EXHIBIT 3

U.S. NUCLEAR REGULATORY COMMISSION

OBSERVATION AUDIT REPORT NO. OAR-00-04

OBSERVATION AUDIT OF THE

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

QUALITY ASSURANCE DIVISION

AUDIT NO. M&O-ARP-00-004

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1.0 INTRODUCTION

Staff of the U.S. Nuclear Regulatory Commission (NRC), Division of Waste Management and the Center for Nuclear Waste Regulatory Analyses (CNWRA) observed the U.S. Department of Energy (DOE), Office of Civilian Radioactive Waste Management (OCRWM), Office of Quality Assurance (OQA), Yucca Mountain Quality Assurance Division performance-based audit of 4 Analysis Model Reports (AMRs) out of 24 AMRs supporting the Unsaturated Zone (UZ) Flow and Transport Process Model Report (PMR) activities performed for the Management & Operating Contractor (M&O). The audit, M&O-ARP-00-04, was conducted January 24-28, 2000 at Lawrence Berkeley National Laboratory (LBNL) in Berkeley, California.

The objective of this audit was to evaluate the implementation of the applicable provisions contained in the OCRWM Quality Assurance Requirements and Description (QARD), DOE/RW-0333P, Revision 8, by reviewing selected analysis model reports (AMRs) supporting the UZ Flow and Transport PMR. During the audit, selected AMRs were subjected to a technical review as well as review to ensure that the applicable programmatic requirements contained in the QARD and implementing procedures were met.

The NRC staff objective was to gain confidence that the M&O and OQA are properly implementing the provisions contained in the QARD and the requirements contained in Subpart G, Quality Assurance, to Part 60, of Title 10 of the Code of Federal Regulations (10 CFR Part 60). Because of the anticipated DOE submittal of the site recommendation (SR) in November 2000, the following observation activities were emphasized: 1) confirming that data, software, and models supporting SR are properly qualified; and 2) reviewing the progress being made by DOE and its contractors in meeting the qualification goals for SR.

This report addresses the NRC staff determination of the effectiveness of the OQA audit and the adequacy of implementation of QARD controls by the M&O in the audited areas of AMR development.

2.0 MANAGEMENT SUMMARY

The NRC staff has determined that OQA Audit M&O-ARP-00-04 was useful and effective. The audit was organized and conducted in a professional manner. Audit team members were independent of the activities they audited and their assignments and checklist items were adequately described in the audit plan. The audit team members' qualifications were reviewed and the members were found to be qualified in their respective disciplines.

The audit team concluded that the OCRWM QA program had been satisfactorily implemented in some of the areas audited. However, the selected AMRs were still in the revision process and the associated software, data, and model packages had not been qualified, verified, or validated. As a result, one "potential" deficiency was identified covering a range of problems with the U0010 AMR and a general software deficiency was identified for all the AMRs and the M&O. Seven recommendations were specified with four directed at particular AMRs and three

directed at the general AMR development process and to the QA program procedures. The NRC agrees with the audit team's conclusion and recommendations. The NRC staff

determined that this audit was effective and that the QA program implementation overall was adequate. The recommendations should prevent future discrepancies in the AMR/PMR development process though the lessons learned from previous audits may not be clearly emphasized in the development of all AMRs.

Further, the NRC staff determined that this audit was effective in identifying deficiencies and recommending improvements in the AMR process. During the conduct of the audit, both the audit team and the NRC observers reviewed data, analysis reports, and software within the scope of the audit to confirm that it was properly qualified. The audit team and the NRC observers determined that the software supporting three of the four AMRs had been generally properly qualified.

The NRC staff generally agrees with the audit team conclusion's, findings, and recommendations. However, as noted in Section 4.7 of this report, the NRC staff expressed a concern about the adequacy of the implementation of the process to close the 4 super-Corrective Action Reports. Further, as discussed in various sections of this report, the NRC staff is concerned about the lack of data qualification activities for the AMRs reviewed during the audit and the three previous audits. This appears to be a condition requiring DOE's management attention.

3.0 AUDIT PARTICIPANTS

3.1 NRC Observers

Ted Carter	Observer (Team Leader - NRC)
Robert Latta	Observer (Senior QA Engineer - NRC)
Jeff Ciocco	Observer (Technical Specialist - NRC)
Randy Fedors	Observer (Technical Specialist - CNWRA)

3.2 DOE Audit Team

Robert Hartstern	Audit Team Lead	OQA/Quality Assurance Technical Support Services (OQA/QATSS)
Michael Eshleman	Auditor	OQA/QATSS
Richard Powe	Auditor	OQA/QATSS
Lester Wagner	Auditor	OQA/QATSS
Ronald Linden	Technical Specialist	OQA/QATSS-MTS, Golder Associates
Keith Kersch	Technical Specialist	OQA/QATSS-Science Applications International Corporation (SAIC)

Bob Hasson of OQA/QATSS also attended the audit as an observer and to present an update status on the 4 super-CARs.

4.0 REVIEW OF THE AUDIT AND AUDITED ORGANIZATION

This OQA audit of the M&O was conducted in accordance with the OCRWM Quality Assurance Procedure (QAP) 18.2, "Internal Audit Program," and the QAP 16.1Q, "Performance/Deficiency

Reporting." The NRC staff's observation of this audit was based on the NRC procedure, "Conduct of Observation Audits," issued October 6, 1989 (Draft).

