ISSUE RESOLUTION STATUS REPORT

KEY TECHNICAL ISSUE:
STRUCTURAL DEFORMATION AND SEISMICITY

Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U. S. Nuclear Regulatory Commission

Revision 0

September 1997

9805290420 971112
PDR WASTE
WM-11 PDR

REC'D W/LTR DTD 9805290418 971112

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ACKNOWLEDGMENTS

This report was prepared jointly by the U.S. Nuclear Regulatory Commission and the Center for Nuclear Waste Regulatory Analyses (CNWRA) staffs. Primary authors of the report are Philip S. Justus (NRC), John A. Stamatakos (CNWRA), H. Larry McKague (CNWRA) and David A. Ferrill (CNWRA). Significant contributions to Appendix D were made by Abou-Bakr K. Ibrahim (NRC).

The authors thank N. King Stablein (NRC), David J. Brooks (NRC) and Abou-Bakr K. Ibrahim, Charles B. Connor (CNWRA), and Budhi Sagar (CNWRA) for their early, repeated, and useful reviews. The patience and skills of Carrie Crawford (NRC) in producing the manuscripts are greatly appreciated.

1.0 INTRODUCTION

1.1 Purpose

Consistent with 10 CFR Part 60 requirements and a 1992 agreement with DOE, staff-level issue resolution can be achieved during the pre-licensing consultation period. However, such resolution at the staff level would not preclude the issue from being considered during the licensing proceedings. Issue resolution at the staff level during pre-licensing is achieved when the staff has no further questions or comments (i.e., open items) at a point in time, regarding how the DOE program is addressing an issue. There may be some cases where resolution at the staff level may be limited to documenting a common understanding regarding differences in the NRC and the DOE points of view. Pertinent additional information could raise new questions or comments regarding a previously resolved issue.

An important step in the staff's approach to issue resolution is to provide DOE with feedback regarding the adequacy of its program, before the viability assessment. Issue Resolution Status Reports (IRSRs) are the primary mechanism that the staff will use to provide DOE feedback on the subissues making up the KTIs. IRSRs comprise 1) acceptance criteria which will be used by the staff to review the DOE license application and prelicensing submittals, as well as indicating the basis for resolution of the subissue, and 2) the status of resolution including where the staff currently has no comments or questions as well as where it does. Feedback is also contained in the staff's annual progress report, which summarizes the significant technical work toward resolution of all KTIs during the preceding fiscal year (FY). Finally, open meetings and technical exchanges with DOE provide opportunities to discuss issue resolution, identify areas of agreement and disagreement, and develop plans to resolve such disagreements.

In addition to providing feedback, the IRSRs will be guidance for the staff's review of information in DOE's viability assessment. The staff also plans to use the IRSRs in the future to develop the Standard Review Plan for the repository license application.

This IRSR documents the status of resolution of seismotectonic subissues determined to have significance to performance evaluations of a candidate high level radioactive waste repository at Yucca Mountain. Parts of two of the subissues are resolved, at the staff level, and the bases for such resolution are provided. For parts of those two subissues unresolved at the staff level, the bases for that status are provided along with at least one mechanism for achieving resolution.

Further, this report ensures that all significant seismotectonic issues are identified and adequately characterized, their significance sufficiently understood and fully considered, used appropriately to evaluate long-term performance and as input to an adequate repository design by DOE.

1.2 Scope of Key Technical Issue

The scope of the Structural Deformation and Seismicity (SDS) Key Technical Issue (KTI) includes the geologic features, events, processes, and conditions in and around the candidate repository which result from tectonic activities (except Igneous Activity, subject of a separate KTI), and which may affect, or affect evaluation of, long-term performance. Subissues that may affect, or affect evaluation of, performance include: fault slip, seismic motion, fracture models, and tectonic models. Matters which concern SDS affects on waste containment and isolation

and repository design for the pre-closure phase and on flow and transport in the post-closure are also within scope, and will be included in a separate report.

1.3 Content of Issue Resolution Status Report Sections

This IRSR is organized to document the NRC staff's current position on resolution of the SDS KTI for the purpose of evaluating the post-closure performance of a repository at Yucca Mountain. The KTI will be considered resolved when all its ancillary subissues are resolved. Section 1, Introduction, describes the purpose and scope of this KTI. Section 2, Issue and Subissue Statements, succinctly states the objectives of the KTI and defines the key issue and the subissues. Section 3, Importance of Subissue to Repository Performance, provides a perspective on the role each subissue has in the TSPA. A quantitative analysis of significance of each subissue to dose will be discussed in FY98 based on sensitivity analyses using NRC's TPA code. Relationship of subissues to DOE's Waste Containment and Isolation Strategy is also discussed.

Section 4, Review Methods and Acceptance Criteria, describes the minimum quantity, quality and level of detail of information required of DOE for NRC staff to evaluate the adequacy of DOE's proposed resolution of each subissue. The section explains why the information is required, and what methods NRC staff may use to determine whether the standard for resolution has been met. The criteria will be used to evaluate DOE's pre-licensing and licensing submittals. Section 5, Status of Subissue Resolution, explains the bases for resolution of Type I Faults and Viable Tectonic Models and, in FY98, and provides paths to resolution of open items. Open items will be tracked by the staff and resolution will be documented in Revision I of this IRSR.

2.0 ISSUE AND SUBISSUE STATEMENTS

The primary objective of this KTI is to effect an evaluation of all aspects of the seismotectonic features, events and processes (FEPs) of the geologic setting of Yucca Mountain that have the potential to compromise the performance of the proposed repository. The secondary objective of this KTI is to develop review procedures and to effect technical evaluations of the adequacy of DOE's characterization of key site- and regional-scale seismotectonic FEPs that may adversely affect performance.

The key technical issue to be resolved, broadly stated, is:

Structural deformation and seismicity (seismotectonic FEPs) that may significantly affect the performance of a repository at Yucca Mountain are identified and adequately characterized, their significance is sufficiently understood and fully considered, and relevant interpretations (e.g., abstractions and models) are used appropriately to evaluate long-term performance by DOE.

Subissues considered important to the resolution of this KTI include:

(i) Fault Slip - What are the viable models of faults and fault displacements at Yucca Mountain?

(ii) Seismic Motion - What are the viable models of seismic sources and seismic motion at Yucca Mountain?

(iii) Fractures and Site Discontinuities - What are the viable models of fractures and site discontinuity features at Yucca Mountain?

(iv) Tectonics and Crustal Conditions - What are the viable tectonic models and crustal conditions at Yucca Mountain?

This IRSR addresses parts of the Fault Slip (i) and Tectonics and Crustal Conditions (iv) subissues.

This report summarizes the data and pertinent conclusions of numerous geologic and seismologic publications that are relevant to Yucca Mountain seismotectonics (in FY97, specifically for Type I faults and viable tectonic models).

3.0 IMPORTANCE OF SUBISSUES TO REPOSITORY PERFORMANCE

The Yucca Mountain site region has been seismically, tectonically and volcanically active on the timescale of a geologic repository. These seismotectonic activities could affect the stability of the repository and the geosphere part of the natural barrier system. For example, seismic and tectonic activities change the in situ stress field and generate faults and fractures (or change the properties and potential behavior of existing discontinuities), in ways that affect many aspects of flow of water, vapor, heat and magma, including fluctuations in the elevation of the water table. Changes to the system of discontinuities in and around a repository may be beneficial (e.g., dilation of a fracture zone may promote drainage around waste packages) or adverse (e.g., fault slip may focus flow quickly through a normally impermeable rock stratum) to waste containment and isolation, to repository (e.g., emplacement drift) design and to long-term performance. Therefore, future changes attributable to seismotectonic activities could significantly influence the ability of a repository to isolate waste, or to perform in a reasonably predictable way.

3.1 Relationship of Subissues to the U.S. Department of Energy's Waste Containment and Isolation Strategy

DOE's Waste Containment and Isolation Strategy (WCIS) continues to rely on multiple barriers to limit radionuclide movement. Therefore, the integrity of the natural barrier system (NBS-Geosphere) would need to be understood. The subissues on faults, fractures, seismic motion and tectonic models focus on the NBS-Geosphere. In addition, the subissues of fault slip and seismic motion focus on containment by waste packages. A primary goal of WCIS is the near-complete containment of radionuclides within waste packages for several thousand years Therefore, the premature breach of containment by mechanical failure modes such as direct disruption by faulting or by seismically induced rockfall (or fall of chunks of concrete liner) onto waste packages, would need to be understood.

Three (of five) system attributes identified by DOE as most important for predicting performance of the engineered barrier system (EBS) and the NBS-Geosphere include: rate of water seepage into the repository; radionuclide transport through EBS and NBS; and dilution in the saturated zone. Therefore, changes to the system of discontinuities through which waters flow, such as fracture permeability, will need to be understood.

DOE stated that WCIS must address potential disruptions to the system that could release radionuclides directly to the accessible environment or otherwise adversely affect the characteristics of the system (DOE, 1996, *Highlights of the U.S. Department of Energy's Updated Waste Containment and Isolation Strategy for the Yucca Mountain Site* - Draft - July 1996). DOE's strategy to address tectonic processes is based upon their likelihood and potential effects. DOE stated that it has initiated analyses through the PSHA and PFDHA expert elicitation process to support assessment of the potential effects of such disruptions (DOE, 1996, ibid.). It has enumerated two hypotheses to be tested: (13) the amount of movement on faults through the repository horizon will be too small to bring waste to the surface, and too small and infrequent to significantly impact containment during the next few thousand years; and (14) the severity of ground motion expected in the repository horizon for

tens of thousands of years will only slightly increase the amount of rockfall and drift collapse (DOE, 1996, ibid.).

3.2 Relationship and Importance of Subissues to Total System Performance

The staff is developing a strategy for evaluating the performance of a proposed repository at Yucca Mountain. As currently visualized by the staff, key elements of this strategy are defined by those elements necessary for DOE to demonstrate repository performance. These elements are illustrated in Appendix A. Acceptance criteria for abstracting each of these elements into an NRC determination of compliance are under development.

Structural deformation and seismicity as defined by the prevailing tectonic, lithostatic, pore-fluid, and thermal stresses interacting with the fractured rocks at Yucca Mountain, are important factors in evaluating repository design and performance because they can cause premature waste package failures and alter the flow regime. SDS is also a factor regarding assumptions about the future integrity of the NBS-Geosphere. Therefore, the acceptance criteria for the resolution of SDS KTI and subissues is designed to complement the broader-level acceptance criteria for the abstraction of the key elements of the repository subsystems in the TSPA flowdown diagram (Appendix A).

As highlighted in the flowdown diagram, SDS needs to be abstracted into five of the key elements of the EBS and NBS-Geosphere subsystems: (1) Mechanical disruption of Waste Package; (2) Fracture vs. Matrix Flow; (3) Spatial Distribution of Flow; (4) Volumetric Flow in Production Zones; and (5) Probability of Volcanism. Also, the SDS KTI and its effects are important factors that need to be abstracted to determine the defense-in-depth contributions of the EBS and NBS-Geosphere subsystems of the Total System (highlighted in Appendix A).

3.2.1 Fault Slip - What Are the Viable Models of Faults and Fault Displacements at Yucca Mountain?

Faults dominate the structure of Yucca Mountain and the surrounding geosphere. Certain existing faults (Type I faults, and faults along flow paths that have a high likelihood of movement during the lifetime of the repository), or their effects, need to be abstracted into the following five key elements of the EBS and NBS subsystems: (1) mechanical disruption of WP (seismicity, faulting, and rockfall); (2) fracture versus matrix flow; (3) spatial and temporal distribution of flow; (4) volumetric flow in production zones; and (5) probability of volcanism (Appendix A). This information needs to be considered because faults could be: (a) loci of rock failure (e.g., rockfall); (b) zones of preferential flow or barriers to flow of water/vapor/heat (e.g., many washes and spring lines reflect surface fault traces); (c) sources of seismic pumping (redistributors of local stress field causing dilation or compression and concomitant local water table fluctuations); and (d) preferential magma conduits (Appendix C-3).

