U. S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
OFFICE OF QUALITY ASSURANCE

AUDIT REPORT

OF

UNITED STATES GEOLOGICAL SURVEY

AT

DENVER, COLORADO

AUDIT NUMBER YM-ARP-96-12
APRIL 29 THROUGH MAY 2, 1996

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Enclosure

1.0 EXECUTIVE SUMMARY

As a result of Performance Based Quality Assurance (QA) Audit YM-ARP-96-12, the audit team determined that the U.S. Geological Survey (USGS) is satisfactorily implementing an adequate and effective QA program and process controls, with the exception of those program areas where deficiencies existed for work performed under Work Breakdown Structure (WBS) 1.2.3.3.1.3.3, "Saturated Zone Hydrologic System Synthesis and Modeling," and WBS 1.2.3.3.1.2.7, "Unsaturated Zone Hydrochemistry." The USGS program examined during this audit is in accordance with U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) Quality Assurance Requirements and Description (QARD) document DOE/RW-0333P, Revision 5, and selected USGS implementing quality and technical procedures.

The audit team identified three deficiencies during the course of the audit which are being included and resolved through open OCRWM deficiency documents that documented similar deficiencies. These similar deficient conditions were previously identified during a compliance based audit YM-ARC-96-10, conducted March 25-29, 1996, by the Yucca Mountain Quality Assurance Division (YMQAD). One deficiency concerned the absence of a documented QA program of a USGS supplier and the lack of appropriate QA requirements being included in the procurement documents. This condition was added to a previous Corrective Action Request (CAR) YMQAD-96-C004. Corrective actions relative to this CAR will also include correction of this identified deficiency. The second deficiency is related to a supplier evaluation not being performed on a USGS supplier This condition was also added to CAR YMQAD-96-C004. Corrective actions associated with this CAR will also address this identified deficiency. The third deficiency involves the implementation of corrective action taken for reported conditions adverse to quality and the timely closure of related corrective action documentation. This condition was added to CAR YMQAD-96-C005. Corrective actions associated with this CAR will include correction of this identified deficiency.

In addition to the above conditions, one deficient condition was corrected prior to the postaudit meeting (see Section 5.5.4 of this report). There were also four recommendations resulting from the audit, which are detailed in Section 6.0 of this report.

2.0 SCOPE

The performance-based audit was conducted to evaluate the adequacy and effectiveness of the USGS controls for performing activities that result in the development of the deliverables, "Preliminary Site Saturated Zone 3-Dimensional Ground Water Flow

Model," under WBS 1.2.3.3.1.3.3, and the "Unsaturated Zone Hydrochemistry Data Synthesis Report," under WBS 1.2.3.3.1.2.7. The audit was intended to determine the progress and development of the deliverables and that the products are being developed in accordance with program requirements and the pertinent sections of the QARD.

The process/activities/end-products evaluated during the audit, in accordance with the approved audit plan, are as follows:

PROCESS/ACTIVITY/OR END-PRODUCT

The performance based evaluation of process effectiveness and product acceptability was based on:

1) Satisfactory completion of the critical process steps;
2) Acceptable results and quality of the end products;
3) Documentation that substantiates quality of products;
4) Performance of trained and qualified personnel; and
5) Implementation of applicable QA Program Elements

Activities involving development of the "Preliminary Site Saturated Zone 3-Dimensional Ground Water Flow Model," were selected for evaluation from WBS element 1.2.3.3.1.3.3, "Saturated Zone Hydrologic System Synthesis and Modeling."

The USGS critical process steps involved in the development of the audited deliverable were as follows:

- Data Compilation
- Data Analysis
- Data Review
- Model Construction
- Model Validation

In addition, activities involving development of the "Unsaturated Zone Hydrochemistry Data Synthesis Report," were selected for evaluation from WBS element 1.2.3.3.1.2.7, "Unsaturated Zone Hydrochemistry."

The USGS critical process steps involved in the development of this audited deliverable were as follows:

- Sample/Data Collection
- Data Analysis
- Data Development and Review
- Interpretation/Reporting

TECHNICAL AREAS

The audit included a technical evaluation of the development processes and adequacy of the "Preliminary Site Saturated Zone 3-Dimensional Ground Water Flow Model," and the "Unsaturated Zone Hydrochemistry Data Synthesis Report." Details of the technical evaluation are included in Section 5.4.

In addition, a sample of the applicable QA program requirements and controls as they applied to the technical areas was examined to evaluate the degree of compliance. The following QA program elements were evaluated for applicability and compliance:

1.0 Organization
2.0 QA Program (Qualification and Training of Personnel)
4.0 Procurement Document Control
5.0 Implementing Documents
6.0 Document Control
7.0 Control of Purchased Items and Services
12.0 Control of Measuring and Test Equipment
15.0 Nonconformances
16.0 Corrective Action
17.0 Quality Assurance Records
Supplement I, Software
Supplement II, Sample Control
Supplement III, Scientific Investigation

3.0 AUDIT TEAM AND OBSERVERS

The following is a list of audit team members and observers and their assigned areas of responsibility:

Name/Title/Organization	QA Program Elements/Requirements, Processes, Activities, or End-Products
Daniel A. Klimas, Audit Team Leader, YMQAD	QA Program Elements directly related to support the end-products, QA Elements 1.0, 4.0, 7.0, 17.0
John R. Doyle, Auditor, YMQAD	QA Program Elements directly related to support the end-products, QA Elements 2.0, 5.0, 6.0, 12.0, 15.0, 16.0, Suppl.I, II, III

Cady L. Johnson, Technical Specialist, Civilian Radioactive Waste Management System Management and Operating Contractor	Supplement III, Process Steps for development of the " Preliminary Site Saturated Zone 3-Dimensional Ground Water Flow Model," WBS 1.2.3.3.1.3.3 and "Unsaturated Zone Hydrochemistry Data Synthesis Report" WBS 1.2.3.3.1.2.7.

