Conf-

SAND--91-2499C

DE92 006553

PRECLOSURE SEISMIC HAZARDS AND THEIR IMPACT ON SITE SUITABILITY OF YUCCA MOUNTAIN, NEVADA*

JAN 21 1992

J. DUANE GIBSON
Sandia National Laboratories
505 844-8823
P.O Box 5800
Albuquerque, New Mexico 87185

ABSTRACT

This paper presents an overview of the preclosure seismic hazards and the influence of these hazards on determining the suitability of Yucca Mountain as a national high-level nuclear-waste repository. Geologic data, engineering analyses, and regulatory guidelines must be examined collectively to assess this suitability. An environmental assessment for Yucca Mountain, written in 1986, compiled and evaluated the existing tectonic data and presented arguments to satisfy, in part, the regulatory requirements that must be met if the Yucca Mountain site is to become a national waste repository. Analyses have been performed in the past five years that better quantify the local seismic hazards and the possibility that these hazards could lead to release of radionuclides to the environment. The results from these analyses increase the confidence in the ability of Yucca Mountain and the facilities that may be built there to function satisfactorily in their role as a waste repository. Uncertainties remain, however, primarily in the input parameters and boundary conditions for the models that were used to complete the analyses. These models must be validated and uncertainties reduced before Yucca Mountain can qualify as a viable high-level nuclear-waste repository.

INTRODUCTION

Yucca Mountain, located approximately 150 km northwest of Las Vegas, Nevada, is being considered as a potential site for a high-level nuclear-waste repository. The U.S. Department of Energy (DOE) is currently examining all factors in the site suitability of Yucca Mountain within the framework of 10 CFR Part 960, "General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories." This discussion concentrates on one aspect of the site suitability: seismic and faulting hazards during the period of building, operating, and decommissioning of the repository, which is known as the "preclosure" period. The regulatory requirements for a high-level nuclear-waste repository must be compared with our knowledge of these hazards at Yucca Mountain and the ability of the planned facilities to retain their integrity during earthquake-induced ground motion or surface rupture.

General guidelines for recommending potential sites for a national high-level nuclear-waste repository are defined in 10 CFR Part 960. An objective of these guidelines is to ensure that a site is located within a geologic setting where any expected seismic hazards during the preclosure period can be mitigated by reasonably available technology. Separate legislation, 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," governs the licensing of a nuclear-waste repository by the Nuclear Regulatory Commission (NRC). Additional requirements, such as 40 CFR Part 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," also must be met. 10 CFR Part 960 directs the DOE in its investigation and evaluation of potential sites for a high-level nuclear-waste repository, while 10 CFR Part 60 is used by the NRC to appraise the license application for a potential high-level nuclear-waste repository.

The preclosure tectonics technical guideline for a potential high-level nuclear-waste repository, as specified in 10 CFR Part 960.5-2-11, establishes six distinct conditions (Table 1). These include one qualifying condition, one favorable condition, three potentially adverse conditions, and one disqualifying condition. Review of only the qualifying and disqualifying conditions is required to assess site suitability. Although the favorable and potentially adverse conditions are listed here, these conditions merely aid in selection of possible alternate sites for a repository.

EXTENT OF REGULATORY COMPLIANCE

An assessment of the Yucca Mountain site relative to the guidelines in 10 CFR Part 960 formed part of an environmental assessment (EA) of Yucca Mountain. This EA[1] presents evidence to evaluate each of the six conditions listed in Table 1. As described in 10 CFR Part 960, evaluations at a lower confidence level ("lower-level findings") for both the preclosure tectonics qualifying and disqualifying conditions are required for nomination and recommendation of the site. Results of higher confidence ("higher-level findings") are required for repository site selection.

When reviewing the favorable and potentially adverse conditions at Yucca Mountain, the EA found that the site does not qualify for the favorable condition because the nature and rates of faulting are not significantly less than those generally allowable for the construction and operation of nuclear facilities. Yucca Mountain is located in a region with known low-to-moderate seismic activity.[1] Because there has been Quaternary

*This work was performed under the auspices of the U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Project, under Contract DE-AC04-76DP00789.

MASTER

Table 1. Preclosure Tectonics Technical Conditions, from 10 CFR Part 960.5-2-11

Issues Used for Evaluation of Site Suitability	Issues Used for Selection of Alternate Sites
Qualifying Condition: "The site shall be located in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity on repository construction, operation, and closure will be such that the requirements in Section 960.5-1(a)(3) can be met." Disqualifying Condition: "A site shall be disqualified if, based on the expected nature and rates of fault movement or other ground motion, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory shaft construction and for repository construction, operation, or closure."	Favorable Condition: "The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities." Potentially Adverse Condition #1: "Evidence of active faulting within the geologic setting." Potentially Adverse Condition #2: "Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits." Potentially Adverse Condition #3: "Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity."

faulting at the site, the first potentially adverse condition is also present at the site. Yucca Mountain still can be considered as a candidate site for a nuclear-waste repository with these results for these two conditions. However, if the same conclusions for these conditions remain after site characterization and supporting analyses are completed, reasonably available technology must negate any adverse effects of these conditions.

