPa	--	350	5	350	5	350	5	350	5
Compress. Wave Velocity, m/s	--	6,000	5	6,000	5	6,000	5	6,000	5
Shear Wave Velocity, m/s	--	3,400	5	3,400	5	3,400	5	3,400	5
Tensile Strength, MPa	--	8.0	5	2.65 - 12.1	2	2.7 - 6.3	2	2.2 - 13.7	2
Distribution Coefficient, ml/g (reducing conditions)	10								
C		0	5	0	5	0	5	0	5
Ni		--	--	--	--	--	--	--	--
Se		15	5	15	5	15	5	15	5
Rb		--	--	--	--	--	--	--	--
Sr		100	5	100	5	100	5	100	5
Zr		100	5	100	5	100	5	100	5
Tc		50	5	50	5	50	5	50	5
Pd		100	5	100	5	100	5	100	5
Cd		--	--	--	--	--	--	--	--
Sn		--	--	--	--	--	--	--	--
I		0	5	0	5	0	5	0	5
Cs		200	5	200	5	200	5	200	5
Sm		100	5	100	5	100	5	100	5
Sb		--	--	--	--	--	--	--	--
Eu		--	--	--	--	--	--	--	--
Ho		--	--	--	--	--	--	--	--
Pb		100	5	100	5	100	5	100	5
Ra		100	5	100	5	100	5	100	5
Ac		100	5	100	5	100	5	100	5
Th		100	5	100	5	100	5	100	5
Pa		100	5	100	5	100	5	100	5
U		50	5	50	5	50	5	17 - 170	3
Np		100	5	100	5	100	5	10 - 1015	3
Pu		200	5	200	5	200	5	150 - 2000	3
Am		100	5	100	5	100	5	100	5
Cm		100	5	100	5	100	5	100	5
INITIAL CONDITIONS									
Hydraulic Head, m > msl	6	118.5 - 124.0	4	121.6 - 129.0	4	121.9 - 122.5	4	121.7 - 124.4	4
Temperature, °C	2	41.8 - 49.3	3	48 - 52	3	56.1 - 58	3	56.6 - 60	3

* Relative importance to subsystem performance calculation (increasing from 1 to 10).

† Performance assessment data quality definitions: 1 = high confidence data base.
2 = moderate confidence data base and sample size.
3 = data base sufficient for bounding value or range.
4 = limited confidence data base.
5 = literature values.

TABLE 4-4
Summary of Properties of Wanapum and Saddle Mountains Basalts and Sedimentary Interbeds

Parameter, unit	WANAPUM BASALT		SADDLE MOUNTAINS BASALT		INTERBEDS	
	Range	Quality*	Range	Quality*	Range	Quality*
Hydraulic Conductivity, m/s	3E-12 - 3E-2	3	4E-7 - 7E-3	3	3E-10 - 3E-4	3
Vertical Hyd. Conductivity, m/s	--	--	--	--	--	--
Storage Coefficient	1.7E-6 - 1.6E-4	3	--	--	1E-4 - 1E-3	--
Effective Porosity, %	0.1	5	0.1	5	0.1	5
Bulk Density, g/cm^3	2.8	5	2.69 - 2.89	2	2.3	5
Dispersivity m	1	5	1	5	1	5
Thermal Properties						
Diffusivity, m^2/s	6E-5	5	3.9E-5 - 7.9E-5	3	6E-5	5
Conductivity, W/m·°K	1.7	5	0.7 - 3.0	3	1.7	5
Specific Heat, kJ/kg·°K	0.96	5	0.82 - 2.5	3	0.96.	5
Expansion Coefficient, /°K	6E-6	5	2.1E-6 - 1.1E-5	3	6E-6	5
Fracture Properties						
Vertical Stress, MPa	8.3	4	8.3	5	8.3	5
Max. Horiz. Stress MPa	16.5	4	16.5	5	16.5	5
Min. Horiz. Stress, MPa	11.7	4	11.7	5	11.7	5
Orientation	N20°E	4	--	--	--	--
Density, fractures/m	--	--	--	--	--	--
Aperture, mm	--	--	--	--	--	--
Mechanical Properties						
Young's Modulus, MPa	80,000	5	52,500 - 112,000	2	80,000	5
Poisson's Ratio	0.24	5	0.018 - 0.33	2	0.24	5
Uniaxial Comp. Strength, MPa	250	5	4 - 525	2	250	5
Triaxial Comp. Strength, MPa	300	5	67 - 575	2	300	5
Compress. Wave Velocity, m/s	5700	5	4910 - 6370	2	5700	5
Shear Wave Velocity, m/s	3400	5	2950 - 3630	2	3400	5
Tensile Strength, MPa	15	5	0.43 - 29	3	15	5
Diffusion Coefficient, m^2/s	--	--	--	--	--	--
Distribution Coefficient, ml/g (reducing conditions)						
C	0	5	0	5	0	5
Ni	--	--	--	--	--	--
Se	--	--	5 - 300	3	2	4
Rb	--	--	--	--	--	--
Sr	100	5	100	5	100	5
Zr	100	5	100	5	100	5
Tc	50	5	30 - 1400	3	70	4
Pd	100	5	100	5	100	5
Cd	--	--	--	--	--	--
Sn	--	--	--	--	--	--
I	0	5	0	5	0	5
Cs	200	5	200	5	200	5
Sm	100	5	100	5	100	5
Sb	--	--	--	--	--	--
Eu	--	--	--	--	--	--
Ho	--	--	--	--	--	--
Pb	100	5	100	5	100	5
Ra	100	5	100	5	100	5
Ac	100	5	100	5	100	5
Th	100	5	100	5	100	5
Pa	100	5	100	5	100	5
U	10	5	19 - 300	3	10	5
Np	10	5	1000 - 9000	3	50	4
Pu	100	5	47	4	470	4
Am	100	5	100	5	10,000	4
Cm	100	5	100	5	100	5
Initial Conditions						
Hydraulic Head, m > msl	116.4 - 125	4	--	--	115 - 136.6	4
Temperature, °C	21.5 - 36.0	3	--	--	16.5 - 24.1	3

* Performance assessment data quality definitions: 1 = high confidence data base.
2 = moderate confidence data base and sample size.
3 = data base sufficient for bounding value or range.
4 = limited confidence data base.
5 = literature values.

4. Limited confidence data base

   - Small number of site-specific measurements
   - Limited data analysis
   - Substantial reliance upon engineering judgment for input
   - Low expected performance sensitivity to parameter range of final quality; demonstration of insensitivity needed

5. Literature values

   - Engineering/scientific judgment and expert opinion
   - Used solely for sensitivity and uncertainty analysis purposes unless demonstrated that this quality is sufficient

The assigned data quality/sufficiency scale will provide a basis to prioritize the various data needs and major BWIP performance assessment milestones. It should be noted that the data quality scale will improve with time as more progressive site characterization activities are undertaken. The data quality, prioritization, and milestone development relationship is in accordance with the concepts of the BWIP System Requirement Tree (SRT) for total project activity integration.

In a recent stochastic groundwater travel-time analysis for preliminary performance assessment (Rockwell, 1984), the following sets of representative data were used:

- An assigned uniform distribution of regional hydraulic gradient (0.001 to 0.0001 meters per meter)
- An assigned log-normal distribution of transmissivity for the various basalt flow tops and interbed units, as presented in Figures 4-5, 4-6, and 4-7 (Runchall et al., 1984)
- An assigned uniform distribution of effective porosity of 1.25×10^{-2} to 1.25×10^{-4} for basalt flow tops.

Two other stochastic groundwater travel-time analyses were conducted by fixing effective porosity (0.5%) only, and by fixing both effective porosity (0.5%) and regional hydraulic gradient (0.001 meters per meter). All analyses assumed an average basalt flow-top thickness of 8 meters.

Table 4-5 presents the results of the three cases of groundwater travel-time analysis. The analysis was simulated by a two-dimensional Monte Carlo finite-element flow code (MAGNUM-MC); see Appendix D for a description of the computer code.

TABLE 4-5

Groundwater Travel Time Analysis and Input Parameters (from Rockwell, 1984)

Case	Transmissivity	Regional hydraulic gradient (meters/meter)	Effective porosity	Median travel time (yrs)
1	Log-normal distribution	0.001	5×10^{-3}	17,000
2	Log-normal distribution	0.001-0.0001*	5×10^{-3}	86,000
3	Log-normal distribution	0.001-0.0001*	1.25×10^{-2} to 1.25×10^{-4}*	81,000

* Uniform distribution

References Cited

Rockwell (1984), Performance Assessment section (Chapter 6) of BWIP Environmental Assessment report, draft of 9/4/84.

Runchall, A. K., M. W. Merkhofer, E. Olmstead, and J. D. Davis (1984), Probability Encoding of Hydrologic Parameters by the Delphi Method, Analytic and Computational Research, Inc., draft report for DOE, Aug. 16, 1984.