John G. Spraul, Observer,
U.S. Nuclear Regulatory Commission (NRC)

John W. Bradbury, Observer, NRC

4.0 AUDIT MEETINGS AND PERSONNEL CONTACTED

The preaudit meeting was held in the USGS offices in Denver, Colorado, on April 29, 1996. A daily debriefing and coordination meeting was held with the USGS management and staff, and daily audit team meetings were held to discuss issues and potential deficiencies. The audit was concluded with a postaudit meeting held at the USGS offices in Denver, Colorado, on May 2, 1996. Personnel contacted during the audit are listed in Attachment 1. The list includes those who attended the preaudit and postaudit meetings.

5.0 SUMMARY OF AUDIT RESULTS

5.1 Program Effectiveness

The audit team concluded that, in general, with the exception of those areas where deficiencies existed, the USGS QA program is adequate and is being effectively implemented for the scope of this audit except for procurement, control of purchased items and services, and corrective action. The process controls for performing activities associated with the development of the "Preliminary Site Saturated Zone 3-Dimensional Ground Water Flow Model," WBS 1.2.3.3.1.3.3 and the "Unsaturated Zone Hydrochemistry Data Synthesis Report," WBS 1.2.3.3.1.2.7 were found to be effective. The due date for both of these deliverables is August 30, 1996.

5.2 Stop Work or Immediate Corrective Actions Taken

There were no Stop Work Orders, immediate corrective actions, or related additional items resulting from this audit.

5.3 QA Program Audit Activities

A summary table of audit results is provided in Attachment 2. The details of the audit evaluation, along with the objective evidence reviewed, are contained within the audit checklists. The checklists are kept and maintained as QA Records.

5.4 Technical Audit Activities

The performance based QA audit focused on those processes and activities associated with the development of the following deliverables: "Preliminary Site Saturated Zone 3-Dimensional Ground Water Flow Model," WBS 1.2.3.3.1.3.3 and the "Unsaturated Zone Hydrochemistry Data Synthesis Report," WBS 1.2.3.3.1.2.7.

5.4.1 The performance-based audit of the USGS Study 8.3.1.2.3.3, "Saturated Zone Hydrologic System Synthesis and Modeling," WBS 1.2.3.3.1.3.3, was conducted in Denver, Colorado at the USGS National Training Center on April 29-30, 1996. The process steps involved in the development of the model have been identified by the USGS as follows: data compilation, data analysis, data review, model construction, and model validation. These steps are evaluated in the following paragraphs:

Data Compilation

Hypotheses and Conceptual Models

A catalog of hydrologic hypotheses has been considered in evaluation of the saturated zone at Yucca Mountain. Thirty hypotheses were identified and are listed as indicated below:

1. The site flow system is adequately represented by 16 hydrogeologic units;
2. Site and regional model domains are of adequate areal extent;
3. The regional flow system is appropriately represented as steady-state;
4. In the framework model, faults are adequately represented by offsets of geologic units;
5. It is appropriate to treat the site-scale flow system as an equivalent porous medium;
6. The site flow system is appropriately represented as steady-state;
7. Boundaries of the site flow system can be identified from a potentiometric-surface map and results of regional simulations;

8. Paleozoic carbonate rocks are more transmissive than volcanic rocks of the region, and constitute the base of the site flow system where present;
9. Based on observations in borehole P1, flow in carbonate rocks is confined by "older tuffs" in the site area;
10. Water temperatures along faults indicate the potential for structural control of flow;
11. Comparison of single-well with multi-well hydraulic test data suggests that; a) permeabilities derived from inverse models are larger than those obtained from aquifer tests, indicating that b) aquifer-test data, particularly from single-well tests, are of limited use;
12. The primary inflow area is north of the site area;
13. The primary outflow area is Franklin Lake Playa;
14. A ground-water "mound" beneath the Greenwater Range limits southward movement of water beneath the Amargosa River;
15. Springs in Furnace Creek Wash are supplied by underflow from Ash Meadows;
16. The distribution of Paleozoic carbonate rocks in the subsurface is appropriately derived from objective interpolation between cross-sections published by T. L. Grose and G. I. Smith;
17. The Large Hydraulic Gradient (LHG) influences saturated zone flux, flow velocities and dilution potential beneath the site;
18. The LHG may be due to: a) low-permeability Calico Hills formation, b) a semi-perched system, c) a fully perched system, d) a drain into the carbonate aquifer, e) a spillway, or f) reflection of effects caused by the deeply buried Eleana formation;
19. The LHG is a stable (permanent) feature;
20. If the LHG has the shape of a ramp, a low-permeability zone would be indicated;
21. If the LHG has the shape of a step, a discrete geologic feature such as a dike or a hidden fault would be indicated;
22. Recharge from overland flow causes ground-water mounding under stream channels;
23. A trough in the potentiometric surface is present beneath Fortymile Wash;
24. Frequency of recharge processes in Fortymile Canyon is linked to global weather patterns (Southern Oscillation Index);
25. A multiple-permeability conceptual model has important waste-isolation implications;
26. Northeast-trending faults are conduits to flow, and northwest-trending faults are barriers;

27. Although most flow occurs along a few discrete paths, attempts to define these discrete paths would be futile;
28. Chemical evolution of groundwater, including considerations of mixing processes, is useful in flow-system delineation;
29. Hydraulic transport parameters at the C-well complex are representative of the site at large;
30. The transmissivity of the southern Funeral Mountains controls deep fluid potentials in the southern Amargosa Desert.

The list was developed by first examining a map depicting postulated regional and sub-regional flow-system boundaries, and then proceeding systematically around the sub-regional system boundaries and discussing what is known and not known. Reference materials that had been provided prior to the audit proved to be extremely useful. Framework information was discussed first, including the manner in which the sub-regional grid is embedded in the regional grid, assumptions regarding the extent and correlations of hydrogeologic units, methodologies for constructing the framework model, and data needs.

