United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

In Reply Refer To:
EGS-Mail Stop 410

AUG 25 1983

Mr. Robert L. Morgan
Project Director, Nuclear Waste
Policy Act Project Office
U.S. Department of Energy
Washington, D.C. 20585

Dear Mr. Morgan:

Our letter to you on May 27, 1983, indicated that we ~~were preparing~~ to send a team of U.S. Geological Survey (USGS) scientists to the Basalt Waste Isolation Project (BWIP) to review data collected to date by your contractor and to attempt to assess the adequacy of this data base and planned future studies to characterize the site. Embedded in this evaluation would be our thoughts on other approaches and techniques which could be employed to properly assess the hydrologic characteristics and lead to site characterization. With the excellent assistance and cooperation of Lee Olson, BWIP Project Manager, and his staff, as well as Rockwell personnel, we accomplished our visit June 7-10. With results of that visit and the review of considerable written material, we have prepared the enclosed report which summarizes our analysis of the earth-science issues associated with characterization of the BWIP proposed site.

Perhaps a little history of events leading up to our visit and the resulting analysis is in order. We first began to examine the data base at BWIP when one of our hydrologists served on the hydrology overview committee which served as an independent peer review group. More recently, personnel from our Water Resources Division District Office in Tacoma, Washington, have participated in a task force organized in February 1982, and composed of personnel from Rockwell Hanford Operations (RHO), Battelle Pacific Northwest Laboratories (PNL), and the USGS. The charge of this group was to examine the assumptions, boundary conditions, and input data for hydrologic models being applied to the BWIP region (RHO, PNL, USGS) in an effort to resolve conceptual differences in the pattern of movement and the discharge of ground water in Pasco Basin. The direction and rate of ground-water movement in this region is of primary importance in considering the Hanford Reservation (BWIP site) as a potential site for the burial of high-level nuclear waste. It had been previously ascertained in earlier USGS modeling efforts that the data base is currently inadequate to permit a reliable model to be constructed that could accurately simulate flow in the Columbia Plateau and the Pasco Basin. In addition to conceptual differences among the task force participants concerning the ground-water flow system, major differences arose as to the interpretation of geochemical data by RHO personnel.

In early May 1983, we transmitted our review of the BWIP Site Characterization Report (SCR) to Lee Olson. This report did not present sufficient data to support the hydrologic conclusions and concepts being presented, and consequently we were quite critical of the document. Although this criticism was justified, based on the information presented in the SCR, we believed that additional, more constructive suggestions could be made if we could examine the actual data and the methods used to collect them. During our meeting on March 31, 1983, and in subsequent phone conversations, you also encouraged us to visit the site and to offer our technical opinions and suggestions which might be helpful to DOE in its site characterization programs and plans.

The group of 10 individuals who visited BWIP had widely varying backgrounds in geology, geochemistry, and hydrology. Although the amount of information that could be reviewed and assimilated within a 4-day period was necessarily limited, they were able to assess the state of collection and interpretation, which led to the SCR, and additional data collected subsequent to the SCR.

Perhaps a few words are in order on our perception of the mission and the purpose of our group during their BWIP visit. Briefly stated, we wished to evaluate whether or not a more thorough understanding of the hydrology and geology existed than was apparent in the SCR. Secondly, we hoped to assess plans for obtaining needed information and perhaps offer helpful suggestions. We would attempt to gain this understanding by:

1. Examining the available data, collection techniques, and overall reliability;

2. Evaluating the existing data base as to its adequacy to answer the hydrologic questions;

3. Hearing the course of action planned for the site; and

4. Offering alternative courses of action, if appropriate.

The enclosed document is the result of this effort and is based on information presented during our visit, as well as review of much more information available from reports and files.

The Rockwell group at BWIP could not have been more accommodating. They made every effort to answer our questions, supply data and methodology, and to display their future plans. Without this extensive cooperation we could have accomplished little; with it we hope we can offer some constructive courses of action in analyzing an extremely complex geohydrologic system.

We must all realize that in dealing with such a complex system as the Columbia River Basalts, a certain level of uncertainty will always exist, and thus the potential for disqualification of a site always exists. We do not now see the full solution to hydrologic definition, nor do we see grounds for rejection of the site based on available information. The data base necessary to define adequately the site will take considerable time and effort to acquire, and the possibility of failure still exists.

We hope you find this analysis useful in planning your future site characterization program and are prepared to continue to work with the Department of Energy in whatever role we feel will be mutually beneficial.

Sincerely yours,

Doyle G. Frederick

Acting Director

Enclosure

cc: Survey General Files, MS 114
Director's Chron, MS 114
AS/EM (2)
Assistant Director--Eng. Geol. MS 106
WRD General Files, MS 402
WRD Reading Files, MS 441
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ENCLOSURE

EXECUTIVE SUMMARY

This statement summarizes a review by the U.S. Geological Survey (USGS), concerning selected earth-science aspects of characterization of the Hanford, Washington, area for the purpose of possibly locating a site for construction of a repository for high-level radioactive waste. Basic critical issues are defined from the USGS' perspective, and suggestions are made, without regard for economics or time frame, that might lead to improved characterization of the site. Topically, the basic earth-science subjects of geology, hydrology, and geochemistry are addressed.

Although certain issues are defined in greater detail in the statement, some of the most salient items of major concern have been identified as follows:

1. The need to study and model the hydrologic system of an area much larger than the vicinity of the Reference Repository Location--The USGS' opinion is that the ground-water system in the area of primary interest cannot be adequately evaluated and characterized until the predevelopment and current regional ground-water flow system in an area large enough to include at least the Pasco Basin has been quantitatively defined.

2. The need to define the distribution and character of geologic features of potentially high vertical permeability--The USGS' opinion is that these features, such as large fractures or fracture zones, are of considerable significance and are particularly important to construction of the repository and to characterizing the ground-water flow path from the repository to the accessible environment. Acknowledged high water pressures due to normal hydrostatic conditions and a recognized disadvantageous state of stress in a potentially fractured geohydrologic environment indicate potential hazards of principal concern that must be considered in the planning and engineering of a mined repository at Hanford.

3. The need for three-dimensionally well-distributed hydraulic and geochemical data of good quality--Much of the data used for analysis to date is concentrated in a small area relative to the larger (Pasco Basin) area, and the validity of some of these data is in doubt because of the techniques used and the conditions under which the data were collected.

Compliance with the suggestions made in this statement for improving the ability to adequately characterize the Hanford site could require several years to collect and analyze data, model the systems, and characterize the site. Some suggested activities could be done concurrently; however, others must be accomplished sequentially because of possible interference between various tests.

This statement addresses only a limited range of the factors necessary for characterizing the Hanford site, and the suggestions herein should not be construed as constituting a complete program of study. Similarly, failure of this statement to address any issue does not indicate that the USGS believes that the issue has been or will be satisfactorily resolved in the current or planned program. It is, however, the opinion of the USGS that the issues discussed herein are the most important earth-science concerns needing attention in an adequate site characterization program.

