Seismic Hazard Criteria for the U.S. Department of Energy Reservation in Oak Ridge, TN

Karen E. Shaffer and R. Joe Hunt
Lockheed Martin Energy Systems, Inc.
Oak Ridge, TN 37831-8218

Harish Chander, EH-31, and J. K. Kimball, DP-311
U.S. Department of Energy
Germantown, MD 20874

ABSTRACT

Seismic hazard criteria have been in use at the U.S. Department of Energy (DOE) reservation in Oak Ridge, TN since the early 1950s. In response to evolving DOE Orders and technical standards, as well as significant advances in earthquake ground motion engineering, site specific seismic hazard criteria for the Oak Ridge Reservation have been developed based on the Lawrence Livermore National Laboratory and Electric Power Research Institute (EPRI) methodologies. This paper presents the site specific criteria development methodology and provides the Oak Ridge site-specific seismic hazard criteria. A comparison of the Oak Ridge site-specific seismic hazard criteria with the results obtained from 1996 U. S. Geological Survey seismic hazard maps is also provided.

The Oak Ridge National Laboratory, the Oak Ridge Y-12 Plant, and the East Tennessee Technology Park comprise the Oak Ridge Reservation. Plant operations are directed by the DOE-Oak Ridge Operations office. Lockheed Martin Energy Systems, Inc. is the managing and operating contractor for the Oak Ridge Y-12 Plant and the East Tennessee Technology Park. Lockheed Martin Energy Research, Inc. is the managing and operating contractor for the Oak Ridge National Laboratory.

KEYWORDS: criteria; ground motion attenuation; response spectra; seismic hazard

1. INTRODUCTION

The U.S. Department of Energy - Oak Ridge Operations (DOE-ORO), based in Oak Ridge, Tennessee, is rich in history, dating back to World War II when the organization played a major role in the production of materials used in the first atomic weapon. The majority of the DOE-ORO site is situated on Federal land known as the Oak Ridge Reservation. Three primary facility complexes are located on the Reservation: the East Tennessee Technology Park (formerly known as the Oak Ridge K-25 Site and the Oak Ridge Gaseous Diffusion Plant), the Oak Ridge National Laboratory, and the Oak Ridge Y-12 Plant. Administrative facilities and many support facilities necessary for plant operations are also located on the Reservation. Lockheed Martin Energy Systems, Inc. is the managing and operating contractor for the East Tennessee Technology Park and the Oak Ridge Y-12 Plant. Lockheed Martin Energy Research, Inc. is the managing and operating contractor for the Oak Ridge National Laboratory.

Since it's original mission, the DOE-ORO has expanded and today supports more than 60 major DOE activities including energy research and development programs, dismantling and storing nuclear weapons components, environmental management, landlord responsibility for the U.S. Enrichment Corporation, and various educational programs.

Seismic hazard criteria have been applied at the DOE-ORO facilities since the early 1950s. Since that time, the behavior of earthquakes in the central and Eastern U.S. has been better understood and methodologies based on this understanding have been developed. In response to evolving DOE Orders and technical standards and facility safety analysis requirements, the seismic hazard criteria for the Oak Ridge Reservation have been reevaluated using the latest Lawrence Livermore National Laboratory (LLNL) and Electric Power Research Institute (EPRI) methodologies. This paper discusses the site specific criteria development methodology and provides the Oak Ridge site-specific seismic hazard criteria.

2. LOCATION OF THE OAK RIDGE FACILITY COMPLEXES

The Oak Ridge Reservation is located in East Tennessee in the Valley and Ridge physiographic province characterized by a series of long, narrow ridges and slightly broader intervening valleys, with a pronounced northeast-southwest trend extending from Alabama to Newfoundland. Seismic activity in the area is thought to be, primarily, the result of continental compression that is reactivating old faults in the basement at depths of 3 to 12 mi.

The site has relatively shallow soil deposits overlying sound, competent bedrock. The surface bedrock is generally limestone and shales in the valleys and sandstones and siliceous carbonate rocks on the ridges. The thickness of the soil overburden ranges from 10 to 50 ft. For some critical structures, the soil overburden has been excavated and the structures' foundations are supported on bedrock.

Based on the site conditions, site-specific response spectra were developed for rock outcrop motions and are being used as input for modeling soil conditions where needed.

