October 17, 2000

Mr. James H. Carlson, Acting Director
Program Management and Administration
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

SUBJECT: U.S. NUCLEAR REGULATORY COMMISSION'S OBSERVATION AUDIT REPORT NO. OAR- 00-09, "OBSERVATION AUDIT OF OFFICE OF THE CIVILIAN RADIOACTIVE WASTE MANAGEMENT, QUALITY ASSURANCE DIVISION, AUDIT NO. M&O-ARP-00-08"

Dear Mr. Carlson:

I am transmitting the U.S. Nuclear Regulatory Commission's (NRC's) Observation Audit Report No.OAR-00-09 of the U.S. Department of Energy (DOE), Office of Civilian Radioactive Waste Management (OCRWM), Office of Quality Assurance (OQA), Yucca Mountain Quality Assurance Division, audit of the Near Field Environment (NFE) Process Model Report (PMR) activities performed by the OCRWM Management and Operating Contractor (M&O). The audit, M&O-ARP-00-08, was conducted on July 24-28, 2000, at the M&O facilities in Las Vegas, Nevada.

The scope of the audit was limited to evaluating the effectiveness of the implementation of the OCRWM Quality Assurance Program described in the "Quality Assurance Requirements and Description" and its implementing procedures for selected analysis model reports (AMRs) supporting the NFE PMR.

The NRC observers determined that OQA Audit M&O-ARP-00-08 was effective in determining the level of compliance of M&O activities associated with the NFE PMR. The NRC observers agreed with the audit team's conclusions, findings, and recommendations as presented at the audit exit. Within the areas evaluated, the audit team identified potential deficiencies in: a) software routines not containing sufficient information; b) input data and assumptions not being clearly stated and justified; and c) the scope of the CAL (Calculation) document exceeded that allowed by the procedure.

As discussed in the attached report, the observers identified and discussed their findings during the course of the audit. The most significant observer concern is that certain aspects of the two AMRs and the one CAL audited were found to be technically insufficient for either the intended purpose or for supporting the stated conclusions. The specific potential deficiencies and/or recommendations are detailed in the sections pertaining to the individual AMRs and CAL. The DOE audit team Technical Specialists identified these potential deficiencies and/or recommendations and brought them to the attention of the originators, and the NRC staff concurred with those findings. The NRC observers generated no audit observer inquiries (AOIs) during this audit.

A written response to this letter and the enclosed report is not required. If you have any questions, please contact Ted Carter of my staff at (301) 415-6684.

Sincerely,

***/ra/***

Janet Schlueter, Chief (Acting)
High-Level Waste Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: NRC Observation Audit Report No. OAR-00-09, “Observation Audit of the Office of Civilian Radioactive Waste Management, Quality Assurance Division, Audit No. M&O-ARP-00-08"

cc See attached list.

cc: R. Loux, State of Nevada
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A written response to this letter and the enclosed report is not required. If you have any questions, please contact Ted Carter of my staff at (301) 415-6684.

Sincerely,

Janet Schuleter, Chief (Acting)
High-Level Waste Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: NRC Observation Audit Report No. OAR-00-09, "Observation Audit of the Office of Civilian Radioactive Waste Management, Quality Assurance Division, Audit No. M&O-ARP-00-08"

cc: See attached list.

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U.S. NUCLEAR REGULATORY COMMISSION

OBSERVATION AUDIT REPORT NO. OAR-00-09

OBSERVATION AUDIT OF THE

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

QUALITY ASSURANCE DIVISION

AUDIT NO. M&O-ARP-00-08


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Enclosure

## 1.0 INTRODUCTION

Staff from the U.S. Nuclear Regulatory Commission (NRC) Division of Waste Management and contractors from 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 the Near Field Environmental (NFE) Process Model Report (PMR) activities performed by the OCRWM Management & Operating Contractor (M&O). The audit, M&O-ARP-00-08, was conducted on July 24-28, 2000, at the M&O facilities in Las Vegas, Nevada.

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) and other documents supporting the NFE PMR. During the audit, selected AMRs and a Calculation (CAL) document were subjected to a technical and programmatic review to ensure that the applicable requirements contained in the QARD 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 U.S. Code of Federal Regulations (10 CFR Part 60). Because of the anticipated DOE submittal of the Site Recommendation Consideration Report (SRCR) in December 2000, the following observation activities were emphasized: (1) confirming that data, software, and models supporting the SRCR are properly qualified; and (2) reviewing the progress being made by DOE and its contractors in meeting the qualification goals for SRCR.

