COMPLIANCE DETERMINATION STRATEGY
RRT 3.2.1.8 POTENTIALLY ADVERSE CONDITION: OCCURRENCE OF MORE-FREQUENT/HIGHER-MAGNITUDE EARTHQUAKES

APPLICABLE REGULATORY REQUIREMENTS

10 CFR 60.21(c)(1)(ii)(B)
10 CFR 60.21(c)(1)(ii)(F)
10 CFR 60.122(c)(14)

TYPES OF REVIEW:

Acceptance Review (Type 1)
Safety Review (Type 3)
Detailed Safety Review Supported by Analysis (Type 4)
Detailed Safety Review Supported by Independent Tests, Analyses, or other Investigations (Type 5)

RATIONALE FOR TYPES OF REVIEW:

Acceptance Review (Type 1) Rationale:

This regulatory requirement topic is considered to be License Application-related because, as specified in the License Application content requirements of 10 CFR 60.21(c) and regulatory guide "Format and Content for the License Application for the High Level Waste Repository (FCRG), it must be addressed by the U.S. Department of Energy (DOE) in its license application. Therefore, the staff will conduct an Acceptance Review of the license application for this regulatory requirement topic.

Safety Review (Type 3) Rationale:

This regulatory requirement is considered to be related to containment and waste isolation. It is a requirement for which compliance is necessary to make a safety determination for construction authorization as defined in 10 CFR 60.31(a) (i.e., regulatory requirements in Subparts E, G, H, I). Therefore, the staff will conduct a Safety Review of the license application to determine compliance with this regulatory requirement.

This regulatory requirement topic, concerning a potentially adverse condition (PAC), focuses on DOE's demonstration, through appropriate investigations, of evidence for (or against) this PAC within the controlled area in order to understand the projected effect of this condition, if present, on the waste retention capability of the geologic repository. It concerns evidence that more frequent earthquakes or earthquakes of higher magnitude may occur within the site. In addition, such investigations must extend beyond the controlled area if it is ascertained that this PAC might adversely impact isolation within the controlled area.

Larger historic earthquakes are commonly of magnitude $M_S = 7+$ in the Basin and Range tectonic province which includes the site. The earthquakes occur in seismic zones such as the Walker Lane to the northwest, which merges with the Nevada-California seismic belt, the East-West seismic zone to the south

of the site and the north-south trending Intermountain Seismic Belt to the east of the site. Seismic activity, however, has proceeded in historic times at a slower rate than in adjacent California.

Although large historic earthquakes have not been known to occur at or immediately adjacent to the proposed site, the 1872 Owens Valley, California (M_S = 8.25) event occurred about 150 kilometers to the west of the Yucca Mountain site, in the Nevada-California zone (DOE 1988). Three substantial Nevada earthquakes have also occurred within about 150 km of the site in the past 83 years, M = 6.3 at Tonopah in 1910, M=6.0 at Caliente in 1966 and M = 5.6 in 1992 at Little Skull Mountain within 30 km of the site. Several smaller earthquakes within about 60 km of the site occurred in 1993. Other moderate to large earthquakes have occurred within Walker Lane which trends northwesterly from the site, and near the eastern boundary of the Basin and Range.

Yucca Mountain, therefore, is located in an area that is tectonically active (See DOE, 1988, pp 1-151 to 1-200). Because of the short period of earthquake history and evidence that seismicity has migrated throughout the Basin and Range tectonic province during Quaternary time (Ryall and VanWormer, 1980), it is unknown if this PAC may apply to Yucca Mountain over a 10,000 year time span.

Detailed Safety Review Supported by Analyses (Type 4) Rationale:

Projections concerning the potential for and effects of the presence of this PAC at Yucca Mountain may contain a large degree of uncertainty. This uncertainty could cause a high risk of non-compliance with the overall system performance objective and the subsystem performance objective for the engineered barrier system specified in 10 CFR 60.113(a)(1). Therefore, the staff considers that findings made under this requirement may be highly uncertain because of the following Key Technical Uncertainty.