Despite the responses the EA contains for these technical conditions, the authors of the EA felt sufficient evidence existed to support "lower-level findings" (see 10 CFR Part 960), as opposed to "higher-level findings" or no findings at all, for both the qualifying and disqualifying conditions for preclosure tectonics. Confidence in the status of technical conditions for preclosure tectonics must be raised before license application by the DOE to the NRC for the Yucca Mountain site.

TECHNICAL BASIS CONSIDERED IN THE EA

As presented in the EA for Yucca Mountain,[1] the only tectonic activity expected at or near Yucca Mountain during the preclosure period are small-magnitude ($M \leq 5$) earthquakes that are within reasonably available design limits. Basic assumptions of the EA are that the rate and style of tectonic activity during the preclosure period will be similar to that during the period documented in the historical record and that the likelihood of a larger-than-historic event is low during the preclosure period. The EA recognizes that Yucca Mountain lies on the boundary between two seismotectonic zones that have different levels of seismic activity. The zone to the south, which includes Las Vegas, Nevada, has a recurrence interval for large ($M \geq 7$) earthquakes of 190,000 years (yr),[2] while the northern zone has recurrence intervals for the same magnitude earthquakes on the order of 7,000 to 10,000 yr.[3] The EA assumes that recurrence intervals for $M \leq 7$ earthquakes at Yucca Mountain are on the order of 25,000 yr; $M \leq 6$ earthquakes would have recurrence intervals of 2,500 yr; and $M \leq 5$ earthquakes would have recurrence intervals of 250 yr. Little was known about how conservative these estimates were.

The peak historical ground acceleration related to earthquake sources recorded near Yucca Mountain was estimated in 1977 as less than 0.1g.[4] In 1984, the United States Geological Survey (USGS) deterministically estimated[5] the most likely peak acceleration at Yucca Mountain would be approximately 0.4g. This acceleration is based on a rupture of the entire length of the Bare Mountain fault, 14 km west of Yucca Mountain. In a separate probabilistic analysis, the USGS predicted[5] that an earthquake resulting in 0.4g ground acceleration at Yucca Mountain has a return period of 900 to 30,000 yr. During the 90-yr lifetime of the respository operations (the preclosure period), the probability of exceeding 0.4g ground acceleration was estimated[5] to be between 3×10^{-3} and 1×10^{-1}.

Quaternary faults at Yucca Mountain were only beginning to be recognized by paleoseismologists at the time of publication of the EA and had not been incorporated into seismic hazard analyses. The EA recognizes that large uncertainties exist in these analyses and states "At this time, it is premature to place much confidence in these estimates, other than using them to provide insight until a more complete assessment can be made of the various input parameters that are required for a probabilistic seismic hazard analysis."[1]

Uncertainties in the seismological input parameters for seismic hazard analyses at Yucca Mountain include the following: (1) the historical seismic record is relatively short, approximately 100 yr, and (2) the regional seismic net at Yucca

Mountain has been active only since 1978. Other uncertainties affecting seismic hazard analyses include the nature of relationships that are appropriate for estimating the ground acceleration, velocity, and displacement associated with an earthquake of given magnitude at a given distance from the site. These uncertainties relate to the geometry of sources or source zones with respect to the site, the distribution of earthquakes of various magnitudes within the source zones, and the appropriate attenuation function for Yucca Mountain. Relationships between fault length and earthquake magnitude have not been well established for the Yucca Mountain region. Calculations of expected earthquake magnitude based solely on fault length contain large uncertainties.

DEVELOPMENTS SINCE THE EA

Geologic Data and Inferred Tectonic Setting

As presented in the Site Characterization Plan for Yucca Mountain[6] and other documents,[7] several tectonic models exist for the mountain. Quaternary faulting in the vicinity of Yucca Mountain may represent deformation above deeper and perhaps different seismogenic structures, representing some type of strain partitioning[8] or decoupling of deformation between the upper and lower crusts. These deeper seismogenic structures may have different strain rates than structures near the surface. Recently, geologic cross sections have been published that include low-angle normal faults, or detachment faults, that may divide the crust into two or more subhorizontal plates.[9] Figure 1 shows schematically the proposed step-like geometry of normal faults at Yucca Mountain, merging at depth into a detachment fault. At depths below 10 to 12 km, there is ductile deformation and a lack of earthquakes; this is the depth of the seismogenic zone. Whether there are multiple plates in the upper crust beneath Yucca Mountain is not known.

Although strictly hypothetical at this time, a speculative tectonic model with structures "hidden" beneath shallow detachment faults that have higher strain rates than structures at the surface may potentially represent the worst-case tectonic scenario at Yucca Mountain. Site characterization efforts will aid in defining the worst-case preclosure tectonic scenario and determining if this scenario poses an unacceptable risk. The higher strain rates on structures beneath a shallow detachment fault for this potential worst-case scenario could result in more frequent, large-magnitude earthquakes than would be predicted only from studying structures at the surface. Historical and instrumental seismic records, although of limited duration and resolution, show no obvious concentration of seismicity in the Yucca Mountain area and would suggest that the likelihood of this worst-case scenario is small. This and other recently developed tectonic models, such as the model proposed by Carr,[10] need to be considered in future evaluation of seismic hazards at Yucca Mountain.