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-00-08 was useful, effective, and conducted in a professional manner. Audit team members were independent of the activities they audited and appeared to be knowledgeable in the quality assurance (QA) and technical disciplines within the scope of the audit. 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 the areas evaluated. However, five potential deficiencies were identified during the audit, and approximately 27 recommendations were offered for improvements and enhancements to the AMRs. Within the areas evaluated, the audit team identified potential deficiencies in: a) software routines not containing sufficient information; b) input data and assumptions not being clearly stated and justified; and c) the scope of the CAL document exceeded that allowed by the procedure. The NRC staff determined that this audit was effective in identifying the deficiencies and recommending improvements in the AMRs. The NRC staff also agrees with the audit team conclusions, findings, and recommendations.

## 3.0 AUDIT PARTICIPANTS

### 3.1 Nuclear Regulatory Commission Observers

| | |
|---|---|
| Ted Carter | Observer (Team Leader-NRC) |
| Debra Hughson | Observer (Technical Specialist-CNWRA) |
| Lauren Browning | Observer (Technical Specialist-CNWRA) |
| Goodluck Ofoegbu | Observer (Technical Specialist-CNWRA) |

### 3.2 OQA Audit Team

| | | |
|---|---|---|
| Robert Hartstern | Audit Team Leader | OQA/Quality Assurance Technical Support Services (OQA/QATSS) |
| Steve Harris | Auditor | OQA/QATSS |
| Richard Weeks | Auditor | OQA/QATSS |
| Chet Wright | Auditor | OQA/QATSS |
| William Roberds | Technical Specialist | DOE/MTS |
| David Sassani | Technical Specialist | DOE/MTS |

## 4.0 REVIEW OF THE AUDIT AND AUDITED ORGANIZATION

This OQA audit of the M&O was conducted in accordance with OCRWM Quality Assurance Procedure (QAP) 18.2, “Internal Audit Program,” and QAP 16.1Q, “Performance/Deficiency Reporting.” The NRC staff’s observation of this audit was based on the NRC draft 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 NFE PMR. AMRs, software, and data were evaluated during the audit process. The audit included review of the programmatic controls governing the AMRs and technical issues discussed in the AMRs. Specifically, the following two AMRs and one CAL supporting the NFE PMR were reviewed by the audit team and the NRC observers during the audit:

Analysis Model Reports

- N000 Thermal Tests Thermal-Hydrological (TH) AMR (ANL-NBS-TH-000001), Rev 00
- N0120 Drift-Scale Coupled Processes Models (Drift Scale Test (DST) and TH-Chemical Seepage) (MDL-NBS-HS-000001), Rev 00

Calculation

- CAL-NBS-MD-000002-00: Premeability Change Due To Coupled TH-Mechanical Effects, Rev 00 (Tracking Number - N0C30)

### 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 the effectiveness of the analyses and models process for the NFE PMR and the quality of resultant end products.

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 DOE 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. Further, the NRC observer reviewed the technical specialists' qualifications (resumes) and found that the technical specialists had sufficient technical education, training, and experience related to the AMRs reviewed.

### 4.4 Examination of QA Programmatic Elements

The OQA programmatic and technical audit activities were conducted simultaneously, using sub-audit teams consisting of a technical specialist and a QA auditor. The limited-scope audit focused on the QA elements closely associated with the development of the AMRs. The NRC staff observed that each of the auditors reviewed related documentation and interviewed a representative sample of M&O personnel to determine their understanding of implementing procedures and processes. Training, education, and experience records were reviewed to assure M&O personnel were in compliance with their individual position descriptions. Objective evidence was provided and reviewed by the auditor and it was determined that all personnel were in compliance.

### 4.5 Examination of Technical Activities

The DOE audit team prepared detailed checklists for the CAL and each of the AMRs. Technical activities examined by the audit team, and in some cases those questions forwarded to the audit team, are summarized below for the CAL and each of the AMRs.

**AMR N0000, Thermal Tests Thermal-Hydrological Analyses/Model Report (Rev 00, 04/00)**

As stated in the AMR, the report had two purposes. First, the AMR was to evaluate the drift scale TH property set derived from the unsaturated zone (UZ) flow and transport analyses for thermally perturbed conditions. Second, the AMR was to conduct sensitivity studies of other TH property sets, including the mountain scale TH property set, and investigate modifications that would result in adequate agreement between simulated and measured TH data. However, the AMR did not fulfill all the purposes as defined in the AMR development plan (CRWMS M&O, 1999). The

development plan requires the AMR to recommend a property set for thermally perturbed flow and transport in the UZ.