3.SITE-SPECIFIC SEISMIC HAZARD STUDIES

The seismic hazard criteria for the Oak Ridge Reservation are defined in terms of (1) seismic hazard curves of peak ground acceleration (PGA) and peak spectral velocities (PSV) at hard rock outcrop, for varying annual probabilities of exceedance; (2) uniform hazard response spectra (UHRS) for rock outcrop, for specified probabilities of exceedance or return periods; and (3) earthquake time histories representing rock outcrop motions that match the UHRS.

1990 - 1992 Oak Ridge Reservation Study

The seismic hazard curves and site-specific response spectra were first developed during the 1990-1992 time frame using two probabilistic seismic hazard methodologies developed for evaluating nuclear power plant sites in the eastern U. S. These two methodologies were the 1988 version of the LLNL methodology [1], and the EPRI methodology [2]. The results from the EPRI methodology were calculated by Risk Engineering, Inc. while LLNL performed the calculations using the 1988 LLNL methodology. The use of the seismic hazard curves to develop the site-specific response spectra considered the following:

- Seismic hazard results from EPRI and LLNL for PGA (rock) and peak spectral velocities (PSV) at frequencies of 25, 10, 5, 2.5, 1.0, and 0.5 Hz in order to define response spectral values. Figure 1 shows the seismic hazard curves for PGA.

- Determined the pseudo-mean PGA following the guidelines in technical standard DOE-STD-1024-92, *Guidelines for use of Probabilistic Seismic Hazard Curves at Department of Energy Sites* [3]. Examination of Figure 1 shows the LLNL and EPRI methodologies resulted in significantly different estimates of the seismic hazard. To resolve these differences and to allow the results of the two methodologies to be used consistently at all DOE sites, DOE developed the guidelines in DOE-STD-1024-92. The first step in the

guidelines was a combination of the PGA results from LLNL and EPRI to obtain a pseudo-mean PGA which considered the uncertainties from both methodologies.

- Determination of dominant magnitudes and distances for the PGA and the maximum PSV at 2.5 Hz. The second step in the DOE-STD-1024-92 guidelines was to determine the dominant magnitudes and distances. The dominant magnitudes and distances for the earthquakes controlling the hazard were determined for the PGA and the maximum PSV (at 2.5 Hz). These parameters were determined for use in the generation of representative time histories and for subsequent use in deterministic evaluations. The EPRI seismic hazard results were used to determine the dominant magnitudes and distances because their spectral velocity hazard curves gave more weight to direct spectral ordinate ground-motion models than on standard spectral shape ground-motion models. The LLNL results were not used for this purpose because their spectral velocity hazard curves were based more on the use of standard spectral shape models, rather that on direct ordinate models. The dominant magnitudes and distances for the Oak Ridge Reservation are controlled by moderate-size earthquakes (m_b of 5.6 to 6.1) at close distances (25 to 85 km).

- Development of response spectra shapes from deterministically derived spectral shapes based on the dominant magnitudes and distances. The third step in the DOE-STD-1024-92 guidelines was development of median response spectra shapes based on the dominant magnitudes and distances. Actual earthquake records with similar site conditions, magnitude, and distance were examined along with eastern U.S. ground motion attenuation models to determine the response spectra shapes.

- Anchored the median response spectral shapes to the pseudo-mean PGA to define the site-specific response spectra and developed time histories to represent the site-specific spectra. The final step in the DOE-STD-1024-92 guidelines was the definition of the site-specific response spectra obtained by anchoring the median response spectra shapes to the pseudo-mean PGA. Then artificial earthquake time histories were developed to represent the site-specific response spectra. These earthquake time histories were developed to use in the analyses of structures supported on hard rock, and for use in analyses of structures supported on soil considering the behavior of the underlying soil deposit.

