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MAY 11 1999

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U.S. DEPARTMENT OF ENERGY (DOE) REVIEW OF U.S. NUCLEAR REGULATORY COMMISSION'S (NRC) STRUCTURAL DEFORMATION AND SEISMICITY ISSUE RESOLUTION STATUS REPORT (IRSR), REVISION 1

As discussed in previous correspondence and in interactions between our respective staffs, we agree with the NRC that the issue resolution process benefits the development of a common understanding of key issues during prelicensing. We appreciate the opportunity to review the issue resolution status reports and provide comments for your consideration. We have reviewed the referenced Issue Resolution Status Report. The enclosure contains both a summary of our comments, and additional detailed comments. The majority of our comments request clarification of the acceptance criteria in Revision 1 of the IRSR. We anticipate that these comments will be considered in the preparation of Revision 2 of the IRSR. Additional comments related to issues identified in the IRSR have been developed based on discussions with the staff during an Appendix 7 meeting on Tectonic Models and Seismicity which was held March 2-3, 1999, in Las Vegas, Nevada.

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We recognize that at the time the IRSR, Revision 1 was completed and when the Appendix 7 meeting was held, the staff had not completed their review of the Probabilistic Seismic Hazards Analyses (PSHA). We believe that the PSHA report contains sufficient information to resolve the open items associated with viable tectonic models identified in Revision 1 of the IRSR. Therefore, upon completion of the staff's review of the PSHA report, we request your evaluation of the status of the items associated with tectonic models identified in Revision 1 of the IRSR. We anticipate that this information will be provided in Revision 2 of the IRSR.

If you have any questions, please contact J. Timothy Sullivan at (702) 794-5589 or April V. Gil at (702) 794-5578.

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OL&RC:JTS-1236

Enclosure:
Comments on IRSR Rev. 1, KTI:
Structural Deformation and Seismicity

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Enclosure

Comment Summary

In *Issue Resolution Status Report Revision 1, Key Technical Issue: Structural Deformation and Seismicity* (IRSR), and at an Appendix 7 meeting held March 2-3, 1999, the NRC identified several concerns associated with tectonic models. In particular, concerns were expressed with the "preferred model" presented in *Seismotectonic Framework and Characterization of Faulting at Yucca Mountain, Nevada* (USGS, 1996) and with the use of tectonic models in evaluating hazards and assessing performance.

As discussed during the Appendix 7 meeting, the approach DOE has taken to address these concerns includes the use of an expert elicitation process for seismic and volcanic hazard analysis. To ensure the experts considered all viable tectonic models, DOE used data packages and workshop presentations to provide the experts with available information on tectonic models. The role of the experts was to evaluate the models in light of available data and to characterize the uncertainty in their hazard inputs accordingly. Although a preferred model has been presented at recent performance assessment workshops and meetings, it was not given any special status in the seismic (CRWMS M&O 1998) or volcanic (CRWMS M&O, 1996, Section 4.2) hazard analyses. In addition, the probabilistic seismic hazard analyses (PSHA) for Yucca Mountain are insensitive to the choice of tectonic model (CRWMS M&O 1998, Volume 1, Section 7.4.2.7). Thus, determination of a preferred model is not important to assessing seismic hazard.

We recognize that at the time the IRSR (Revision 1) was completed and when the Appendix 7 meeting was held, the staff had not completed their review of the PSHA. Their concerns were based on evaluation by the USGS in their 1996 report and a preliminary seismic hazard analysis carried out for the Exploratory Studies Facility (Wong et al. 1995). We believe that the final PSHA report (CRWMS M&O 1998) contains sufficient information to resolve the open items associated with viable tectonic models identified in Revision 1 of the IRSR. Therefore, after completion of the staff's review of the PSHA report, we are requesting NRC feedback on the resolution status of the items associated with tectonic models in Revision 2 of the IRSR.

Comments on Issue Resolution Status Report Revision 1, Key Technical Issue: Structural Deformation and Seismicity (NRC 1998b)

1. Section 4.1.2.1, Page 24, Criterion 3: The acceptance criterion states that "The nature of faulting within the repository block (principal and secondary) was adequately evaluated from the range of possible interpretations. For example, were DOE's interpretations of trench investigations geologically consistent with the range of viable tectonic models . . ."