The Key Technical Uncertainty associated with techniques to predict the likelihood of earthquake occurrence for 10,000 years is considered to require a Type 4 review because there is a risk of non-compliance with the performance objectives related to containment and waste isolation. This risk necessitates analyses above and beyond that required for Type 3 reviews to assure that the uncertainty, and the effects on performance, have been reduced to the extent practical.

Key Technical Uncertainty Topic: The inability to predict the likelihood of earthquake occurrence over the next 10,000 years.

Description of the Uncertainty: Because of the complexity and variability in time of tectonic processes, the lack of knowledge concerning their behavior in the Yucca Mountain area, and the short period of time over which historical and instrumental earthquake data have been collected, it will be difficult to accurately predict the recurrence rate of seismic activity at the site. Existing earthquake data for the site can be used for predictions over a relatively short time period (e.g., to 100 years). However for extrapolations to 10,000 years, as required by 10 CFR Part 60, there will be a large associated uncertainty which may be difficult to quantify.

Performance Objectives at Risk: 10 CFR 60.112 and 10 CFR 60.113(a)(1).

Explanation of Nature of Risk: A lack of knowledge about the rate of earthquake occurrence may lead to an underestimation of the design earthquake needed for structures, systems and components important to containment and waste isolation. For example, uncertainty regarding the effects of vibratory ground motion on the stability of a corroded waste package canister, or changes to the waste isolation

characteristics of the repository block could introduce significant uncertainty in analyses used to determine compliance with the performance objectives of 10 CFR 60.113(a)(1) and 10 CFR 60.112 respectively. Therefore the uncertainty in understanding the processes, features and characteristics related to earthquake activity, both direct and secondary, will be propagated into assessments of compliance with the performance objectives.

Description of Resolution Difficulty: Closure of this issue will be difficult because, currently, there are no proven methods for extrapolating relatively short-term earthquake data during the 10,000 years after repository closure. Methods are needed to provide reasonable assurance that the effects of more frequent occurrence of earthquakes of higher magnitude than are typical of the area of the geologic setting are identified and that predictions regarding these effects will not underestimate the actual effects of earthquakes on design of the repository and performance. As research in this area has not been done, the resolution difficulty for this Key Technical Uncertainty cannot be determined at this time. It is expected that a considerable amount of expert judgement will be used in extrapolating short-term seismic data. If no methods for extrapolating relatively short term data over the period of regulatory concern are developed, the staff would consider this Key Technical Uncertainty to require a Type 5 review.

Detailed Safety Review Supported by Independent Tests, Analyses, or Other Investigations (Type 5) Rationale:

Because the following Key Technical Uncertainties may be difficult to resolve, there may be the highest potential risk of non-compliance with the performance objectives specified below.

Key Technical Uncertainty Topic: Paleofaulting data indicates that seismic activity has migrated randomly from one major range front fault system to another in the Basin and Range tectonic province. Therefore there is considerable uncertainty that the relatively low seismicity at Yucca Mountain will continue over a 10,000 year period.

Description of Uncertainty: Analysis of available paleofaulting data (Ryall and VanWormer, 1980, VanWormer and Ryall, 1980 and Wallace, 1985 and 1987) indicates that seismic activity has migrated randomly from one range front fault system to another in the Basin and Range tectonic province. They imply that faults which are long enough to support a magnitude 7 earthquake are subject to this phenomenon. Yucca Mountain lies at the intersection of northwest-southeast and north-south trending major lineations. Several faults in the vicinity are estimated as capable of supporting a magnitude 7 or greater earthquake (DOE, 1988). Without additional analysis, at least the most frequent and highest magnitude earthquakes observed in the Basin and Range tectonic province must be assumed possible, over a 10,000 year period, at the site. Because of the relatively short historical record of seismicity, it is not possible to prove, without additional paleofault-offset data and analysis of seismicity to tectonic structure relationships, that more frequent or higher magnitude earthquakes than is typical of the area of the geologic setting will not occur at Yucca Mountain within a 10,000 year time period. Further, there may not be sufficient data available to make an adequate analysis. It is possible that a better understanding of tectonics may result in a rationale that would limit future seismic activity to a lesser degree than the highest level possible in the Basin and Range tectonic province.

