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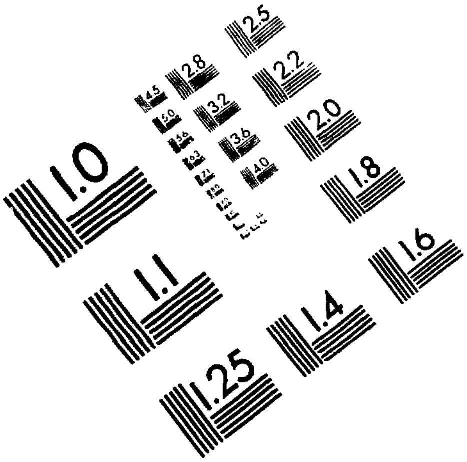

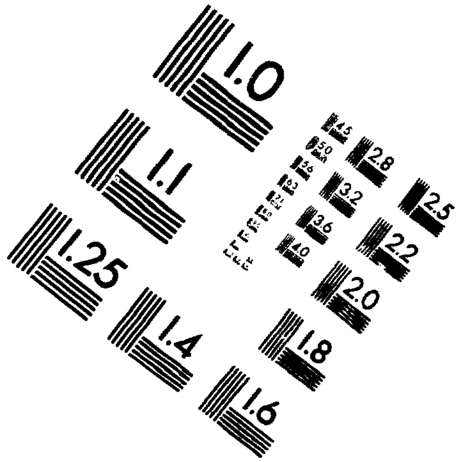

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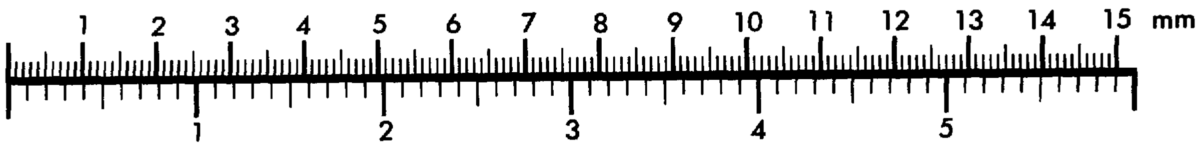

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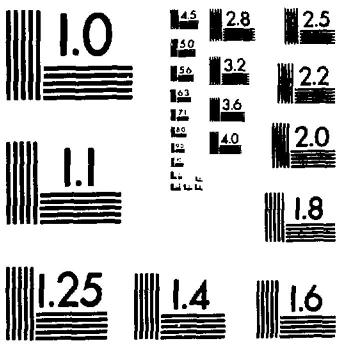

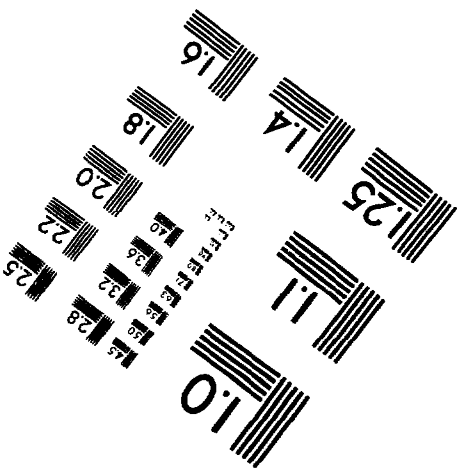

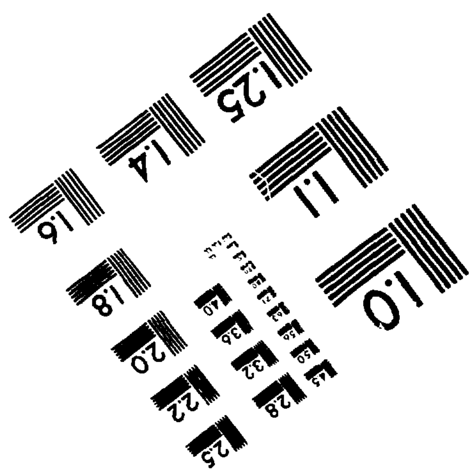

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DYNAMIC ANALYSIS AND DESIGN CONSIDERATIONS FOR HIGH-LEVEL NUCLEAR WASTE REPOSITORIES

Proceedings of the Symposium
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Quazi A. Hossain, Editor

