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STATUS REPORT

NNWSI HYDROGEOLOGIC INVESTIGATIONS

DRAFT

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Saturated Zone Hydrology

Status

Yucca Mountain, a north-south oriented structural mountain block composed of Tertiary tuffs, is faulted and fractured, with stratigraphic units tilted gently to the east. Northerly trending faults occur within the repository block and generally block out the long linear ridges. The water table is deep at the repository site, generally ranging between 500 to 600 m below land surface. The dominant general direction of regional groundwater flow apparently is from north to south, but the detail of flow patterns in the immediate vicinity of Yucca Mountain has yet to be determined. Local structural control on flow directions and two or more areas of closely related groundwater fluid potential (flat gradient) creates the possibility of flow from the repository block in more than one direction. To date, insufficient information has been established on the relationships of flow across structurally controlled(?) fluid potential discontinuities that occur within the western part and to the north of repository block.

At least 24 geologic and hydrologic test holes and wells within and near the repository area have provided the saturated zone hydrologic data to date. Westward from the westernmost part of the repository block to well into Crater Flat the potentiometric surface is between 769 and 780 m above MSL. To the east of this area the potentiometric surface is between 724 and 731 m above MSL and the zone appears to extend into Jackass Flats at about the same elevation. Immediately to the north and northeast of the repository block two data points indicate a significantly higher potentiometric surface at 1029 to 1020m above MSL. Low to almost flat gradients are indicated by the available control in the eastern and western zone separated by the discontinuity near the western edge of the repository block.

Single well pump tests and tracer injection tests in the hydrologic test holes indicate that the distribution of permeability is not dominated by tuff units, but rather by fractures or fracture zones in or through them. Yields of the test wells vary greatly, as do the relative positions and number of permeable fracture zones yielding water to the wellbores. Wellbore and core studies indicate that the welded tuff units contain more fractures per unit volume than unwelded units; however, the hydrologic tests indicate that permeable zones may occur in both lithologies.

Since the January, 1983 workshop additional drilling has been accomplished at the NNWSI site. The drilling consisted of eleven new wells (WT series, drilled to the water table) designed primarily to establish better control in mapping the uppermost potentiometric surface within the tuffs.

Plans for testing future wells C1, C2 and C3 were described at the September, 1983 workshop. These three wells will be used for the first multiple-well test at the site. The wells will be oriented (at 300 foot spacings) such that the line between at least two of the wells will be along the dominant fracture strike. Short term point dilution and pump-back tests are planned to measure effective porosity and evaluate anisotropy.

Preliminary testing of well UE25p#1, drilled into Paleozoic carbonate rocks beneath the tuffs east of the repository block, indicates high transmissivities (not measured precisely) near the Tertiary-Paleozoic contact zone. Head measurements in this well indicate that the head is higher in the Paleozoic aquifer than in overlying tuff aquifers.

Borehole flow testing in wells in the tuffs suggests that water producing zones may not be correlatable areally. Permeable zones within different boreholes occur at different elevations or different stratigraphic locations.

Observations/Concerns

1. The new water table test wells have helped to clarify the potentiometric surface (and possible flow paths) within and surrounding the repository block. Preliminary analysis of new head data indicates apparent, large hydraulic gradients from north to south and west to east towards the repository block. These relatively steep gradients may constitute fluid potential discontinuities. The relationship between these fluid potential discontinuities and known faults (such as the Solitario fault) is not known. The hydraulic characteristics of these faults are not known, including whether they act as barriers or conduits to groundwater flow.

   A. It is our opinion that data on vertical head distribution are needed (along or within the area encompassing these steep gradients) to help determine the hydraulic significance of the faults and flow relationships.

   B. It is our opinion that the testing program outlined to date should be modified to measure the hydraulic characteristics of faults which generally bound the repository block. Multiple well tests planned for the C wells appear to be directed at evaluating effective porosity, anisotropy, and to a more limited extent, hydraulic continuity and interconnectivity of the fracture network. It may be possible that on a repository to accessible environment scale the effect of faults on groundwater flow can be evaluated by applying hydraulic properties to the faults and mapping them accordingly. The distribution of head data suggests that at least some of the faults are affecting the flow field by acting as aquifers whose properties cannot be defensibly extrapolated over a large area. Therefore, in order to assess groundwater flow from the repository to the accessible environment adequately a testing program by which the hydraulic properties and hydraulic continuity of faults can be determined is necessary. In addition, such a testing program needs to include sufficient measurements to delineate lateral variations and distributions in hydraulic properties. A similar recommendation is outlined in NUREG/CR-2937, "Respository Site Data Report for Tuff: Yucca Mountain, Nevada", prepared by Sandia National Laboratories for the NRC. The delineations of these lateral variations can be transformed into uncertainty analyses.

2. The proposed tracer test program is a useful first step in evaluating effective porosity (necessary for travel time calculations and radionuclide transport), anisotropy and the general hydrogeologic nature of part of the portion of the porous medium that constitutes the fracture network system at Yucca Mountain. This fracture system as used herein is intended to constitute the porous medium that contains fractures or joints but are not major faults.