Performance Objectives at Risk: 60.112, 60.113(a)(1) and 60.113(b).

Explanation of the Nature of Risk: There are about 80 to 100 range front fault systems in Nevada. Some are currently highly active. Others, like those near Yucca Mountain, currently show a relative low

rate of seismic activity. Paleo-faulting studies indicate that seismic activity skips randomly from one range front fault system to another with a periodicity of about 1200 years (Ryall and Van Wormer, 1980; Van Wormer and Ryall, 1980; and Wallace, 1985 and 1987). This suggests that there will be about 10 skips of seismicity from one range front to another in 10,000 years. It follows that there is about a 10 percent chance that Yucca Mountain will become as seismically active as the presently most active system in Nevada, during the next 10,000 years. If the causes of skipping or migrating seismicity are not better defined, this basis may have to be accepted. Magnitude 7+ earthquakes adjacent to or within Yucca Mountain may become the design basis.

Description of Resolution Difficulty: Resolution of this Key Technical Uncertainty is also dependent upon resolving the Key Technical Uncertainties associated with the PAC addressed in Review Plan 3.2.1.7 ("Correlation of Earthquakes with Tectonic Processes") in both space and time. These PACs are also potentially mitigated if design for magnitude 7+ earthquakes adjacent to or within the repository can be shown to be feasible.

Key Technical Uncertainty Topic: Many fault plane solutions from the historical seismic record do not agree with the fault movement indicated by striae (slickensides) on exposed fault planes, therefore fault movement, earthquake strong motions and their radiation patterns, which will be used in tectonic models, are uncertain.

Description of Uncertainty: Neither the nature of earthquakes nor the stress systems in which they occur are well understood in the Yucca Mountain region. Therefore there is substantial uncertainty concerning variations in seismic activity now and estimations for a 10,000 year period in the future.

Performance Objectives at Risk: 10 CFR 60.112 and 10 CFR 60.113(a)(1).

Explanation of the Nature of the Risk: Either the method of fault plane determination is inaccurate or the nature of faulting at depth is not understood in the Basin and Range tectonic province. Stress across a fault and consequently the acceleration which will result from a breaking fault are a function of fault type. If the fault type is in question, any projection of the potential acceleration that could be developed by movement on that fault is in question. A consequence is to assume that all faults will generate accelerations commensurate with the maximum stress observed across faults. This may result in very conservative designs or designs which cannot be implemented resulting in higher probabilities of damage to canisters, shafts and seals which in turn may provide more rapid pathways to the accessible environment.

Description of Resolution Difficulty: Theories concerning future tectonic movement are based upon an ambiguous understanding of earthquakes and causative fault movement. If this ambiguity cannot be resolved, these theories must be assumed ineffective in predicting future fault movement based upon historical movements. The degree of uncertainty that results may require conservative assumptions. Resolution may require basic research into earthquake mechanisms using digital seismic recordings to differentiate between initiating and overall fault slip directions.

Key Technical Uncertainty Topic: Correlation of earthquakes with tectonic features.

Description of the Uncertainty: There is a large uncertainty in the ultimate cause and source of earthquakes in the Basin and Range. Surface manifestations of faulting may not represent conditions at several kilometers depth where earthquake foci occur. Therefore, whether earthquakes are more frequent

or of higher magnitude than is typical of the area of the geologic setting, over a 10,000 year period, are characteristic of the controlled area may not be determinable unless the tectonics and current tectonic processes of the area are well understood. Additional paleo-faulting investigations may not determine whether this PAC applies to Yucca Mountain.

Performance Objectives at Risk: 60.112 and 60.113(a)(1).