   DOE agrees that alternate interpretations should be considered and evaluated in light of all available evidence. We are concerned, however, that this criterion could be misunderstood to mean that interpretations of trench investigations should be consistent with viable tectonic models. That is, the last sentence might be interpreted to mean that viable tectonic models are "given" and that other interpretations must be consistent with the models. Therefore, to clarify the NRC's intent with respect to this issue, we suggest the criterion be revised to state that tectonic models must be consistent with trench evidence, because these data are primary observations, whereas competing tectonic models represent hypotheses. This revision would appropriately emphasize the primary status of the fault trenching data relative to the derived models.

2. Section 4.2.1.1, Page 29, Criterion 6: DOE understands NRC's requirements that adequately documented, coherent, and technically defendable hazard calculations are required no matter what method is employed. We suggest that the phrase "If expert elicitations were not used" be deleted from the statement of the criterion.

3. Section 4.3.1.1, Page 34, Criterion 4: This criterion requires adequate definition of origins of fractures. However, properties of fractures that may affect performance are not necessarily related to the origin of the fractures; in addition, properties of fractures that may affect performance are evaluated under Criterion 3. Therefore, DOE believes that Criterion 4 is unnecessary and suggests that it be deleted.

4. Section 4.4.1.1, Page 41, Criterion 3: It is not clear what is meant by "purposes of each model." The DOE's evaluation of tectonic models adopts and follows standard professional practice. Applying standard practice, a viable tectonic model must reasonably explain observed tectonic elements. For Yucca Mountain, these include (1) the structural nature and origin of the boundaries of the Crater Flat basin, (2) the evolution of basin subsidence and extension with respect to faulting at Yucca Mountain and basin boundaries, and (3) the origin and spatial distribution of vertical axis rotation in Crater Flat basin. Such a model must also be consistent with the tectonic framework of the southern Great Basin. Since these purposes are common to all tectonic models of Yucca Mountain and the surrounding area, there is no apparent advantage in including guidance to describe the "purposes of each model." The DOE suggests that the guidance be deleted from the criterion.

<u>Comments on the IRSR that were also discussed at the Appendix 7 meeting</u>

5. The NRC identified several concerns with the concept of a preferred tectonic model for Yucca Mountain. DOE believes that staff issues related to the fault displacement and ground

motion hazards and associated with the definition of a "preferred model" are resolved by information presented in the PSHA report. Therefore, we are requesting written acknowledgment of the resolution of these issues from the NRC staff when they have completed their review of the PSHA.

One of the issues identified in the IRSR derives from a report prepared contemporaneously with the Probabilistic Volcanic Hazard Analysis (PVHA) and during the early stages of the Probabilistic Seismic Hazard Analyses (PSHA). This report, *Seismotectonic Framework and Characterization of Faulting at Yucca Mountain, Nevada* (USGS, 1996), summarizes existing tectonic models and describes a "preferred model" for the Yucca Mountain region. In identifying a "preferred model," the intent was to describe a model that best depicted the observed geologic features, events, and processes at Yucca Mountain. This exercise, however, was carried out independently of the PVHA and PSHA and was not meant to define a preferred model for those analyses. Rather, within the expert elicitation process used for hazard analyses, DOE sought to ensure that the subject matter experts were provided with available information on all proposed tectonic models, including the preferred tectonic model put forward by the USGS in their 1996 report. The DOE relied on the experts to evaluate the models in light of available data and to characterize the uncertainty in their hazard inputs accordingly. Thus, the determinations of volcanic, ground motion, and fault displacement hazards all appropriately incorporate uncertainties in our knowledge of tectonic models that are applicable to Yucca Mountain. For those cases in which the consequence analyses use the hazard results as input, uncertainty in tectonic models is already incorporated in the hazard results making it unnecessary to carry out separate consequence analyses for different tectonic models.

