U.S. NUCLEAR REGULATORY COMMISSION OBSERVATION AUDIT REPORT OAR–06–06, OBSERVATIONS OF BECHTEL SAIC COMPANY, LLC, AUDIT BQA–BSC–06–09 OF SCIENTIFIC INVESTIGATIONS FOR THE SEISMIC CONSEQUENCE ABSTRACTION MODEL AND MAJOR INPUT CALCULATIONS

/RA/ 10/06/06
Thomas Matula
Division of High-Level Waste
Repository Safety
Office of Nuclear Material
Safety and Safeguards

/RA/ Thomas Matula for 10/06/06
Jack Parrott
Division of High-Level Waste
Repository Safety
Office of Nuclear Material
Safety and Safeguards

/RA/ 10/06/06
Abou-Bakr Ibrahim
Division of High-Level Waste
Repository Safety
Office of Nuclear Material
Safety and Safeguards

/RA/ Thomas Matula for 10/06/06
Robert Brient
Center for Nuclear Waste
Regulatory Analyses

/RA/ Thomas Matula for 10/06/06
Luis Ibarra
Center for Nuclear Waste
Regulatory Analyses

/RA/ Thomas Matula for 10/06/06
Michael Simpson
Center for Nuclear Waste
Regulatory Analyses

/RA/ Thomas Matula for 10/06/06
Thomas Wilt
Center for Nuclear Waste
Regulatory Analyses

Reviewed and Approved by:

/RA/ N. King Stablein for 10/06/06
Frank Akstulewicz, Acting Deputy Director
Licensing and Inspection Directorate
Division of High-Level Waste
Repository Safety
Office of Nuclear Material
Safety and Safeguards

Enclosure

1.0 INTRODUCTION

On August 21–September 7, 2006, staff from the U.S. Nuclear Regulatory Commission (NRC), Division of High-Level Waste Repository Safety, and the Center for Nuclear Waste Regulatory Analyses (CNWRA) observed the Bechtel SAIC Company, LLC (BSC), internal quality assurance audit BQA–BSC–06–09 in Las Vegas, Nevada. The title of the audit was Audit of Scientific Investigations for the Seismic Consequence Abstraction Model and Major Input Calculations. The scope of the audit was to evaluate model development and scientific investigation activities regarding the Seismic Consequence Abstraction and to evaluate four technical reports providing direct input to the abstraction. The technical reports subject to this audit are identified in the table below.

Technical Report Audited	Abbreviated Title*
Seismic Consequence Abstraction (MDL–WIS–PA–000003, Revision 02)	Abstraction Report
Mechanical Assessment of the Waste Package Subject to Vibratory Ground Motion (CAL–WIS–AC–000001, Revision 0B)	Waste Package Report
Mechanical Assessment of the Drip Shield Subject to Vibratory Ground Motion and Dynamic and Static Rock Loading (CAL–WIS–AC–000002, Revision 00A)	Drip Shield Report
Peak Ground Velocities for Seismic Events at Yucca Mountain, Nevada (ANL–MGR–GS–000004, Revision 00)	Peak Ground Velocities Report
Development of Earthquake Ground Motion Input to Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada (MDL–MGR–GS–000003, Revision 01)	Ground Motion Report
* Abbreviated titles of the technical reports audited are used in this report.	

The primary objective of this audit was to determine whether the inputs provided to the Abstraction Report had been developed and calculated using methods that are technically sound and defensible with adequate transparency and traceability. The audit team's Technical Specialists also evaluated the work to determine whether it met selected elements of the five criteria in Section 2.2.1.3.2.3 of the Yucca Mountain Review Plan, Final Report, NUREG–1804, Revision 2. The objective of the NRC observation was to assess whether the BSC audit team effectively met the objective of the audit.

2.0 MANAGEMENT SUMMARY

During the conduct of the audit, the NRC observers identified a weakness in the audit planning and preparation. The observers determined that the BSC auditors apparently reduced the scope of the audit, and did not prepare sufficiently to meet the primary objective of the audit.