Explanation of the Nature of the Risk: By definition, tectonic models are a simplification of reality. Both conceptual and mathematical models will be used in the high-level waste program. The conceptual model selected may have a significant effect on the scope of the field investigation program and on the interpretation of data (e.g., seismic, paleofaulting and geodetic and geophysical) obtained. In addition, the regulatory requirement itself relates to more than just the presence of certain features; it also requires an assessment of what may be present and undetected. Without a conceptual model of what is being investigated, it is impossible to comply with either the regulatory requirement for this PAC or the regulatory requirement related to overall system performance. Conceptual models can be used to describe the assumed physical and/or chemical processes which have been, are, or will be taking place within the system. Mathematical models are used in performance assessment to "predict" the behavior of a system. It is impossible to sample and describe any physical system which is as complex as that represented by the tectonic activity in the vicinity of Yucca Mountain. Because uncertainty will exist in the data and parameters, there will be an inherent uncertainty in the understanding of the physical system being represented by the model, and a consequent uncertainty in the correctness or validity of any conceptual model used. This uncertainty will be propagated through performance assessment, along with mathematical uncertainties, introducing an unknown amount of uncertainty in final results.

Description of Resolution of Difficulties: The Key Technical Uncertainty related to correlating earthquakes with tectonic features is considered to require a Type 5 review because very little has been done to reduce the risk of non-compliance with the performance objectives related to containment and waste isolation at this time. According to Davis *et al.* (1990), there is currently no methodology designed to quantify the uncertainty in conceptual models. Also, selection of the model(s) to be used, to correlate seismic activity and tectonic features, will be based, at least in part, on subjective judgement of experts and can, at best, be formalized and documented only to the extent that the assumptions used are clear, reasonable and traceable. Research to devise new methods of analysis, the collection of new data and the formulation and testing of tectonic models are required.

Summary: The reasons for a Type 5 review can be summarized as follows:

(1) The ability to quantitatively predict the occurrences of earthquakes in the Yucca Mountain area is, and is likely to remain, uncertain.

(2) An inability to differentiate between alternative tectonic models, necessary to resolve this PAC, is likely to continue to the time of licensing.

(3) Alternative models for the probability of earthquake activity and its effects may span several orders of magnitude.

(4) No proven method is available to extrapolate historic seismicity to a 10,000 year period.

(5) Whether or not the site will experience higher magnitude earthquakes or more frequent earthquakes than is typical of the geologic setting for 10,000 years is dependent on a known spatial and temporal clustering of seismic activity that is not adequately explained by existing theories. This topic is likely to remain highly contentious during licensing.

REVIEW STRATEGY:

Acceptance Review:

In conducting the Acceptance Review of the potentially adverse condition (PAC) concerning more frequent or higher magnitude earthquakes than are typical of the area in which the geologic setting is located, the reviewer should determine if the information present in the license application and its references for determining compliance with the applicable regulatory requirements is complete in technical breadth and depth as identified in regulatory guide, "Format and Content for the License Application for the High Level Waste Repository" (FCRG). The reviewer should determine whether all appropriate information necessary for the staff to review this PAC is presented such that the assessments required by the regulatory requirements associated with total system and subsystem performance objectives can be performed.

The information in the license application should be presented in such a manner that the assumptions, data and logic leading to a demonstration of compliance with the requirement are clear and do not require the reviewer to conduct extensive analyses or literature searches. The reviewer should also determine whether controversial information and appropriate alternative interpretations and models have been adequately described and considered.

Finally, the reviewer shall determine if the U.S. Department of Energy (DOE) has either resolved all the NRC staff objections that apply to this regulatory requirement topic or provided all the information requested in Section 1.6.2 of the FCRG for unresolved objections. The reviewer will evaluate the effects of any unresolved objections, both individually and in combinations with others, on: (1) the reviewer's ability to conduct a meaningful and timely review; and (2) the Commission's ability to make a decision regarding construction authorization within the three-year statutory period.

Safety Review (Type 3):

This regulatory requirement topic is limited to consideration of whether there are more frequent occurrences of earthquakes or higher magnitude earthquakes than is typical of the area in which the geologic setting is located, during a 10,000 year period of concern. It does not specifically address changes to hydrologic conditions caused by seismic activity. These topics will be covered under Sections 3.2.2.7 through 3.2.2.9 of the license application and its attendant review plans.