For effects that are not directly related to hazard parameters, it may still be necessary to evaluate the effect of different tectonic models. For example, potential changes in permeability related to an earthquake may not be directly related to ground motion level or amount of fault displacement. If different tectonic models result in different effects on hydrologic parameters, given that an earthquake occurs, then the consequences of different models could be evaluated. Alternatively, it may be possible to demonstrate even for these cases that the consequence is not sensitive to tectonic model.

Details of the tectonic models that were considered in the PSHA are presented in Table 4-1 of the PSHA (CRWMS M&O, 1998). As noted above, the DOE believes that the staff issues related to the estimates of ground motion and fault displacement hazards and associated with definition of a "preferred model" (e.g., IRSR pages 45-47) are resolved by information presented in the PSHA report and, as discussed above, the DOE is requesting the status of resolution of these items in Revision 2 of the IRSR.

6. The IRSR (page 47) notes that studies of dike and volcano alignments in Crater Flat and Amargosa Desert are being reviewed at CNWRA and NRC and will be presented in FY 99. Discussions during the Appendix 7 meeting indicated that the NRC is concerned that DOE's Probabilistic Volcanic Hazards Assessment (PVHA) could have used a "preferred" tectonic model for the evaluation of the volcanic hazard. DOE notes that the Probabilistic Volcanic Hazard Analysis (PVHA) (CRWMS M&O, 1996) evaluated the viable models for volcanism

in Crater Flat and developed an estimate of the aggregate hazard (PVHA, Section 4.2). Rather than use a preferred model to explain the volcanic hazard, DOE used the weighted interpretations of the ten experts, who provided inputs for the probabilistic volcanic hazard analysis. We believe this approach appropriately described scientific uncertainty in volcanic models.

7. The IRSR (page 51) discusses the recent strain studies of Wernicke et al. (1998). Based on preliminary results of the most recent USGS Global Positioning System strain survey (Savage, Svarc et al., 1998) and a radar interferometry strain study presented at the Appendix 7 meeting, on the results of previous USGS strain studies (Savage, Lisowski et al., 1994), and on results of CNWRA studies (Marrett et al. 1998), the strain rates reported by Wernicke (et al., 1998) have not yet been validated. DOE recognizes that resolution of this issue is pending final results from the USGS Global Positioning System and radar interferometry studies, continued monitoring by Dr. Wernicke, and evaluation of all results by the NRC staff. Until the validity of the observations has been determined, DOE believes it would be premature to speculate about any possible impacts on the seismic and volcanic hazard estimates based on these unconfirmed observations.

8. During the Appendix 7 meeting, the CNWRA and NRC expressed interest in how tectonic models are incorporated in TSPA consequence analysis. As explained below, the PSHA results are apparently not sensitive to tectonic model. DOE intends to document the insensitivity of the seismic hazard estimate to the choice of tectonic models in future reports. Based on our understanding to date, further consideration of tectonic models in TSPA consequence analyses, independently of the evaluations reflected in the PSHA results, appears to be unnecessary.

   The consequence analyses for seismic effects (both ground motion and fault displacement) that are incorporated into TSPAs rely on the PSHA to provide hazard curves of occurrence frequencies. The hazard curve for peak ground velocity (PGV) relates the magnitude of ground motion to its frequency of occurrence; this information is used to model rockfall on waste packages in the repository, and other phenomena. Similarly, the hazard curve for fault displacement is used in TSPA analyses to relate the amount of displacement in the repository to its frequency of occurrence; this information is used to model potential waste-package damage and groundwater-flow alterations.

   The PSHA experts considered all viable tectonic models in their evaluations, and they incorporated all available data and observations to evaluate credible weights for each tectonic model. The tectonic models and the experts' assessed uncertainty on those models are thus fully incorporated in the uncertainty in the hazard curves. For example, the Peak Ground Velocity hazard curve (shown in Figure 10-59 of the Technical Basis Document, Chapter 10) (CRWMS M&O 1998b) includes values for the 15th and 85th percentiles of the PGV distribution on annual frequency of occurrence. This distribution expresses the scientific knowledge (epistemic) uncertainty on the annual frequency of occurrence of any peak ground velocity value. Some portion of this uncertainty reflects the assessed scientific uncertainty on various tectonic models considered by the experts. The PSHA results, which are provided to the PA modelers, have been found to be insensitive to choice of tectonic model (CRWMS

M&O 1998, Volume 1, Section 7.4.2.7) as described during the DOE-NRC Appendix 7 meeting on Tectonic Models and Seismicity on March 3, 1999 (Youngs, 1999). Since uncertainties associated with viable tectonic models are already incorporated in the hazard estimates, further consideration of tectonic models is expected to have little or no bearing on the TSPA consequence modeling for seismic activity.

