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Cost-Benefit Assessment of the Seismic Design of the Tuff Repository Waste Handling Facilities

by

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This paper summarizes a cost-benefit assessment of the seismic design of the waste-handling facilities associated with the prospective high-level waste repository at Yucca Mountain, Nevada. It provides a very brief description of the methodology used and the costs and benefits of varying design levels for vibratory ground motions and surface fault displacements for structures, components, and equipment that are important to safety in the waste-handling facilities.

Cost-Benefit Assessment Methodology

A cost-benefit study determines the optimum solution for the problem under consideration. The independent variable in a cost-benefit analysis could be a continuous function, such as ground motion acceleration or a set of discrete alternatives, such as specific fault rupture displacements. The optimum seismic design level for a given structure can be obtained by simply setting to zero the first derivative of the total cost objective function, C_T, with respect to the design acceleration, a:

$$\frac{dC_T}{da} = 0 \quad (1)$$

In this case, the objective function is the total cost of the initial investments and consequences, expressed in terms of the design acceleration. Obviously, other cost parameters could be used: e.g., total cost per health effect (deaths) or the incremental cost per reduction in health effect could be optimized. These concepts are in common use and could be employed to arrive at a decision regarding the design level. In this paper, total cost is used.

The total cost is divided into two elements: accident-related costs and nonaccident-related costs. An estimate of accident-related costs is associated with the probabilities of both earthquake occurrences and system, structure, and component failures; thus, this estimate requires the calculation of expected rather than direct costs. An estimate of nonaccident-related costs is direct and straightforward.

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Accident-related costs resulting from a seismic event are difficult to quantify in dollars. Hence, such a quantification is made with built-in uncertainties in the estimates. Accident-related costs resulting from a seismic event are evaluated for the following attributes:

- offsite public exposures;
- short-term occupational exposure;
- offsite property damage/cleanup;
- onsite damage, repair, and/or decontamination; and
- mission delays.

Nonaccident-related cost attributes considered include

- engineering construction for both structures and equipment,
- licensing,
- site characterization, and
- nonregulatory delays.

The steps needed to obtain the optimum design level are summarized below.

Accident-Related Costs

1. An earthquake could cause a spectrum of different damage states. However, different earthquake events would cause different damage states on a given structure. Each damage state could result in different offsite and onsite consequences. Further, events that are within the design basis are assumed to cause no damage. Therefore, the damage state of the structure is determined for the "beyond-design-basis" conditions for each of the specific design levels.

   For critical facilities designed for realistic ground motions and expected to withstand any ground motion without collapsing, four damage states are deemed sufficient and meaningful. Based on this, the following four damage states were defined in terms of the complete structural response:

   - Light (L),
   - Moderate (M),
   - Heavy (H), and
   - Total (T).

   The damage state L is associated with an earthquake occurrence slightly beyond the design basis earthquake. The other states correspond to increasing levels of beyond-design-basis events.

2. For each specific design level, the levels of the beyond-design-basis events that would cause the given damage states to occur was determined. For each damage state, a list of structural failures, such as potential falling concrete and concrete crack widths and lengths, was also identified. Given the falling concrete, concrete crack widths and lengths, and associated radioactive material inventories, the offsite radioactive release and associated dose for each of the damage states was calculated.

3. Because of uncertainties in modeling parameter values, the damage states were represented as a conditional probability of the event level. For each damage state, this can be shown as a probability density function and a cumulative probability function (the graphical representation of which is often referred to as fragility curves). A fragility curve is defined as the useful limit of the prescribed damage state. A set of fragility curves for each design level was developed so that all damage state fragilities were known.

4. The seismic hazard data for the Yucca Mountain Repository site was determined by evaluating the relationship between the annual probability of exceedance and the peak ground acceleration or fault displacement.

5. The seismic hazard data for the site was convoluted with the fragility curves for the structure to determine the damage state probabilities. Because each damage state is related to a radioactive release, computational results can be summarized for each design level.