3.2.1.1 NRC/CNWRA Sensitivity Studies

Sensitivity of dose to faults and fault slip is being investigated by NRC staff in several scenarios. Simulations of faults occurring within emplacement drifts, faults intersecting waste package(s) and faults of sufficient displacement affecting waste package failure(s), are being

conducted via a computer model called FAULTO. The resulting number of waste package failures at particular times is input to the Total System Performance Assessment (TPA) code, whereby incremental increases in dose from a faulting scenario, if any, may be calculated. This sensitivity study will be documented in a separate report in FY98.

Sensitivity of dose to fault-dominated flowpath in the unsaturated zone (UZ) is being investigated by NRC staff via the TPA total system code. One or more of the unsaturated flow-zones aggregated in TPA will simulate flow over a range of parameters that approximate conditions in fault zones. This sensitivity study will be documented in a separate report in FY98.

Sensitivity of magma flow (from depth to repository level) to structural controls (e.g., fault geometry, dilation tendency) is being simulated by modeling. The significance of structural controls on magma transport laterally and vertically in the Crater Flat-Yucca Mountain area will be documented in separate report in FY98.

3.2.2 Seismic Motion - What Are the Viable Models of Seismic Sources and Seismic Motion at Yucca Mountain?

Moderate to large earthquakes have a high likelihood of being repeated in the Yucca Mountain region. The major effects of vibratory ground motion on the EBS and NBS-Geosphere at Yucca Mountain are from such naturally-occurring earthquakes. Vibratory ground motion, that is, seismic motion, needs to be abstracted into the following three key elements of the EBS and NBS subsystems: (1) mechanical disruption of WP (seismicity, faulting, and rockfall; (2) volumetric flow in production zones; and (3) probability of volcanism (Appendix A). This information needs to be considered because seismic motion could: (a) disrupt waste package(s) by inducing rockfall (or fall of chunks of concrete liner) in emplacement drifts; (b) induce faults to slip that are on the verge of slipping (thereby inducing secondary earthquakes); (c) induce fluctuations of the water table (so-called seismic pumping); and (d) re-distribute the local stress field which may redirect flow.

3.2.2.1 NRC/CNWRA Sensitivity Studies

Sensitivity of dose to seismic motion is being investigated by NRC staff in several scenarios. One study of waste package disruption involves simulations of ground accelerations within emplacement drifts using: (a) the varying geometry of fractures (joints) comprising fractured blocks of rock; (b) the distribution of 'ground conditions;' (c) the layout of waste packages in unbackfilled drifts; and (d) ranges of resistance of waste packages to rupture by free-falling rocks of sufficient momentum, conducted via the computer codes called UDEC and SEISMO. The resulting number of failed waste packages at particular times is input to the TPA code whereby incremental increase in dose, if any, is calculated. This sensitivity study will be documented in a separate report in FY98.

3.2.3 Fractures and Site Discontinuities - What Are the Viable Models of Fractures at Yucca Mountain?

Observations and tests at the repository level of the ESF show that the site is highly fractured. Pneumatic testing indicates that fractures are open and connected from depth to surface. Chlorine-36 data indicate that some fractures conduct water to repository depths. Fracture flow is recognized by NRC and DOE as an operative process at YM. Given that fractures can conduct water, vapor, heat, and perhaps magma, it is necessary to understand the fracture systematics and characteristics. Fractures or their effects need to be abstracted into the following four key elements of the EBS and NBS subsystems: (1) mechanical disruption of WP (seismicity, faulting, and rockfall); (2) spatial and temporal distribution of flow; (3) fracture versus matrix flow; and (4) volumetric flow in production zones (Appendix A). This information needs to be considered because they are likely to be loci of rock failure (e.g., rockfall), and be pathways or barriers to flow of fluids and heat (different hydraulic and thermal conductivity relative to rock matrix).

3.2.3.1 NRC/CNWRA Sensitivity Studies

Sensitivity of dose to fracture flow in the UZ is being investigated by NRC staff via the TPA total system code. The TPA code will simulate focused fracture flow onto a fraction of waste

4.0 REVIEW METHODS AND ACCEPTANCE CRITERIA

Resolution of the structural deformation and seismicity KTI requires data on and estimates of: the prevailing hydrostatic, lithostatic, thermal and seismotectonic stresses; future states of such stresses; and the behavior of fractured, faulted, layered rocks in continual interactions with the variable stresses and the hydrogeologic and magmatic systems. These data enable performance of the natural barrier - geosphere to be evaluated. Also needed for resolution of the SDS KTI, are data on and estimates of: construction-induced perturbations of the rocks surrounding the repository operations area; the waste-package-induced thermal stresses and resulting rock-mechanical strains and perturbations of flow and transport pathways. DOE is in the process of obtaining data on and estimates of all of the relevant FEPs and geophysical conditions. Such data or estimates, followed by issue resolution, will enable performance of the engineered barrier system to be evaluated for any phase of performance.

The NRC staff has determined that the seismotectonic activities that may significantly affect the future (10,000 to a 100,000 years or more) performance of a repository at Yucca Mountain can be adequately identified and assessed by existing methods, models and codes. The current methods of analyses of site and regional geology and tectonic history, based on identification and analysis of past and current seismotectonic activities and their projected effects on repository design and performance can be evaluated. With prudent projections of changes of processes and conditions, and analyses of uncertainties attendant upon performance of engineered and natural systems, forward-modeled concepts of seismotectonic hazards and their effects can be reasonably applied.

Insights into the future structural deformation and seismicity of the Yucca Mountain region will continue to emanate from field observations and measurements, seismic and geodetic monitoring, scale model experiments, and 3D conceptual geologic and geophysical modeling. The NRC staff's review of DOE's conclusions about future seismotectonic behavior of the site will be based on the staff's professional judgment regarding the completeness and acceptability of DOE's data and interpretations.

The staff will determine whether DOE has complied with the acceptance criteria described below for resolution of the structural deformation and seismicity issue, and subissues. The staff will evaluate DOE's demonstration that it has identified and adequately characterized seismotectonic activities, has sufficiently understood and fully considered their significance, and appropriately used relevant interpretations (abstractions and models) to evaluate long-term performance. Application of such standards of review is expected to result in NRC evaluations (and DOE assessments) that are technically defensible and, when uncertainties are appropriately considered, would be deemed to be reasonable and prudent.

4.1 Fault Slip

The existence or absence of faults and certain attributes (such as continuity and orientation) may be observed directly, interpreted from results of geophysical surveys, or inferred from geologic and tectonic models. The future behavior of faults (including the propagation of new ones) in the Yucca Mountain region can be inferred from forward-modeling and by expert judgment. Uncertainties in the degree of understanding of fault occurrence, properties, connectivity and activity need to be sufficiently analyzed so that all faults that may be significant

to design and performance are identified, investigated, understood, considered and appropriately used.

Faults are easiest to find in terrain like Yucca Mountain which is largely unvegetated and thinly veneered with regolith. Excavations into the mountain greatly facilitated observation and measurements of faults, both previously known and newly discovered, but attributes of some of them remain uncertain. There are hundreds of faults in the area. About five dozen are significant to repository design or performance (see Type I faults, below). Nevertheless, it is expected that potentially significant faults will be found, due to the concepts of "blind" faults (faults that did not propagate to the surface), and "buried" faults (faults that reached the surface and were covered). Certain useful characteristics of some known significant faults at Yucca Mountain, such as the total amount of slip that has occurred (amount of displacement), the slip rate, the age of the last slip, the connectedness to another fault, will continue to have high uncertainty.

At Yucca Mountain, faults and associated fracture zones that are aligned north-northeast tend to be on the verge of slipping (faulting; Morris, et al., 1996). Such faults that are favorably oriented for movement in the existing stress field may respond to a distant earthquake by slipping. This, in turn, generates vibratory ground motion (e.g., Little Skull Mountain earthquake swarm; Harmsen, 1994).

Faults in and around Yucca Mountain have been identified and investigated by numerous methods, including: (a) geologic mapping of surface exposures and underground openings; (b) geophysical surveying; (c) construction of balanced structural cross sections and 3D geologic framework models; (d) borehole video-viewing; (e) geophysical logging; core logging; (f) conceptual tectonic modeling; (g) experimental scale modeling; and (h) 3-D graphing of earthquake hypocenters. It will be necessary for DOE to make assumptions and develop estimates of future fault displacements based on all relevant data. The staff will evaluate DOE's assumptions and projections by applying its standards of completeness, quality, consistency and consideration of uncertainty.

4.1.1 Type I Faults

Type I faults are defined as faults or fault zones that are subject to displacement and of sufficient length and located such that they may affect repository design and/or performance of structures, systems and components important to safety, containment or waste isolation (sscis/wi) and/or may provide significant input into models used in the design or in the assessment of sscis/wi (McConnell, et al.,1992). The concept of Type I faults in this IRSR (McConnell, et al., 1992) applies only to those faults that can directly affect the geologic repository design or performance by ground motion or direct fault slip. Thus, faults that may affect groundwater flow in the saturated or UZ, distribution or frequency of future igneous activity, or other performance issues are not considered to be within the scope of Type I faults.

The definition of Type I faults applies only to faults that are both known and mapped. Faults that are blind or buried, hypothesized in tectonic models, or whose existence is otherwise inferred from geologic, geophysical or seismological data are not considered Type I faults because useful attributes, such as their location, extent, age of last movement, or geometry, cannot be completely known. However, such faults may be considered in PSHA. The potential effects of blind, hypothesized, or inferred faults on seismic and fault-displacement hazards need

to be considered in the probabilistic evaluations that follow from the Type I fault analyses, where attendant uncertainties can be more adequately accommodated.

Faults within or outside the controlled area pose different potential hazards to repository performance. Fault-displacement hazards are relevant only to those faults that lie within the controlled area. Therefore, the criteria for the identification of Type I faults outside or inside the controlled area differ. Outside the controlled area, only those Type I faults large enough to generate sufficient seismic energy during an earthquake to shake the site beyond a given threshold of ground motion need to be considered.

4.1.1.1 Acceptance Criteria

(1) Approved quality assurance and control procedures and standards were applied to collection, development and documentation of data, methods, models and codes.

(2) If used, expert elicitations were conducted and documented in accordance with the guidance in NUREG-1563, or other accepted approaches.

(3) Faulting component of the geologic setting (10 CFR Part 60.2) was adequately determined. For example, has DOE investigated all known faults within an adequate distance (100 km) from the site to ensure that all candidate Type I faults have been investigated (U.S. Geological Survey, 1996)?

(4) Maximum earthquake for each candidate Type I fault was adequately determined. For example, has DOE used an appropriate and adequate fault length vs. magnitude relationship that tended not to underestimate the seismic hazard (U.S. Geological Survey, 1996)?

(5) Maximum trace length of each candidate Type I fault was measured from acceptable sources. For example, has DOE relied on appropriate primary map sources and adequate interpretations of segmented faults that tended not to underestimate the seismic hazard (U.S. Geological Survey, 1996)?

(6) Peak ground motion acceleration for each Type I fault was adequately determined. For example, has DOE used appropriate and adequate attenuation models that tended not to underestimate the seismic hazard (U.S. Geological Survey, 1996)?

(7) Shortest distance to site boundary of each Type I fault was adequately measured. For example, has DOE used appropriate (the latest version of the smallest scale) primary geologic map and site-boundary sources (U.S. Geological Survey, 1996)?

(8) Geologic age of last movement of each Type I fault was adequately determined. For example, has DOE used appropriate and adequately conservative interpretations of evidence of Quaternary Period movement (U.S. Geological Survey, 1996)?

(9) Potential for future slip was adequately determined. For example, when low potential for future slip on a Type I fault was determined, did DOE use appropriate magnitudes and orientations of principal stresses and fault-orientations and adequately conservative interpretation of slip-tendency (U.S. Geological Survey, 1996)?