INTRODUCTION

The U.S. Geological Survey is involved, to varying degrees, in several parts of in the National Waste Terminal Storage Program. Until recently, the USGS has had limited knowledge of and only peripheral participation in the repository-siting activities at the Hanford location. Our knowledge of the conditions and program relevant to repository siting at Hanford consisted principally of the expertise of a few individual scientists familiar with earth-science aspects of the Columbia Plateau and the Pasco Basin, of information gained from presentations at national meetings, and of awareness of results of review by various committees and interested scientific groups. Significant differences of opinion between the USGS and Rockwell Hanford Operations (RHO) about some basic issues concerning the geohydrology and ground-water flow system of the Pasco Basin and the Hanford site have recently been recognized and acknowledged. In response to these differences of opinion, and at the urging of the Nuclear Regulatory Commission (NRC), a hydrologic task force consisting of scientific representatives of the USGS, Battelle Pacific Northwest Laboratories (PNL), and RHO was established in 1982 to more clearly define the issues involved and to attempt to design approaches of study and investigation that might offer resolution of these issues. Based on results of U.S. Department of Energy/ U.S. Geological Survey Coordination Committee meetings, of USGS review of the Site Characterization Report (SCR) for the Basalt Waste Isolation Project (BWIP), and of subsequent communications between the Project Director of the Nuclear Waste Policy Act Project Office of the Department of Energy (DOE) and the Director of the USGS, a decision was made that the USGS might, in some way, contribute to the ability to more clearly define and characterize the geohydrologic conditions and system of the Hanford (Pasco Basin) region. A subsequent decision was then made that the USGS would analyze the situation and issue a statement, including recommendations wherever appropriate and possible, concerning the earth-science aspects of characterizing the Hanford region for the purpose of possibly locating a site for construction of a repository for high-level radioactive waste. DOE and RHO arranged a briefing on their investigation for USGS personnel by which to refine our knowledge of objectives, plans, and conditions at Hanford. This 4-day briefing at Hanford in June 1983 was attended by 10 USGS scientists with backgrounds in geology, hydrology, and geochemistry. Personnel from RHO presented the committee with requested data and discussions about conditions of data and sample collection, data-analysis techniques, conceptual models, status of investigation, and plans for future drilling, testing, sampling, and modeling. Topically, the basic earth-science subjects of geology, hydrology, and geochemistry were addressed in detail, and this is generally the framework within which this statement is presented.

The fundamental purpose of this USGS effort is to define basic critical issues from our perspective and to offer advice or suggestions that might result in an enhanced ability to characterize the site within the context of the regional (Pasco Basin) geohydrologic system. The time required to accomplish suggested operations is estimated whenever such estimates are possible and appropriate; however, consideration is not given in this statement to whether or not any or all suggested changes or operations can be performed in any given time frame. A general theme will persist throughout this statement and will consist generally of evaluating the adequacy of available data in terms of both distribution and validity, evaluating plans for future investigation, identifying critical earth-science issues, and presenting opinions of steps needed to satisfy perceived inadequacies in both data and plans. Certain of these elements will be addressed in greater depth than others, and the elements will be discussed in varying degrees of detail from one subject to another, depending upon our state of knowledge and ability to respond.

The USGS extends its appreciation to the DOE and to RHO for the professional manner with which information was exchanged and ideas were communicated. The ability and willingness of the RHO personnel to respond to our requests were conducive to obtaining the maximum amount of information and optimum knowledge within the time available.

GEOLOGY

MAJOR CONCERNS

A major unresolved geologic issue is how to deal with unpredictable zones of potentially high vertical permeability in the repository host rocks. Such zones are commonly observed where basalt flows are cut by canyons and subsequently filled with younger basalt flows in the Columbia Plateau. If these zones were encountered in construction of a repository, they may present major construction problems because of the high hydrostatic water pressures in the surrounding aquifers. Also, their unknown character and distribution within and beyond the proposed repository introduces a large unknown in modeling the hydrologic system and solute transport, and they could result in short flow paths from the repository into the surrounding aquifers.

The nature of basalt flows at the Reference Repository Location (RRL) is known only from boreholes spaced from one to several miles apart. Knowledge of the flows provided by such widespread points is extremely limited compared to that obtained where there are continuous exposures along the walls of canyons. Therefore, it must be assumed that features seen in such surface exposures are also present at depth in and around the repository site.

The features of concern are of three types:

1. Locally thickened flow-top breccia (the partially welded broken rock formed in the upper part of a flow by explosion or flowage of a partly congealed flow).

2. Zones of potentially high vertical permeability formed by emplacement and cooling of the lava flows. These include margins of individual flows, zones formed by interaction of hot basalt and water, and joints formed by cooling but not sealed by secondary mineralization.

3. Faults (particularly the strike-slip variety) and shear zones.

Predicting the location, extent, and character of these features is complicated by the fact that they originated in several very different ways.

Within the most intensively drilled part of the RRL, there is about one borehole every square mile. The fact that borehole RRL-2 showed a much greater thickness of flow-top breccia in the Umtanum than had been anticipated suggests how variable that type of feature might be. Perhaps a clearer picture is provided by figure 3-29 in the BWIP SCR, which shows a cliff exposure of the Umtanum flow at Emerson Nipple. According to the caption for figure 3-28, the Umtanum is approximately 350 feet thick at this locality; therefore, the exposure shown in figure 3-29 must be about 1,500 feet in length. Within this 1,500 feet, there are three locations at which the flow-top breccia locally thickens to about half the total thickness of the flow and connects downward to a fanning of the underlying entablature columns, which in turn connect to the colonnade at the base of the flow. These three local thickenings of the flow-top breccia make up about 20 percent of the exposure. If this frequency of occurrence is projected areally into the subsurface, about 1 drillhole in 5 could be expected randomly to encounter such zones if they are elongate in area, and 1 in 25 if they are roughly circular. Thus a square mile of repository might be expected to consist of between 4 and 20 percent of such zones by area. Studies of the regional geology suggest that such zones are probably most numerous in the Umtanum and less abundant in other flows.

Trying to locate such zones from the surface would require an unreasonable number of drillholes since the zones should occupy only a relatively small percentage of the area and are unpredictable in both shape and distribution. Therefore, we conclude that the existing drillhole data do not tell us the distribution of such features, and increasing the number of drillholes still would not yield sufficient information to avoid such features in developing a repository or to account for such features in a model. Consequently, drilling additional coreholes will not appreciably improve our knowledge of either the statistical or actual distribution of such features in the subsurface. However, detailed examination of all nearby surface exposures should yield some better measure of their frequency of occurrence than our analysis of a single exposure in a photograph.

The distribution of various types of zones that could provide increased vertical permeability through or from the repository horizon cannot be predicted from the surface using geophysics or geology, and no reasonable number of new drillholes would materially increase the predictability of such features. Therefore, there is little that can be done until workings are available underground from which horizontal boreholes can be drilled in advance of mining.

The only specific geologic feature discussed in detail during the meeting at Hanford was a question of resolving the nature of a geophysical anomaly, which appears to coincide with a hydrologic barrier or change in hydrologic properties west of the RRL. While additional holes may be needed to identify this and other similar features, we have no criticism of the past core studies, which appear to have been thorough and of satisfactory quality.

STEPS NEEDED TO RESOLVE INADEQUACIES IN DATA AND PLANS

We feel that the planning and design of a repository in the Pasco Basin must anticipate that some high-permeability features of the types described will inevitably be encountered in an area the size of a repository. Therefore, the only prudent approach is to determine now, in detail, exactly what can or cannot be done when such features are encountered. One should assume the features will be of the types known to occur in this region and have properties appropriate to such features. These zones will contain water at high hydrostatic pressures and could potentially produce water at high flow rates. The following questions should be addressed:

A. How can such features be explored underground in advance of mining and their extent determined while avoiding the hazards presented by the high water pressure? An alternative at the Hanford site that would tend to avoid the problem was conceptually espoused by the National Research Council--National Academy of Sciences in their 1978 report "Radioactive Wastes at the Hanford Reservation--A Technical Review." The basic concept was to tunnel under the Rattlesnake Hills and situate the waste above the regional water table in the unsaturated zone. A followup study of this recommendation reportedly has been made, but to our knowledge, the results of the study have not been published. Therefore, justification, if any, for rejection of this concept is unknown.