4.1 Scope of the Audit

The audit team conducted a limited scope, performance based audit of activities and processes related to the development of the AMRs supporting the UZ Flow and Transport PMR. AMR content, software, and data were evaluated during the audit process. The audit included review of the programmatic controls governing the AMRs and technical requirements contained in the AMRs. The following procedures and AMRs supporting the UZ Flow and Transport PMR were reviewed by the audit team and the NRC observers during the audit:

Procedures

a) AP-2.13Q, "Technical Product Development Planning," Revision 0, with Interim Change Notice (ICN) No. 1
b) AP-SI.1Q, "Software Management," Revision 2, with ICN No. 0
c) AP-3.15Q, "Managing Technical Product Inputs," Revision 0, with ICN No. 1
d) AP-SIII.2Q, "Qualification of Unqualified Data and the Documentation of Rationale for Accepted Data," Revision 0, with ICN No. 0
e) AP-3.10Q, "Analysis and Models," Revision 1, with ICN No. 0
f) AP-2.14Q, "Review of Technical Products," Revision 0, with ICN No. 0
g) AP-SIII.3Q, "Submittal and Incorporation of Data to the TDMS," Revision 0
h) YAP-SV.1Q, "Control of the Electronic Management of Data," Revision 0, with ICN No. 1
i) QAP-SIII-1, "Scientific Investigations", Revision 3

Analysis Model Reports

a) ANL-NBS-HS-0000015, "Development of Numerical Grids for UZ Flow and Transport Modeling," Revision 00 (U0000)
b) ANL-NBS-HS-000032, "Simulation of Net Infiltration for Modern and Potential Future Climates," Revision 00A (U0010)
c) ANL-NBS-HS-000005, "In Situ Field Testing of Processes," Revision 00E (U0015)
d) MDL-NBS-HS-000004, "Seepage Calibration Model and Seepage Testing Data," Revision 00D (U0080)

4.2 Conduct and Timing of the Audit

The audit was performed in a professional manner and the audit team demonstrated a sound knowledge of the applicable M&O and DOE programs and procedures. Audit team personnel were persistent in their interviews, challenged responses when appropriate, and performed an acceptable audit. The NRC staff believes the timing of the audit was appropriate for the auditors

to evaluate ongoing UZ Flow and Transport PMR activities. However, the audit team was unable to confirm that data supporting the AMRs had been properly qualified since other related AMRs are developed in parallel, or in many cases, not as far along in the development process.

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The NRC staff considers the lack of data qualification activities during this audit and the three previous PMR audits to be a condition requiring OQA management attention. The NRC staff suggests that OQA management evaluate the need to conduct audits specifically to evaluate the qualification of data.
The DOE audit team and NRC observers caucused at the end of each day. Also, meetings of the audit team and M&O management (with the NRC observers present) were held each morning to discuss the current audit status and preliminary findings.

4.3 Audit Team Qualification and Independence

The qualifications of the audit team leader and the OQA audit team members were found to be acceptable in that they met the requirements of QAP 18.1, "Auditor Qualification," as verified by the NRC observation audit lead. The audit team members did not have prior responsibility for performing the activities they audited. In addition, training, education and experience records for audit team members were reviewed and found acceptable.

4.4 Examination of Quality Assurance and Administrative Requirements

The observation team determined that audit activities were appropriately conducted in accordance with the OCRWM QA Audit Plan for Audit M&O-ARP-00-04. The auditors reviewed selected project documents identified in the audit plan and employed a detailed checklist as the basis for their reviews. The audit team also examined related project technical documentation to verify the accuracy of source material and the status of data qualification activities. Cognizant personnel directly responsible for the development of the AMRs or representatives with appropriate levels of knowledge were interviewed by the auditors. During the conduct of these interviews the auditors effectively used the audit checklist to focus their inquiries on areas of technical concern. The audit team also afforded adequate opportunities for the NRC observers to provide comments and to seek clarification on technical issues.

The NRC observers determined that the programmatic elements of Quality Assurance Procedure (QAP) 18.2, "Internal Audit Program", were appropriately implemented by the audit team. Specifically, the well developed planning and implementation aspects of this audit were demonstrated during the conduct of the audit entrance meeting, coordination and communications between team members, the development of preliminary audit findings and the clear articulation of these findings during the daily audit caucus meetings. The NRC observers also concluded that the audit team's preliminary findings were accurately conveyed to M&O management personnel on a daily basis and that the audit results were effectively conveyed to M&O management personnel during the post audit meeting.

Within this area, the NRC observation team did not document any audit observation inquiries and it was concluded that the audit team conducted a thorough evaluation of the four AMRs which support the UZ Flow and Transport PMR.

4.5 Examination of Technical Activities

The NRC staff observed the DOE audit team technical specialists conducting detailed checks of the technical adequacy of the subject AMRs. A performance-based audit is used to address the adequacy of results given in the AMRs for the stated purpose of the work described in the

document. The technical specialists used a combination of technical issue probing and procedural compliance checks and verifications to thoroughly consider both the technical adequacy of the AMRs and the effectiveness of implementation of the QA program. NRC staff found the qualifications of the DOE technical specialists satisfactory for the audit.

4.5.1 NRC Observation Team Technical Specialists General Comments

An important concern of NRC over the determination of adequacy for any AMR is that much of the supporting data cannot be assessed during the audit since other related AMRs are developed in parallel, or in many cases, not as far along in the development process. Many of NRC's questions were addressed by LBNL and U.S. Geological Survey (USGS) staff by simply stating that the basis and limitations of the input data were in another AMR. For example, fracture characterization data was used to support grid discretization in AMR U0000. The source of the fracture data could only be referenced as "another AMR," though the source could be tracked through the data tracking number (DTN) to AMR U0090, which itself had not progressed far enough for review in this audit. This is a limitation imposed on the audit team, whereby AMRs are evaluated prior to their completion of the development process.

Another general concern is the transparency of the equations and technical bases of assumptions and conclusions presented in the AMRs. Many of the comments noted in the following section allude to transparency. LBNL attempted to develop the AMRs as all inclusive; meaning that reference to milestone reports was to be reduced to usage for secondary or corroborating arguments. The USGS took a different stance and developed the AMR U0010 as a supplement to Flint et al. (1996). Better transparency is one of the DOE audit team's general recommendations for all AMRs. Since the specific items are not spelled out in the DOE audit summary, they are included in the following section.