A. We are concerned that one experiment (C well tests with 300 foot spacings will not be adequate to establish and characterize the REV (representative elemental volume)) for the varying conditions of fractures and faults of the entire area of interest. This one experiment must be shown to be sufficient to reflect a representative REV and its hydraulic properties as they vary from area to area due to differences in fracture density, character, orientation and changes in lithology. Alternatively, a worst case analysis must be demonstrated. Based on discussions at the September workshop, it appears that the location of the C well test area was constrained by topography. However, regardless of the difficulty in the determination of

REV's and effective porosity in varying scales and localities, they must be accomplished in order to establish defensible travel times.

B. We are concerned that the planned multiple-well test is focused on tracer testing to such an extent that testing related to other hydraulic properties (e.g., hydraulic conductivity) could be inadequate. Effective porosity and hydraulic conductivity are equally important parameters in equations used to calculate groundwater flow velocity and travel times. Therefore, the problems discussed in 2A above related to effective porosity are also applicable to hydraulic conductivity. Although past discussions on pump testing were somewhat limited, we were left with the impression that determination of hydraulic conductivity may be based largely on single hole tests. We are of the opinion that a multiple-well testing program should be focused as much on determining an "effective" hydraulic conductivity as on determining effective porosity in a range of the structural environment. These statements apply to porous media consisting of major faults (possibly important aquifers) and porous media dominated by fractures (possibly less permeable than faults).

3. Paleozoic test hole data that revealed highest heads in the Tertiary-Paleozoic contact zone, and higher heads in the Paleozoic carbonate than those in the overlying tuff sequence suggest that groundwater flow may be upward into the tuffs. Data derived from geothermal heat flow studies have been interpreted to reflect downward flux of water in the unsaturated and uppermost saturated zone (Sass, 1982). The three regions of relatively uniform fluid potential strongly suggest important structural control on repository area flow. Therefore, the local repository area flow is very complex, and will require additional data to resolve the complexities.

4. The regional groundwater flow model (refer to Waddell, 1982) sets forth a useful quantitative model for conceptual purposes. Work on the subregional model, which is a segment of the regional model, has progressed. Based on discussions at the September workshop it appears that the Solitario fault (west of repository block) is being considered as a linear feature which affects the flow field around the repository block. Forty-mile wash is no longer considered as a significant linear feature affecting the flow field (geophysical evidence supports this). We are unaware of any other faults included in the current

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conceptual model of the subregion. Sensitivity analyses on various hydrogeologic parameters are planned for the subregional model as was done for the regional model.

As indicated above, most of the values for hydrologic parameters that constitute input to the models are estimates. These include the properties of faults, the estimates of recharge and to some extent discharge. The estimated discharge or flux of the subregional area is based on estimates of discharge at regional discharge areas, generally associated with carbonate rocks ultimately are controlled by those estimated inputs. Connecting such discharge areas with flow lines to the Yucca Mountain area is speculative and may be difficult to defend. The estimated rate of discharge in the area north of Ash Meadows, determined from evapotranspiration and soil moisture measurements appears particularly weak.

5. The overall modeling strategy appears to be one of first modeling the regional flow system and then modeling the subregional flow system as a segment of the regional system. This approach may then lead to modeling the repository block and environs to assess a repository's isolation capability. Based on observations in 3, 4, and 5, above, we have reached the following conclusions:

A. It is our opinion that the regional model, for which transmissivities and boundary conditions are estimated and extrapolated, usually from sparse data, must be justified carefully with respect to the establishment of boundary conditions for the subregional or repository flow models.

B. Current field data may be insufficient to defend a reliable subregional flow model. Data that are used for this purpose must be justified thoroughly, especially the extrapolation of existing data.

C. Further refinement that will yield additional reliable information seems unlikely without a large amount of new data from test wells as described in previous sections herein. Reference is made in particular to establishing hydraulic properties of faults (that constitute aquifers or aquicludes) and of inter-fault blocks wherein permeability is controlled by joints and fractures.

D. A strategy which relies heavily on calculations from very large scale (regional and subregional) modeling studies as a basis for performance assessment calculations probably will result in uncertainties that must be assigned uncertainties from a licensing standpoint.

Questions for Future NRC/DOE Discussion

1. How will the structural control of fracture networks on groundwater flow be determined?

   A. How will bulk transmissivities, which average out the effects of the fracture network over an REV, be determined?

   B. How will anisotropy of bulk transmissivity related to fracture networks be determined?

   C. How will standard pump tests be conducted and analyzed with respect to defending the validity of their application?

   D. What is the strategy for re-evaluating the tracer test plans (for determining effective porosity) based on the results of the transmissivity tests?

2. How will the structural control of faults on groundwater flow be determined?

   A. How will the distribution of hydraulic head data be interpreted relative to the distribution of fault zone aquifers as mapped by techniques other than head distribution?