B. If such features are planar and have a finite thickness (such as a steeply dipping fault zone as much as 10 meters wide), what is the likelihood that they can be mined safely? Under what conditions will they set a new and arbitrary boundary on the shape of the repository, and what is the probability of this happening? State-of-the art mining engineering should be able to handle these conditions, if they are properly anticipated.

C. How close can hot waste safely be placed to such zones without the thermal-mechanical effects of the waste creating problematic new hydraulic connections by opening old fractures or making new ones?

D. Once such zones are encountered, how can their effect on the performance of a repository be minimized? Can tunnels encountering them be effectively sealed to withstand the water pressures? How would such seals be affected by the thermal pulse?

E. Can the repository design be made sufficiently flexible to accommodate such features when they are encountered? What is the likelihood of the ultimate size of the repository being determined by such features if they cannot be bypassed?

If it has not been done already, features of possibly high vertical permeability should be closely examined where the host rocks or similar lava flows crop out, even though they are many miles away from the RRL. Experts with appropriate engineering background should examine these same features and assume that they, and appropriate hydraulic heads, will be encountered underground. These experts should then develop appropriate scenarios as to what can and cannot be done in such situations, and the likely consequences of these scenarios on the design, construction, and performance of the repository should be evaluated.

Between 1 and 2 years would probably suffice to make this analysis and to determine whether the constraints that the aforementioned features place on a repository are acceptable.

GEOMECHANICS

This is a supplement to the review of the SCR and review of SD-BWI-TP-007, Rev. 0-0 "Test Plan for Exploratory Shaft - Phase I and Phase II" and is based on data made available at the Hanford site briefing and discussions at the Exploratory Shaft Test Plan workshop held in Richland in April 1983. It is assumed that the revised test plan currently in preparation will alleviate many of the concerns expressed in the criticism of the original plan.

A waste repository will perturb natural conditions in a rock mass in two principal ways: (1) by excavation of underground openings in the rock mass and (2) by heating the rock around the repository. The overall geomechanics problem is to understand and predict the processes associated with these perturbations and their impact on isolation and containment of the waste. This involves a complex coupling of thermomechanical and hydrologic-chemical phenomena.

A number of specific objectives must be accomplished: (1) development of the methodology necessary to characterize the rock mass; (2) development and verification of computer models that can predict the rock-mass response to the perturbations which result from the construction phase and the subsequent operation of the repository; (3) design and instrumentation of in situ tests that can provide the field data needed to understand repository behavior and verify the computer models which must be used for design studies and long-range predictions of repository performance.

The principal geomechanical issues of concern in the development of a repository in the basalt at Hanford can be categorized according to four separate but closely related activities which encompass the entire range of rock mechanics effort. These activities are:

1. Rock-mass characterization

   - fracture geometry including spacing, orientation, continuity, aperture, and heterogeneities,

   - stress-deformation law for discontinuities including influence of temperature, effective stress, pore pressure, and aperture,

   - permeability of discontinuities as a function of stress, temperature, aperture, and change under normal and shear deformations,

   - thermomechanical and hydrologic scale effects from laboratory to field,

- temperature-controlled dehydration and mineral diagenesis of materials comprising the fracture fillings in the rock mass,

- time-dependent mechanical behavior of the rock mass during and following the thermal pulse.

2. Modeling and analysis

   - Predictions for a discontinuous rock mass with regard to thermal field, induced stresses, displacement, and hydraulic behavior,

   - predictions for nonelastic rock-mass behavior (fracture, creep, etc.),

   - verification of models for specific rock types,

   - can a discontinuous rock mass be modeled by a continuum representation?

3. In situ testing

   - Design and conduct tests of coupled thermomechanical and hydraulic-chemical response of the repository,

   - limiting conditions for thermal decrepitation, disintegration, and induced fracturing in the near field,

   - structural stability of rooms and pillars under thermal loading,

   - influence of the thermal pulse on repository performance.

4. Engineering design

   - Definition of methodology and criteria for repository design,

   - definition of engineering conservatism to ensure long-term isolation of nuclear waste given the uncertainties in the definition of the geologic/hydrogeologic system.

Present Status of Studies

Studies on basalt core in the laboratory have yielded considerable data on the material properties of intact basalt, and expansion of this data base is continuing. Testing at the near-surface test facility has included two heater tests, block tests, and other phenomenological tests intended to provide information for code development concerning the constitutive behavior of basalt and for developing testing techniques and procedures for use in a test facility at repository depth. Characterization of the rock mass at depth by in situ tests in the exploratory shaft and at repository depth are currently in the planning stage.

Characterization of in situ initial conditions is in progress for the thermal regime and state of stress. Borehole data indicate that ambient temperature at the potential repository horizon in the Umtanum is about 136°F. In situ stress measurements in holes DB-15, DC-12, and RRL-2 in and near the reference repository location, have been made using the hydraulic fracturing method. Results to date indicate the orientation of the maximum horizontal stress is nearly north-south, which is in good agreement with the predicted orientation based on geologic inferences. The ratio of maximum horizontal to vertical stress averages about 2.3:1 although ratios as low as 2.1:1 and as high as 2.7:1 were obtained. As the current conceptual design criterion is based on a horizontal to vertical stress ratio of 2:1, it would seem prudent to modify these design criteria to conform to available in situ stress measurements and to include a margin of conservatism in these design criteria. Perhaps a ratio of 3:1 might be more appropriate for conceptual design purposes. Additional in situ stress measurements using the hydraulic fracturing method are planned to define the in situ stress field with depth. It is suggested that greater success of future tests could be realized with adequate knowledge of borehole conditions before testing is attempted. Recent television pictures of RRL-2 and DC-14 indicate the presence of breakout features in these holes that would preclude successful hydraulic-fracturing tests at various horizons and, indeed, did preclude successful testing at some places in RRL-2. Existing fractures at various test horizons caused another problem. These fractures accepted enough water during testing that a breakdown pressure in the test interval was not possible with the capacity of the pump being employed. It is our experience that the acoustic televiewer is the best tool available to map these and other features in a borehole and to provide information for selecting test intervals and packer settings. Furthermore, the televiewer can provide a record of pre-test conditions in the borehole which can be compared to post-test conditions including the orientation of induced fractures. Breakout features apparently develop owing to deformation of the borehole in response to the high horizontal stress and involve spalling of the rock on the well bore along the axis of least principal horizontal stress. Results to date indicate that examination of core provides an inadequate basis for selection of intervals for hydrofracture tests and of settings for the packers. Detailed knowledge of conditions in the borehole is essential to the design and conduct of successful tests. The acoustic televiewer appears to have the potential to provide the needed information and should be considered for future use in the hydraulic fracturing tests.

Modeling

The major deficiency in the modeling capability of fractured rock masses such as basalt is characterization of the rock mass itself. This problem must be resolved by studying the relationship of measured parameters and system behavior during large-scale, in situ tests of long duration. The planning of such tests should be a major concern of the plans being developed for in situ testing at BWIP. The needs and priorities of this plan should be established on the basis of the potential effect upon repository-performance prediction.