After the development of the site-specific response spectra using the guidelines from DOE-STD-1024-92, there were additional concerns raised during an expert peer review about the response spectra shapes in the low frequency range. Because the hazard is dominated by small to moderate magnitude earthquakes at relatively close distances, the spectral shape did not contain any significant energy in the low frequency range. The ratio between PGA and PSV was not consistent with most ground motion attenuation models plus there is much greater uncertainty associated with PSV than with PGA. To address the peer review concerns, the following additional evaluations were performed to supplement the DOE-STD-1024-92 guidelines for determining the PSV for site-specific response spectra:

- Ratios of PSV/PGA using various ground motion attenuation functions for the Eastern U.S. were determined. The attenuation functions used were McGuire et al [4] and Atkinson and Boore [5]. These ratios were used with the pseudo mean PGA to determine the PSV for the Reservation. The differences between Eastern and Western U.S. ratios were examined by comparing the above with the results obtained from the ground motion attenuation by Joyner and Boore [6]. The PSV/PGA ratios ranged from 11 to 20 for the Eastern U.S. attenuation functions for magnitudes and distances associated with annual probabilities of exceedance of 2×10^{-3} and 1×10^{-5}. For Western U.S. attenuation functions, the PSV/PGA ratios ranged from 20 to 38. These comparisons suggest that PSV/PGA ratios for rock sites are smaller in

the Eastern U.S. for moderate magnitude earthquakes at closer distances to the site and about the same for moderate magnitude earthquakes at longer distances for the sites. The main reason the ratios are smaller for the closer distances is that the PGAs are larger for the near-field type Eastern U.S. earthquakes.

- The EPRI 85th percentile peak spectral velocities for 2.5, 1.0, and 0.5 Hz were reviewed. The LLNL 85th percentile peak spectral velocities were not used because, as discussed earlier, their ground motion attenuation models are controlled by standard spectral shapes and therefore do not reflect site-specific conditions.

- The sensitivity of the UHRS obtained as a result of incorporating the DOE-STD-1024-92 guidelines to a range of dominant magnitudes and distances obtained from the hazard analyses for the annual probability of exceedance of 1×10^{-3} was determined. The dominant magnitudes were increased by about one-half magnitude units, and the dominant distances were reduced by about one-half. For the Oak Ridge Reservation, increasing the magnitude controlled the maximum PSV.

- The site-specific response spectra developed for the Perry and Sequoyah Nuclear Power Plants were scaled to the site pseudo mean PGAs. These nuclear plant sites are rock sites and have similar magnitudes and distances as the Oak Ridge Reservation for it's site-specific earthquake. The Perry plant site-specific earthquake was defined as a magnitude 5.3 $\pm$ 0.5 at a distance of 0 - 25 km. The Sequoyah plant earthquake was a magnitude 5.8 $\pm$ 0.5 at a distance of 0 - 25 km. Both plants obtained actual earthquakes with these characteristics for rock sites and determined the 50th and 85th percentile response spectra.

The PSV values obtained from the above evaluations indicated that the PSVs should be increased to account for the larger uncertainties in the low frequency range of the site-specific response spectra. All of the above considerations were factored into the development of the site-specific response spectra shown in Figure 2.

Additional information regarding the development of the seismic hazard curves and the site-specific response spectra may be obtained from *Development of the Site-Specific Earthquake Response Spectra for Eastern U.S. Sites* and it's related references [7].

Updated 1995 Site-Specific Oak Ridge Reservation Study

During the early 1990's, both DOE and the Nuclear Regulatory Commission (NRC) worked with LLNL to determine the reasons for the significant differences between the EPRI and the LLNL seismic hazard methodologies. From this work, it was determined that the main reasons the EPRI and LLNL methodologies gave significantly different results were the uncertainty characteristics assigned by some of the LLNL experts which tended to dominate the hazard and the uncorrelated a and b values assigned to the LLNL recurrence relationships. Based on this, LLNL revised their methodology, and published the results of their revised seismic hazard methodology [8] in late 1993. In addition to changes in the methodology DOE also issued technical standard DOE-STD-1020-94, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities* [9]. This standard specifies performance categories, target performance goals, and specified probability levels from which natural phenomena hazard loading is developed.