Hydrochemistry and Paleohydrology Inputs

Hydrochemical data from the region have been compiled, reviewed, and published in both complete and edited versions in a recent USGS Open-File Report (94-305). Data from the saturated zone at the site are thought to be of generally poor quality, primarily because of insufficient well development prior to sampling. The question of how to bring hydrochemical data into the site flow model was discussed only briefly, since the USGS had not yet formally interpreted the hydrochemical data. A question as to whether the saturated zone can be considered to be well-mixed in terms of chemistry could not be answered, primarily because boreholes were pumped over large intervals for sampling, and the appearance of uniform compositions may be an artifact of the manner in which the samples were acquired. The selection of a 50-meter mixing depth for Total-System Performance Analyses, TSPA-95, calculations was judged to be arbitrary.

Paleohydrologic information is also insufficiently developed to be of much use to the flow modeling effort, although USGS staff did indicate that next year the regional model will be used to look at various climate scenarios.

Data Analysis

USGS staff indicated that a large data void exists in the up-gradient (Timber Mountain) area, and there will be heavy reliance on the regional model to establish inflows at the northern boundary of the site flow system. Conceptual uncertainties in the Timber Mountain area relate to the possibility of a groundwater divide in the Pinnacles Ridge area, which might divert flow from Pahute Mesa westward toward Oasis Valley. It is also possible that high fluid potentials to the north of Yucca Mountain represent a potentiometric high that is in the process of draining.

Fluxes along the east side of the postulated flow domain are attributable to juxtaposition of Tertiary sediments and Paleozoic carbonates in the vicinity of the Ash Meadows spring alignment. While it is possible that major underflow occurs between Ash Meadows and Death Valley, any such fluxes have not been quantified. Chemical similarities between major springs at Ash Meadows and springs in Furnace Creek wash suggest that such a hypothesis is credible. USGS staff acknowledges the need for additional potentiometric and hydrochemical information along the east flank of the southern Funeral Mountains.

An apparent potentiometric mound beneath the Greenwater Range is taken as evidence that outflow beneath the channel of the Amargosa River is minor. Modeling to date has treated the flow system boundary south of Franklin Lake Playa as a no-flow boundary.

Leakage between the carbonate aquifer and the tuff-alluvium flow system cannot be quantified within the postulated flow domain, partly because the distribution of Paleozoic rocks is poorly known and partly because deep potentiometric data are so sparse. The bottom layer of the site-scale model is presently within the Paleozoic carbonates, where carbonates are thought to occur, rather than at some hydraulic basement.

As the discussion of flow-system boundaries progressed, it became increasingly evident that there are major uncertainties, in many, if not most, cases unquantifiable at present. These uncertainties have been effectively documented by USGS staff in reports and memoranda.

Data Review

Model Calibration

Given that the USGS strategy for calibration of the site-scale model involves running Finite Element Heat and Mass (FEHM) in inverse mode by utilizing Model Independent Parameter Estimation, a commercially-available parameter-estimation routine, several details of the calibration process were explored. Because the unsaturated zone is embodied in the model domain, it will be possible to calibrate against saturations in addition to the more conventional heads and fluxes. The question of when the calibration process will have progressed sufficiently for application of the model is essentially one of cost versus benefit, for example, when very small permeability zones are required to improve the fit between predicted and "observed" parameters such as head or saturation. The question of when residuals have tapered off sufficiently is subjective, but can be addressed by demonstrating a convergence between predictions and observations.

Restrictions on the calibration process relate to the level of detail that can realistically be incorporated in the site flow model. Tradeoffs relate primarily to the number of nodes and to execution times. Obviously, features smaller than the tetrahedral model elements cannot be accommodated without mesh refinement. Some adjustments to material properties must be made where contrasts between adjacent blocks are extreme; to prevent numerical instabilities the properties must be "smoothed." Perhaps the most severe limitation on the modeling process is, however, the requirement that at least one flux must be specified (i.e., known) to fit pressures and constrain fluxes in the model domain. Boundary fluxes are so poorly known in the site model domain that uncertainty in these fluxes cannot yet be quantified. Finally, since the site model does not extend downward to hydraulic basement, any questions about the behavior of deep flow systems will need to be addressed with the regional model.

Delineation of GroundWater Flow Paths

Flow paths will be deduced primarily from the site flow model, although regional studies are providing information related to how orientation of faults in the crustal stress field can influence their hydrologic behavior. As of the time of the audit, the site flow model had not yet been successfully run, and for this reason USGS staff felt that it would be premature to speculate as to the nature of potential flow paths. Because

observations indicate that "almost anything can be connected to almost anything" via fractures, the USGS approach has been regional in nature. Although USGS staff is not confident that aquifer-test results are necessarily indicative of flow paths, they will attempt to replicate responses to a planned 120-day pumping test at the C-well complex using the site-scale flow model with particle tracking. They do not expect to match local-scale effects very well with the site model, partly because very few connections appear to exist in the fracture networks that have been studied in detail. Even with a "big picture" approach, such as the USGS has adopted; however, analyses will be hampered by insufficient understanding of storage properties and anisotropy in aquifer systems at the site.

Model Construction

Grid Refinement and Handling of Faults in the Model

In the hydrogeologic framework models, faults are represented as vertical offsets of hydrogeologic units. In preparing the tetrahedral FEHM mesh from the framework model, rectilinear grid blocks will be subdivided into tetrahedral elements. There is no fundamental difficulty with reassigning material properties to these tetrahedra so as to represent a fault as a dipping flow domain with unique properties.

Application of Discrete-Fracture Flow Models

The USGS is not using TRINET, a discrete-fracture flow code, in their analyses of the site hydrologic system. Although the software and user's manual were developed by Lawrence Berkeley National Laboratory (LBNL) under subcontract to the USGS, USGS staff indicated that application of TRINET was the sole responsibility of LBNL.

