FROM:	DATE OF DOCUMENT	DATE RECEIVED	NO:
Office of National Waste Terminal Storage Integration, Battelle ~~Memorial Institute~~	August 1981	1/15/82	WM-82-025
	LTR.	MEMO:	REPORT: XX with note from JBM · OTHER:
TO: Miller	ORIG.: XX	CC:	OTHER:
	ACTION NECESSARY XX · NO ACTION NECESSARY ☐	CONCURRENCE ☐ · COMMENT ☐	DATE ANSWERED · BY: 2/8/82
CLASSIF.: · POST OFFICE · REG. NO:	FILE CODE: ~~3413~~		

DESCRIPTION (Must Be Unclassified)

Review of Geologic and Hydrologic Issues Related to Waste Isolation in Columbia River Basalts with questions for HJMiller from JBM

ENCLOSURES

CLOSED 2/4/82 by informal note to JBMartin from HJMiller

REMARKS

REFERRED TO	DATE	RECEIVED BY	DATE
HJMiller	1/15		

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PDR WASTE
WM-10 PDR

U S NUCLEAR REGULATORY COMMISSION

MAIL CONTROL FORM

FORM NRC-326 (1-75)

3413

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(not sent to PDR)

See Pocket 1 for encls.

2/4/82

WRIGHT (w orig copies)
GREEVES
JUSTUS
COPLAN

WM-10
PDR
(Return to WM, 623-SS

FYI - JBM'S COMMENTS RE: RACKOUT OF ISSUES AT BWIP

WHILE WRIGHT WILL BE TAKING LEAD IN RESPONDING TO SPECIFIC QUESTIONS JBM HAS ON BWIP, THE GENERAL THRUST OF JBM'S QUERRIES CONCERNS THE NEED FOR A SYSTEMATIC, COMPREHENSIVE RACKOUT OF ISSUES AT EACH SITE.

WE SHOULD BUILD THIS INTO THE PROJECT PLANS AND RAPIDLY COMPLETE THE FIRST CUT OF SUCH A RACKOUT.

00049

NIPOR
Pocket 1

Ticket for Miller
due 2-X8

End. to 1071
2-4-82
note fm
MJM

(1) How are the concerns in this report being handled? Are we in agreement
(2) what systematic actions have you taken to categorize all concerns we know of from our work, reports such as this, peer reviews etc. re The Hanford site? This should be done and we should explicitly decide whether DOE is addressing these adequately.

(3) How are you sure that you have all the peer review reports?

REVIEW OF GEOLOGIC AND HYDROLOGIC ISSUES
RELATED TO WASTE ISOLATION IN
COLUMBIA RIVER BASALTS

#3 - 1/1/82 - 5/31/82

TECHNICAL REPORT

August, 1981

James O. Duguid

and

Stephen J. Kowall

Office of National Waste Terminal Storage Integration
Battelle Memorial Institute
Columbus, Ohio 43201

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ABSTRACT

The Office of National Waste Terminal Storage Integration has the primary role of integration and coordination of the components of the NWTS Program. A part of this role is accomplished through review of various aspects of the program coupled with recommendations to the Department of Energy concerning changes that could increase the rate of progress. This report identifies key geologic and hydrologic issues that are related to the development of a repository in basalt. These issues are discussed and placed in priority order, and recommendations that could aid in their resolution are made.

INTRODUCTION

Since 1968 the basalts of the Columbia Plateau have been studied as a potential host rock for isolation of high-level radioactive waste. During the period from 1968 to 1972 the studies were conducted by the Atlantic Richfield Hanford Company for the U.S. Atomic Energy Commission. This work formed the basis for planning subsequent studies under the U.S. Energy Research and Development Administration and later by the U.S. Department of Energy (DOE). In 1976 the National Waste Terminal Storage (NWTS) Program was established, and in 1977 additional funds were provided to begin the Basalt Waste Isolation Project (BWIP) which is operated for the DOE by Rockwell Hanford operations.

The Office of National Waste Terminal Storage Integration (ONI) has the primary role of integration of the components of the NWTS Program (BWIP, the Office of Nuclear Waste Isolation, and the Nevada Nuclear Waste Storage Investigations). This integration role is accomplished through advising the DOE on key issues that require resolution for continued progress of the NWTS Program. The information necessary for defining key issues is obtained from published reports, peer review committee meetings and reports, and interactions with project staff.

This report contains a discussion of key geologic and hydrologic issues related to BWIP's evaluation of the Columbia River basalts as potential host rock, for isolating high-level radioactive wastes. For the purposes of this discussion a key issue is one that could, dependent on the ability to resolve it, either confirm or eliminate these formations as a potential repository site. In order to determine key issues, the more important issues are identified, discussed, and placed in order of importance. This is followed by subjectively selecting the higher ranking issues (e.g., those where engineering cannot substantially alter a negative result) as key issues.

Geologic Setting. The Pasco basin is a structural and topographic basin within the western Columbia Plateau that occupies approximately 5,180 square kilometers and is underlain by more than 1400 meters of basalt flows and interbeds (Figure 1). Structural deformation was occurring during deposition of younger basalt flows and interbeds with the principal horizontal stress axis oriented north-south.

FIGURE 1. STRATIGRAPHIC NOMENCLATURE OF THE HANFORD SITE

Period	Epoch	Group	Subgroup	Formation	K-Ar Age Years x 10^6	Member or Sequence	Geologic Mapping Symbol	Sediment Stratigraphy or Flows or Beds	
Quaternary	Pleistocene/Holocene					Surficial Units	Ql	Loess	
							Qs	Sand Dunes	
							Qa,Qaf	Alluvium & Alluvial Fans	
							Qls	Landslides	
							Qt	Talus	
							Qcb	Colluvium	
	Pleistocene			Hanford		Touchet Beds/ Pasco Gravel	Qht/Qhp		
Tertiary	Pliocene			Ringold			Tru	Upper Ringold	Ringold-Fanglomerate
							Trm	Middle Ringold	
							Trl	Lower Ringold	
							Trb	Basal Ringold	
	Miocene	Columbia River Basalt Group	Yakima Basalt Subgroup	Saddle Mountains Basalt	8.5	Ice Harbor Member	Ti { Tig	Goose Island Flow	Ellensburg Formation Tel
							Tim	Martindale Flow	
							Tib	Basin City Flow	
								Levey Interbed	
					10.5	Elephant Mountain Member	Tem { Tem_2	Upper Elephant Mtn Flow	
							Tem_1	Lower Elephant Mtn Flow	
								Rattlesnake Ridge Int.	
					12.0	Pomona Member	Tp { Tp_2	Upper Pomona Flow	
							Tp_1	Lower Pomona Flow	
								Selah Interbed	
						Esquatzel Member	Te { Te_2	Upper Gable Mtn Flow	
								Gable Mtn Interbed	
							Te_1	Lower Gable Mtn Flow	
								Cold Creek Interbed	
						Asotin Member	Ta	Huntzinger Flow	
						Wilbur Creek Member	Tw	Wahluke Flow	
						Umatilla Member	Tu { Tu_s	Sillusi Flow	
							Tu_u	Umatilla Flow	
								Mabton Interbed	
				Wanapum Basalt	13.5	Priest Rapids Member	Tpr { Tpr_1	Lolo Flow	
							Tpr_r	Rosalia Flows	
								Quincy Interbed	
						Roza Member	Tr { Tr_2	Upper Roza Flow	
							Tr_1	Lower Roza Flow	
								Squaw Creek Interbed	
						Frenchman Springs Member	Tf { Tf_a	Aphyric Flows	
							Tf_p	Phyric Flows	
								Vantage Sandstone	
				Grande Ronde Basalt	14.5	Sentinel Bluffs Sequence	Tsb	High Chrome Flows	
								Intermediate Chrome Flow	
								Low Chrome Flows	
								McCoy Canyon Flow	
						Schwana Sequence	Ts	Intermediate Mg Flow	
								Low Mg Flow Above Umtanum	
								Umtanum Flow*	
								High Mg Flow Below Umtanum	
								Very High Mg Flows	
					16.5			At Least 30 Low Mg Flows	
						Picture Gorge and Imnaha Basalts			

*Reference repository horizon.

The Columbia River basalt flows overlie Precambrian to early Tertiary units and are overlain in part by sediments of Pliocene and Pleistocene age. The two basal formations are the Imnaha and the Picture Gorge basalts.

The Grande Ronde basalt, the oldest formation of the Yakima basalt subgroup was extruded 14.5 to 16.5 million years ago. It consists of over 50 flows and is the most areally extensive unit of the Columbia River basalt group. It comprises approximately 85 percent of the basalt group and is more than 1000 meters thick in the Pasco basin.

The Umtanum flow of the upper Schwana sequence of the Grande Ronde has been identified since 1968 as a possible reference repository horizon. The BWIP interprets that the flow is laterally continuous for a distance of at least 20 kilometers from the reference repository location (RRL) in the Cold Creek syncline. The Umtanum is generally about 65 meters thick, 1,110 meters below the ground surface and 285 meters below the contact of the overlying Wanapum basalt, where several high-yield aquifers occur.

The Wanapum basalt is the middle formation of the Yakima basalt subgroup. It is the second most voluminous unit, comprising about 15 percent of the Columbia basalt group. It is the most extensively exposed unit and comprises 11 to 14 flows.

The Saddle Mountains basalt, the youngest formation in the group, was extruded 6 to 13.5 million years ago in approximately 10 flows. Many of the flows in the Wanapum and the Saddle Mountains basalts are separated by laterally discontinuous sedimentary interbeds.

Overlying the basalts and their interbeds are two sedimentary formations, the Ringold formation consisting of river flood plain units and the Hanford formation which is composed of catastrophic-flood deposits.

Major discontinuities in the basalt stratigraphic sequences are the interbeds and the flow tops of each individual basalt flow. The major discontinuities at angles to the stratigraphy are cooling cracks, tectonic fractures and faults, and the edges of flows. There are also discontinuous pillowed zones. A typical flow is illustrated in Figure 2. Flow interiors are composed of two distinct zones, an upper chaotically fractured section with a higher glass content, called the entablature; and a lower, columnar jointed section, called the colonnade.

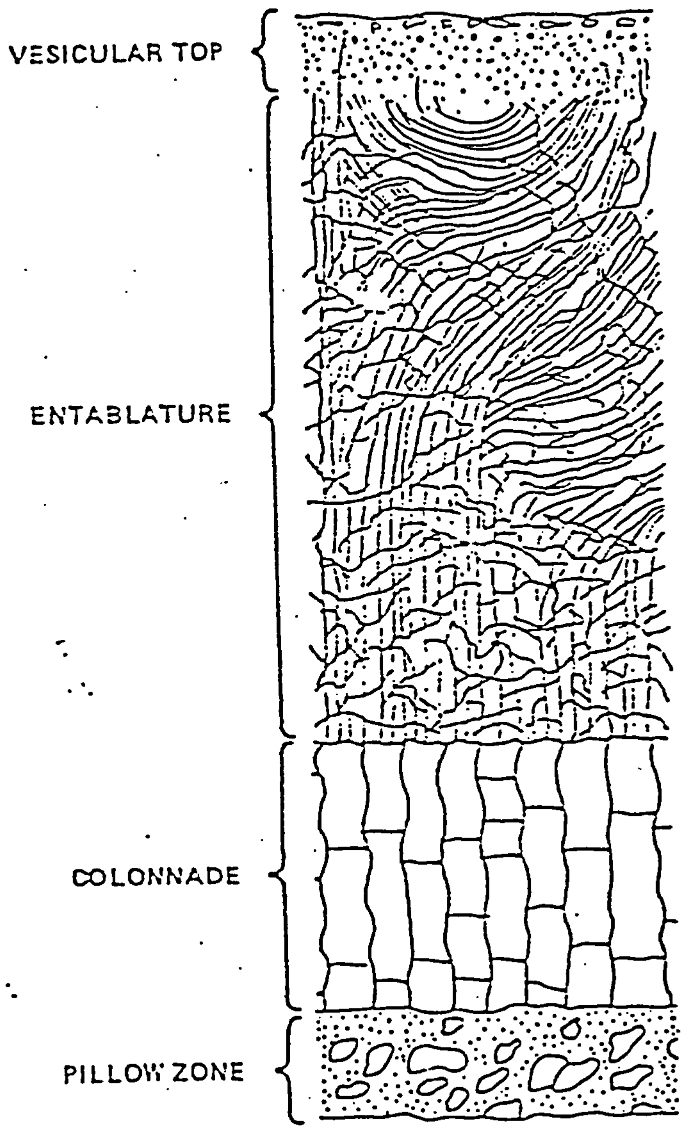

FIGURE 2. SCHEMATIC DRAWING TO ILLUSTRATE THE STRUCTURE OF A COLUMBIA RIVER BASALT FLOW

Stratigraphic studies of basalt in the Pasco basin use exposed stratigraphic sequences, geochemistry, paleomagnetics, and borehole geophysical logs during drilling to identify formations.

Several deep holes have been drilled on or near the Hanford Site for purposes of defining the stratigraphy, structure, and hydrology of the Saddle Mountains, Wanapum, and Grande Ronde basalts (Figure 3). In particular, the Grande Ronde basalt has been penetrated by 14 deep holes drilled in the Pasco basin (DC-2/DC-1, DC-4/DC-5, and DC-8/DC-7 are core hole/rotary hole pairs, drilled at the same location). There is, however, no complete inventory of all information on the Umtanum available for peer review.

Current plans for the exploratory shaft test facility (ESTF, Figure 3) are to drill a rotary hole to obtain stratigraphy and use this information to design the shaft. A second hole, a core hole, would then be drilled for hydrologic testing. Both holes would be outside of the shaft area.