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ABSTRACT

This proceedings, *Dynamic Analysis and Design Considerations for High- Level Nuclear Waste Repositories*, consists of papers presented at the Symposium sponsored by the Nuclear Dynamic Analysis Committee of the Structural Division of the American Society of Civil Engineers held in San Francisco, California on August 19-20, 1992. It brings together the ideas of industry experts, outstanding researchers, program managers, policy makers and practicing engineers in the field of seismic and dynamic analysis and design. These ideas are arranged by six broad categories: 1) General overview of analysis and design; 2) characterization of faulting; 3) characterization of design ground vibratory ground motion; 4) considerations for underground facilities; 5) considerations for surface facilities; and 6) guidelines for instrumentation and monitoring. This proceedings provide discussions on the relative merits and inadequacies of state-of-the-art design/analysis practices and methodologies in the seismic and dynamic analysis and design field in relation to high-level nuclear waste repositories.

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SYMPOSIUM STEERING COMMITTEE

CURRENT PLANS TO CHARACTERIZE THE DESIGN BASIS GROUND MOTION AT THE YUCCA MOUNTAIN, NEVADA SITE

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Abstract

A site at Yucca Mountain Nevada is currently being studied to assess its suitability as a potential host site for the nation's first commercial high level waste repository. The DOE has proposed a new methodology for determining design-basis ground motions that uses both deterministic and probabilistic methods. The role of the deterministic approach is primary. It provides the level of detail needed by design engineers in the characterization of ground motions. The probabilistic approach provides a logical structured procedure for integrating the range of possible earthquakes that contribute to the ground motion hazard at the site. In addition, probabilistic methods will be used as needed to provide input for the assessment of long-term repository performance. This paper discusses the local tectonic environment, potential seismic sources and their associated displacements and ground motions. It also discusses the approach to assessing the design basis earthquake for the surface and underground facilities, as well as selected examples of the use of this type of information in design activities.

Introduction

The occurrence of significant historical earthquakes in the Great Basin and the presence of faults in the Yucca Mountain area with Quaternary movement indicates the need for a detailed evaluation of ground motion hazards in the design of repository facilities and the evaluation of repository performance at Yucca Mountain. The selection of a seismic design basis must include consideration of differing design and performance concerns that are applicable during various time periods over the 10,000 year repository lifetime. The preclosure time period (<100 yrs) is the period when surface facilities will be in operation, waste will be emplaced, and over which retrievability must be maintained. The postclosure time period (10,000 yrs) is the period over which releases to the accessible environment from the repository must be controlled and remain within limits prescribed by regulation. Included within the postclosure time period is the first 300 to 1,000 years when the engineered barrier system in the repository must provide substantially complete containment. In addition to the differing time periods and performance concerns, the repository is also composed of surface and underground facilities that may have different requirements when considering seismic design.

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Title 10, Chapter 1, Part 60 of the Code of Federal Regulations (10 CFR 60) specifies the performance objectives and general design criteria for a mined geologic repository. 10 CFR 60 requires that repository facilities be designed so that protection is afforded against radiation exposures and releases in accordance with standards established by the U. S. Nuclear Regulatory Commission (NRC) (10 CFR 20) and the U. S. Environmental Protection Agency (EPA) (40 CFR 191). 10 CFR 60 also requires that structures, systems, and components that are important to safety be designed so that natural phenomena anticipated at the repository will not interfere with necessary safety functions. Those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ, of 0.5 rem or greater at or beyond the nearest boundary of the controlled area during the preclosure period are considered important to safety. Any proposed methodology for developing a seismic design basis for repository facilities must satisfy these requirements. While 10 CFR 60 imposes performance objectives to be met in the design of facilities, it does not specify a particular methodology to be used in developing a seismic design basis as was done for nuclear power plants in 10 CFR 100, Appendix A. For a repository, it is the applicant's responsibility to develop the seismic design basis and then demonstrate that the NRC performance objectives will be met.

Local Tectonic Environment At Yucca Mountain

Regional and local tectonic models. Tectonic models for faulting in the Yucca Mountain area fall into three general categories: detachment, high-angle normal, and strike-slip faulting models. Scott (1990) has proposed that the north-trending faults that bound Yucca Mountain are listric and merge with a shallow-dipping detachment fault at depths of about 2 km. Scott (1990) has also suggested that this detachment is part of a system of regional extent on which the majority of late Tertiary extension in the region has occurred. Maldonado (1990) and Carr and Monsen (1988) indicate that movement on the detachment fault surfaces that are found in the area ceased about 7.5 my ago. Therefore, detachment faults are not considered significant seismic sources in the Quaternary.