Appropriateness of the Equivalent Continuum Representation

Two considerations were offered in defense of the equivalent continuum representation of the site hydrologic system. First, it would be hard to argue fault-controlled flow in the flat gradient area. Second, cross-hole tests of uncased boreholes appear to give an equivalent continuum response. Pumping response at Oversight Nye County-1 borehole, for example, appears to fit the Theis curve nicely. While noting that cross-hole test data is extremely limited in the site area, USGS staff suggested that probably not more than a few discrete features would need to be incorporated in the site model.

Consistency with Nevada Test Site Flow Model

USGS staff was familiar with modeling activities being conducted by International Technologies Corporation (IT) in support of DOE's ongoing remediation of the Nevada Test Site. IT's model domain is shifted somewhat to the north of the Death Valley regional flow system that has been the focus of the Yucca Mountain Site Characterization Project (YMP) hydrologic investigations. Furthermore, IT used a very different method to build their framework. The hydrogeologic framework for the YMP relied on published cross-sections and objectively interpolated between those cross-sections in developing the regional framework. IT took a more creative approach, inferring the presence of thrust faults in pretertiary rocks based on a kinematic model of regional geology.

Implications for a Waste Isolation Strategy

Previous waste isolation strategy has made it difficult to focus the saturated zone hydrologic investigations on particular strategy-related issues. In a million-year time frame, the saturated zone would be expected to play a central role in limiting doses to the biosphere. Saturated zone studies would be expected to contribute to identification of the shortest flow paths to the accessible environment. In a wetter climate scenario, it should be possible to demonstrate correspondence between groundwater discharge deposits observed in the field and outflow locations predicted by the model when recharge is increased. Saturated zone models could also be used in a transient mode to simulate the progressive lowering of the regional potentiometric surface during Quaternary time, as inferred by Ike Winograd some years ago, from paleohydrologic evidence. USGS staff felt that the scale of the saturated zone model domains is probably too large to help much with evaluations of external criticality; i.e., where might reduction fronts occur. There is something of a dilemma in that the "pathways" that will be explored with the site-scale flow model are thought to be too large to test using borehole-based methods. Finally, because porosity and effective saturated thickness are not well-understood, the utility of the site-scale flow model as a basis for transport evaluations is questionable at present.

Model Validation

Conceptual Issues and Concerns

The site flow model is not effectively embedded in the regional flow model at the present time, nor is it likely to be in the 1997 time frame.

The major information needs relate to lateral boundary fluxes, to the distribution of carbonate rocks in the site area, and to the distribution of basement rocks to the south, where Neogene extension is greater. Leakage fluxes between the Paleozoic carbonates and the tuff aquifers could be of the same order of magnitude as lateral-boundary fluxes, yet cannot be quantified without additional data on the vertical distribution of materials and fluid potentials at the base of the site model domain. The hydrologic implications of any continuous fractured-rock pathways south of the site area are completely unknown, primarily because the distribution of pretertiary rocks beneath the Amargosa Desert has not been established. As indicated above, uncertainties in boundary fluxes derived from the regional flow model will be very difficult to quantify.

Conclusions

The persistence of major, unquantified uncertainties at this late stage in a mature site investigations program raises some programmatic concerns that beg resolution. For example, the Svensk Karnbranslehantering AB geochemistry tool has been cut from the Project budget each year its purchase was proposed. Boreholes to resolve the cause of the large hydraulic gradient north of the site have not been drilled. The Southern Tracer Complex, which would provide qualified core and an opportunity to cross-check results of the C-well tests, is not progressing toward completion. Boreholes to test the carbonate aquifer at a second location have been canceled. Testing of Solitario Canyon has been canceled. Existing boreholes in the Amargosa Desert have not been sampled or instrumented, and drilling to establish the transmissivity of the southern Funeral Mountains has not occurred. Water-level instrumentation has been removed from numerous boreholes and mothballed.

These actions are inconsistent with expectations of a useful saturated zone flow model in government fiscal year 1997, particularly insofar as such a model would be used to support radionuclide transport evaluations.

Given that programmatic support for saturated zone investigations is at a subsistence level, the USGS saturated zone hydrology team has made commendable progress toward compilation and synthesis of available information. Regional and site framework information has been organized into computer-based models from which grids for flow and transport modeling can be generated automatically. Regional hydrochemical information has been critically reviewed and published. Data needs have

been explained in considerable detail in reports and memoranda, and classified as key issues, potential issues, important issues and resolved issues.

In summary, no deficiencies were identified nor concerns noted that would reflect unfavorably on the performance of the USGS in Saturated Zone Hydrologic System Synthesis and Modeling. It is the opinion of the Technical Specialist that the USGS has made efficient use of available resources but is severely handicapped, for example, by the absence of high-quality hydrochemical data from the site and from the elimination of most drilling from the Program Plan. The issues and concerns noted above appear to have root causes that are beyond the control of the USGS, namely unrealistic expectations for "bounding" system performance in the absence of data that would allow uncertainties to be quantified.

5.4.2 The performance-based audit of the USGS Study 8.3.1.2.2.7, "Unsaturated Zone Hydrochemistry," WBS 1.2.3.3.1.2.7, was conducted in Denver, Colorado at the USGS National Training Center on May 1, 1996. The audit focused on those processes and activities associated with the development of the "Unsaturated Zone Hydrochemistry Data Synthesis Report." The process steps involved in the development of this report have been identified by the USGS as sample/data collection, data analysis, data development and review, and interpretation/reporting. These steps are evaluated in the following paragraphs:

Sample/Data Collection

Hypotheses and Conceptual Models

A catalog of hydrologic hypothesis has been considered in the evaluation of the unsaturated zone hydrochemistry at Yucca Mountain. Fourteen hypotheses were identified and are listed as indicated below:

1. Temperature-driven or barometrically-driven moisture flow can occur as water vapor, especially within the interconnected fractures of the Topopah Spring welded (TSw) unit;
2. Gas-water exchange reactions result in equilibrium between gas and liquid phases;
3. Gas transport within the unsaturated zone is predominantly by diffusion, and is little affected by advection;