B. What is the design of pump tests used to determine the hydraulic characteristics of fault zone aquifers?

C. How will standard analytical solutions to differential equations for pump test analyses be redesigned to account for nonparallel, nonlinear boundaries?

D. How will standard pump test analyses, without redesign, be screened with respect to the validity of their application?

E. What is the type and design of tests used to determine the effective porosity of fault zone aquifers?

The following questions are applicable to pump test programs related to either fracture network testing or fault zone aquifer testing.

3. What methods, other than analysis of pump test responses in observation wells, will be used to define the boundaries of hydrostratigraphic units or hydrogeologic units in the saturated zone?

4. Will borehole geophysical data be used for this purpose and if so, how?

5. How will the location of observation wells be selected relative to the location of pumping wells?

6. How will the open (screened) sections of observation wells be selected relative to the open or screened section of pumping wells?

7. What will be the density and distribution of testing?

8. What is the rationale supporting this density and distribution?

The following questions deal with the Paleozoic carbonate rocks.

9. How will the relationships between near field flow (repository block and environs) and regional-subregional flow, including the carbonate rock flow system, be established?

   A. How will the carbonate aquifer be incorporated into the design of pump tests?

   B. How will the recently measured vertical gradients affect testing strategy?

   C. What is the implication of these vertical gradients to the relationship between the tuffs and carbonate rocks?

The following questions deal with modeling the saturated zone, primarily the regional and subregional systems. Additional questions dealing with modeling the unsaturated zone and combined saturated/unsaturated considerations are identified later in this report.

10. What is the strategy behind modeling the regional and subregional systems?

    A. What is the value of these models in assessing travel times, flux and transport from the repository to the accessible environment?

    B. Will boundary conditions for performance assessment scale modeling be derived from regional-subregional models or from geologic features and field data?

11. Given the opinion that uncertainties in regional-subregional models are high and are likely to remain so, and assuming tentatively that DOE Site Characterization strategy places a high value on the products of such models to assess repository to accessible environment scale system performance, how will uncertainties in hydrogeologic parameters (or boundary conditions) that can significantly influence travel times and flow paths be treated in quantitative travel time analyses.

12. As a corollary, assuming that all saturated zone field investigations in the area of the repository block are completed and are acceptable for licensing purposes. how will the remaining uncertainties (as anticipated in 10CFR60 related to hydrogeology) be treated in quantitative analyses (repository to accessible environment) aimed at establishing groundwater travel times and subsequent transport assessments?

Unsaturated Zone Hydrogeology

Status

Prior to describing current and planned unsaturated zone characterization studies a brief review of the geologic framework is in order. The geologic framework upon which conceptual models of groundwater flow through the unsaturated zone will be imposed is summarized, in increasing order of depth, as follows:

1. Surficial Units - Partly unconsolidated materials of varying thickness (0 to 15 m, colluvium and alluvium) and partly, densely to moderately welded tuff (Tiva Canyon Member of Paintbrush Tuff).

2. Upper Clastic Unit - Bedded and non-welded tuffs of Pah Canyon and Yucca Mountain Members of Paintbrush Tuff.

3. Densely Welded Unit - All within Topopah Spring Member of Paintbrush Tuff.

4. Lower Clastic Unit - Series of non-welded ash-flow, ash-fall and reworked tuffs which includes lowest part of Topopah Spring Member and tuffs of Calico Hills. This unit is above the water table in the western part

of Yucca Mountain and partly below the water table to the east.

5. Older Volcanics - Non-welded to moderately welded tuffs including intervals of densely welded ash-flow tuff, bedded ash-flow tuff, Dacitic Lava and Flow Breccia. These volcanics are partly above the water table to the west.

Since the January, 1983 workshop, studies to characterize the unsaturated zone and other planning have continued. One of the major planned activities is a surface based drilling program. In this program a series of 6 wells (UZ-1 to UZ-6) are to be drilled to varying depths in the unsaturated zone. Well UZ-1, located about 1,000 feet west of well G-1, already has been drilled to a depth of about 1,200 feet where saturation was encountered (interpreted as drilling fluid from G-1) and greater penetration proved impossible. Fiscal year 1984 plans call for dry coring well UZ-2 and drilling wells UZ-4 and UZ-5. Plans for drilling UZ-3 and UZ-6 are indefinite. One of the UZ wells will be drilled to the water table.

Some of the UZ wells (UZ-1, 4, 5 and possibly 6) will be instrumented to obtain direct field observations of changes in vertical distribution of moisture content with time. This information coupled with direct measurement of ambient moisture content from large and small drill cuttings (laboratory measurements) and cores can lead to direct field estimates of recharge. The instrumentation scheme consists of an elaborate column of various unsaturated zone hydraulic property measuring devices sealed off by zone. Instruments that have been considered for use include: tensiometers. heat dissipation probes, soil thermocouple psychrometers. gypsum blocks and fiber glass or nylon resistance wafers. The U.S.G.S. has concluded that gypsum blocks and resistance wafers would be unsuitable. At the January, 1984 University of Arizona Unsaturated Zone Workshop Bill Wilson reported that the installation was completed successfully and the instruments were yielding consistent data.