Currently available computer codes are inadequate to represent discrete fractures within a rock mass or to provide complete coupling of phenomena and processes of concern for a fractured rock mass. Thus, code development is needed to support performance assessment and to resolve uncertainties concerning the interactions between phenomena in the basalt at Hanford. The models must be verified before any confidence can be placed in them. Verification is defined as the establishment of truth by measurement or observation and, to the extent possible, should be based on a comparison of a priori predictive analysis to the measured response of an in situ test. Verification is complete when predicted and measured responses agree within acceptable limits. If this comparison is poor, modifications to the model must be made and will require an assessment of whether the phenomena involved are adequately modeled. It is important to identify the presence of phenomenological mechanisms early to facilitate appropriate modification of the models. Verification of thermomechanical models has not yet been successful for basalt or other fractured media, but initial verification of thermal models has been accomplished. Verification of most models involving coupled phenomena await the results of rock-mass characterization, including in situ testing at repository depth to investigate phenomenological mechanisms. Fully coupled thermal/mechanical, hydrologic, and chemical models require extensive development to enable parametric/sensitivity studies to be conducted to highlight the significance of particular couplings. Detailed and direct verification of fully coupled models can only be obtained by the monitoring of large, repository-scale experiments because of the large distances and long times involved in contaminant transport.

In Situ Tests

Largely as a result of the emphasis placed on scheduling, most of the in situ tests conducted to date have not been operated for a sufficiently long time, and have been restricted to the very near field. This is especially true of the phenomenological tests, which include almost all of the tests run to date. In such tests, there is at least some uncertainty in the basic phenomena that will result from emplacement of a heat source. In fact, the number of potential interactions and uncertainties appears to increase in proportion to the geometric scale and time span of any given experiment. The problems must be resolved by studying the relationship between measured parameters and system behavior during large-scale, long-term, in situ testing. Such tests are needed to address issues ranging from characterization of the rock mass and determination of phenomenological understanding of rock mass behavior, to rock support requirements, rock mass damage, model and design validation, and repository performance. Many of these needs can be satisfied by room-scale tests extending over a period of 5 to 10 years. Such tests should be included in the plans for in situ testing when access is available from the exploratory shaft. In addition to the longer operational periods, more extensive instrumentation may be required than in past tests because of the nature of the phenomena being investigated. Without this major increase in scale and duration of in situ testing, such tests will continue to be focused on near field and short-term concerns that are largely operational and engineering oriented and not on repository performance and ultimate containment.

HYDROLOGY

Determining the flow path and rate of travel of radionuclides potentially released to the ground-water system from a repository are major factors in evaluating a site's potential for a repository. RHO's general approach for evaluating the Hanford site's potential consists of constructing a digital model that simulates the ground-water flow system of the Hanford area and combining the results of this model with radionuclide-transport properties of the basalt to determine flow path and rate via a transport model. Such an approach is generally sound, but our participation on the RHO/PNL/USGS hydrologic task force, the review of the SCR, and most recently, our trip to Richland, Washington, during the week of June 6, 1983, has led to concerns about some of RHO's conceptual approaches to the overall task, about the reliability of existing data, and about the soundness of the data-collection program.

MAJOR CONCERNS

1. It will probably not be possible for RHO to evaluate the ground-water system within the area of primary interest, particularly past and future changes in ground-water levels, flow directions, and flow rates under stress imposed by man, until the predeveloped ground-water flow system (natural flow system) of the Pasco Basin is quantitatively defined. It will also be necessary to predict man's future impact on the ground-water system at the basin's boundary.

2. There is a scarcity of data needed to calibrate a ground-water model of the Pasco Basin. RHO's efforts have centered heavily on the Hanford Reservation, and the data base needs to be expanded beyond the Reservation area.

3. RHO's interpretation of water-level data collected during its drilling and testing program assumes that the ground-water system at Hanford is in a steady-state condition. This assumption needs justification. No data are presently available to indicate that this assumption is valid; however, sufficient data are available with which to question the validity of the assumption.

4. Water levels and lateral hydraulic-conductivity values determined by RHO during their drilling and testing program for the more permeable zones of the basalts and interbeds appear to have been affected by the presence of drilling mud. However, the degree to which the presence of drilling mud may have affected the values cannot be determined at this time. Based on a review of available data, it is suspected to have significant impact in many cases. Density corrections for drilling mud in the fluid column during water-level measurements are necessary, but the corrections cannot be made because the amount of mud present was not confirmed by samples of fluid.

5. Water levels collected by RHO in its drilling and testing program are further in doubt owing to the short time allowed for system equilibration.

6. Gas appears to have been present during some attempts by RHO to measure lateral hydrologic conductivity, and the presence of gas definitely affects measured water levels and estimated values of lateral hydraulic conductivity.

7. Frequent contamination of water samples with drilling mud needs to be considered during interpretation of chemical data.

8. Values for vertical hydraulic conductivity are not available. RHO's plans for obtaining these values need additional consideration with regard to timing of the tests relative to interference with and by other activities, including drilling the exploratory shaft. Methodology of its plans needs to be modified for vertical hydraulic conductivity of major fractures to be determined.

9. Values for effective porosity also are not available. Because of the size of the area of primary interest, values at many places probably will be needed. Values for the effective porosity of the major vertical fractures will be needed to identify rate of vertical movement. No plans for testing of effective porosity were presented at the briefing.

10. Although not completely formalized, RHO plans for resolving issues raised by the RHO/PNL/USGS hydrologic task force appear inadequate. In particular, it will not be able to address the questions of whether or not the ground-water system at Hanford is at a steady-state condition, the validity of water levels measured in their drilling and testing program, and the validity of the reported values for lateral hydraulic conductivity.

The following comments expand on these concerns, particularly on those not addressed in detail in our review of the SCR.

SCOPE OF THE MODELING EFFORT

The area of primary interest for evaluating the site is that area through which ground water flows from the repository to the accessible environment. The geohydrologic setting of this area must be well established to properly characterize and evaluate the performance of the site. In order to understand the ground-water flow system within the site and its potential changes with time, it is necessary to evaluate the ground-water system on a regional basis, far beyond the area of primary interest. Man's activities beyond the area of interest probably can and probably will affect ground-water flow direction and rates within the area.

Since at least the 1950's, the activities of man have altered ground-water levels and thus flow direction and rates in the Columbia River Basalts. Significant ground-water level changes have been documented on and just outside the Hanford Reservation during this time period.

Water-level measurements by RHO, the U.S. Bureau of Reclamation, and the USGS indicate that these changes continue to this day. Irrigation pumpage west of the Hanford Reservation is creating annual water-level variations of about 50 feet and annual water-level declines of about 10 feet. These facts indicate the need to expand the data beyond the area of primary interest and beyond the Hanford Reservation boundaries. The minimum area that must be considered to understand the ground-water flow system within the area of primary interest is the Pasco Basin. Available data on the geohydrologic setting of the Pasco Basin are very limited and are not sufficient to permit a total understanding of the ground-water flow system in the Pasco Basin. For the most part, RHO has restricted its data collection to within the Hanford Reservation, and thus its ability to acceptably simulate the ground-water flow system of the Pasco Basin is limited. Past efforts by RHO and others to model the ground-water flow system of the Pasco Basin are probably inadequate to allow understanding of the ground-water system and thus evaluation of the site. The distribution and rates of ground-water withdrawal used in the models appear to be inconsistent with available data, steady-state conditions probably do not exist, boundary conditions are generally unknown (those used in the models severely affected modeling results), and water levels and hydraulic properties used in the models for the Hanford area are questionable and unreliable. An effort by the RHO/PNL/USGS hydrologic task force to model an area far larger than the Pasco Basin is currently underway, but the capability of this model to adequately define the ground-water flow system in the Pasco Basin is still uncertain.