The DOE Technical Specialist/auditor (hereafter referred to as the DOE auditor) found that this purpose as stated in the development plan had not been met. The NRC observer concurred with this finding. Specifically, the DOE auditor noted that quantitative comparisons between simulations and test results were made only for temperature data while simulated hydrological responses for thermally perturbed flow and saturations detected by geophysical techniques in the test environments were characterized in the AMR only subjectively as being in "good agreement." In addition, the significantly differing moisture distributions simulated using the various property sets indicated to the DOE auditor that this AMR did not succeed in discriminating between various TH property sets for predicting hydrological responses to thermal perturbations for use in PA. The DOE auditor pointed out that measured and simulated temperatures were compared quantitatively by weighted statistical measures but the criteria by which the comparisons were deemed acceptable were subjective and not adequately justified. Finally, the DOE auditor noted, and the NRC observer concurred, that the criteria for acceptable matches between simulations and temperature data were set so that all the property sets were found to be acceptable.

The DOE auditor also found the following additional potential deficiencies and/or recommendations in this AMR during the audit.

- Although the purpose of this AMR was to evaluate property sets for thermally perturbed flow and transport in the UZ, only one unit, the middle non-lithophysal unit of the Topopah Spring Tuff which comprises about 10 percent of the proposed repository, was investigated.

- Assumptions about boundary and initial conditions were not clearly stated nor justified and appeared to be inconsistent.

- Focusing of condensate drainage and preferential flow in fractures is observed in the thermal tests and is acknowledged to be the source of water collecting in several boreholes at the DST. This phenomenon is a mechanism by which water may enter drifts during the thermal period and may be important to performance, yet this AMR neglects spatial heterogeneity. The water collected and removed from boreholes in the DST is not included in the models.

- Leakage through the thermal bulkhead of the DST was not well represented by the models. The AMR acknowledged that leakage through the bulkhead remains one of the largest uncertainties in the DST results.

The NRC observer agreed with these findings as they were conveyed to the AMR originators during the audit. NRC recommends that DOE more thoroughly evaluate thermally driven moisture redistribution, such as focused condensate drainage through fractures, that are important to repository performance.

CRWMS M&O 1999, *Thermal Test Thermal-Hydrological Analysis and Models Report, DI#ANL–NBS–TH–000001.* TDP–NBS–TH–000002, Rev. 0 ICN 0. Las Vegas, Nevada, CRWMS M&O. ACC: MOL.20000124.0319.

**AMR N0120, Drift-Scale Coupled Processes (DST and THC Seepage) Models, Rev 00**

This report evaluated coupled thermal-hydrologic-chemical (THC) processes associated with the

DST, and then extended the model calculations to time frames appropriate for the evaluation of a potential waste-emplacement drift at Yucca Mountain, NV. Analytical data from the DST were used to appraise the conceptual and numerical models. Results from this study will be used as input for the performance assessment, "UZ Flow and Transport PMR," and the NFE PMR.

Although this AMR used state-of-the-art techniques, several limitations and areas for improvement were identified by the DOE auditor. The NRC observer concurred with all technical recommendations made by the DOE auditor/technical specialist. The following paragraphs summarize those technical recommendations.

The following model assumptions should be explicitly stated and supported by stronger technical bases:

- Reaction rates of most minerals in the systems described by Cases 1 and 2 of this AMR are known to be pH dependent. However, the DOE observer/technical specialist noted that this AMR employs a simplified version of the rate law that does not account for non-linear variations in effective reaction rates due to H+ dependency. The intrinsic rate constants were calculated assuming a fixed pH of 7. It is assumed in this AMR that these simplifications will have negligible effects on the model results. The NRC observer concurs with the DOE auditor/technical specialist that this assumption should be explicitly stated, and that technical bases should be given to support a specific pH range under which these assumptions are valid.

- Current design specifications require 70 percent heat removal by ventilation, but the DOE auditor/technical specialist noted that this AMR assumes 50 percent heat removal in calculations of effective thermal conductivities. The DOE auditor/technical specialist recommended that this discrepancy in heat loss be clearly indicated in the text, and that an impact analysis should be performed to evaluate the effects on the model results. The NRC observers agree with this recommendation, and also noted that the discussion of heat removal in this AMR lacks appropriate references. The DOE auditor/technical specialist recommended that appropriate references be included.