(10) Minimum trace length for a Type I fault to be considered in a fault displacement hazard analysis was adequately determined. For example, has DOE used appropriate historic seismic records and surface-rupture data to determine the minimum surface-faulting earthquake and back-calculate the associated trace length (U.S. Geological Survey, 1996)?

4.1.1.2 Technical Bases for Review Methods and Acceptance Criteria

Results of the analysis of McKague, et al. (1996) reveal 52 Type I faults in the YM region. USGS (1996, Table 11-1) tabulated 100 faults in the YM region, but these were not specifically subdivided into Type I faults. Of those faults tabulated by USGS, 67 were categorized as relevant or potentially relevant, which the staff assumes is equivalent to the Type I classification. Type I faults and relevant or potentially relevant faults are compared in Appendix B. Both compilations relied on essentially the same data sources (Simonds, et al., 1995; Faulds, et al., 1994; Frizzell and Schulters, 1990; Scott and Bonk, 1984; Piety, 1996; and Nakata, et al., 1982), and both studies assumed moment magnitude scales as a function of fault trace length according to Wells and Coppersmith (1994).

The main differences between the NRC and USGS studies were interpretations of fault lengths in regions in which the mapped trace lengths are ambiguous, the choice of an appropriate attenuation function, and utilization of the mean or 84th percentile for identifying 0.1-g criterion. A comparison of the two sets of fault data and predicted peak accelerations forms the basis for the subsequent discussion of the status of issue resolution regarding Type I faults. For simplicity, relevant or potentially relevant faults are referred to as USGS Type I faults.

Median peak accelerations calculated by McKague, et al. (1996) and Pezzopane (1996) differ by as much as several tenths of a g (Appendix B). Some of this difference is caused by application of different attenuation functions. For some faults, this difference is greater than can be accounted for by the attenuation function difference alone. In these cases, different interpretation of fault length that leads to a different estimate of the maximum capable earthquake is the source of the discrepancy. The discrepancy in length may result from obtaining the length from different technical sources (i.e., paper maps vs. electronic maps), or different interpretations of how discontinuous fault traces (blind, buried or segmented) are linked.

Fault lengths are often poorly determined. This results from variable scales of mapping, buried or otherwise obscured fault terminations or fault splays, obscured connections with other fault segments, and faults mapped by remote imaging. These factors contribute to variations in estimates of individual fault length, maximum capable earthquake, and peak acceleration at the YM site. Faults that yield peak ground motion values less than but near the 0.1 g minimum value (i.e., 0.09 g, or greater) should be carefully examined to ensure that alternative fault-length determinations would not lead to acceleration values above the 0.1 g threshold (McKague, et al., 1996).

McKague, et al., (1996) relied on the attenuation function of Campbell (1987), because it yields the largest (most conservative) accelerations of the available published attenuation functions for the western U.S., especially for near-field (within 10 km) faults. Pezzopane (1996) provided two sets of attenuation functions to determine peak horizontal acceleration. The first function derived an average acceleration value based on equal weighting of attenuation equations of

Campbell (1981), Idriss (1991), Joyner and Boore (1981) and Boore, et al. (1993). The second function was the Sea96 equation based on a new formulation by Spudich, et al. (1997). The Sea96 equation yields the smallest peak accelerations for near-field earthquakes and was not used by Pezzopane to identify USGS Type I faults. At distances greater than approximately 30 km, all the attenuation functions yield similar peak accelerations for a given moment magnitude earthquake and source-to-site distance.

Both the median (McKague, et al., 1996) and the 84th percentile (Pezzopane, 1996; Seismotectonic Synthesis Report, Ch. 11) of the average peak acceleration have been used as criterion for establishing Type I faults. Because the 84th percentile is more conservative, the use of that criterion for identifying Type I faults by the DOE is acceptable.

Pezzopane (1996) uses the terms "relevant" for faults that have documented Quaternary displacement and if the maximum magnitude earthquake on the fault could produce 84th percentile peak acceleration greater than or equal to 0.1 g, and "potentially relevant" for faults that are considered subject to displacement on the basis of potential structural association with seismicity. Because the use of the 84th percentile peak acceleration is more conservative than the mean or median values, DOE's "relevant" and "potentially relevant" faults, and NRC's Type I faults, are in general agreement.

Both McKague, et al. (1996) and Pezzopane (1996) conclude that the faulting component of the geologic setting has a radius of 100 km around YM. For fault displacement hazard analysis, both staff and the USGS (Seismotectonic Synthesis Report, Ch. 11) agree that the controlled area constitutes the area of concern.

Both NRC (McKague, et al., 1996) and DOE (Pezzopane, 1996; Seismotectonic Synthesis Report, Ch. 11) used the Wells and Coppersmith (1994) equation to estimate the maximum earthquake for each fault in the faulting component. The 36 faults listed in Appendix B-1 are faults considered by both McKague, et al. (1996) and Pezzopane (1996) to be Type I faults. The 33 faults listed in Appendix B-2 are considered Type I faults by Pezzopane (1996). NRC accepts this classification for 30 of these faults. These faults were not considered as either Type I or Type III by McKague, et al. (1996). The 33 faults listed in Appendix B-3 are considered Type III faults, i.e., those faults that will not affect repository design or performance, by both McKague, et al. (1996) and Pezzopane (1996).

Both McKague, et al. (1996) and Pezzopane (1996) used the 0.1 g threshold ground motion value as suggested in NUREG-1451. McKague, et al. (1996) use the mean peak acceleration to determine the 0.1 g threshold while Pezzopane (1996) uses the 84th percentile. Pezzopane (1996) cites the minimum surface-faulting earthquake at Mw = 5.8 based on the Fort Sage 1950 event. That value is reasonable and technically defensible given the historic seismic record. Both Pezzopane (1996) and McKague, et al. (1996) use the same data sources (mainly Piety, 1995) to determine the age of last motion on potential Type I faults.

The 18 faults listed in Appendix B-4 are faults considered to be Type I by McKague, et al. (1996), but are not considered USGS Type I faults by Pezzopane (1996). These faults all lie within 13 km of the center of the repository, and NRC considers them Type I faults.

DOE estimates of peak ground motion are less conservative than NRC's because it uses less conservative ground motion attenuation functions. However, this is in part compensated for by

DOE's use of the more conservative 84th percentile peak acceleration. DOE has not considered in situ stress in its analysis of USGS Type I faults. In McKague, et al. (1996), the Pagany Wash, Sever Wash, and Yucca Wash faults were eliminated from the list of Type I faults based on their unfavorable orientation within the in situ stress field.

4.1.2 Probabilistic Fault Displacement Hazard Analysis

Review methods, acceptance criteria, and technical bases will be provided in Revision I of this IRSR in FY98.

4.2 Seismic Motion

4.2.1 Probabilistic Seismic Hazard Analysis

Review methods, acceptance criteria, and technical bases will be provided in Revision I of this IRSR in FY98.

4.3 Fractures and Site Discontinuities

4.3.1 Viable Fracture Models

Review methods, acceptance criteria, and technical bases will be provided in Revision I of this IRSR in FY98.

4.4 Tectonics and Crustal Conditions

4.4.1 Viable Tectonic Models

Much of the specific technical criteria for tectonic model development and subsequent evaluation is predicated on how the models will be used in the evaluation of repository performance. Technical bases for review and acceptance criteria are primarily derived from consideration of the application of the models as tools to evaluate seismic sources, faulting probability, structural control of groundwater flow, and related SDS subissues.

4.4.1.1 Acceptance Criteria

(1) Approved quality assurance and control procedures and standards were applied to collection, development and documentation of data, methods, models and codes.

(2) If used, expert elicitations were conducted and documented in accordance with the guidance in NUREG-1563, or other accepted approaches.

(3) Alternative tectonic models of Yucca Mountain and surrounding region were determined from among the published applicable tectonic models. For example, has DOE provided a comprehensive explanation of the bases for its selection of viable tectonic models, including purposes of each model and demonstrations that each is internally consistent with the appropriate structural style and deformation mode, and

compatible with the tectonic framework of the southern Cordillera and Basin and Range province (U.S. Geological Survey, 1996)?

(4) The viable tectonic models are consistent with existing geophysical, geological, seismological, and geodetic data, and explained how data that are inconsistent with the model were accounted for. For example, has DOE considered all appropriate data (geophysical: gravity, magnetics, paleomagnetics, seismic refraction/ reflection, teleseismic; geological: structural, geothermal, geochronological; seismological: historical seismicity, paleoseismicity; and geodetic: GPS, trilateral survey), and adequately accounted for inconsistent data (U.S. Geological Survey, 1996)?

(5) The viable tectonic models clearly elucidate the tectonic, structural, or seismic elements, and the uncertainties associated with the quantification of each element, critical for the model's intended purpose. For example, has DOE used appropriate scaling tools such as geologic maps, block diagrams, and restorable cross sections, and adequately conservative interpretations of geologic, geometric and kinematic relationships to constrain the key uncertainties (U.S. Geological Survey, 1996)?

4.4.1.2 Technical Bases for Review Methods and Acceptance Criteria

Geological and geophysical investigations to characterize the YM site have been ongoing for almost two decades. In addition, the region has been the subject of detailed geological and geophysical investigations related to weapons testing activities at the Nuclear Test Site (NTS), academic research in the Basin and Range, and mineral and petroleum exploration. All of these efforts have provided the DOE (and subcontractors) and the NRC (and subcontractors) with a plethora of geological and geophysical data and interpretations. It is beyond the scope of this report to review all these data and interpretations. The list below highlights those data and interpretations considered by staff as most pertinent to the development and evaluation of viable tectonic models.

Regional and Local Stratigraphic Elements

Critical regional and local stratigraphic elements to consider in tectonic models are:

- Archean and Proterozoic rocks that make up the basement in the YM region (e.g., Bowring and Karlstrom, 1990).

- Neoproterozoic, Paleozoic, and Mesozoic rocks that constitute the bulk of the seismogenic crust in the YM region (e.g., Cornwall and Kleinhample, 1961, 1964; Stewart, 1970; Cornwall, 1972; Monsen, 1983; Poole, et al., 1992, and references therein; Stevens, et al., 1991; Trexler, et al., 1996).

- Cenozoic sedimentary and igneous rocks that underlie most of the Quaternary basins and make up YM itself (e.g., Ransome, et al., 1910, Byers, et al., 1976; Christiansen, et al., 1977; Vaniman and Crowe, 1981; Swadely, et al., 1984; Carr, et al., 1986a;

Bradshaw and Smith, 1994; Sawyer, et al., 1994; Connor and Hill, 1995; Crowe, et al., 1995; Buesch, et al., 1996; Fleck, et al., 1996; Hill and Connor, 1996).

Regional and Local Tectonic Elements

Critical regional and local tectonic elements to consider in tectonic models are:

- Paleozoic and Mesozoic tectonic features including the Mississippian Antler (e.g., Nilsen and Stewart, 1980; Burchfiel and Davis, 1972; Oldow, 1984), Permian Last Chance (Snow, 1992a), Permian Sonoma (e.g., Gabrielse, et al., 1983), and Mesozoic Sevier (e.g., Armstrong, 1968; Camilleri and Chamberlain, 1997) orogenies.

- Oligocene and older extensional features (e.g., Wernicke, et al., 1987; Hodges and Walker, 1992; Axen, et al., 1993) including those presently exposed along the southwestern face of BM (Ferrill et al., in review; Stamatakos and Ferrill. 1996a).

- Neogene Tectonic features including plate motions (e.g., Atwater, 1970; Dokka and Travis, 1990; Bohannon and Parsons, 1995; Dickenson, 1996), Walker Lane seismotectonics (Stewart, 1988; Hardyman and Oldow, 1991; Oldow, et al., 1994), Basin and Range detachment faulting (e.g., Anderson, 1971; Wright and Troxel, 1973; Stewart, 1978; Wernicke, 1981; Burchfiel, et al., 1987, 1992; Hamilton, 1987; Wernicke, et al., 1988; Maldonado, 1990), and Basin and Range core complexes (e.g., Davis and Coney, 1979).