Until the ground-water flow system of the Pasco Basin is adequately defined, it will probably not be possible for RHO to evaluate the ground-water system within the area of primary interest, including past and future changes in ground-water levels, flow directions, and rates. RHO has participated fully in the hydrologic task force, but its plans for extending its knowledge of the Pasco Basin to allow detailed analysis of the Hanford site must be expanded and formalized.

MODEL CONSTRUCTION AND CALIBRATION

The following general sets of data are required to acceptably simulate the ground-water flow system of the Pasco Basin and the area of primary interest: (1) the geologic setting and hydraulic properties of individual geohydrologic units; (2) hydrologic conditions at the model's boundaries in terms of water levels and/or rate and direction of flux; (3) historic and future changes in the boundary conditions; (4) temporal-spatial variations in ground-water levels, including pre-stress ground-water levels (at least in the more permeable units of the basalts and interbeds); (5) the temporal-spatial distribution and rates of water entering and leaving the modeled area; and (6) if water quality is used to help understand the ground-water flow system, it is necessary to collect data on the temporal-spatial changes in selected water-quality parameters.

It is recognized that all these data are not available, nor can they be collected in the short term. Nevertheless, it is suggested that every effort must be made to assemble all available information; evaluate the validity of available data; collect new information at critical locations; and construct, calibrate, and verify the necessary models to an acceptable level. On the basis of our involvement in the hydrologic task force, the USGS review of the SCR, and the results of our review of RHO's data during the last month, we offer the following comments on the data-collection and model-development programs since 1978 at Hanford.

Temporal-Spatial Variations in Water Levels

Determination of temporal-spatial variations of water levels in the more permeable zones of the basalts and interbeds is mandatory in order to define the direction and rate of ground-water flow. Such water-level information is also one of the most important parameters needed for model construction and calibration. Without the head information, model calibrations cannot be successfully accomplished, and conclusive definition of the ground-water system is not possible. Water-level information must be collected simultaneously in all zones at selected time intervals in order to determine the configuration of the ground-water levels and to assess the magnitude of seasonal changes in recharge and changes in water levels due to natural and artificial stresses such as pumping, irrigation, and others.

As indicated in the USGS review comments of the SCR, RHO's data-collection program has not produced enough reliable data with which to construct reliable potentiometric maps for any of the permeable zones in the basalts either in the Hanford Reservation area or in the Pasco Basin. It is doubtful that data-collection plans described to the USGS can accomplish this. Modification of RHO's data-collection program in order to accomplish this is possible, but sufficient time must be allowed for water levels to equilibrate and for natural and man-induced changes to be measured. Based on experience in the Columbia Plateau, the time required could be as much as 3 years or more after wells are drilled and instrumented.

Hydraulic Characteristics

Hydraulic characteristics needed for construction and calibration of the RRL, Pasco Basin, or a larger area ground-water flow model include the spatial distribution of: horizontal hydraulic conductivity, Kh; vertical hydraulic conductivity, Kv; and the coefficient of storage, S, of the basalts and interbeds. For modeling movement of radionuclides in the area of primary interest, one must also include the distribution of effective porosity and the anticipated changes induced in the above parameters caused by waste emplacement and other stresses.

RHO's collection of these data has been confined to the Hanford Reservation and, except for one test for effective porosity, confined to determination of Kh and S. As indicated in our review of the SCR, values of Kh determined by RHO often appeared inconsistent with the amount of fluid loss during drilling, and available data indicated that drilling mud was still present in the formation for a significant number of the tests. In addition, the very small hole diameter (about 3 inches), low pumping rates, and use of airlift pumping all increase the likelihood that the Kh values obtained are poorly representative of true conditions.

These conclusions were reinforced by the additional data on drilling history that were discussed during the week of June 6. Values of Kh in those boreholes drilled with mud are, therefore, highly questionable. With one exception, values of S reported by RHO were generated from single-well tests and are also highly questionable. Finally, the presence of gas in the water during at least some of the testing would further weaken the reliability of values of Kh or S as determined by the techniques used.

As reported by RHO, the results of its one test, to date, for effective porosity were inconclusive. There is a definite need to expand the plans for determination of Kh, Kv, and S, both within the Hanford Reservation and within the Pasco Basin.

At the present time, RHO has several plans for determining Kv of some of the basalt flows in the immediate vicinity of the proposed repository. It is believed that some modification of these plans is required, but the general approach is consistent with available analytical techniques. A major problem is that several future activities appear to conflict with the timing of the test for Kv including installation of piezometers for determining ground-water levels and drilling of the exploratory shaft. Both the vertical hydraulic-conductivity test and shaft drilling must be delayed if the nested piezometers are to be used to determine the necessary background water levels. Drilling of the shaft could easily perturb conditions sufficiently that any vertical hydraulic-conductivity testing near the site might not be possible for a period of years. For determining or estimating Kv in the area of primary interest, some other modifications to the testing program are required (see discussion in "Suggested Steps Needed to Resolve Inadequacies in Data and Plans"). The importance of timing for the data-collection programs cannot be overstressed.

Temporal-Spatial Distribution and Rates of Ground Water Entering and Leaving the Modeled Area

The magnitude of items in the water budget of the Pasco Basin and the area of primary interest and their changes with time need to be established. Most important of these items for the Pasco Basin include recharge and surface-water and ground-water uses. Some information on these has been collected by RHO, PNL, or the USGS; however, large gaps in knowledge still exist. RHO's plans to collect this information should be expanded and formalized. Determination of the historic distribution and rates of ground-water withdrawal in the Pasco Basin with acceptable accuracy may not be possible, but the possibility of obtaining the best possible information should be explored.

Geologic Setting

The areal distribution and thickness of basalt flows and interbeds must be established in order to construct a realistic ground-water flow model of the area of primary interest. Also, those features that affect distribution of Kh and Kv need adequate definition. Geologic and geophysical work being conducted by RHO to map those features affecting Kh is consistent with existing technology. However, zones of relatively high vertical conductivity can be missed entirely by all existing techniques of investigation. Since Kv is one of the most important parameters with regard to direction and rate of ground-water flow, failure to adequately measure the distribution of this parameter would severely weaken the ability to evaluate the site. Geologic features that could affect the distribution of Kv in the basalts include flow margins, zones related to the interaction of basalt with water, cooling joints, dikes and vent materials (particularly in the Grande Ronde), old canyon walls, and faults. Distribution of Kv in the interbeds is affected by the amount of silt and clay present in the deposit. There is no reason to believe that at least one or more of the above features does not exist in the RRL or surrounding area. Every effort should be made, using all available field and analytical techniques and modifications, to determine if such features of potentially high vertical permeability are in or near the RRL.

RHO has evidence that a low-permeability barrier probably exists several miles northwest of the proposed repository site. The potential existence of this barrier has been referred to by others, including the USGS. Data available to support this concept are circumstantial, and RHO's plans to investigate the geohydrologic nature of this phenomenon should be well defined and accelerated. This particular feature and the possibility that others of a similar nature might also exist are important with regard to accurately modeling the Pasco Basin in general and the area of primary interest in particular.