- The following model assumption should be explicitly stated: Aqueous fluid properties may be affected by changes in dissolved constituent concentrations over a range of temperatures. In this AMR, these effects are assumed to be negligible. The DOE auditor/technical specialist recommended that this assumption be explicitly stated in Section 5, and the NRC technical observer agreed.

Several modifications should be made to the text to improve its transparency. These are explained below.

- The DOE auditor noted that modifications to the rate law given in Equation 8 are likely to have a significant effect on the model results, and recommended that these modifications be explicitly described in the AMR (not just the scientific notebook). The NRC observer concurred.

- The DOE auditor identified incorrect values of the fracture reactive surface area for the units "ptnf3" and "tswf7" in Table III-I of this AMR. Although these errors were not propagated into the model input files, the DOE technical specialist and the NRC observer agreed that these values must be corrected in the AMR.

- The DOE auditor recommended that direct linkage to data derivation be improved by adding input Tables and Data Tracking Numbers to DIRS and then removing the Data Tracking Numbers and Input Tables from the list of model outputs in Section 8.4. These modifications were requested for Table 4 and Attachments II-IV. The NRC observer agreed with this recommendation.

This AMR addressed model validation by comparing model predictions with measured parameters from the DST. Several recommendations were made to strengthen this comparison and increase confidence in long-term predictions of the THC Seepage model. These recommendations are explained below.

- The NRC observer noted that a number of water and gas samples from the DST were analyzed, but many of these were not used as benchmarks for comparison with model predictions. The NRC observer was concerned that the measurements used in this AMR may not be representative. Alternatively, measurements that were not used in this AMR may reflect important processes that need to be considered. The DOE auditor agreed, and recommended that the full range of water and gas samples be evaluated to determine which measurements, if any, should be excluded from further consideration. Both the DOE auditor and the NRC observer emphasized that all assumptions used in the evaluation of water analyses should be stated explicitly and supported by technical bases.

- The DOE auditor/technical specialist and the NRC observer agreed that additional data for uncertainty analyses are needed to strengthen the Case 2 comparison against DST measurements. Because model validation relies on a comparison with analytical water and gas compositions, the DOE auditor recommended that the reliability of these data be assessed in a quantitative fashion. This AMR included some discussion of data uncertainties and limitations, but more comprehensive evaluations should be performed to strengthen the validation of the THC Seepage model. Uncertainties may stem from the analytical measurements themselves or from incomplete knowledge about the physical location(s) and condition(s) that contributed to the measured values. Data uncertainties should be evaluated, and corresponding bounds should placed on model results.

- Both the DOE auditor and the NRC observer were concerned that simulations performed using extended (Case 1) and abbreviated (Case 2) sets of minerals led to incongruous results. The NRC observer concurs with the DOE auditor that stronger technical bases are needed to support the conclusion that Cases 1 and 2 approaches are well-suited to predict THC processes over different time frames. Case 2 provides a closer match with the DST measurements than Case 1, and is used to validate the model over short time frames. However, the NRC observer noted that the explanation given for excluding Case 1 as a benchmark for comparison with the DST measurements p. 57( i.e. uncertainties in thermodynamic and kinetic data) can be applied equally well to Case 2. The DOE auditor and the NRC observer agreed that additional work is needed to reconcile differences between Case 1 and Case 2 results. The DOE auditor/technical specialist recommended that additional sensitivity studies be performed to identify the input parameters that contribute most significantly to model uncertainties, and to place bounds on the model results. The NRC observer concurred with these recommendations.

**Calculation CAL–NBS–MD–000002–00: "Permeability Change Due To Coupled Thermal-Hydrological-Mechanical Effects" (Tracking Number - N0C30)**

This report described a calculation performed to provide a bounding estimate of fracture permeability change owing to thermal-mechanical effects at the proposed Yucca Mountain repository. The estimate would be used to support PA abstractions of drift seepage and the NFE

PMR. Results from the calculation were used to suggest that thermal-mechanical effects on permeability would be limited to a permeability increase by a factor of 10 or less within a zone extending up to two drift diameters from a drift wall. However, the NRC observer concurred with the DOE auditor that the calculation is inadequate to support such a conclusion for the following reasons.