Geometric Elements

Critical geometric elements to consider in tectonic models are:

- Seismic reflection data (Majer, et al., 1997; Brocher, et al., 1993, 1996; Young, et al., 1992a)

- Gravity and aeromagnetic data (Snyder and Carr, 1982; Kane and Bracken, 1983; Langenheim, et al., 1991, 1993; Ponce, et al., 1992; Oliver and Fox, 1993; Langenheim and Ponce, 1995; Ponce and Oliver, 1995; Brocher, et al., 1996)

- Ground magnetic data (Brocher, et al., 1996; Connor, et al., 1997; Stamatakos, et al., 1997)

- Geologic maps (Cornwall and Kleinhample, 1961; Nakata et al., 1982; Scott and Bonk, 1984; Swadely and Parrish, 1988; Frizzel and Shulters, 1990; Maldonado, 1990; Monsen et al., 1992; Faulds et al., 1994; Simonds et al., 1995a; Day et al., 1997)

- Borehole data (e.g., Carr and Parrish, 1985; Carr, et al., 1986b, 1995)

- Structural cross-sections (Scott and Bonk, 1984; Scott, 1990; Young, et al., 1992b; Ferrill, et al., 1996b; Fridrich, in press)

Kinematic Elements

Critical kinematic elements to consider in tectonic models are:

- Vertical-axis rotation markers from paleomagnetism (Gillett and Van Alstine, 1982; Nelson and Jones, 1987; Rosenbaum, et al., 1991; Hudson, 1992; Gillett and Geissman 1993; Holm, et al., 1993; Snow, et al., 1993; Zhang, et al., 1993; Hudson, et al., 1994, 1996; Sonder, et al., 1994; Ferrill, et al., 1995; Stamatakos and Ferrill, 1996b; Fridrich, et al., in press; Stamatakos, et al., in review) and sedimentological markers (e.g., Snow and Prave, 1994)

- Exhumation and horizontal-axis tilting from radiogenic thermochronology studies (Noble, et al., 1989; Maldonado, 1990; Noble, et al.,1991; Monsen, et al., 1992; Hoisch and Simpson, 1993; Sawyer, et al., 1994; Ferrill, et al., 1996b; Weiss, 1996; Hoisch, et al., 1997, Ferrill, et al., in review), calcite-twin deformation studies (Ferrill, et al., in review; Stamatakos and Ferrill, 1996a), conodont color alteration indices (Grow, et al., 1994), and paleomagnetic data (Stamatakos and Ferrill, 1996b; Stamatakos, et al., in review)

- Three dimensional (3D) motions from regional reconstructions based on palinspastic markers (Prave and Wright, 1986; Stewart, 1983; Snow and Wernicke, 1989; Carr, 1990; Stevens, et al., 1991; Caskey and Schweickert, 1992; Snow 1992a, b; Axen, et al., 1993; Snow, 1994; Serpa and Pavlis, 1996; Schweickert and Lahren, 1997).

- Fault displacement analyses (Wesnousky and Jones, 1994; Minor, 1995; Ofoegbu, and Ferrill, 1995; Ofoegbu and Ferrill, in press; Bruhn and Schultz, 1996; Ferrill, et al., 1996a; Piety, 1996; Ferrill, et al., 1997; Stamatakos, et al., 1997).

- Geodetic and GPS results (Gilmore, 1992; Savage, et al. 1994; Ferrill, et al., 1996b; Bennett, et al., in press).

- Stress analyses (Stock, et al., 1985, 1986; Zoback, 1992; Zoback, et al., 1992; Bellier and Zoback, 1995; Morris, et al., 1996) or seismic moment analysis (e.g., Smith, et al., 1989; King, et al., 1994).

Paleoseismic and Historical Seismic Elements

Critical paleoseismic and seismic elements to consider in tectonic models are:

- Historic seismicity in the YM region including the Little Skull Mountain earthquake (e.g., Arabasz and Julander, 1986; Harmson, 1991; Rogers, et al., 1991; Smith and Arabasz, 1991; Harmsen and Bufe, 1992; Harmsen, 1993, 1994; Stover and Coffman, 1993; Meremonte, et al., 1995).

- Paleoseismic data from trenching studies along fault scarps and aerial photography analyses of surface deformation studies (Reheis, 1988, 1994; Anderson and Klinger, 1994; Menges, et al., 1995; Pezzopane, 1995; U.S. Geological Survey, 1996), including triggered and clustered seismicity (e.g., Anderson, et al., 1994; Bodin and Gomberg, 1994).

Viable Tectonic Models

Review of the geologic literature by staff suggests that tectonic interpretations of the YM region can be organized into 11 tectonic models. Staff from the NRC, CNWRA, DOE, USGS, and State of Nevada met in San Antonio on May 7-8, 1996, for an Appendix 7 meeting to discuss conceptual tectonic models. In this meeting, the 11 tectonic models proposed for the YM region were reviewed in the context of the most recent geological and geophysical data.

From discussions in the meetings, it was clear that five out of the eleven tectonic models were presently supported by the existing data (Appendix C-1). Although new data may promote one of the other six models currently considered not viable (Appendix C-2), the five models listed in Appendix C-1 form the basis for issue resolution at this time. In addition, there was no general consensus on which models are truly independent and which models may function as subsets of others. In a broader sense these five models can be considered in two general categories of deformation. The first three are dominantly related to extensional deformation and the latter are dominantly related to strike-slip deformation. Moreover, the five models are not mutually exclusive. Locally extensional-dominated deformation (within CF for example) can exist within a larger region of trans-tensional deformation related to a pull-apart basin. The implications of the five viable models to repository performance subissues are summarized in Appendix C-3. Unless new data or scientific arguments can be developed to allow one or more of the models to become preferred, all five models should be used to bound the impact of faulting and seismicity on repository performance. DOE's PSHA expert elicitation process appears to be heading in the direction of consideration of an appropriate range of tectonic models.

O'Leary (U.S. Geological Survey, 1996) proposed a reclassification of the eleven tectonic models and suggested the elastic-viscous model was the "preferred model." O'Leary (U.S. Geological Survey, 1996), organized tectonic models into three generic classes, based on what O'Leary termed "bulk mechanical behavior" (U.S. Geological Survey, p. 8-51). These classes were simple shear, pure shear, and lateral shear. The caldera model of Carr (1982, 1984. 1988, 1990, and Carr, et al., 1986a) was considered as a fourth unique model. The synclinorium model of Robinson (1985) was not discussed in U.S. Geological Survey (1996). By simple shear, O'Leary (U.S. Geological Survey, 1996) actually refers to models which evoke some form of detachment faulting, that is the deep, intermediate, and shallow detachment models described in Appendices C-1 and C-2. By pure shear, O'Leary (U.S. Geological Survey, 1996), refers to models which evoke horsts and graben fault block models like the planar fault

block and domino fault block models (Stewart, 1978; Fridrich, in press). By lateral shear, O'Leary (U.S. Geological Survey, 1996) refers to strike-slip dominated models like the Amargosa Shear model of Schweickert and Lahren (1997).

In summary, O'Leary (U.S. Geological Survey, 1996), presents a USGS "preferred" model of planar, steeply-dipping faults. Fault blocks are considered to deform internally and voids between fault blocks are allowed to be filled by a ductile (fluid) middle crust. The model is based on the boundary element modeling of Janssen (1995). In the model, the seismogenic crust is treated as a quasi-elastic layer resting on a viscous middle and lower crust. According to O'Leary (U.S. Geological Survey, 1996) the model addresses the following important geological and geophysical considerations:

- Faulting and basaltic volcanism are episodic and coupled.
- The CF domain is essentially a half-graben with YM faults antithetic to the master BM fault.
- The vertical-axis rotations from strike-slip faulting are a secondary phenomena, related to a discrete period of oroclinal bending.
- Faults are planar to the base of the seismogenic crust and dip between 30° and 60°. They are essentially linear cracks in which displacements are treated as stress perturbations.
- Stress conditions at the base of the crust control distribution of basaltic volcanism.
- Faulted blocks are in isostatic equilibrium.
- Elastic behavior of the crust (brittle and ductile) during an earthquake with relaxation creep in lower crust between earthquakes.
- Rollover into faults in CF especially the BM fault is not a result of fault geometry but of elastic flexure of the hangingwall.

4.4.2 Crustal Conditions

Review methods, acceptance criteria, and technical bases will be provided in Revision I of this IRSR in FY98.

5.0 STATUS OF SUBISSUE RESOLUTION

The Structural Deformation and Seismicity issue is an open item because the ancillary subissues are not resolved. When the four subissues are resolved, the SDS KTI will be resolved.

5.1 Fault Slip

5.1.1 Items Resolved at the Staff Level

5.1.1.1 Type I Faults

DOE (ref. Seismotectonic Synthesis Report, U.S. Geological Survey, 1996) uses the terms relevant and potentially relevant in describing faults. Relevant faults are defined as those having documented Quaternary displacement and the capability of the maximum magnitude earthquake on the fault to produce 84th percentile peak acceleration greater than or equal to 0.1 g. Potentially relevant faults are considered subject to displacement or the basis of potential structural association with seismicity. Because the use of 84th percentile peak acceleration is more conservative than the mean or median values, the DOE terms relevant and potentially relevant generally correspond to NRC's guidelines on Type I faults. Therefore, the following items are resolved:

(a) Eighty-four specific faults are considered to be Type I faults by NRC staff. This is an aggregate of faults considered by either or both DOE and NRC to be candidate Type I faults. These are listed in Appendices B-1 and B-2. Appendix B-1 compares the key criteria for Type I fault identification for 36 faults that both DOE and NRC have investigated. Appendix B-2 lists the key criteria for Type I faults for 33 faults that DOE has investigated, that were not analysed in detail by NRC (McKague, et al., 1996). The staff considers them to be Type I faults. NRC and DOE have mutually resolved the identifications of 66 faults (Appendix B-4, Section 5.1.2.2).

(b) DOE's identification of faults that do not need to be investigated in detail: Appendix B-3 lists 33 faults that both DOE and NRC have investigated and consider to be Type III faults. Type III faults are faults or fault zones that either are not subject to displacement, or if subject to displacement are of such length, or located in such manner, that they will not affect repository design and/or performance (NUREG-1451).

(c) DOE's boundaries of areas to be investigated: the faulting component of the geologic setting has a radius of 100 km around the Yucca Mountain site center, and the controlled area constitutes the area of regulatory concern about direct effects of fault displacement.

(d) DOE's use of Wells and Coppersmith (1994) equation to estimate the maximum capable earthquake for each fault in the faulting component.

(e) DOE's use of 0.1 g threshold ground motion at the site, as suggested in NUREG-1451.

(f) DOE's use of the 84th percentile peak ground acceleration value, which is more conservative than the mean value used by NRC, as long as it compensates for DOE's use of non-conservative attenuation model (for faults closer than about 30 km to the site).

(g) DOE's selection of the minimum faulting earthquake of Mw = 5.8, based on the Fort Sage 1950 event. Staff considers that value reasonable in light of the historic record.

(h) DOE's use of Piety (1995) as the principal source of data on age of faulting events younger than about 2 million years.

5.1.2 Items Open and Path to Resolution

5.1.2.1 Fault Slip

Open Item. The entire Fault Slip subissue - have faults and faulting that may significantly affect the performance of a repository been identified, characterized, understood, considered and used to evaluate performance? - is an open item because the PFDHA component is not resolved. When the component is resolved, it is expected that the subissue will be resolved.