Additional plans include installing a series of shallow neutron probe access tubes. The purpose is to determine changes with time of moisture content in the alluvium and shallow unsaturated tuff units beneath the alluvial washes. This is an approach to analyzing the recharge from the losing stream through the alluvium into the underlying tuffs. An elaboration of this study will be conducted using wells UZ-4 and UZ-5. One well will be drilled adjacent to, and the other within Abandoned Wash to obtain comparative observations in order to evaluate the hypothesis that most of the recharge to the unsaturated zone occurs through the wash bottoms. Wells UZ-4 and UZ-5 will be drilled to a depth of about 300 feet into the Upper Clastic Unit.

Preliminary plans include some "cross-hole testing" in some of the UZ wells using air, steam or water. Details of these plans have not yet been presented to the NRC staff.

To date, the NRC staff is knowledgeable of only the general scope of the exploratory shaft test plans (as related to hydrology). In general, during the construction phase plans are for measuring moisture content and fluid potential. extraction of pore water for geochemical analysis (including age dating), testing perched water zones , if present, and evaluation of the disturbed zone. Plans include drilling boreholes radially outward from the shaft and constructing break-outs (short drifts) for future infiltration and bulk permeability tests. A break-out is planned at or near the Topopah Springs-Calico Hills contact in order to determine the hydrogeologic nature of this contact (i.e., a contact between highly-welded, fractured tuff and non-welded, ash-flow/fall tuff (lower clastic unit).

During the September, 1983 workshop the U.S.G.S. indicated that there are other testing programs they feel are needed but which are not planned currently. These testing programs include a break-out in the Upper Clastic Unit, gas tracejestor surveys of the unsaturated zone in existing wells, instrumentation of shallow bore holes, additional UZ wells west of Yucca Mountain (UZ-4, 5 type - triplet wells) and thermal IR surveys.

To date, the U.S.G.S. has described to the NRC staff three general, alternative conceptual models of groundwater movement through the unsaturated zone. Assuming an east-west cross section through the repository block which is bounded by faults, these conceptual models are, in brief:

1. Recharge is uniform in time and space (.45 cm/yr.). Matrix flow dominates; consequently little flow is diverted to fractures. Strong horizontal component of flow (down dip, to east) exist in the Upper Clastic Unit; therefore, little flow is downward through the densely welded unit (Topopah) to the lower clastic unit and to the water table. Some perching of water at the Topopah-Lower Clastic Unit is possible (down dip at eastern fault boundary).

2. Recharge is uniform in time and space (.45 cm/yr). Matrix flow dominates; little flow is diverted to fractures. No horizontal component of flow occurs in either the Upper or Lower Clastic Units; therefore, only vertical flow downward to water table occurs.

3. Recharge is uniform in time and space (.45 cm/yr). Fracture flow dominates while some horizontal component of flow exists in both the Upper and Lower Clastic Units. Some downward flow occurs at the fault boundaries.

Recently, Matthew Gordon of WMGT attended the Materials Research Society (MRS) meeting in Boston. At this meeting William Dudley presented three alternative conceptual models of groundwater flow through the unsaturated zone. These appear to be an evolution of those presented at the September workshop which were outlined previously. Based on Mr. Gordon's trip report, these modified conceptual models are:

1. Recharge is uniform in time and space at 8mm of maximum downward flux. Little flow is diverted to faults or fractures. Flow is vertical to the water table [same as alternative 2 above].

2. Widely spaced intense recharge events cause temporarily saturated conditions in the non-welded tuff. Fast flux pulses result with little matrix diffusion. The potential for perched water tables exists with a consequent strong horizontal flow component in densely welded unit. Flow is diverted into fractures.

3. Periodic recharge events. Flow is diverted into fractures and down to the water table. A "capillary barrier" exists within the Paintbrush non-welded units [Clastic Units]. Vapor diffusion occurs with convective currents. Matrix diffusion occurs but is limited.

It appears that three new elements (processes) have been incorporated into the conceptual models. These are: 1) consideration of varied recharge events as opposed to only long term average recharge, 2) potential horizontal flow components within the densely welded unit (Topopah), and 3) vapor diffusion.

The NRC staff is not aware of any comprehensive modeling studies of the unsaturated zone accomplished by DOE to date. However, a number of estimates of travel times through portions of the unsaturated zone have been made. These estimates either have been mentioned in meetings or quoted in various letters or reports. These include:

1. 21000 years - This estimate was provided by Sandia (L. Tyler) to T. H. Pigford and presented in the National Research Council's Report, "Study of the Isolation System for Geologic Disposal of Radioactive Waste", 1983. This estimate is based on a one-dimensional analytic solution (Darcy's Law), thus only downward,

vertical flow is considered. Assuming a constant, average annual recharge flux of .3 cm/yr Darcian velocities were calculated by assuming input values of porosity, fraction saturation and thickness. The calculated value of 21000 years is the estimated travel time from the repository horizon (Topopah Spring) down to the water table. The same estimate was provided by L. Tyler to the NRC staff during the January, 1983 workshop.