Doser and Smith (1989) have reviewed the source parameters for large historic Basin and Range earthquakes. They found that all the earthquakes occurred on faults with dips greater than about 40°, that the faults were generally planar with no evidence of listric or low angle faulting, and that focal depths were generally 8 km or greater. This would indicate that significant earthquakes in the region are most likely to occur on relatively high-angle faults that penetrate the crust.

A strike-slip faulting model that predicts that faulting patterns would be similar to the 1932 Cedar Mountain earthquake has been proposed for the faults at Yucca Mountain (Bell, 1988). Several studies indicate that strike-slip faulting may have been increasingly important in the Walker Lane zone during Pliocene and Pleistocene time (e.g., Reheis and McKee, 1991). Wright (1989) proposed that Crater Flat is part of a larger strike-slip fault zone. He concluded that a series of negative gravity anomalies extending from Stewart Valley to Crater Flat represent a series of pull-apart basins he called the "Amargosa Desert rift zone" that formed at the northern end of the Pahrump Valley strike-slip fault zone (Figure 1). Schweickert (1989) also proposed that significant amounts (up to 26 km) of right-lateral offset has occurred along a northwest-trending fault zone in the southern Amargosa Valley and Crater Flat areas on the basis of offset Mesozoic structural features.

Local Faulting Rates and Patterns. The Yucca Mountain site area is located in series of eastward tilted blocks of Miocene tuff that are bounded by dominantly normal, north-trending faults. The potential underground repository is located in one of these fault-bounded blocks. Apparent vertical displacement of the 13-my-old tuffs is about 300 m on these faults. Preliminary trenching studies conducted early in the program indicated that most of these faults experienced some movement during the Quaternary time period (Swadley et al., 1984). To date, detailed studies of fault movement histories have been limited to a few localities.

The Paintbrush Canyon fault (Figure 1) is located just to the east of the proposed surface facilities and ramp portals along the east side of Midway Valley. Whitney and Muhs (1991) give a fault length of 33 km and have found that the fault is divided into 5 segments with Quaternary faulting extending for distances of 3-4 km in each of the southern three segments. Maximum known Quaternary displacement occurs at Busted Butte where the oldest of four soil horizons near the base of a sand ramp is displaced 4.1 m (Whitney and Muhs, 1991). The soil is estimated to be about 700 ka old since it overlies an eolian unit containing the 738-ka-old Bishop ash (Whitney and Muhs, 1991). Five episodes of faulting have offset the 4 soils at Busted Butte. Whitney and Muhs (1991) note that slickensides indicate a left-lateral component of movement on the fault resulting a total oblique slip of about 5.8 m over the past 700 ka or a slip rate of 0.0083 mm/yr.

The Solitario Canyon fault forms the western boundary of the potential repository block and has a total fault length of about 30 km, including two main splays at the south end of the fault (Figure

1). Swadley et al. (1984) report Quaternary displacement in trenches across the fault, but these trenches do not provide information on slip rates or single event displacements. Bell (1988) used low-sun-angle photography and scarp profiling to identify a Holocene scarp on the fault with a displacement of about 0.2 m. A nearby scarp in Early to Middle Pleistocene deposits has a displacement of about 1 m. Bell (1988) found that nearly continuous scarps extend for about 12.5 km along this fault but that displacements in thick calcretes were small, indicating that large vertical offsets (several meters) have not occurred along this fault in the late Quaternary.

The Fatigue Wash and Windy Wash faults are two closely-spaced, parallel faults that lie west of the Solitario Canyon fault in Crater Flat. Analysis of low-sun-angle photographs by Ramelli et al. (1989) indicates that these faults form low scarps in the alluvium of Crater Flat and that they intersect toward the south (Figure 1). The