5.1.2.2 Type I Faults

Open Item. Eighteen specific faults listed in Appendix B-4, described by DOE (Simonds, et al., 1995) are considered Type I faults by NRC (McKague, et al., 1996), but have not been considered to be of significance to design or performance by DOE. However, these 18 candidate Type I faults and the mutually resolved Type I faults have been brought to the attention of DOE's expert panelists (PSHA expert elicitation) who are considering them all. Staff expect DOE's PSHA/PFDHA report and Topical Report #3, both due in FY98, to contain DOE's evaluation of such potential Type I faults, and re-evaluation of the agreed-upon Type I faults (Appendices B-1, B-2). Thus, staff expects to update status of remaining Type I faults in FY98, following review of PSHA/PFDHA and TR#3. Staff have found (McKague, et al., 1996) that the differences in DOE's and NRC's classification of particular faults are rooted in just a few parameters, which can generally be resolved. The parameters are: fault trace length, attenuation function, selection of mean or 84th percentile for identification of 0.1 g criterion. Resolution of significance of any specific faults that remain in contention should be discussed parameter by parameter with DOE experts, to constrain points of disagreement and mutually understand those points.

5.1.2.3 Probabilistic Fault Displacement Hazard Analysis

Status will be provided in Revision I of this IRSR in FY98.

5.1.2.4 Site Characterization Analysis (SCA) Items

To date, NRC staff has identified 10 unresolved comments (Numbers 36, 48, 59, 60, 61, 62, 63, 64, 69, and 71) in the general area of fault slip in the SCA of DOE's Site Characterization Plan. All remain open items (Appendix D).

5.2 Seismic Motion

Status will be provided in Revision I of this IRSR in FY98.

5.2.1 Items Resolved at the Staff Level

5.2.1.1 Site Characterization Analysis (SCA) Items

To date, NRC staff has identified one unresolved comment in the general area of seismic motion in the SCA of DOE's Site Characterization Plan. Comment 66 on 10,000-year cumulative slip earthquake is resolved (Appendix D).

5.2.2 Items Open and Path to Resolution

5.2.2.1 Probabilistic Seismic Hazards Analyses

Status will be provided in Revision I of this IRSR in FY98.

5.3 Fractures and Site Discontinuities

Status will be provided in Revision I of this IRSR in FY98.

5.4 Tectonics and Crustal Conditions

5.4.1 Items Resolved at the Staff Level

5.4.1.1 Viable Tectonic Models

The following items are resolved:

(a) DOE's general description of which tectonic models are currently viable and which are not viable: of eleven tectonic models proposed, five were currently supported by existing data, i.e., are viable tectonic models (Appendix C-1), and six are not viable (Appendix C-2).

(b) DOE's consideration that the Bare Mountain fault is the dominant or master dip-slip fault of the extensional half graben that characterized the CF-BM region.

(c) DOE's consideration that the dominant mode of deformation is that of extension with secondary effects from strike-slip faulting.

(d) DOE's concept of structural domains—regions that have a similar structural style and distinctive lithology evident at a scale of about 1:100,000 separated by discrete boundaries usually composed of faults or shear zones.

5.4.2 Items Open and Path to Resolution

5.4.2.1 Tectonics and Crustal Conditions

Open Item. The entire Tector[illegible] Conditions subissue is an open item because the PFDHA and PSHA compon[illegible] When the components are resolved, it is expected that the subissue[illegible]

5.4.2.2 Site Characte[illegible] A) Items

To date, NRC staff has identified four unre[illegible]d comments (Numbers 8, 47, 68, and 98) in the area of alternative conceptual and alternative tectonic models in the Site Characterization Analysis of DOE's Site Characterization Plan. All items remain open (Appendix D).

5.4.2.3 Site Characterization Analysis (SCA) - Other Geoscience

To date, NRC staff has identified two comments (Numbers 32 and 51) and one question (Number 8) that are resolved in areas of geology and geophysics related to SDS KTI in the SCA of DOE's Site Characterization Plan. All are open items. (Appendix D, 'Other Geoscience,'). ['Other Geoscience' is an arbitrary grouping of items from the SCA that did not fit into the four subissues categories].

5.4.2.4 Crustal Conditions

Status will be provided in Revision I of this IRSR in FY98.

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APPENDIX A

FLOWDOWN DIAGRAM

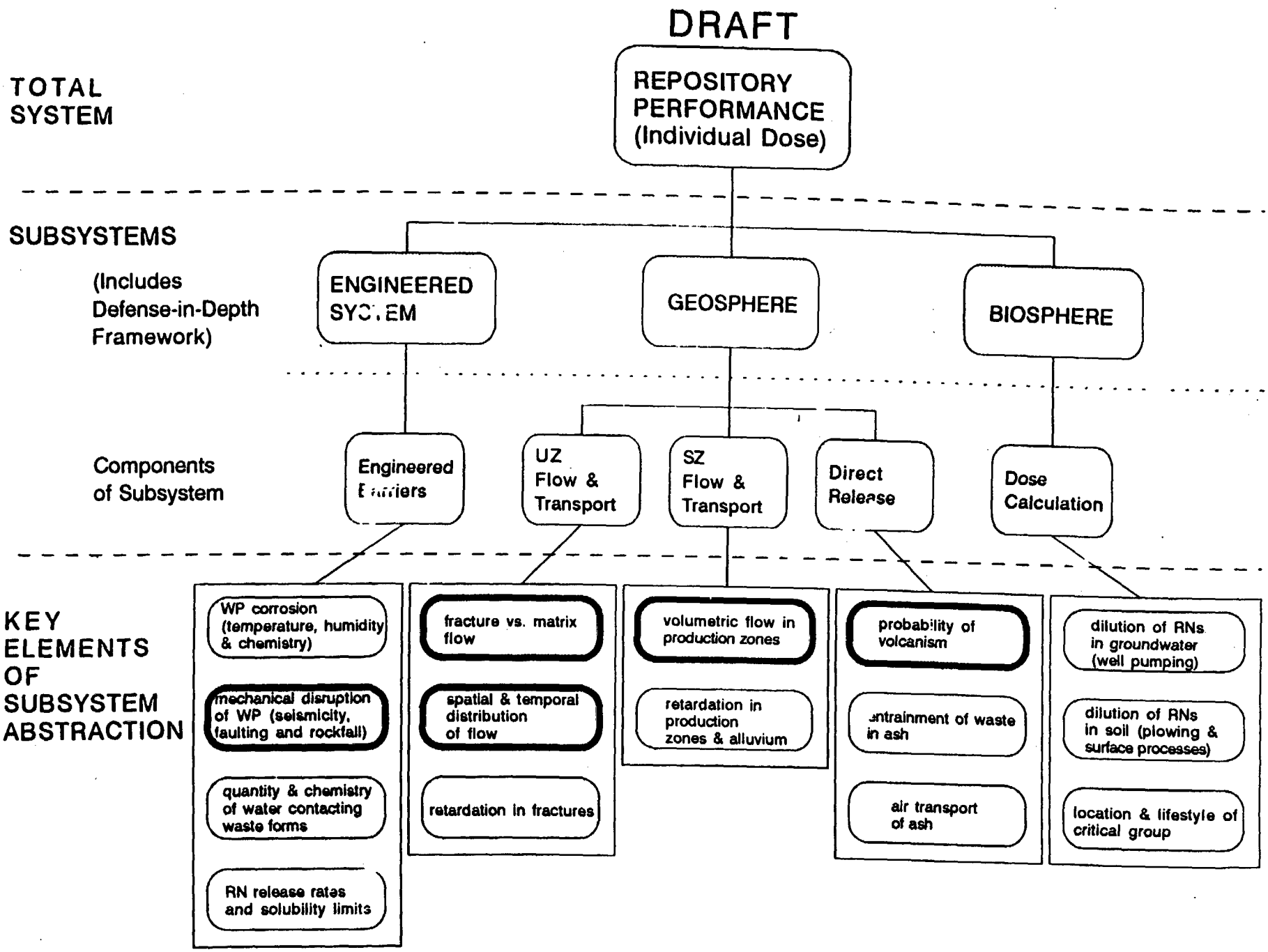

Figure A-1. Flowdown diagram for total system performance assessment. The KTI, "Structural Deformation and Seismicity" provides input to the highlighted key elements.

APPENDIX B

CLASSIFICATION OF QUATERNARY FAULTS WITHIN 100 KM of YUCCA MOUNTAIN

	DEPARTMENT OF ENERGY					NUCLEAR REGULATORY COMMISSION				
Name of Fault	Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)		Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)	Comments
				Median	84th					
(1) Faults classified as Type I by both McKague et al. (1996) and Pezzopane, in USGS (1996)										
Amargosa River	15	6.4	38	0.09	0.15	15	6.4	40	0.1	
Amargosa River—Pahrump	130	7.5	38	0.18	0.28	130	7.5	40	0.20	Pahrump fault in McKague et al., 1996
Ash Meadows	60	7.1	34	0.16	0.26	60	7.1	34	0.2	
Bare Mountain	16	6.5	14	0.27	0.44	21	6.6	15	0.31	
Black Cone	7	6.1	8.5	0.35	0.58	7	6.1	6	0.45	
Belted Range	54	7.1	55	0.09	0.15	54	7.1	55	0.10	
Boomerang Point	5	5.9	2.5	0.48	0.79	5	5.9	2	0.56	
Bow Ridge	10	6.2	2.5	0.52	0.85	8	6.1	2.3	0.61	
Cane Spring	27	6.7	29	0.17	0.27	14	6.4	29	0.13	
Carpetbag	30	6.8	43	0.10	0.17	30	6.8	43	0.11	
Crater Flat	18	6.5	6	0.48	0.79	12	6.3	10	0.36	
Death Valley	100	7.4	55	0.12	0.19	61	7.2	50	0.12	
Eleana Range	13	6.4	37	0.09	0.16	13	6.4	37	0.1	
Fatigue Wash	17	6.5	3.5	0.56	0.92	33	6.8	2	0.79	
Furnace Creek	145	7.6	50	0.14	0.23	123	7.5	49	0.15	
Ghost Dance—Abandoned Wash	5	5.9	0	0.48	0.79	9	6.2	0.4	0.69	Listed as Ghost Dance in McKague, et al., 1996

	DEPARTMENT OF ENERGY					NUCLEAR REGULATORY COMMISSION				
Name of Fault	Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)		Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)	Comments
				Median	84th					
Iron Ridge	9	6.2	2.5	0.52	0.85	9	6.2	3	0.59	
Kawich Range	84	7.3	57	0.11	0.17	84	7.3	57	0.11	
Keane Wonder	25	6.7	43	0.10	0.16	33	6.8	42	0.12	
Midway Valley	8	6.1	3	0.50	0.83	8	6.1	3	0.58	
Mine Mountain	27	6.7	19	0.23	0.38	6	6.0	24	0.12	
Oasis Valley	20	6.6	24	0.17	0.28	16	6.5	24	0.18	
Paintbrush Canyon	24	6.7	4	0.60	0.97	24	6.7	4	0.66	
Plutonium Valley—North Halfpint Range	26	6.7	46	0.09	0.14	26	6.7	46	0.10	
Rock Valley	65	7.2	27	0.22	0.35	43	7.0	25	0.23	
Rocket Wash—Beatty Wash	17	6.5	19	0.23	0.39	17	6.5	19	0.23	
Sarcobatus Flat	51	7.1	52	0.10	0.17	51	7.1	52	0.10	
Solitario Canyon	20	6.6	1	0.58	0.94	19	6.6	1	0.76	
Stagecoach Road	9	6.2	10	0.36	0.60	8	6.1	11	0.30	
Tolicha Peak	22	6.6	42	0.10	0.16	22	6.6	42	0.10	
Wahmonie	15	6.4	22	0.18	0.30	15	6.4	22	0.19	
West Specter Range	9	6.2	33	0.10	0.16	N/A	N/A	N/A	N/A	
West Spring Mountain	60	7.1	53	0.10	0.16	60	7.1	53	0.11	