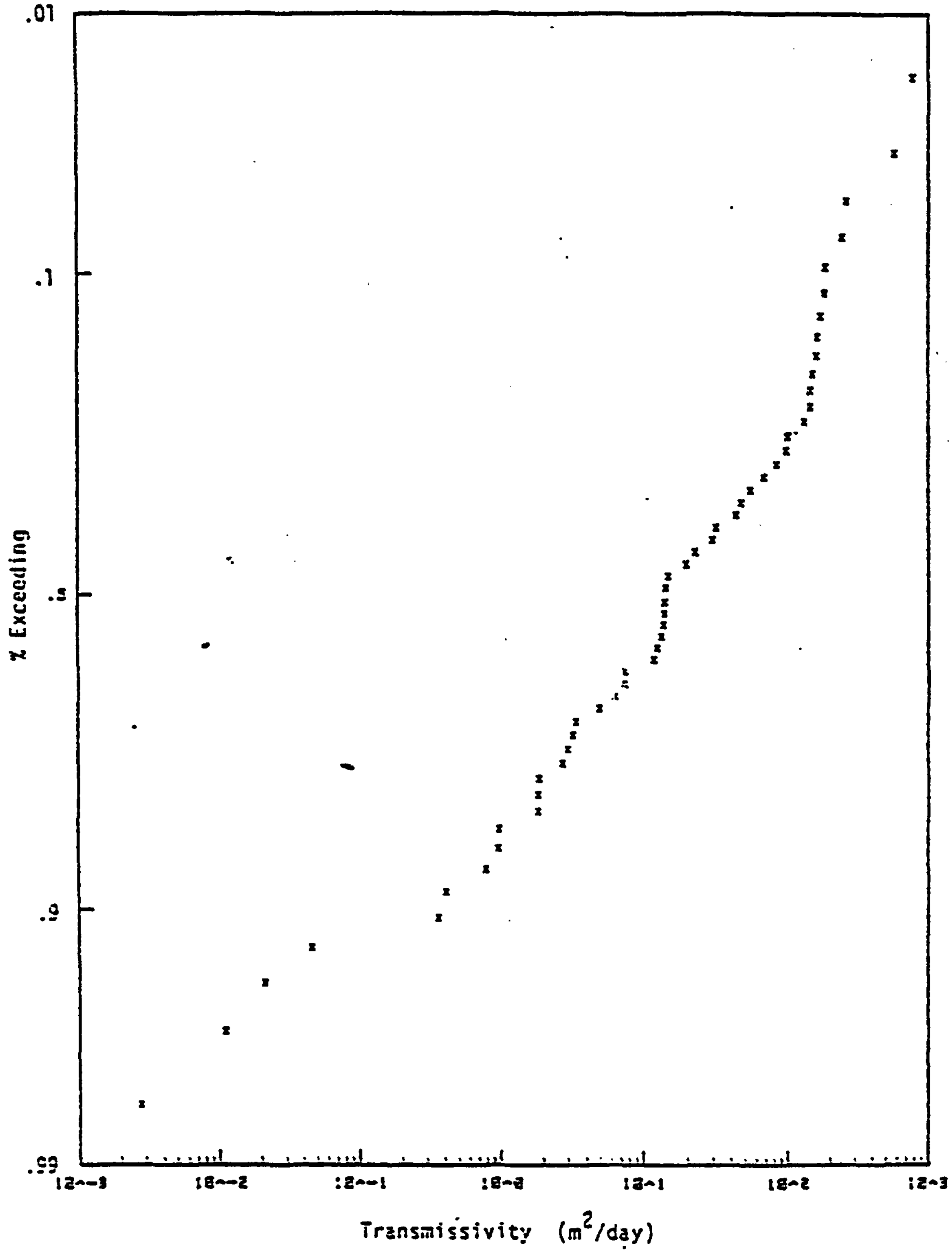

FIGURE 4-5. Log-Normal Probability Plot of Transmissivity Data from Saddle Mountains Basalt Flow Tops and Interbeds (from Runchall et al., 1984).

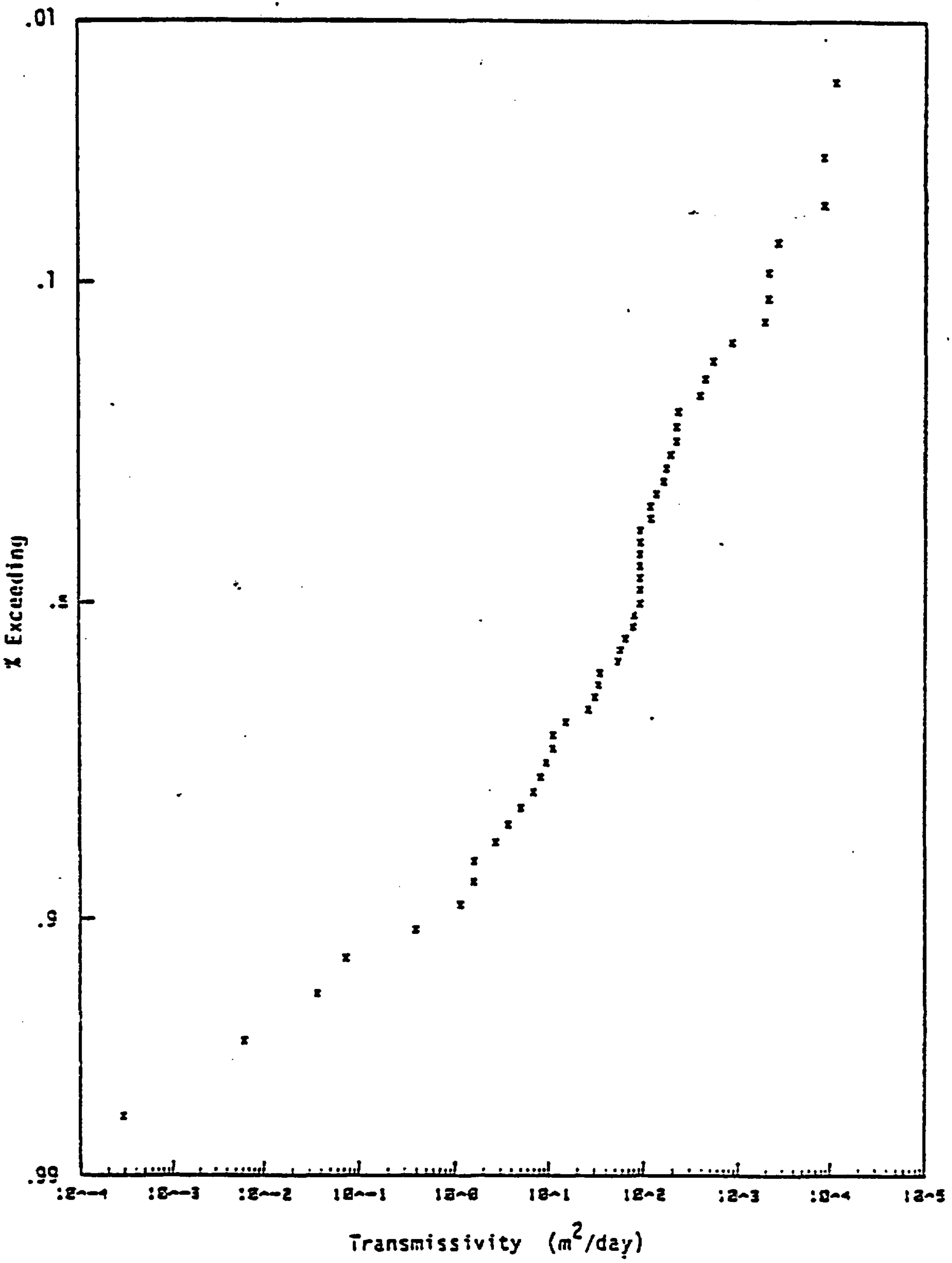

FIGURE 4-6. Log-Normal Probability Plot of Transmissivity Data from Wanapum Basalt Flow Tops (from Runchall et al., 1984).