As part of the documentation for TSPA, DOE plans to include a summary of the tectonic models considered for the Yucca Mountain region. Part of the documentation would also be the PSHA sensitivity study results, presented at the Appendix 7 meeting on March 3 which demonstrate that hazard results are insensitive to the choice of tectonic models.

9. During the Appendix 7 meeting, the CNWRA and NRC also expressed considerable interest in how fracture and fault data are incorporated in hydrologic models. The following information is intended to summarize how fracture and fault data are incorporated in the unsaturated zone model and saturated zone model.

<u>Site-Scale UZ Flow and Transport Model</u>

Fracture information is used in the unsaturated zone (UZ) models to represent the flow field as a dual permeability system that contains permeability components from the both rock matrix and fractures. Faults and fractures are represented at three levels of scale. At the finest scale are microfractures that are indistinguishable from the matrix at the field test scale. Microfractures are included with the matrix properties because of their high frequency. At the intermediate scale are fractures that can be characterized by air permeability testing to determine permeability, porosity, van Genuchten fitted parameters, frequency, and effective apertures (Wang 1998). These data are used to represent the fractures in the dual permeability UZ models. At the coarsest scale are large-feature faults that have been mapped at the surface. The testing of these features includes forced-air permeability testing and ambient monitoring during barometric variations (LeCain 1997). The major faults are explicitly represented in the site scale model as three-dimensional curving and angled surfaces that match the known fault configurations. The faults are given permeability properties similar to very coarse material.

The three-dimensional unsaturated zone model of Yucca Mountain (Bodvarsson, et al. 1997) incorporates a variety of geological and hydrological data to represent subsurface flow processes in the unsaturated zone at Yucca Mountain.

The development of mean fracture and fault hydraulic properties for the model layers follows the general strategy outlined below.

a) Fracture frequency and intensity are tabulated for each model unit using fracture data from underground excavations and boreholes. This synthesis has been done by the USGS (Sweetkind, et al. 1997) and by LBNL (Bodvarsson and Bandurraga, 1996; Bodvarsson et al. 1997). Measured fracture attributes, such as observed fracture frequencies, are used to calculate fracture spacing.

b) For each model layer, mean hydraulic properties of the fractured rock mass are calculated as functions of fracture spacing and assumed permeability (Schenker, et al. 1994).

Overall fracture permeability is calculated from air permeability measurements in the ESF and in vertical boreholes and from pneumatic data from boreholes (Wang et al. 1998). Fracture porosity is estimated from gas tracer tests conducted between bores in the ESF (e.g., LaCain 1998)

c) Refined fracture properties are then estimated for model application thorough inverse modeling.

Saturated Zone Model

The saturated zone (SZ) model represents the coarser-scale groundwater gradients and fluxes within the vicinity of Yucca Mountain. Fault and fracture data are used both in the flow and transport components of the SZ site-scale flow and transport model. Incorporation of faults and fractures in the SZ site-scale flow and transport model is handled in one of two ways depending on the size of the fault or fracture.

Large-scale fractures and faults, such as Solitario Canyon fault, are incorporated in the flow model through representation in the hydrogeological framework model as offset units, each with its own hydraulic properties. The hydraulic properties are considered as calibration parameters in the flow model.