Paleoseismic studies since the EA have recognized that certain faults near Yucca Mountain have been active within the Quaternary; these studies have begun to quantify movement[9] and to recognize segmentation[11] and the possible distributive nature of faulting[12] at Yucca Mountain. The details of fault segmentation during seismic events are still under investigation. Evidence exists that multiple faults may be active during the same or a closely related seismic event.[12] The implications of this distributive faulting on seismic hazards at Yucca Mountain are not well understood.

The Paintbrush Canyon fault (Figure 2) and its southern extension, the Stagecoach Road fault, now are considered the dominant source of ground-motion hazard at Yucca Mountain, instead of the Bare Mountain fault.[13] The Paintbrush Canyon fault, which lies to the east of and dips westward toward Yucca Mountain, is thought to extend for approximately 33 km.[6] Slip rates on the Paintbrush Canyon and other nearby faults have

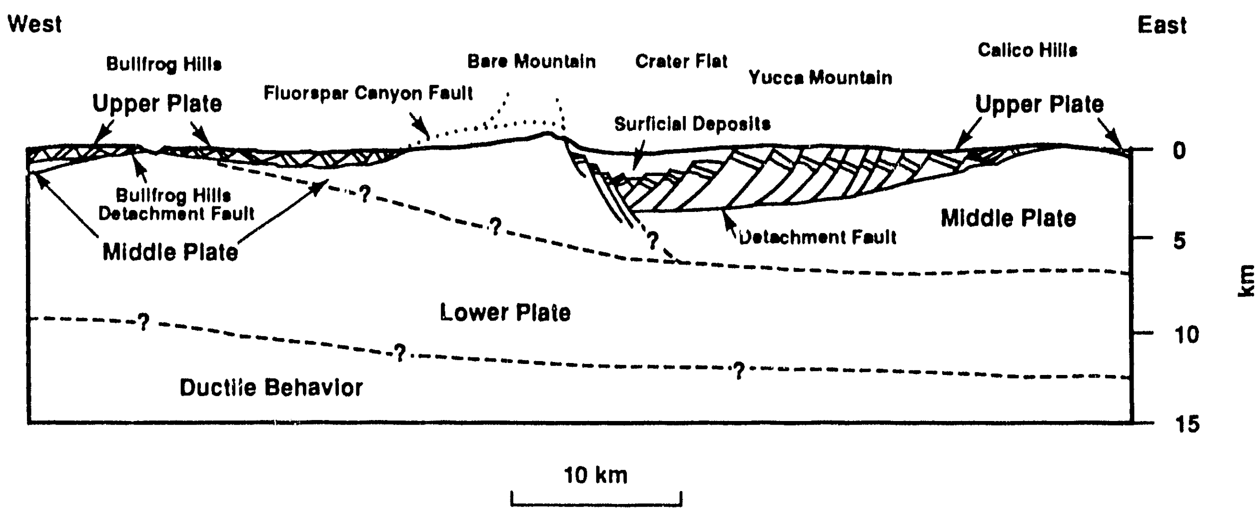

Figure 1. Conceptual Cross Section From the Calico Hills to the Bullfrog Hills, Modified From Scott[9]