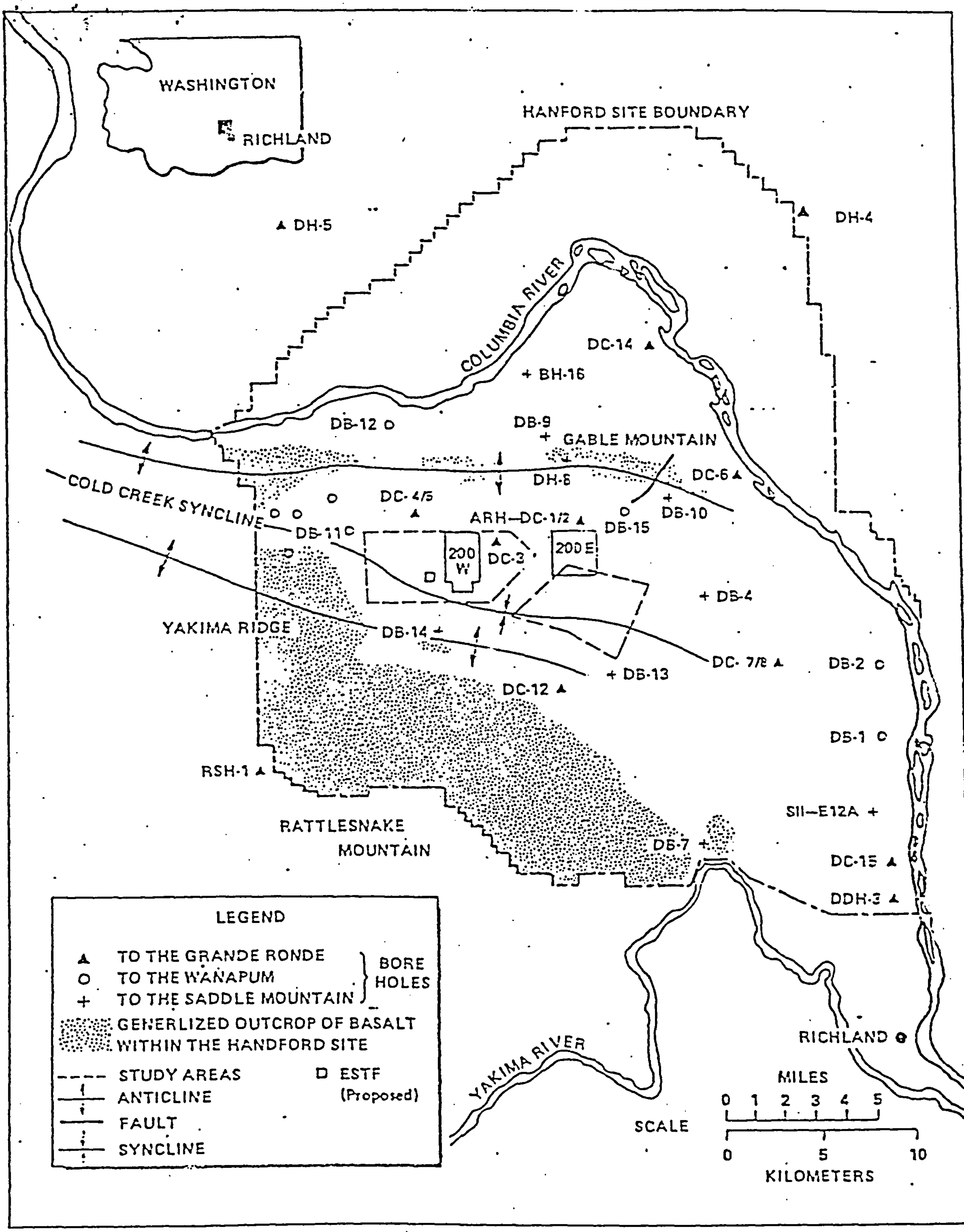

FIGURE 3. LOCATIONS OF DEEP BORE HOLES

DISCUSSION OF ISSUES

A technical question or issue has importance relative to the state of understanding of a particular subject; i.e., when an issue is first defined it usually appears to be of extreme importance and as work proceeds and an issue is resolved, its priority diminishes. The converse of this observation is also true; if resolution cannot be attained, the issue will grow in importance and, for key issues, will lead to abandonment of the site. Thus, the importance of an issue and the priority placed on it are temporal and depend on the state of understanding at the time of ranking. The discussion of issues that follows is based on information presented by the BWIP staff or through Rockwell publications that were available during the period from February through July, 1981.

Because transport of radionuclides by ground water is the most likely means of bringing these materials into contact with people, the issues center around the following four aspects: (1) the amount and rate of supply of radionuclides to the ground water; (2) the volume and velocity of the ground water movement; (3) the length of the transport pathways; and (4) the character of the pathways, i.e., the degree of retardation of radionuclide movement caused by absorption or chemical interactions with the rocks through which the radionuclides are transported. Of these four aspects, item one can be controlled through design of the waste package and of the repository. This means that key issues could be present only in items two through four: the volume and velocity of ground-water movement is controlled by the geohydrology of the site and the relative permeability and porosity of the basalt sequence; the path length is controlled by the stratigraphy and structural geology of the site, including past and future tectonics; and the character of the transport path is controlled by and indicative of the geochemical and thermal character of the system of basalt flows. Thus, items such as geology, hydrology, and geochemistry were selected as areas in which key issues could be found.

Geologic Issues. In the vicinity of the Pasco basin, the Columbia Plateau exhibits considerable, intense structural deformation of a young age (recent movement is younger than approximately 13,000 years at the Gable

Mountain Fault). This includes tight, overturned anticlines and associated thrust faults. These structural features, along with the primary structural features of the basalt flows and the interbeds, make for a domain that will be difficult to model hydrologically. This is compounded by the fact that the geology of the basin is covered with Cenozoic sediments which mask the geologic structure superimposed on the basin..

The principal means currently available to define the structure of the RRL is stratigraphic correlation of core holes (based principally on geochemistry and paleomagnetic data) and geophysics, which is for the most part restricted to defining deep, possibly basement structures, and shallow, top-of-basalt features. There is no certainty that geophysics can define the setting of the Umtanum layer with the necessary precision. Anticlinal ridges plunge below the sediments and surface faults, such as the Gable Mountain fault, are only exposed near the resistant anticlinal ridges. (1)

The tectonic setting of the region is not well understood. The mode of deformation of the Columbia Plateau and the possible seismic significance of the Cle Elum-Wallula zone of deformation bounding the Pasco basin on the south remain open to debate. In addition, the state of stress at the reference repository horizon has never been measured. The horizontal-to-vertical stress ratio at depth is expected to be greater than unity. (2) (3)

All of these geologic issues must be considered in any evaluation of the ability of the basalts of the Columbia River Plateau to successfully isolate radioactive wastes. In particular, the distribution of structures and stratigraphic discontinuities and their tectonic history can influence the pathway of fluid migration. The in situ stress ratios will influence the development of the repository itself. A clear and concise evaluation needs to be made of the in situ stress at the location of the exploratory shaft, the seismic and hydrologic significance of the Gable Mountain fault, and the mode of deformation of the Columbia Plateau.

In situ stress is a key issue only at the reference repository location. Sections of basalt core from different core holes and different stratigraphic horizons tend to break spontaneously into disc-like sections. This indicates that residual stress is present in the basalts, at least locally. The cause of this discing, and its implication on repository development and host rock permeability, are at present unknown, but, in general, discing is associated with high horizontal stress. There are no known measurements of stress at depth, although the horizontal-to-vertical stress ratio is expected to be as high as 3.

While the stress conditions will be grossly uniform over the extent of the basin, they will vary locally due to the variations in stiffness and strength characteristics of the rock. There may be local anomalous zones (stress gradients) that could be a factor in repository design. Considering the thickness constraints of the Umtanum and the possible lateral change of rock characteristics over the scale of a repository, stress considerations will influence the design of the repository openings.

The Columbia River basalts have undergone north-south compression within the last 6 million years which has resulted in generally east-west trending features such as faults, anticlines, and synclines. One of these features, the Gable Mountain fault, lies close enough to the reference repository location so that tectonic stress buildup and release associated with fault movement could have altered the permeability of the basalt near the proposed repository site. Both the lateral and vertical extent of the fault zone should be mapped in detail. Since the fault may be considered capable by the Nuclear Regulatory Commission (NRC) for U.S. Geological Survey and Washington Power Public Supply System (WPPSS), it will also be a factor in the licensing of a nuclear waste repository. The significance of small offsets in the gravels above the fault, as well as any linear extent of the fault below the Cenozoic sediments in the direction of the RRL, needs to be evaluated for seismic design consideration. (4)

Core hole DB-10, down dip of the Gable Mountain fault, 0.5 miles south of Gable Mountain, revealed two fault zones that have the same sense of movement as the Gable Mountain fault. They were not, however, oriented cores.

The combination of the young age of the Gable Mountain Fault and the lack of a definative evaluation of its tectonic order together with the high horizontal to vertical stress ratio and the finite strain rate for the region, raises serious questions as to the future (seismic) activity of the fault, as well as other similar and related features. This could raise serious licensing issues from both hydrologic and tectonic points of view. (5)

The mode of deformation of the Columbia Plateau is a measure of its past tectonic and seismic history and a key to future performance. The two schools of thought on the issue include a thin-skinned model, involving north-south compression of the basalts above the basement, and a thick-skinned approach with basement involvement. The latter approach relates deformation to faulting and/or rotation of deeper basement fault blocks. Interpretations of the seismic stability of the site vary, depending upon the theory used in an analysis. There are open debates on the significance of regional features, such as the Cle Elum-Wallula zone of deformation. A neotectonic model for the Columbia Plateau with emphasis on possible seismic source zones needs to be developed. (7)

The primary geologic issues in priority order are:

1. Evaluation of in situ stress at the location of the exploratory shaft
2. Evaluation of the Gable Mountain fault
3. Determination of the mode of deformation of the Columbia Plateau

Does Plan site Ch. address these?

Hydrologic Issues. Hydrology plays a key role in determining the isolation potential of any host-rock formation. Key issues in hydrology are related to the ability to predict the velocity of flow and in our ability to determine the expected path of ground-water flow. Measurement of characteristics of the geologic system such as permeability and porosity, driving forces such as hydraulic head, and the use of models to aid in understanding and interpreting hydrologic data, are key factors in the determination of the adequacy of a repository in the Columbia River basalts.

The basalt sequence can be generalized as a layered system of partially confined aquifers made up of basalt interflows and sedimentary interbeds. The confining units are formed by the dense basalt interiors, the entablature and colonnade, that are highly fractured. Movement of ground water through the fractures has led to the formation of secondary clay minerals that fill or partially fill the fracture apertures. The regional hydrologic system is characterized by recharge in the higher elevation outcrop areas and discharge in the lower elevations at the Columbia River. A simple conceptual model of the ground-water flow system is shown in Figure 4. In the simple conceptual system ground-water flow would be downward in the vicinity of the recharge areas and upward in the discharge areas.

The hydrologic system in the basalt sequence, at the current stage of understanding, is far more complex than shown by the conceptual model. The

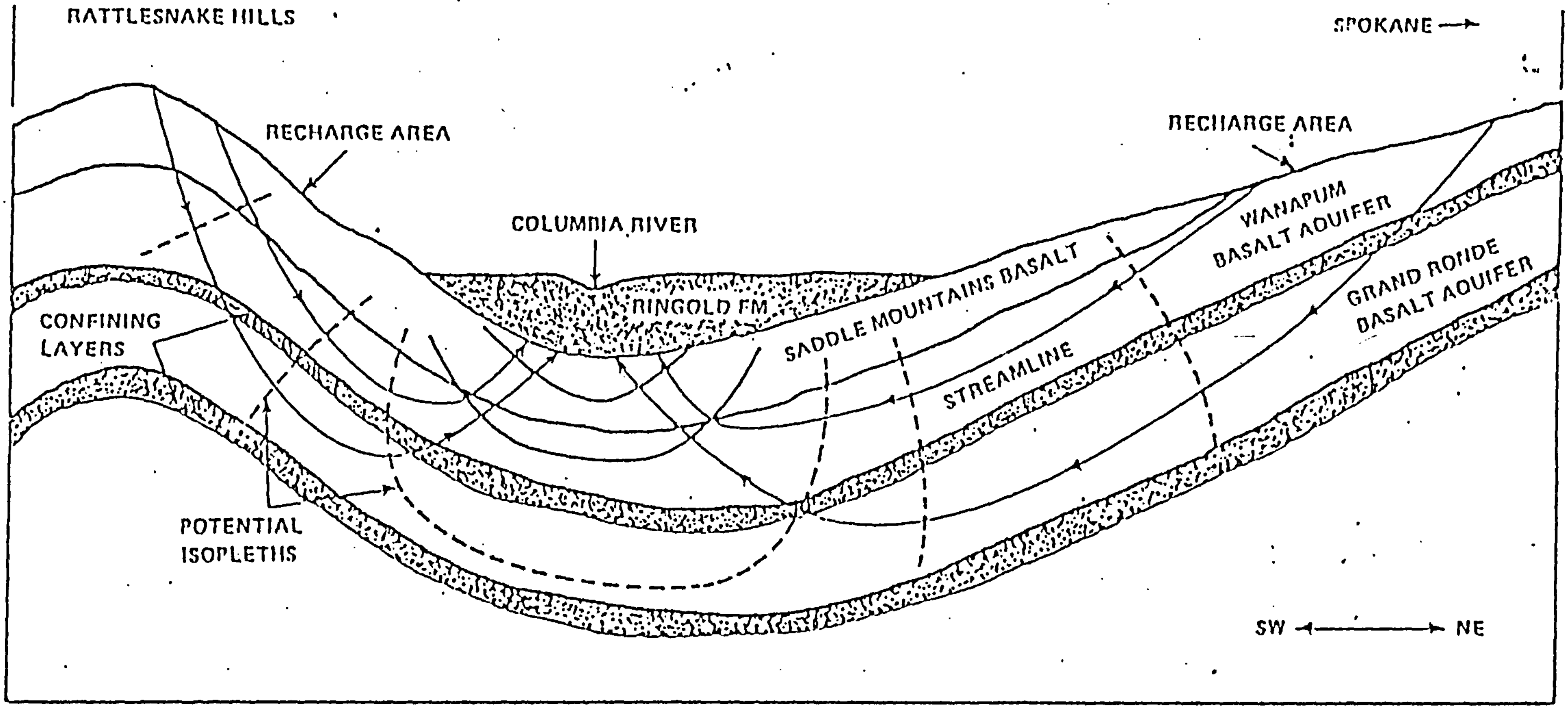

FIGURE 4. CONCEPTUAL MODEL OF THE REGIONAL GROUND-WATER FLOW IN THE COLUMBIA RIVER BASALTS

complexities arise from local structural features such as synclines and anticlines and the changes in vertical permeability that can be associated with folding of the basalt units. These changes of vertical permeability, although not measured, are expected to be in the range of one to two orders of magnitude. Changes in vertical permeability laterally, coupled with local variation of horizontal permeability caused by features such as the amount of secondary mineralization in fractures, could cause extreme local variation in the conceptualized flow; e.g., downward flow locally in the discharge zone. However, such local perturbations, while they require larger amounts of data to analyze, do not diminish the usefulness of the conceptual model for determining the types of data required to understand the ground-water flow system.