Also, there was some confusion between validation and verification during the audit. The DOE definitions were not known or were not clear to the DOE auditors. The NRC defines software validation as confirmation that the software performs as designed; as such, software validation is equivalent to verification, which may otherwise be determined by hand-calculations to confirm that the code functions as expected (Eisenberg, et al, 1999). Model validation involves the process of assuring that model predictions adequately represent the physical system being modeled. Conceptual model validation and model validation are taken as synonymous. The level of accuracy required for model validation depends on the objectives of the modeling. Benchmarking is often associated with software validation whereby a comparison is made with an existing documented code that represents the same conceptualization as the code being tested. The discussion at the audit was precipitated by section 7.2, Model Verification, in the Infiltration AMR (U0010). Based on Eisenburg, et al. (1999) the section should be labeled as "Model Validation" although DOE may choose to use different definitions.

4.5.2 Specific NRC Technical Comments

This section contains specific comments on each AMR. The title and AMR number are listed at the beginning of the discussion for each AMR. Other LBNL and USGS staff present at the audit are mentioned as warranted for specific discussion points.

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AMR U0000, Development of Numerical Grids for UZ Flow and Transport Modeling

The purpose of this AMR is to provide a basis for the 2D and 3D grids that will be used in the Calibrated Properties Model Data AMR (U0035), UZ Flow Model and Submodels AMR (U0050), and the Mountain-Scale Coupled Processes (TH) Model AMR (U0105). The Grid Generation AMR uses data from the GFM3.1, ISM3.0, fracture data sets, hydrogeologic units, water table map, and repository layout configuration. To streamline the text, this AMR is referred to as the Grid Generation AMR throughout the discussion below.

Throughout Grid Generation AMR, the horizontal locations are stated as being the Nevada State Plane projection. It is not clear to the NRC observers which coordinate projection is used, NAD27 or NAD83. The difference between NAD27 and NAD83 projections is about 196 m north-south and 80 m east-west in the vicinity of Yucca Mountain (YM); this is comparable to the shift from wash bottom to ridgetop on the east flank of YM. Since the grid development uses data from multiple sources, NRC recommends that LBNL staff confirm that there was no mixing of projections for the various input data used and that the projection is clearly stated in the AMR so that end users of output can ascertain which projection was used for spatial data.

> [Work after the audit by CNWRA staff appears to indicate that there was a problem with the conversion of alcove positions along the ESF to State Plane NAD27 (m) coordinates as listed in table 9. It is not clear if the error is caused by a projection conversion, or if there is another type of error in the calculations performed in the spreadsheet cited in the footnote of the table. This spreadsheet was reviewed by a DOE technical auditor as a check on traceability, but it is not known if the actual calculations were reviewed. The error leads to the alcoves being located as much as 100 m east of the ESF, assuming that the EDA II design coordinates from DOE are correct. Preliminary design GIS data dated October 1999 was obtained from DOE.]

The question of whether the grid was sufficiently refined for the intended usage was not included in the AMR but was discussed with LBNL staff. The DOE auditors determined that the basis for sufficiency of grid refinement to support transport calculations should be in another AMR, but that the basis to support spatial heterogeneity of shallow infiltration should be in the Grid Generation AMR. There are two grids described in the Grid Generation AMR; a calibration grid with highly refined horizontal and vertical discretization in the repository footprint and a performance assessment (PA) grid used to predict flow fields for PA usage. For grid refinement to support transport calculations, the NRC staff must review the transport AMRs, the UZ Flow

AMR, and UZ Flow and Transport PMR to determine if the grid is sufficiently refined since this audit team concluded that the Grid Generation AMR did not directly feed the transport AMRs. For grid refinement to account for spatial variability of shallow infiltration, however, the bases for grid size sufficiency should be presented in the Grid Generation AMR for better transparency. Although the PTN may smooth out the spatial heterogeneity of shallow infiltration, the NRC staff believes that the coarse grid size (relative to the grid size for shallow infiltration) artificially smooths the shallow infiltration. Using distribution of percolation at the repository horizon for

comparison, an analysis of results from two different grid sizes was described by LBNL staff. The NRC recommends that the grid refinement analysis be included in a scientific notebook and the text of the Grid Generation AMR should be modified to reflect the basis for the choice of the grid size.

The Grid Generation AMR states the assumption of a uniform, flat water table elevation of 730 m msl as opposed to the use of a sloping water table as suggested by data from the northwest corner of the repository block for a water table at 775 m msl (borehole H-5). This difference of 45 m would reduce the UZ travel path by 15% in the northwest portion of repository. This may not warrant a change in the grid if the initial conditions of the flow model account for the difference in the water table position. It is surmised that the flow calibration would have a difficult time matching water potential data in the northwest portion of the repository if the water table was assumed to be 45 m lower. The NRC agrees that there is little data to support the shape of the sloping water table, however, the decision to ignore a data point when there is only sparse data may not be acceptable. If the DOE contends that the effect of using a uniform, flat water table is negligible, then NRC recommends that the basis must be presented in the Grid Generation AMR or the UZ Flow AMR.

In the calibration grid, the finite volumes (blocks) in the repository footprint are vertically refined with five blocks laterally connected to one block outside the footprint. The NRC observers requested confirmation that the lateral connection of five stacked grid blocks all connected laterally to a single block outside the footprint did not lead to significant circular flow (horizontal counter-current flow) being created by the connection network. The LBNL staff discussed efforts that led to their conclusion that the circular flow effect was not significant, however, this was not presented in a scientific notebook or the text of the Grid Generation AMR. The NRC agrees that the artificial lateral dispersal of flow created by the network of connections is likely minimal, but recommends that the bases be included in a scientific notebook and noted in the AMR. If this grid was used for calculation of velocities for transport, artificial dispersion would be created. The DOE technical specialist pointed out that the PA grid does not have the refined block sizes in the repository footprint, hence, this is not considered an issue.