Specifically, the observers concluded after the fourth day of the audit that the auditors were deviating from the audit plan by not evaluating the Ground Motion Report, one of the technical reports identified in the Audit Plan. The observers noted a lack of questioning of technical staff responsible for the Ground Motion Report by the audit team's Technical Specialists during interviews, and the absence of associated checklist questions that should have been developed by the Technical Specialists while preparing for the audit. The observers expressed concern to the Audit Team Leader whether this reduced level of technical evaluation would be adequate to meet the audit objective. As a result of the expressed observers' concern, the Audit Team Leader issued Condition Report 9035 reflecting inadequate audit planning. BSC immediately extended the audit end date from August 31 to September 7, 2006, and added one additional auditor to provide sufficient time and resources to evaluate the Ground Motion Report. With the inclusion of evaluating the Ground Motion Report during the audit as originally planned, the observers determined that the BSC audit team effectively met the objective of the audit. It is noted that during the August 15-31, 2005, BSC audit BQAP–BSC–05–07, the NRC observers identified a similar weakness in audit planning and preparation. The observers note that improvement is needed in BSC's planning and preparing for performance-based audits.

At a Post-Audit Meeting with DOE and BSC management, the BSC audit team presented its findings. The audit team found that, overall, the scientific investigations that provide input to the Abstraction Report had been developed and calculated using methods that were technically sound and defensible with adequate transparency and traceability. The audit team did not identify significant issues related to scientific investigations supporting the Abstraction Report but did identify documentation and transparency issues related to calculations which provide input to the Abstraction Report. The observers agreed with the audit team's findings, recommendations, and overall conclusions.

3.0 AUDIT PARTICIPANTS

BSC Audit Team Members
Roxanna VanDillen, Audit Team Leader
Kenneth Gilkerson, Auditor
Gerard Heaney, Auditor
Richard Maudlin, Auditor
Stephen Schuermann, Auditor
Charles Warren, Auditor
Quazi Hossain, Lawrence Livermore National Laboratory (LLNL), Technical Specialist
Lawrence Hutchings, LLNL, Technical Specialist

Observers
Thomas Matula, NRC, Observation Team Leader
Jack Parrott, NRC, Observation Team Co-Leader
Abou-Bakr Ibrahim, NRC, Technical Specialist
Robert Brient, CNWRA, Quality Assurance (QA) Specialist
Michael Simpson, CNWRA, QA Specialist
Luis Ibarra, CNWRA, Technical Specialist
Thomas Wilt, CNWRA, Technical Specialist

U.S. Department of Energy (DOE) Office of Quality Assurance
Bruce Foster, QA Observer, Navarro Quality Systems

4.0 REVIEW OF THE AUDIT AND AUDITED ORGANIZATION

The auditors conducted the audit in accordance with BSC procedure QA–PRO–1046, QA Internal Audit Program. The auditors identified issues (adverse conditions and recommendations) in accordance with Administrative Procedure (AP)–16.1Q, Condition Reporting and Resolution. The observers followed NRC Manual Chapter 2410, Conduct of Observation Audits.

4.1 Scope of the Audit

The scope of the audit was to evaluate model development and scientific investigation activities related to the Abstraction Report and utilize a vertical slice technique to evaluate activities with a focus on four technical reports that provided input to the Abstraction Report. The primary objective of the audit was to determine whether inputs provided to the Abstraction Report had been developed and calculated using technically sound and defensible methods with adequate transparency and traceability. The observers concluded after the fourth day of the audit that the auditors were deviating from the audit plan by not sufficiently evaluating the Ground Motion Report, one of the technical reports identified in the audit scope. The observers noted a lack of questioning of technical staff responsible for the Ground Motion Report by the audit team's Technical Specialists during interviews, and the absence of associated checklists questions that should have been developed by the Technical Specialists while preparing for the audit. The observers expressed concern to the Audit Team Leader whether this reduced level of technical investigation would be adequate to meet the audit objective. As a result of the expressed NRC concern, the Audit Team Leader issued Condition Report 9035 reflecting inadequate audit planning. BSC immediately extended the audit end date from August 31 to September 7, 2006, and added one additional auditor to provide sufficient time and resources to evaluate the Ground Motion Report.