The path of ground-water flow from the repository to the Columbia River is important because the travel time of the water is dependent not only on the path length but also on the water velocity along different paths. The system is characterized by low ground-water velocity in the dense basalt interiors and relatively high velocities in interflow zones and in some interbeds (some of the interbeds have relatively low permeabilities). The shortest travel time in this system would take a path of vertical movement to the nearest high-permeability zone (an interflow or interbed) and horizontal flow to a point of discharge. Calculations by Intera Environmental Consultants, Pacific Northwest Laboratories, and BWIP staff indicate that the bulk of the travel time between the repository site and the river is expended in vertical movement upward through the Grande Ronde basalts. These calculations bound the regional mean vertical permeability between 10^{-3} and 10^{-5} feet per day. No measured values of vertical permeability exist. Measured values of horizontal permeability in the same unit vary one to three orders of magnitude and a similar range of vertical permeability can be expected.

Measurement of vertical permeability is key to the determination of ground-water flow travel times, especially in the dense interiors of the basalt flow which contribute to the bulk of the travel time. Calculated ground-water travel times to the Columbia River range from 15,000 to approximately 100,000 years and were calculated based on a repository located in an area of average vertical permeability. Without field measurements of vertical permeability prior to siting the repository there is no assurance that the most favorable location has been selected with regard to this key parameter.

Hydraulic head is the primary driving force for the flow of ground water. High values of head develop in confined or partially confined aquifers simply because the recharge areas are at higher elevations than the discharge areas and resistance to flow at low velocities does not substantially decrease the pressure head. Thus, in lower elevation areas along the Columbia River (see Figure 4), artesian conditions would be expected. Where hydraulic heads are greater than the elevation head of land surface, flowing wells will exist. These conditions exist in the aquifers of the basalt sequence and flowing conditions have been encountered in Wells DC-14 and DC-6 which both lie close to the Columbia River.

Pressure gradients are generally downward in the recharge areas or higher elevations and upward in discharge areas. Locally, pressure gradients vary within a given well; this may indicate pressure drops associated with higher permeability zones and until proven otherwise should be associated with a large range of permeability in the horizontal, and probably the vertical, direction. Pressures representative of undisturbed values are difficult to measure in boreholes because of (1) leakage around the packer system between the packer and the rock or within the fractured rock itself, (2) clogging of the natural interstices in the rock by drilling mud or particles generated by drilling, and (3) the time necessary to reach pressure equilibrium in low-permeability formations.

The calculation of ground-water flow is dependent on permeability and pressure gradient, and in general is more sensitive to variation of permeability than to changes in pressure. However, small changes in pressure across low permeability formations of considerable areal extent can result in flow of large volumes of water in a relatively short period of time. For this reason, and because pressure gradients are key to determination of ground-water velocity and associated travel time, the measurement of hydraulic heads is important in establishing the viability of a repository in the Grande Ronde basalts.

Within the Saddle Mountain and Wanapum basalts, a considerable amount of pressure head data exist. Fewer data are available for the Grande Ronde. Work is under way to collect head data for the deep basalt units; however, existing data should be analyzed for anomalous values (either high or low) and these values should be remeasured before they are given much weight in future calculations. The additon of the deeper head data, and verificaton of data that appear to be anomalous, will lead to greater certainty in understanding of the flow system.

The data base for basalt is adequate to conduct preliminary modeling of regional ground-water flow in the Columbia Plateau and in the Pasco basin. Recent modeling by BWIP staff and Pacific Northwest Laboratories has aided greatly in interpretation of hydrologic data. The direction of ground-water flow from a site near the 200W area is shown to range from northwest to east dependent on model boundary conditions and values of permeability. The models should be used to conduct sensitivity analysis of flow direction to variation in permeability and boundary conditions and the results should be used to guide the field exploration program. In this way, areas can be determined where increased data would improve model results and anomalous values of pressure and permeability can be determined for field rechecking. (8)

Measured geothermal gradients are available in about 16 wells in the basalt sequence in and near the Pasco basin. The gradients range from 0.88° to 1.52°C/100 ft, with bottom-hole temperatures ranging from 20°C to 97°C. The depths of these holes range from 400 to 9,500 feet. There appears to be enough variation in the gradients to make these data useful in the interpretation of ground-water flow. Accurate temperature data, combined with three-dimensional modeling of water movement and heat transport, could aid greatly in confirmation of the understanding of the ground-water flow system. (9) wel agr.

Calculation of ground-water travel time requires that the velocity and path length be known. Velocity is obtained using the ground-water flow equations and then dividing the resulting water flux by the effective porosity of the formations along the path. In dense, fractured basalts such as the entablature and colonnade, the effective porosity is less than 0.01; because the denominator in determining velocity is small, small changes in porosity can cause large changes in calculated velocity and travel time.

Recent travel-time calculations using estimated effective porosities indicate that porosity can be bounded within a reasonable range without adversely affecting the predicted travel time. For fractured rock in general, effective porosities are of the order 10 to 10^{-3} percent and because of the highly fractured nature of basalts the lower values would not be expected.

No measured values of effective porosity have been made in the basalts. However, tracer tests are planned for either paired holes DC-4 and 5 or DC-7 and 8. If these tests are successful, every effort should be made to determine the range of effective porosities along the expected path of radionuclide transport to the biosphere. Measured values are extremely important for the lower porosity units and interflow zones. Laboratory measurement of effective porosities of interbed materials may be adequate if appropriate samples are available. (1t)

Prediction of the point of ground-water discharge from the site to the Columbia River is somewhat uncertain. Models based on pre-1979 data (PNL, Intera, and Rockwell) predict northward flow to the river. The Rockwell version predicts northwesterly flow. These models are based on the assumption that known pressure heads in the Saddle Mountain and Wanapum can be projected into the deeper Grande Ronde basalts where little head information is available.

Modeling by Rockwell staff based on sparse but more recent data (that include head measurements in the Grande Ronde basalt) indicates a southeasterly flow with discharge near Wallula Gap. Much more data are needed to substantiate this result, which appears counter to hydrologic intuition. At present, much more data are available to support the case of northward flow. For either case, travel times for flow of ground water from the repository to the river are in excess of 15,000 years; but the travel-time calculation contains a large amount of uncertainty. The uncertainties arise from the measured or estimated ranges of parameters used in the calculation; e.g., horizontal permeability with a measured range of three orders of magnitude, vertical permeability with an estimated range of three orders of magnitude, sparse head measurements in the Grande Ronde basalt with not enough data to construct a head contour map, an estimated range in effective porosity of about two orders of magnitude, and path lengths that range over a factor of three. If these uncertainties can be reduced through additional refinement of existing data and collection of missing data, then a travel time of 10^4 years is adequate if the uncertainty can be shown to be less than one order of magnitude. In doing this work, the path of flow and point of discharge will be further refined. In this work there is a trade-off between path length and reliability of hydrologic parameters; e.g., if the path length can

What we doing to settle path length

11

conclusively be shown to be longer, say to Wallula Gap, then more uncertainty can be tolerated in the hydrologic parameters.

Because ground-water travel time calculations are based predominately on permeability values that are averaged over several hydrologic units, there is a need to know the largest values of permeability. Highly permeable zones, such as interflows and some interbeds, have the potential of producing shorter travel times than predicted by ground-water flow models that use average values of permeability. The vast amount of data required to include all highly permeable units in a three-dimensional simulation may never be available. If the flow rates in interflows and interbeds are substantially greater than the average flow obtained by modeling, the travel times predicted by the model will not be conservative. When data are available for the highly permeable zones, the conservatism of model calculations can be checked through a comparison with flow directly to the high permeability zone, travel along it, and flow across the upper units to the point of discharge.

The primary hydrologic issues in priority order are:

1. Evaluation of vertical permeability
2. Measurement of hydraulic heads in the Grande Ronde
3. Using hydrologic models to guide field exploration
4. Using temperature data to aid in interpretation of ground-water flow
5. Evaluation of effective porosity
6. Determination of the location of ground-water discharge to the Columbia River
7. Evaluation of flow rates in highly permeable zones.

<u>Geochemical Issues</u>. Geochemical data from boreholes show a vertical distribution of hydrochemistry: water in the Saddle Mountains is of a sodium-bicarbonate type; waters in the Wanapum are sodium-bicarbonate to sodium-chloride-bicarbonates; and within the Grande Ronde the ground water is of sodium-chloride type. In addition, higher concentrations of total dissolved solids, different isotope ratios, and older ground waters occur with increasing depth. The deeper waters contain fluoride; nitrogen increases with depth; and methane is present in all waters, with its highest concentrations occurring above the Grande Ronde.

Geochemical stratification of the waters in the basalt sequence has been presented as support for the argument that the flow in the Grande Ronde is separated from that of the overlying Saddle Mountains and Wanapum basalts. However, this argument can only be supported by showing that the simple conceptual flow model of the basalt sequence (Figure 4) is not compatible with the geochemical stratification.

Geochemical models such as EQ3/EQ6 and FASTPATH should be used to determine whether chemical differences are compatible with the existing interpretation of the ground-water flow system. Achievement of agreement among geochemical data, geochemical modeling, and ground-water flow modeling would provide strong evidence that the predicted ground-water flow is correct. Also, if temperature data were shown to be compatible with geochemistry and flow, their would be little doubt of the adequacy of the understanding of ground-water flow through the basalt sequence of the Columbia River Plateau. Currently enough data exist to begin geochemical modeling in the Saddle Mountains and Wanapum, and by the end of fiscal 1981 enough data will be available to begin preliminary geochemical modeling of the Grande Ronde basalts.

The presence of methane in ground water of the basalt sequence is not suprising; during deposition basalt flows encountered lakes and marshes, as is evident from their basal pillow structure. Organics present in these situations and the presence of thin coal seams in some interbeds, are probably responsible for formation of methane. The quantities of gas in the Grande Ronde should be evaluated and the data used in design of the repository ventilation system, if necessary.

Interaction of ground water flowing through the fractured basalt has caused the formation of secondary minerals. These minerals fill or partially fill the fractures and reduce the permeability of the basalts. The fracture fillings are predominately composed of smectite clays and zeolites. In the presence of relatively low temperatures these minerals are known to undergo chemical changes that decrease mineral volume and release interlayer water (such as the transformation from montmorillonite to illite). If a volume reduction in fracture-filling material were to occur during the thermal pulse, the permeability across the host unit (the Umtanum) could increase and allow more water than anticipated to flow through the repository.

Some recent work indicates, that at the expected values of in situ stress, the temperature is not high enough to cause volume reduction. This laboratory work shows that, with increased stress, the temperature necessary to cause mineralogic phase changes is higher. However, field evidence from deep formations in the Gulf Coast shows that changes in smectite minerals occur at temperatures caused by the natural geothermal gradient. Work should continue and should include geologic analog data collected from geothermal deposits in similar basalt sequences.

The three primary geochemical issues in priority order are:

1. Interpretation of the regional geochemical system
2. Evaluation of the behavior of secondary minerals at increased temperature
3. Determination of the quantity of methane expected in a basalt repository.

Site Selection Issues. Site selection for nuclear-waste repositories generally begins with a set of criteria and a screening process that considers successively smaller land units: conterminous United States, regions, areas, locations, and potential sites. This process can be done either for a particular host rock or in search of favorable hydrologic conditions, irrespective of the host rock present in the identified geologic environments. In addition to these approaches, exploration was begun on federal lands that have already been committed to nuclear activities (the Hanford Reservation and the Nevada Test Site). This exploration was initiated to determine whether these federal lands were suitable for the isolation of nuclear waste. At both locations some attempt has been made to screen land outside but adjacent to the nuclear reservations.

In the case of identification of potential sites in basalt, the use of a mixture of the screening processes described above has left an unclear picture of how the potential sites were selected; no single document either begins with the Hanford Reservation and narrows to potential sites within it or begins with a rock type, basalt, and narrows to potential sites within the Columbia Plateau. This leaves the reader with two possible impressions: that sites on the reservation were predetermined, or that the potential sites selected could not withstand the rigor of either the host rock or the geohydrologic approaches.

The site-selection documents for basalt should be rewritten based on the premise that the Hanford Reservation was selected for exploration because it was dedicated to nuclear activities and, because of this, every attempt to find an adequate repository site on these federally controlled lands was being made. To dispel doubt as to the adequacy of the potential sites selected, the selection documents must clearly begin with the Hanford Reservation and narrow to potential sites, while showing strict adherence to criteria contained in NWTS-33(2) and NRC 10 CFR 60. The primary issue in site selection is not the site selected but the inadequacy of the description of the methods by which it was selected.

From the potential sites on the Hanford Reservation, the most likely site for isolation of radioactive waste will have been selected when the site for an exploratory shaft has been chosen. The exploratory shaft and related testing, while part of site characterization, should also be viewed as confirmation of exploration data that were used to select its location.