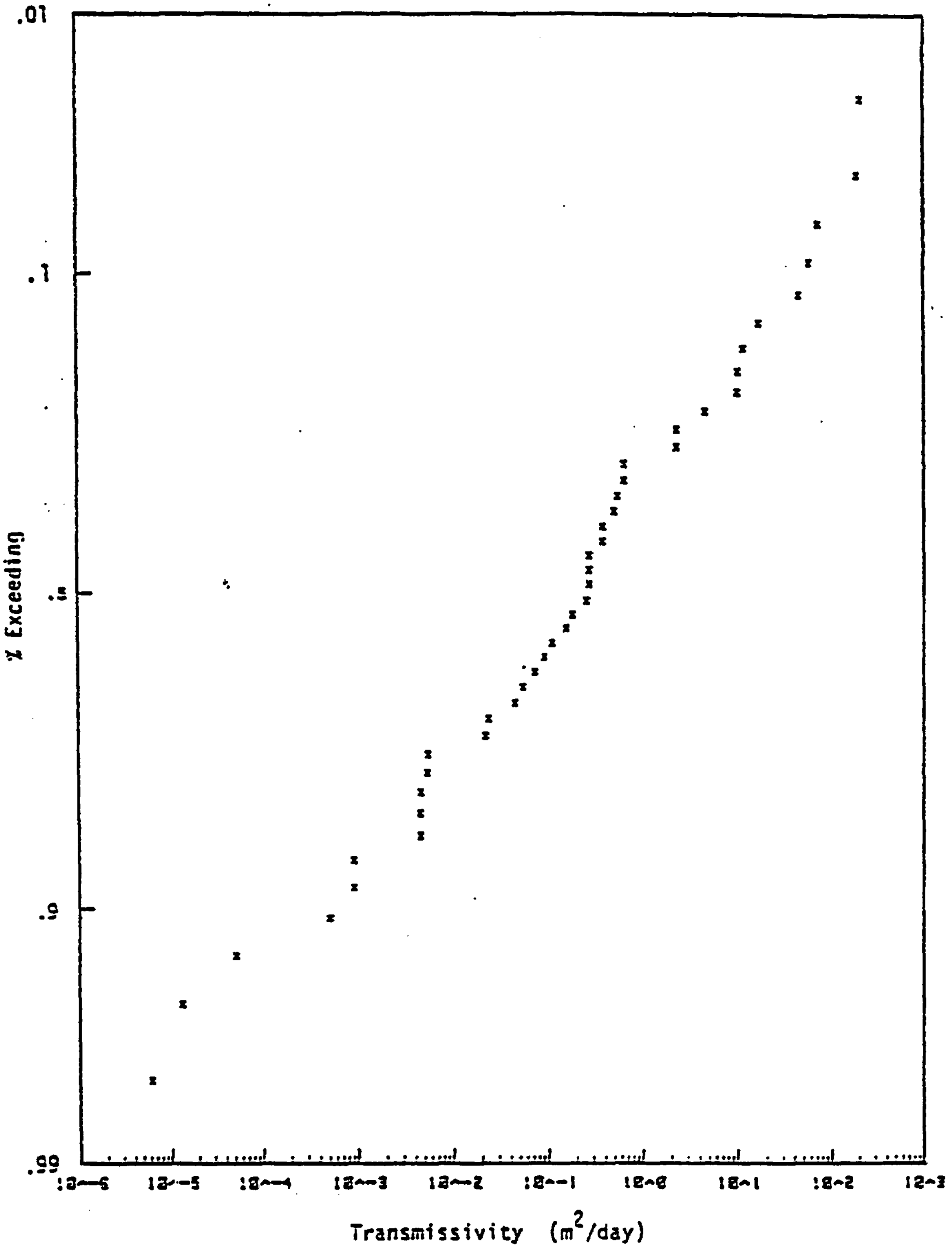

FIGURE 4-7. Log-Normal Probability Plot of Transmissivity Data from Grande Ronde Basalt Flow Tops (from Runchall et al., 1984).

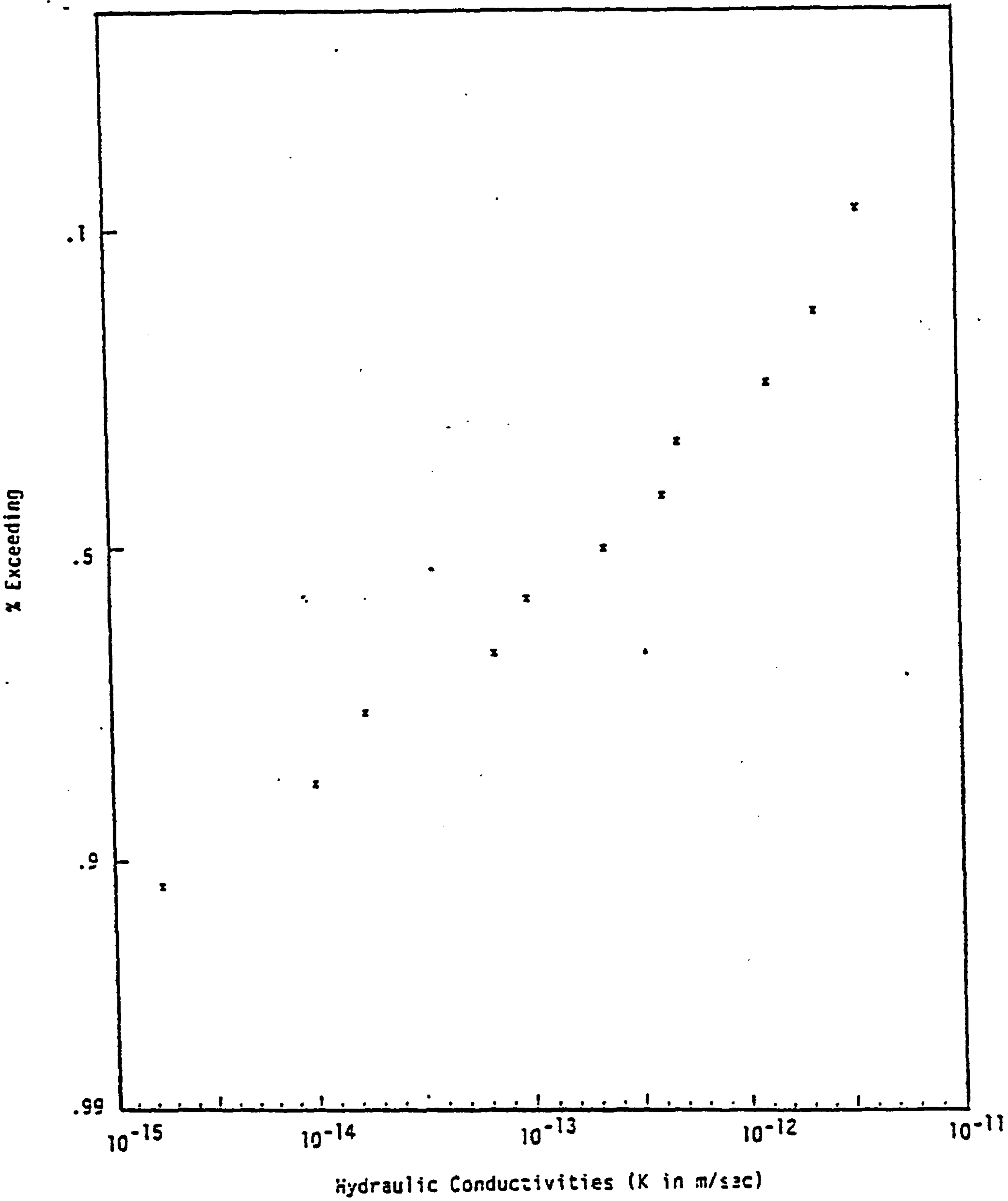

FIGURE 4-8. Log-Normal Probability Plot of Hydraulic Conductivities from Dense Basalt Flow Interiors (from Runchall et al., 1984).

5.0 REPOSITORY SEALS SUBSYSTEM PARAMETERS

5.1 Introduction

The repository isolation system consists of both engineered and natural barriers to radionuclide migration. From a systems analysis standpoint, it is useful to represent these barriers as three major subsystems: (1) site, (2) repository seals, and (3) waste package. The nature and function of each subsystem and its components have been described in detail elsewhere (Rockwell, 1984). In this section, the repository seals subsystem and the model input parameters characterizing it are briefly reviewed. Data tables of values for these parameters are found in Appendix B (Volume 2) of this report.

5.2 The Repository Seals Subsystem*

The "repository seals subsystem" is defined as the underground repository facility (excluding the waste package), including the access shafts. The repository seals subsystem consists of the materials and barriers placed in the underground openings and beyond the boundary of the waste package subsystem. (Figure 5-1 depicts a conceptual model of the repository seals subsystem). Materials placed in boreholes drilled from the ground surface within the controlled zone are also included as components of this subsystem. The repository seals subsystem is thus made up of four major components: (1) backfill, (2) emplacement-room seals, (3) drift seals, and (4) shaft seals.

Backfill material placed in the engineered facility will be designed to inhibit groundwater flow and retard potential radionuclide migration. In addition, backfill material may provide structural support to underground openings in some areas of the repository. Backfill will also probably be placed in the vertical access shafts. Crushed basalt with bentonite clay is proposed for backfilling the drifts and emplacement rooms. The optimum composition and physical characteristics of backfill material to be used in shafts and boreholes would be determined during site characterization.

Drifts are the man-made horizontal underground openings other than waste-emplacement boreholes. They provide access for personnel, materials, utilities, and ventilation during repository development and opera-

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* This section is taken from the BWIP's Environmental Assessment report (Rockwell, 1984).

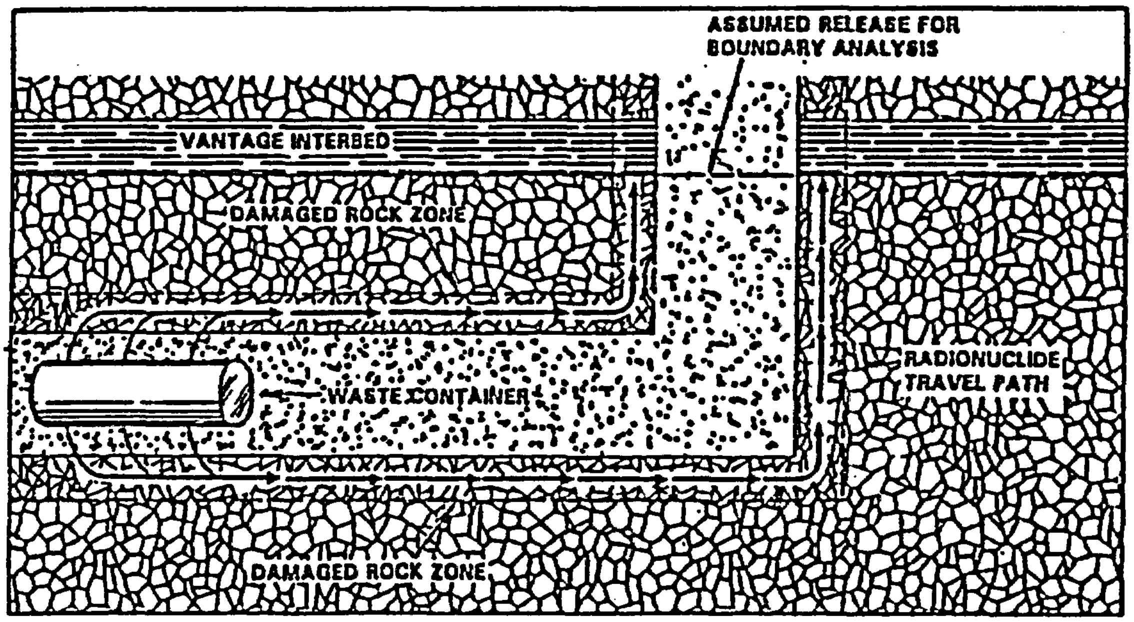

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FIGURE 5-1. Conceptual model used in repository seals subsystem performance assessment. From Rockwell (1984).

tion. Drifts that provide access to boreholes in which waste will be emplaced are termed emplacement rooms. Seals may be placed as barriers at the entrance to each emplacement room, or within drifts accessing groups of rooms. Seal installations for emplacement rooms or drifts may require removal of local rock support systems, excavation of damaged rock, and installation of a low-permeability material to fill the cross section of the room. A well established technology such as injection grouting or a similar process, together with a bonding agent, may be used if deemed necessary between the seal material and the rock to seal fractures that may exist in the exposed rock at these seal locations.