In general, except for the abovementioned low-permeability barrier and thickness of the Grande Ronde, sufficient stratigraphic and structural information is available to construct an acceptable regional-scale, geohydrologic-system model of the Pasco Basin. However, detailed geologic information necessary to construct a transport model of the smaller-scale area of primary interest from the repository to the accessible environment is not yet available.

Boundary Conditions

The nature of the Pasco Basin's hydrologic boundaries is essentially unknown. Man's activities are known to have caused substantial water-level changes in some boundary areas, including the northeastern part of the area between the Columbia and Snake Rivers and within the Cold Creek Syncline. Methods for estimating the nature of these boundaries and changes in water levels with time need to be explored. Considerable effort with regard to establishing the hydrologic nature of some of these boundaries is currently underway in the RHO/PNL/USGS hydrologic task force. In addition, methods for predicting the effect of man's activities outside the Pasco Basin on water levels within the basin need to be investigated.

A sufficient number of wells does not presently exist from which to obtain adequate water-level data for the majority of the Pasco Basin. Water levels for the unconsolidated deposits and the Saddle Mountains Formation are adequate to map water levels within the basin, but only a few wells are completed in the Wanapum or the Grande Ronde.

SUGGESTED STEPS NEEDED TO RESOLVE INADEQUACIES IN DATA AND PLANS

The following general approach is recommended as a means of addressing the major concerns:

1. Construct a model that simulates ground-water flow in the Pasco Basin. The model would be utilized to: (1) identify the nature of the hydrologic boundaries of the Pasco Basin, (2) investigate the effects of man's past and present activities on ground-water levels in the Pasco Basin, (3) determine potential water-level changes in the Pasco Basin as a result of man's future activities, and (4) provide appropriate boundary conditions for the detailed model simulating the flow system in the area of primary interest.

In order to accomplish the above stated goal, a digital model simulating a ground-water system larger than the Pasco Basin needs to be built. The location of the boundaries for this larger model must be chosen so that their treatment in the model does not preclude identification of the nature of the hydrologic boundaries of the Pasco Basin or affect simulated ground-water flow and water levels in the Pasco Basin. Data necessary for the construction of this larger model include:

A. The geologic setting of the model area and the hydraulic characteristics of the major geohydrologic units including Kv, Kh, and S.

B. The temporal-spatial distribution of water levels within the model area and, where possible, at the basin's boundaries, distribution and rates of water withdrawal and addition.

Among the most difficult of these variables to determine will be Kv. It is recommended that the model be used to "back out" this variable. This approach requires that the other parameters be established with a high degree of accuracy from field measurements. It also may require drilling of additional test wells in the Pasco Basin both outside and inside the Hanford Reservation. The extent that additional drilling is needed cannot be determined before all available data are examined and initial runs are conducted on a preliminary model.

2. Construct a digital flow model of the area of primary interest that utilizes results of the Pasco Basin model for boundary conditions. The model will be used to: (1) determine ground-water flow directions and rates in the modeled area, (2) determine values of Kv in the modeled area, and (3) predict changes in flow directions and rates resulting from future activities of man.

Data necessary for the construction of this model are similar to those needed for the Pasco Basin model except that effective porosity and changes in hydraulic parameters induced by waste burial and other stresses must be considered.

Vertical hydraulic conductivity is the parameter least susceptible to adequate field measurement. Large vertical fractures that could have relatively high values of vertical hydraulic conductivity can easily exist in the area of primary interest. Regional geologic evidence indicates that spacing of these fractures is likely to be on the order of thousands of feet. The fractures can cut across one or more basalt flows. A possibility also exists that dikes and vent material may cut across basalt flows of the Grande Ronde. Horizontal fractures also are believed to exist in the entablatures, and these fractures may provide access for ground-water flow to vertical fractures. It is doubtful that existing plans for determining values for Kv from field testing will be adequate to test for the features discussed above. Plans for obtaining field values of Kv should be altered to allow for measurement of Kv of at least one of the larger fractures. Field measurements will provide data for model calibration, but the basic technique for determining Kv should be adjustment of Kv values to achieve model calibration. Such an approach will result in a range of "acceptable values" for Kv. Utilization of the model to determine the potential range in Kv will require a high degree of confidence in the other parameters such as Kh, S, water levels, and hydraulic stresses. Information on the three-dimensional distribution of head in the various basalt layers is critical.

TIME REQUIRED TO ACCOMPLISH SUGGESTED STEPS

1. Model construction of the Pasco Basin

Geologic setting.--Available data are sufficient to permit the extent and thickness of the unconsolidated deposits, the Saddle Mountains Formation, and the Wanapum Formation to be mapped. Thickness of the Grande Ronde cannot be determined from available data. Sensitivity of a preliminary model to this parameter should be investigated before undertaking an extensive data-collection program to determine the bottom of the Grande Ronde. Time involved for model construction and experimentation could be as much as 1 to 2 years.

Hydraulic Properties.--The degree that available data will allow determination of lateral and vertical hydraulic conductivity and coefficient of storage of the major formations and interbeds is limited, and very little data are available for the Grande Ronde. All available data for these parameters need to be collected before a reasonably valid estimate can be made of the time required to determine these parameters. The hydraulic nature of the "low-permeability barrier" in the Cold Creek Syncline needs to be more fully understood in terms of its physical nature, geometric extent, and hydraulic properties. This determination could require as much as 2 years of data collection and analysis.

Boundary Conditions.--Collection of data to define boundary conditions for the Pasco Basin would require considerable drilling along most of the boundaries of the basin unless other means of estimating conditions can be developed. Once drilling is completed, at least a few years of data collection would be required to allow equilibration of the water levels from drilling activity and to understand changes with time due to man's activities and natural seasonal fluctuations. An alternative approach to investigate the hydrologic nature and potential water levels at the basin boundaries is via a model such as the one being constructed by the hydrologic task force. Even with this approach, some additional field data will be required. The latter approach will probably require from 1 to 3 years.

Temporal-Spatial Changes in Water Levels.--Sufficient wells are not available to measure temporal-spatial water levels in all of the formations. An adequate number of wells are available in the unconsolidated deposits and Saddle Mountains Formation. Drilling would be required for the Wanapum and Grande Ronde Formations. Based on experience on the Columbia Plateau, as much as 3 years would be required to allow water levels to equilibrate from drilling and to measure natural and man-induced changes once drilling was complete.

Temporal-Spatial Distributions and Rates of Water Entering and Leaving the Modeled Area.--These data need to be collected over a several-year period both within and outside the Pasco Basin. Data need to be collected over a broad enough area so that those activities of man outside the basin that can influence water levels within the basin can be identified and monitored.

2. Model Construction within the Area of Primary Interest

Temporal-Spatial Changes in Water Level.--No activities within the Hanford area that could induce substantial water-level changes over large areas of the reservation should be undertaken until temporal-spatial distribution of water levels is known for the more permeable interbeds and basalts and the unconsolidated deposits within the reservation. Several years of data should be collected.

A sufficient number of wells does not presently exist with which to measure these temporal-spatial water levels for all of the formations and particularly for the Grande Ronde. It will probably be necessary to undertake new drilling efforts to collect the necessary data. Wells should be designed, drilled, and constructed to obtain the best possible values for hydrologic properties, water samples, and records of water levels. Time required for the drilling effort cannot be addressed since this will be a function of several presently unknown variables.