Assumption No. 6 pertaining to the fault geometry representation seems reasonable to the NRC observers, however, the basis is relegated to some unspecified AMR. Similarly, the fracture properties presented in table 5 (pages 20-21) are important for creating connection parameters for the grid, yet no basis is given for the fracture characteristics; no limitations are stated; and no indication of sensitivity of grid parameters to these highly uncertain data is mentioned. LBNL staff pointed out that the DTN for fracture properties would lead auditors towards documents

that might answer the questions of basis and limitations for the fracture characteristics. Again, it is understood that the M&O removed references to other AMRs from the text, and, that this audit is reviewing AMRs that are works in progress and not yet complete.

The equations for connection spacing were stated in the AMR as coming from Warren and Root (1963). This reference, however, only provides a conceptual basis that may be used to estimate the coefficients in equations 4-6 on page 55. The coefficients for these equations were described by LBNL staff as being derived from modeling based on an assumption of

single-phase, quasi-steady state flow for three different types of fractures. The NRC recommends that the calculations be added to a scientific notebook and the basis clarified in the text of the AMR. Equations 4-6 use coefficients of D/6, D/8, and D/10 instead of the widely used D/2 for connection lengths. The basis for DOE estimates of these coefficients appears to be valid. In going to this level of detail, a discussion of the anisotropy of the fracture frequency should also be included. The DOE auditors chose to explicitly draw out the transparency of the basis for the equations and state it as a separate recommendation of the audit.

Clarification was requested by the NRC observers on the estimation of the volume-area factor (A_{fm}) for matrix-fracture interaction. The basis for the A_{fm} values was stated as being in the AMR U0090, which could not be referenced since it was not yet completed. Also, without the AMR U0090, it was not clear in the Grid Generation AMR text how the A_{fm} parameter was used in the model; particularly, if there was a change in approach from that used for the Viability Assessment. The LBNL staff reaffirmed that the matrix-fracture interaction area is further modified by a calibration-derived coefficient that is dependent on saturation. This illustrates the problem with auditing AMRs when supporting AMRs are not yet completed and serves to emphasize that the purpose of the current audits is to analyze the progress of AMR development.

The equation relating 1-dimensional and 3-dimensional porosity in the footnote of table 5 on page 21 required further explanation. The proportionality of permeability with the cube of porosity is remindful of the parallel plate flow approximation but the terms used in the equation are not defined. LBNL staff responded by saying that it was not important for the development; the audit team concurred. The NRC recommends that the terms in the equation be clarified and that basis described in the AMR.

The choice of boundary conditions and the choice of the grid domain, often significantly affects flow model results. For the UZ site-scale model, the boundary conditions most likely to affect results pertain to flow below the repository where the lateral component of flow is prominent. Above the repository, 1D flow predominates in the current conceptualization of flow at YM. A discussion by LBNL staff was provided in written form describing the potential effect, or lack thereof, of boundary conditions on flow below the repository. The NRC staff recommends that their discussion be added to the Grid Generation AMR.

AMR U0010, Simulation of Net Infiltration for Modern and Potential Future Climates

This AMR produces spatially heterogeneous infiltration maps of average, high, and low infiltration rates for modern, monsoonal, and glacial transition climates for YM that will be used in Analysis of Infiltration Uncertainty AMR (U0095), Calibrated Properties Model AMR (U0035), UZ Flow Model and Submodels AMR (U0050), and Mountain-Scale Coupled Processes (TH) Models AMR (U0105). The Infiltration AMR uses data from surface geologic maps, rainfall data from stations at Nevada Test Site and YM, and output from the Climate AMR (U0005). To streamline the text, this AMR is referred to as the Infiltration AMR throughout the discussion

below.

The decision to make the Infiltration AMR a supplement to the Flint et al. (1996) report meant that the Flint et al. (1996) report should also have been reviewed as part of this audit. Whereas the LBNL AMRs attempted to be self-contained, the Infiltration AMR stated as its first assumption that the model presented in Flint et al. (1996) was adequate to describe infiltration at YM. The data and results in the Flint et al. (1996) report are presently considered nonqualified, the model is not considered validated, and the report has not been released by the USGS. The NRC recommends that the Flint et al. (1996) report be directly incorporated into the Infiltration AMR.

Uncertainty analysis was stated as necessary in the Infiltration AMR but was relegated to the Analysis of Infiltration Uncertainty AMR. The objective of the Infiltration AMR was to present a methodology for estimating infiltration at YM. In doing so, the output of the model is presented as a single realization for YM; thus, the AMR is more than a methodology. The model validation of the infiltration model was said to be part of the Analysis of Infiltration Uncertainty AMR (U0095). Since the model is considered difficult to validate, the sensitivity of results to reasonable ranges of all parameters becomes an important tool for addressing the predictive reliability of the infiltration model. The NRC staff concurs with the DOE auditor recommendation that the sensitivity analysis be directly incorporated into the infiltration AMR.

The importance of a sensitivity analysis for evaluation of the model's predictive capability is illustrated by the uncertain calibration process. The infiltration model was calibrated for point estimates at locations where neutron probe (water content) and temperature data were collected. The neutron probe data may not reflect the entire flow through a fracture network since it is a point measurement of the matrix water content. This is not as severe a limitation, however, for the temperature data. The model was also calibrated at the watershed scale against sparse (2 events) streamflow data with root zone storage and percent area where runoff occurs as the primary calibration parameters. A final adjustment was made in the calibration process to ensure that the paleo-record of infiltration was not exceeded. The paleo-record is reflected in the recharge estimates based on geochemical data as will be described in another AMR (not yet completed). Each component of the calibration process has an associated uncertainty. Furthermore, given the uncertainty in the hydrologic properties of the soil and bedrock and the precipitation records, the predictive utility of the model should be considered suspect, thus the importance of a sensitivity analysis.