	DEPARTMENT OF ENERGY					NUCLEAR REGULATORY COMMISSION				
Name of Fault	Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)		Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)	Comments
				Median	84th					
Windy Wash	25	6.7	4.5	0.56	0.91	28	6.8	4	0.69	
Yucca	32	6.8	40	0.11	0.18	31	6.8	43	0.10	
Yucca Lake	17	6.5	36	0.10	0.17	17	6.5	36	0.11	
(2) Faults classified as Type I by Pezzopane, in USGS (1996), but not by McKague et al. (1996)										
Abandoned Wash										See Ghost Dance—Abandoned Wash fault
Area Three	12	6.3	44	0.07	0.12	N/A	N/A	N/A	N/A	
Bullfrog Hills	7	6.1	38	0.07	0.12	N/A	N/A	N/A	N/A	
Buried Hills	26	6.7	53	0.08	0.13	N/A	N/A	N/A	N/A	
Checkpoint Pass	7	6.1	44	0.06	0.11	N/A	N/A	N/A	N/A	
Cockeyed Ridge—Papoose Lake	21	6.6	53	0.07	0.12	N/A	N/A	N/A	N/A	
Crossgrain Valley	9	6.2	48	0.06	0.10	N/A	N/A	N/A	N/A	
Death Valley—Furnace Creek	205	7.8	50	0.16	0.26	N/A	N/A	N/A	N/A	DOE represents combined Death Valley—Furnace Creek fault system

	DEPARTMENT OF ENERGY					NUCLEAR REGULATORY COMMISSION				
Name of Fault	Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)		Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)	Comments
				Median	84th					
Death Valley—Furnace Creek—Fish Lake Valley	288	7.9	50	0.17	0.27	N/A	N/A	N/A	N/A	DOE represents combined Death Valley—Furnace Creek Fish—Fish Lake Valley Fault System
Drill Hole Wash	4	5.8	1.5	0.46	0.74	N/A	N/A	N/A	N/A	Not considered Type I fault because of orientation in modern *in situ* stress field, McKague, et al., 1996
Dune Wash	3	5.6	2	0.44	0.74	N/A	N/A	N/A	N/A	Fault too short to be included in initial study; see McKague, et al., 1996
East Pintwater Range	58	7.1	81	0.06	0.10	N/A	N/A	N/A	N/A	
Emigrant Valley North	28	6.8	60	0.07	0.11	N/A	N/A	N/A	N/A	
Ghost Dance	3	5.6	0	0.44	0.74	N/A	N/A	N/A	N/A	See Ghost Dance—Abandoned Wash Fault
Grapevine	20	6.6	58	0.06	0.10	N/A	N/A	N/A	N/A	
Grapevine Mountains	31	6.8	67	0.06	0.10	N/A	N/A	N/A	N/A	

	DEPARTMENT OF ENERGY					NUCLEAR REGULATORY COMMISSION				
Name of Fault	Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)		Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)	Comments
				Median	84th					
Hunter Mountain—Panamint Valley	185	7.7	95	0.07	0.12	N/A	N/A	N/A	N/A	
Indian Springs Valley	28	6.8	67	0.06	0.10	N/A	N/A	N/A	N/A	
Kawich Valley	43	7.0	61	0.08	0.13	N/A	N/A	N/A	N/A	
Mercury Ridge	10	6.2	48	0.06	0.10	N/A	N/A	N/A	N/A	
Oak Spring Butte	21	6.6	57	0.06	0.11	N/A	N/A	N/A	N/A	
Pagany Wash	4	5.8	2.5	0.46	0.77	N/A	N/A	N/A		Not considered Type I fault because of orientation in modern *in situ* stress field, McKague, et al., 1996
Pahrump	70	7.2	70	0.08	0.12	N/A	N/A	N/A	N/A	See Amargosa River—Pahrump
Pahute Mesa	9	6.2	48	0.06	0.10	N/A	N/A	N/A	N/A	
Paintbrush Canyon—Stagecoach Road	33	6.8	4	0.62	1.00	N/A	N/A	N/A	N/A	DOE represents combined Paintbrush Canyon—Stagecoach Road fault system

	DEPARTMENT OF ENERGY					NUCLEAR REGULATORY COMMISSION				
Name of Fault	Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)		Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)	Comments
				Median	84th					
Panamint Valley	100	7.4	95	0.06	0.10	N/A	N/A	N/A	N/A	
Sever Wash	4	5.8	3	0.46	0.77	N/A	N/A	N/A	N/A	Not considered Type I fault because of orientation in modern *in situ* stress field, McKague, et al., 1996
South Ridge	19	6.6	50	0.08	0.12	N/A	N/A	N/A	N/A	
Spotted Range	30	6.8	59	0.07	0.12	N/A	N/A	N/A	N/A	
Sundance	1	5.1	0	0.38	0.66	N/A	N/A	N/A	N/A	
West Pintwater Range	60	7.1	76	0.07	0.11	N/A	N/A	N/A	N/A	
West Specter Range	9	6.2	33	0.10	0.16	N/A	N/A	N/A	N/A	
Yucca Wash	9	6.2	5	0.47	0.78	N/A	N/A	N/A	N/A	Not considered Type I fault because of orientation in modern *in situ* stress field, McKague, et al., 1996
(3) Faults classified as Type III by both Pezzopane, in USGS (1996) and McKague, et al. (1996)										
Bonnie Claire	27	6.7	74	0.05	0.08	N/A	N/A	N/A	N/A	
Boundary	7	6.1	51	0.05	0.09	N/A	N/A	N/A	N/A	
Cactus Flat	50	7.1	84	0.06	0.09	N/A	N/A	N/A	N/A	

	DEPARTMENT OF ENERGY					NUCLEAR REGULATORY COMMISSION				
Name of Fault	Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)		Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)	Comments
				Median	84th					
Cactus Flat—Mellan	35	6.9	80	0.05	0.09	N/A	N/A	N/A	N/A	
Cactus Range—Wellington Hills	29	6.8	87	0.05	0.07	N/A	N/A	N/A	N/A	
Cactus Springs	14	6.4	59	0.05	0.09	N/A	N/A	N/A	N/A	
Chalk Mountain	20	6.6	87	0.04	0.07	N/A	N/A	N/A	N/A	
Chert Ridge	14	6.4	65	0.05	0.08	N/A	N/A	N/A	N/A	
Chicago Valley	20	6.6	90	0.04	0.06	N/A	N/A	N/A	N/A	
Emigrant Valley South	20	6.6	66	0.06	0.09	N/A	N/A	N/A	N/A	
Fallout Hills	8	6.1	70	0.04	0.06	N/A	N/A	N/A	N/A	
Fish Lake Valley	83	7.3	135	0.04	0.06	N/A	N/A	N/A	N/A	
Garlock	251	7.9	150	0.05	0.08	N/A	N/A	N/A	N/A	
Gold Flat	16	6.5	60	0.06	0.09	N/A	N/A	N/A	N/A	
Groom Range Central	31	6.8	82	0.05	0.08	N/A	N/A	N/A	N/A	
Groom Range East	20	6.6	85	0.04	0.07	N/A	N/A	N/A	N/A	
Hunter Mountain	85	7.3	95	0.06	0.09	N/A	N/A	N/A	N/A	
Jumbled Hills	27	6.7	77	0.05	0.06	N/A	N/A	N/A	N/A	
La Madre	33	6.8	82	0.05	0.08	N/A	N/A	N/A	N/A	
North Desert Range	24	6.7	81	0.05	0.07	N/A	N/A	N/A	N/A	

	DEPARTMENT OF ENERGY					NUCLEAR REGULATORY COMMISSION				
Name of Fault	Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)		Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)	Comments
				Median	84th					
Oak Spring Butte	21	6.6	57	0.06	0.11	N/A	N/A	N/A	N/A	
Owens Valley	110	7.4	126	0.04	0.07	N/A	N/A	N/A	N/A	
Pahranagat	91	7.4	106	0.05	0.09	N/A	N/A	N/A	N/A	
Penoyer	56	7.1	97	0.05	0.08	N/A	N/A	N/A	N/A	
Racetrack Valley	22	6.6	97	0.03	0.06	N/A	N/A	N/A	N/A	
Ranger Mountains	5	5.9	49	0.05	0.08	N/A	N/A	N/A	N/A	
San Andreas	420	8.1	291	0.03	0.05	N/A	N/A	N/A	N/A	
Stonewall Mountain	22	6.6	92	0.04	0.06	N/A	N/A	N/A	N/A	
Stumble	33	6.8	74	0.05	0.09	N/A	N/A	N/A	N/A	
Three Lakes Valley	27	6.7	84	0.04	0.07	N/A	N/A	N/A	N/A	
Tikaboo	33	6.8	92	0.04	0.07	N/A	N/A	N/A	N/A	
Tin Mountain	29	6.8	90	0.04	0.07	N/A	N/A	N/A	N/A	
Towne Pass	38	6.9	76	0.06	0.09	N/A	N/A	N/A	N/A	
White Mountains and Cedar Mountain	115	7.5	185	0.03	0.05	N/A	N/A	N/A	N/A	
(4) Faults classified as Type I by McKague, et al. (1996), but not by Pezzopane, in USGS (1996)										
Simonds Number 1 fault	N/A	N/A	N/A	N/A	N/A	3	5.6	7	0.32	See McKague, et al., 1996; figure 1-2

	DEPARTMENT OF ENERGY					NUCLEAR REGULATORY COMMISSION				
Name of Fault	Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)		Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)	Comments
				Median	84th					
Simonds Number 2 fault	N/A	N/A	N/A	N/A	N/A	7	7.28	6	0.44	See McKague, et al., 1996; figure 1-2
Simonds Number 3 fault	N/A	N/A	N/A	N/A	N/A	5	5.9	5	0.44	See McKague, et al., 1996; figure 1-2
Simonds Number 4 fault	N/A	N/A	N/A	N/A	N/A	5	5.9	5	0.45	See McKague, et al., 1996; figure 1-2
Simonds Number 5 fault	N/A	N/A	N/A	N/A	N/A	5	5.9	6	0.42	See McKague, et al., 1996; figure 1-2
Simonds Number 6 fault										Windy Wash fault; See McKague, et al., 1996; figure 1-2
Simonds Number 7 fault	N/A	N/A	N/A	N/A	N/A	5	5.9	8	0.32	See McKague, et al., 1996; figure 1-2
Simonds Number 8 fault	N/A	N/A	N/A	N/A	N/A	7	6.1	9	0.36	See McKague, et al., 1996; figure 1-2
Simonds Number 9 fault	N/A	N/A	N/A	N/A	N/A	4	5.8	9	0.28	See McKague, et al., 1996; figure 1-2
Simonds Number 10 fault	N/A	N/A	N/A	N/A	N/A	5	5.9	9	0.30	See McKague, et al., 1996; figure 1-2

	DEPARTMENT OF ENERGY					NUCLEAR REGULATORY COMMISSION				
Name of Fault	Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)		Fault Length (km)	Maximum Magnitude	Distance to Fault (km)	Peak Acceleration (g)	Comments
				Median	84th					
Simonds Number 11 fault										Black Cone Fault; see McKague, et al., 1996; figure 1-2
Simonds Number 12 fault	N/A	N/A	N/A	N/A	N/A	8	6.1	6	0.47	See McKague, et al., 1996; figure 1-2
Simonds Number 13 fault	N/A	N/A	N/A	N/A	N/A	8	6.1	2	0.64	See McKague, et al., 1996
Simonds Number 14 fault	N/A	N/A	N/A	N/A	N/A	4	5.8	4	0.47	See McKague, et al., 1996; figure 1-2
Simonds Number 15 fault	N/A	N/A	N/A	N/A	N/A	4	5.8	7	0.34	See McKague, et al., 1996; figure 1-2
Simonds Number 16 fault	N/A	N/A	N/A	N/A	N/A	10	6.2	8	0.40	See McKague, et al., 1996; figure 1-2
Simonds Number 17 fault	N/A	N/A	N/A	N/A	N/A	3	5.6	13	0.19	See McKague, et al., 1996; figure 1-2
Simonds Number 18 fault	N/A	N/A	N/A	N/A	N/A	8	6.1	8	0.39	See McKague, et al., 1996; figure 1-2