Based on these changes, it was decided to re-evaluate the seismic hazard using the new 1993 LLNL results along with the EPRI results. Figure 3 shows a comparison of the old 1988 LLNL and the new 1993 LLNL seismic hazard results for PGA at the Oak Ridge Reservation. Figure 4 shows a comparison of the EPRI and 1993 LLNL mean seismic hazard curves for PGA. Comparison of Figures 1, 3, and 4 show the new 1993 LLNL results are very similar to the EPRI results. Figure 5 shows a comparison of the EPRI and 1988

LLNL pseudo-mean (DOE-STD-1024-92) and EPRI and the 1993 LLNL geometric mean PGA seismic hazard curve. Examination of these seismic hazard curves show that combining the new 1993 LLNL hazard with the EPRI hazard results in a significant reduction in the seismic hazard at the Oak Ridge Reservation for a specified annual probability of exceedance.

Based on the previous 1990-1992 studies for response spectra shapes, the following ratios were determined for 5% damping:

$$\frac{Max\ PSA}{PGA} = 2.1 - 2.2$$

where PSA is defined as peak spectral acceleration, and

$$\frac{Max\ PSV}{PGA} = 22 - 25$$

Using these spectral shapes, the EPRI and 1993 LLNL geometric mean PGA was used to develop the updated site-specific response spectra for the Oak Ridge Reservation.

To use the new 1993 LLNL results for defining design response spectra at nuclear power plants, the Nuclear Regulatory Commission (NRC) has proposed a target median exceedance probability of exceeding the Safe Shutdown Earthquake of 1×10^{-5} in the 5 to 10 Hz and the 1.0 to 2.5 Hz range. Since the seismic design criteria for the DOE performance category (PC)4 facilities are similar to nuclear power plants, a comparison was made of the PC-4 site-specific response spectra obtained following the NRC guidelines. Based on this comparison, the site-specific response spectra were increased about 10%.

The final seismic hazard curve and site-specific response spectra for rock at the ORR sites are shown in Figures 6 and 7 respectively.

Comparison of the Site-Specific Oak Ridge Seismic Hazard with the 1996 U.S. Geological Survey Seismic Hazard

The U. S. Geological Survey (USGS)[10] has just recently completed an update to their seismic hazard maps. The USGS seismic hazard maps were developed for firm rock conditions, therefore a direct comparison of their seismic maps with the Oak Ridge site-specific hard rock seismic hazard cannot directly be made. The USGS seismic hazard has been converted to hard rock conditions using the approximate conversion factors discussed in the USGS Open-File reports. A comparison of the USGS seismic hazard (converted to hard rock) and the Oak Ridge seismic hazard is shown in Table 1. This comparison shows reasonable agreement for the PGA and the 0.2 second spectral values. The Oak Ridge seismic hazard is slightly lower than the USGS seismic hazard at the 1.0 second spectral value. The primary reason the USGS seismic hazard is higher at the 1.0 second spectral value is one of the conservative ground motion attenuation models which they used to represent the long period ground motions. Additional work is needed to obtain more consensus among the experts concerning ground motion attenuation models in the Eastern U.S.

4. CONCLUSIONS

The seismic hazard criteria has been updated for the Oak Ridge Reservation to provide site-specific response spectra for use in evaluating existing facilities and for the design of new facilities. New methodologies for estimating earthquake ground-motion are continuing to be developed. Evaluation of the new methodologies may be needed to ensure the appropriate site-specific spectra are being used.

5. ACKNOWLEDGMENTS

The authors would like to thank these individuals who contributed to the development of the seismic hazard results and the site-specific response spectra: R. K. McGuire and G. T. Toro of Risk Engineering, Inc., J. B. Savy and B. Davis

of Lawrence Livermore National Laboratory, and R. W. Rucker and E. G. Tourigny of the Department of Energy.

REFERENCES

[1] D. L. Bernreuter, et al., *Seismic Hazard Characterization of 69 Nuclear Plant Sites East of the Rocky Mountains,* NUREG/CR-5250, UCID-21517, USNRC, 1988.

[2] Technical Report NP-4726-A, Electric Power Research Institute, *Seismic Hazard Methodology for Central and Eastern United States,* Vols. 1-11, Rev. 1, 1988.

[3] U.S. Department of Energy, *Guidelines for Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites,* DOE-STD-1024-94, April 1994.

[4] R. K. McGuire et al, *Engineering Model of Earthquake Ground Motion for Eastern North America,* Technical Report NP-6074, EPRI, 1988.

[5] G. M. Atkinson and D. M. Boore, *Stochastic Prediction of Ground Motion and Spectral Response Parameters at Hard-Rock Sites in Eastern North America,* Bulletin of the Seismological Society of America, Vol. 77, 1987.