The highly uncertain hydrologic properties of the bedrock are derived from a composite matrix and fracture property data set presented in table 2 of Flint et al. (1996). USGS staff clarified during the audit that this data set has not changed, only the bedrock material defined for each pixel has changed since the 1996 report. The Day et al. (1998) map of the YM block is used where possible and other geologic maps are used to fill-in for surrounding areas. It was also clarified that the composite, or bulk, permeability values used in the model are the ones listed for the 250 μm filled fracture column, not the last column that lists a composite estimate in table 2 of Flint et al. (1996). The values from the "250 μm filled fracture" column best matched neutron probe data according to the USGS team at the audit. Even though the fracture data used to develop table 2 of Flint et al. (1996) has little supporting bases, the bulk permeability

estimates were essentially calibrated parameters using the point estimates of temperature as constraints. The NRC recommends that a more complete description of the bases for the bulk permeability values for each bedrock layer be included in the AMR.

Soil depth is likely the most important porous media property for determination of shallow infiltration and it is another highly uncertain parameter. Soil depth is difficult to assess in the field, especially for shallow thicknesses where there is a strong sensitivity to shallow infiltration estimates. During the audit, the USGS team provided a more thorough description of the soil thickness model. Though the map is not presented in the Infiltration AMR, the YM area is divided into map areas of three soil-depth categories. Equations for slope dependent soil thickness for each category are presented in the AMR. Where surficial soil is thick, bedrock properties are not used because the soil at the bedrock/soil interface would be near saturation. Uncertainty in soil depth would be expected to be significant using this soil thickness model, though the output generally seems reasonable. The NRC recommends that a more complete description of the soil map generation be included in the AMR.

Several concerns of NRC pertaining to the precipitation records were discussed during the audit. The first one is that spatial and temporal smoothing of the records would serve to under-predict infiltration. The use of 2 hour (summer) and 12 (winter) durations and the use of spatially uniform precipitation events, though adjusted for elevation, may not adequately reflect the actual localized, temporally varying storm events that occur, particularly during the summer. The second concern is that the length of the meteorologic data records from stations around YM are short, hence, large magnitude, long return period events are likely not represented in the short records. The 100-yr synthetic precipitation record constructed for the AMR explicitly limits the magnitude of storms to those seen in the short records. The smoothing of spatial and temporal precipitation events and the exclusion of large storms, otherwise expected in long precipitation records, would both lead to under-predictions of shallow infiltration because the BUCKET model compares precipitation rate (or flux input at the top of each layer) with saturated hydraulic conductivity to determine if infiltration proceeds down the UZ column. And lastly, the NRC is concerned that the infiltration model is constrained by future climate predictions that extend only to 10,000 yrs. Although proposed 10 CFR Part 63 specifies the compliance period as 10,000 yrs, there is a proposed specification that the analysis continue beyond 10,000 yrs to insure that peak dose does not occur during a short time period following the end of the compliance period. The NRC recommends that a discussion or an analysis be included in the AMR to address the

sufficiency of the meteorological records to capture focused precipitation events and long-return period events and their effect on shallow infiltration estimates for a period up to and beyond 10,000 yrs.

The BUCKET model assumes plug flow through the multiple layers of the UZ vertical columns. An implicit assumption is that capillarity is not an important component of UZ flow processes for the objective of estimating annual average infiltration rates in the semi-arid climate of YM. The INFIL version 2.0 contains both the BUCKET and the RICHARDS modules and could readily be used to confirm the basis for this assumption. Although Flint et al. (1996) extensively describe the RICHARDS module, it was never used to validate the reasonableness of the plug flow assumption used in the BUCKET module. Confidence in the BUCKET model would be

enhanced by a comparison with the RICHARDS module or any other Richards equation-based numerical code. Infiltration rates are fastest when capillarity drive predominates at early times in storm events. However, the coarse layering used in the BUCKET model would tend to move water more quickly through the system as compared to results from a fine discretization, thus compensating for the neglect of capillary drive. The NRC recommends that the assumption of plug flow used in the BUCKET model be validated by comparison against a numerical Richards equation-based code to assure that mean annual shallow infiltration estimates are not under-predicted.

A number of items discussed during the audit fell under the category of transparency of equations, data, and scientific bases. The NRC had a number of specific concerns and is listing them here to support the DOE general recommendation of transparency:

1. The basis for the choice of a standard root zone depth of 2 meters were missing from the AMR. USGS staff noted that the support for the estimate was contained in a report by Hudson and Flint (1996), which is not in the Infiltration AMR reference list.

2. Correction of the text defining field capacity to remove the word “significantly” since field capacity is the saturation at which capillary forces exceed gravitational forces (page 13).

3. A discussion is needed on the Markov chain analysis for wet-dry day prediction. The only source of information on the procedure was the comment lines in the Fortran code itself, although USGS staff believed that there might be an expanded discussion in another document. The handling of extremely low or zero-probability event sequences needs to be clarified.

4. During the audit, the justification for the time step for overland flow calculations was discussed as being inferred from work by Savard (1995). This should be in discussed in the AMR.

5. The value of the slope in equation 3 for future climates (monsoonal and glacial transition) is never presented. Also, the modern coefficients for equation 3 are referenced to
French (1983), however, Hevesi reported that coefficients estimated from the YM stations (14 stations, USGS and SAIC) were similar in magnitude to those reported in

   French (1983). The meteorological datasets used for this confirmation should be clarified in the AMR.

6. Equations 4 and 5 are presented with no basis or source reference.

7. A justification for the assumed changes in vegetation type and density and the evapotranspiration for future climates is needed. Also, rooting parameters that approximate 20% cover under modern climate are increased so that cover is 40% for the upper-bound of the monsoonal climate, and 60% for the upper-bound for the glacial transition. The percentages may be excessive, thus leading to an over-prediction of evapotranspiration and under-prediction of shallow infiltration. As discussed during the

audit, justification might be obtained by analysis of analog sites. It is also noted that this item could be addressed as part of the uncertainty analysis slated for another AMR (if the DOE audit recommendation is not followed).