In view of the hydrologic and geologic issues, the shaft location should be based to a large extent on a few key parameters (e.g., vertical permeability which in turn is a controlling factor in ground-water travel time, and in situ stress which determines whether design of a facility is feasible under the expected high horizontal stress conditions).

Vertical permeability is expected to vary laterally by about two orders of magnitude. Hence, it would be prudent to locate the shaft at a point of known low vertical permeability. Values of vertical permeability can be measured in boreholes; even though borehole methods are less accurate than testing in mine openings, they can serve as a basis on which to select the shaft location.

The horizontal component of in situ stress is of major importance only at the repository site, and primarily in the host formation. The value of the ratio of horizontal to vertical stress influences the mine layout, the shape of drifts, and the size and shape of disposal rooms. If this ratio were too high, higher than say 3 to 4, it could rule out design of a functional repository because the thickness of the host formation is limited. Therefore, it is prudent to attain some measure of in-situ stress prior to investing in the construction of the shaft itself.

Because of the large quantities of water expected from interflows and interbeds, the design of a shaft should include a performance assessment of its construction.

The two site-selection issues in priority order are:

1. Defining the basis for location of the exploratory shaft
2. Describing the screening process for selecting potential sites.

RANKING OF ISSUES

The ranking of issues at any given moment in time depends on: (1) the state of technical understanding of the subjects to which the issues relate; (2) the project emphasis at that time; and (3) the schedule for development of a repository.

The state of technical understanding of geology related to the issues presented can be briefly summarized as follows: (1) in situ stress is known to have a horizontal to vertical ratio of greater than one, no measurements of in situ stress exist, and measurements are planned in the near future; (2) the Gable Mountain fault is known to have had recent movement, yet no detailed studies of the extent and character of the fault zone (plane) are available; and (3) there is controversy over the mode of deformation of the Columbia Plateau, and some efforts outside BWIP are being made to resolve this controversy.

The state of understanding of the hydrology of the basalt is as follows: (1) vertical permeability has been known to be a key issue since 1978 and the first measurements of it are planned in the FY 1981-1982 time frame; (2) measurement of hydrologic heads has proceeded since the beginning of the program, and every effort is being made to obtain measurements in the Grande Ronde in the FY 1981 and beyond; (3) no attempt has been made to use temperature data for interpretation of ground-water flow; (4) the BWIP staff are beginning to use hydrologic models to guide the field exploration program; (5) no measurements of effective porosity have been made but they are planned in FY 1981 and 1982; (6) recent modeling has shown that ground-water flow is generally northward from the site with discharge to the Columbia River; however, there is still considerable controversy over sparse data that indicate southeasterly flow; and (7) some work has been done on evaluation of flow rates in highly permeable zones.

The state of technical understanding of the geochemistry-related issues is briefly as follows: (1) enough geochemical data exist to begin interpretation of the regional geochemical system, but this modeling work is in a very preliminary stage; (2) some laboratory work has been done on the behavior of secondary minerals at increased temperature that appears to be in disagreement with field evidence from other locations; and (3) methane is known to exist, but no calculations of the quantities expected in a repository are available.

The status of site-selection issues is as follows: (1) attempts to define the basis for location of an early shaft have been under way since the beginning of FY 1981 and considerable work remains to establish this basis; and (2) work is currently under way to rewrite the documents dealing with the screening process used to establish potential sites.

The BWIP project emphasis is currently to: (1) to develop enough geologic and hydrologic data to use these data to select potential sites within the Hanford Reservation (nearly completed); (2) characterize the most favorable potential site to the extent that a shaft and related test facility can be designed; and (3) construct the shaft and related test facility to be used for continued site characterization and to some extent for confirmation of prior site exploration data.

The schedule of the above activities is to complete site selection and shaft and test facility design by early FY 1983. When these designs are completed, shaft construction is scheduled to begin in FY 1983 and completion of both the shaft and shaft test facility is scheduled for the FY 1984-1985 time frame. Preliminary testing in the exploratory shaft test facility will be completed in FY 1985. The conceptual design of the repository is currently under way, with Title I design scheduled to begin in FY 1992. A considerable amount of in situ testing is scheduled between FY 1985 and FY 1992.

Priority Listing. Based on the state of understanding of geology and hydrology, the project emphasis, and the current BWIP schedule, the issues shown in Table 1 were placed in priority order 1 through 15. The first eight of these issues (items 1 through 8 in Table 1) are of nearly equal priority and should be considered key issues that must be resolved in order to establish the adequacy of Hanford for isolation of radioactive waste. Of these key technical questions, issues 4, 5, and 6 should be viewed as convenient tools for confirmation of the level of understanding of the regional and local hydrologic systems. The remaining issues (items 9 through 15) are important but should not be considered key issues because, at the current state of understanding, they can be either compensated for through engineering design or

TABLE 1. RANKING OF IMPORTANT GEOLOGIC AND HYDROLOGIC ISSUES RELATED TO A REPOSITORY SITE IN COLUMBIA RIVER BASALT

Rank	Issue
1	Evaluation of vertical permeability
2	Measurement of hydraulic head in the Grande Ronde
3	Evaluation of in situ stress at the location of the early shaft
4	Using hydrologic models to guide field exploration
5	Interpretation of the regional geochemical system
6	Using temperature data to aid in interpretation of ground-water flow
7	Evaluation of the Gable Mountain fault and related structures
8	Evaluation of effective porosity
9	Defining the basis for location of the early shaft
10	Determination of the mode of deformation of the Columbia Plateau
11	Describing the screening process for selecting potential sites
12	Determination of the location of ground-water discharge to the Columbia River
13	Evaluation of flow rates in highly permeable zones
14	Evaluation of the behavior of secondary minerals at increased temperature
15	Determination of the quantity of methane expected in a basalt repository

described adequately through considerable effort. One of these issues, issue 13, is of great importance in the design of the exploratory shaft.

Issues Related to Shaft Location. Two key issues described in Table 1 relate to the selection of the location for the exploratory shaft. They are evaluation of the Gable Mountain fault and evaluation of vertical permeability.

The evaluation of the Gable Mountain fault is important because it is a young fault trending toward the proposed site. The determination of the the extent of this feature is crucial to the shaft location because any existing lateral extension of it in the direction of the site could affect the site, based on its proximity to a young fault. The character and extent of the Gable Mountain fault must be conclusively evaluated along with any associated linears that may be discovered through analysis of geophysical data. (14)

Evaluation of vertical permeability is important to the location of an exploratory shaft because of the expected range of variation in vertical permeability. Vertical permeability is a major controlling factor in ground-water travel time. Locating the repository at a point of higher values of permeability (within the expected range) could rule out the repository site based on ground-water flow travel time.

Issues Related to Shaft Design. Two key issues and one other issue relate directly to the design of the exploratory shaft. They are measurement of hydraulic head, evaluation of in situ stress, and evaluation of flow rates in highly permeable zones.

Good pressure head data are required for all units having the potential of producing significant quantities of water -- for all aquifers between the surface and several hundred feet below the Umtanum. These data, combined with permeability data and geometry of the aquifers, are used to predict the amount of water expected to flow into the mined or drilled shaft. Because the shaft will bottom more than 100 feet below the Umtanum head, permeability data are extremely useful to evaluate the potential for repository flooding in the event of bottom-seal failure.

The ratio of horizontal to vertical stress is important to evaluate the potential for rock bursts during excavation where conventional mining methods are used. These rock bursts are expected to be of a slow stress release nature, such as spalling. In the case of drilling the shaft, the pressure of drilling mud minimizes the potential for rock bursts.

The value of horizontal stress is especially important to the design of the repository. It controls the size, shape, and spacing of drifts and rooms. Stress ratios greater than four could preclude the design of an economical or functional repository. Therefore, every attempt to measure or predict in situ stress should be made prior to construction of the exploratory shaft.

Evaluation of flow rates in highly permeable zones is important to shaft design for estimating expected inflow during construction. Preliminary estimates of flow into a shaft range from 10^5 to 10^6 gpm, primarily derived from flow-top breccaias and interflows. These values and ranges will have to be carefully revised based on data from the shaft exploratory hole. Dependent on the mode of shaft construction, large quantities of flow can prevent freezing the formation when freezing and conventional mining are used, or may result in washing out highly fractured zones into the hole when the shaft is being drilled.

METHODS USEFUL IN ISSUE RESOLUTION

In this section, methods of analysis and/or issue resolution are discussed for selected issues where measurements and/or resolution are not yet under way. Data collection for issues that are not discussed is either relatively straightforward, requiring only time to obtain enough data, or resolution is near at hand.

Measurement of vertical permeability, because it is required along the areal extent of the transport path from the repository to the biosphere, must be determined by borehole methods. An appropriate method, such as the ratio test, should be applied in paired boreholes. The pulse test could possibly be used in paired holes, one inclined and one vertical, if there appears to be any advantage over the ratio test. At the shaft location, borehole methods of measuring vertical permeability can be compared with later testing from the shaft that will be conducted in horizontal openings or drill holes. The latter method, testing from the shaft, should prove to be more reliable than measurements from the surface in vertical boreholes.

In situ stress measurements comparable to the depth of the Umtanum are made routinely in oil exploration using the method of hydraulic fracturing. However, it is unclear whether this method can be used to determine the high horizontal stress because the most likely direction of fracture should be at right angles to the minimum principal stress.

Overcoring has been used successfully in drill holes to a depth of about 500 feet. It appears likely that, with some development, this method could be extended to measurements in deeper holes.

A third alternative is to estimate the magnitude of the horizontal stress using laboratory methods. Horizontal to vertical stress ratio can be calculated by constructing a curve of radial to axial stress through testing cores to shear failure in the laboratory. Then the axial (vertical) stress can be assumed to be the weight of the overburden and the corresponding value of radial (horizontal) stress can be determined from the radial/axial stress curve.

The geochemical data from the Saddle Mountains, the Wanapum, and the Grande Ronde are currently extensive enough to begin preliminary calculations using the more complex geochemistry models, such as FASTPATH and EQ3/EQ6.

Some preliminary work on these data has been done by Pacific Northwest Laboratories based on limited available data. Enough data are currently available to begin detailed analysis using geochemical models and to compare the results with the predicted ground-water flow system. Also, available ground-water temperature data should be interpreted using flow models that are capable of including heat transport. The results of temperature and geochemical modeling, if successful, could considerably reduce the uncertainty of the ground-water flow predictions.

The controversy over the mode of deformation of the Columbia Plateau could be reduced considerably through a workshop where participants presented their views and interpretations and agreed on which theories merit further work. This workshop should be sponsored by DOE with close coordination with the U.S. Geological Survey (USGS) and Washington Public Power Supply System (WPPSS).

The determination of the point of discharge to the Columbia River and the apparent disagreement caused by recent data and new interpretations that have not been released by Rockwell should be resolved. An approach to resolution would be for Rockwell to release the data, and their interpretation of it, to interested parties. After a reasonable review period (say 4 to 6 weeks to allow other investigators time to analyze the data and results), there should follow a presentation of the data and their interpretation by the Rockwell staff.

The laboratory results showing that volume reduction of secondary minerals at increased temperature is not a problem at repository depth should be substantiated. One way of doing this is through the use of geologic analogs. In this case, a good geologic analog is available from geothermal deposits in layered basalt sequences. The secondary minerals from these geothermal areas, from depths equivalent to the depth of the Umtanum, should be analyzed to determine whether volume reduction has occurred through phase changes in the fracture fillings.

CONCLUSIONS AND RECOMMENDATIONS

The adequacy of the Columbia River basalts for isolation of high-level wastes in a mined repository can only be confirmed after key issues are resolved. Steps to resolve these issues can be taken prior to sinking an exploratory shaft and preliminary evaluations of items such as vertical permeability and in situ stress would aid in the location and design of the shaft and related test facilities.

At the current state of understanding of the geologic and hydrologic systems, the isolation capability of the proposed site appears adequate, with a considerable amount of uncertainty in the predictions that have been made. As the geologic and hydrologic data base for the basalt sequence is increased, the uncertainties associated with ground-water flow, transport, and travel time of water and radionuclides to the biosphere will be reduced. However, because of the structural and stratigraphic complexities of the basalt flows, and the partially confined aquifer system they contain, uncertainty of predictions will always remain higher than for comparable sedimentary sequences. The basis for this belief is that basalts contain some of the largest freshwater aquifers in the western United States. The Pasco basin lies in the discharge zone for these partially confined aquifers, which results in upward pressure gradients. Flow of ground water through fractured systems is not as well understood as for anisotropic homogeneous materials. Also, geologically speaking, the deposition of the basalt sequence and the tectonics associated with their folding and faulting are relatively recent; e.g., the processes that produced the geologic structures in the basalts are still proceeding at a finite rate. If the uncertainties associated with predicting repository performance cannot be reduced substantially, they will lead to problems in licensing a repository on the Hanford Reservation.

In general, the authors found that data contained in BWIP reports were not presented in a very usable form (e.g., to answer any given question many reports, maps, tables, and cross sections are required). Usually an appropriate section or page of the report could be found that should have addressed the given question; however, it was always lacking in the amount of detail needed. The data needed were always found, but with considerable effort.

For this reason, the authors believe that the descriptive reports will have to be entirely reworked before they can serve as useful references for future licensing documents. The primary reason for recasting the documents is to significantly reduce the time required for review during a licensing procedure.

Every attempt should be made for rapid release of geologic, geochemical, and hydrologic data so that other investigators in the NWTS Program can review and use them in their calculations. Early release of data and interpretations would tend to take advantage of expertise in other parts of the program that currently is not being applied to the potential basalt site.

A summary of the discussion of issues is presented in Table 2. The issues are presented in priority order, along with a brief status, recommended methods of resolution, and the primary use of the information (Table 2).