4. Flow in the TSw is vertical and occurs under steady-state conditions. Flow is primarily in the matrix when the flux is less than some value related to the saturated matrix hydraulic conductivity, and flow is primarily in the fractures at flux rates higher than that value;
5. No significant recharge from the unsaturated zone to the saturated zone occurs beneath Yucca Mountain;
6. Increasing sodium/calcium rations would be expected with depth in the unsaturated zone, reflecting chemical evolution along downward flow paths;
7. Flow paths of infiltrating water into the unsaturated zone is likely through fractures, bedded units, contacts between units, or Calico Hills formation, with lateral or inclined flow;
8. Dispersion occurs from fractures to matrix along flow paths;
9. Interpretations of chemical evolution and fluid flow are consistent, such that inferred chemical evolution can be used to deduce flow paths;
10. Where calcite is present in fractures, former flow paths are indicated;
11. Minimal evaporation occurs in the unsaturated zone;
12. All unsaturated zone water is Holocene in age;
13. The hydrochemical expression of recharge would be recognizable in the uppermost saturated zone if recharge is occurring at the site;
14. Apparent residence times of matrix water determined by radiocarbon dating, though younger than indicated by chlorine-36 dating, are valid.

Several field-scale conceptual models were discussed, including those for carbon transport at the Unsaturated Zone (UZ)-1/UZ-14 locality, tritium transport for Yucca Mountain in general, chemical evolution of groundwater, and isotopic evolution of groundwater. Especially noteworthy is the evolving conceptual model related to how zeolitized rocks imbibe and exchange pore water and channel water; i.e., the explanation of why waters extracted by distillation in some cases differ isotopically from those extracted by squeezing the core. Now that extraction effects appear to be understood, the isotopic data from pore waters can confidently be applied to hydrologic investigations.

Data Analysis

Geochemical Models

Applications of geochemical models WATEQ (which calculates the distribution of dissolved species in dilute waters), PHREEQE (which performs reaction-path calculations) and NETPATH (which identifies a number of alternate conceptual models for reaction progress using the mass balance approach) were discussed. Three examples of WATEQ speciation calculations were provided and discussed. Pore-water compositions are available from only two boreholes (UZ-14 and UZ-16), and significant variations with depth are evident. Hydrochemical information will be used in an attempt to constrain flow paths, which are not known beforehand.

Interfaces with Other Hydrochemical Modeling Activities

The USGS is responsible for an Exploratory Studies Facility (ESF) Hydrochemistry study. The ESF study differs from the surface-based study that is the subject of this audit in that the ESF study is largely feature-oriented, whereas UZ Hydrochemistry seeks to resolve stratigraphic influences on water chemistry.

Given that geochemical modeling is underway both at Los Alamos National Laboratory (LANL) and at Lawrence Livermore National Laboratory (LLNL), the nature of interfaces between the modeling groups was explored. The USGS is aware of both efforts, and was effective in explaining that the task of the USGS is to utilize hydrochemistry to help understand the site hydrologic system, whereas the other activities are focused on the solubility of actinides (LANL) and waste package degradation (LLNL). USGS staff suggested that UZ-14 perched water may be more representative than UE-25J#13 well water of the type of fluid that would be expected to contact the waste containers. The USGS expects a resurgence of modeling activities now that pore-water and perched-water chemistry is available, but had not received from LANL sufficient mineralogical data by the time of the audit to support comprehensive reaction-path and mass-balance analyses.

Insights into Evaporative Processes

Information related to the influence of evaporation on pore-water chemistries was discussed at length. The USGS has provided partial support for a doctoral dissertation entitled "The Isotopic Chemical

Characterization of the Unsaturated Zone at Yucca Mountain" which is presently in draft form. It appears that discrepancies between the deuterium and oxygen-18 values for squeezed and distilled samples are now understood, which is very significant given that water can only be extracted from the welded tuffs by distillation. The dissertation paves the way for a correction methodology for distilled samples based on the zeolite content of the core. It appears that both pore water and channel water (in the zeolites) acquire the isotopic composition of the most recent water that has been in contact with the rock, and that fractionations occur during extraction by distillation. Fortunately, zeolites are less prevalent in welded tuffs than in non-welded tuffs.

Diffusive versus Advective Gas-Flow Domains

An eleven-year record of gas-phase chemical and isotopic compositions is available from borehole UZ-1; data collected since 1989 were collected in accordance with the approved USGS YMP QA program. Gas compositions are similar to atmospheric air, with slightly more carbon dioxide. Roughly five years of semi-annual sampling were required before drilling air was removed from the hole and pristine rock-gas compositions were revealed.

Preliminary Carbon-13 (C-13) values for pore waters from UZ cores (UZ-14 and UZ-16) range from -10 to -25 per mil. Rock gas in equilibrium with such waters would have a C-13 composition about 8.5 per mil lighter, or between -18.5 and -33.5 per mil. The average C-13 value of about 20 per mil in UZ-1 suggests that rock gas samples were collected from dry fractures, with little contribution from pore gas which is in equilibrium with pore water.

An absence of pneumatic connections to the surface in the vicinity of UZ-1 is suggested by the steady decrease in Carbon-14 (C-14) values with depth. The C-14 profile is indicative of downward diffusion of radiocarbon from the surface, and strongly suggests that advective gas transport is not significant at the UZ-1 locality. The unchanging composition of rock gas as nearly 2 million cubic meters of rock gas were discharged from borehole UZ-6s suggests that the rock gas is not interacting with a large aqueous-phase carbon reservoir. Existing data are insufficient to establish whether such nonequilibrium conditions exist between gaseous and aqueous phases throughout Yucca Mountain.