AMR U0015, In Situ Field Testing of Processes

This AMR summarizes the ambient field testing of processes using air and water injection tests performed in the ESF. This AMR directly feeds the Seepage Calibration Model and Seepage Testing Data AMR (U0080). To streamline the text, this AMR is referred to as the In Situ Field Testing AMR throughout the discussion below.

The oft-mentioned problems of representativeness of the tests to long-term, low flux rate, ambient conditions expected in any closed drift in the repository footprint were discussed by LBNL as part of this performance-based audit. Limited applicability for predicting seepage into drifts because of the high flux rate, short time-scale and length-scale injection tests from a limited number of locations and lithologies have all been discussed previously in peer reviews,

other audits, and this audit as discussed in the section on the Seepage Calibration Model and Seepage Data Testing AMR. The applicability constraint will not be repeated here. The stated objective by LBNL staff for the In Situ Field Testing AMR during the audit was that it simply presented field and laboratory data that addressed flow processes adjacent to and into a drift. The limitations of the data were mentioned in the AMR.

The effect of ventilation on the liquid injection tests was drawn out as a separate recommendation by the DOE auditors. Some of the test schedules for Niche 3650 included short time periods between injections. Though this injection schedule established that initial conditions significantly affect seepage results, it was not clear how the results of the test might relate to ambient conditions. Also, the ventilation effect has strong implications for physical, process-based modeling and the comparison of parameters between tests at one location and between test areas. Without establishing consistency for the ventilation effect, the parameter estimates for fracture porosity (which is assumed to account for initial condition and imbibition effects in the Seepage Model AMR) will vary solely due to the extent of the ventilation effect. LBNL staff discussed the efforts they have made to establish conditions similar to ambient

including the grouting of rock fractures around bulkheads and artificial elevation of relative humidity. Monitoring relative humidity would allow for the ventilation effect to be integrated into the analysis. Experience noted by LBNL and USGS staff suggest that it is difficult to maintain high humidity in a closed niche when the Exploratory Studies Facility is ventilated. Also, the measurement error of probes used to measure relative humidity in the niches was stated in the discussion by LBNL staff as being ±2%. Even at high humidity, this magnitude of error may have a significant effect on seepage results for low flux rates prior to and during tests (Or and Ghezzehei, 1999). The magnitude of the effect caused by measurement error for high flux rate injections is not as significant, though knowledge of the relative humidity variations will remain important. The NRC recommends that DOE either explore alternative testing methods that control the ventilation effect or incorporate a ventilation model in their analysis of data and improve accuracy of relative humidity measurements.

There were a number of transparency, justification, and clarification questions directed to the authors during the audit that when addressed, should improve the AMR and improve any end users' understanding of the limitations of the output from this AMR. These are discussed below. The NRC recommends that these items be addressed in the AMR.

Table 19 on page 146 of the In Situ Field Testing of Processes AMR includes a psychrometer measurement of 0.4 meter for water potential. LBNL staff verified the data point, noted that the measurement error was ±5%, and concluded that this value reflected a small negative water potential since psychrometers cannot measure positive values of pressure head. The discussion switched to the meaning of the wide range of values of water potential in this table and the possible reflectance on flow pathways in fracture networks.

Confusion over the conversion of injection volume (or mass) over time values to linear rates of flow over time (e.g., Figure 20 of the In Situ Field Testing of Processes AMR) was clarified by LBNL staff. The area over which flow occurs is taken as the wetted half perimeter of the borehole times the test length along the borehole. Conversion of the volumetric (or mass) injection rates to linear measures of percolation and seepage ignores the dimensionality difference, and hence may be misleading. Flow from a point source injection leads to 3-dimensional spreading over the niche ceiling. Ambient percolation over the entire projected areas of the niche is predominantly 1-dimensional except when capillary diversion takes place.

Four reasons were presented at the audit to explain the increase in permeability found by air injection tests in the small zone surrounding Niche 3650. Clearly, stress-induced fracturing should be considered as assumed in the In Situ Field Testing AMR. Other explanations include a skin effect due to dust filling fractures not being accounted for in the solution method, a change in the boundary conditions from pre- to post-excavation, and a change in the water content from pre- to post-excavation because of drying caused by ventilation. LBNL discussed their rationale at the audit for not addressing reasons other than stress-induced fracturing. The skin effect can not be separated from the permeability estimate using the analytical approach described in the In Situ Field Testing AMR. LBNL indicated that the fines were blown out as part of the air injection testing thus eliminating any skin effect. The change in the boundary conditions between pre- and post-excavation was not believed to affect the analysis because the volume of influence estimated by LBNL for the injection tests translated to a radius of 1 or 2 feet, which is slightly less than the distance between the borehole and niche ceiling (0.65 meter or 2.1 feet). Water content changes were believed to be minimal and relegated to the smallest fractures where any changes to permeability estimates were thought to be insignificant if they did de-water. Since the permeability is estimated directly from the air injection tests, and the van Genuchten α values are scaled to the permeability, and both are strongly important for estimating seepage threshold. The NRC staff recommends that a supporting basis for the assumed conceptual model describing pre- and post-excavation testing be included in the AMR.

AMR U0080, Seepage Calibration Model and Seepage Testing Data

This AMR develops a methodology for numerically modeling seepage rates and estimating

seepage threshold values consistent with liquid injection tests performed in Niche 3650. This AMR produces parameter sets and calibrated models used in the Abstraction of Drift Seepage AMR (U0120), Drift-Scale Coupled Processes (DST, THC, Seepage) Models AMR (U0110), and Seepage Models for PA Including Drift Collapse AMR (U0075). To streamline the text, this AMR is referred to as the Seepage Model AMR throughout the discussion below.