In addition to the recommendation made above, recommendations related to specific issues are as follows:

- Vertical permeability should be evaluated using two-well tests at the site and in several other locations prior to shaft sinking.
- A potentiometric map of the Grande Ronde should be constructed as soon as possible.
- In situ stress should be measured or estimated in the Umtanum at the site prior to shaft sinking.
- Work should be initiated to interpret geochemical data using hydrochemical models and the results should be compared with predicted ground-water flows.
- Detailed temperature data should be collected from available boreholes, and analyzed using thermal-hydrologic models, and the results compared with interpretations of ground-water flow.
- Work by BWIP on the analysis of the extent and character of the Gable Mountain fault should proceed as rapidly as possible.
- The basis for selecting the location of the exploratory shaft should include a performance assessment of its construction.
- A DOE-sponsored workshop should be held on the mode of deformation of the Columbia Plateau. Participants should include ONI,

TABLE 2. SUMMARY OF GEOLOGIC AND HYDROLOGIC ISSUES FOR DEVELOPMENT OF A REPOSITORY IN COLUMBIA RIVER BASALT

Rank	Issue	Category	Status	Recommended Methods of Resolution	Primary Use of Information
1.	Evaluation of Vertical Permeability	*	Key issue since 1978, first measurements planned in FY 81-82	Two well tests by ratio or pulse testing; confirmation at repository site by testing in horizontal openings	Calculation of ground-water travel time both at the repository and along the flow path to the biosphere
2.	Measurement of Hydraulic Head in the Grande Ronde	*	Primarily shallow measurements to date with emphasis on Grande Ronde since FY 81	Same as being applied	Interpretation of both local and regional flow systems
3.	Evaluation of In Situ Stress at the Location of the Exploratory Shaft	*	Horizontal-to-vertical ratio of about 3, no field measurements; field measurements planned	Hydrofracture, overcore in deep holes if possible, or laboratory evaluation	Repository and shaft design
4.	Using Hydrologic Models to Guide Field Exploration	*	Beginning to use hydrologic modeling to guide field exploration	Same as being applied	Reduction in time and cost of exploration
5.	Interpretation of the Regional Geochemical System	*	Current data adequate for these interpretations; work not initiated	Interpretation using currently available geochemical models	Confirmation of interpretation of ground-water flow
6.	Using Temperature Data to Aid in Interpretation of Ground-Water Flow	*	Some data available but no work initiated	Interpretation using available models	Confirmation of interpretation of ground-water flow
7.	Evaluation of the Gable Mountain Fault and Related Structures	*	Capable fault trending toward the repository site, no detailed analysis of extent and character of fault zone available	Standard geotechnical methods	Licensing and determination of meeting criteria
8	Evaluation of Effective Porosity	*	Has been bounded to some extent through modeling, no field measurements available; tracer tests planned in FY 81-82	Tracer tests as planned	Calculation of ground-water travel time; needed along path length
9.	Defining the Bases for the Location of the Early Shaft		Currently being defined	Same as being applied	Documentation of decision to begin shaft
10.	Determination of the Mode of Deformation of the Columbia Plateau		Open to debate, some work under way outside NWTS program	DOE-sponsored workshop with coordination with USGS and WPPSS	Licensing
11.	Describing the Screening Process for Selecting Potential Sites		Work currently under way	Same as being applied	Licensing
12.	Determination of the Location of Ground-Water Discharge to the Columbia River		Disagreement based on FY 1981 data; otherwise agreement of southward flow to Columbia River	Release of new data and interpretation by Rockwell followed by presentation meeting	Determination of ground-water flow path length to the biosphere
13.	Evaluation of the Flow Rates in Highly Permeable Zones		Some work has been done; work continuing	Same as being applied	Check of conservatism of travel-time calculations and shaft design
14.	Evaluation of the Behavior of Secondary Minerals at Increased Temperature		Disagreement between laboratory data and field observation	Comparison of laboratory data with data from geothermal deposits in layered basalt	Repository thermal loading and/or changes in permeability
15	Determination of the Quantity of Methane Expected in a Basalt Repository		No calculation available	Standard techniques	Repository ventilation design

*Key issues.

Rockwell staff and contractors, USGS staff and contractors, WPPSS staff and contractors, and selected experts in tectonics. In planning this workshop there should be careful coordination with USGS and WPPSS.

- Documents describing the site selection process on the Hanford Reservation should be based on the premise that the area was selected for exploration because it is dedicated to nuclear activities, and that every attempt is being made to find an adequate isolation site on these federally owned lands that are dedicated to nuclear activities.
- The Rockwell interpretation of southeasterly flow from the site should be documented along with all supporting data, the document should be distributed for a six-week review period, and the review should be followed by a Rockwell presentation of results.
- Geological analog data on the behavior of secondary minerals in basalt at increased temperature should be collected from geothermal deposits in comparable basalt settings.
- A calculation of the amount of methane expected in a basalt repository should be made.

Groundwater Hydrology
P.O. Box M, Station A
Champaign, Illinois 61820

(1) Miller
(2) Martin

June 24, 1980

1. Should we have Schlomo Neuman assist us in future Hanford evaluations?
2. See A 4.5 This may be the best resolution of the "accessible biosphere" impasse as applied to Hanford.
3. See A 5.1. Is this an issue with us? Have we seen Geology overview panels report?

TO: R. B. Goranson, Project Manager
Basalt Waste Isolation Program
U.S. Department of Energy
Richland Operations Office
Richland, Washington 99352

FROM: Hydrology Overview Committee
Patrick Domenico
William Dudley
R. Allan Freeze
Peder Grimstad
Shlomo Neuman J.
Frank Parker J
F. J. Pearson

Dear Dick:

Enclosed you will find our report dealing with the site and program assessment at Hanford along with some recommendations for further studies. We look forward to exchanging views with both DOE and RHO in early fall.

Sincerely,

Patrick Domenico

Patrick Domenico
Chairman

PAD:jr

Enclosure

4. B 2.2. Are we assessing this?
5. B 2.3 Get me the Neuman-Witherspoon paper. ('69 and '72) Do we have all the papers referenced here? Have they been thoroughly digested?
6. In B 6.7(3) what meant by "anomalously low heads"?
7. When will we have a comprehensive rackout of all the problems these people, Duguid, & us have raised?

H Y D R O L O G Y   O V E R V I E W   C O M M I T T E E

Report On Hydrologic Studies
Within The Columbia Plateau,
Basalt Waste Isolation Project

Patrick Domenico
William Dudley
R. Allan Freeze
Peder Grimstad
Shlomo P. Neuman
Frank L. Parker
F. J. Pearson

INTRODUCTION

The comments contained in this report are based on a level of understanding of the Hanford site and ongoing investigative program obtained from the Geology and Hydrology Integration Reports, the Planning Documents of December, 1979 and May 7, 1980, and various other documents requested by members of the Overview Committee. This information has been supplemented by discussions with and presentations by Rockwell staff actually performing the work. These presentations were conducted on a highly professional basis and the Rockwell staff is to be commended for their candid and frank approach in discussing the hydrologic aspects of the Hanford site.

With regard to these hydrologic aspects, two tasks are identified and addressed in this report. The first deals with our own preliminary hydrologic assessment of the Hanford site. These discussions admittedly focus on the negative component of our response along with some serious questions that require further assessment. This is not meant to be a site suitability analysis in that we recognize that hydrology is only one part of the technical attributes of a potential repository, political, social, and engineering feasibility being others. In this section, we restrict ourselves to our respective areas of professional competence and focus only on those hydrologic conditions that are considerably less than ideal insofar as a repository location is concerned.

The second part of this report is our assessment of the investigative program. Much of this information has already been presented in our individual letters to R. Goranson and the purpose here is to update our response in view of the new (May, 1980) Planning Document and to present our concensus opinion.

A. SITE ASSESSMENT

A1. Initial Statement

On page I-2 of the Hydrology Integration Report, it is stated that the Hanford Reservation is under study "because of the favorable geology of the site". We trust that this is not a representative attitude. There is really only one solid justification for studying this site and it is the sociopolitical fact that the land is a U.S. nuclear reservation. The true state of affairs is that the Columbia River Basalt Group as a whole is not well suited for a high-level waste repository. It may well be that with further data and/or careful engineering design it can be shown to be acceptable, but it cannot be stated that the "geology is favorable". *

A2. Flow Patterns

A2.1. The HIR makes the case that the most likely discharge area for the Columbia River basalts is the Lake Wallula portion of the Columbia River (Region II, enclosed Figure 1). The reason for the espousal of the Lake Wallula discharge area appears to be the apparent lack of hydraulic interconnection between the interbed aquifers beneath the Columbia River in the vicinity of the Hanford Site (HIR II-147; III-199(b);

III-202(b); III-203(c); III-205; III-208(b)). The Wallula discharge area is quite at variance with the usual conceptual models of regional groundwater flow in that a valley of the prominence of the Columbia River Valley is almost always a regional discharge area all along its length. The hydraulics of the situation forces this to be the case. This latter interpretation is borne out by the available data. The potential surface for both the unconfined aquifer (HIR III-67 and Plate III-4) and the Mabton interbed (HIR III-98) at the base of the Saddle Mountain basalts indicates that flow in Region I is eastward and perhaps somewhat southeastward toward the Columbia River. The composite potential map of the Wanapum basalts (Plate II-10) indicates a groundwater divide in the vicinity of the southwestern border of the Hanford Site, with flow directed eastward or northeastward through the Hanford Reservation and toward the Columbia River. In addition, composite potentials west of the River in the Wanapum aquifers suggests that flow entering from Region IV (Figure 1) cannot readily pass under the candidate sites in Region I, but must instead discharge into the Columbia River along its reach. In short, the Columbia River appears to be a major sink for groundwater discharge from the unconfined, Saddle Mountain and Wanapum aquifers. As will be discussed in A3, it is not necessary that there be a highly permeable hydraulic connection across the basalt flows in order for this discharge to take place.

A2.2. The question of whether the lowermost basalts (Grande Ronde) will discharge into the Columbia River or transmit underflow into a more regional system depends on the thickness of various layers, the overall hydraulic gradient from the divides to the Columbia, the relative hydraulic conductivity values of the component flows and interflows, and the existance of a regional sink of greater prominence than the Columbia River. The report suggests such an interbasin transfer, not only from but to the Grande Ronde System. Although data are apparently not sufficient to resolve this question of discharge location, we would be quite surprised if the flow pattern discussed in A2.1 fails to hold up for the deep hydrology. Again, the prominence of the Columbia River sink would seem to rule out interbasin transfers across it.

A2.3. Interbasin transfers to the Grande Ronde system would have to cross some of the topographic ridges, such as the Rattlesnake Hills. Although the Rattlesnake Hills may not be a major topographic high in the region in the same sense that the Columbia River is the major topographic low, the evidence to support this conceptualization is not persuasive.

A3. Vertical Communication

A3.1. The details of groundwater discharge into the Columbia River are not well known and perhaps will never be fully ascertained. However, one thing is reasonably certain: the flow patterns alluded to in A2 and in the conceptual models of HIR II-110, II-141 and, in particular, the finalized conceptual model of HIR III-194 virtually assure that vertical flow must take place in order that discharge be completed. The groundwater discharge may take place directly by vertical movement in the vicinity of the Columbia River or, more prevalently, by a combination of vertical movement though fractures and horizontal movements through permeable interbeds and interflows. Most likely, both take place. It is not necessary that there be a highly permeable hydraulic connection across the basalt flows. Whatever the most likely route (probably both), it is clear that some sort of vertical permeability exists. This permeability may be described on two separate scales. One scale of permeability is well demonstrated on HIR II-23, which shows both entabulature and colonnade basalts criss-crossed by vertical and other fractures. We note further the reference in the Geology Integration Report (GIR III-98) to "hackly entabulature" in drillholes in the Grande Ronde. GIR III-81 records vertical fractures that "transect portions of the interiors of individual flows and, in some cases cross flow boundaries". Fracture measurements in drillholes (GIR III-92) show an average of 3-5 fractures per foot. At yet another scale are included the tectonic fractures of large vertical extent that criss-cross anticlinal structures (HIR III-194). This vertical permeability has not yet been measured on either of these scales although, again, the regional flow pattern provides prima facie evidence that a vertical permeability must exist.

A3-2. In spite of two recognized scales of vertical permeability, Rockwell seems to imply that any vertical hydraulic communication including those pathways for recharge/discharge mechanisms can occur only along major features, say tectonic fractures. We suggest that communication could possibly take place by leakage across even the "low permeability" entabulature and colonnade structures. At any rate, the extent to which such communication occurs, if any, across cooling fractures, tectonic fractures, or both, is not clear at the present time. On the one hand, there is evidence that water levels appear to be responding to surface phenomena such as the importation of surface water for irrigation purposes (HIR II-103, 104). On the other hand, it is not clear to what extent water levels in one formation respond to pumping in another. This is important because if such a response is measurable, it would further increase our suspicion that vertical permeabilities and hydraulic communication between interflows and interbeds is possible across "low permeability" entabulature and colonnade structures.

A3-3. Hydraulic data are the most reliable insofar as providing evidence of vertical communication between the various units. The prospect for such communication is well supported by the data. For example, the potentials in the Mabton (HIR III-28) are greater than the potentials in the overlying unconfined

This is one of our major issues w/ Rockwell & the site characterization program didn't adequately address this. Hoy? are looking over this issue now. Jan 15 meeting

NOW

This is why we are insisting on pump tests relationship holds in spite of the induced water table rise beneath the Hanford Site over the period 1944-1978 (HIR III-64). For the deeper formations, the composite potentials of the Wanapum basalts (Plate III-10) are higher than the composite potentials of the Saddle Mountain basalts (plate II-9).. Other than these obvious conclusions drawn from potential surface maps, the scarcity of available data in deep boreholes limits the conclusions that can be drawn about the vertical distribution of heads in deep basalts beneath the Hanford Site. On the basis of what is known, however, the vertical distribution of hydraulic head indicates a component of vertical movement.