Small-scale features are handled in a sensitivity analysis of the effects of heterogeneity at the sub-grid-block scale. The sensitivity analysis does not require changing the discretization of the SZ flow model. Rather than making the SZ flow model heterogeneous at the grid-cell level, a representative number of cells within the flow model are modified to include a fine-scale discretization and populated with heterogeneous permeabilities through geostatistical simulation. These detailed permeability models are then used as input to the new transport model being implemented in the Finite Element Heat and Mass Transfer (FEHM) numerical simulator. The results of the comparison of the results from the original and new transport models is an analysis of the sensitivity of sub-grid-block heterogeneity on the overall transport, specifically with respect to dispersion and variation in advective velocity. Several conceptual models of fracture permeability could be implemented through the geostatistical simulations. Fine-scale heterogeneity could be incorporated in a three-dimensional fashion.

References

Arnold, B.W., Altman, S.J., Robey, T.H., Barnard, R.W., Brown, T.J., 1995, "Unsaturated-zone Fast-path Flow Calculations for Yucca Mountain Groundwater Travel Time Analyses" (GWTT-94): Yucca Mountain Site Characterization Project Report SAND95-0857, UC-814 Sandia National Laboratories, Albuquerque, New Mexico. MOL.19960327.0336

Bandurraga, T.M., Finsterle, S., and Bodvarsson, G.S., 1996, "Saturation and Capillary Pressure Analysis" in, G.S. Bodvarsson, and T.M. Bandurraga, eds, *Development and Calibration of the Three-Dimensional Site-scale Unsaturated Zone Model of Yucca Mountain, Nevada*: Lawrence Berkeley National Laboratory Report 39315, Lawrence Berkeley National Laboratory, Berkeley, California, p.62-130. MOL.19970211.0176

Bodvarsson, G.S., and Bandurraga, T.M., 1996, *Development and Calibration of the Three-Dimensional Site-scale Unsaturated Zone Model of Yucca Mountain, Nevada*: Lawrence Berkeley National Laboratory Report 39315, Lawrence Berkeley National Laboratory, Berkeley, California, 539 p. MOL.19970211.0176

Bodvarsson, G.S., Bandurraga, T.M., and Wu, Y.S., 1997, *The Site-Scale Unsaturated Zone Model of Yucca Mountain, Nevada, for the Viability Assessment*: Lawrence Berkeley National Lab. Report LBNL-40370, Lawrence Berkeley National Laboratory, Berkeley, California,. MOL.19971014.0232

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1996, *Probabilistic Volcanic Hazard Analysis for Yucca Mountain Nevada*, BA0000000-0717-2200-00082, Rev. 0. Las Vegas, Nevada. TRW Environmental Safety Systems. MOL.19971201.0221.

CRWMS M&O, 1998, *Probabilistic Seismic Hazards Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada Final Report*. Wong, I.G. and Stepp, J. C. Report Coordinators. Milestone Report SPG28NM3. Oakland, California, Final Report Prepared for the U. S. Geological Survey, Volumes 1-3. CRWMS M&O: Oakland, California. MOL.19981207.0393

CRWMS M&O, 1998, Chapter 10 *Total System Performance Assessment – Viability Assessment (TSPA-VA) Analyses Technical Basis Document, Disruptive Events*, B00000000-01717-4301-000010, Rev 00. Las Vegas, Nevada, TRW Environmental Safety Systems. MOL.19980724.0399.

LaCain, G.D. 1997, *Air-Injection Testing in Vertical Boreholes in Welded and Nonwelded Tuff, Yucca Mountain, Nevada*. USGS Water Resources Investigation Report 96-4262. Denver Colorado. MOL 19980223.0580.

Marrett, R., Stamatakos, J.A., Ferrill, D.A., Connor, C.B., and Hill, B.E., 1998. "Extension Rate Estimates From Faults, Fracture Opening, and Earthquakes Near Yucca Mountain, Nevada:" EOS, Transactions, American Geophysical Union, 79, no. 45, F203, Washington, DC. American Geophysical Union. 243125.