6. The accident-related costs were quantified in dollars for each attribute, and for each damage state, the total cost was summed and presented as a function of the associated radioactive release.

7. Given the annual probability of release and the cost of the release, the expected cost, E(c), can be computed as

$$E(c) = \int_{-\infty}^{\infty} c(x)f(x)dx \ , \qquad (2)$$

where c(x) and f(x) are functions of cost and release.

The relationship shown above can be algebraically approximated by

$$E(c) = \sum_{i} \frac{c(x_i) + c(x_{i+1})}{2} P(x_i < \hat{x} \le x_{i+1}) \qquad (3)$$

The terms of this equation are shown for a release resulting in $\hat{x}$ rems between x_i and x_{i+1}. The summation of incremental expected costs for each accident-related attribute resulted in the annual expected cost of the accident-related effects.

8. These steps were repeated for all of the accident-related attributes listed earlier for each design level considered, and the results were plotted.

Nonaccident-Related Costs

9. The calculation of nonaccident-related costs does not involve the probability of the release of radioactive material. These costs are incurred regardless of whether an accident occurs. These are directly calculated costs for each of the nonaccident-related attributes listed earlier.

10. The individual cost elements were summed to give total nonaccident-related cost.

11. The accident-related and nonaccident-related costs were summed to obtain total present cost, C_T, as a function of design level. This relationship was plotted graphically to obtain the optimum design level.

This methodology was applied to evaluate the waste-handling facilities of the proposed Yucca Mountain repository for both ground motion and hypothetical fault displacements. More details of the methodology may be found in References 1 and 2.

Application and Results

In this study, the methodology described above was focused primarily on the seismically-induced damages to the main waste-handling structures, systems, and components that result in radiological releases. Waste-handling building used in this study is based on the configuration shown in Reference 3. A plan view and cross-section of the same are shown in Figures 1 and 2. The structural system of this building consists of shear walls and slabs ranging from 2.0 to 5.5 ft thick. This building is used for the receiving, preparing, and packaging in containers of light-water reactor wastes and defense high-level wastes before being transported underground for storage. The seismic design basis for this facility is 0.4 g ground motion with no specific requirements for fault displacement (Reference 3). The design level for this building was varied, and each design was evaluated for ground motion levels between 0.2 and 1.0 g and fault displacement between 0 and 100 cm.

Seismic hazard curves for both ground motion and fault displacement at the repository site are shown in Figures 3, 4, and 5. Details of the methodology used to develop these curves are given in Reference 1. These curves indicate that the annual probability of exceedance for horizontal acceleration of 0.4 g is about 5×10^{-4} and the annual probability of a fault rupture >1 cm under the waste-handling building is about 10^{-7}. Hence, although the ground rupture hazard is more uncertain than the acceleration hazard, the very low probabilities of the former make it insignificant in the cost-benefit evaluation.

Spalling and cracking of concrete were the primary structural damage types investigated. Massive or total structural collapse was ruled out because of the inherent strength of the waste-handling building design. The basic accident scenarios were identified for different degrees of damage. In these scenarios, spalling of concrete pieces was assumed to damage spent fuel assemblies or containers and generate airborne radioactive particles within the hot-cell structures. Such particles can escape through the cracks of the damaged structures into the atmosphere. The quantity of the radioactive release depends on various factors, including the amount of spalling and cracking. Therefore, the probability of a radioactive release is coupled to the probability that a specific amount of spalling and cracking will occur. In the study reported here, four damage states for the structure were defined and quantified in terms of structure deformations, crack sizes, and spalling concrete pieces. These are light, moderate, heavy, and total damage states.

Cracks and spalling pieces were estimated for these damage states. Using the damage states as limit states, fragility curves with probabilities expressed as a function of peak ground acceleration or fault displacements were developed for each structural elements.

