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Revision of siting regulation - earthquake engineering and seismic and geologic considerations - an update

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ABSTRACT: In September of 1990, the U.S. Nuclear Regulatory Commission began the formal process to revise the seismic and geologic siting criteria for nuclear power plants. The proposed regulation and draft guidance documents were published for public comment in October and November of 1992, respectively. Based upon the public comments and Commission guidance, the proposed regulation and draft regulatory guidance have been revised and published for public comment in October 1994 and February 1995, respectively. This paper will describe the philosophy and content of the regulation and regulatory guidance.

1 BACKGROUND

On April 12, 1962, the U.S. Atomic Energy Commission (AEC) issued its regulation regarding the siting of reactors, 10 CFR Part 100 (Title 10, 1994a). On November 13, 1973, the AEC issued Appendix A to 10 CFR Part 100 (Title 10, 1994b). Appendix A to 10 CFR Part 100 contains requirements for both siting and seismic design (earthquake engineering) of nuclear power plants.

There have been significant advancements in the state-of-the-art of the earth sciences and earthquake engineering since 1973. The Nuclear Regulatory Commission (NRC) published for comment a proposed revision to Appendix A for future nuclear power plants on October 20, 1992 (NRC 1992a). The availability of draft guidance documents that describe methods acceptable to the NRC for implementing the regulations was published November 25, 1992 (NRC 1992b).

Extensive comments, both domestic and international, were received. Based on these comments NRC revised the proposed regulations and guidance documents. The second proposed revision of the regulation was published for comment on October 17, 1994 (NRC 1994); the availability of the draft regulatory guidance was published on February 28, 1995 (NRC 1995a).

2 SITING ASPECTS OF THE PROPOSED RULE

2.1 Philosophy and Content

The proposed changes to the regulations and guidance documents reflect new information and research results and comments from the public on

the first proposed revision of the regulations. The proposed changes reflect the philosophy that the regulation is for future nuclear power plants and that it only contains basic requirements; the detailed guidance which is contained in the current regulation (Appendix A to 10 CFR Part 100) is removed and placed in guidance documents. Thus, the proposed regulation contains (a) required definitions, (b) a requirement to determine the geological, seismological, and engineering characteristics of the proposed site, and (c) a requirement to determine the Safe Shutdown Earthquake Ground Motion (SSE) and its uncertainty, to determine the potential for surface deformation, and to determine the design bases for seismically induced floods and water waves. The guidance documents describe procedures acceptable to the NRC staff on how to carry out these required determinations.

The key elements of the approach to determine the SSE are presented in the following section and are described in the guidance documents.

2.2 Geologic and Seismic Siting

The proposed regulation, a new Section 100.23 to 10 CFR Part 100 (NRC 1994), would replace Appendix A to Part 100 for future nuclear power plants and would identify and establish basic seismic and geologic siting factors. Detailed guidance, that is, procedures acceptable to the NRC staff for meeting the requirements, would be contained in Draft Regulatory Guide DG-1032 (NRC 1995b). Review guidelines for the NRC staff will be provided in Draft Standard Review Plan (SRP) Section 2.5.2 (NRC 1995c). Two other SRP sections, Draft SRP Section 2.5.1 (NRC 1995d) and Draft SRP Section 2.5.3 (NRC 1995e), will also be revised to assure consistency among the proposed rule, Draft SRP Section 2.5.2, and Draft Regulatory Guide DG-1032.

The existing approach for determining an SSE for a nuclear reactor site, embodied in Appendix A to 10 CFR Part 100, relies on a "deterministic" approach. Using this deterministic approach, an applicant develops a single set of earthquake sources, develops for each source a maximum earthquake to be used as the source of ground motion that can affect the site, locates the postulated earthquake according to prescribed rules, and then calculates ground motions at the site.

Although this approach has worked reasonably well for the past two decades, in the sense that SSEs for plants sited with this approach are judged to be suitably conservative, the approach has not explicitly recognized uncertainties in geoscience parameters. Because of the uncertainty about earthquake phenomena (especially in the eastern United States), there have often been differences of opinion and differing interpretations among experts as to the characteristics of the seismic sources and the largest earthquakes to be considered and the ground-motion models to be used, thus often making the licensing process relatively cumbersome.