To restrict groundwater flow through the repository, seals will probably be placed within the shafts (see Figure 5-2). These seals will be designed to inhibit potential vertical migration of radionuclides through the repository shafts and to inhibit communication between aquifers in the strata above the repository through which the access shafts will pass. At specific locations in shafts where seals are placed, shaft liners and grout many be removed prior to seal emplacement, and the exposed surface prepared for sealing. Detailed methods and strategy for grouting and sealing will be developed in conjunction with the preliminary repository design.

Figure 5-3 is a generalized schematic diagram of the subsystem.

5.3 Repository Seals Subsystem Parameters

Parameters used to characterize the repository seals subsystem are the following

- Hydraulic Conductivity
- Effective Porosity
- Bulk Density
- Dispersivities
- Geometry and Dimensions
- Thermal Properties
    - Diffusivity
    - Conductivity
    - Specific Heat
    - Expansion Coefficient
- Diffusion Coefficient
- Distribution Coefficient (Sorption Coefficient)

The performance-assessment source data compiled for the repository seals subsystem are tabulated in Appendix B (Volume 2) of this report. The data

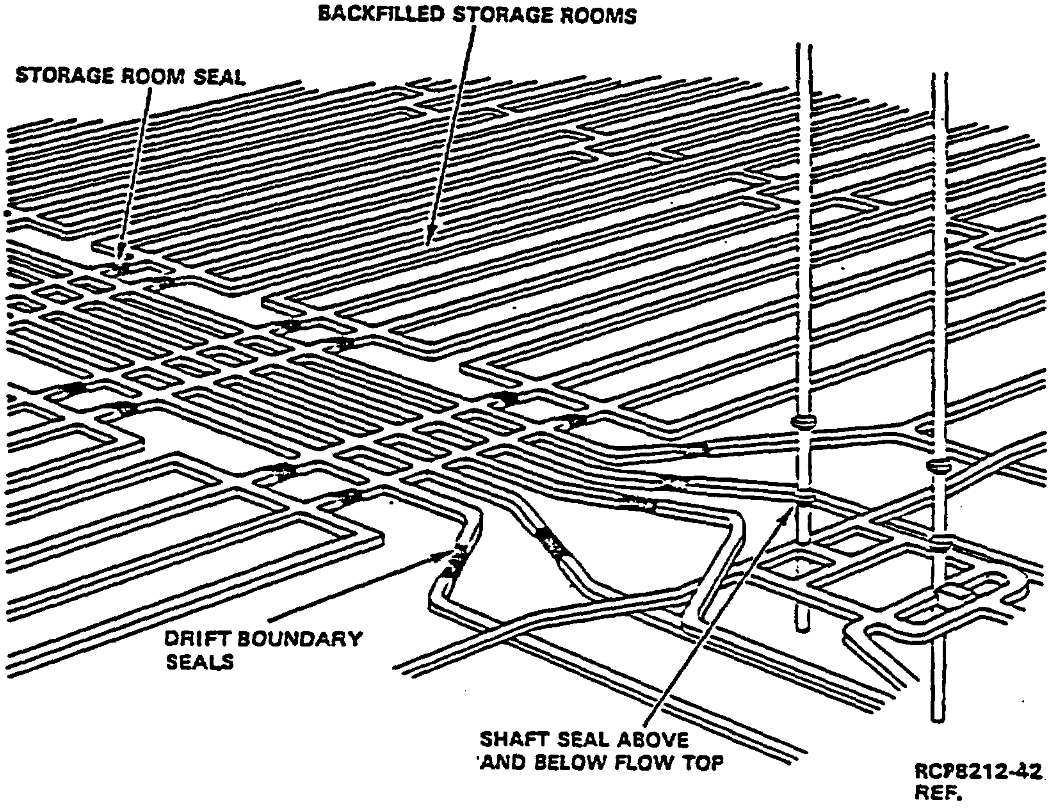

FIGURE 5-2 Typical Drift-Shaft Seal System for a Repository in Basalt.

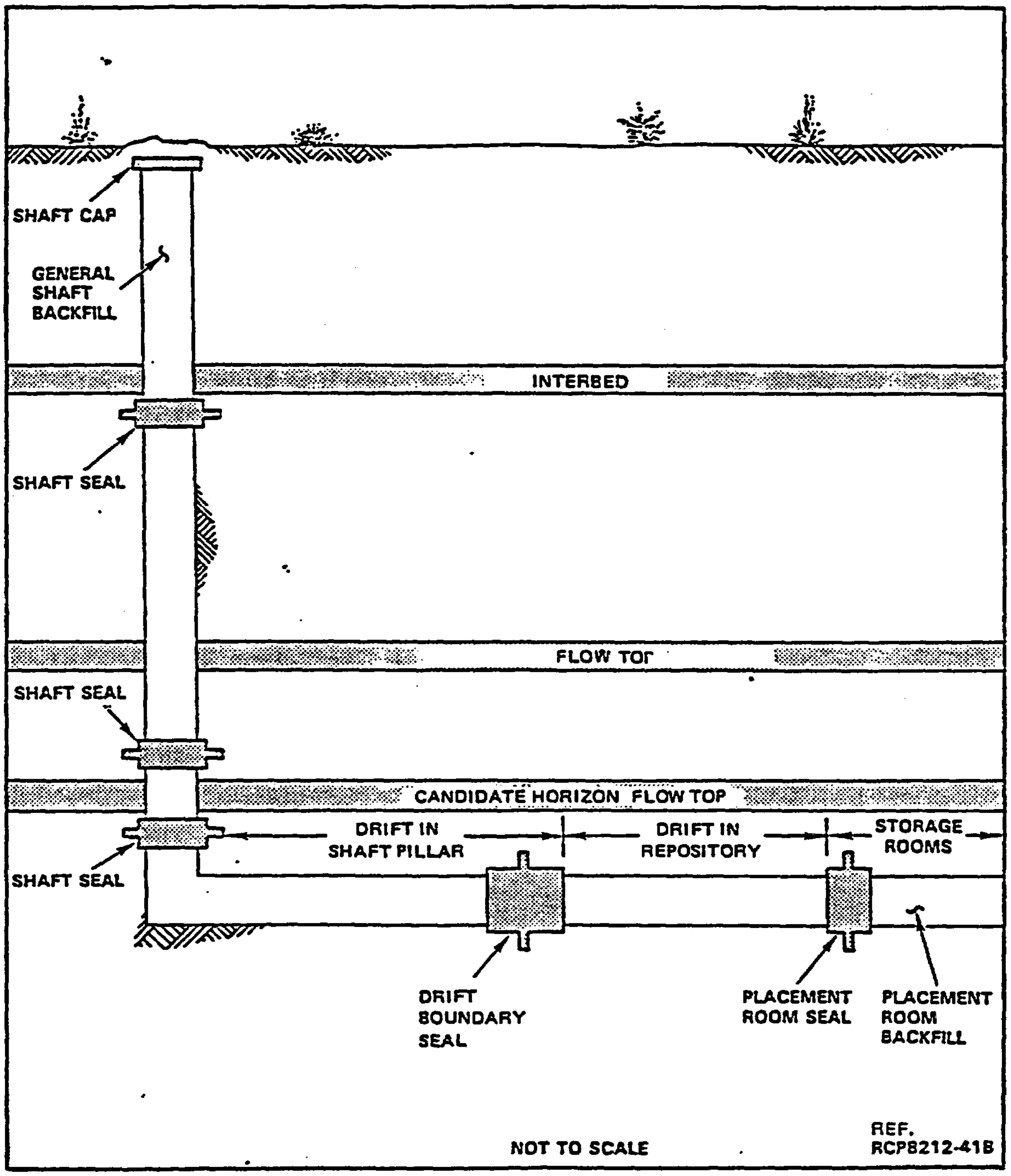

FIGURE 5-3 Generalized Schematic Diagram of Repository Seals Subsystem.

are arranged in tables by parameter, and references are provided citing the source of each value reported. Concise definitions of the parameters are given in Section 2 (Definitions of Terms) of this report. Information about the methodologies for measuring or calculating the various parameters are in Section 3 (Methodologies for Parameter Testing and Analysis) of this report.

Brief remarks on the scope, quality, or significant implications of the data are listed in Table 5-1 for each parameter.

Table 5-2 summarizes the data found in Appendix B for various types of plug or backfill material. This table includes a ranking (on a scale of 1 to 10) of the relative importance of each parameter to subsystem performance calculations. It also includes a rating (on a scale of 1 to 5) of the performance assessment data quality (see Section 4.0, p. 4-8, for scale definition).