Utilizing the information on crack sizes and the number of concrete pieces that would potentially spall for each of the damage states and the information on the waste inventory inside the waste-handling building, the quantities of radioactive materials released inside the waste-handling building and to the outside environment for each damage state were evaluated. These results were used to estimate various accident consequences, including offsite public exposures, short-term occupational exposures, damage to offsite properties, damage to onsite structures and equipment, and mission delays caused by disruption of repository operation. The dollar costs related to these consequences were estimated and then summed to obtain the total costs for each of the four damage states. These total costs were then combined with the probability of exceedance of the damage states to give the expected values of accident costs for the different design levels. The probability of exceedance of a damage state (or the corresponding offsite dose) was obtained by integrating the product of the probability density function of the seismic hazard and the fragility probability function corresponding to the damage state. Probable cost of accident as a function of the seismic design level is shown in Figure 6. The most striking feature of Figure 6 is the extremely low expected accident-related costs for all possible design levels considered in the study.

The next step in the evaluation was to determine the nonaccident-related costs for the attributes listed earlier. These are design and construction activities for structures and equipment, licensing activities, site characterization activities, and mission delays. As indicated earlier, these costs are incurred regardless of whether an accident occurs. These are direct costs and are straightforward to compute. The individual cost elements for these attributes were computed for each design level and then summed to give the total nonaccident-related cost as shown in Figure 7. This figure indicates that the nonaccident-related costs are rather insensitive in the mid-range (0.2−0.6 g) of design levels. A comparison of Figure 7 with Figure 6 indicates that the accident-related costs are extremely small compared to the direct or nonaccident-related costs. Further, summation of the accident-related costs from Figure 6 to the nonaccident-related costs in Figure 7 does not alter the basic shape of Figure 7. This indicates that for this repository site and for the seismic design criteria, consequences of seismic events are irrelevant to the selection of the design level.

As a last step, an evaluation was done to determine the effects of the uncertainties in the various parameters on the results discussed above. It was concluded that the overall uncertainty in these parameters needs to be very large (on the order of 10^4 or greater) before they would affect these results.

Complete details of this study can be found in Reference 1.

Conclusions

Some of the important conclusions derived from this study are given below. These conclusions can be drawn notwithstanding uncertainties and approximations used in the study.

- The expected cost and risk to the public at all design levels are very low. This implies that this facility is a low seismic risk facility.
- The total nonaccident-related cost is fairly constant for design levels between 0.2 and 0.6 g.
- The increase in nonaccident-related costs if the design level is changed from 0.4 g to 1.0 g is on the order of $150 million.
- The waste-handling building appears to be quite resistant to potential fault displacement. Hence, specifying a fault-offset design with a goal of no damage is not necessary. It would be costly to achieve and would not readily gain acceptance owing to the lack of established design and construction code requirements.

References

1. C. V. Subramanian, N. Abrahamson, A. H. Hadjian, L. J. Jardine, J. B. Kemp, 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, February 1989.

2. C. V. Subramanian and A. H. Hadjian, "Cost-Benefit Assessment Methodology for Seismic Design of High-Level Waste Repository Facilities," SAND88-1931, Sandia National Laboratories, Albuquerque, NM, March 1989 (to be published in SMiRT 10 Conference Proceedings, Anaheim, CA, August 1989).

3. H. R. MacDougall, L. W. Scully, J. R. Tillerson (Editors), "Site Characterization Plan Conceptual Design Report," SAND84-2641, Sandia National Laboratories, Albuquerque, NM, September 1987.