The observers noted that some of the technical reports being audited were planned for revision in the near future. Therefore, the auditors focused on calculation, modeling, and scientific investigation processes. The observers also noted that the audit team developed Noteworthy Practices, as presented in the Attachment to this report, based on a focused audit using a vertical slice technique and limited sample size. The Programmatic and Technical Issues also presented in the Attachment indicate that additional work may be required to assure that the Abstraction Report is of high quality.

4.2 Conduct and Timing of the Audit

The observers determined that the audit team performed demonstrated sound knowledge of the applicable implementing procedures and QA program requirements. The audit team members conducted thorough interviews, challenged and questioned responses when appropriate, and effectively employed their checklists. The auditors caucused daily with the observers to discuss the current audit status and potential issues. The auditors, BSC management, and observers met daily to discuss the audit status and any new and developing issues. The timing of the

audit was appropriate in relation to ongoing seismic consequence-related activities.

4.3 Audit Team Qualifications and Independence

The observers reviewed the qualifications of the audit team members and verified their qualifications and independence of the areas reviewed. Technical Specialists had technical qualifications appropriate for the activities audited and had received training in appropriate audit procedures and processes.

4.4 Examination of Quality Assurance Elements

QA auditors prepared checklists to evaluate the Abstraction Report and the technical reports providing direct input to the Abstraction Report identified in Section 1.0 above. As discussed in Section 4.1 above, an additional auditor was assigned to the audit team to evaluate the Ground Motion Report. During the audit, the newly added auditor prepared a detailed checklist to evaluate the Ground Motion Report, which should have been accomplished while planning for the audit.

The QA auditors organized their checklists according to the critical process steps identified in the audit plan: planning, development and documentation of models (including inputs, assumptions, and software control), checking and review, product output, approvals, and change control. The QA auditors also followed up on previously closed Condition Reports related to the technical reports audited and identified no recurrences of those conditions.

QA auditors and Technical Specialists interviewed BSC technical staff together. They also reviewed online records to assess areas such as data inputs, checking and review, approvals, and change control.

4.5 Examination of Technical Elements

The Abstraction Report provided direct inputs to the Total System Performance Assessment (TSPA) code associated with the mechanical response of engineered barrier system components to seismic hazards. The abstractions used results from calculations of kinematic and structural response to vibratory ground motions. The Abstraction Report received direct input from the Drip Shield, Waste Package, and Peak Ground Velocities Reports, which are included in the audit scope, and the Drift Degradation Analysis, which was not within the scope of this audit. The Ground Motion Report provided the time histories used in several of the reports contributing to the Drip Shield Report, and the Drift Degradation Analysis Report provides loading input for the detailed drip shield structural calculations.

The Waste Package Report included an overview of previous calculation reports (e.g., the Structural Calculation of Waste Package Exposed to Vibratory Ground Motions), as well as additional calculations performed with more complex representations of the engineered barrier system components. The Drip Shield Report summarized the results of a series of supporting engineering calculations developed to evaluate the effect of static and dynamic loads on the mechanical performance of the drip shield. The Peak Ground Velocities Report described an analysis that bounds the horizontal peak ground velocity at the waste emplacement level 300 meters below the surface at Yucca Mountain and presented results as a probability

distribution for horizontal peak ground velocities to represent uncertainties in the analysis. The Ground Motion Report described a site response model and its implementation using the RASCALS software and provided spectral acceleration including peak ground acceleration, peak ground velocity, and dynamically induced strains as a function of depth. The Ground Motion Report also described the development of model inputs, implementation of the model, its results, and the development of earthquake time history inputs based on model results.

The audit Technical Specialists prepared checklists based on detailed reviews of the subject reports and associated Technical Work Plans. The Technical Specialists developed several checklists during the conduct of the audit to address reports not covered by other checklists and to address the evaluation of the Ground Motion Report. These checklists should have been developed while planning for the audit. The audit team interviewed the lead authors of the technical reports evaluated and key contributors.

4.6 Potential Audit Findings

As presented in the Post-Audit Meeting, the audit team concluded that, overall, scientific investigations that provide input to the Abstraction Model had been developed and calculated using methods that were technically sound and defensible with adequate transparency and traceability. The audit team did not identify significant issues related to scientific investigations; however, the audit team identified several documentation and transparency issues related to calculations providing input to the Abstraction Model.