2. 1900, 2600, 5600 years - These are travel time estimates from an August 19, 1983 letter from Bill Dudley, USGS, to Don Vieth, DOE. These estimates are travel times based on Darcian flux for the lower clastic unit assuming 8 mm of recharge and an effective porosity of .30, with several possible hydraulic conductivities based on samples of 200 litic and uitric tuff, and a range in thickness of 70 m to 150 m. The lower value is obtained when all of the flow is diverted to the zolitic facies through one half of the cross sectional area where the lower clastic unit is 100 m thick.

Due to the uncertainties of evaluating the unsaturated zone, the DOE and the NRC have agreed upon a joint workshop on the unsaturated zone at the earliest feasible date. As yet, the date has not been established. In January, 1984 a workshop on unsaturated zone research was held at the University of Arizona; it was attended by a limited representation invited from national laboratories, the USGS, the NRC, the University of Arizona, and several soil physicists from several universities. Problems discussed included modeling of the fracture flow, field collection of data and appropriate methodology, scale of both field and laboratory data, validation of the codes being developed or currently available, and solute transport. None of the problems were fully resolved in all aspects; some issues are in the early stages of investigation.

Observations/Concerns

Confident characterization of the moisture regimes and repository performance in the fractured, unsaturated tuff is of prime concern to the NRC staff. Three fundamental problems are recognized which lead to this concern:

1. The methodologies for collecting field data for characterizing the moisture regimes in thick, unsaturated fractured tuff are unestablished for such environments; therefore, they are highly experimental.

2. In fractured rock terrain such as the unsaturated zone of Yucca Mountain, there is a serious, unresolved problem in establishing the correct scale of data collection on hydrogeologic parameters. When dealing with fracture flow transport, the potential range in scale is that produced by the range in small laboratory samples (a few cubic centimeters to several cubic meters in volume) to field scale which may involve hundreds to thousands of cubic meters of fractured rock. Fracture characteristics which may influence the transport of fluids (such as fracture density, orientation, interconnection, aperture size and shapes, fracture plane, minerals, solutes, rock stress fields, etc.) may vary greatly within the repository block.

3. Numerical codes developed for the modeling of liquid vapor, heat, and solute transport in unsaturated fractured rocks presently are unvalidated at field (and laboratory) scales; these codes will be difficult to validate in the absence of reliable field data at various scales. Uncertainties associated with the transport processes in fractured tuff require code validation for licensing considerations.

Methodologies for collecting field data on moisture content and fluid potential are being adopted from classical soil physics techniques for the most part. The success of separating the effects of matrix moisture and fracture moisture have not been established. The instrumentation being used requires that boreholes be constructed without the addition of drilling fluids. This greatly increases the difficulty of instrument hole construction, and restricts or eliminates the opportunity for cores that have not been subjected to drilling fluids. The first successful deep borehole (UZ-1) designed to monitor soil moisture potential and other variables was vacuum drilled without drilling fluid and proved to be costly (approximately 2 million dollars). It appears to be successful in terms of hole construction and instrument emplacement. It is unlikely that the density of such installations will be increased greatly; furthermore, it is too soon to evaluate the utility of the moisture potential data now being collected. Most of the other planned unsaturated zone monitoring holes consist of shallow installations.

The exploratory shaft is being viewed by DOE as a source of additional unsaturated zone moisture regime assessment. Details of planned experiments are as yet unavailable to the NRC team, but many objectives have been discussed, including possible experiments with tracers and efforts to establish information on representative elemental volume (REV's) as well as the geochemistry of unsaturated zone moisture. Our concern is two-fold with respect to these efforts: 1) How representative of the range of moisture regime conditions will the data be as it is established from the limited test locations, and 2) since the methodologies that are to be employed are generally experimental, how reliable are the data that will be developed?

Another area of concern is that of application of numerical models based on codes that have not been validated at the various field scales to which they may be applied. We anticipate that, judging from the direction of effort currently being demonstrated by DOE and associated contractors, validation of codes adapted to Yucca Mountain analyses must be established at either small scale laboratory or field experiments.

Questions for Future NRC/DOE Discussion

1. How will the correct conceptual model of the unsaturated zone flow be established?

   A. What data (and methodology) can be collected to establish matrix flow, fracture flow, or both?

   B. What data (and methodology) will establish steady or pulse flow?

   C. What data (and methodology) will establish vertical vapor transport?

   D. How will the 3-D relationships of the above be established throughout the repository block?

2. How will the in situ water content (3-D) be measured within the repository block?

3. How will the total flux to the repository horizon be determined?

4. How will perched water zones be recognized and their extent delineated within the repository block?

5. What is the influence of perched water on flow paths?

6. How will short-term and long-term climatic influences on the unsaturated zone hydrology be determined?

7. How will pluvial climate unsaturated zone hydrology be evaluated in terms of recharge flux, perched water (and perhaps local spring discharge) and position of the water table?