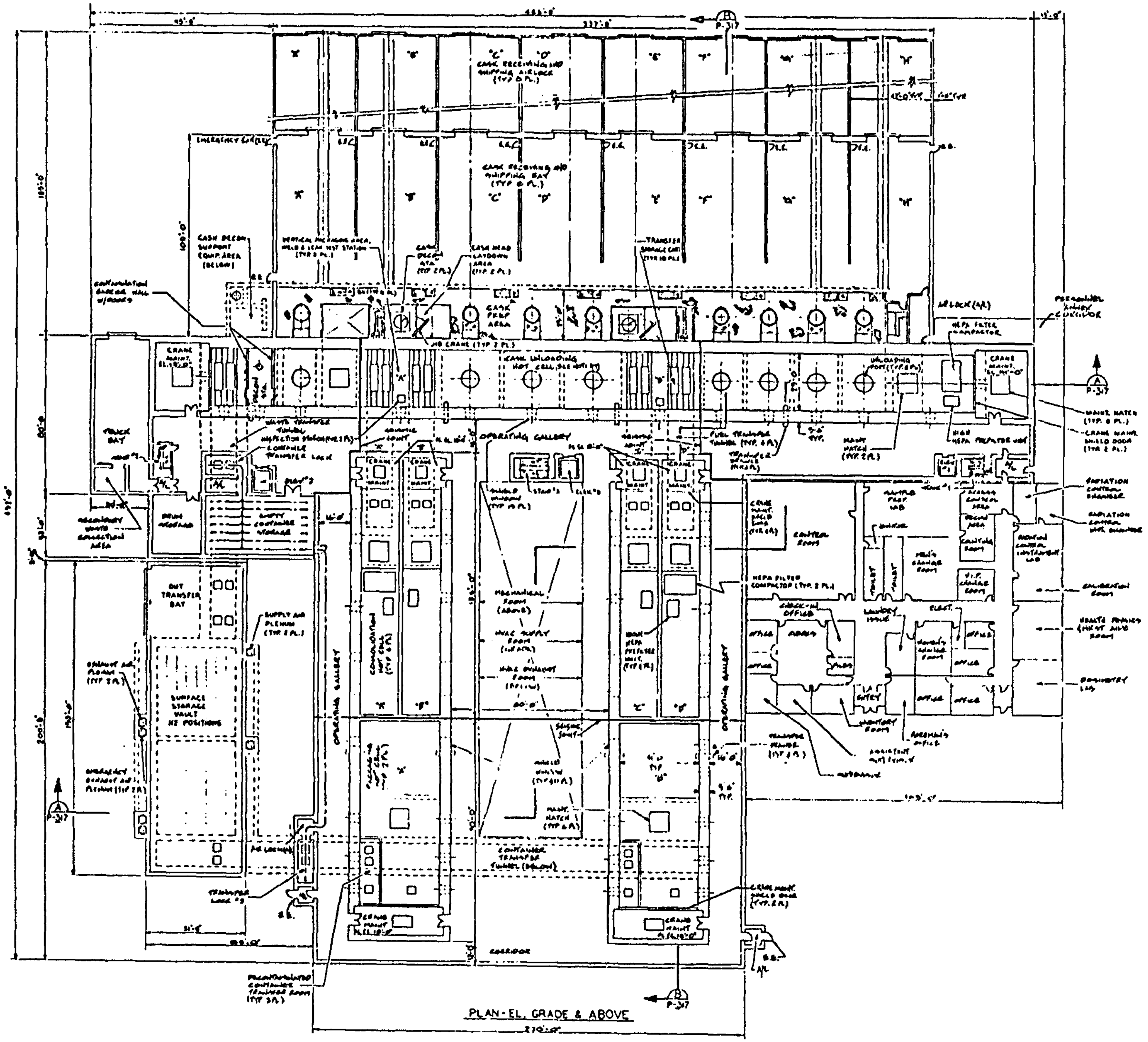