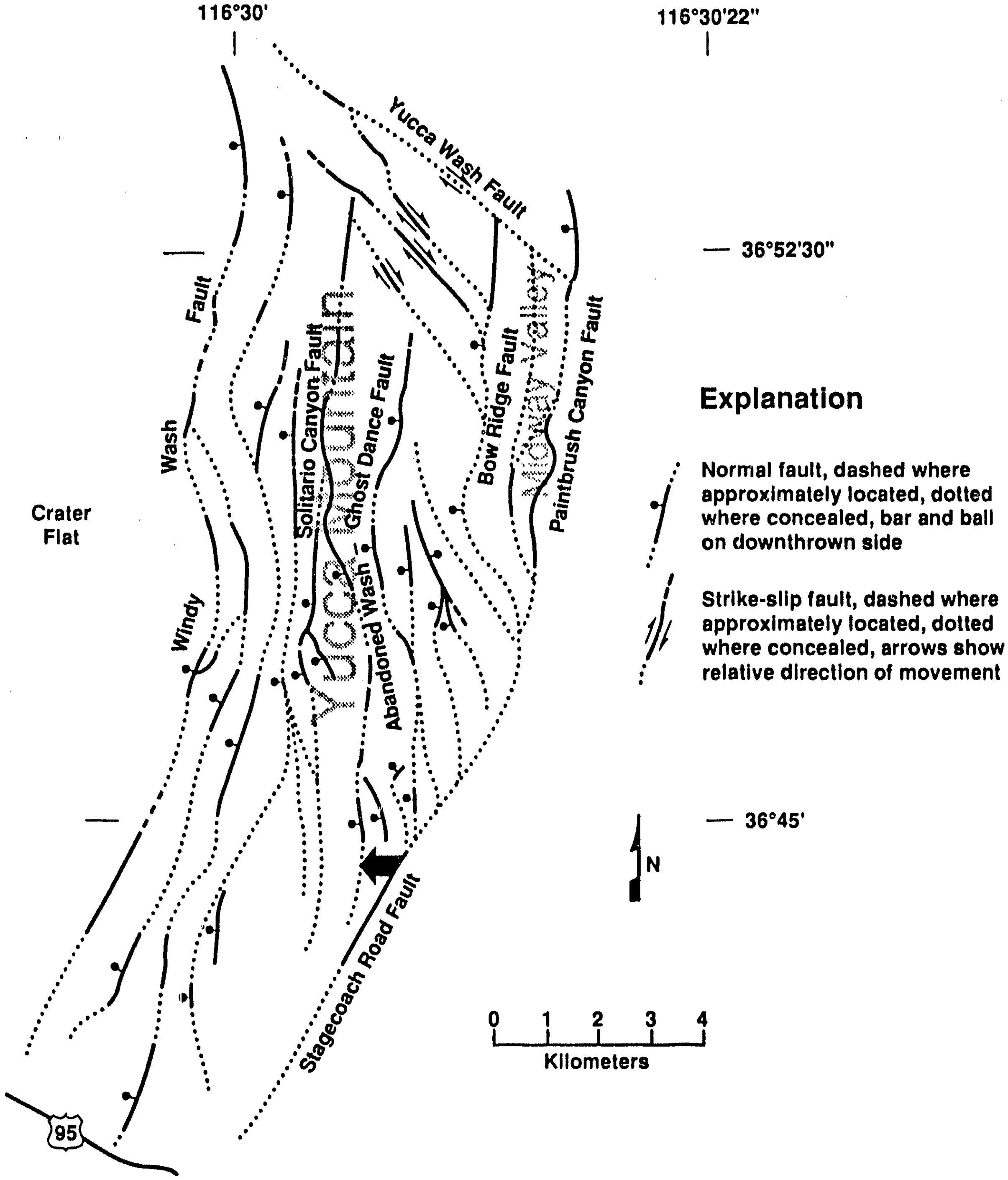

Figure 2. Fault Map of Yucca Mountain, Nevada, Modified From Scott[9]

varied both temporally and spatially from the Tertiary into the Quaternary.[9] Vertical slip rates from 10 to 13 million yr ago for the Paintbrush Canyon and Stagecoach Road faults average about 0.04 mm/yr and 0.45 mm/yr, respectively, synchronous with eruption of the Paintbrush Tuff that makes up Yucca Mountain. Higher percentages of E-W extension are seen in the southern portion of the mountain than in the north.[9] Rates on both faults have slowed to about 0.005 mm/yr in the Quaternary. Recent results indicate a left-lateral component to displacements on the Paintbrush Canyon fault.[14]

Potential for Ground Motion and Surface Rupture

Recent studies on seismic hazards at Yucca Mountain have concentrated on the critical surface facilities, including the waste-handling buildings where waste would be received and repackaged for placement underground during the preclosure period. It is thought that the hazard for seismically induced damage to the underground facilities is less than for the critical surface facilities during the preclosure period. Waste is most vulnerable to potential release to the environment while it is being received and repackaged for placement underground. This handling occurs within the hot cells of the waste-handling buildings. At other times, the spent fuel is sealed within waste canister and containers. URS/Blume[13] studied the contribution by nearby faults to the ground-motion hazard (Figure 3) for these buildings at their proposed location within Midway Valley at the eastern base of Yucca Mountain. They found that, of the local faults, the Paintbrush Canyon fault dominates the ground-motion hazard at all levels of ground acceleration.

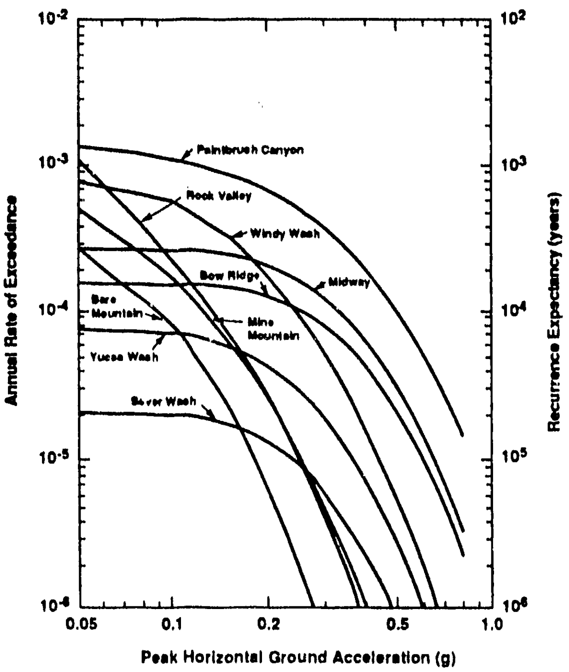

Figure 3. Contribution From Nearby Faults to the Seismic Hazard at Yucca Mountain, From URS/Blume[13]