Materials considered for backfill and plugs include basalt, Oregon and Wyoming bentonite, Ringold clay, Oregon zeolite, quartz sand, zeolite, and various types of Portland and hydrothermal cements. Many of the properties will have values similar to those found for packing material in Section 6.0 (Waste Package Subsystem) of this report.

Construction of underground facilities will result in altering rock properties in the vicinity of any construction activities. Hydraulic conductivity is expected to increase relative to that of undisturbed rock primarily due to stress relief and damage due to blasting. Analytic modeling and limited testing of the disturbed rock zone suggest that increases in permeability greater than one order of magnitude are contained in an area extending not more that 1 to 1.5 radii from a shaft or tunnel wall (D'Appolonia, 1984). Since the disturbed rock zone will probably have appreciably greater permeability than the adjacent undisturbed rock and backfill zones, it will likely become a flow path for groundwater.

Table 5-3 is the preliminary postclosure performance assessment data set for modeling the repository seals subsystem.

Table 5-4 shows the cumulative radionuclide release at the repository seals subsystem boundary.

TABLE 5-1
Summary of Parameters Characterizing the Repository Seals Subsystem

Parameter	Remarks
Hydraulic Conductivity	Values for backfill and plugs are generally low, less than 1E-10 m/s, for saturated material. Such low permeabilities and the small potentionmetric gradient in the repository environment suggest a negligible groundwater flow rate; thus, transport of radionuclides through saturated backfill may be diffusion-controlled (DOE, 1982).
Effective Porosity	No values reported. Porosities for compacted backfill materials are 1.2-4.7%, depending on degree of compaction. Effective porosity can be expected to be somewhat less than total porosity for a given material, since some of the pore volume is likely to be unavailable for fluid flow.
Bulk Density	Bulk density is highly dependent on compaction. Hydraulic conductivity, porosity, and mechanical properties, among others, vary with density. Control of density can be used to some extent to design backfill or plug materials to meet specific requirements.
Dispersivity	No values found from laboratory tests on backfill or plug materials.
Geometry and Dimensions	Some values are available for preliminary repository design.
Thermal Properties	Very few measurements were found, but values should be similar to those for the Waste Package Subsystem, since the materials used in both are the same.
Diffusion Coefficient	Some values were found. Diffusion may be an important mechanism for radionuclide transport in the repository system due to the slow groundwater flow velocity found for the backfill and plug materials.
Distribution Coefficient	Many of the backfill materials can retard the transport of radionuclides by sorption. Distribution coefficients from laboratory methods for 8 radionuclides were found for a variety of materials and conditions.

TABLE 5-2
Summary of Repository Seals Subsystem Parameters

		PLUG OR BACKFILL MATERIAL									
		Basalt		Soil Materials		Soil Materials Mixtures		Basalt/Soil Materials Mixtures		Cement/Soil/Basalt Mixtures	
Parameter, unit	Rank*	Range	Qual.†	Range	Qual.†	Range	Qual.†	Range	Qual.†	Range	Qual.†
Hydraulic Conductivity, m/s	10	E-11	2	2E-14 - E-13	2	1E-11 - 9.5E-10	2	3.6E-13 - 4.1E-10	2	1.2E-11 - 9.6E-11	2
Effective Porosity, %	10	1	5	--	--	--	--	--	--	--	--
Bulk Density, g/cm^3	9	2.8 - 2.9	2	1.75 - 2.85	2	1.3 - 2.0	2	1.56 - 2.3	2	2.0 - 3.3	2
Dispersivity, m	5	--	--	--	--	--	--	--	--	--	--
Thermal Properties	4										
Diffusivity, m^2/s	4	8E-9	5	8E-9	5	8E-9	5	8E-9	5	8E-9	5
Conductivity, W/m·°K	4	1.5E-3	3	0.4 - 1.4	3	1.0	5	0.3 - 1.3	3	1.0	5
Specific Heat kJ/kg·°K	4	1.0	5	1.0	5	1.0	5	0.96	3	1.0	5
Expansion Coefficient, /°K	4	5.4E-6	4	5E-6	5	5E-6	5	5E-6	5	5E-6	5
Diffusion Coefficient, m^2/s	5	E-13	5	3.2E-15 - 6.3E-11§	3	2.0E-14 - 1.4E-12‡	3	E-13	5	E-13	5
Distribution Coefficient, ml/g (reducing conditions)	9										
C		0	5	0	5	0	5	0	5	0	5
Ni		--	--	--	--	--	--	--	--	--	--
Se		--	--	--	--	--	--	8	4	--	--
Rb		--	--	--	--	--	--	--	--	--	--
Sr		44 - 93	3	439 - 2900	3	50	5	50	5	50	5
Zr		100	5	--	--	100	5	100	5	100	5
Tc		5	5	2 - 50	3	5	5	0	4	5	5
Pd		100	5	100	5	100	5	100	5	100	5
Cd		--	--	--	--	--	--	--	--	--	--
Sn		--	--	--	--	--	--	--	--	--	--
I		0	5	1 - 600	3	0	5	0	5	0	5
Cs		200	5	12 - 1400	3	200	5	200	5	200	5
Sm		100	5	100	5	100	5	100	5	100	5
Sb		--	--	--	--	--	--	--	--	--	--
Eu		--	--	--	--	--	--	--	--	--	--
Ho		--	--	--	--	--	--	--	--	--	--
Pb		100	5	100	5	100	5	100	5	100	5
Ra		100	5	100	5	100	5	100	5	100	5
Ac		100	5	100	5	100	5	100	5	100	5
Th		100	5	6000	4	100	5	100	5	100	5
Pa		100	5	5000	4	100	5	100	5	100	5
U		10	5	21 - 5000	3	10	5	60	4	10	5
Np		10	5	120 - 5000	3	10	5	100	4	10	5
Pu		89 - 1300	3	3500	4	200	5	200	5	200	5
Am		100	5	6600	4	100	5	100	5	100	5
Cm		100	5	100	5	100	5	100	5	100	5

* Relative importance to subsystem performance calculation (increasing from 1 to 10).

† Performance assessment data quality definitions:
1 = high confidence data base.
2 = moderate confidence data base and sample size.
3 = data base sufficient for bounding value or range.
4 = limited confidence data base.
5 = literature values.

§ For radionuclides including Sr, Cs, Th, Pa, U, Np, Pu, Am.

‡ For radionuclides including I, Tc, U, Np.

TABLE 5-3

Data set for assessment of the repository seals subsystem (from Rockwell, 1984)

Parameter	Median value	Distribution	Standard deviation[a]
Hydraulic gradient			
Constant horizontal	5.0×10^{-4}	lognormal	1.0
Constant vertical	10^{-3}	lognormal	1.0
Decaying vertical (initial gradient value)	2.9×10^{-2}	lognormal	1.0
Half-life (yr) of initial decay	1,100	lognormal	1.0
Hydraulic conductivity (K)			
Zone of damaged rock around repository seal subsystem	10^{-10} m/s	lognormal	2.30
Porosity (Φ)	$2.15 \times K(m/s)^{1/3}$	c	c
Sorption			
Retardation factor (R)	$1 + \rho \times K_d/\Phi$	c	c
Repository geometry			
Borehole diameter	89.0 cm	discrete	b
Borehole length	6.1 m	discrete	b
Placement room length	920.0 m	discrete	b
Access drift length			
minimum	322.0 m	discrete	b
maximum	1,929.0 m	discrete	b
Shaft path length	133.0 m	normal[d]	b

[a] Standard deviation for the normal distribution of the natural logarithm of the parameter, except where otherwise indicated.

[b] Not applicable.

[c] Distribution of parameter is governed by distribution of input variables.

[d] A normal distribution was used to account for variations in the basalt flow thickness, except that only values less than or equal to 133.0 were used.

TABLE 5-4
Mean (average) cumulative radionuclide release at the repository seals subsystem boundary during 10,000 years (from Rockwell, 1984)

References Cited

D'Appolonia Waste Management Services (1984), STEADYFLOW: Groundwater Flow Computer Program for Repository Seal Systems, User's Manual.

Rockwell (1984), Performance Assessment section (Chapter 6) of BWIP Environmental Assessment report, draft of 9/4/84.

Smith, M. J., et al. (1980). Engineered Barrier Development for a Nuclear Waste Repository Located in Basalt: An Integration of Current Knowledge, Rockwell Hanford Operations, Richland, WA, RHO-BWI-ST-7, Aug. 1980.

6.0 WASTE PACKAGE SUBSYSTEM PARAMETERS

6.1 Introduction

The repository isolation system consists of both engineered and natural barriers to radionuclide migration. From a systems analysis standpoint, it is useful to represent these barriers as three major subsystems: (1) site, (2) repository seals, and (3) waste package. The nature and function of each subsystem and its components have been described in detail elsewhere (Rockwell, 1984). In this section, the waste package subsystem and the model input parameters characterizing it are briefly reviewed. Data tables of values for these parameters are found in Appendix C (Volume 2).

6.2 The Waste Package Subsystem

The term "waste package" includes the waste form and any containers, shielding, packing and other adsorbent materials immediately surrounding an individual waste container, or canister. The waste package is required to provide substantially complete containment of the nuclear waste for at least 300 to 1,000 years after respository closure. The current waste package design for the proposed mined geologic repository in basalt consists of three major components: (1) waste form (spent fuel), (2) container, and (3) packing.