NRC (U.S. Nuclear Regulatory Commission), 1998a. "Issue Resolution Status Report - Revision 1, Key Technical Issue: Structural Deformation and Seismicity," Letter from M. J. Bell to S, J. Brocoum, September 30, 1998. Washington, D.C., U.S. Nuclear Regulatory Commission. MOL.19981202.0549

NRC (U.S. Nuclear Regulatory Commission), 1998b. *Issue Resolution Status Report Revision 1, Key Technical Issue: Structural Deformation and Seismicity*, September 1998. Washington, DC, U.S. Nuclear Regulatory Commission.. MOL.19981202.0550

Savage, J.C., Lisowski, M., Gross, W.K., King, N.E., Svarc, J.L., 1994. "Strain Accumulation Near Yucca Mountain, Nevada, 1983-1993:" American Geophysical Union Journal of Geophysical Research, pages 18,103-18,107. 235681

Savage, J.C., Svarc, J.L., and Prescott, W.H., 1998. "Strain Accumulation at Yucca Mountain, Nevada, 1983-1998:" EOS, Transactions, American Geophysical Union, 79, no. 45, F203, Washington, DC. American Geophysical Union. 243124.

Schenker, A.R., Robey, T.C., Guerin, D.C., and Barnard, R.W., 1994, "Hydrogeologic parameter development," in, M.L. Wilson and 24 others, *Total-system performance assessment for Yucca Mountain – SNL second iteration (TSPA-1993)*, Yucca Mountain Site Characterization Project Report SAND93-2675, Sandia National Laboratories, Albuquerque, New Mexico. MOL.19971211.0013

Schenker, A.R., Guerin, D.C., Robey, T.C., Rautman, C.A., and Barnard, R.W., 1995, *Stochastic hydrogeologic units and hydrogeologic properties development for Total-System Performance Assessments*: Yucca Mountain Site Characterization Project Report SAND94-0244, Sandia National Laboratories, Albuquerque, New Mexico. 172 p. MOL.19960318.0524.

Sweetkind, D.S., Barr, D.L., Polacsek, D.K., Anna, L.O., 1997, *Integrated Fracture Data In Support Of Process Models, Yucca Mountain, Nevada*: U.S. Geological Survey Administrative Report to the U.S. Department of Energy, 145 p. MOL.19971017.0726

USGS, 1996 *Seismotectonic Framework and Characterization of Faulting at Yucca Mountain, Nevada.* Whitney, J.W. Report Coordinator. U.S. Geological Survey Milestone Report 3GSH100M, Denver, Colorado. U. S. Geological Survey. MOL.19970129.0041

Wang, J. S., Trautz, R.C., Cook, P.J., and Salve, R., 1998. *Drift Seepage and Niche Moisture Study: Phase 1 Report on Flux Threshold Determination, Air Permeability Distribution, and*

Water Potential Measurement, Version 1.0, Chapter 3. Yucca Mountain Site Characterization Project Level 4 Milestone SPC315M4. Lawrence Berkeley National Laboratory, Berkeley, California. June 16, 1998. MOL 19980806.0713.

Wernicke, B., Davis, J.L., Bennett, R.A., Elosegui, Pedro, Abolins, M.J., Brady, R.J., House, M.A., Niemi, N.A., and Snow, J.K., 1998. "Anomalous strain accumulation in the Yucca Mountain area, Nevada:" Science, v. 279, p. 2096-2100. Washington, DC. National Association for the Advancement of Science. 235956.

Wittwer, C.G., Chen, G., Bodvarsson, G.S., Chornack, M.P., Flint, A.L., Flint, L.E., Kwicklis, E., and Spengler, R.W., 1995, *Preliminary development of the LBL/USGS three-dimensional site-scale model of Yucca Mountain, Nevada*: Report LBL-37356, UC-814, Lawrence Berkeley National Laboratory, Berkeley, CA. MOL.19960924.0538

Wu, Y.S., Finsterle, S., and Pruess, K., 1996, "Computer models and their development for the unsaturated zone model at Yucca Mountain," in G.S. Bodvarsson, and T.M. Bandurraga, eds. *Development and calibration of the three-dimensional site-scale unsaturated zone model of Yucca Mountain, Nevada*: Lawrence Berkeley National Laboratory Report 39315, p.62-130. Berkeley, CA. MOL.19970211.0176

Youngs, R. R., 1999. "Yucca Mountain PSHA Summary of Use of Tectonic Models by Seismic Source Characterization Teams," Presentation at the NRC - DOE Appendix 7 Meeting, March 3, 1999, Las Vegas, NV. MOL.19990406.0225