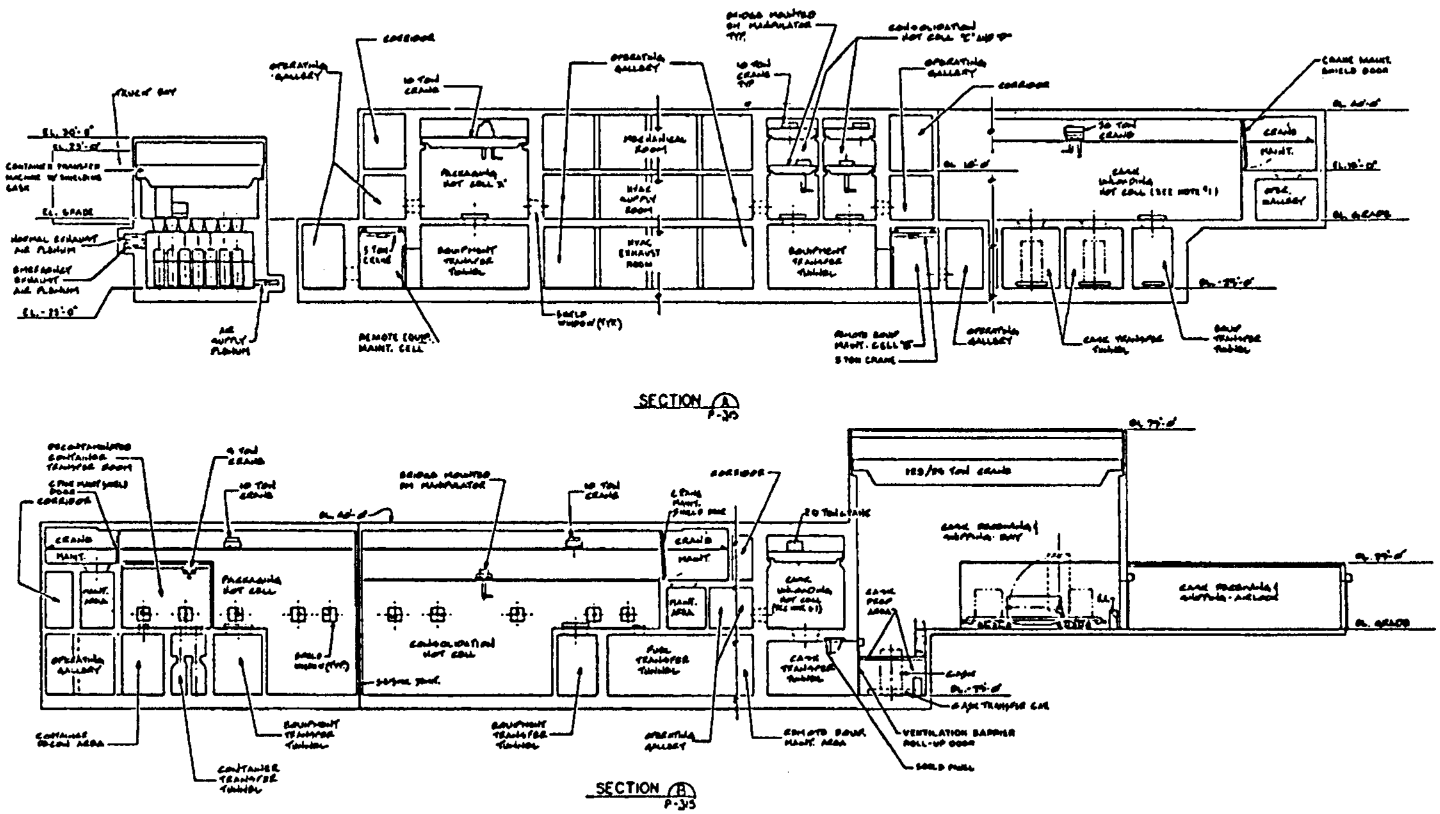