Over the past decade and a half, probabilistic methods for incorporating these different interpretations have been developed and used. These "probabilistic" methods have been designed to allow explicit incorporation of different models for zonation, earthquake size, ground motion, and other parameters. The advantage of using these probabilistic methods is their ability to not only incorporate different models and different data sets, but also to weight them using judgments as to the validity of the different models and data sets, thereby providing an explicit expression for the uncertainty in the ground motion estimates and a means of assessing sensitivity to various input parameters. Another advantage of the probabilistic method is that a target exceed-

ance probability can be set by examining the probability of exceeding the seismic design bases of more recently licensed nuclear power plants.

The proposed revision to the regulation explicitly recognizes that there are inherent uncertainties in establishing the seismic and geologic design parameters and allows for the option of using a probabilistic seismic hazard methodology capable of propagating uncertainties as a means to address these uncertainties. The rule further recognizes that the nature of uncertainty and the appropriate approach to account for it depend greatly on the tectonic regime and parameters, such as, the knowledge of seismic sources, the existence of historical and recorded seismic data, and the understanding of tectonics. Therefore, methods other than the probabilistic methods, such as sensitivity analyses, may be adequate for some sites to account for uncertainties.

The staff has achieved an appropriate balance between deterministic and probabilistic seismic hazard evaluations in the revision of the seismic and geologic siting criteria for nuclear power plants. The key elements of this balanced approach are:

1. *Conduct site-specific and regional geoscience investigations.* These investigations are performed to determine specific characteristics of the proposed site, such as, the presence or absence of potential seismic sources, capable faults, characterization of the geological rock and soil strata, and earthquake history of site and environs. In addition to characterizing the site, these data are needed to verify that regional characteristics used in the Lawrence Livermore National Laboratory (LLNL) (Bernreuter et al. 1989, Savy et al., 1993), or the Electric Power Research Institute (EPRI), (EPRI 1989) probabilistic seismic hazard assessments (PSHA) are valid for the proposed site.

2. *Target exceedance probability is set by examining the design bases of more recently licensed nuclear power plants.* In order to determine an appropriate level of ground motion from a PSHA for use in design, a non-exceedance annual probability must be chosen. This non-exceedance annual probability, termed the target exceedance probability, was chosen by examining the non-exceedance annual probability of the SSE values for operating nuclear power plants that were designed to Regulatory Guide 1.60 or to a similar spectrum. This value has been determined to be 1E-5/year for LLNL (Sobel 1994) or EPRI PSHA for median hazard curves.

3. *Determine if information from geoscience investigations change probabilistic results.* Since the LLNL and EPRI methods also contain seismic source models,it is necessary for an applicant to conduct an evaluation that demonstrates that the data obtained from the site investigations (Step 1 above) do not provide information that would necessitate revision of the existing LLNL and EPRI seismic sources and their characteristics or attenuation models.

4. *Conduct probabilistic seismic hazard analysis and determine Ground motion level corresponding to the target exceedance probability.* The applicant conducts a LLNL or EPRI PSHA for the proposed site to obtain a seismic hazard curve, i.e., ground acceleration vs. annual probability of exceedance. The hazard curve is deaggregated to determine a controlling (See Paper 580, "Determination of Controlling Earthquakes from Probabilistic Seismic Hazard Analysis for Nuclear Power Plants.") seismic event described by an average earthquake magnitude and distance (distance from earthquake to the nuclear power plant site) which contributes most to the ground motion level corresponding to the target exceedance probability. This magnitude and distance is then used in subsequent steps to determine site-specific spectral shape.

5. *Determine site-specific spectral shape and scale this shape to the ground motion level determined above.* The applicant will use the seismic event of magnitude and distance determined in Step 4 to develop a site-specific spectral shape in accordance with Draft SRP 2.5.2 procedures and additional guidance to be provided in Draft Regulatory Guide DG-1032. The SRP procedures, in part, are based on use of seismic recorded motions or ground motion models appropriate for the event, region and site under consideration.