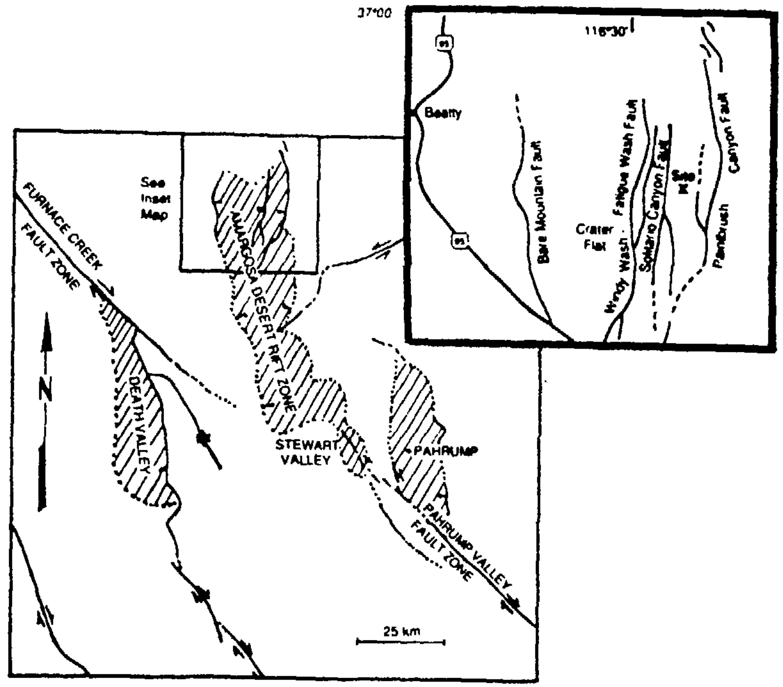

FIGURE 1. Regional model for Quaternary faulting in the Yucca Mountain Region modified from Wright (1989). Solid lines are faults with Quaternary movement, patterned areas are pull-apart basins formed by movement on major strike-slip faults. Inset shows location of faults near Yucca Mountain.

combined total length of the faults is about 37 km. Trenches across a scarp on one of the faults were investigated by Whitney (1986). Whitney distinguished at least 7 episodes of fault movement in the trenches with 4 episodes occurring in the last 300 ka; indicating an average recurrence interval of about 75 ka for events at this location. Maximum cumulative vertical offset during these last 4 episodes is 0.4 m (Whitney, 1986) to 2 m (Shroba et al., 1990). The youngest event recorded in the trench is believed to be Holocene in age with displacement less than 0.1 m. This information is consistent with a Quaternary slip rate of 0.008-0.01 mm/yr on this fault system.

The Bare Mountain fault lies along the western edge of Crater Flat at the base of Bare Mountain. It is about 23 km long. The fault is marked by the steep range front of Bare Mountain with faceted spurs truncating the ridges between drainages (Reheis, 1986). Reheis (1986) found evidence for Holocene or late Pleistocene movement on the fault along two 3-km-long segments of the fault. Reheis (1986) also found evidence that this event may have resulted in a displacement of 1.75 m on the southern segment.

Planned Approach for Selecting a Ground-Motion Design Basis

Any strategy for selecting a ground-motion design basis for repository facilities must consider the various factors that affect the decision. In the case of the Yucca Mountain site, a ground-motion design basis must recognize the differing nature of surface and subsurface structures with varying design lifetimes covering the preclosure (<100 yr) or postclosure (up to 10,000 yr) periods. The design basis must also consider the relative hazards posed by the facilities being designed as compared to other critical facilities in determining the level of safety that is acceptable. Any method that is used must demonstrate to the NRC and the public that the resulting design adequately protects the public health and safety against any credible earthquake ground motion. The method used must also be defensible, robust, and reasonably reproducible by other workers in order to withstand the intense review to which the project will be subjected. King (1990) defines robustness to mean that the design basis that is provided should not be sensitive to new information other than major changes in the perception of the seismic hazard.

King (1990) also notes the need for a ground-motion design basis that is cost effective. It is always possible to increase the safety of a structure or system. However, at some point the cost of doing so cannot be justified by the amount of increased safety achieved or because of the competing demands for financial resources. Cost effectiveness can be determined by evaluating the costs of adopting different design bases against their effectiveness in preventing earthquake damage and maintaining safety functions when subjected to a range of anticipated seismic events.

A final consideration in adopting a design basis is the nature of faulting and seismicity in the site area. At Yucca Mountain, the

low rate of activity on the faults and the apparent long recurrence intervals for seismic events on the faults (50 to 100 ka) indicates that methodologies that are used in more active areas, such as coastal California, may not be suitable or yield comparable results when applied in this case.

After considering the factors discussed above, the DOE decided to use the method that is described in the Site Characterization Plan (SCP) (DOE, 1988), King et al. (1989), and King (1990). The method adopted for determining the ground-motion design basis for preclosure facilities uses a specific deterministic approach supplemented by a probabilistic hazard analysis. A deterministic approach was selected as the primary method because a reproducible method can be defined and because of the NRC's continued emphasis on the deterministic approach for determining ground-motion design bases. These considerations were felt to outweigh the use of a probabilistic assessment as a primary basis even though it was the opinion of most of the technical staff that a probabilistic assessment was a technically more defensible approach in this setting.

