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May 25, 1994

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Dr. Andrew J. Murphy
Chief, Structural and Seismic Engineering Branch
Division of Engineering
Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Dr. Murphy:

Enclosed for your information is a copy of NEI draft report on Seismic Siting Decision Process. This report has been prepared in response to the NRC staff questions raised during our November 30, 1993, meeting with you which are included in your January 6, 1994, memorandum.

We hope this report is responsive to the questions listed in your January 6, 1994, memorandum. If you have any questions or comments, please contact Mehdi Sarram of the NEI staff.

Sincerely,

J. R. Pietrangelo for

David J. Modeen
Manager, Technical Division

DJM/MS/rs
Enclosures

c: B. Sheron
L. Shao
G. Bagchi

6/14/94
Per telecon w/ Dave Modeen, NEI
OK to put this report in the PDR
R M Kenneally

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Seismic Siting Decision Process

Prepared By

Nuclear Energy Institute
Washington, D.C.

May 24, 1994

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Appendix C

Site-Specific Consideration of the Reference Probability

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C.1 Background

The U.S. Nuclear Regulatory Commission's (USNRC) proposed Appendix B to 10 CFR Part 100 (1) provides a seismic siting criterion for future commercial nuclear power reactors. An acceptable procedure to determine the safe shutdown earthquake ground motion (SSE) is described in DG-1015. The procedure in DG-1015 takes advantage of the availability of seismic hazard studies performed by Lawrence Livermore National Laboratory (LLNL) and the Electric Power Research Institute (EPRI) for the Stable Continental Region (SCR) of the eastern U.S. (2, 3).

An important element of the seismic siting procedure is the use of a Reference Probability (RP) to determine the SSE and the mean magnitude and distance for a site. The basis for the procedure in DG-1015 and the determination of the RP is:

1. The USNRC has stated that existing commercial nuclear power plants are safe. Using the existing plants as a reference, a procedure is developed to determine the seismic design basis for future plants. The implementation of this concept is described in Appendices B and C to DG-1015 (1).

2. The RP is based on the data base of seismic hazard information for existing commercial nuclear power plants located in the SCR.

The assessment of the RP was based on the availability of the EPRI and LLNL seismic hazard curves available for sites located in the SCR of the eastern U.S. To the extent that the characteristics of seismic hazard curves at future commercial nuclear power plant sites are consistent with those used to develop the procedure in DG-1015, the RP is an appropriate basis to determine the SSE for a future plant site. When a site-specific hazard curve deviates from the characteristics of hazard curves at existing plant sites, an option exists to revise the RP for a site-specific application, while maintaining the same level of seismic safety.

A review of seismic hazard curves indicates a high degree of similarity in terms of the shape (slope) of the hazard curves for sites in different tectonic environments. There are locations however, where the characteristics of the site hazard are different. These differences are illustrated in Figure C-1. One of the hazard curves is for a site located in the western U.S. It is characterized by higher probabilities of exceedance and steeper slopes (within a given decade of probability), particularly at higher ground motions. The second curve is typical of median seismic hazard curves for sites located in the SCR.

Using the procedure in DG-1015 to determine the seismic design basis for the sites in Figure C-1, these curves would be entered at the RP. The ground motion corresponding to the RP would be used as the basis for determining the mean magnitude and distance and ultimately

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the SSE ground response spectrum[1]. For the western U.S. site the design basis ground motion would be considerably higher than for the site in the east. A higher seismic design level at the western U.S. site is appropriate, due to the higher hazard. However, due to the differences in the shape of the hazard curves, the seismic risk at these sites is very different. The seismic risk at the western U.S. site is less than at the eastern U.S. site. Depending on the details of the two hazard curves, the differences in risk can be significant (i.e., greater than a factor of 10). Two factors contribute to this difference. The first is the fact that at the western U.S. site, there is considerably higher ground motion at the RP, due to the higher hazard. Thus, the median capacity of the plant iS high. Due to the steepness of the hazard curve at ground motions at or near the actual seismic capacity of the plant (3-5 times the design basis), the probability of these ground motions is falling off rapidly and thus the seismic risk is low. Therefore, assuming an objective of the seismic regulation is to establish a consistency among future plants in terms of their design basis and level of seismic safety, this example illustrates that conditions may exist in which the Reference Probability should be adjusted.

The purpose of this appendix is to describe the conditions for which an adjustment of the RP for a site might be considered by an applicant. It is important to note that it is anticipated that at the majority of locations the procedure described in DG-1015 (i.e., the RP) will be applicable, without modification.