Hydrogeochemistry

Status

Prior to describing the current and planned studies in hydrogeochemistry, a brief discussion of their importance is warranted. Hydrogeochemistry studies encompass both solute chemistry of groundwater and isotope hydrology. It generally has been observed that hydrogeochemistry studies are useful for characterizing groundwater flow systems and determining certain boundary conditions or flow relationships that at times cannot be demonstrated readily by other more conventional hydraulic techniques or studies. The data on hydrogeochemistry, when combined with the relationships established by fluid potential measurement, geology, and various hydraulic tests, often can increase greatly the degree of confidence in describing or characterizing the flow system. In the case of both saturated and unsaturated fractured rock flow systems of Yucca Mountain, the data on fluid potential and hydraulic properties are difficult to collect and interpret due to the great depths to saturation, the fracture permeability, and uncertainties in appropriate field data collection methodologies (particularly in the unsaturated zone).

Therefore, the hydrogeochemistry data are of considerable interest in that they may either support or refute interpretations derived from the other lines of evidence used to establish flow system characteristics, including such aspects as age of water, flow velocity, mixing, and flow paths.

Hydrogeochemisty studies have not been established as yet for the Yucca Mountain site to an important degree: the data available to the NRC are minimal. Water samples have been pumped from the wells in Forty Mile Wash and several of the hydrologic test holes and a few chemical analyses have been reported. Most of these samples are of questionable value for detailed interpretation because of the following problems:

1. Many of the pumped samples taken to date are from composite aquifer zones.

2. Many of the pumped samples have uncertain amounts of drilling fluid present.

3. Water samples from the unsaturated zone consist of drilling fluid or are contaminated by drilling fluid.

4. Deep boreholes with open zones located along the saturated portion of a borehole facilitate circulation of water from permeable zones of higher fluid potential

to permeable zones of lower fluid potential. Therefore, samples collected from any one of the multiple zones may not reflect the original water chemistry of the zone sampled.

The above problems can impact the following hydrogeochemical characteristics of the samples: water chemistry (identity of solutes and their concentrations), stable isotope compositions (D/H and $^{18}O/^{16}O$) radioactive isotopes (^{14}C, tritium and others). To date ^{14}C determinations have been made for several sampling points along Forty Mile Canyon and the repository block area, but the resulting data generally are unreported. Claassen (1983) has also considered ^{14}C in the Amargosa Desert study that is about to be released. However, there are unofficial reports of reversals in age with respect to the apparent direction of regional flow based on head data and model output. If true, the observations can be related to sampling methods, (composite mixtures of water from more than one horizon in any given well) or they may be related to age correction techniques. Certain basic assumptions are necessary with respect to applying correction formulae to radiocarbon determinations. One conceptual model proposed to explain the reversal of age dates along the Forty Mine Wash sampling transect is that recharge of younger water occurs from infiltrating wash water that mixes with older waters recharged during the latest pluvial climate.

In the workshop of September, 1983 the U.S.G.S. indicated that a hydrogeochemistry program was planned, but they detailed only the objectives. None of the specifics as to methodology, such as sampling procedures and locations, or a detailed discussion of planned constituent evaluation was presented. The general plan included sampling of the unsaturated zone as opportunities arise during the construction of the exploratory shaft, and perhaps sampling perched water identified by borehole geophysical studies of existing hydrologic test holes.

Regional hydrogeochemistry studies have aided significantly the conceptual understanding of the flow systems of the region (see, for example, Winograd and Thordarson, 1975). Differences in basic water chemistry have been noted in waters associated with the volcanic rock terrain and the carbonate rock terrains. Mixed waters, where water recharging the carbonate aquifer is derived from volcanic rock terrain, are recognized also. The regional or local natures of the carbonate rock flow systems discharging at major spring areas in southern and eastern Nevada have been demonstrated on the basis of hydrogeochemistry (Mifflin, 1968; Winograd and Pearson, 1976). The Ash Meadows Springs display water chemistry and isotopic constituents characteristic of large, regional carbonate rock flow systems. These hydrogeochemical relationships are consistent with the available NTS region-supporting data of fluid potential and water budgets.

The majority of groundwater in the Amargosa Desert area has the chemical characteristics of the volcanic terrain water. However, the most recent study (by Hans Claassen of the U.S.G.S.) has yet to be released. Results of this study should prove important for determining contributions of recharge to the alluvial basin from the volcanic terrain (including the Yucca Mountain area), the carbonate rock flow system (which extends to or near the Yucca Mountain repository block area in the subsurface) and the recharge directly from the alluvium within the basin.