Figure 6-1 is a schematic representation of the waste package subsystem. Figure 6-2 shows the conceptual model used in assessing waste package performance.

The waste packages will be designed to contain spent fuel from either pressurized water reactors (PWR) or boiling water reactors (BWR). The waste form will consist of spent fuel assemblies or individual fuel rods consolidated into a more tightly packed arrangement. A typical spent fuel rod is approximately 3.7 meters (12 feet) long. The cladding (fuel rod tubing) is made of a zirconium-based metal called zircaloy, which is highly resistant to corrosion. The nuclear fuel inside the tube typically consists of compressed and sintered cylindrical ceramic pellets of uranium oxide. Other waste forms (e.g., borosilicate glass) may eventually be placed in the repository.

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* This section is taken from the BWIP's Environmental Assessment report (Rockwell, 1984).

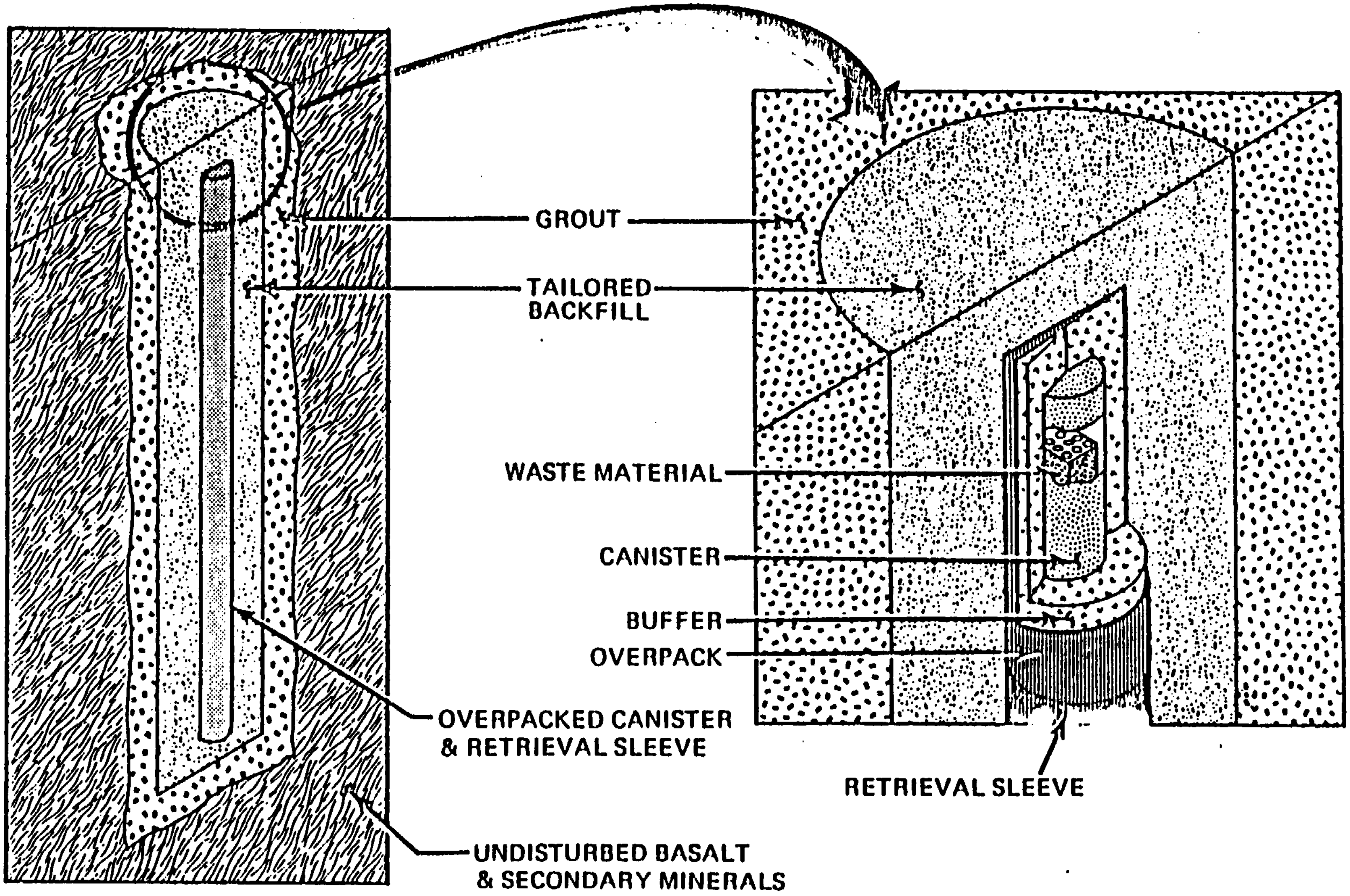

FIGURE 6-1. Schematic Diagram of the Waste Package Subsystem

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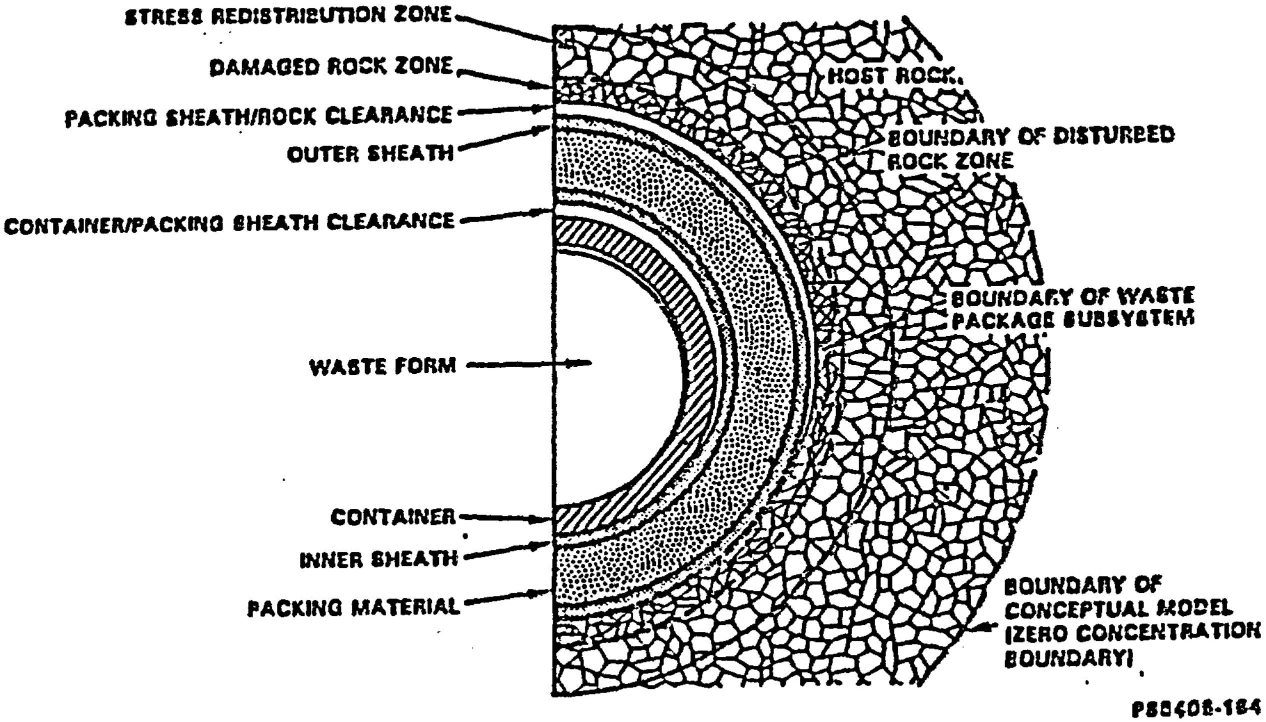

FIGURE 6-2. Conceptual model used in waste package performance assessment. From Rockwell (1984).

The spent fuel waste form will be contained within a carbon steel canister, whose function is to maintain complete containment of the waste for 1,000 years or longer. Based on current information, the amount of corrosion of containers in an air/steam environment during the initial 50 years after emplacement is expected to be minor. Corrosion of the container is likely to affect container lifetime after permanent closure of the repository, when the packing placed around the container becomes saturated with groundwater. The rate at which corrosion proceeds is determined by the thermal and chemical environment at the surface of the container. The thickness of the container will be selected (1) to compensate for corrosion, (2) to withstand the in-place stresses, and (3) to minimize effects of radiation on container life.

The main function of the packing surrounding the container is to control radionuclide release rates to the host rock by (1) limiting the rate of of groundwater flow past the container, and (2) maintaining a reducing (i.e., low-Eh) environment to enhance low solubilities of many radionuclides. A low-permeability medium with strong adsorption properties is used to minimize radionuclide migration through the packing. Because of the low projected groundwater flow rates around the waste package, the principal radionuclide transport mechanism through the packing material will be molecular diffusion. Radionuclide release rates are also controlled by radionuclide solubility, and by adsorption in the packing material and host rock. The proposed packing material is a tailored mixture of 25 percent sodium bentonite clay and 75 percent (by weight) crushed basalt.