A3-4. As mentioned above, hydraulic data are the most reliable insofar as providing evidence of vertical communication between the various units. Other types of data may be considered in a supplemental capacity but do not have the same degree of reliability. Included here are water dating and hydrochemical evidence. Unfortunately, Carbon 14 data are scarce, with eight values in the Mabton (HIR III-167), two values from the Wanapum (HIR III-178), presumably the Priest Rapids, and no values reported from the Grande Ronde. The quantitative usefulness of these data is suspect due to drilling fluid contamination and cross communication (HIR III-177). Of the data available, however, waters in the Wanapum are not that "older" (indeed some are younger) than waters from the overlying beds of Saddle Mountain, and some sort of vertical mixing cannot be ruled out (compare Tables on HIR III-167 and III-178). See also Section B5-2 of this report.

A3-5. On the basis of hydrochemical work, Rockwell suggested that "the distinct areal difference in chemical types suggest a lack of communication between aquifers of the Saddle Mountains and Grande Ronde basalts (HIR III-189)". The evidence indicates a sodium bicarbonate type of water in the Saddle Mountains and upper Wanapum, and a sodium-chloride, bicarbonate water for the Grande Ronde (HIR III-189). The suggested lack of communication may or may not be existent. For example, the vertical distribution of waters clearly reflect largely sedimentary rock (interbed) waters in the Saddle Mountains and upper Wanapum where interbeds are quite common, and volcanic rock type waters in the Grande Ronde where sedimentary interbeds are rare. Any degree of mixing between these waters may be masked by dilution mechanisms in the more permeable upper Wanapum and Saddle Mountain units, especially in the highly permeable Priest Rapids and Mabton units.

A4. Horizontal Flow Paths

A4.1. The basalt flows of The Columbia River Basalt Group are separated by interbeds that are relatively thick and in many cases very permeable. The Mabton interbed for example, may be up to 150 feet thick (GIR III-17, III-45), and has hydraulic conductivity values of 1 to 100 ft/day (HIR III-131). The Rattlesnake Ridge, Selah, and Cold Creek interbeds have similar hydraulic conductivities, and thicknesses that reach 50 to 100 feet. Transmissivities of these interbeds are high enough that they are referred to as "large yield aquifers" (HIR II-93). Taking an interbed conductivity K of 100 ft/day, a porosity of 20% (HIR II-19, II-122), and dh/dx equal to 0.005, the average linear velocity (the rate at which the unretarded nondispersed contaminant transport will take place) could be as high as 1000 ft/yr.

A4.2. It is apparent from Table 3.20 (HIR III-95) that the percentage of sedimentary interbeds in the Grande Ronde is significantly smaller than in the Wanapum or Saddle Mountain Formations. Nevertheless the stated 6% of 2055 feet still constitutes over 120 feet of interbed thickness. This thickness could be sufficient to deliver significant quantities of discharge to the regional discharge areas at linear velocities on the order noted in A4.1.

A4.3. As high as the permeabilities are in the interbeds, the interflows appear to have yet an even higher permeability, and are numerous and omnipresent, even in the Grande Ronde. Of the seventeen values of hydraulic conductivity measured in the Saddle Mountains, all except one pertains to interbeds (HIR, p. III-128, III-129). It is noted that the one value of hydraulic conductivity measured in the interflow (Elephant Mtn.) is one to three orders of magnitude larger than the interbed conductivity. Of the six values of hydraulic conductivity measured in the Wanapum, four are in the Priest Rapids unit, which is cited as having up to five separate flows (HIR II-16). The four measurements indicate a hydraulic conductivity of 10^3 to 10^4 ft/day (HIR III-133), indicating that Priest Rapids interflows may be the most permeable units yet encountered in the Columbia River Basalts. These measurements indicate a hydraulic conductivity of one to two orders of magnitude greater than Saddle Mountain interbeds that have already been classified as "large yield aquifers" (HIR II-93). Hence, travel times similar to those calculated in A4.1 above could be on the order of 10,000 ft/yr.

A4.4. The low hydraulic head measurements in the Grande Ronde are disturbing. The most likely explanation of these low heads is a high conductivity interbed or interflow beneath the Umtanum Member in the lower Grande Ronde or underlying pre-Grande Ronde sequence. Such a high permeability zone could provide yet another high velocity transport route to the biosphere.

A4.5. Given the short travel times afforded by the permeable interbed and interflow zones, it seems quite reasonable to conclude that once a contaminant reaches such a zone, it has, for all practical purposes, reached the biosphere. Acceptance of this view, either in whole or in part, has several implications. First, it may render as secondary the question of

Rockwell, in Region II (HIR I-10), which is almost twice the distance from a potential repository. This could provide some guidance in the location of and purpose for future boreholes. Second, it makes clear that the main line of defense against radionuclide transport (other than the engineered repository) lies in the basalt flows themselves. That is to say, the containment will be determined by the degree of vertical hydraulic communication between the repository and the various permeable interbeds and interflows. It is with regard to this second point that we reemphasize our arguments on vertical permeability discussed throughout section A3 and reiterate our concern that this permeability has not yet been measured on either of the scales of occurrence suggested by the geology. Thirdly, this point of view provides a theoretical appreciation of the geometry of the field problem that has not yet been recognized in the numerical modeling aspects (Section B7).

This is our major problem with Rockwell

A5. Integrity Of The Umtanum Member

A5.1. There is little doubt that the Umtanum Member is the target unit for a potential repository. The Umtanum has been presented as one thick flow (in excess of 200 feet) so that high permeability interflow zones will not be present. This is at least partly supported by the data obtained to date (HIR III-147). It is not yet proven, however, that the low conductivity zones reported on HIR III-147 are sufficiently thick or laterally continuous. A thickness of 400 feet, which would appear to be the maximum likely entablature thickness, leaves leakage routes protected by less than 200 feet of at least slightly fractured rock. In addition to the small values reported on HIR III-147, there are some large values of hydraulic conductivity in the Grande Ronde (300 ft/day, HIR III-140), as well as numerous lost circulation zones (HIR III-139). There is also the question of lateral continuity of thick flows, especially in the vicinity of Pillow Palaginite complexes (GIR III-86, III-88). The intraflow structural details reported on GIR III-100 points to the possibility of interbeds elsewhere in the Umtanum. Does all of this imply that the chances of finding a suitably massive block of Umtanum that has low permeability throughout are small? Because of the permeable interbeds and interflows that are known to exist in younger rocks, the integrity of the Umtanum is of first rank importance and has not yet been sufficiently demonstrated. We would be most interested in the Geology Overview Panel's views as to the data that points to a single flow origin.

Is this an issue in our report?

Have we seen this report?

B. PROGRAM ASSESSMENT

B1. Initial Statement

The Hydrology Overview Committee is in complete accord with the following directions of investigation initiated and advanced by Rockwell personnel:

a) The attempt to evaluate the Pasco Basin hydrology within the context of the overall regional hydrology of the Columbia Plateau.

b) An attempt at establishing and verifying conceptual models of flow, both regionally and locally. A demonstrated consistency between the field data and the final conceptual model is the essence of field hydrogeology, and is the starting place for the quantitative predictive models.

Although we are in agreement with this general approach to the hydrology of Columbia River Basalts, our focus in this section is on the negative component aspects of the total program. One general comment seems appropriate here. Namely, the HIR engages in too much speculation and too little analysis of hard data. Such data are currently scarce and, in some cases, confusing. Priority item #1 must be a rational and comprehensive data collection program guided by modeling studies based on current information. At present, the modeling effort (HIR IV) seems divorced from the interpretive work of the hydrologists (HIR II and III). There is a strong need for more interaction between modelers and hydrologists in order to help interpret available data and to help design the collection of additional data.

B2. Field Testing Program

B2.1. The field testing program does not appear to be tailored specifically either to low permeability rocks in general or to fractured rocks in particular. It includes very few tests designed to measure fracture parameters as such. For example, there is no mention of utilizing oriented core samples, downhole televiewers, cameras, acoustic logs, or impression packers to delineate fracture densities, orientations, apertures, roughness, and mineral coating. The utility of performing laboratory tests on core samples to obtain a continuous log of porosity, compressibility, permeability, and distribution coefficients for each new borehole is not explicitly recognized. The integration report does not quote any results of core analyses.

Have these now been done?

B2.2. Of the parameter evaluation techniques used, few are designed specifically for low permeability fractured rocks. However, fractured rocks may often respond to pressure tests in a manner which differs from that of a porous material. For example, the permeability of a fractured rock may depend strongly on the applied pressure. Fractured rocks appear to be anisotropic, and their principal permeabilities need not, in general, be oriented in the horizontal and vertical directions. If the blocks between the fractures are porous or traversed by relatively small cracks, they may yield or absorb water under pressure, leading to a characteristic "delayed yield" response during testing. During the last decade, there has been a considerable effort to develop pumping and packer

Are we assessing this?

tests which take into account the peculiar nature of fractured rocks. Some of these may be applicable to the Hanford Site.

B2.3. As described throughout this report, one of the most important hydraulic parameters affecting the possibility of contaminant migration is vertical permeability. According to the HIR, this parameter is to be evaluated by means of the conventional Theis (1935) and Hantush-Jacob (1955) type curves. There appears to be some misunderstanding here in that Theis' formula does not involve vertical permeability and therefore, cannot be used for this purpose. The Hantush-Jacob leaky aquifer formula is based on simplifying assumptions which are most probably not satisfied in the deep formations of the Pasco Basin. Neuman and Witherspoon (1969) have shown that if one tries to apply this formula to situations where the underlying assumptions are violated, the computed permeabilities may suffer from large errors. Furthermore, the Hantush-Jacob method is unsuitable for cases where the permeability of the confining layers is very low. A more suitable method for determining the vertical permeability of confining layers is the ratio method of Neuman and Witherspoon (1972). The vertical permeability of a confined aquifer can be determined with the aid of Hantush's solution for a partially penetrating well (Weeks, 1969). However, all of these methods have the disadvantage that they require the installation of piezometers either into the confining beds, or into the aquifer. Thus, it may sometimes be more convenient to consider single well measurement techniques such as those proposed by Burns (1969), Prats (1970), and Hirasaki (1974). A good summary can be found in the book of Earlougher (1977). The use of inclined boreholes can also be considered in this context. However, the ultimate test of vertical permeability on a scale meaningful for mathematical modeling of repository conditions is probably that based on horizontal boreholes and galleries as proposed by Witherspoon (1979) on the basis of his recent experience in Stripa, Sweden. Packer tests affect only a very small volume of the rock mass, within a radius of only a few feet from the center of the borehole. This implies that hydraulic parameters measured by means of packer tests are meaningful only on a local scale. In order to obtain estimates of these parameters on a larger scale, one must resort to interference tests involving piezometers and observation wells; and gallery tests of the kind described by Witherspoon (1979). Such tests are either completely ignored or if mentioned (e.g., the Hantush-Jacob method), it is not clear how the drawdown observations will be performed with the limited number of wells to be drilled.

well test

B2.4. So far, no tracer tests have been performed to determine effective porosities, dispersivities, sorption characteristics and ground water velocities. There is no discussion on any means for determining the manner in which dispersivities in fractured rocks vary with the scale of the experiment (as done for porous media by Sauty), or for evaluating the sorptive characteristics of the fractured formation in situ. These parameters will be needed for the transport modeling.

B2.5. Boreholes have been and are to be tested only along selected intervals. The criteria for selecting these intervals are not clear. We believe that continuous testing of each borehole, repeated over intervals of different lengths to study vertical scale effects might be more meaningful.

B2.6. Data are quoted concerning values of effective porosity, storativity, and vertical and horizontal hydraulic conductivity (HIR II-122, II-124). More information is needed about the exact manner in which these data were obtained. For example, how has the storativity been ascertained when there have been no interference tests encompassing two or more wells?

B3. Regional Hydrologic Studies

B3.1. The division of the system into local, intermediate, and regional flow systems as portrayed on HIR II-151 through II-165 is highly schematic and speculative. It does not seem to be based on available measurements of head, hydraulic conductivity, or details relating to stratigraphy and structure. Rather the concept is based on assumptions such as

a) Suspected recharge/discharge areas of local systems coincide with topographic highs and lows.

b) Intermediate recharge/discharge areas are indicated by water levels which indicate "exchange between other systems and the surface" (not clear).

c) Regional discharge is assumed to take place along the margins of the Columbia Plateau whereas local discharge areas are designated on the basis of "judgement".

Hence, as an objective, the conceptualization is fine, but to test the accuracy and precision of the conceptual model one needs to have a sufficient amount of field data. Is this possible with the data (limited) available at the present time?

B3.2. The cross sections showing flow patterns in HIR II-155 and II-160 make little hydrologic sense and may be misleading in that they show predominately horizontal flow in some of the low permeability layers. It should be possible to draw quantitative two dimensional cross sections at true scale based on original data and interpreted potential maps. Back and forth iteration between areal maps and the vertical sectic can often be a rewarding exercise in understanding the three

B3.3. The linear barrier of HIR II-146 and Plate II-13 is an extremely peculiar hydrogeologic interpretation.

B3.4. Regional hydrogeologic cross-sections are best taken along lines that are parallel to the groundwater flow directions (usually parallel to the direction of topographic dip). Such lines are usually curvilinear rather than linear (see HIR III-195).

B3.5. The report speculates on the effect of basalt structure and lithology on anisotropy of hydraulic conductivity, but the speculation does not appear to be based on hard data (HIR II-117 - II-170). Early in the report, the lava was said to have solidified in stagnant pools. On HIR II-120, anisotropy is said to be related to the direction of lava flow. Did the lava flow or was it stagnant during cooling? Where does the information about hydraulic anisotropy come from? Where does the information about the effects of cooling fractures versus tectonic fractures on flow come from? Hard data are needed to elucidate these points.

B3.6. We doubt the relevance of the water-budget calculations (HIR II-85 - II-90) carried out on a basin-wide basis. As noted on HIR II-80, the failure to account for spatial and temporal variability in evapotranspiration (and soil-water holding capacity, and groundwater recharge rates, etc.) probably places the approach in the category of an academic exercise. In addition, we have several questions:

a) Are the totals larger than the error bounds in all cases?

b) Have sensitivity analyses been carried out on the coefficients, especially the 6-inch water-holding capacity? It is usually an unmeasured parameter, and budget results are often very sensitive to its value.