[6] W. B. Joyner and D. M. Boore, *Measurement, Characterization, and Prediction of Strong Ground Motion,* Proceedings of Earthquake Engineering & Soil Dynamics II, Geotechnical Division, American Society of Civil Engineers, 1988.

[7] J. E. Beavers et al, *Development of Site-Specific Earthquake Response Spectra for Eastern U.S. Sites,* Proceedings of the 4th DOE Natural Phenomena Hazards Mitigation Conference, 1993.

[8] U.S. Nuclear Regulatory Commission, *Revised Livermore Seismic Hazard Estimates for 69 Nuclear Power Plant Sites East of the Rocky Mountains,* NUREG-1488, 1993.

[9] U.S. Department of Energy, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities,* DOE-STD-1020-94, April 1994.

[10]Frankel, et al., *National Seismic-Hazard Maps: Documentation, June 1996,* U. S. Geological Survey Open-File Report 96-532, 1996.

Table 1. Comparison of the Site-Specific Oak Ridge Seismic Hazard and the 1996 USGS Seismic Hazard

Annual Probability of Exceedance				
		2×10^{-3}	1×10^{-3}	4×10^{-4}
PGA, g's	USGS	0.07	0.10	0.20
	Site-Specific	0.06	0.08	0.15
0.2 sec., g's	USGS	0.11	0.17	0.28
	Site-Specific	0.12	0.16	0.28
1.0 sec., g's	USGS	0.037	0.06	0.10
	Site-Specific	0.025	0.033	0.06