6. *NRC staff review of ground motion.* The NRC staff will review the applicants proposed SSE ground motion to assure that it takes into account all available data including insights and information gained from previous licensing experience.

7. *Update the data base and reassess probabilistic methods at least ever ten years.* To keep the regulatory guidance on the probabilistic methods and their seismic hazard data base current, the NRC would reassess them at least every ten years and update them as appropriate.

Thus, the above proposed approach requires thorough regional and site-specific geoscience investigations. The proposed approach reflects some of the comments of the U.S. utility industry. The U.S. Geological Survey provided a series of comments and recommendations that led to and can be met by the above balanced approach.

3 EARTHQUAKE ENGINEERING

The earthquake engineering requirements currently contained in Appendix A to 10 CFR Part 100 for current plants will be placed into a new proposed Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," to 10 CFR Part 50 (NRC 1994) for future nuclear power plants. Procedures acceptable to the NRC staff for meeting the requirements in the regulation are contained in Draft Regulatory Guides DG-1033, DG-1034, and DG-1035, (NRC 1995f, 1995g and 1995h).

3.1 Operating Basis Earthquake Ground Motion (OBE)

The proposed regulation would allow the value of the OBE to be set at (a) one-third or less of the SSE, where OBE requirements are satisfied without an explicit response or design analyses being performed, or (b) a value greater than one-third of the SSE, where analysis and design are required. If an OBE of one-third of the SSE is used, the OBE serves the function of an inspection and shutdown earthquake. There is high confidence that, at the one-third SSE ground-motion level with other postulated concurrent loads, most critical structures, systems, and components will not exceed currently used design limits.

3.2 Required Plant Shutdown

The proposed regulation would treat plant shutdown associated with vibratory ground motion exceeding the OBE or significant plant damage as a condition in every operating license. A new paragraph would be added to the regulations to require a process leading to plant shutdown for licensees of nuclear power plants that comply with the earthquake engineering criteria in Proposed Appendix S to 10 CFR Part 50. Immediate shutdown could be required unless it is determined that structures, systems, and components needed for safe shutdown are not functional. The regulation includes a provision that requires the licensee to consult with the Commission and to propose a plan for the timely, safe

shutdown of the nuclear power plant if systems, structures, or components necessary for a safe shutdown or to maintain a safe shutdown are not available (possibly due to earthquake related damage).

4 RELATED REGULATORY GUIDES AND STANDARD REVIEW PLAN SECTIONS

As discussed earlier, the NRC has developed the following draft regulatory guides and standard review plan sections to provide prospective licensees with the necessary guidance for implementing the proposed regulation.

1. Draft Regulatory Guide DG-1032 (NRC 1995b), provides general guidance and recommendations, describes acceptable procedures and provides a list of references that present acceptable methodologies to identify and characterize capable tectonic sources and seismogenic sources.
2. Draft Regulatory Guide DG-1033 (NRC 1995f), Third Proposed Revision 2 to Regulatory Guide 1.12, "Nuclear Power Plant Instrumentation for Earthquakes." The draft guide describes seismic instrumentation type and location, operability, characteristics, installation, actuation, and maintenance.
3. Draft Regulatory Guide DG-1034 (NRC 1995g), "Pre-Earthquake Planning and Immediate Nuclear Power Plant Operator Post-Earthquake Actions." The draft guide provides guidelines for a timely evaluation of recorded seismic instrumentation data and to determine whether or not plant shutdown is required.
4. Draft Regulatory Guide DG-1035 (NRC 1995h), "Restart of a Nuclear Power Plant Shut Down by a Seismic Event." The draft guide provides guidelines for performing inspections and tests of nuclear power plant equipment and structures prior to restart of a plant that has been shut down because of a seismic event.
5. Draft Standard Review Plan Section 2.5.1 (NRC 1995d), describes procedures to assess the adequacy of the geologic and seismic information cited in support of the applicant's conclusions concerning the suitability of the plant site.
6. Draft Standard Review Plan Section 2.5.2 (NRC 1995c), describes procedures to assess the ground motion potential of seismic sources at the site and to assess the adequacy of the SSE.
7. Draft Standard Review Plan Section 2.5.3 (NRC 1995e), describes procedures to assess the adequacy of the applicant's submittal related to the existence of a potential for surface faulting affecting the site.