Figure 1. General Layout of Waste Handling Building - Yucca Mountain Project



WASTE HANDLING BUILDING 2

Figure 2. Cross-Section of Waste Handling Building - Yucca Mountain Project

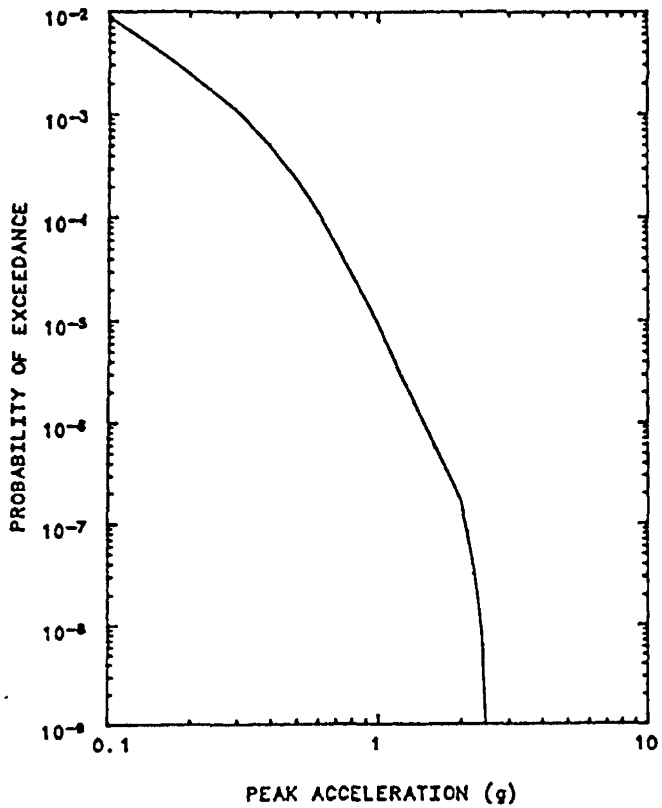


Figure 3. Horizontal Ground Acceleration Seismic Hazard Curve for the Yucca Mountain Site