Observations/Concerns

1. On the basis of using the existing boreholes and hydrologic test holes in the Yucca Mountain area, the planned hydrogeochemistry studies may prove difficult to execute to the degree desirable. The deep hydrologic test wells are cased with perforations open to several zones. The fluid potentials in various permeable zones have been equilibrating for over a year or more; consequently original fracture-zone chemistry may have been changed by borehole circulation among zones of varying fluid potential open to the borehole. Also, drilling fluid losses have been significant during some of the drilling operations. Thus, reliable water samples depicting a three-dimensional picture of hydrogeochemistry in the saturated zone of Yucca Mountain may be difficult to establish and/or the density of reliable samples may be sparse. The shallower "watur table" test holes may prove to be useful for controlled sampling in the upper 100 meters of saturation.

2. Water sampling in the unsaturated zone is even more problematic. Evidence to date of perched saturation suggests that drilling fluid has caused at least part of the saturation observed within the unsaturated zone.

Moisture samples from the exploratory shaft may be the only opportunity to collect water samples that are not suspect. However, the shaft area may not be representative of the range of conditions throughout the repository block. Methodology to collect unsaturated zone pore water is not very well developed, although some methods such as vacuum lysimeters have been used.

In summary, nearfield and subregional hydrogeochemistry studies have the potential to increase greatly the understanding of the associated flow systems and perhaps add perspective to flow velocities. We believe them to be highly desirable to compare with the results of other lines of testing. However, we are concerned that hydrogeochemistry has not been a priority objective to date; therefore most water samples that have been taken are samples of opportunity rather than samples from an optimally designed program for hydrogeochemistry studies. As of September, 1983, no detailed plan was available for review in the U.S.G.S. program; serious problems could be encountered in obtaining ideal samples for analyses due to the nature of the site and the condition of the existing boreholes. The reliance on water samples of opportunity does not maximize the potential utility of hydrogeochemistry in establishing flow relationships, and could lead to erroneous results.

One important note to append to this discussion is the potential influence of the solutes in the unsaturated zone on rates and direction of radionuclide transport. In the January, 1984 workshop on unsaturated zone research at the University of Arizona Oracle Conference Center, a strong point was made by a prominent soil physicist, Don Nielson (University of California, Davis). He pointed out that, based on what is known from solute/water transport studies in agricultural soils, transport of water and transport of solutes are quite different in unsaturated vs. saturated environments. In partially saturated pores with thin films of water containing solutes, various chemical forces (osmotic potentials for example) become important in determining the transport of both the water and solutes. Therefore, radionuclide transport will be a complex problem, dependent upon solutes present, degree of saturation, pore size, pore surface minerals, and perhaps other factors not directly related to water and vapor transport. Work on this aspect of the problem at Yucca Mountain has not been brought to our attention.

Questions for Future NRC/DOE Discussion

These questions are necessarily broad and limited at the present time due to the level of the NRC teams knowledge of the design and use of pending hydrochemical studies.

1. Will hydrogeochemistry investigations be used to supplement other hydrologic and geologic data and interpretations of it?

   A. How much weight will be given to hydrogeochemical relationships versus the relationships established by other forms of testing?

2. How will samples be collected in the saturated zone to avoid mixing of water from more than one horizon.

   A. How will the potential influence of drilling fluid be handled?

3. How will samples be collected in the unsaturated zone to determine the solute chemistry and other constituents?

   A. How will fugitive drilling water and in situ perched water be identified?

4. Will ^{14}C be used to establish or support groundwater velocities?

Climate Change (Paleohydrology)

Status

Prior to describing the current and planned studies addressed to determining climate change (paleohydrology), a discussion of the issue is warranted.

The arid and semi-arid climates of the Great Basin produce a delicate balance in the hydrologic systems. Minor changes in precipitation or temperature can produce important changes in runoff and recharge, as well as ponded surfaces which accumulate in hydrographically closed basins. Abundant evidence suggests that late Quaternary hydrologic systems were impacted markedly by pluvial climates that were generally contemporaneous with the glacier-producing climates elsewhere on the North American continent. To the north of Yucca Mountain in the Great Basin nearly all basins that are hydrographically closed periodically contained perennial pluvial lakes on the basin floors from between 80,000 years B.P. to as recently as 12,000 to 10,000 years B.P. The evidence for these lakes consists of shoreline beach deposits and lacustrine sediments; they provide good evidence for pluvial climate water tables a few tens of meters to several hundreds of meters higher than current water tables in the basins. To the south of Yucca Mountain the evidence for perennial pluvial lakes is generally absent, but nearly all hydrographically closed basin floors are significantly lower in elevation than those to the north; most catchment basins are also lower in average elevation. The evidence suggests that more arid pluvial climates prevailed, but areas of basin sediments do exist that are believed to be related to shallow groundwater or active groundwater discharge far beyond the extent of modern groundwater discharge and shallow saturation. The regional evidence indicates that water tables were shallower in the basins during pluvial climates.

The issue of climate change relates directly to a repository in the unsaturated zone. Several important hydrologic factors at Yucca Mountain could change with a future shift to a pluvial type of climate. Increase in unsaturated zone flux, development of perched water zones, rises in the position of the water table, and changes in the location of groundwater discharge are postulated hydrologic system changes associated with cooler and/or wetter climates. Quantitative estimates of past pluvial climates or associated paleohydrologic conditions are the best estimates of a climatically-induced change that is judged possible.