Deterministic methodologies usually attempt to define a "maximum" earthquake tied to a specific fault that is believed to be the source of the strongest motions to which a site could be subjected. One of the major areas of controversy in applying this method is the determination of what constitutes the appropriate "maximum" event. Another concern is that using a "maximum" event approach at Yucca Mountain would produce a result that is unrealistically conservative given the long recurrence intervals and low slip rates in the area and the operational functions of surface facilities. The DOE adopted a conservative method that would produce results comparable to exceedance probabilities for the design-basis ground motions used on more hazardous facilities such as U.S. nuclear power plants. Studies of a number of these power plants indicate that the annual exceedance probability for the deterministically derived Safe Shutdown Earthquake at these plants is generally in the range of 10^{-3} to 10^{-4} (Reiter and Jackson, 1983).

The method proposed by DOE (1988) uses a 10,000 year Cumulative Slip Earthquake (CSE) as the design basis for preclosure facilities important to safety. The CSE is a hypothetical earthquake that would produce the observed or estimated average Quaternary slip rate on a fault, were it to recur at equal, 10,000-year-time intervals. This approach is considered to produce reproducible results because the interval of concern is defined and not subject to varying interpretations of what constitutes an undefined "maximum" event. This approach is also considered to be robust in that application of the CSE methodology is expected to identify only one or two faults that will control the design basis. The average slip rate for a fault is a parameter that is more readily determined than other parameters, such as the age or magnitude of individual paleoseismic events, and is less likely to be subject to large variations. The approach also has advantages over techniques that use fault-rupture length because of the uncertainties in fault rupture patterns noted by Bell (1988) for the Basin and Range Province.

It is concluded that the use of a 10,000 year CSE meets the intent of establishing a design basis with an annual probability of exceedance of 10^{-3} to 10^{-4}. However, it should be noted that such an earthquake, like any design earthquake, is purely hypothetical and that actual events that occur in the future may be larger or smaller than this event. The CSE methodology is intended to define the seismic design basis that ensures minimal disruption to the operation of facilities that are important to safety when subjected to earthquakes up to this level. As noted by King (1990), greater-than-CSE events during the preclosure period are unlikely but possible. Therefore, it must be demonstrated that safety functions can be maintained for such events, including maximum-magnitude earthquakes. Engineering analyses to demonstrate large safety margins to accommodate earthquake loads which exceed the nominal CSE design basis are an inherent part of the method.

It is also planned to conduct a comprehensive probabilistic hazard analysis as part of site characterization. For preclosure design, the probabilistic analysis will be used to confirm that the deterministically derived design basis falls within the desired probability range. The probabilistic analysis will also allow alternate conceptual models of regional and local tectonics and alternative, non-Poisson models of earthquake occurrence to be analyzed and incorporated, if appropriate. As more site characterization data is collected and the technical position of the NRC becomes better defined, the DOE will periodically re-evaluate the relative weight that should be given to deterministic and probabilistic approaches in selecting a preclosure design basis.

The probabilistic analysis will also be the primary tool in postclosure design and performance analysis. As noted by the SCP and Lee et al. (1991), a primary postclosure design concern is the performance of the engineered barrier system. The basic elements of the engineered barrier system (according to the current reference design) are the waste emplacement borehole, the air gap around the waste container, and the waste container itself. The multiple occurrence of strong motion during the postclosure phase may be an important consideration for waste container design because of: (1) direct mechanical effects caused by movement of container within the waste emplacement hole and subsequent puncture or rupture of the container, especially at times of increased corrosion; and/or (2) stress-induced rock spall within the waste emplacement hole that can reduce or eliminate air space surrounding the waste package, resulting in container puncture or permanent waste container-wall contact, potentially amplifying corrosion rates. Thus, there may be a requirement for a design to address lateral movement within the emplacement hole or a requirement for increased material strength.

When considering the 1,000- or 10,000-year performance periods for the repository, it is possible that the repository will be subjected to a number of ground motion events of varying magnitude

from both local and regional sources. Repeated or long-term wall contact from an earlier event may result in slight container damage and increased corrosion at contact points or damage locations. The container would then be more susceptible to further damage and corrosion due to shaking and additional repeated wall contact during subsequent events, potentially reducing container performance. The cumulative effect of a number of events producing moderate ground motion at the repository may be more significant to long-term waste package performance than the effects of a single large event, because (unlike other facilities such as a nuclear power plant) there will be no provision for repairs at the repository after an event occurs.