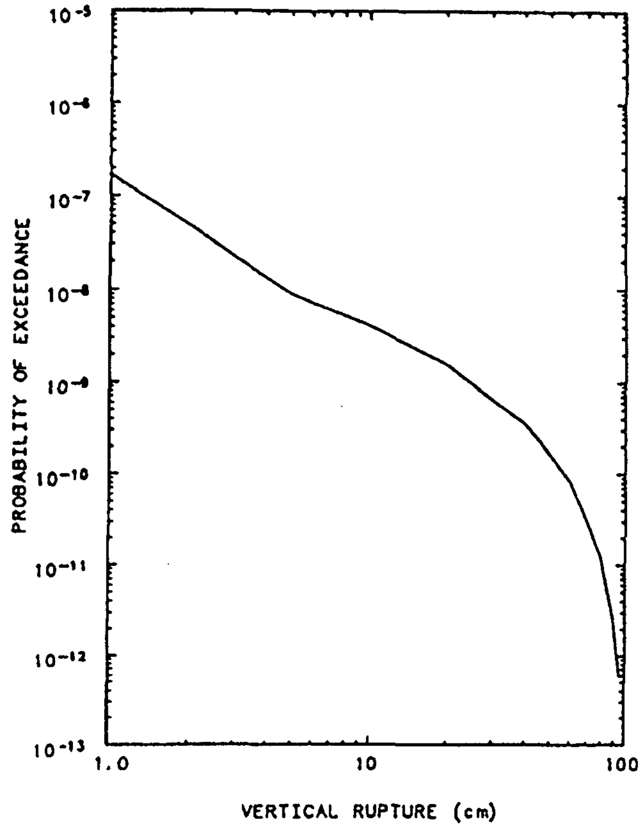


Figure 4. Ground Rupture Hazard Curve for the Yucca Mountain Site

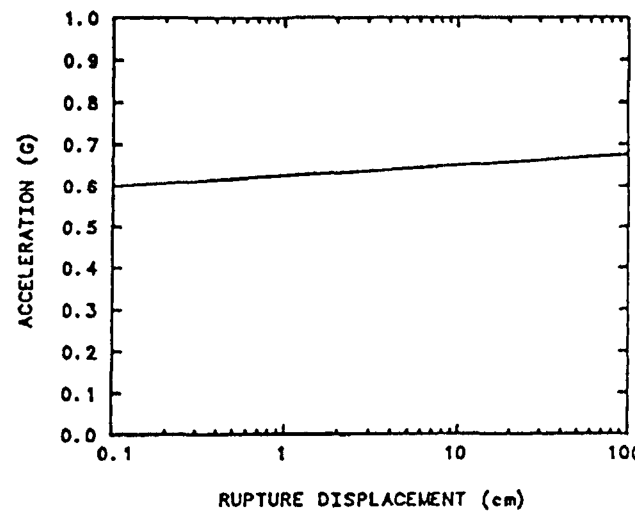


Figure 5. Median Acceleration Associated with Ground Rupture at the Yucca Mountain Site

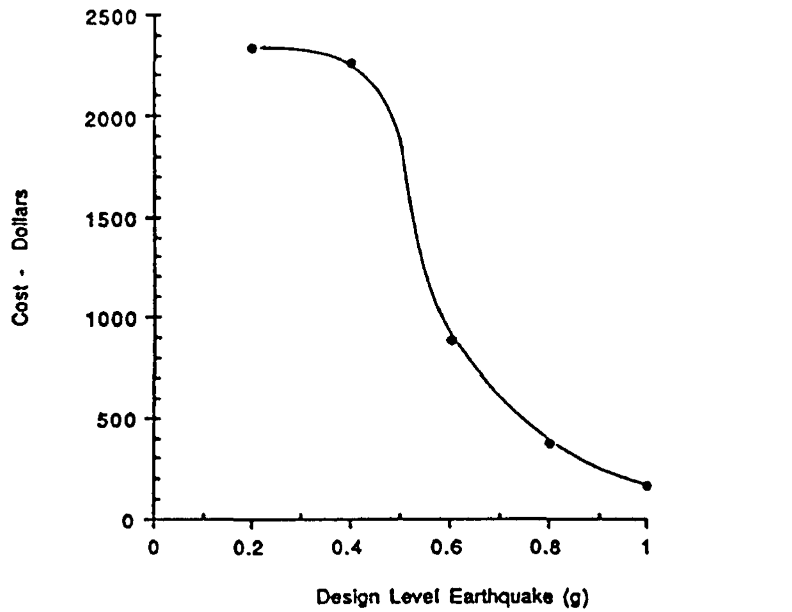


Figure 6. Probable Cost of Accident as a Function of the Seismic Design Level

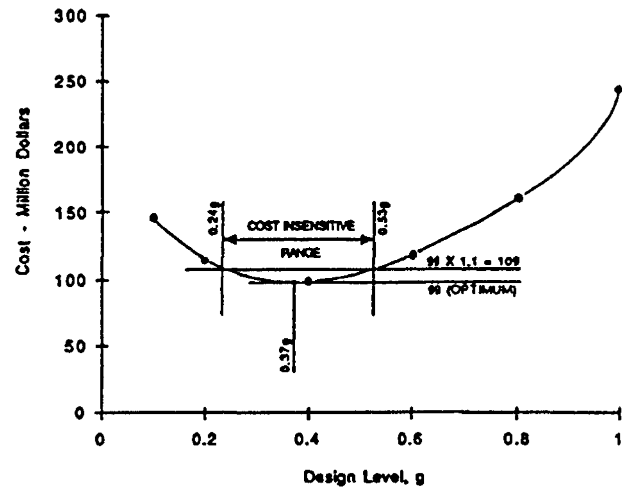


Figure 7. Total Nonaccident-Related Costs as a Function of Design Acceleration

APPENDIX

Information from the Reference Information Base Used in this Report

This report contains no information from the Reference Information Base.

Candidate Information for the Reference Information Base

This report contains no candidate information for the Reference Information Base.

Candidate Information for the Site & Engineering Properties Data Base

This report contains no candidate information for the Site and Engineering Properties Data Base.