The technical content of the seepage model AMR was considered to adequate by the DOE auditors based on the stated objectives. The Seepage Model AMR clearly states the limitations of the model; the seepage model is only valid for prediction of liquid injections 0.65 m above Niche 3650 at the high (relative to average annual ambient percolation rates for YM) injection rates used in the tests. In addition, the liquid injection tests are point sources of water above a large niche ceiling, rather than the ambient condition of percolation over the entire footprint of the niche. As such, the NRC staff views the seepage model as simply a transfer function model calibrated not only to this particular zone of fractured rock, but also to the conditions of the tests and the grid size used in the numerical inversions. The DOE auditors did include a general recommendation related to end users use of data from the audited AMRs, however, the author of the Seepage Model AMR clearly and adequately stated all limitations. The onus was put on the other seepage AMRs (U0075 and U00120) to apply this model to all of YM; this audit team was not charged with the task of auditing the other seepage AMRs. In spite of the declared limitations, the NRC is seriously concerned with the end use of the results from the Seepage Model AMR as discussed in the following paragraphs.

The three important hydrologic parameters estimated for the seepage model are fracture permeability, van Genuchten α, and porosity. The initial conditions are set using a uniform flux of 3 mm/yr. Permeability is estimated from the single-hole air injection tests reported in the In Situ Field Testing AMR. For the homogeneous case, the van Genuchten α is calibrated to the seepage threshold using data from the liquid injection tests. For the heterogeneous case, the Leverett scaling rule is specified in the Seepage Model AMR as the basis for the relationship between the permeability and the van Genuchten α. The fracture porosity is calibrated in all instances. As such, the calibrated porosity used in the analysis can be viewed as accounting not only for fracture porosity but also for matrix imbibition and water loss from measurement

error or evaporation during the test. In the homogeneous case, the van Genuchten α can be viewed as accounting for fracture aperture distribution, particularly at the large aperture range as it varies across the niche ceiling; but the α value also accounts for film flow and rivulet flow in the fracture and roughness or irregularities of the niche ceiling. The NRC staff views this lumping of fracture hydraulic properties, test conditions, and grid size into hydrologic parameters acceptable if the seepage model is viewed strictly as a transfer function and the end users of the results used it as such.

Presuming that many in situ field tests are completed to support parameter ranges at YM for the seepage model, there is also a grid dependency of the parameter values. The model inversions assume a set grid discretization, any changes to the grid size will negate any comparison of parameter values between tests or any PA predictions. For example, seepage threshold is strongly correlated with the value of the van Genuchten α used in grid blocks adjacent to the drift opening (Winterle et al., 1999). When modeling seepage into drifts using grid independent parameters, the inverse of the van Genuchten α value (when converted to

water pressure head) should remain smaller than the grid discretization near the drift opening. This is particularly important for large α values so that the strong non-linearity near saturation is captured by multiple grid blocks rather than being lost entirely in one large grid block adjacent to a drift opening. If large α values are used and the grid is not sufficiently refined, the model will lead to an over-prediction of the seepage threshold (the value of percolation below which there is no seepage into the drift) and an under-prediction of seepage rate at low flux rates. The calibration process within the Seepage Model AMR does not exhibit this problem because the model is clearly used as a transfer function for the specified injection tests, hence it does not matter that the $1/\alpha$ value is 2 cm (converted from table 10) and the first connection is 5 cm and the block dimension is 10 cm. The NRC recommends that a grid refinement (and connection length) analysis be done for large values of the van Genuchten α, similar to that done by Hughson and Codell (2000) before any Monte Carlo analysis of seepage threshold is performed using the seepage model.

Although grid refinement may be necessary to correctly capture seepage threshold because of the large van Genuchten α values, the fracture continuum approach still suffers from lack of supporting basis from the perspective of representative element volume. Based of borehole data and ESF data, the fracture spacing is larger than the grid block sizes. The NRC staff concurs with LBNL staff that alternative methods need to be explored; such efforts were said by LBNL staff to be underway, particularly in the area of discrete fracture models.

Since the seepage model has the trappings of a physical, process-based model, but is essentially a transfer function model, the parameters cannot be extrapolated to other areas, other injection rates, or even to a uniform flow or pulses percolating towards the drifts. The Monte Carlo analyses reported in Seepage Model AMR imply that the goal is to establish a methodology for applying the seepage model to YM. The LBNL staff deferred questions on the basis for determination of ranges of parameters to another AMR, and then assumed ranges for the Monte Carlo analyses. The staff NRC considers the recommendations for more injection tests, at lower rates and longer durations, and in many locations that were included in the AMR to be an extremely important component of this approach. Until those tests are done, the NRC

believes that there will be little basis for the hydrologic parameters of the seepage model because it is a transfer function model based on the conditions of the injection test and the grid size used for the inversions.

There were a number of comments raised by the DOE auditors and the NRC observers directed on clarity and transparency of the Seepage Model AMR, they were: (i) the discrete features model was describe as including elongated features with “low permeability obstacles” (p.22). The term “obstacles” was clarified to mean variation in discrete feature width, rather than an obstruction; (ii) the reference to “matrix” implied a dual-continuum model for the discrete feature model whereas the reader is otherwise led to infer that a single-continuum is used. The LBNL staff stated that “matrix” referred to the zones between discrete features (page 22 and 30). The discrete feature model and the fracture continuum model are just two different representations of a heterogenous domain; (iii) on page 25, Figure 3, the arrow pointing to “Flux entering the top of the model” refers to the flux going through the top layer of the model. It was clarified during the audit that the flux entering the top of the model does not refer to the top boundary condition. There is a uniform flux applied as a top boundary condition. The NRC staff is concerned that the use of a uniform boundary condition a few meters above

the drift for PA could have the effect of smoothing the inherent natural variability of seeps and preferential flow paths, thus lowering seepage rates and raising seepage threshold values.