Figure 4 shows the estimated total seismic hazard for the proposed site of the surface facilities within Midway Valley from the URS/Blume study.[13] At the lowest values of ground acceleration, the highly active California faults, such as the Garlock and Death Valley fault zones, control the ground-motion hazard. For acceleration values in the 0.1 to 0.2g range, background earthquakes dominate. These background earthquakes are not associated with any recognized fault. At ground accelerations above 0.2g, the Paintbrush Canyon fault dominates the seismic hazard.

URS/Blume[13] present ground-motion-hazard curves for three different speculative tectonic models (Figure 5). The total seismicity varies between models with changes in slip rates that result from differing fault dimensions. The results of URS/Blume suggest that different tectonic models may not have a significant impact on the expected ground-motion hazards at Yucca Mountain.

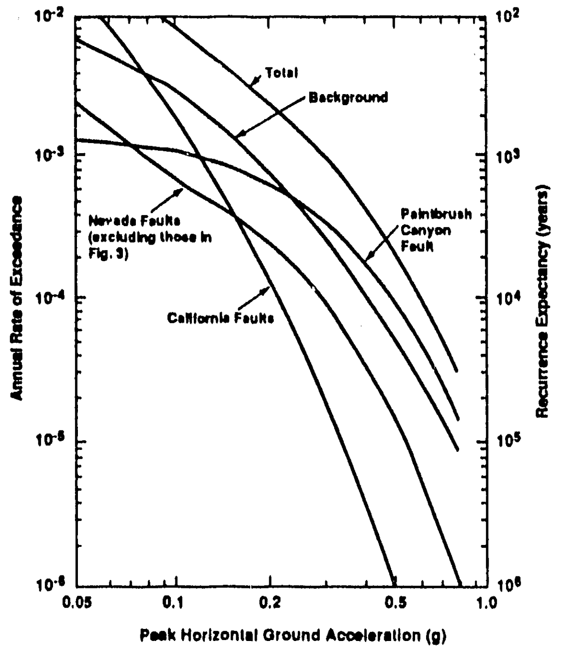

Figure 4. Contribution to Seismic Hazards at Yucca Mountain by Selected Faults and Groups of Faults, From URS/Blume[13]

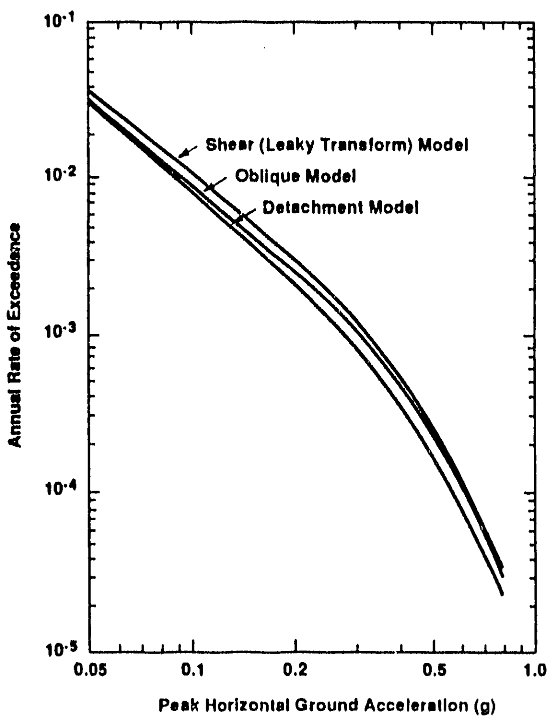

Figure 5. Total Seismic Hazard for Yucca Mountain Based on Three Different Tectonic Models, From URS/Blume[13]

The "oblique" tectonic model assumes that faults at Yucca Mountain have horizontal slip on strike-slip and normal-oblique faults, and vertical slip on normal-oblique and normal faults. Horizontal and vertical slip rates are assumed to be the same. Background seismicity rates were calculated based upon a total seismicity of 0.015 events of magnitude 4 or greater per year per 1,000 km^2. A b-parameter of 0.9 (used in defining the relation between earthquake frequency and magnitude), the rupture-magnitude relations of Bonilla et al.,[15] the Utah attenuation model of Campbell,[16] and the 2-slope power-law relation between slip rate and fault length were assumed. In this model, the seismogenic zone extends to a depth of 15 km.

A second tectonic model, the "detachment" model that has some similarities to that of Scott,[9] assumes the same slip vectors on faults as in the "oblique" model, but incorporates a subhorizontal detachment fault that truncates these faults at depth. For this model, plastic deformation below the detachment fault limits the seismogenic zone to only 7.5 km depth. Because of the truncation of faults at depth by a detachment fault and the resulting reduced width of fault surfaces, the upper bounds of magnitudes for earthquakes on faults in the immediate vicinity of Yucca Mountain are reduced in accordance with the reduction in maximum seismic moment. The URS/Blume study found that the detachment model has a lesser seismic hazard than the oblique tectonic model.