6.3 Waste Package Subsystem Parameters

Groundwater interaction with the waste package and thermal stress due to generation of heat by the radioactive wastes are important factors determining the mobility of radioactive species in the waste package subsystem. Parameters characterizing this subsystem have been grouped into three categories (waste form, canister, and packing material), as follows:

<u>Waste Form</u>

- Radionuclide Half-Lives
- Specific Activities
- Decay Heat Factors
- Radionuclide Solubilities
- Radionuclide Inventory
- Geometry and Dimensions

Canister

- Canister Lifetime
- Corrosion Rate
- Density
- Thermal Properties
    - Diffusivity
    - Conductivity
    - Specific Heat
    - Expansion Coefficient
- Geometry and Dimensions

Packing Material

- Hydraulic Conductivity
- Effective Porosity
- Bulk Density
- Dispersivity
- Thermal Properties
    - Diffusivity
    - Conductivity
    - Specific Heat
    - Expansion Coefficient
- Diffusion Coefficient
- Distribution Coefficient

The performance-assessment source data compiled for the waste package subsystem are tabulated in Appendix C (Volume 2) of this report. The data are arranged in tables by parameter. References are provided in each table citing the source of each value reported. Concise definitions of the parameters are given in Section 2 (Definitions of Terms) of this report. Information about the methodologies for measuring or calculating the various parameters are in Section 3 (Methodologies for Parameter Testing and Analysis) of this report.

6.3.1 Waste Form

Brief remarks on the scope, quality, or significant implications of the data are listed in Table 6-1 for each parameter required to characterize the waste form.

Information available on the decay heat factor indicates that the heat release rate compared to the rate at 1 year after discharge is as given in Table 6-2.

TABLE 6-1
Summary of Parameters Characterizing the Waste Form

Parameter	Remarks
Radionuclide Half-Lives	Species with long half-lives that require low release rates (<1 E-3/year) to meet U.S. EPA Release Draft Limits include U (233, 234, 235, 236, 238), Np 237, Pu (239, 242), Am 243, Th 230, Ra 226, Cs 135, Sn 126, Pd 107, Se 79, Tc 99, Zr 93, I 129, and C 14.
Specific Activities	Radionuclides with high values for specific activity include Sr 90, Cs 137, Sm 151, Eu 154, Am (241, 242), Cm (242, 243), Ra 226, and Pu (238, 241).
Decay Heat Factors	Three sources of decay heat factor data were found.
Radionuclide Solubilities	Many experiments have been conducted under widely varying conditions to determine the solubility of at least 40 species of radionuclides and waste form components (see Table 6-3). Radionuclides with high solubility are C 14, Cs 135, I 129, N 237, Rb 87, Se 79, Sn 126, Sr 90, and Tc 99.
Radionuclide Inventory	Based on the relative amounts of components of spent fuel and projections of nuclear generating capacity at the year 2000, the expected time of peak generation, the nuclear waste inventory can be estimated. Several radionuclide inventories were found; among the more abundant species are U (236, 238), Pu (239, 240, 242), I 129, Am (241, 242, 243), Np 237, Se 79, Tc 99, Sn 126, Zr 93, Cm (245, 246), Cs 135, and C 14.

TABLE 6-2
Decay Heat Factor

t Time after discharge, yrs	$\frac{\text{Heat release rate at t}}{\text{Heat release rate at 1 yr}}$
1	1
10	0.058 - 0.10
100	0.0043 - 0.020
1000	1.3E-4 - 0.0030

The values for t = 1000 years lie within one order of magnitude of the value given by

$$R(t) = 1/t,$$

where

$$R(t) = \frac{\text{Heat release rate at t}}{\text{Heat release rate at 1 year}},$$

t = time after discharge, years.

Radionuclide solubilities are highly dependent on concentrations, groundwater composition, geologic materials, and temperature, as well as the waste form. Numerous experiments have been conducted under widely varying conditions to determine the solubility of at least 40 species of radionuclides and waste-form components. Table 6-3 lists solubilities of key radionuclides under a wide range of conditions. Table 6-4 presents the radionuclide data set used for preliminary assessment of performance.

TABLE 6-3
Solubility of Key Radionuclides

Species	Solubility, M	
	Range	Geometric Mean
Ra	<~1E-8	--
Np	1E-15 - 1E-6	5E-10
U	1.3E-11 - 1E-4	3E-7
Pu	3.3E-12 - 6.2E-7	1E-9
Am	7.6E-12 - 5.9E-7	5E-10
I	3.1E-6 - 8.8E-5	3E-5
Se	1E-15 - 0.01	1E-8
Tc	1E-14 - 5.3E-4	3E-9
Cs	3E-7 - 1.1E-3	1E-4
Sr	4.6E-8 - 1E-5	9E-7
Sn	3.6E-19 - 2.1E-17	3E-18
Pa	1E-10*	--
Zr	1.5E-7 - 1.3E-6	3E-7

* Expected value

TABLE 6-4

Radionuclide data set for assessment of performance (from Rockwell, 1984)

Isotope	Inventory (Ci/mtu)	EPA[a] limit (Ci/mtu)	Half-life (yr)	Specific activity (Ci/g)	Radioisotope solubility[b] (mg/L)	Adsorption coefficient (ml/g)
Carbon-14	7.4×10^{-1}	1.0×10^{-1}	5.73×10^{3}	4.457	$4.0 \times 10^{-6} - 4.0 \times 10^{-9}$	0
Iodine-129	3.3×10^{-2}	1.0×0	1.59×10^{7}	1.74×10^{-4}	$1.0 \times 10^{0} - 1.0 \times 10^{-2}$	0
Neptunium-237	1.1×10^{0}	1.0×10^{-1}	2.14×10^{6}	7.05×10^{-4}	$1.0 \times 10^{-7} - 3.0 \times 10^{-9}$	2 - 10
Plutonium-239	2.9×10^{2}	1.0×10^{-1}	2.41×10^{4}	6.20×10^{-2}	$1.2 \times 10^{-8} - 1.8 \times 10^{-11}$	4 - 21
Plutonium-240	4.5×10^{2}	1.0×10^{-1}	6.53×10^{3}	2.28×10^{-1}	$6.0 \times 10^{-9} - 9.0 \times 10^{-12}$	4 - 21
Plutonium-242	1.6×10^{0}	1.0×10^{-1}	3.76×10^{5}	3.93×10^{-3}	$2.0 \times 10^{-9} - 3.0 \times 10^{-12}$	4 - 21
Technetium-99	1.3×10^{1}	1.0×10^{1}	2.13×10^{5}	1.70×10^{-2}	$5.0 \times 10^{-4} - 2.0 \times 10^{-8}$	0 - 15
Selenium-79	3.5×10^{-1}	1.0×10^{0}	6.50×10^{4}	6.96×10^{-2}	$1.0 \times 10^{-4} - 1.0 \times 10^{-8}$	0.8 - 4
Tin-126	4.8×10^{-1}	1.0×10^{0}	1.00×10^{5}	2.84×10^{-2}	$3.0 \times 10^{-6} - 3.0 \times 10^{-11}$	2 - 5

[a] U.S. Environmental Protection Agency.

[b] Computed by multiplying the element solubility by the isotopic fraction.

6.3.2 Canister

The canister provides physical support and protection for the waste form during the pre-emplacement period and acts as a barrier to groundwater intrusion. At least twenty materials have been studied for possible use in canister construction. The interaction with groundwater under various conditions and the effect of radiation have been studied for a number of candidate materials. For all materials under all conditions, the corrosion rate was in the range of 1.2 to 71 um/yr. Materials showing a corrosion rate less than 5 um/yr include 2.5% Cr, 1% Mo cast steel; 1.25% Cr, 0.5%Mo cast steel; 1025 cast steel; and Fe9 Crl Mo.

The only other parameter values found for the canister were for thermal conductivity of aluminum, 304 stainless steel, mild steel, and titanium. The physical and thermal properties of any reference canister material can be easily determined by standard methods.

Table 6-5 is the container data set used for preliminary performance assessment.

TABLE 6-5
Container Data Set for Assessment of Performance
(from Rockwell, 1984)

Item	Current design specification
Container material type	Low-carbon steel
Container outer radius	25.15 cm (9.9 in.)
Container wall thickness	8.3 cm (3.26 in.)
Container capacity (PWR* fuel)	1.85 tonnes (approx. 1.94 short tons) of uranium
Borehole radius	44.5 cm (16.5 in.)
Damaged rock thickness	2.5 cm (1 in.)
Disturbed rock thickness	44.5 cm (16.5 in.)

* Pressurized water reactor.

6.3.3 Packing Material

In the multiple barrier system concept, packing materials function to minimize contact between the canister and the host environment and to control release of radionuclides into the host environment in case of waste package failure. Major component candidates for packing material include bentonite, bentonite-quartz sand, crushed basalt, and zeolites.

Table 6-6 summarizes the physical, hydraulic, thermal, and mechanical properties of the major packing material components, alone or in combination, in various proportions, and at various densities.

The data available for diffusion coefficient are quite limited in view of the fact that diffusion is likely to be a significant controlling factor in the waste package system.

Reference Cited

Rockwell (1984), Performance Assessment section (Chapter 6) of BWIP Environmental Assessment report, draft of 9/4/84.