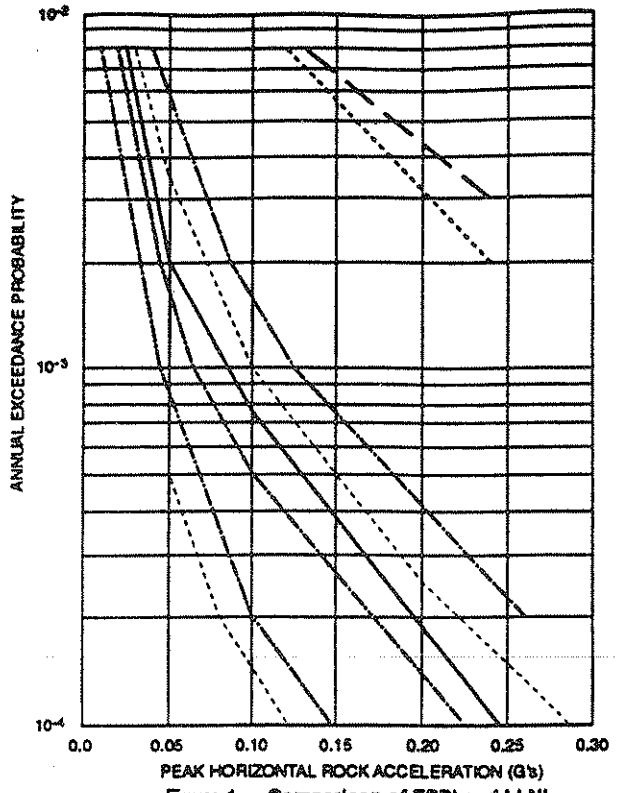

Figure 1 — Comparison of EPRI and LLNL Oak Ridge Seismic Hazard

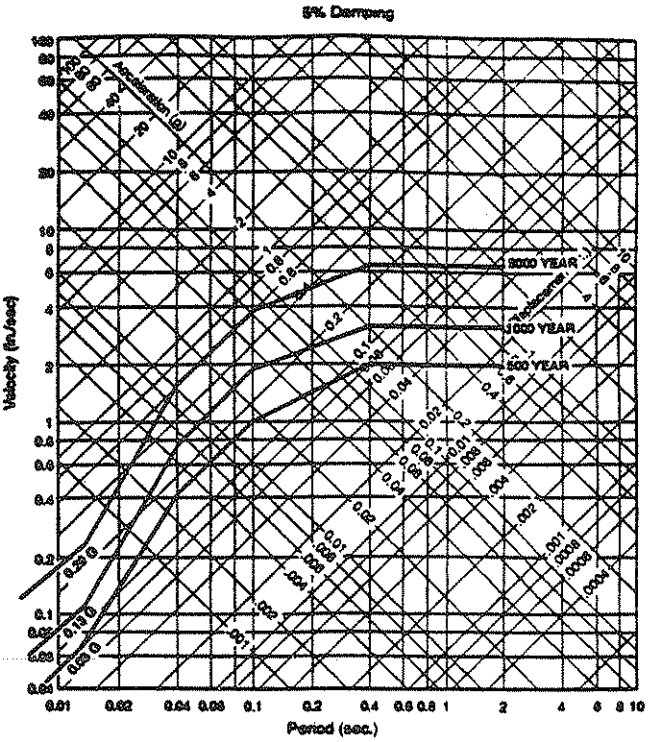

Figure 2 — OAK RIDGE - SITE SPECIFIC UNIFORM HAZARD RESPONSE SPECTRA FOR HORIZONTAL ROCK MOTION

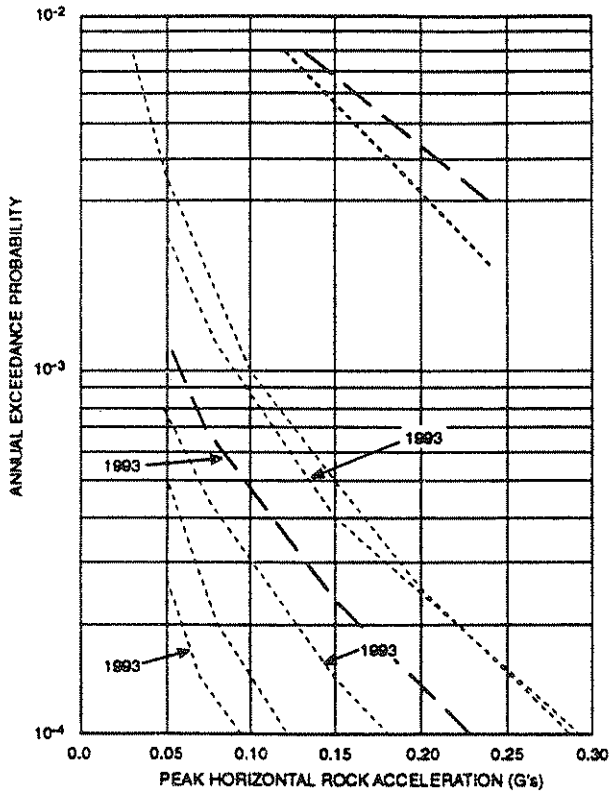

Figure 3 — Comparison of LLNL and 1993 LLNL Oak Ridge Seismic Hazard

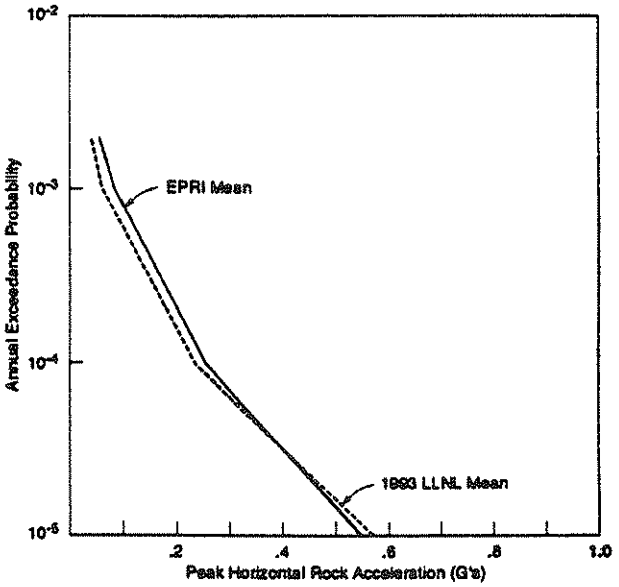