The following are specific investigations directed toward the changing climate issues. At the September, 1983 workshop the U.S.G.S. discussed a number of possible studies; they stated that the current approach is essentially a "scoping" program to determine the importance of the issue. Not all of the studies discussed at the September, 1983 workshop have been adopted to date. Studies completed to date are as follows:

1. An analysis by Winograd and Doty (1980) which estimated the probable pluvial climate discharge of the NTS carbonate rock flow system at the Ash Meadows area and the associated differences in the position of saturation. Based on the sparse evidence recognized and assumptions adopted in the analysis, a maximum of a 50 meter rise in the potentiometric level in the carbonate aquifer system in the Ash Meadows area, and possible rise of 6 meters to 90 meters in the saturation level beneath Frenchman Flat were concluded.

2. A study of fossil packrat middens in the NTS region is currently in U.S.G.S. review. Brief examination of the draft copy at the September, 1983 workshop indicated that the general conclusion was that colder, but not significantly wetter, climates occurred during the late Quaternary. The latest recognized cooler or wetter period, dated about 11,000 to 9,000 years B.P., reflected higher summer precipitation based on the

composition of vegetation assembledges. Analyses of fossil packrat middens are proving useful to date; they have identified past plant communities at site specific locations.

Studies in progress are as follows based on a January 20, 1984, communication between Carl Johnson, State of Nevada, and William Dudley, U.S.G.S.:

1. The paleoclimatic history of the region as can be established by study of cores taken from playa lake beds and lake beds: This study considers relationships of sedimentation, lithology, tephrachronology (ash beds, source, dates), mineralogy, pollen, fossils, and isotopic studies to determine temperature and hydrologic relationships. Cores collected to date include drill hole core from Kawich Valley; plans call for cores from Dry Lake Valley and Walker Lake. This approach should provide information on the pluvial climates of the region and subregion near Yucca Mountain.

2. A study of fossil packrat middens at Yucca Mountain and Forty Mile Wash is in progress. This study involves a concentrated collection of packrat middens on Yucca Mountain. It should give more information in a site

specific basis on past vegetal communities in the Yucca Mountain area and on their timing of occurrence.

3. A study consisting of lake bed and associated deposit mapping in the Ash Meadows area is being conducted to determine past discharge relationships. This study is reported to be at a stage where the report is expected (for U.S.G.S. review) within a few months. The study follows up, in part, on the Winograd and Doty study mentioned above.

4. A flood study (past and modern) is being conducted to establish past and current flood hazards. This study includes the establishment of stream flow gaging stations on drainages to monitor runoff events; mapping of old flood deposits in the area of Yucca Mountain is included to facilitate comparison of current and historic data with the record of past events.

A number of other past studies have addressed the pluvial paleoclimates of the Great Basin. However, some of the resulting interpretations of paleoclimates differ widely, with disagreements primarily between how wet, or how cold the pluvial climates actually were. The geomorphic and geologic evidence generally does not allow the separation of the importance of the two climatic parameters. The combination of evapotranspiration (temperature dependent) precipitation (and timing) determine the net hydrologic responses, both in terms of surface-water runoff and recharge. Therefore, the paleoclimate assessment of recharge is complex, as is the modern assessment of recharge. Under modern climatic conditions the potential annual evaporation throughout all but the very highest terrain in the region is greater than the mean annual precipitation; therefore, theoretically no recharge should occur. In fact, recharge does occur, probably due to the timing of availability of moisture in depressions at land surface, and the associated rate at which the vegetal communities can transpire the moisture as it passes the root zone.

Observations and Concerns

A repository in the unsaturated zone in an arid or semi-arid area is subject to potentially important changing moisture regimes produced by climatic changes. The available evidence of markedly different past hydrologic systems in the region raises the questions of the suitability of the unsaturated zone for long term respository performance because of the potential sensitivity of the unsaturated environment to climatic changes. The principal concern at this point is whether or not a valid assessment of the pluvial climate unsaturated and saturated zone hydrologic regimes can be accomplished. A pluvial climate type of change apparently constitutes a reasonable worst case scenario. Studies performed and initiated to date basically are directed toward developing data on past climatic conditions. Translating these climatic estimates into site specific unsaturated zone hydrologic parameters such as flux, position of water table, and presence or absence of perched water may prove difficult. From the perspective of licensing, the ideal result of these efforts will link the recharge flux in the unsaturated zone to paleoclimate parameters and delineate potential differences in position of water tables and perched water at Yucca mountain. In addition, any important differences in distribution of groundwater discharge and associated flow paths should be established.

Questions for Future NRC/DOE Discussion

1. How will paleoclimate indicators, such as past plant communities, temperature estimates, and precipitation estimates, be used to determine pluvial hydrologic conditions including unsaturated zone flux, probability of perched zones, and position of the water table at Yucca Mountain?

2. How will the general relationships of groundwater flow paths and positions of discharge during a pluvial climate condition be established.

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