The specific aspects of the license application on which the reviewer will focus are described below, and the Acceptance Criteria are identified in Section 3.0 of this review plan. In conducting the Safety Review, the reviewer will, at a minimum, determine the adequacy of the data and analyses presented in the license application to support DOE's demonstrations regarding 10 CFR 60.122(c)(14). Specifically, DOE will need to: (1) provide information to determine whether and to what degree evidence of more frequent or higher magnitude earthquakes may be present than in the area of the geologic setting during 10,000 years; (2) provide information to determine to what degree the PAC is present; (3) assure the sufficiency of the lateral and the vertical extent of the data collection; and (4) evaluate the information presented in support

of Items (1) and (2), with assumptions and analysis methods that adequately describe the presence (or absence) of more frequent or higher magnitude earthquakes and ranges of parameters. Examples of the specific review activities that will be required of the staff include confirmation that DOE has fully considered the historically reported and instrumentally reported earthquakes, site and regional tectonic models, and paleoseismic events that are appropriate for this analysis.

DOE will also need to provide an explanation of the measures used to support the tectonic models used to assess the presence (or absence) of evidence for higher magnitude or more frequent earthquakes. Analyses and models that will be used to predict future conditions and changes in the geologic setting shall be supported by using an appropriate combination of such methods as field tests, *in-situ* tests, laboratory tests that are representative of field conditions, monitoring data, and natural analog studies.

In conducting the aforementioned evaluations, the reviewer should determine that DOE uses: (1) analyses that are sensitive to evidence of more frequent or higher magnitude earthquakes; and (2) assumptions which are not likely to underestimate its effects. In general, the reviewer will assess the adequacy of DOE's investigations for evidence of more frequent or higher magnitude earthquakes, both within the controlled area and outside the controlled area, as necessary in the manner outlined in Section 60.21(c)(1)(ii)(B).

In order to conduct an effective review, the reviewer will rely on staff expertise and independently acquired knowledge, information and data such as the results of research activities being conducted by the NRC's Office of Nuclear Regulatory Research, in addition to that provided by the DOE in its license application. For example, the reviewer may use U.S. Geological Survey Preliminary Determination of Epicenters (PDE) data to supplement historical data presented by DOE, or investigate NRC sponsored research projects which attempt to describe the relationship between tectonic structure and seismicity in finer detail than the use of regional statistics. The reviewer should focus on additional data which can refine knowledge of whether more frequent or larger earthquakes occur at the site over a 10,000 year period of concern. It is incumbent upon the reviewer to have acquired a body of knowledge regarding these and other critical considerations in anticipation of conducting the review to assure that DOE's program to resolve concerns related to this potentially adverse condition (See DOE, 1988, page 8.3.5.17-62) is sufficient in scope and depth.

Finally, investigations in the following DOE site characterization program study plans are expected to result in data and analyses needed to help in the review described above to address the presence or absence of this PAC:

Study Plan No.	Title
8.3.1.17.3.1	Relevant Earthquake Sources (DOE, 1990)
8.3.1.17.4.1	Historical and Current Seismicity at Yucca Mountain (DOE, 1991)

Reports on additional study plans related to this PAC, when available, will also be reviewed.

Detailed Safety Review Supported by Analysis (Type 4):

A Detailed Safety Review supported by analysis will be needed for the Key Technical Uncertainty regarding the inability to predict the likelihood of earthquake occurrence during the next 10,000 years.

This will ensure that DOE has adequately demonstrated Items (1)-(4), listed in the previous section (see Section 2.2.1 ("Safety Review"), paragraph 2).

However, the evaluation of this Key Technical Uncertainty will be addressed in Review Plan 3.2.1.7 "Correlation of Earthquakes With Tectonic Processes" of the License Application Review Plan.

Detailed Safety Review Supported by Independent Tests, Analyses, or Investigations (Type 5) Review:

A Detailed Safety Review and Analysis will be needed for evaluation of the Key Technical Uncertainties regarding (1) migration of seismic activity from one fault system to another; (2) the disparity between earthquake fault plane solutions and fault movement striae (slickensides); and (3) the correlation of earthquakes with tectonic processes. This will ensure that DOE has adequately demonstrated Items (1)-(4) listed in the section on "Safety Review" (see Section 2.2.1, paragraph 2).