The eleven-year carbon-isotope record from UZ-1, which shows steady decrease in C-14 "ages" as a function of depth with consistent C-13

values, is the only dependable rock-gas data set so far in the Topopah Spring tuff and below. The observation that simple Fickian diffusion can account for the depth distribution of C-14 in the fractured Topopah Spring tuff at UZ-1 is in marked contrast to system behavior near open boreholes, where it appears impossible to account for observations without major advection in the system. There is no assurance whatsoever that findings at the UZ-1/UZ-14 locality are representative of the site at large.

Data Development and Review

Test Interference Considerations

There are concerns about surface-based gas sampling being done sufficiently far in advance of the Tunnel Boring Machine to ensure pristine samples and whether the USGS is confident that uncontaminated gas samples can be obtained from alcoves. USGS staff indicated that the scatter of isotope data in Table 9 of Water Resources Investigations Report (WRIR) 96-4058, "Interpretations of Chemical and Isotopic Data from Boreholes in the Unsaturated Zone at Yucca Mountain, Nevada," by Yang and others may indicate leaky packers or insufficient evacuation of the holes prior to sampling. This statement is consistent with those on page 42 of WRIR 96-4058:

> "The reason for the heavier del C-13 values and younger C-14 values at depths could be due to contamination with atmospheric air as a result of leaking packer or incomplete removal of drilling air. It has been observed in many locations at Yucca Mountain that topographic effects cause the gas to inhale or exhale through the open borehole."

It is an open question as to whether pristine samples can ever be obtained from boreholes whose environments have been modified by pneumatic tunnel effects. These would include several boreholes associated with the "Accelerated Surface-Based Testing Program," including North Ramp Geologic (NRG)-6, NRG-7a, and Systematic Drilling, SD-12.

Dating Methods and Apparent Discordances

The fact that gas squeezed from core does not contain sulfur hexafluoride, which was added to drilling air, gives confidence that cores have not been contaminated by drilling air. From UZ-1, gas from the base of the Topopah Spring formation gave an apparent age of 9000 years, while pore water from the Calico Hills in UZ-14 yields apparent ages on the order of

2500 years. The observed apparent age differences may result from gravity-flow of liquid water being faster than diffusive movement of gas. Gas samples from the Calico Hills interval of UZ-14 will be required, however, to confidently address the gas-water disequilibrium issue in pre-Topopah rocks at that locality.

The issue of why chlorine-36 dating tends to give order-of-magnitude greater ages than radiocarbon methods was discussed. USGS staff suggested that chlorine-36 obtained by leaching cuttings is being diluted by "old" chlorine in the rock, and that perhaps radiocarbon methods provide "ages" that are more representative of water residence times.

The USGS felt that chlorofluorocarbon (CFC) dating held great promise for hydrologic investigations at Yucca Mountain, but indicates that CFC dating was "dropped" when the Accelerated Surface-Based Testing Program was implemented. At the present time, the ESF has probably irreversibly contaminated much of the system with respect to CFCs.

The utility of dating fluids using argon-39 and krypton-85 has been evaluated by the USGS, but their short half-lives of 270 and 10.7 years, respectively, mean that they would be only marginally useful at Yucca Mountain.

Interpretation/Reporting

Delineation of Groundwater Flow Paths

The geometry of groundwater flow pathways is not known, and USGS staff indicated that the best the UZ Hydrochemistry Study will be able to do is to address the prevalence of fracture flow rather than delineate discrete pathways. For example, UZ-16 is in an imbricate fault zone where fracture flow would be expected, and observed apparent age inversions support the existence of fracture-dominated flow at that locality. Fracture-network modeling may allow flow paths to be represented stochastically, but discussion of such work was beyond the scope of the subject audit.

Implications for a Waste Isolation Strategy

USGS staff indicate that if flux were high, perched-water zones would have high tritium and other indicators of very short residence times; such

indicators are not found in perched water. This is a key point; the USGS is confident that the flux associated with fracture flow must be low based on the observed isotopic composition of perched-water bodies. Shallow infiltration still has to be accounted for.

Conclusions

The identified concerns noted should not reflect unfavorably on the performance of the USGS in Unsaturated Zone Hydrochemistry. It is the opinion of the Technical Specialist that the USGS has made efficient use of available resources, but has been placed at risk due to low confidence in the integrity of gas-phase chemical data from boreholes near the ESF. These data may be irrecoverable, and as a result any claim that hydrochemical conditions at the UZ-1/UZ-14 locality are representative of the site at large cannot be supported.

5.5 Summary of Deficiencies

The audit team identified three deficiencies during the audit. These deficiencies were added to similar conditions that were previously identified and documented on CARs YMQAD-96-C004 and YMQAD-96-C005 during Audit YM-ARC-96-10. Corrective action associated with these CARs will address the deficient conditions identified during this audit. One additional deficiency was identified and corrected during the audit.

Synopses of the deficiencies identified during this audit and those corrected during the audit are detailed below. The CARs were issued by separate letter (YMQAD-96-C004, YMQAD: RBC-1073, dated April 10, 1996; YMQAD-96-C005, YMQAD: RBC-1547, dated April 12, 1996) to the responsible individuals in accordance with Administrative Procedure (AP)-16.2Q, Revision 0, "Corrective Action and Stop Work."

5.5.1 Corrective Action Requests (CAR)

YMQAD-96-C004

The QARD, Revision 5, Section 4.0, Paragraphs 4.2.1 and 4.2.1C(1), "Procurement Document Control," requires that procurement documents issued by each Affected Organization include provisions, as applicable, for the item or service being procured and that suppliers have a documented QA Program that implements the applicable portions of the QARD.

Contrary to the above requirements, the procurement documents for a USGS supplier, University of Colorado, INSTAAR, supporting the Unsaturated Zone Hydrochemistry activities did not include the appropriate quality and technical requirements. Also, they do not have a documented QA Program.

AP-7.4Q, Revision 1, "Maintenance of the OCRWM Qualified Suppliers List," Section 5.0, requires the qualifier to complete the Supplier Evaluation Report (SER) and submit to the Qualified Suppliers List (QSL) Coordinator.