C.2 Comparison of Seismic Hazard Curves

As an initial evaluation to assess similarities and differences between the shapes of seismic hazard curves, hazard results for sites in the SCR of the eastern U.S. and in active plate boundary regions were obtained. For sites in the SCR, EPRI hazard results were used. The sites in this dataset are listed in Table C-1. As an initial comparison, the log-log slope of the mean peak ground acceleration (PGA) hazard curves was determined for defined ground motion intervals. The intervals are 0.10-0.20, 0.20-0.40, 0.40-0.80, 0.80-1.60, and 1.60-2.50g PGA.

Figure C-2 shows the mean and mean plus/minus one standard deviation of the (absolute value) slope in each PGA interval for sites in the SCR. A similar result is shown in Figure C-3 for sites in plate boundary regions.

Based on the one standard deviation range, the slope of hazard curves for sites in the SCR is very consistent. Over all ground motion intervals, the coefficient of variation (ratio of the standard deviation to the mean) is less than ten percent.

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[1]For purposes of this discussion the specific details of the DG-1015 process are not described.

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Another consideration is the effect of the size of the SSE on the median/SSE capacity ratio. The results in References 6 and 8 correspond primarily to SSEs below 0.30g. As the SSE is increased the benefit of other design loads and construction practices will not increase, and the margin from the SSE to the median capacity will not go up as rapidly. On the other hand the engineering profession has learned a lot about seismic vulnerabilities in the last 20 years and how to avoid them in the future. It is expected that the lessons learned will be carried out in future designs, which will benefit new plants compared to older ones.

Based on these considerations it is judged that for new plants in the SCR a median/SSE capacity ratio of 5.0 is representative for future plants. However, for sites in the western U.S. where higher SSE values will be required a ratio of 4.0 would be more appropriate for new nuclear power plants.

C.7 Evaluation of Seismic Risk

To develop guidance when a site-specific modification of the RP may be warranted an evaluations for selected sites located in the SCR are conducted. The purpose of this assessment is to characterize the hazard at these sites in terms of hazard curve slopes and ground motions that contribute to the risk of seismically initiated core damage at future reactors. A similar evaluation is performed for sites located in active plate boundary regions. The results of these assessments are compared and provide the basis for the guidance that is developed.

To assess the risk of a seismically initiated accident at a future commercial nuclear power plant, two approaches are considered. The alternatives apply to the basis for the design of future plants.

1. In the first case it is assumed that a future reactor will be a standard plant design with a 0.30g peak ground acceleration (PGA) SSE. In this case the plant is assumed to have a predefined seismic capacity as represented in terms of a core damage fragility curve. For sites in the SCR a ratio of 5 between the plant median capacity and the SSE is used. For sites in active plant boundary regions this ratio is 4.

2. In the second case it is assumed the future plant is designed and constructed to the site-specific SSE determined at a Reference Probability of $2x10^{-5}$ (which may be lower or higher than 0.30g PGA). The same median capacity/SSE ratios are used.

The following subsections present the results for sites in the SCR and in active plate boundary regions.

C.7.1 Plants in the Eastern U.S.

The mean frequency of core damage is calculated for the sites listed in Table C-1 which are located in the SCR of the eastern U.S. For each site the seismic risk (frequency of failure) and the ground motion corresponding to the point where 50 percent of the risk has been accumulated is listed, and the slope of the hazard curve at this ground motion level. These results are reported for the two alternative assumptions regarding the plant seismic fragility described above. For the second case, the estimated median capacity based on the site-specific SSE is also listed.

The results for each site are listed in Tables C-5 and C-6. The results in Table C-5 are based on the assumed median capacity for advanced light water reactors of 1.5g (5 times the SSE of 0.30 PGA). The results in Table C-6 correspond to the determination of a site-specific SSE and a corresponding median capacity. The two sets of results are similar in a number of respects. First, the seismic risk is low (less than 10^{-6}) and similar in both cases. In addition, the hazard curve slopes and ground motion interval corresponding to the 50 percent contribution to seismic risk are similar as well.

C.7.2 Sites Located in the Western U.S. or Plate Boundary Region

The mean frequency of core damage is calculated for the sites listed in Table C-1 which are located in active plate boundary regions. For each site the seismic risk (frequency of failure) and the ground motion corresponding to the point where 50 percent of the risk has been accumulated is listed, as is the slope of the hazard curve. This assessment is made assuming that a future plant is designed to a 0.30g PGA and to a site specific SSE as described above. For sites in active plate boundary regions the seismic median capacity is taken as 4 times the SSE.

The results for each site are listed in Tables C-7 and C-8. The two sets of results based on different capacity assumptions are different. For the 1.20g capacity plant, the seismic risk at some sites is considerably higher than the site-specific result. This is reflected in the fact that the site specific median capacity values tend to be higher for these sites.