In addition, the different design purpose of the ground motion evaluation for the postclosure period, in comparison to an engineered facility such as a nuclear power plant, must be considered. For a nuclear power plant, a single large event is hypothesized in order to design for the ability to safely shut down the reactor in response to that event. For the postclosure period of a repository, the concern is in evaluating the range of events that are reasonably likely to occur over a long time period in order to assess the performance of a system that may not have active human monitors or operators. Because of these differences, a deterministic methodology using a single postulated design earthquake on a single source structure is considered inappropriate. A probabilistic model will allow consideration of the full range of events and seismic sources that could contribute to the ground motion hazard affecting the repository during the postclosure time period. A probabilistic model will also allow an explicit consideration of the uncertainties present in this type of analysis.

Current Ground-Motion Estimates and Data Needs

Deterministic Estimates. As discussed above, implementing the CSE methodology requires estimating the expected displacement associated with the hypothetical CSE from the average slip rate on the fault and then estimating the size of the earthquake from empirical correlations using historical earthquake data. For this paper, a correlation between the seismic moment and maximum displacement of historic events in the Basin and Range Province is used. The correlations used in this study use only data from the Basin and Range Province because the parameters of fault rupture appear to vary from province to province and data from a single province appears to be a better predictor of events in that province. Seismic moment was used in this study because published values for this parameter are available for nearly all Basin and Range earthquakes; moment may be calculated using either geologic, geodetic, or seismologic information; and rupture length and displacement are more directly related to this measure than to other measures of earthquake magnitude.

Figure 2 shows a correlation between log moment and log maximum displacement. The formula for the regression line shown on the figure is

$$\text{Log Moment} = 26.005 + 1.123\,(\log D) + 0.209\,(\log D)^2.$$

The upper limit for slip rates on faults in the immediate site are currently appears to be about 0.01 mm/yr. The average slip on these faults would then be 0.1 m for a 10,000 year CSE calculation. Multiplying this by 3 to estimate a maximum displacement (Bonilla, 1982) and using the equation above yields a moment of 3.0×10^{25} dyne-cm or moment magnitude of 6.3. This corresponds to a Peak Ground Acceleration (PGA) of about 0.5 g (Campbell, 1982), if the closest fault (Paintbrush Canyon) is considered as the source. The annual probability of exceedance for this hypothetical design event on the Paintbrush Canyon fault is then about 1.5×10^{-5} using Molnar (1979).

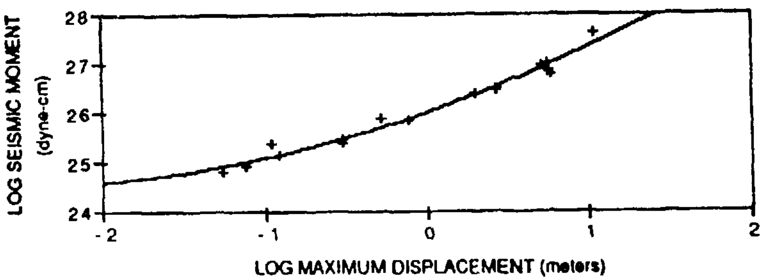

FIGURE 2. Relationship between log seismic moment and log maximum displacement for historic Basin and Range earthquakes.

Bell (1988) argues that distributive faulting should be considered in evaluating potential ground motion at Yucca Mountain and that an event similar to the 1932 Cedar Mountain earthquake (M_w 6.9) could occur in the area with fault movement occurring on several of the faults in the area. Maximum displacement during the Cedar Mountain earthquake was about 2 m (Bell, 1988). As shown on Figure 2, there is a good correlation between moment and maximum displacement for larger earthquakes. This shows that larger Basin and Range earthquakes have always been accompanied by maximum surface displacements of commensurate size. There is currently no documented evidence to suggest displacements associated with individual events are larger than about 0.5 m indicating this scenario may not apply to Yucca Mountain. However, this and other types of multiple fault or multiple event hypotheses should be evaluated when analyzing facility performance and safety margins.