If the water balance has any validity, it should be possible to relate the net recharge (NR) figures (HIR II-163) to a quantitative analysis of the regional groundwater flow nets. There is no reason to limit the water budget studies to surface water (HIR II-79). One should attempt to close the circle with a quantitative analysis of the groundwater flow.

B3.7. Why are the flooding discharges due to a 100% breach not included (HIR III-46)?

B4. Pasco Basin Hydrology

B4.1. The emphasis thus far seems to favor the shallow system with very little information collected for the Wanapum, Grande Ronde, and pre-Grande Ronde system.

a) Seven boreholes have been drilled into the Wanapum, with five of them clustered in the Cold Creek area (HIR III-23, III-24). These five give head data for the uppermost Priest Rapids member. A total of 10 head measurements have been taken in the other two holes (DC-1 and DC-8). Data is not sufficient to provide a potential surface map for any unit in the Wanapum. Six values of hydraulic conductivity have been measured.

b) Four boreholes have been drilled into the Grande Ronde, two of which are very close together. Several head-with-depth measurements have been taken, but the areal distribution of data is insufficient to provide a map of the potential surface in any of the units. Several values of hydraulic conductivity with depth are known from the boreholes, but the regional coverage is inadequate.

c) Apparently, only RSH-I has penetrated pre-Grande basalts, with only one reliable head measurement at about 6000 ft. Hydraulic conductivity is known at two depths in RSH-I.

d) With regard to Carbon 14 dates, two values are known from the Wanapum (HIR III-178), presumably the Priest Rapids unit, and no values are reported for the Grande Ronde. In all cases, the report suggests that the results are suspect due to drilling fluid contamination, cross aquifer communication, or for some other reason.

Clearly more detailed information is required for the Wanapum, Grande Ronde, and Pre-Grande Ronde basalts.

B4.2. The hydraulic head data from individual boreholes (HIR III-96 - III-126) are somewhat confusing. There may be some question as to their reliability. A very thorough and careful program is needed to measure heads at various elevations in all existing wells or the flow regime will never be understood.

B4.3. On HIR III-189 - III-210, tectonic fractures in anticlinal structures are said to be highly prevalent. To what extent do they create high vertical permeability and vertical communication between the hydrologic units? For synclines, groundwater movement is said to be controlled by interflows, interbeds, and cooling fractures. These concepts need to be investigated on the basis of hard data and tested with the numerical models.

B4.4. The basis for the following assumptions on HIR III-159 is not clear:

a) Groundwater flows downdip in interflows and interbeds, and vertical flow across other units is important only near major structural features.

b) Major recharge/discharge areas occur only where basalt is close to the surface unless there is direct contact between high permeability units, or there are structural/stratigraphic complexities.

Given these assumptions, it is clear that the details of flow in the Pasco Basin are in many ways as speculative as in the regional picture (Section B3).

B5. Geochemical Studies And Models

B5.1. There are two main reasons for concern with regional or basin-wide ground-water chemistry. The first is simply that knowledge of the geochemistry of a system helps in understanding the movement of water within the system. In particular, geochemical patterns often are indications of flow paths and, from simple mixing calculations, relative flow amounts. Equally important, an understanding of the rock-water chemical reactions giving rise to the observed regional patterns is prerequisite to using any isotopic method to estimate ground-water ages and flow rates. The second reason for interest in regional geochemistry is to evaluate the potential for radionuclide transport within the regional hydrologic system. Were a repository to be built in basalt at Hanford, and were it to be breached, the most likely transport path to the biosphere would be through ground-water. The existing, natural aqueous geochemistry of the system will be as important as the flow of water in determining nuclide transport rates because the rock and other natural parts of the system will dominantly control nuclide solubilities, sorbtion and other transport parameters in the far field. The geochemical aspects of the HIR, the Hydrology Planning Document, and RHO's ongoing program as presented orally have been considered in the light of these dual objectives. The sum of these considerations are that while the use of geochemical patterns to elucidate the flow systems has been admirable, there does not yet exist a sufficient understanding of the mineral-water chemical reactions which give rise to the observed water chemistry either to provide water ages or to specify potential radionuclide-rock reactions which may affect transport.

B5.2. The Hydrochemistry section of the Pasco Basin Hydrology chapter of the HIR (III-153 - III-210) displays an understanding of the relationship between such overall water chemistry features as major ion percentages and total dissolved solids contents to flow within individual interbed aquifers. In

B6.3. In the RIR, Rockwell states that the ambient temperature is approximately 65 degrees in the Grande Ronde and fracture fillings of clays are predominately smectite, indicating they are the stable phase in the basalt environment. This comment represents a defensive attitude for the site that we do not understand. We have raised here what might be a serious issue that has obviously not been addressed in any detail by RHO, and, in addition, with no apparent commitment to do so. These clays are indeed stable for all practical purposes at the above cited temperature, but what happens under repository temperatures? Included here is a figure (Figure 2) from Eberl and Hower (1976) that shows the % expandable clays at 60 degrees C is about 75% (that is, at 60 degrees the mixed layer clay is initially 75% smectite and 25% illite). At 100 degrees C, the mixed layer is 20% smectite and 80% illite. In the Gulf Coast, this reaction zone coincides with an excess fluid pressure zone which is the result of interlayer water being converted to free water in a low permeability environment. Such excess pressures are not anticipated in a fractured medium such as basalt as a result of this mechanism, but certainly free water and permeability increase are. If the solid volume decrease results only in a porosity increase (that is noninterconnected openings in the fractures), excess pressures can develop if the free water is subject to thermal expansion. Contrary to the RIR, this does not require vaporization (see Domenico and Palciauskas, 1979).

B6.4. Considerably more information is required in terms of the type of smectite in these basalts and a laboratory confirmation of reacting temperatures, volume changes, and interlayer waters made available. Does the nontronite and beidellite, being dioctahedral like montmorillonite, behave similarly in response to temperature rises? Is it possible to drive off interlayer water by heating alone without actually completing the smectite/illite reaction? These questions cannot be dismissed in view of the fact that there exists here a possible site failure mechanism that thus far has not been addressed nor even recognized in any detail by RHO.

B7. <u>Numerical Modeling</u>

B7.1. The most important point to clarify with respect to the hydrologic modeling effort at Hanford is the basic question of the <u>role</u> of modeling in the siting of high level waste repositories. With regard to this current effort, we express some skepticism toward model predictions of specific sites. The worth of such predictions clearly rests on the quality of the input data. This data is in general very difficult to obtain, and at Hanford has proven especially so. The input-data-base (hydraulic conductivities) reported in the HIR is far from sufficient, and the calibration-data-base (hydraulic heads) is completely inadequate. It is questionable whether further drilling results will alter this overall assessment of data-worth significantly.

addition, variation of overall water chemistry with depth as an indication of vertical separation of water masses was described orally. The Hydrochemistry section also reports measured Carbon-14 contents as years (Tab III-40, III-44). The text (HIR III-168) does recognize that these values are not true water ages, but nonetheless reporting them erroneously as years will probably lead unsophisticated readers to consider them as real ages. The point that there exists insufficient hydrochemical data in the Pasco Basin to provide unambiguous age interpretations from measured Carbon-14 data has been made by Pearson and Roden (1975) and LaSala, Doty, and Pearson (1973).

B5.3. The section of the HIR on transport modeling (HIR IV-34 – IV-60) is conventional in its discussion of the effects of dispersion and linear sorbtion processes on radionuclide movement. Such an approach can in no sense be considered a geochemical modeling effort. Water-rock interaction models – geochemical models proper – are being used in the BWIP project by LBL in support of the Engineered Barriers effort. It is regretable that this technology is not even by reference incorporated into the description of regional hydrologic work.

B6. Potential For Phase Transformations

B6.1. In both the geologic (GIR III-91) and hydrologic (HIR II-25) reports, montmorillonite has been reported as a major fracture filling (85% of the fractures, GIR III-91). In a recent RIR, Rockwell cites a 1979 report of Ames that lists the fracture fillings as 35% montmorillonite, 50% nontronite, and 15% beidellite. All of these clays are dioctahedral, which are considerably less stable than trioctahedral clays at high temperatures. Saponite, for example, is a trioctahedral clay that does not readily react below 400-600 degrees C. In addition, saponite is a common mineral associated with basalts, and it is somewhat strange that no saponite was reported. Further, the x-ray patterns for the dioctahedral clays look quite similar to each other, and it is questioned how the percentages cited above were obtained if the clays occur in the fractures as mixtures.

B6.2. Little is known about the reaction temperatures of nontronite and beidellite. Montmorillonite, on the other hand, begins to react at about 60 to 70 degrees C (several in situ observations, Gulf Coast). The reaction produces a large solid volume decrease due to the release of interlayer water. Under repository conditions, it would appear that these fractures containing montmorillonite would be subject to opening, causing (a) an increase in fracture permeability, and (b) the conversion of interlayer water to free water. If this permeability increase takes place between the repository and a permeable interbed or interflow, the integrity of the repository medium is highly questionable. On the other hand, even without a through-going permeability increase, the reaction will produce a considerable amount of free water that is likely to drain into the repository in much the same manner that a tunnel acts as a drain for the water filled fractures that it inter-

B7.2. The transport algorithms are particularly prone to high uncertainties in predictive values that grow out of the data sparseness noted above. The theoretical reliability of the current formulations of the transport equation, especially in low-conductivity fractured rock, is also being questioned in academic circles.

B7.3. Data is too sparse for the long section on model uncertainty (HIR IV-76 - IV-95) to be pertinent at this point in time. It is written at an entirely different level from the other sections, and the approaches it describes are far too sophisticated for the sparse, low-quality data available at Hanford. We appreciate that the RHO staff was attempting to respond to suggestions that model uncertainty ought to be analyzed, but this apparently verbatim quotation of McLaughlin's report does not seem to serve a practical purpose. In addition, there appears to be some misunderstanding of McLaughlin's work. In HIR IV-87, the measurement error is defined as the difference between measured head and predicted head. This is not measurement error but computed residual error.

B7.4. Some comments should be made concerning the near field modeling, in particular the preliminary transport modeling of waste migration given on HIR IV-113 - IV-126. The boundary conditions for this simulation, which create horizontal flow in all formations lead to nonconservative results. In reality, the natural groundwater flow system will produce horizontal flow in the high-permeability interbeds, and vertical flow in the low-permeability basalt layers (as is recognized in point a. on HIR III-199). We would prefer boundary conditions that specify the hydraulic heads at the 4 end points of the two sandstone layers, the rest of the boundaries being impermeable. Contaminant transfer paths will be considerably shorter in this case over that considered in the HIR. This comment appears to also apply to the more recent, more sophisticated, near field models described to the committee on May 9.

B7.5. The preliminary Pasco Basin test model (HIR IV-103 - IV-113) is not very useful. Admittedly, it is presented with much apology, and it is noted that this one-layer case is a first step, but its presentation places in the public domain results of absolutely no significance to the actual hydrogeologic conditions at Hanford. We might also note that the next step that is proposed (a 4-layer model with the layers corresponding to the major formation boundaries) will not be conceptually superior. The minimum level of sophistication in this environment must include representation of the (interbed/flow) aquifer/aquitard geometry. We refer here to our comments in A4.5 regarding an appreciation for the geometry of the field problem.

B7.6. In spite of the negative comments above, hydrologic modeling does have a major role to play in the assessment of sites. It should be used to improve qualitative understanding of system behavior, to carry out parametric and sensitivity studies, to aid in the design of data collection and monitoring programs, and to aid in the design of the near-field repository barriers. We would urge RHO to continue to carry out a major modeling effort, but to switch the focus from the site-specific predictions which appear to be the purpose behind the simulations reported in the HIR to the parametric sensitivity studies suggested here.

B6.7. With regard to an improved qualitative understanding of system behavior, some of the simulations cited below may be helpful.

a) The question of whether the lowermost basalts will discharge into the Columbia or transmit underflow into a more regional system depends on the thickness of the various layers, the overall hydraulic gradient from the divides to the Columbia, and the relative hydraulic conductivity values of the component flows and underflows. A sensitivity analysis of this system is best carried out with a set of steady-state regional groundwater flow simulations in vertical two-dimensional cross-sections through the basin. These cross sections should be true to nature to the extent that data are available and the simulated head distribution should be at least qualitatively similar to those observed in the field.

b) Such simulations can also be used to develop hypotheses for the anomalously low heads in the Grande Ronde (see A4.4 above). These heads must fit into the overall three-dimensional potential field in the Columbia basalt system.

c) Simulations in reference to understanding the three-dimensional potential field (B3.2) and vertical communication (B4.3).

d) During the last two decades there have been significant changes in groundwater levels throughout the Columbia Plateau due to irrigation and water resources development. An effort should be made to utilize these changes as a means of understanding the dynamics of the groundwater system. One approach might be to try and reproduce the observed temporal variations in groundwater levels by suitable numerical models.

e) The problem of mineral transformations and the change over from interlayer water to free water under thermal loading has already been mentioned (B6). Simulations leading to estimates of the volume of water made available are not overly difficult. The process can be described by a first order reaction governed by the familiar Arrhenius equation and for which activation energies are already known. The rate and extent of thermal loading of the rock mass is known from the energy transport phases of the study, and the initial volume of expandable structured clay (collapsable) subject to thermal loading can be estimated from the core studies.

C. AREAS NEEDING FURTHER STUDY

C1. Initial Statement

Many recommendations have been presented throughout this document. We do not intend to repeat them all here but merely to focus on what we consider to be the most important.

C2. Field Studies

C2.1. Hydraulic head distributions in the horizontal and vertical across the Pasco Basin must be carefully and reliably ascertained. In order to be sure that the measurements represent heads at equilibrium between the measuring instrument and the formation, time must be allowed for such equilibrium to be established. This implies head measurements in permanent installations or in packed off intervals which stay undisturbed for sufficient time. It also implies providing data about head variations with time. There is also a need for permanent head measuring installations in order to investigate long term water level fluctuations in response to pumping, earthquakes, etc.