Hydraulic Properties.--Following drilling and measurement of water levels during a period of several years, tests for Kv and effective porosity need to be undertaken. These tests, including data analysis, could require as much as 2 or 3 years to be completed. As discussed earlier, such drilling and testing, as well as shaft construction, should not be done concurrently with equilibration of the system to determine temporal-spatial changes in water levels because of possible interference with the equilibration. Alternatively, it can be recognized that shaft sinking will create a major disturbance to the hydrologic system and proceed with this assumption in mind. The observation wells suggested in the preceding sections can be installed and monitored before, during, and after the shaft is installed to obtain a time-serial, water-level history of the disturbance. When the data being collected indicate a predictable hydrologic system is being observed, the tests for vertical permeability can be initiated. This procedure might yield data adverse to repository integrity after the shaft and some underground test facilities are already in place; however, assuming adverse conditions are not found, it would compress the time required to reach the initial shaft completion stage. In addition, observation of significant water-level disturbances in zones below the depth at which shaft drilling was taking place would also strongly indicate significant vertical interconnection of aquifers before any vertical permeability tests are run.

GEOCHEMISTRY

This discussion is a supplement to the review of the SCR based on data made available at the Hanford site briefing. Criticism of the hydrogeochemistry section of the SCR was raised regarding the lack of data; the data presented at the briefing alleviated some, but not all, of this problem. The technical issues raised in the geochemical portion of the SCR review (p. 33-47) should be viewed as a suggestion to begin integration of the geochemical and hydrologic data, interpretation, and models. The emphasis in the SCR review, and here, on geochemical data and interpretation might be inferred to imply an attempt to propose a geochemical study for its own sake. However, all of the geochemical points raised are specifically aimed at the use of geochemistry to support or refute hydrologic-flow models. That is, any flow model must be consistent with the observed geochemical data.

Because of the emphasis placed on hydrogeochemical concepts and the difficulty of obtaining reliable hydrologic information in this system, a few brief comments regarding the type and scope of problems to which geochemical concepts can contribute are mentioned here. Defining the hydrologic flow system at Hanford is one of the major priorities at this time. The available data on the distribution of dissolved chloride, deuterium, and oxygen-18 imply the existence of multiple water sources in the system and put constraints on the flow system in which they occur. One conceptual hydrologic model with which the data are consistent invokes upward vertical leakage of deep, high-chloride water in the Cold Creek Syncline with mixing and dilution occurring both upward and down gradient from the recharge area. Confirmation or refutation of this conceptual model must be based in part on the hydrochemical character of ground water in the system and on chemical changes that occur in the vicinity of major structural features in the Hanford area. As another example of geochemical input to hydrologic inferences, consider the possibility raised in the SCR that waters in the present flow system may have originated in glacial or interglacial periods; the Pasco Basin is known to have been the site of a major glacial lake. Whether the influence of the paleohydrologic system is still present in the hydrologic regime can only be determined from detailed deuterium and oxygen-18 data for the surface- and ground-water system.

Hydrochemical-data interpretation within the Hanford Reservation alone, without consideration of the Columbia Plateau as a whole, is inappropriate. Regional consideration is a prerequisite to site characterization. In a study being conducted by the USGS Water Resources Division's (WRD) Washington District Office in cooperation with the Washington State Department of Ecology, solute and isotopic data collected from aquifers throughout the Columbia Plateau will provide insight to the geochemical controls affecting the areal and vertical distribution of various dissolved constituents. While the problem initiating this study and providing input to justify the funding is agricultural, the overall ramifications take on a far greater significance when considering the location of the proposed repository. As a consequence, the USGS has the opportunity to provide regional hydrologic, solute, and mineralogic data to supplement RHO activities within the Hanford Reservation.

Three broadly defined topics relevant to solute chemistry of the aquifers will be considered in the following section: (A) conservative constituents (solutes and solvent), (B) isotopes, and (C) solubility and reaction modeling.

CONSERVATIVE CONSTITUENTS

Solutes in ground waters in the Hanford area that should be conservative (undergo no reactions once introduced to the aqueous phase) are Cl, He, and Ar; other constituents that might be conservative in all or part of the ground-water system include B (based on parallel behavior to Cl), Br (unless high pH), N_2, and CH_4 (if oxidizing conditions and/or sulfate are not present). Deuterium and oxygen-18 are included here because they are assumed to act conservatively in ground waters in the area. All of the questions raised in the SCR review regarding the distribution of major anions, cations, and dissolved gases (SCR review, p. 34-43) remain. However, the data obtained at the June briefing [for boreholes McGee, DC-16A (one depth only), RRL-2, DB-15, DC-12, 14, 15] allow much better definition of the hydrochemistry at the pertinent sites and also allow some conclusions to be drawn. The discussion pertains only to Cl; however, the distribution of B is nearly identical, and the distribution of F generally similar. Quantitative data are unavailable for other constituents.

The distribution of Cl appears to be controlled by depth and site location--not by stratigraphy and not by temperature. In the Grande Ronde, highest Cl values occur at repository locations (DC-16, 16A, RRL-2), intermediate values at DC-14, 15, and lowest values at DC-12. If the Cl distribution is controlled by rock-water interaction and/or temperature, these differences should not occur.

Cl concentrations at shallow depths are low, independent of stratigraphic interval. At DC-12, Cl concentration is low at all depths and shows a slight decrease with depth; this might be attributed to input from local recharge or structural control of water flow (DC-12 is near the Rattlesnake Hills and just inside the southwestern border of the Cold Creek Syncline). The areal distribution of boreholes for which data were made available is not sufficient to determine whether lateral chemical variations are sharp or transitional or can be associated with major structural features such as syncline boundaries.

Values of $\delta\,^{18}O$ correlate well with Cl concentrations; thus the above questions all apply to the distribution of ^{18}O as well as Cl. In addition, the following issues specific to ^{2}H and ^{18}O must be considered. Temperatures are too low to account for the observed shifts in ^{2}H and ^{18}O simply by isotopic exchange. Fractionation during secondary mineral formation would imply roughly equal-volume ratios of reacting rock and water. Different water sources, in space and/or time, appear to be a necessity. Deuterium: oxygen-18 plots for repository location boreholes do not parallel the meteoric water line; the same plots (with scatter) for other boreholes do roughly parallel the meteoric line, raising the possibility of a third water source; that is that the repository waters are a mixture of two other waters. Lack of data from the unconfined aquifer precludes the possibility of detailed interpretation of the ^{2}H and ^{18}O data for the deeper aquifers.

Regional data collection to date by the USGS/WRD Washington District Office, has provided chemical data which serves well to illustrate an apparent striking contrast between ground-water compositions in the vicinity of the proposed repository and the remainder of the plateau, at least with respect to those conservative chemical constituents just discussed. For example, wells DC16, DC16A, and RRL2 in the Cold Creek Syncline have chloride concentrations of 400 to 500 mg/L in the Grande Ronde Formation, whereas elsewhere within the Columbia River Basalts the maximum observed chloride concentration in this formation is 44 mg/L.

Discussion at the briefing revealed that methane is by far the predominant dissolved chemical species in some Hanford ground waters. The general distribution of methane and other dissolved gases is undefined at this time (see SCR review, p. 34-43).

Present sample treatments and analytical techniques generally appear to be of high quality. An important exception, discussed at the briefing, is the dissolved gas analyses, which must be improved. Also discussed was the need to add Br to the analytical schedule.

The distribution of data is inadequate. Partial or complete depth coverage for the eight boreholes available at this writing define three distinctly different depth distributions for the conservative constituents, but large depth intervals are missing in some cases. ^{2}H and ^{18}O data for surface waters and the shallow aquifer are totally absent. The available dissolved-gas data are qualitative only.