The bounds on preclosure ground motion for use in engineering analyses of the performance of a particular design during low-probability events can be examined by considering a number of scenarios. These scenarios should consider possibilities including full-length rupture on individual faults, coseismic movement on several faults (e.g., Bare Mountain, Windy Wash, Solitario Canyon, and Paintbrush Canyon), and possible longer rupture lengths on faults than currently documented (e.g., Bare Mountain fault extends into Amargosa Desert with strike-slip movement). These scenarios yield maximum magnitudes of about M_w 7 to 7 1/4.

These analyses should also include multiple-event scenarios where separate events occur on several faults with time intervals as short as a few minutes between events. An example of this type of behavior would be the 1954 Dixie Valley-Fairview Peak earthquake sequence. This sequence consisted of 4 events that produced surface ruptures on different faults defining a zone about 40 km wide. The earthquakes ranged from M_w 6.1 to 7.2 and the intervals between events ranged from about 4 minutes to 4 months (Thompson, 1984). Coseismic or multiple-event faulting is suggested by the occurrence of volcanic ash deposits filling voids along several faults and a potentially synchronous Holocene event on some faults (Bare Mountain, Windy Wash, Bow Ridge). Such a sequence of events might include an event on the Bare Mountain fault (M_w=7) and separate events on the Paintbrush Canyon, the Solitario Canyon, and the Fatigue Wash-Windy Wash fault systems of M_w=6-6 1/2. This scenario would be in agreement with the short rupture segments and relatively small displacements observed on these faults.

Probabilistic Estimates: The most comprehensive probabilistic assessment performed to date for the Yucca Mountain site is by URS/John A. Blume (1987). Because of the uncertainty in estimating the rate of seismicity in a region with low activity and long recurrence intervals from the historic record, this study included both area and fault sources. Earthquake occurrence on faults that were considered significant to the site was described by a truncated Gutenberg-Richter density function. Faults were assigned seismicity by developing a correlation between fault length and average fault deformation rate. Fault activity was constrained by slip rate, maximum magnitude, and b-value, while area sources were constrained by fault activity, and pre-underground weapons testing historical seismicity for the period 1932-1962. Average activity is about 0.015 events of $M \geq 4$/1,000 km^2/yr over a 20,000 km^2 area that excludes seismicity of eastern California, and lower seismicity regions both north and south of the site. Several alternate faulting models were evaluated in this study. The preferred model of the study assumed that deformation accumulates equally for both horizontal (strike-slip) and vertical components. A b value of 0.9 was used, and ground motion attenuation with source distance and magnitude were estimated the relationships of Campbell (1982). The preferred probabilistic hazard results were similar to results of an earlier evaluation based on historically averaged seismicity. From the preferred hazard model (Figure 3), a design basis of 0.4 g was recommended using a probability of exceedance of 5×10^{-4} for the preclosure surface facilities.

Ground motion concerns related to the postclosure period have been reviewed by Lee et al. (1991). This study used the URS/John A. Blume (1987) study as a basis for for its estimates. As discussed previously, postclosure considerations involve concerns related to both the size of potential ground motion and the number of strong-motion events that might occur during periods of interest. This study found that a peak ground motion of 0.6 g had an approximate 10% chance of exceedance in a 1,000 year period (the substantially complete containment period for the engineered barrier system). For the same design acceleration and a 10,000 year period, there was a nearly equal probability of occurrence for two or more events (0.283) as for one event (0.366). Figure 4 shows the cumulative probability of the number of ≥ 0.4 g events that occur in 10,000 years equaling or exceeding a given value for the preferred model. It was also estimated that the most probable number of occurrences of 0.1 g and greater in 1,000 years ranges from about 8 to 12.

Data Needed From Site Characterization. The deterministic and probabilistic estimates given above are presented solely to illustrate the models and do not represent final positions on design bases. There are sufficient uncertainties concerning the nature of seismicity in the site area that additional information is needed from site characterization. For all methods of seismic hazard evaluation, data are needed on the slip rates of local faults (including any potential strike-slip component), the displacement

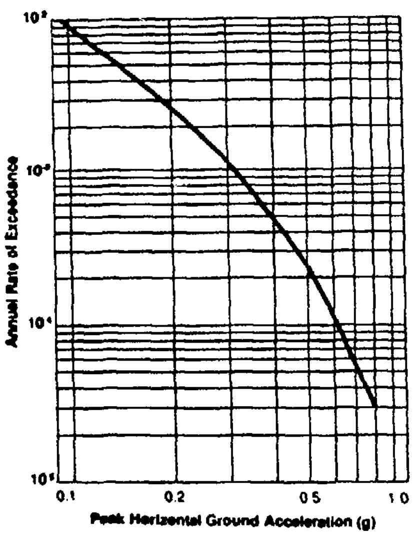

FIGURE 3. PGA exceedance rates for the preferred model of URS/John A. Blume (1987).