Contrary to the above requirements, the SERs for two USGS suppliers supporting the Unsaturated Zone Hydrochemistry activities, University of Colorado, INSTAAR and Certified Balance Services did not have or were missing SERs and had not been submitted to the QSL Coordinator.

YMQAD-96-C005

QARD, Revision 5, Section 16.0, Paragraph 16.2.5, "Corrective Action," requires the QA organization to close corrective action documentation in a timely manner when actions are complete.

Contrary to the above requirements, during evaluation of related deficiency documents it was discovered that USGS Quality Deficiency Reports were closed, but verification documentation and the log did not reflect the correct status.

5.5.2 Deficiency Reports (DR)

None

5.5.3 Performance Reports (PR)

None

5.5.4 Deficiencies Corrected During the Audit

Deficiencies which are considered isolated in nature and only requiring remedial action can be corrected during the audit. The following deficiency was identified and corrected during the audit:

During review of the processes involved in Hydrologic Procedure (HP)-268, Revision 0, "Method for Core Preparation for Pore Water

Extraction by One Dimensional Compression Methods," it was observed that the cutting and preparation of the core was not being done by a saw in accordance with the technical procedure.

The technical procedure was revised, reviewed and approved to reflect the actual practices of cutting and preparation of the core samples which was determined to be acceptable.

5.5.5 Follow-up of Previously Identified Deficiency Documents

Follow-up action on five Nonconformance Reports (NCR), NCR-YMPO-94-0042 and 0048, NCR-YMSCO-95-0094, 0126, and 0127 revealed actions have been completed by USGS and NCRs are awaiting review and closure. Corrective action for updating technical procedures related to sample control was completed and CAR YM-94-048 was closed on September 7, 1995.

6.0 RECOMMENDATIONS

The following recommendations resulted from the audit and are presented for consideration by USGS management:

1. Through conversations with cognizant personnel, it appears that technical procedure HP-252, "Method for Sealing Selected Core Samples During Drilling at Unsaturated Zone Boreholes," has not been implemented for approximately two years. If it is no longer used, recommend cancellation.

2. While no core to date has been damaged during transport to the USGS, recommend that some method of accept/reject criteria be included in HP-268, "Method for Core Preparation for Pore-Water Extraction by One-Dimensional Compression Methods," and that rejected or indeterminate core be identified and tagged.

3. While there appears to be no impact on the quality of the processes that were evaluated during the audit, it is recommended that all procedures be reviewed and references to superseded or canceled procedures be deleted.

4. Ensure that those individuals responsible for submitting lists of cited references in administrative, technical, or scientific reports, published since May 17, 1995, as required by Yucca Mountain Administrative Procedure (YAP)-17.1Q, Revision 0,

Interim Change Number 4, "Records Management and Requirements Responsibilities," for the "Saturated Zone Hydrologic System Synthesis and Modeling," and the "Unsaturated Zone Hydrochemistry," are aware of this requirement.

7.0 LIST OF ATTACHMENTS

Attachment 1: Personnel Contacted During the Audit
Attachment 2: Summary Table of Audit Results

ATTACHMENT 1

Personnel Contacted During the Audit

Name	Organization/Title	Preaudit Meeting	Contacted During Audit	Postaudit Meeting
Beasley, M	USGS/Hydrologic Technician		X	
Burnham, P.	USGS/Records Coordinator		X	
Chaney, T.	USGS/QA Manager	X	X	X
Craig, R.	USGS/Technical Project Officer	X		X
Czarnecki, J.	USGS/Hydrologist	X	X	
Faunt, C.	USGS/Hydrologist	X	X	
Gillies, D.	USGS/UZ Team Chief	X	X	
Luckey, R.	USGS/SZ & EM Team Chief	X	X	X
Lykins, A.	USGS/QA Specialist		X	
McKinley, P.	USGS/Data Coordinator		X	
Miller-Corbett, C.	USGS/ Software QA Specialist		X	
Mustard, M.	USGS/Hydrologist	X	X	X
Nelson, M.	USGS/Training Coordinator		X	
O'Brien, M.	USGS/QA Implementation Specialist	X	X	X
Parks, B.	USGS/Assistant Chief ESIP	X		X
Rathray, G.	USGS/Hydrologist	X	X	
Rodriguez, P.	USGS/QA Specialist		X	
Scanieoek, E.	USGS/Quality Training Coordinator		X	
Schofield, K.	USGS/Hydrologic Technician		X	
Shaeffer, D.	USGS/QA Implementation Specialist		X	
Tucci, P.	USGS/Hydrologist		X	X
Whiteside, A.	USGS/QA Implementation Specialist	X	X	X
Williams, R.	USGS/Chief ESIP.	X	X	X
Woolverton, J.	USGS/QA Implementation Specialist	X	X	
Yang, A.	USGS/Hydrologist	X	X	

Legend:
ESIP ..... Earth Science Investigation Program
SZ & EM ... Saturated Zone and Environmental Monitoring
UZ ..... Unsaturated Zone

ATTACHMENT 2
Summary Table of Audit Results

AUDIT YM-ARP-96-12 DETAIL SUMMARY

QA ELEMENT/ ACTIVITIES	DOCUMENTS REVIEWED	CHECKLIST DETAILS YM-ARP-96-12-01	CAR (5.5.1)	DR (5.5.2)	PR (5.5.3)	CDA (5.5.4)	REC (6.0)	ADE-QUACY	COM-PLIANCE	OVE[ALL
PROGRAMMATIC CHECKLIST YM-ARP-96-12-01										
1	QMP 1.01, Rev. 5, "Organization Procedure"	Page 1	N	N	N	N	N	SAT	SAT	SAT
2	YAP 2.2Q, Rev. 0, "Preparation, Review, Approval of Site Characterization Study Plans"	Pages 2 & 3	N	N	N	N	N	SAT	SAT	SAT
	QMP 2.02, Rev. 6, "Federal Personnel Qualification"	Pages 4 & 5	N	N	N	N	N	SAT	SAT	
	QMP 2.01, Rev. 2, "YMP-USGS Training"	Page 5	N	N	N	N	N	SAT	SAT	
	QMP 2.08, Rev. 2, "Non-Federal Contractor Personnel Qualification"	Page 4	N	N	N	N	N	SAT	SAT	