The hydrogeochemistry plans that were discussed by RHO personnel at the site briefing were preliminary but appeared to be headed in the right direction for better definition within the Hanford boundaries. The study by the USGS/WRD Washington District Office will supply greatly needed regional data.

Estimated needs for more conservative-constituent data are as follows:

1. Precipitation, surface water (including Columbia River), and shallow aquifer data for ^{2}H and ^{18}O, particularly; general chemical and isotopic data from the shallow aquifer.

2. Boreholes with complete chemical and isotopic data as follows:

A. Several holes southwest of the Cold Creek Syncline to evaluate the depth distribution of constituents in the presumed local recharge area. This would appear to be a necessity for the interpretation of all conservative constituents.

B. Boreholes located to examine the nature of hydrochemical transitions across major structural features--boundaries of the Cold Creek Syncline (both sides) and also across the "hydrologic barrier" located northwest of the RRL.

C. Boreholes to define changes that occur within the syncline, downgradient from the repository location, to examine the question of how repository water is altered to compositions seen at locations such as DC-15.

3. Chemistry of other basalt waters outside of the Hanford area. If the chemistry of Cold Creek Syncline waters is unique, as it may be, its uniqueness must be explained.

4. Information on the nature of the sedimentary interbeds is needed (general lithologic and mineralogic information, presence or absence of carbonaceous material, lateral continuity, etc.).

5. The regional study being conducted by the USGS/WRD Washington District Office is an essential component in understanding the hydrologic characteristics of the basalts at the Hanford Reservation. As part of any additional water-data collection in this study, parameters suggested for additional study are stable isotopes and gas analysis.

Given the chemical variability already observed in ground water in the Pasco Basin, it is difficult to see how these questions could be addressed without data from several intervals in a minimum of ten additional boreholes. Some of the necessary data might be available by resampling existing boreholes; sufficient information is not presently available for the USGS to evaluate this suggestion. The general solute concentrations of ground waters in basalt in the area can probably be established, at least in large part, from published data and studies presently being conducted; however, the deeper Grande Ronde might not be adequately represented.

ISOTOPES

Considerable discussion on this subject among RHO and USGS geochemists occurred at the June briefing. Although there was disagreement over the interpretation of the SCR and its review, there was fundamental agreement on the scientific principles and issues involved and on the contribution to these issues to be gained from the study of isotope geochemistry. The major issues are: 1) the inferences that can be drawn regarding the origin of the dissolved methane, based on its ^{2}H and ^{13}C characteristics and on the ^{13}C signature of the associated bicarbonate; 2) the need for complete knowledge of all sources and sinks of carbon and chlorine isotopes in the system before relative age estimates can be made from ^{14}C or ^{36}Cl data; and 3) the need for quantitative reaction models along known flow paths before travel time estimates can even be attempted. Specific issues regarding isotopes were raised in the SCR review (p. 44-47).

There is a great deal of scatter in the ^{13}C data for dissolved bicarbonate. This might be real, or it might result from analytical procedures or sample contamination by drilling fluid. Various constituents added to the drilling fluid ("causticized lignite," organic polymer, and sodium carbonate) could contribute to spurious ^{13}C and other solute data. With the sampling techniques used, only carbonate (from Na_2CO_3) should directly precipitate with the sample; however, the presence of organic polymer and lignite also pose potential sample contamination problems that must be evaluated. Present sample-collection and treatment techniques appear adequate. The scatter in ^{13}C data might be analytical and should be checked by running multiple samples for ^{13}C. The suite of isotopic analyses being run appears to be adequate; however, the spatial distribution of data is not, and earlier comments are applicable here. Plans presented at the briefing for correcting the deficiencies were preliminary but appeared to be headed in the right direction.

Estimated needs for isotope chemistry are as follows:

1. A more comprehensive spatial distribution of data is needed, as discussed above. For the carbon and chlorine isotopes, emphasis in future data collection must be placed on local recharge areas and on the unconfined aquifer.

2. Checks on the effects of drilling fluid must be carried out. (They might be in progress.)

3. Needs for ^{2}H and ^{18}O data were discussed under "CONSERVATIVE CONSTITUENTS."

4. The potential isotopic input from sedimentary interbed materials must be evaluated.

SOLUBILITY CONTROLS AND REACTION MODELING

The immediate priority in the Hanford system is the definition of the hydrologic flow regime, which must be consistent with the distribution of conservative dissolved constituents and the distribution of deuterium and oxygen-18. The flow model development for Hanford must also be consistent with all solubility and/or reaction path models proposed for the system. This requires that a balance be maintained in terms of emphasis given to the different aspects of the geochemical program because, in most instances for a given borehole and depth interval, all geochemical data must be collected in the same time interval. Thus, the adequacy of data collection must be ensured at the time of collection, even if detailed modeling efforts are not carried out until later.

Reasonable solubility/reaction models would appear to be a necessity for any attempt at radionuclide transport modeling. Solubility/reaction models are based on the ability to calculate saturation indices. Calculation of saturation indices for the appropriate minerals in the Hanford hydrologic system will require highly accurate values for pH, dissolved Al and Fe (among others), and the redox potential "seen" by species involved in some mineral-water reactions. Solubility/reaction modeling also assumes the existence of an adequate aqueous speciation chemical model. Detailed discussion of this problem seems inappropriate here. Experts in this field are available and should be consulted.

The issue of redox potential has implications far beyond simply defining saturation indices for solubility/reaction modeling. A major assumption raised in the SCR (questioned severely in the SCR review, p. 47-48; 52-53) is that the basalts will produce a strongly reducing environment in the ground water through the action of hematite-magnetite control on redox potential. However, measured Eh values are far too high to be consistent with hematite-magnetite control on redox potential. The observed values are consistent with a Fe^{2+} - FeOOH redox couple. The question of redox potential has major implications for radionuclide transport - if redox potentials are governed by Fe^{2+} - FeOOH equilibria, they can be ~0.5 volt higher and considerably more variable than if governed by redox couples such as CH_4/CO_2. The importance of redox potential as a control on radionuclide transport is heavily stressed in the SCR; an uncertainty on the order of 0.5 poses a major problem.

Present sampling and analytical techniques appear adequate, based on discussions at the June briefing (whether this can be said of data collected earlier in the study is unknown). However, adequate collection and analysis of samples for minor and trace elements is very difficult. Again, experts in this area are available and should be consulted.

The distribution of geochemical data is inadequate, and earlier comments are also applicable here.

General plans are again preliminary but further along in terms of the extended and detailed sampling study at DC-14, which in our understanding was designed in large part to assess the adequacy of data for solubility/reaction modeling. Estimated needs in the field of solubility and reaction modeling are as follows:

1. A more comprehensive distribution of data is needed, as discussed in earlier sections.

2. The question of ground-water redox reactions as related to redox effects on radionuclide transport must be addressed.

3. A knowledge of the minerals present in the sedimentary interbeds would seem necessary here (i.e., the presence or absence of abundant carbonate minerals - caliche, for example, is abundant in the present alluvial deposits). Secondary-mineral analysis to develop flow-path reaction models is presently being done by the USGS Washington District Office. This work could be continued and perhaps expanded to provide greater insight to the Hanford environment.

4. Additional knowledge of the distribution of secondary minerals may be needed; it should be possible to evaluate this need as the modeling progresses.

5. Expert consultation should be sought in the area of minor and trace element chemistry.