APPENDIX C

CLASSIFICATION OF TECTONIC MODELS AT YUCCA MOUNTAIN VICINITY

Appendix C-1. Summary of Viable Tectonic Models

Model Name	References	Comments
Half Graben with Moderate Depth Detachment	Young, et al. (1992b) Ferrill, et al. (1996b)	Supported by CNWRA balanced cross sections (e.g.,Young, et al., 1992b). Also consistent with pull-apart model (Stamatakos and Ferrill, 1996a). Supported by regional observations (e.g., Wright and Troxel, 1973; Burchfiel, et al., 1987). Seismic data (e.g., Brocher, et al., 1996) neither support nor refute the models because validity of seismic data below 6 km depth is questionable (cf. Brocher, et al., 1996; Majer, et al., 1997).
Half Graben with Deep Depth Detachment	Young, et al. (1992b) Ferrill, et al. (1996b)	Supported by CNWRA balanced cross sections (e.g.,Young, et al., 1992b). Also consistent with pull-apart model (Stamatakos and Ferrill, 1996a). Supported by regional observations (e.g., Wright and Troxel, 1973; Burchfiel, et al., 1987). Seismic data (e.g., Brocher, et al., 1996) neither support nor refute the model because validity of seismic data below 6 km depth is questionable (cf. Brocher, et al., 1996; Majer, et al., 1997).
Crater Flat Pull-Apart Basin	Fridrich, (in press)	Supported by regional seismo-tectonic framework (e.g., Oldow, et al., 1994). Fault geometries at depth unspecified. Requires existence of additional blind seismic sources (McKague, et al., 1996). Requires blind strike-slip fault south of CF (Stamatakos and Ferrill, 1996a)
Elasco-Viscous Graben	Janssen (1995)	Consistent with pull-apart basin interpretation. Assumes mobile ductile middle crust and internally deformable upper crustal blocks. Requires very thin effective elastic crust (thickness of only 2 km) and blind large-displacement faults in CF and external to the model (See Section 4.3).
Amargosa Desert Fault	Schweickert and Lahren (1997)	Explains selected geometric features (e.g., State Line fault and CF basaltic cone alignment) but requires unrecognized shallow detachments within calderas north of CF (e.g., Hardyman and Oldow, 1991). Inconsistent with thermochronologic data (e.g., Ferrill, et al., 1996b).

C-2. Summary of Tectonic Models Considered Not Viable

Model Name	References	Comments
Collapsed Caldera	Carr (1982, 1988) Carr and Parrish (1985)	Inconsistent with geometric and kinematic data. Geophysical data (Brocher et al., 1996; Rosenbaum et al., 1991) and structural data (e.g., Scott, 1990; Young et al., 1992b; Ferrill et al., 1996b) show CF as a fault bound half graben. Thermochronological data show CF and BM fault probably existed prior to Miocene volcanism (e.g., Ferrill et al., 1996b).
Kawich-Greenwater Rift	Carr (1984)	Inconsistent with kinematic data. Rifting assumes contemporaneous faulting and volcanism, but BM fission track data indicate significant uplift (faulting) prior to Miocene volcanism (e.g., Ferrill et al., 1996b).
Yucca Synclinorium	Robinson (1985)	Inconsistent with nearly all geological and geophysical studies.
Planar-Domino Faults	Stewart (1978)	Inconsistent with known geometry and kinematics of faults (e.g., Fridrich, in press; Ferrill et al., 1996b). Domino faulting layering requires all fault blocks to have similar dips and faulting to be coeval.
Regional Detachment	Wernicke (1992) Snow (1994)	Inconsistent with existing kinematic and geometric data. No evidence for shallow detachment east of BM (e.g., Simonds et al., 1995b; Ferrill et al., 1996b). Paleomagnetic data (e.g., Stamatakos and Ferrill, 1996b) show no large-scale vertical-axis rotation of BM as indicated in model of Snow (1994).
Shallow Detachment	Scott (1990) Hamilton (1988)	Inconsistent with geometric and kinematic data. Balanced cross sections require a minimum detachment depth of 6 km (e g., Young et al., 1992b; Ferrill et al., 1996b). No detachment visible on seismic data (Brocher et al., 1996) Thermochronology data (e.g., Ferrill et al., in review) indicate BM exhume prior to Bullfrog Hills-Fluorspar Canyon detachment faulting (Ferrill et al., 1996b).

C-3. Summary of effects on performance of viable tectonic models

Model Name	Comments
Half Graben with Moderate Detachment	Has least adverse effect on repository performance. Connectivity between the BM fault and the CF-YM detachment fault can lead to compensatory slip on the CF-YM faults in response to slip on the BM fault. However, the response behavior depends on the details of the strain accommodation mechanism in the BM fault hanging wall (e.g., flexural shear and outer arc extension versus oblique simple shear or vertical simple shear). Since the CF-YM faults extend to a lesser depth in this model, the potential rupture area (the area with high slip tendency) and earthquake magnitudes are smaller than those for a deep detachment (Ofoegbu and Ferrill, 1995; McKague, et al., 1996). Moreover, faults with dips coalescing into a moderate detachment are less likely to serve as magma pathways.
Half Graben with Deep Detachment	Possibility of the CF-YM domain producing large magnitude earthquakes in the future. The CF-YM faults extend to considerable depth (~15 km), hence they have large potential rupture areas with high slip tendency and can produce large-magnitude earthquakes (McKague, et al., 1996). In addition, slip on the BM may trigger slip on one or more CF-YM faults because of the supposed link at depth. Faults that maintain steep dips to the base of the seismogenic crust are also good candidates for capturing igneous dikes, thus serving as preferred magma pathways.
Crater Flat Pull-Apart Basin	Mix of strike-slip and dip-slip faulting could increase seismic hazard because the current PSHA (Wong, et al., 1995) considers only dip-slip motion on most CF-YM faults. More importantly, the hypothesized regional strike-slip system is a major seismic source that could dominate the PSHA. Such a source is not considered in the existing PSHA (Wong, et al., 1995). The pull-apart model has CF-YM faults maintaining steep dips to depth, so the structures are favorable for dike capture.
Elasco-Viscous Graben	Possibility for large rupture areas and attendant earthquakes associated with planar faults extending as deep as 15 km. Faults could also serve as easily exploitable magma pathways. In contrast to the detachment models, slip on the CF-YM faults is not directly linked to movement on the BM. The planar model also predicts a significant west-dipping blind fault with 3 km of offset beneath CF (in order to contain deformation within CF).
Amargosa Shear or Amargosa Desert Fault	Raises the possibility of the most significant adverse effect on repository performance. As with the pull-apart models, the Amargosa shear requires a major strike-slip fault capable of generating earthquakes with maximum magnitudes up to M_w = 8.0, which would greatly affect PSHA. Furthermore, such a fault could have a major impact on rock hydrologic properties between CF and Amargosa Valley. The link with igneous activity suggests that a strike-slip event may be able to trigger another phase of basaltic activity in CF.

APPENDIX D

SITE CHARACTERIZATION ANALYSIS OPEN ITEMS RECONSIDERED

Site Characterization Analysis Open Items Reconsidered

Based on several meetings, workshops, field trips, and visits to the ESF, the staff considers that most of the SCA open-items are being considered by DOE. The staff believes that the recently-collected data and the results of the several workshops that will be discussed in FY98 reports will form suitable bases on which to reconsider SCA open items.

Items are organized by Comment and Question, numerically, according to subissues in this IRSR, and 'Subissue: Other Geoscience.'

Numbers in parentheses refer to NUREG-1347, *NRC Staff Site Characterization Analysis of the DOE's Site Characterization Plan, Yucca Mountain*, NV, 1989

SUBISSUE: FAULT SLIP

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COMMENT 36 **Faults in Perimeter Drift**

"The technical rationale for this investigation states that the perimeter drift defines an area of a significantly lower concentration of faults than has been mapped in surrounding areas. However, based on other parts of the SCP, this concept may not be accurate. Further, there is no apparent indication that studies in the SCP address the potential impact on system performance of the presence within the perimeter drift (i.e., in emplacement areas) of a significant number of faults, some of which may be favorably oriented for failure under the present stress regime." (4-38)

RECOMMENDATIONS

* "Rectify the apparent contradiction as to whether a zone of imbricate faulting is present within the perimeter drift.

* If the imbricate fault zone is present within the perimeter drift, an assessment should be made to demonstrate that the requirements of 10 CFR 60.133(h) will be met." (p. 4-38)

DISPOSITION

Open. DOE's ESF reports, WCIS, Total System Performance Assessment-Viability Assessment Plan, plan to conduct perimeter drifting, and proposed enhanced drifting and drilling alleviate this concern. Also DOE is planning to move the perimeter drift to a location west of ghost dance fault where concentration of faults is less than the present location. Resolution is pending reviews of the DOE reports.

****

COMMENT 48 **Fault Slip Rate**

"The use of fault slip rates to determine the level of hazard posed to repository facilities b-14y faults does not appear to be a conservative approach and may result in overly optimistic predictions about the effects of faulting on system performance." (p. 4-45)

RECOMMENDATIONS

* "Demonstrate that the use of slip rates for determining hazard does not provide overly optimistic predictions of the effects of faulting on repository performance.

* Consider alternative methods (e.g., maximum event offset) or a combination of methods (e.g., maximum event offset and slip rates) to assess the level of hazard to the surface facilities and EBS posed by faulting." (p. 4-45)

DISPOSITION

Open. DOE's methodology described in Topical YMP/TR-002-NP *"Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain" and in Topical Report YMP/TR-003-NP "Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain"* adequately addressed the issue of slip rate. However, the results of slip rates will be presented in an upcoming report in FY98. Resolution is pending reviews of the DOE reports.

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COMMENT 59 **Sequencing Fault Investigations**

"The information presented for the program of investigations for faulting does not allow the NRC staff to determine what investigations will actually be conducted. In addition, the sequencing of many geophysical and geologic activities related to faulting may lead to data collection activities that are inadequate to support assessments of performance and design bases." (p. 4-53)

RECOMMENDATION

* "Consideration should be given to re-examining the sequence of all activities dependent on input from other activities." (p. 4-53)

DISPOSITION

Open. DOE's geological and geophysical site characterization activities which bear on fault characterization are largely completed. DOE collected several seismic reflection, gravity, and magnetic data. These sets of data were utilized in PSHA, PFHA, and PVHA. CNWRA also collected several gravity and magnetic data to enhance the identification of buried volcanic cones and blind faults. Pending receipt and review of DOE reports in FY98, this comment remains open.

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COMMENT 60 **Fault Parameters**

"The NRC staff does not consider that the basis and rationale for the design and performance parameters, characterization parameters, and goals proposed in the SCP for fault displacement, in particular for fault investigations for facilities important to safety (FITS), have been justified. The staff is concerned as these values appear to be used to limit the exploration program prior to having sufficient data to evaluate the site." (p. 4-53)

RECOMMENDATION

* "DOE needs to strengthen its justification for the design and performance parameters, characterization parameters, and goals for preclosure fault displacement as related to FITS, or revise these values. The justification should include a discussion of the interrelationship of the characterization parameters, performance and design parameters, and goals with the design criteria and the performance objectives of 10 CFR Part 60." (p. 4-54)

DISPOSITION

Open. DOE had held several workshops on PSHA and PFHA to address this particular issue. DOE will present the results in upcoming reports in FY98. Resolution is pending reviews of the results of the upcoming reports.