Figure 4 — Comparison of EPRI and 1993 LLNL Oak Ridge Seismic Hazard

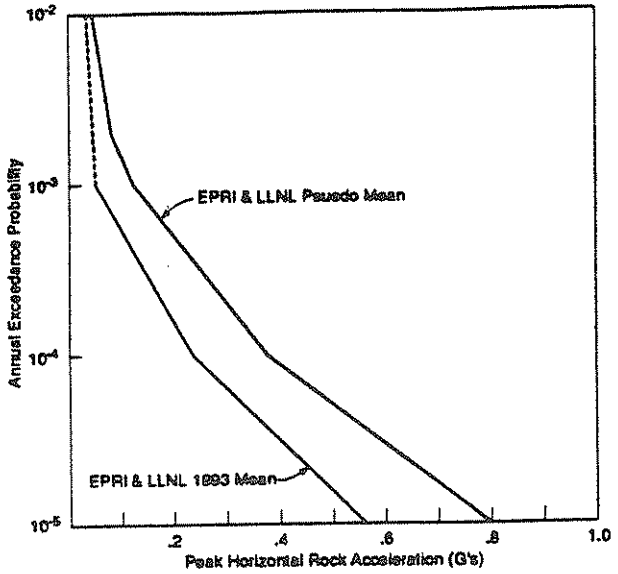

Figure 5 — Comparison of EPRI & LLNL Pseudo Mean and EPRI & 1993 LLNL Mean at Oak Ridge

Y-GA 95-2200

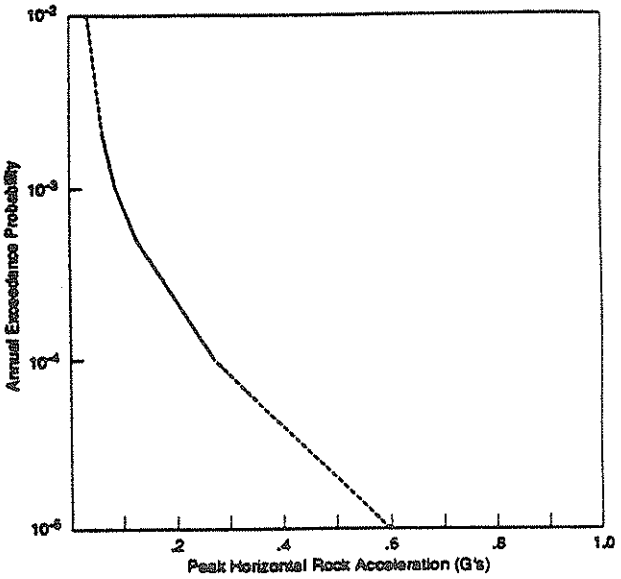

Figure 6 — Oak Ridge Mean Seismic Hazard Curve

Y-GA 95-2201

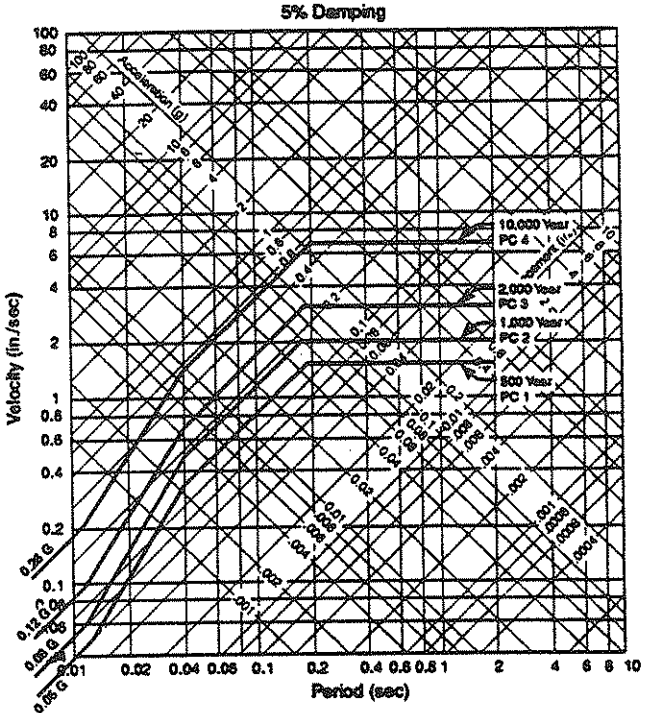

Figure 7 — OAK RIDGE - SITE SPECIFIC RESPONSE SPECTRA FOR HORIZONTAL ROCK MOTION

Y-GA 95-844R