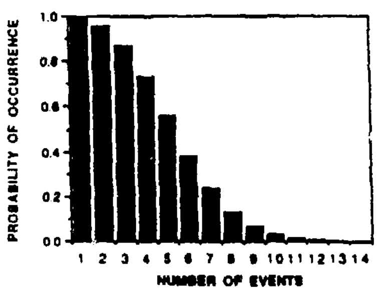

FIGURE 4. Cumulative probability of N and greater episodes of site accelerations >0.4 g over 10,000 year period using model in Figure 3. From Lee et al. (1991).

and recurrence intervals of individual events on local faults, the synchronicity of events (or lack of) occurring on different faults, dynamic soil properties at the site, and the 3D geometry and interconnections of the different local faults.

Comparison of Results. Both the probabilistic estimates and the deterministic 10,000 year CSE estimates given above appear capable of providing a ground motion design basis that meets the goal of having exceedance probabilities in the 10^{-3} to 10^{-4} range. For example, the CSE estimate of a PGA of about 0.5 g corresponds to an exceedance probability about 2×10^{-4} using the results of the URS/John A. Blume (1987) study. While the DOE has stated in the SCP that the level of conservatism contained in the above goals is adequate for protecting public health and safety, the question remains as to what level of conservatism will eventually be found to be acceptable from a regulatory and public perception viewpoint. In order to provide background on this question, a study was conducted by Subramanian et al. (1989) to evaluate the cost effectiveness of adopting various ground motion design bases for preclosure facilities on meeting public health and safety requirements. The results of this study are discussed in the next section.

Impact of Ground-Motion Design Basis on Safety and Site Suitability

Subramanian et al. (1989) have assessed the costs and benefits associated with varying the seismic design basis of the preclosure waste-handling facilities. The assessment was based primarily on expert judgment solicited in an interdisciplinary workshop environment. The estimated costs for individual attributes and the assumptions underlying these cost estimates (seismic hazard levels, fragilities, radioactive-release scenarios, etc.) were subject to large uncertainties at this early stage of the project. These uncertainties were generally identified but not treated explicitly. The assessment considered a range of vibratory ground-motion levels with PGAs between 0.2 and 1.0 g (vertical PGA = horizontal PGA). Both accident- and nonaccident-related costs and benefits (attributes) were quantitatively estimated as a function of the design basis. The assessments were based on expert opinion derived from previous analyses and observed performance of heavy industrial facilities, rather than a facility-specific quantitative analysis.

Accident-related attributes considered in the Subramanian et al. (1989) study included the probabilistically derived costs of public radiological exposure, worker radiological exposure, offsite property damage and cleanup, onsite damage, mission delays. Nonaccident-related attributes considered included structural design and construction costs, equipment procurement and qualification costs, licensing costs, site characterization costs, and the costs of potential programmatic delays. The assessment focused on the main waste-handling building. Shielding requirements for the hot cells in this building result in a structure with 5-foot-thick reinforced concrete shear-wall construction. The resulting structure is therefore inherently resistant to ground motion.

Subramanian et al. (1989) found that, notwithstanding the uncertainties and approximations of the study, the repository surface facilities are low seismic risk facilities because the expected cost and risk to the public (i.e., accident-related costs) is very low at all design levels. The assessment found that accident risks associated with any seismic-design level above 0.2 g would be extremely small. For example, the study found there would be at least a 95% chance that, if the building were designed to 0.4g (the basis of the current conceptual design), it would suffer only light damage with no loss of containment if an event producing 1.0-g ground motion should occur. The study concluded that, from a cost-benefit standpoint, the optimum design level could vary from 0.24 to 0.53 g. In the view of the study, a design basis below 0.3 g was not precluded by safety considerations but would most likely result in increased licensing costs. However, it was found that choosing a design basis above 0.3 g would have little impact on reducing risk to the public.

The results of the Subramanian et al. (1989) study indicate that while the selection of a ground-motion design basis may be a major licensing, design, and cost issue, it does not significantly affect site suitability determinations or public safety even if relatively minimal values (0.2 g or above) are selected.

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