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COMMENT 61 **Location of New Faults**

"The program of investigations for faulting appears to assume that any future faulting will follow old faulting patterns. The NRC staff considers that this in not a reasonably conservative assumption, and does not consider that this assumption is technically justified." (p. 4-55)

RECOMMENDATION

* "DOE needs to review its assumptions used to plan the exploration program for FITS to assure unconservative assumptions, such as future faulting only occurring at the exact locations of past faulting, do not bias the program." (p. 4-55)

DISPOSITION

Open. DOE recently presented its tectonic models and fault characterization for Yucca Mountain in several workshops. Resolution is pending reviews of the DOE reports.

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COMMENT 62 **Fault Standoff**

The information presented for the program of investigations for study of faulting at the surface facilities does not allow the NRC Staff to determine how DOE is proposing to use standoff distances in designing the program of investigations and in performing the resultant design and analysis." (p. 4-56)

RECOMMENDATION

* "The DOE needs to demonstrate that:

(i) the program of investigations for faulting at not near FITS will adequately evaluate all faults that have a potential of movement, and/or

(ii that the evaluation of the effects of faulting, taking into account the degree of resolution of the investigation, will not underestimate the effects, and

(iii) the effect of faulting will not compromise the ability of the FITS to meet the performance objectives." (p. 4-56)

DISPOSITION

Open. DOE is planning to avoid areas where concentration of active faults are located and relocate the repository perimeter west of the Ghost Dance fault. DOE plans to design for faults that it can not avoid. Resolution is pending review of the DOE reports.

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COMMENT 63 **Integrating Fault Data**

"The information presented for the program of investigations for study of faulting at the surface facilities does not appear to have integrated pre-existing information and makes assumptions about pre-existing information and on-going investigations which the NRC cannot evaluate because the NRC has not seen the background information." (p. 4-56)

RECOMMENDATION

* "Prior to the NRC staff being able to evaluate the program of site investigations, the DOE needs to complete at least the planning step of integration of the site program. This should include not only a separate integration of drilling, or a separate integration of geophysics, but a complete integration of the planned program of investigations. This integration should show how ongoing activities and pre-existing information has been incorporated into the program, and should demonstrate what assumptions are being made on the qualification of pre-existing data." (p. 4-57)

DISPOSITION

Open. The adequacy of DOE's fault characterization program is expected to be evaluated by reviews of DOE reports scheduled for FY98.

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COMMENT 64 **Significant Faults**

"The characterization parameters for the identification and characterization of "significant Quaternary faults" in the area of the repository block do not appear to fulfill the requirements in

10 CFR 60, such as investigating and evaluating the effects of potentially adverse natural conditions." (p. 4-57)

RECOMMENDATION

* "The site characterization program and performance allocation process should be designed to assure that any fault that could have an adverse impact on waste isolation will be characterized." (p. 4-58)

DISPOSITION

Open. Staff have resolved the disposition of all potentially significant Quaternary faults (Section 5.1.2.3). Resolution is pending the outcome of staff review of the use of such faults by DOE in its design and performance analyses.

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COMMENT 69 **NW-Trending Faults**

"The SCP does not appear to integrate and synthesize data resulting from the planned activities characterizing northwest-trending faults." (p. 4-61)

RECOMMENDATION

* "Consideration should be given to specifically outlining a program of study to integrate and synthesize all activities that will collect data on northwest-trending faults." (p. 4-61)

DISPOSITION

Open. DOE provided a report on the integration of the different activities to characterize the N-W trending faults (U.S. Geological Survey, 1996). The results of this integration will be presented in DOE reports in FY98. Resolution is pending the outcome of staff reviews of the upcoming report.

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COMMENT 71 **Significant Fault**

"The tentative goal, design parameter, and expected value relating faulting (e.g., "significant Quaternary fault") and performance allocation for System Element 1.1.2 are not sufficient for adequately characterizing the hazard posed by faulting in the repository." (p. 4-61)

RECOMMENDATIONS

* "Consideration should be given to using alternative fault models as a conceptual basis for assessing the preclosure hazard to the repository."

* Demonstrate that from a scientific perspective, the program of drifting in the northern part of the repository combined with the systematic drilling program and feature sampling program will provide the information necessary to ensure that conditions and processes encountered are representative of conditions and processes throughout the site and that potentially adverse conditions will be adequately investigated." (p. 4-62)

DISPOSITION

Open. DOE and staff have some disagreements on the distribution of significant Quaternary faults. Resolution is pending the outcome of staff reviews of the upcoming DOE reports.

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SUBISSUE: SEISMIC MOTION

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COMMENT 66 **10,000-Year Earthquake**

"Since the 10,000-year cumulative slip earthquake (10-kyr CSE) methodology assumes that average cumulative slip over 10,000 years is released in a single event, it appears that recurrence is implied to be fixed at 10,000 years. It is questionable whether such a methodology can properly characterize fault activity, and the related seismic activity, in the site region." (p. 4-58)

RECOMMENDATION

* "Recurrence-rate estimates should be given special emphasis. In particular, differences between the true maximum magnitude and the 10-kyr CSE, based on evaluations of the recurrence interval associated with the maximum earthquake determined from magnitude-frequency relationships, should be thoroughly explained. The planned site characterization activities, which are designed to provide all types of information that are material to the characterization of seismic hazard, should be conducted in a manner that will allow for a clear comparison of the 10-kyr CSE methodology with other alternative methodologies." (p. 4-59)

DISPOSITION

Resolved. DOE is not using the 10-Kyr CSE concept. DOE's current methodology presented in TR#1 (DOE, 1997; *Topical Report YMP/TR-002-NP: Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at YM*, August, 1997) is acceptable. No staff questions at this time.

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SUBISSUE: FRACTURE MODELS

A cross walk to fracture flow subissues will be provided in Revision I of this IRSR in FY98.

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SUBISSUE: TECTONIC MODELS

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COMMENT 8 **Alternative Tectonic Models**

"Alternative tectonic models for the site do not appear to be fully integrated into the site characterization plan and as a result alternatives are apparently not considered in the preliminary performance allocations and the design of the Engineered Barrier System (EBS). The site characterization program appears to be directed toward providing data that confirm the preferred tectonic model rather than determining what the '"preferred model"' should be." (p. 4-14)

RECOMMENDATIONS

* "Alternative tectonic models should be thoroughly integrated into preliminary performance allocations and the design of the EBS.

* Consideration should be given to prioritizing investigations giving high priority to those investigations associated with tectonic features, events, or processes that could lead to the determination of whether the site has unacceptable adverse conditions, or to a substantial change in the site characterization program." (p. 4-16)

DISPOSITION

Open. DOE is fully considering alternative tectonic models. Seismotectonic scenarios reports, PFHA, and PSHA expert elicitation results will be reported in FY98. Resolution is pending review of the DOE reports.

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COMMENT 47 **Integrate Tectonics Into PA**

"The approach to incorporating data derived in the postclosure tectonics program into an assessment of whether performance issues related to the waste package and engineered barrier system (EBS) requirements (10 CFR 60.113(a)) will be met is confusing and may result in an inaccurate assessment of performance." (p. 4.44)

RECOMMENDATION

* "Consideration should be given to establishing a direct path for the integration of data collected in the Postclosure Tectonics program into issues 1.4 (Will waste package meet the performance objective) and 1.5 (Will the waste package and repository engineered barrier system meet the performance objective)." (p. 4-44)

DISPOSITION

Open. DOE's WCIS, Seismotectonic Scenarios Report, and TSPA-VA will consider effects of seismotectonics on performance. Resolution is pending review of the DOE reports.

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COMMENT 68 **Detachment Fault Model**

"Other aspects of detachment faulting in addition to those described in Section 8.3.1.17.4.5 regarding key questions to be answered on earthquake sources do not appear to be treated as similarly potentially significant." (p. 4-60)

RECOMMENDATIONS

* "The significance of detachment faulting as a key element in assessing the potential for faulting at the site needs to be readdressed giving consideration to other key concerns related to detachment faulting.

* Consideration should be given to having the results of Study 8.3.1.17.4.5 input directly into postclosure tectonics performance issues." (p. 4-61)

DISPOSITION

Open. DOE has considered detachments faults (U.S.Geological Society, 1996). Fault models were discussed in several workshops. Resolution is pending review of DOE reports due in FY98.

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COMMENT 98 **Alternative Conceptual Models**

"Weighting alternative conceptual models according to the judgment that they are likely to be correct and using such "probabilities" to weight consequences in the construction of the CCDF is not a conservative estimate of repository performance, nor is it an advisable approach for demonstrating compliance." (p. 4-78)

RECOMMENDATIONS

* "The SCP should recognize that the approach of incorporating alternative conceptual model likelihoods into the computation of the CCDF of cumulative releases of radionuclides may not provide information about repository performance in an acceptable format because uncertainties are not delineated distinctly.

* "Plan to incorporate consideration of unresolved alternative conceptual models into the CCDF in a conservative fashion by choosing the alternative that gives the poorest performance (greatest releases of radionuclides) or by some combination of the two alternatives that ensures no underestimates of releases and develop the site characterization program accordingly." (p. 4-79)

DISPOSITION

Open. Based on expert elicitation DOE will provide alternative models to be considered in the performance assessment. Different weights will be assigned to these models based on their credibility. The range in uncertainty in these models will be addressed in an upcoming DOE report in FY98. Resolution is pending the review of this report.

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SUBISSUE: OTHER GEOSCIENCE

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COMMENT 32 Geophysical Data Integration

"The program for geophysical integration as presented in the SCP is insufficiently described. The correlation between the different geophysical investigations is not presented and, in addition, the approach that will be used to integrate the geophysical activities and how these different activities will complement each other does not appear to be discussed in the SCP." (p. 4-35)

RECOMMENDATIONS

* "Integrate and evaluate existing geologic and geophysical data and provide overlays of the existing coverage and evaluations.

* Based on this integration, provide a coherent geophysical program to be implemented in the Yucca Mountain area that would provide sufficient characterization of the site." (p. 4-35)

DISPOSITION

Open. DOE has completed reports on its geophysical surveys (seismic reflection, gravity, and magnetic data). The results are being utilized in several workshops held during 1996 and 1997. CNWRA recently collected gravity and magnetic data and plan to integrate the results from the different geophysical methods. The resolution of this issue is pending the outcome of staff reviews of the DOE reports due in FY98, and of the CNWRA results.
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COMMENT 51 Correlate Deep & Shallow Geophysical Surveys

"Geophysical survey programs as indicated in the SCP may not be sufficient to identify and characterize both the deep crustal and shallow geologic features and their interrelationship." (p. 4-47)

RECOMMENDATIONS

* "Provide a geophysical investigation program plan that is comprehensive, integrated and sufficient to identify and understand the interrelationships of the deep crustal structure and shallow geologic structural features, and to assure that no significant structural features have gone undetected.

* Consider including a gridded program of exploratory surveys and measurements that would allow for cross-line correlations and more complete spatial definition of anomalies at the site and specifically at the locations of the exploratory shafts." (p. 4-47)

DISPOSITION

Open. DOE collected more seismic reflection data, gravity, and magnetic since the issuance of the SCP. CNWRA also collected gravity and magnetic data in the vicinity of Yucca Mountain. Staff expects that these data will be sufficient to characterize the shallow and deep structures and their interrelationship. The resolution of this issue is pending the outcome of the review of DOE's and CNWRA's reports due in FY98.

****

QUESTION 8 **Variability of Model Input**

"What measure of predictability will accompany the computer models, maps, and other illustrations? How will uncertainties be explicitly transmitted to the model users?" (p. 4-105)

RECOMMENDATION

"SCP updates should describe how local variability in the data will be presented in the block model." (p. 4-106)

DISPOSITION

Open. DOE's ISM 2.0 and related process models will address uncertainty in data and interpretations. DOE requested NRC feedback on the adequacy of ISM 2.0 for its intended purposes. Appendix 7 interactions were held in July and September, 1997. to provide preliminary staff feedback and to brief staff on the operation of the ISM 2.0 code. Resolution is pending staff's review of DOE's ISM 2.0 model.

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