TABLE 6-6
Summary of Properties of Packing Material

		PACKING MATERIAL							
		Bentonite		Bentonite/ Quartz-sand		Bentonite/ Crushed Basalt		Crushed Basalt/Zeolite	
Parameter, unit	Rank*	Range	Qual.†	Range	Qual.†	Range	Qual.†	Range	Qual.†
Hydraulic Conductivity, m/s	10	E-14 - E-13	2	9.5E-10	5	3.6E-13 - 4.2E-10	2	E-10	5
Bulk Density, g/cm^3	9	1.75 - 2.3	2	1.9	5	1.56 - 2.03	2	1.9	5
Porosity, %	10	30	5	30	5	40	4	30	5
Thermal Conductivity, W/m·°K	9	0.4 - 1.4	3	1.0	5	0.3 - 0.9	3	1.0	5
Specific Heat, kJ/kg·°K	9	1.0	5	1.0	5	0.96	5	1.0	5
Young's Modulus, MPa	2	41 - 81§	2	60	5	60	5	60	5
Uniaxial Compr. Strength, MPa	2	0.8 - 2.7§	2	1.7	5	1.7	5	1.7	5
Diffusion Coefficient, m^2/s	10	2E-15 - 4E-12‡	3	E-13	5	E-13	5	E-13	5
Distribution Coefficient, ml/g (reducing conditions)	10								
C		0	5	0	5	0	5	0	5
Ni		--	--	--	--	--	--	--	--
Se		8	4	--	--	--	--	8	4
Rb		--	--	--	--	--	--	--	--
Sr		439 - 2900	3	50	5	50	5	50	5
Zr		100	5	100	5	100	5	100	5
Tc		2	4	5	5	5	5	5	5
Pd		100	5	100	5	100	5	100	5
Cd		--	--	--	--	--	--	--	--
Sn		--	--	--	--	--	--	--	--
I		1 - 800	3	0	5	0	5	0	5
Cs		2 - 1400	3	200	5	200	5	200	5
Sm		100	5	100	5	100	5	100	5
Sb		--	--	--	--	--	--	--	--
Eu		--	--	--	--	--	--	--	--
Ho		--	--	--	--	--	--	--	--
Pb		100	5	100	5	100	5	100	5
Ra		100	5	100	5	100	5	100	5
Ac		100	5	100	5	100	5	100	5
Th		6000	4	100	5	100	5	100	5
Pa		5000	4	100	5	100	5	100	5
U		3 - 5000	3	10	5	10	5	60	4
Np		100 - 5000	3	10	5	10	5	100	4
Pu		3500	4	200	5	200	5	200	5
Am		6600	4	100	5	100	5	100	5
Cm		100	5	100	5	100	5	100	5

* Relative importance to subsystem performance calculation (increasing from 1 to 10).

† Performance assessment data quality definitions:
1 = high confidence data base.
2 = moderate confidence data base and sample size.
3 = data base sufficient for bounding value or range.
4 = limited confidence data base.
5 = literature values.

§ For bentonite mixed with clay.

‡ For radionuclides including I, Sr, Tc, Cs, Th, Pa, U, Np, Pu, Am.

7 QUALITY ASSURANCE

In-Situ Inc. recognizes that this reference source data documentation report will provide an important basis for project licensing, safety and environmental concerns of the Basalt Waste Isolation Program. A quality assurance program on procedure, traceability and technical quality was developed for this investigation effort. The quality assurance program is based on the following objectives:

- development of traceability and continuity in the reference source data base
- assessment of technical quality of the reference source data base
- procedures for updating the data base
- procedures for establishing a data storage/retrieval system for performance assessment models.

By the date of completion of the draft report, only the first two objectives had been completed.

The quality assurance personnel for this project are Dr. T. D. Steele of In-Situ's Engineering and Environmental Science Office and Dr. L. E. Holichek, an In-Situ technical editor. Dr. Steele supervised the technical aspects of the quality assurance program and Dr. Holichek the non-technical aspects.

In technical areas, Dr. Steele was responsible for

- monitoring the overall execution of the quality assurance plan
- reviewing the technical approach
- reviewing the data analysis methodologies
- providing for checks of all calculations performed for reporting purposes.

In non-technical areas, Dr. Holichek was responsible for

- maintaining records in a secure location
- cataloging BWIP records and reports

- overseeing the checkout and return of materials from the secure location
- monitoring project activities and reports for compliance with Rockwell standards and formats,
- monitoring progress according to the project schedule.

It is important to achieve a reference source data base with a schedule of transfer of raw or refined technical data and procedures for its traceability. As a first step, In-Situ Inc. approached professional staff members within Rockwell working groups for leads to data sources, and they are as follows:

Performance Assessment Group:	Dr. R. G. Baca
	Mr. W. W. Loo
	Mr. R. C. Arnett
	Mr. M. S. Bensky
	Dr. P. M. Clifton
	Mr. J. D. Davis
	Mr. E. A. Fredenburg
	Dr. B. Sagar
Engineered Barriers Group:	Dr. M. I. Wood
Site Analysis Group:	Dr. S. M. Baker
	Mr. R. W. Bryce
	Dr. T. O. Early
	Dr. L. S. Leonhart
	Dr. A. H. Lu
	Mr. R. D. Mudd
	Dr. R. M. Smith
	Mr. P. Rogers
Drilling and Testing Group:	Dr. F. A. Spane
	Dr. R. Stone
	Mr. S. R. Strait
	Mr. G. L. Setbacken
Site Department:	Mr. G. S. Hunt

After consultation with Rockwell technical personnel, In-Situ Inc. requested and received a total of 277 reports from Rockwell. Requested technical reports and data were obtained from Rockwell's technical coordinator, Mr. W. W. Loo, who subsequently obtained BWIP published documents from various in-house departments. These reports were divided into four categories:

1) RHO series (147)
2) SD series (94)
3) RSD series (15)
4) Others (21)

These reports and other related documents were catalogued and maintained in a secure area with authorized access limited to R. Koenig, J. Reverand, and S. C. Way. All reports were thoroughly researched; only those enumerated by series and subsystem in Table 7-1 were found to contain relevant data. Persons transcribing data were limited to A. Bumb, C. Johnson, R. Koenig, and S. C. Way. A complete inventory of documents received is included in Appendix E.

TABLE 7-1
Summary of Utilization of BWIP Documents

	Number of Reports*		
	Site Subsystem	Repository Seals Subsystem	Waste Package Subsystem
BWIP Reports			
RHO Series	30	9	22
SD Series	36	3	4
RSD Series	--	--	1
Other Reports	6	6	6

* Refer to Appendices A, B, and C for specific document reference lists.

The review of tabulated data required particular attention on this project, to be certain that all values were verifiable and accurately transcribed. Transcribed data was entered into the data base by K. Cady, S. Peterson, and E. Valora. S. Peterson made a final check of the data base output compared to the original source documents. A second, independent check was performed by R. Koenig on all statisical calculations used for reporting purposes.

In-Situ Inc.'s effort in the review of these documents is considered to be an independent third-party review of BWIP documents. A further enhancement of the credibility of the reference source data document is by expert peer reviewing. Five independent peer reviewers were selected based on their credentials and qualifications. They are:

Reviewer	Organization	Expertise
Prof. J.I. Drever	Univ. of Wyoming	Geochemistry
Prof. C. Fairhurst	Univ. of Minnesota	Rock Mechanics
Prof. L.W. Gelhar	M.I.T.	Geohydrology
Dr. J.H. Lehr	Director, National Water Well Association	Geohydrology
Dr. S.S. Papadopulos	Pres., S. S. Papadopulos & Associates, Inc.	Geohydrology

The credentials and qualifications of the peer reviewers are included in Appendix F.

The future objective of the quality assurance program is to establish procedures for updating the existing data base and also for the installation of a reference data file system (via computer data storage/retrieval) for performance assessment models.

8.0 OBSERVATIONS

- Data Deficiencies

This document points out the data base deficiency for certain performance assessment model parameters (Table 8-1). Ongoing efforts should be directed toward expanding the data base in these areas and upgrading data in areas where uncertainties exist, particularly where the quality of the data (as displayed, for example, in Tables 4-2, 4-3, 5-2, and 6-6) is low. A ranking of 1 or 2 is suitable for performance assessment and repository licensing.

- Formation Tests

Nearly all of the hydrologic testing performed to date has used single-well testing methods. Single-well tests are generally applicable to confined aquifers and give fairly accurate values of hydraulic conductivity in a formation, but they may not yield reasonable values of storage coefficient. Since basalt formations are likely to be neither isotropic nor homogeneous, multi-well tests will be necessary in the future to determine storage coefficient, leakage, and directional properties. Because of low hydraulic conductivity associated with basalts, the well test duration may become excessively long. Proper well testing and wellfield design is essential for obtaining maximum information from a minimum number of wells in a reasonable amount of time.

- Consistency

An effort should be made to develop greater consistency in nomenclature for reference to stratigraphic units, parameter measurement units, and well identification.

- Well Locations

In converting well locations to longitude and latitude, In-Situ Inc. found discrepancies of as much as 4000 ft between Hanford coordinates and State coordinates Well locations as currently reported should be checked for accuracy.

- Data Storage and Retrieval

This is a live document which can serve as a common information source for Rockwell as well as for regulatory agencies to evaluate long-

TABLE 8-1
Areas of Current Data Base Deficiency

Site Subsystem	Repository Seals Subsystem	Waste Package Subsystem
Directional horizontal hydraulic conductivity Vertical hydraulic conductivity Storage coefficient Effective porosity Dispersivity Diffusion coefficient	Effective porosity Dispersivity Thermal properties Diffusion coefficient	Effective porosity Dispersivity Thermal properties Mechanical properties Diffusion coefficient

term repository performance. For each performance assessment model input parameter, the degree of uncertainty decreases as more reliable information becomes available. Because of the large amount of information collected to date and the increasing availability of additional information, a computerized data storage and retrieval system is the most cost-effective way to keep this document current. Each piece of information can then be easily accessed by the users and traced back to its original source if needed.

Section 3 of this report, testing methodologies, should be updated as new testing procedures applicable to the Hanford Site conditions appear in the literature.