CONCLUSION

In summary, the proposed approach incorporates advancements in the state-of-the-art in the earth sciences such as new geological and geophysical investigation techniques, latest characterization of sources and ground motion, and explicit recognition of uncertainties in ground motion estimates and the requirement that these uncertainties must be addressed through an appropriate analysis, such as a probabilistic seismic hazard analysis or suitable sensitivity analyses. It is anticipated that the final regulations will be published in late 1995 and the guidance documents in early 1996.

REFERENCES

Bernreuter et al., 1989. "Seismic Hazard Characterization of 69 Nuclear Plant Sites East of the Rocky Mountains," NUREG/CR-5250, Volumes 1-8, January 1989.

EPRI 1989. "Probabilistic Seismic Hazard Evaluations at Nuclear Power Plant Sites in the Central and Eastern United States," Electric Power Research Institute, EPRI NP-4726, All Volumes, 1989-1991.

NRC 1992a. "Reactor Site Criteria Including Seismic and Earthquake Engineering Criteria for Nuclear Power Plants and Proposed Denial of Petition from Free Environment, Inc. et al.," *Federal Register*, Volume 57, October 20, 1992, p. 47802.

NRC 1992b. "Draft Regulatory Guides and Standard Review Plan Section; Issuance, Availability," *Federal Register*, Volume 57, November 25, 1992, p. 55601.

NRC 1994. "Reactor Site Criteria Including Seismic and Earthquake Engineering Criteria for Nuclear Power Plants and Proposed Denial of Petition from Free Environment, Inc. et al.," *Federal Register*, Volume 59, October 17, 1994, p. 52255.

NRC 1995a. "Draft Regulatory Guides and Standard Review Plan Sections; Issuance, Availability," *Federal Register*, Volume 60, February 28, 1995, p. 10880.

NRC 1995b. Draft Regulatory Guide DG-1032, "Identification and Characterization of Seismic Sources and Determination of Shutdown Earthquake Ground Motions," NRC, February 1995

NRC 1995c. Draft Standard Review Plan Section 2.5.2, Second Proposed Revision 3 "Vibratory Ground Motion," NRC, February 1995.

NRC 1995d. Draft Standard Review Plan Section 2.5.1, Proposed Revision 3, "Basic Geologic and Seismic Information," NRC, February 1995.

NRC 1995e. Draft Standard Review Plan Section 2.5.3, Proposed Revision 3, "Surface Faulting," NRC, February 1995.

NRC 1995f. Draft Regulatory Guide DG-1033, Third Proposed Revision 2 to Regulatory Guide 1.12, "Nuclear Power Plant Instrumentation for Earthquakes," NRC, February 1995.

NRC 1995g. Draft Regulatory Guide DG-1034, "Pre-Earthquake Planning and Immediate Nuclear Power Plant Operator Post-Earthquake Actions," NRC, February 1995.

NRC 1995h. Draft Regulatory Guide DG-1035, "Restart of a Nuclear Power Plant Shut Down by a Seismic Event," NRC, February 1995.

Savy et al., 1993. "Eastern Seismic Hazard Characterization Update, Lawrence Livermore National Laboratory, UCRL-ID-115111, June 1993.

Sobel 1994. "Revised Livermore Seismic Hazard Estimates for Sixty-Nine Nuclear Power Plant Sites east of the Rocky Mountains," NRC, NUREG-1488, April 1994.

Title 10, 1994a. *Title 10, Code of Federal Regulations, Energy (10 CFR Part 0 to 199)*, Revised as of January 1, 1994, Part 100, "Reactor Site Criteria," Office of the Federal Register, National Archives and Records Administration, Washington, DC. USA

Title 10, 1994b. *Title 10, Code of Federal Regulations, Energy (10 CFR Part 0 to 199)*, Revised as of January 1, 1994, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," to Part 100, "Reactor Site Criteria," Office of the Federal Register, National Archives and Records Administration, Washington, DC. USA.