Detailed descriptions of the audit team's findings presented during the Post-Audit Meeting, including adverse conditions, recommendations, and noteworthy practices, are provided in the attachment to this report. These findings form the basis for the audit team's determination that the Abstraction Model appeared to meet the five acceptance criteria of NUREG–1804, Section 2.2.1.3.2.3, with the exception of the following:

1. Criterion 1, Subcriterion 3, transparency issues

2. Criterion 2, Subcriterion 1, data (modulus damping reduction curves) interpretation and use

3. Criterion 3, Subcriterion 1, H2 (horizontal transverse ground motion) component not considered

4. Criterion 3, Subcriterion 2, drip shield separation issue

5. Criterion 5, Subcriterion 3, unacceptable Engineered Barrier System structural models

The audit team determined that the modeling process satisfactorily addressed applicable critical process steps, with the exception of the development and documentation of the models. Specifically, the audit team identified several technical issues in the areas of transparency, conservatism, and data inconsistencies. Overall, the audit team determined the modeling process to be effective.

The audit team determined that the methodology and structural models used in the mechanical

assessment calculations (i.e., Waste Package and Drip Shield Reports) were not always conservative. However, since the calculations had been performed using extremely conservative peak ground velocity values, the audit team judged the Seismic Consequence Abstraction Model, which used the calculation results, to be adequate.

5.0 NRC STAFF FINDINGS

5.1 NRC Observation Summary

During the conduct of the audit, the NRC observers identified a weakness in the audit planning and preparation. The observers determined that the BSC auditors apparently reduced the scope of the audit, and did not prepare sufficiently to meet the primary objective of the audit. After the mid-audit adjustments to include evaluating the Ground Motion Report, the audit team adequately evaluated technical activities to meet the audit objective. It is noted that during the August 15-31, 2005, BSC audit BQAP–BSC–05–07, the NRC observers identified a similar weakness in audit planning and preparation. The observers note that improvement is needed in BSC's planning and preparing for performance-based audits.

The observers determined that the audit team demonstrated sound knowledge of the applicable implementing procedures and QA requirements. The auditors conducted thorough interviews, challenged and questioned responses when appropriate, and effectively employed their checklists. The observers determined that the audit team identified substantive adverse conditions that, when addressed, should provide for improved processes and improved technical products. The observers agreed with the audit team's findings, recommendations, and overall conclusions.

5.2 NRC Audit Observer Inquiry

The observers initiated no Audit Observer Inquiries during this audit.

ATTACHMENT

Audit Team Findings

Programmatic Issues—Adverse Conditions

- Verification of assumptions in calculations that were issued as preliminary and later updated to committed status lacked transparency.
- Procedure inadequacy relating to software problem reports for failures encountered during independent verification and validation of legacy software codes that were not required to be issued.
- Engineering design calculation and analysis procedures did not describe the interface with engineering calculations to support final scientific documents.
- All inputs directly used to develop the model had not been listed in the report. Input information only identified one of two values used as direct input to the Abstraction Report.
- Information presented in products was not consistent with planning documents for the products.
- An exemption regarding software exemption criteria was misstated in a technical product.

Programmatic Issues—Recommendations

- Provide justification for acceptability of software regarding issues in results that had not been resolved.
- Ensure that the integrity of the technical review process is not compromised due to the perceptions of conflicts of interest in the forthcoming revisions of the Abstraction Report.
- Revise the Technical Work Plan to be consistent with the Ground Motion Report.

Technical Issues——Abstraction Report Adverse Conditions

- The description of the development of the abstractions and the methodology for using these abstractions in the Abstraction Report was not transparent enough for a technical reader to understand without recourse to the originator.
- Deficiencies regarding insufficient duration of vibratory ground motions were identified in the Abstraction Report, Waste Package Report, and Drip Shield Report.

Technical Issues——Abstraction Report Recommendations

- Use LS-DYNA to model and analyze impact scenarios involving deformable structural and mechanical systems in future revisions to the Abstraction, Waste Package, and Drip Shield Reports.

Technical Issues—Drip Shield Report Adverse Conditions

- The Drip Shield Report did not consider the H2 (horizontal transverse) ground motion component when evaluating the fragility of the drip shield components and determining the potential for separation of drip shield segments.