C2.2. Vertical permeabilities must be investigated on a local and regional scale. The effects of cooling fractures and tectonic features must be elucidated. The latter can, as a first step, be studied through model calibrations; later, the answer will have to be confirmed through exploratory shafts, drifts, and tunnels.

C2.3. To answer questions relating to transport, the effect of tectonic features on the possibility of channeling radionuclides into the biosphere must be emphasized via methods discussed above. Some idea must be obtained about effective porosities of cooling fractures and the tectonic features (conduits); about dispersivities in the horizontal and vertical directions, on various scales; and sorption coefficients must be examined in the field. To the extent that such parameters cannot be obtained within the constraints of existing budget and technology, they must be assigned conservative values during the process of quantitative analysis.

C3. Model Studies

C3.1. Models should be used to a larger extent than heretofore as interpretive tools, aiding the hydrologist in his effort to understand the meaning of available data. Next, such models should be used to guide the hydrologist in his decision on what additional data to collect, where, when, and how, i.e., on what scale of measurement. The latter aspect implies appear to be divorced from hydrologic practice, experience, and intuition.

C4. Laboratory Studies

C4.1. The possibility of phase transformations and/or the release of interlayer water must be investigated completely on the laboratory scale. Later, the results of such tests may be verified by in situ tests in the exploratory shafts and tunnels. In addition, it is important that the LBL work on water-rock interactions be incorporated into the description of the regional hydrology.

CONCLUDING STATEMENT

After reviewing what has been discussed in the above pages, a logical conclusion might be "reasonably good program, potentially poor site". Although the Overview Committee is in general accord with this statement, it should be recognized that technical experts of good and equal competence and of good will might, without prejudice, arrive at very different conclusions based upon their experience and upon how risk-adverse they may or may not be. For example, as shown in Figure 3, a risk-adverse person might follow a curve that would be essentially only the abscissa.* That is, he would not have any confidence in the success of a repository until the repository had been in place for 10,000 years or more. At the opposite pole would be a person who, from a cursory glance at the literature, would have 100% belief in the success of a repository. His curve would lie along the ordinate.

These are extreme positions. However, the two positions shown are generalized as the envelope within which most competent geologists, geohydrologists and earth science people would find themselves. They would have some confidence from a survey of the literature to eliminate spots that are unlikely to be successful and their confidence would increase as one made further investigations both at the surface and below ground. The pessimistic person (responsible pessimist) would still not have 100% confidence even after the repository itself was closed, whereas a responsible optimist would believe that, after a reasonable amount of underground exploration, he would have high confidence in the development of a 'successful' repository.

From this envelope of confidence, one can see why there is so much emotion and so much difficulty in convincing all responsible earth scientists that a geological containment is successful or will be successful. We might also note that these envelopes would shift fairly drastically for different rock types. For example, one would expect for rock salt or granite that the envelope would be nearer the optimistic curve, whereas, for some material such as basalt, the envelope of responsible estimates would be closer to the pessimistic lines on the curve. This does not mean that, at specific sites, a rock medium might not be better than a supposedly better rock medium at another site. Obviously, each site must be individually investigated.

But, on a generic basis (which is not a satisfactory way of specifying a site), one would expect certain rock types to have certain inherent advantages over other rock types. Consequently, if all the other processes that go into determining the location of a repository were to be evaluated then one would try, at first, to locate the repository within a certain rock type. Under these conditions, fractured basalt would not rank very high. However, the other conditions cannot be excluded, and, consequently, it is worthwhile, as the President has suggested, to look at a variety of rock types. But one should bear in mind that there are inherent differences between rock characteristics of the different rock types.

At this stage of the investigation of the Columbia River basalts, the program is still within the drill hole phase of Figure 3 and, from the point of view of hydrological attributes, the envelope of confidence lies within the pessimistic region. There is one solid reason for this, namely, that "proving" the Hanford site is equivalent to "proving" the integrity of the individual basalt flow in which the repository is to be emplaced, in this case, most likely the Umtanum. That is to say, the main line of defense against radionuclide transport (other than the engineered repository) would appear to lie in the basalt flows themselves. We do not believe that such "proving" can be accomplished by drilling alone. It is unlikely that the scientific community, or the public, will be persuaded as to site suitability without a deep test facility; i.e., embarking on the exploratory shafts, tunnels, drifts, and in situ testing of the type shown on Figure 3 and espoused by Dr. P. A. Witherspoon in his letter of November 23, 1979, to Colin Heath.

On the other hand, we cannot support a recommendation for a deep test facility at this time. The expense of constructing such a facility could only be justified if positive data is forthcoming from the 1980-81 drilling and testing programs as to the suitability of the Grande Ronde as a repository site. This would include proof of significant thickness, lateral continuity, and low hydraulic conductivity over a considerable test area, supported by measurements in several drill holes. It will also require supporting studies by the modeling group along the lines discussed in this report as well as factual information obtained in laboratory investigations, and the integrated use of all this information as it pertains to the integrity of the Grande Ronde. Clearly, at some point in time, it would be worthwhile to have a combined meeting of all the overview committees (hydrology, geology, engineering barriers). The overlapping technical aspects would make this a worthwhile effort.

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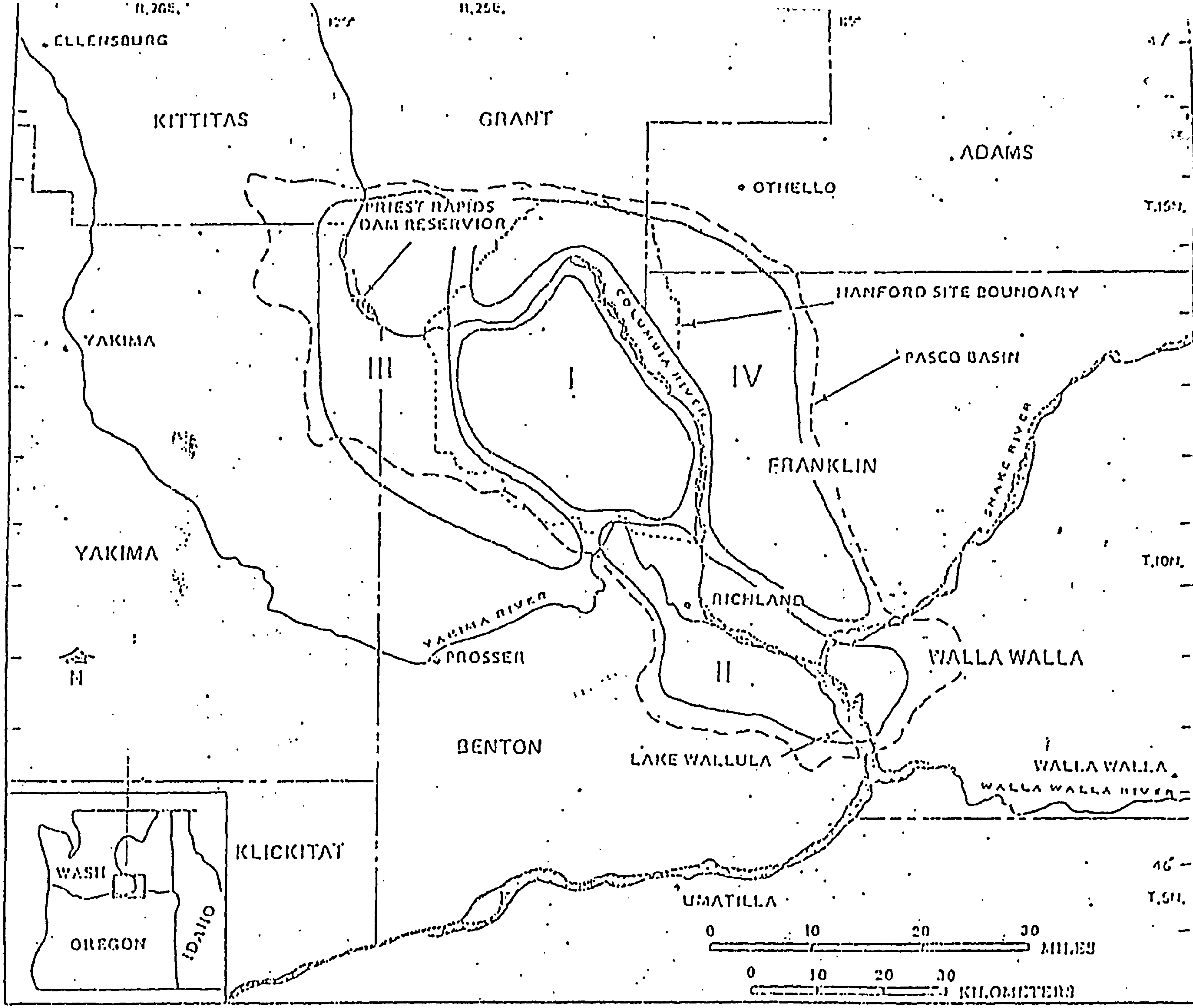
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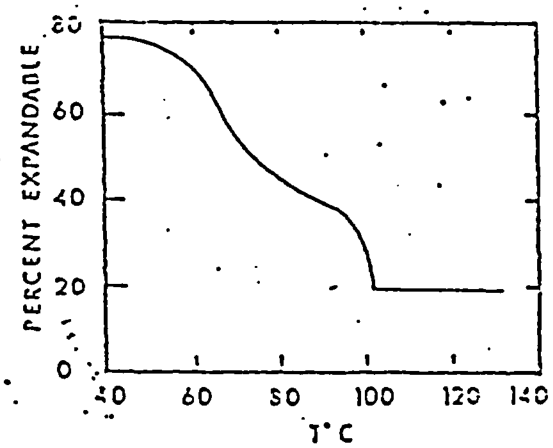

Figure 1. Relationship between expandability and temperature for I/S from well "E" of Perry and Hower (1970).

From Eberl, D. and J. Hower, 76, Kinetics of illite formation: Geol. Soc. Amer. Bull. , v. 87, p. 1326-1330

Fig. 2

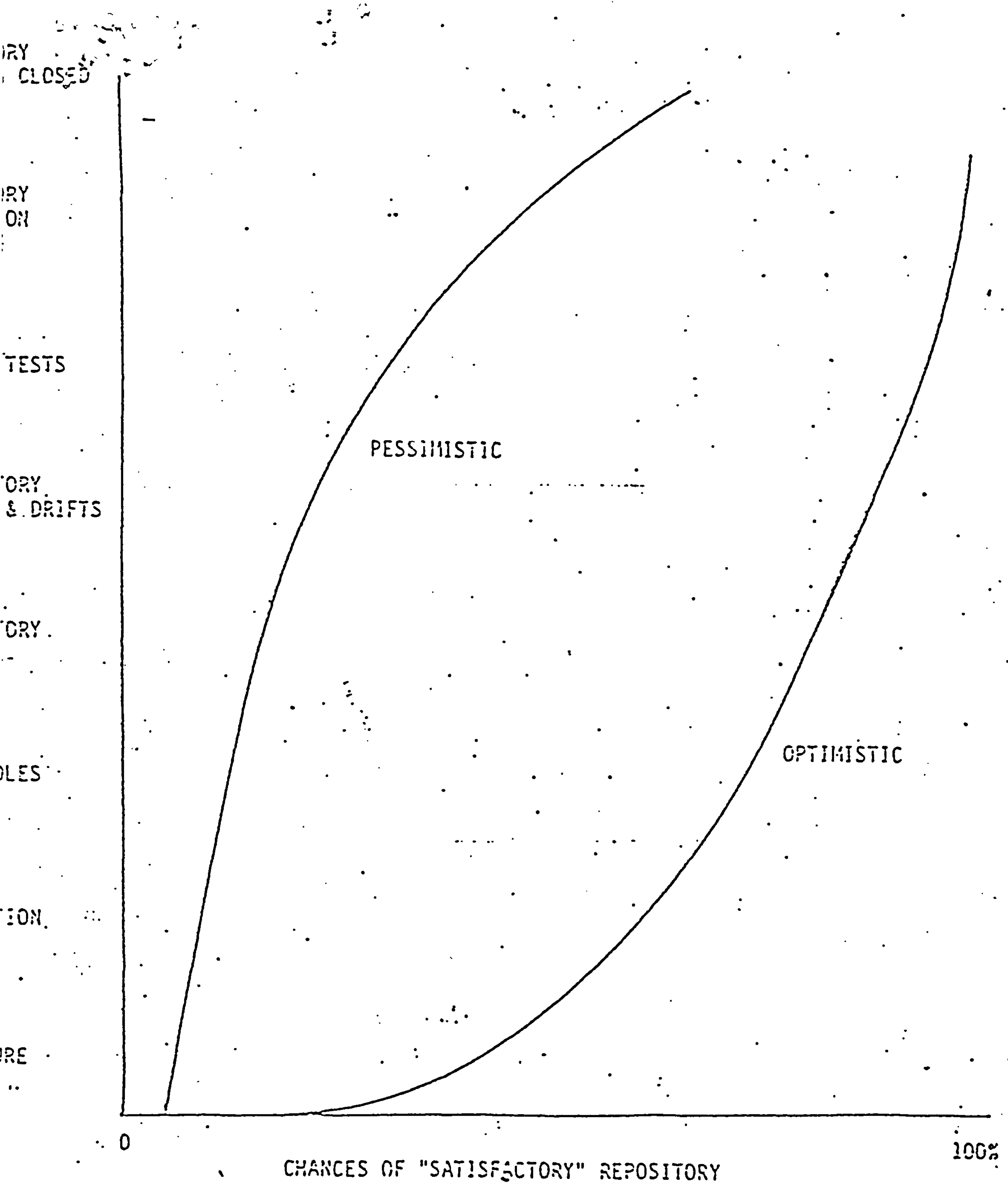

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Fig. 3