A major difference between the detachment models of URS/Blume[13] and Scott[9] is that the model of URS/Blume has a single detachment fault that lies at the brittle-ductile transition, while the model of Scott, as seen in Figure 1, potentially has multiple detachment faults that lie within the zone of brittle deformation of the upper crust. The model for detachment faulting as depicted by Scott could result in seismogenic sources of an unknown nature below a shallow, upper crustal detachment fault. The implications of various styles of detachment faulting on ground-motion hazards at Yucca Mountain have not been addressed.

The third tectonic model considered by URS/Blume,[13] the "shear" model, assumes that Crater Flat, located to the west of Yucca Mountain, lies within a broad "leaky" transform fault zone; the Quaternary volcanism in Crater Flat is related to this transform zone. In this model, Crater Flat represents a pull-apart basin with associated volcanism. The basin is assumed to have formed between the NW-trending Bare Mountain fault and an unmapped extension of the NW-trending Yucca Wash fault. The extension of certain NW-trending faults, such as the Yucca Wash fault, beyond their present assumed lengths causes the slightly higher predicted ground-motion hazards for this model.

The other seismic hazard to be considered at Yucca Mountain is earthquake-related surface rupture (Figure 6). Fault displacements could affect the foundations of the waste-handling buildings as well as the underground repository. Subramanian et al.[17] concentrated their study of surface-rupture hazard on the surface facilities and assumed a location for these facilities immediately east of Exile Hill within Midway Valley. They also assumed that any Quaternary faults beneath the foundations would be found during trenching studies. The probabilities of exceedance for significant vertical ruptures, as shown in Figure 6, are at least two orders of magnitude less than the probabilities for significant ground motion shown in Figure 5. Subramanian et al. concluded that surface rupture is less of a hazard than ground motion to the critical surface facilities.

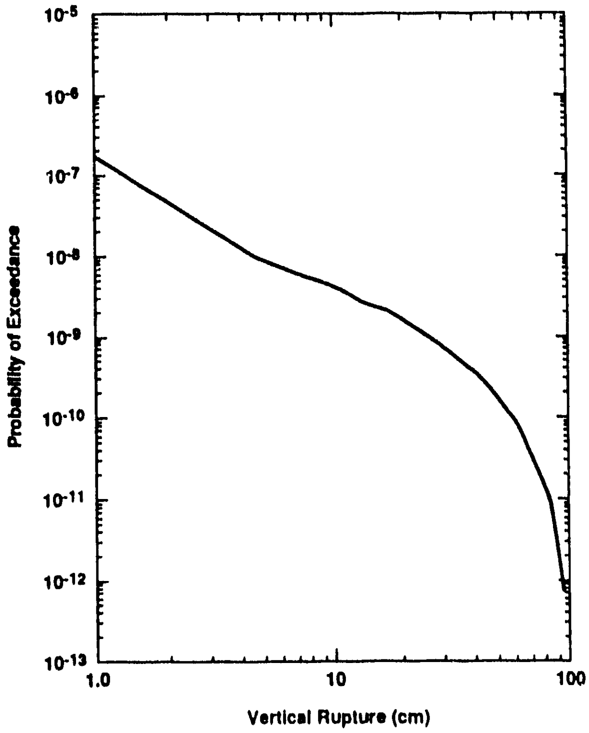

Figure 6. Surface Rupture Hazard Curve for the Waste-Handling Building, Assuming a Location East of Exile Hill in Midway Valley, From Subramanian et al.[17]

Failure Hazard

To evaluate the failure hazard of the surface facilities, the ground-motion and surface-rupture hazards must be integrated with a design level for the facilities. Subramanian et al.[17] assumed five design levels from 0.2g to 1.0g for the surface facilities. The surface facilities are intrinsically robust structures because of the radiation shielding requirements. These shielding requirements include several feet of reinforced concrete around the hot cell within the waste-handling building.

Subramanian et al.[17] present fragility curves for the waste-handling building for different design levels. These fragilities present the probability of failure for different peak ground accelerations and surface displacements (Figures 7 and 8). They define four different damage levels, from a light damage level (walls are cracked but there is no release of radioactive material) to total damage (the facilities are completely destroyed and all the radionuclides are released). For the ground-acceleration curves, a cut-off acceleration of 2.5g was chosen. This cut-off value is very conservative since it is equivalent to the largest earthquake-induced ground motion ever recorded. Portions of