- The Drip Shield Report did not consider the rubble-covered scenario (the dynamic analysis) when evaluating the fragility of the drip shield components and determining the potential for separation of drip shield segments.

- Inconsistencies existed between the Abstraction Report and the Drip Shield Report. Section 1.2 of the Abstraction Report states that “the structural response calculations include corrosion of the waste package over a 20,000 year time frame.” Section 1.3 of the Drip Shield Report has been considered for only 10,000 years.

- For drip shield separation as a result of vibratory ground motion, the structural integrity of the drip shield to drip shield connector component (failure of which would result in drip shield separation) was evaluated for the loads predicted from a simplistic UDEC kinematic analysis model that did not consider all three spatial components of vibratory ground motion.

- Because Section 5.2.3.1.4 of the Drip Shield Report states that computational meshes used for the damaged area calculations might be too coarse to realistically simulate a puncture or tear and that the predicted stresses might be unconservative, the model is unreliable for predicting a puncture or tear.

Technical Issues—Waste Package Report Adverse Conditions

- In Section 6.5 of the Abstraction Report, two waste package impact scenarios and the resulting damage prediction results were assumed to be independent of each other even though both scenarios were consequences of the same vibratory ground motion.

- Potential damage from waste package to drip shield impacts was not included in the seismic damage abstractions in the Abstraction Report and Waste Package Report.

Technical Issues—Peak Ground Velocities Report Adverse Conditions

- The peak ground velocity scaling approach used to develop time histories for structural response calculations in the Abstraction Report cannot be performed theoretically or empirically to represent earthquakes with larger peak ground velocities without changing the magnitude of the earthquake.

- The Peak Ground Velocities Report does not address how incremental strains used in numerical modeling and laboratory testing can represent *in-situ* behavior due to cyclic shear strains associated with seismic wave propagation.

Technical Issues—Peak Ground Velocities Report Recommendations

- Revise Section 6.3 of the Peak Ground Velocities Report to address geologic observations regarding seismically induced damage transparency issues in the development of arguments and presentation of observations.

- Eliminate the extrapolated values from the second part of Table 6-3 in the Peak Ground Velocities Report because they are not used in the Peak Ground Velocities Report or the Abstraction Report.

- Regarding inputs of peak ground velocity, provide a stronger clarification of the use of two values on page 4-1 of the Peak Ground Velocities Report and further clarify with the document.

Technical Issues—Ground Motion Report Adverse Conditions

- Validation of modulus reduction and damping curves was only partially accomplished in the Ground Motion Report by comparison to laboratory data and modeling nonlinear observed records.

- Regarding RASCALS calculations in the Ground Motion Report, validate the possibility that two-dimensional/three-dimensional effects at Yucca Mountain have particular combinations that are not easily approximated as one dimensional.

- The Ground Motion Report validations had model values using different input parameters for vertical and horizontal components for the same earthquake.

Technical Issues—Ground Motion Report Recommendations

- Identify studies in the Ground Motion Report that have validated the “Spectral Analysis of Surface Waves” method with actual velocity profile data.

Noteworthy Practices

- The Technical Specialist found the quality of the Ground Motion Report to be noteworthy. It was stated that the document provides the most comprehensive, validated, scientifically sound, and careful work ever performed for a site response model and input ground motion calculation and that, in that sense, it is a historical document that will be a template for future hazard studies.

- The Abstraction Report presents the evaluation that was performed to assess the adverse consequences of seismic events during the postclosure period. The evaluation was performed to meet the regulatory requirement that is extremely conservative and unprecedented. Compliance to such an extreme requirement necessitated the use of the seismic hazard determination methodology for annual exceedance frequencies well

beyond the range for which the methodology could be validated. This resulted in extremely high peak ground velocity for which the Engineered Barrier System components are required to be evaluated. At these high peak ground velocity values, the drift materials and the Engineered Barrier System components behave nonlinearly and the determination of their responses becomes very complex and uncertain. However, the seismic consequence abstraction performed accounted for most of these complexities, uncertainties, and nonlinearities. Even though some of the methodology and dynamic models used in assessing the damage to the Engineered Barrier System components are not necessarily conservative, in an overall sense, the rigor and thoroughness used in the seismic consequence abstraction process is remarkable and noteworthy.