C.7.3 Comparison of Results

A number of comparisons can be made between the results for sites in the SCR and sites in active plate boundary regions. Focusing on the site specific results for each region, the seismic risk tends to be very low, less than 10^{-6} per year in each case. Secondly, the ground motions that dominate the seismic risk tend to be as high in the SCR as they are in the active plate boundary regions. Lastly, the slope of the hazard curve tend to be similar between the two regions, with the exception of the Diablo Canyon and Taiwan sites. The slope of the hazard curve at these sites is much steeper than at other sites in the SCR or in the active plate boundary regions. In the Diablo Canyon case, the steepness of the hazard curve and the high median capacity lead to the lowest estimate of seismic risk in both tectonic groups.

The results of these evaluations suggest the following observations:

1. The seismic risk associated with future reactors is low (less than 10^{-6}) when they are designed to ground motions corresponding to $2x10^{-5}$ per year, based on the margins assumed here.

2. The ground motions that dominate the risk and the slope of the seismic hazard curve at these ground motions is similar for many sites in active plate boundary regions to sites in the SCR.

3. At some sites in active plate boundary regions the ground motions and corresponding hazard curve slopes are greater than in the SCR. At these sites the seismic risk is lower (although not in all cases).

To perform these risk calculations, certain judgments regarding plant margins (median capacity to SSE ratio) are made. These judgements are based on past SPRA and SMA experience and design experience. The observations and conclusions provided here are not believed to be sensitive to reasonable changes in these judgements.

The following section provides guidance for revising the Reference Probability.

C.8 Guidance for Revising the Reference Probability

The foregoing evaluation of seismic risk shows that seismic hazard curves have a general characteristic shape over a range of tectonic environments. In selected circumstances there are significant differences between the slope of seismic hazard curves at some sites which may lead to a very different estimate of the plant risk. Where such differences exist, a site specific assessment of the Reference Probability can be considered by an applicant.

As general guidance the slope of the seismic hazard curve at ground motions that dominate risk should be approximately five or greater. For sites with slopes less than five, the opportunity to demonstrate that a consistent safety level is provided at a reduced SSE will be limited.

A trial and error procedure can be used to determine the appropriate Reference Probability. The following steps can be followed:

1. Starting with the determination of the SSE at the Reference Probability provided in DG-1015, an estimate of seismic risk can be determined based on

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an assumed seismic median capacity (using a median/SSE ratio of 4 to 5).

2. Select a target risk level.

3. The ratio of the target risk level and the seismic risk (frequency of failure) estimated in Step 1, can be used as a first a trial factor to adjust the Reference Probability.

4. Based on the new Reference Probability, the SSE and revised median capacity are determined. This median capacity is used to obtain another estimate of the seismic risk. If the estimated risk equals the target risk level, this defines the site specific Reference Probability. If the target risk level is not met, Step 3 is repeated.

C.9 References

1. U.S. Nuclear Regulatory Commission, "Proposed Rulemaking 10 CFR Part 50, 52, 100, Reactor Siting Criteria," 57 Federal Register 47802 - October 20, 1992 and 55601 - November 25, 1992.

2. D. L. Bernreuter et al., "Seismic Hazard Characterization of 69 Nuclear Plant Sites East of the Rocky Mountains," NUREG/CR-5250, January 1989.

3. Electric Power Research Institute, "Seismic Hazard Methodology for the Central and Eastern United States," Volumes 1 through 10, EPRI NP-4726-A, Palo Alto, California, 1988.

4. Pacific Gas and Electric Company, "Final Report of the Diablo Canyon Long Term Seismic Program," Docket Nos. 50-275 and 50-323, San Francisco, California, July 1988.

5. R.P. Kennedy and S.A. Short, "Basis for Seismic Provisions of DOE-STD-1020-92," prepared for the U.S. Department of Energy, UCRL-CR-111478, S/C-B235302, BNL-52418, April 1994.

6. Electric Power Research Institute, "Use of Probabilistic Seismic Hazard Results: General Decision Making, the Charlesotn Earthquake Issue, and Severe Accident Evalaution," prepared by Risk Engineering, Inc., TR-103126, Palo Alto, California, October 1993.

7. Kennedy, R.P., "Commentary on the Treatment of Seismic Events in the Implementation of the Severe Accident Policy Statement, "Prepared for Industry Degraded Core Rulemaking Program (IDCOR), April 1987.

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8. Kennedy, R.P. and M.K. Ravindra, "Seismic Fragilities for Nuclear Power Plant Risk Studies," Nuclear Engineering and Design. Vol. 79, No. 1, May 1984.

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