The mechanical model used for the calculation did not represent the anticipated mechanical environment at the proposed repository. The model used for the calculation consisted of a rectangular prism 60m-high (vertically), 30m-wide, in the drift direction, and 50m-wide in the drift-normal direction. The emplacement drift was represented by a horizontal circular opening, 5.5m in diameter and 30m-long, which is located at the mid-height of the prism. The applied mechanical boundary conditions consisted of zero vertical displacement at the base (i.e., at 30m below the emplacement-drift axis) and zero stress change on all other surfaces. The value of fixed stress at the stress boundary surfaces was set equal to the initial *in-situ* stress (i.e., before thermal loading) for the repository depth. These boundary conditions permitted free thermal expansion of the heated domain and, consequently, the resulting stress states are substantially different from the anticipated stress states during the thermal regime at Yucca Mountain. For example, the maximum principal compressive stress calculated from the model remained vertical throughout a 1000-year simulation period. On the other hand, the maximum principal compressive stress was expected to be horizontal during the thermal regime at Yucca Mountain because of higher restraint in the lateral than vertical direction. The document originator explained that the boundary conditions were chosen to promote rock loosening and, therefore, maximum permeability increase, in the roof area of the emplacement drift. However, thermal-mechanical models of the repository, with boundary conditions that appropriately represented the anticipated mechanical environment, indicated that stress-driven slip on subhorizontal fractures is an important mechanism of permeability change. The NRC observer concurred with the DOE auditor that, because of focusing on a mechanism that is inconsistent with the anticipated mechanical environment at Yucca Mountain, the calculation may produce nonconservative conclusions regarding the magnitude of potential permeability change and the geometrical characteristics of the zones of such change.

The fracture pattern at Yucca Mountain was represented in the model as three orthogonal (i.e., two vertical and one horizontal) fracture sets. This fracture pattern was different from the pattern used in previous DOE analyses of thermal-mechanical effects. The analyses presented in each of the following previous DOE documents were based on nonorthogonal fracture sets with dips of about 80 degrees for each of two subvertical sets and about 20 degrees for a subhorizontal set: ”Exploratory Studies Facility (ESF) Ground Support Design” (BABEE0000–01717–0200–00002–00D); “Seismic Topical Report II” (YMP/TR–003–NP–2); “Drift Ground Support Design Guide” (BCAA00000–01717–2500–00001–00); “Repository Ground Support Analysis for Viability Assessment” (BCAA00000–01717–0200–00004–01); and the “Drift Degradation Analysis AMR (ANL–EBS–MD–000027–00). The NRC observer concurred with the DOE auditor that the use of a fracture pattern that is not representative of the fracture pattern at Yucca Mountain may result in nonconservative conclusions regarding the magnitude of potential permeability change.

The thermal-mechanical property values used in the analyses were inconsistent with values in the DOE database. For example, the calculation used a thermal expansivity of $3 \times 10^{-6}$/K, whereas thermal expansivity varies with temperature from about $7 \times 10^{-6}$/K at 25–50 degrees C, to about $20 \times 10^{-6}$/K at 225–250 degrees C, based on information in the “Yucca Mountain Site Geotechnical Report” (B00000000–01717–5705–00043–01). Smaller values of thermal expansivity gave smaller values of thermal stress. Therefore, the use of a value of thermal expansivity that is small compared with values in the DOE database would lead to calculated thermal stress that is small compared with the anticipated thermal stress based on information

from the DOE database. Smaller stresses imply reduced magnitudes of inelastic response and, therefore, permeability change. Therefore, the NRC observer concurred with the DOE auditor that the potential deficiencies in the audited calculation may produce nonconservative conclusions regarding the magnitude of potential permeability change.

### 4.6 NRC Staff Findings

The NRC staff has determined that OQA Audit M&O-ARP-00-08 was effective in determining the level of compliance of M&O activities associated with the subject AMRs. The NRC staff agreed with the audit team conclusion that the OCRWM QA program had been satisfactorily implemented. The NRC staff also determined the following:

- The NRC staff found the OQA Audit M&O-ARP-00-08 to be thorough, comprehensive, technically detailed, and professional.

- Specific aspects of the two AMRs and the one CAL audited were found to be technically insufficient for either the intended purpose or for supporting the stated conclusions. The specific potential deficiencies are detailed in the sections pertaining to the individual AMRs and CAL. The DOE audit team Technical Specialists identified these potential deficiencies and recommendations for improvement and brought them to the attention of the originators, and the NRC staff concurred with those findings.

- The NRC staff found this audit to be effective in identifying deficiencies and recommending improvements in the audited documents. However, the DOE OQA should verify that the recommendations of this audit are satisfactorily addressed by the originators of the AMRs and the CAL.

#### 4.6.1 Audit Observer Inquiries

There were no audit observer inquires opened during this audit and all previous audit observer inquiries are closed.