4.6 NRC Staff Findings

The NRC staff agreed with technical findings of the audit team. The following findings are added by the NRC staff. They are associated with the umbrella DOE audit recommendation regarding transparency. These findings were resolved in the audit and it is expected that they will be addressed in the next revision of the AMRs. Some of these items may also be addressed in other AMRs as those AMRs are completed:

NRC Staff General Findings

1. It was difficult to assess the adequacy of AMRs since much of the supporting data were in other incomplete, and/or unavailable AMRs.

2. The transparency of the equations and technical bases of assumptions and conclusions were lacking. LBNL developed AMRs as all inclusive, while the USGS developed an AMR as a supplement to a milestone report.

3. The distinction between validation and verification was not clear to the DOE audit team and the NRC observers, and was considered synonymous to the USGS.

NRC Staff Specific Findings

AMR U0000, Development of Numerical Grids for UZ Flow and Transport Modeling

4. The AMR did not clearly identify the horizontal projections used. Input data projections

   should be stated and end-users need to know what projections were used for the spatial data output.

5. The grid refinement analysis was not included in a scientific notebook and the AMR did not reflect the bases for the choice of grid size.

6. The basis for using a flat water table was not presented. The AMR ignored a 45 m higher water elevation data in the northwest corner of the model.

7. Neither the scientific notebook or AMR text discussed the effects of grid connection network near the refined grids in the repository footprint.

8. No basis, limitation, or indication of sensitivity was presented for the fracture characteristics on page 20-21. This is considered highly uncertain data.

9. The basis for the equations on page 55, and the calculations used for connection spacing were not in the scientific notebook or in the text.

10. The basis for the volume-area factor (A_{fm}) was not stated in the text. This parameter

has been modified since the Viability Assessment by a calibration-derived coefficient that is now dependent on saturation.

11. A discussion on the potential effect of lateral boundary conditions was not presented in the text.

AMR U0010, Simulation of Net Infiltration for Modern and Potential Future Climates

12. The Flint et al. (1996) report is unqualified, invalidated, and has not been released by the USGS. Yet, the AMR is a supplement to this report.

13. The model is difficult to validate; as such, uncertainty analysis is needed to assess the calibration process and evaluate the model's predictive ability. The uncertainty analysis was relegated to another, yet uncompleted, AMR.

14. The basis for the choice of a standard root zone depth of 2 m was not included in the text or references.

15. The exclusion of large storms from long meteorological records, temporally variable, and localized events may under predict shallow infiltration.

16. Confidence in the BUCKET model would have been enhanced if a direct comparison was made with the RICHARDS model in INFIL version 2.0.

17. The description of the development and methodology for using the third-order Markov chain analysis to predict wet-dry days was not included in the text.

18. The infiltration model is constrained to a 10,000 year analysis. Yet, proposed 10 CFR Part 63 requires an analysis beyond 10,000 years to insure peak dose does not occur shortly after the compliance period.

19. A complete description of the bases for the bulk permeability values for each bedrock layer was not included in the AMR.

20. The justification for the time step for overland flow calculations was not included in the text.

21. Equations 4 and 5, pages 22 and 23, are presented with no references or bases.

22. No justification was provided for the assumed changes in vegetation type, density, and the evapotranspiration for future climates.

AMR U0015, In Situ Field Testing of Processes

23. The high-flux rate, short time and spatial scale in-situ tests offer limited applicability for predicting seepage into drifts under ambient conditions.

24. Ventilation effects on liquid injection were not consistently established for the liquid

release tests.

25. The AMR lacked a supporting bases for the assumed conceptual model describing pre- and post-excavation testing. The bases supporting stress-induced fracturing as the only significant explanation for the increase in permeability is needed.

AMR U0080, Seepage Calibration Model and Seepage Testing Data

26. The goal to establish a methodology to apply to YM seepage modeling was not accomplished. The seepage calibration model is simply a transfer function and is only valid for application to injection tests 0.65 m above Niche 3650 at rates much higher than the average annual ambient percolation rates. Until the recommended low rate, long duration injection tests are completed, there will be little basis for the transfer function parameters of the seepage model.

27. The difficultly in applying the transfer function seepage model to YM as a physical, process-based model lies in the lumping of test conditions and grid discretization characteristics into parameters that are otherwise hydrologic-based. Use of this seepage model in AMR U0075, where presumably ranges are defined for the parameters for this transfer function model, would be highly suspect, particularly the estimates of seepage threshold.

28. The use of a uniform boundary condition a few meters above the drift for performance assessment could smooth the natural variability of seeps and raise the seepage threshold values.

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4.6.1 Audit Observer Inquiries

No NRC audit observer inquiries were generated during this audit.

4.6.2 Closure of Previous NRC Audit Observer Inquiries

No audit observation inquires were closed during the conduct of this observation.

4.6.3 Open NRC Audit Observer Inquires (AOIs)

The following NRC audit observation inquiries remain open:

a. Audit Observation Inquire (AOI) No. OCRWM-ARC-99-015-1, dated September 22, 1999: OQA agreed to provide information to the NRC on the qualification status and use of the “Waste Stream Profiles” addressed in the “Design Basis Waste Stream for Interim Storage and Repository” and the “Waste Quantity, Mix and Throughput Study” documents.

b. AOI No. M&O-ARP-00-02-1, dated November 18, 1999: AP-3.10Q, “Analysis and Modeling” and the QARD are not specific regarding which calculations/analyses are subject to model validation and the timing of model validation. M&O Environmental, Safety, and Regional Programs Office involved with the biosphere AMRs do not appear to have an understanding or strategy of model validation as it applies to the biosphere AMRs/PMR.

c. AOI No. M&O-ARP-00-02-2, dated November 18, 1999: Documented resolution of individual comments is not required for checks of analysis and models (AP-3.10Q) and is optional for reviews of technical products (AP-2.14Q). A lack of documented resolution is inconsistent with the QARD section 2.2.10 (f) which requires that mandatory comments shall be documented and resolved before approving the document. Note that the audit of the Integrated Site Model (ARP-99-009) also identified

several recommendations concerning the review processes of AP-3.10Q and AP-2.14Q.

END