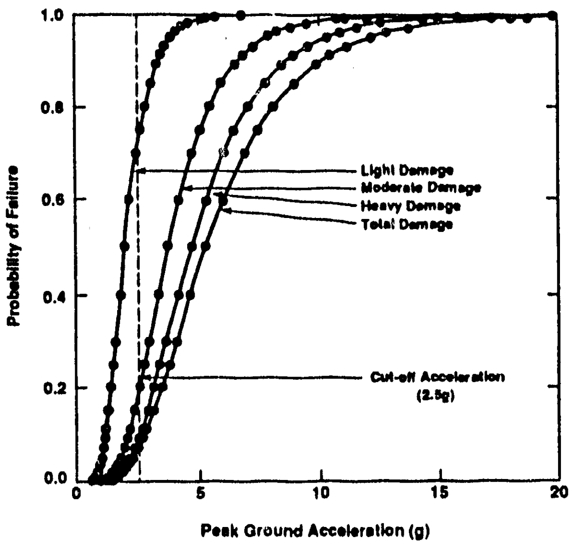

Figure 7. Ground Motion Fragility Curves for an Average Wall of the Waste-Handling Building, 0.4 g Design, From Subramanian et al.[17]

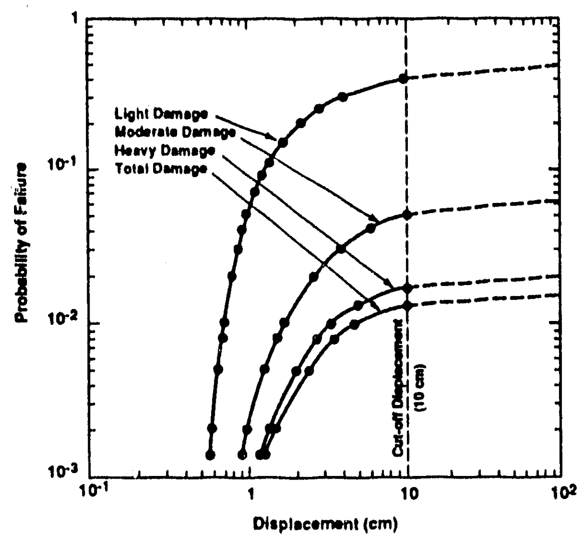

Figure 8. Fault Displacement Fragility Curves for the Tilted Building Mode, Waste-Handling Building, 0.4 g Design, From Subramanian et al.[17]

the curves to the right of this cut-off acceleration are not geologically realistic. The probability of failure for a light damage level becomes significant only over 1.0g ground acceleration. For moderate-to-total damage levels that include release of radionuclides, much stronger ground accelerations are required than are expected at Yucca Mountain. If a higher design level than 0.4g is chosen, all of these curves are shifted to the right, reducing the probability of failure for a given peak ground acceleration.

In addition, Subramanian et al.[17] assumed different amounts of fault displacements beneath the foundations of these facilities (Figure 8). They used the same definitions for damage levels in these calculations as with the ground-motion hazards. Displacements less than 1 cm should have little effect on the surface facilities. These authors used a cut-off displacement of 10 cm for the maximum expected surface-rupture displacement. Although surface ruptures with vertical separations in excess of 10 cm are seen throughout the world, the authors considered this value to be conservative at this site because they assumed that no Quaternary faulting would be found during a trenching study of the facilities' foundations. The low probabilities for surface rupture found on Figure 6 also indicate a low hazard from surface-rupture displacement.

CONCLUSIONS

The EA for Yucca Mountain, published in 1986, compiled and evaluated the existing preclosure tectonics data and compared these data with the technical guidelines presented in 10 CFR Part 960 for evaluating a potential site for a high-level nuclear-waste repository. Lower-level findings were made for both the qualifying and disqualifying preclosure tectonics conditions at Yucca Mountain. These findings allow site nomination and recommendation to proceed, but higher-level findings are required if Yucca Mountain is to be selected as a repository.

Analyses have been performed in the past five years that better define the seismic hazards and the potential effects of these hazards on a nuclear-waste repository at Yucca Mountain. Confidence has been increased that the planned designs for structures within the repository will be able to withstand the expected ground motion and surface ruptures without release of radionuclides. These analyses have concentrated on the critical surface facilities, which include the waste-handling building. Limited quantitative data on fault activity were acquired during this period. These data were incorporated, at least in part, into new analyses. Perhaps most significant, faults within the immediate vicinity of Yucca Mountain, such as the Paintbrush Canyon fault, are now recognized as the dominant seismogenic sources.

A hiatus of several years has occurred in collection of site-specific data at Yucca Mountain, because of programmatic delays, although field work has now recommenced. These site-specific data are needed to refine and validate the seismic hazard and failure analyses. As additional information becomes available, new probabilistic and combined probabilistic/deterministic seismic hazard analyses are needed to update assessments. Explicit quantitative goals for evaluating potential hazards at a potential nuclear-waste repository are not included in 10 CFR Part 960. Additional site-specific data are needed until a point when the DOE has sufficient confidence in understanding the seismic hazards at Yucca Mountain so that higher-level findings for both the qualifying and disqualifying conditions for preclosure tectonics can be made. Otherwise, another site for a potential nuclear-waste repository must be considered. Preliminary assessments of the ground-motion and the surface-rupture hazards indicate that there is a low probability of either of these hazards occurring at the site and that the hazard from surface rupture is significantly less than from ground motion.