For the Key Technical Uncertainties (1) and (2) listed in the previous paragraph, the staff's detailed safety review will also be supported by conceptual and numeric models developed by the staff to determine if the models being used by DOE provide an adequate explanation of the phenomenon of earthquake activity. In conducting this review, the staff must evaluate the different conceptual models to determine if they are consistent with those being proposed for other related processes. Through modeling exercises, the staff will develop various tectonic models and attempt to define the correlation between earthquake data and tectonic structures presented by the model.

For the Key Technical Uncertainty (3) concerning "Correlation of Earthquakes With Tectonic Processes," a Detailed Safety Review will be required. However, the evaluation of this Key Technical Uncertainty will be addressed in Review Plan 3.2.1.7.

Examples of specific review activities that will be required include: (1) determining whether, a) an adequate base of paleoseismic data has been acquired and analyzed to support the brief historic earthquake record, b) adequate methods have been developed to test and evaluate models which may have been developed to limit or verify observed historic and paleoseismicity, and c) conclusions are supportable by data as well as expert opinion (continuing evolution of the Basin and Range tectonic province over the next 10,000 years will be predicted by assuming credible seismotectonic models developed by DOE and independently by the NRC); (2) examining the consistency of DOE's models with field observations made during site characterization; and (3) comparing the results presented by DOE in its license application, to the results of NRC's independent confirmatory analysis. In conducting this review, investigations may also include collecting field data and constructing 3-D models.

When reviewing and creating models, it should be recognized that, in addition to field data, subjective judgement will also be required. It is important that the various assumptions necessary for models be carefully documented and thoroughly reviewed. Probabilistic assessments, field data, and results of research activities should be included to narrow and distinguish between alterative models proposed. It is anticipated that several conceptual models may be reasonable at the time of licensing. The staff must assure that they reflect the degree of resolution permitted by experimental and investigative methods, including phenomena that may be present but undetected because of limitations of the methods employed. The staff must assure that the models used incorporate all appropriate field data and assumptions.

The following DOE study plans and resulting studies should be reviewed to determine if the existence of this PAC is adequately resolved in the License Application:

Study Plan No.	Title
8.3.1.4.2.2	Characterization of Structural Features in the Site Area (DOE, 1992)
8.3.1.17.2.1	Faulting Potential at the Repository (DOE, in preparation)
8.3.1.17.4.3	Quaternary Faulting Within 100km of Yucca Mountain, Including the Walker Lane (DOE, 1993)
8.3.1.17.4.5	Detachment Faults at or Proximal to Yucca Mountain (DOE, 1992)
8.3.1.17.4.6	Quaternary Faulting Within the Site Area (DOE, 1990)
8.3.1.17.4.12	Tectonic Models and Synthesis (DOE, in preparation)

Reports on additional study plans related to this PAC, when available, will also be reviewed.

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Date of Analysis: 06/16/1993

RATIONALE FOR REVIEW STRATEGY (OPTIONAL):

In view of the complexity of the key technical uncertainties described, it is appropriate that the NRC conduct independent activities to: (1) develop licensing tools and technical bases necessary to judge the adequacy of DOE's license application; (2) assure sufficient independent understanding of the basic physical processes taking place at the geologic repository; and (3) maintain an independent but limited confirmatory research capability under NRC auspices.

APPLICABLE REGULATORY REQUIREMENTS FOR REVIEW TYPES:

Type 1:
10 CFR 60.21(c)(1)(ii)(B)
10 CFR 60.21(c)(1)(ii)(F)
10 CFR 60.122(c)(14)
Type 3:
10 CFR 60.122(c)(14)
Type 4:
10 CFR 60.122(c)(14)
Type 5:
10 CFR 60.122(c)(14)

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U.S. Department of Energy, "Study Plan for Tectonic Models and Synthesis." Office of Civilian Radioactive Waste Management, Study Plan 8.3.1.17.4.12, In Preparation.

U.S. Department of Energy, "Study Plan for Quaternary Faulting Within 100KM of Yucca Mountain, Including the Walker Lane." Office of Civilian Radioactive Waste Management, Study Plan 8.3.1.17.4.3, 1993.

U.S. Nuclear Regulatory Commission, "NRC Staff Site Characterization Analysis of the Department of Energy's Site Characterization Plan, Yucca Mountain Site, Nevada." NUREG-1347, 1989.

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