ATTACHMENT 2
Summary Table of Audit Results

QA ELEMENT/ ACTIVITIES	DOCUMENTS REVIEWED	CHECKLIST DETAILS YM-ARP-96-12-01	CAR (5.5.1)	DR (5.5.2)	PR (5.5.3)	CDA (5.5.4)	REC (6.0)	ADE-QUACY	COM-PLIANCE	OVER-ALL
4	QMP 4.01, Rev. 7, "Procurement Document Control" (Re: QARD, Section 4.0)	Page 6	YM QAD-96-C004	N	N	N	N	UNSAT	UNSAT	UNSAT
	QMP 4.02, Rev. 6, "Control of Agreements"	Page 6	N	N	N	N	N	SAT	SAT	
5	QMP 5.01, Rev. 6, "Preparation of Technical Procedures"	Pages 7, 8, & 9	N	N	N	N	#1 & #3	SAT	SAT	SAT
	QMP 5.02, Rev. 8, "Development and Maintenance of Quality Management Procedures"	Pages 9 & 11	N	N	N	N	N	SAT	SAT	
6	QMP 6.01, Rev. 6, "Document Control"	Pages 10, 12, & 13	N	N	N	N	N	SAT	SAT	SAT
7	QMP 7.04, Rev. 2, "Supplier Evaluation" (Re: AP-7.4Q, Rev. 1)	Pages 14 & 15	YM QAD -96-C004	N	N	N	N	UNSAT	UNSAT	UNSAT

ATTACHMENT 2
Summary Table of Audit Results

QA ELEMENT/ ACTIVITIES	DOCUMENTS REVIEWED	CHECKLIST DETAILS YM-ARP-96-12-01	CAR (5.5.1)	DR (5.5.2)	PR (5.5.3)	CDA (5.5.4)	REC (6.0)	ADE-QUACY	COM-PLIANCE	OVER-ALL
12	QMP 12.01, Rev. 4, "Instrument Control"	Page 16	N	N	N	N	N	SAT	SAT	SAT
15	YAP 15.1Q, Rev. 2, "Control of Nonconfomances"	Page 17	N	N	N	N	N	SAT	SAT	SAT
16	AP-16.1Q, Rev. 0, "Performance/Deficiency Reporting" (Re: QARD, Section 16.0)	Pages 18 & 19	YM QAD -96-C005	N	N	N	N	UNSAT	UNSAT	UNSAT
	AP-16.2Q, Rev. 0, "Corrective Action and Stop Work"	Page 18	N	N	N	N	N	SAT	SAT	
17	QMP 17.01, Rev. 8, "YMP-USGS Records Management for Record Sources" (Re: YAP-17.1Q, Rev. 0)	Pages 20, 21, & 22	N	N	N	N	#4	SAT	SAT	SAT
Supplement I	QMP 3.03, Rev. 5, "Software"	Pages 23 &24	N	N	N	N	N	SAT	SAT	SAT

ATTACHMENT 2
Summary Table of Audit Results

QA ELEMENT/ ACTIVITIES	DOCUMENTS REVIEWED/ PROCESS STEPS	CHECKLIST DETAILS YM-ARP-96-12-01	CAR (5.5.1)	DR (5.5.2)	PR (5.5.3)	CDA (5.5.4)	REC (6.0)	ADE-QUACY	COM-PLIANCE	OVER-ALL
Supplement II	QMP 8.01, Rev. 4, "Identification and Control of Samples" (Re: USGS TP HP-268)	Pages 25, 26, & 26a	N	N	N	#1	#2	SAT	SAT	SAT
Supplement III	QMP 03-07, Rev. 5, "YMP-USGS Review Procedure"	Pages 23 & 24	N	N	N	N	N	SAT	SAT	SAT
	QMP 3.07, Rev. 4, "Scientific Notebook"	Pages 27 - 30	N	N	N	N	N	SAT	SAT	
TECHNICAL CHECKLIST YM-ARP-96-12-02										
Preliminary Site Saturated Zone 3-D Groundwater Flow Model	Data Compilation	Pages 1 & 2	N	N	N	N	N	SAT	SAT	SAT
	Data Analysis	Pages 3 - 7	N	N	N	N	N	SAT	SAT	
	Data Review	Pages 8 & 9	N	N	N	N	N	SAT	SAT	
	Model Construction	Pages 10 - 12	N	N	N	N	N	SAT	SAT	
	Model Validation	Pages 13 & 14	N	N	N	N	N	SAT	SAT	

ATTACHMENT 2
Summary Table of Audit Results

QA ELEMENT/ ACTIVITIES	PROCESS STEPS	CHECKLIST DETAILS YM-ARP-96-12-03	CAR (5.5.1)	DR (5.5.2)	PR (5.5.3)	CDA (5.5.4)	REC (6.0)	ADE-QUACY	COM-PLIANCE	OVER-ALL
TECHNICAL CHECKLIST YM-ARP-96-12-03										
Unsaturated Zone Hydro-chemistry Data Synthesis Report	Sample/Data Collection	Page 1 & 2	N	N	N	N	N	SAT	SAT	SAT
	Data Analysis	Pages 3, 4, & 5	N	N	N	N	N	SAT	SAT	
	Data Development/Review	Pages 6-9	N	N	N	N	N	SAT	SAT	
	Interpretation/Reporting	Page 10	N	N	N	N	N	SAT	SAT	
TOTAL		55	2	N	N	1	4			

LEGEND:
CDA ..... Corrected During the Audit
N ..... None
REC ..... Recommendations
SAT ..... Satisfactory
TP ..... Technical Procedure
UNSAT .. Unsatisfactory