The low probability of strong ground motions and large surface-rupture displacements, combined with the intrinsically robust nature of the surface facilities, results in an extremely small probability of release of radionuclides from these facilities. The results of more detailed seismic hazards analyses and failure analyses have increased confidence that the Yucca Mountain site can meet regulatory requirements. However, the assumptions made during these analyses must be validated by site-specific data before license application for the site.

REFERENCES

1. U.S. DEPARTMENT OF ENERGY (DOE), Environmental Assessment, Yucca Mountain Site, Nevada Research and Development Area, Nevada, Office of Civilian Radioactive Waste Management, Washington, DC (1986).

2. R. W. GREENSFELDER, F. C. KINTZER, and M. R. SOMERVILLE, "Probable Earthquake Ground Motion as Related to Structural Responses in Las Vegas, Nevada," JAB-000999-120, URS/John A. Blume and Associates, Engineers, San Francisco, CA (1980).

3. A. S. RYALL and J. D. VANWORMER, "Estimation of Maximum Magnitude and Recommended Seismic Zone Changes in the Western Great Basin," Bulletin of the Seismological Society of America, 70(5), 1573-1582 (1980).

4. A. M. ROGERS, D. M. PERKINS, and F. A. MCKEOWN, "A Preliminary Assessment of the Seismic Hazard of the Nevada Test Site Region," Bulletin of the Seismological Society of America, 67(6), 1587-1606 (1977).

5. UNITED STATES GEOLOGICAL SURVEY (USGS) (comp.), "A Summary of Geological Studies through January 1, 1983, of a Potential High-Level Radioactive Waste Repository Site at Yucca Mountain, Southern Nye County, Nevada," USGS-OFR-84-792, U.S. Geological Survey, Menlo Park, CA (1984).

6. U.S. DEPARTMENT OF ENERGY (DOE), Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada, Office of Civilian Radioactive Waste Management, Washington, DC (1988).

7. J. L. KING, G. A. FRAZIER, and T. A. GRANT, "Assessment of Faulting and Seismic Hazards at Yucca Mountain," Radioactive Waste Management and the Nuclear Fuel Cycle, 12(1-4), 155-170 (1989).

8. W. R. LETTIS and K. L. HANSON, "Crustal Strain Partitioning: Implications for Seismic-Hazard Assessment in Western California," Geology, 19, 559-562 (1991).

9. R. B. SCOTT, "Tectonic Setting of Yucca Mountain, Southwest Nevada," Geological Society of America Memoir 176, 251-282 (1990).

10. W. J. CARR, "Styles of Extension in the Nevada Test Site Region, Southern Walker Lane Belt: an Integration of Volcano-Tectonic and Detachment Fault Models," Geological Society of America Memoir 176, 283-303 (1990).

11. J. W. WHITNEY and D. R. MUHS, "Quaternary Movement on the Paintbrush Canyon-Stagecoach Road Fault System, Yucca Mountain, Nevada," Proceedings of the Geological Society of America, Annual Meeting, 1991, San Diego, 23(5), A119 (1991).

12. A. R. RAMELLI, J. W. BELL, and C. M. DEPOLO, "Evidence for Distributive Faulting at Yucca Mountain, Nevada," Proceedings of the Geological Society of America, Annual Meeting, 1988, Denver, 20(7), A383 (1988).

13. URS/J. A. BLUME AND ASSOCIATES, "Technical Basis and Parametric Study of Ground Motion and Surface Rupture Hazards Evaluations at Yucca Mountain, Nevada," SAND86-7013, Sandia National Laboratories, Albuquerque, NM (1987).

14. J. M. O'NEILL, J. W. WHITNEY, and M. R. HUDSON, "Strike-Slip Faulting and Oroclinal Bending at Yucca Mountain, Nevada: Evidence from Photogeologic and Kinematic Analyses," Proceedings of the Geological Society of America, Annual Meeting, 1991, San Diego, 23(5), A119 (1991).

15. M. G. BONILLA, R. K. MARK, and J. J. LIENKAEMPER, "Statistical Relations Among Earthquake Magnitude, Surface Rupture Length, and Surface Fault Displacement," Bulletin of the Seismological Society of America, 74, 2379-2411 (1984).

16. K. W. CAMPBELL, "A Preliminary Methodology for the Regional Zonation of Peak Ground Acceleration," Proceedings of the Third International Microzonation Conference, Seattle, Washington, June 28 - July 1, 1982, 1, 365-376 (1982)

17. C. V. SUBRAMANIAN, N. ABRAHAMSON, A. H. HADJIAN, L. J. JARDINE, J. B. DEMP, O. K. KICIMAN, C. W. MA, J. KING, W. ANDREWS, and R. P. KENNEDY, "Preliminary Seismic Design Cost-Benefit Assessment of the Tuff Repository Waste-Handling Facilities," SAND88-1600, Sandia National Laboratories, Albuquerque, NM (1989).

END

DATE FILMED

3/11/92