SELECTION OF THE DESIGN EARTHQUAKE GROUND MOTION REFERENCE PROBABILITY

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EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) is amending its licensing requirements for dry cask modes of storage of spent nuclear fuel, high-level radioactive waste, and power reactor-related greater than Class C waste in an independent spent fuel storage installation (ISFSI) or in a U.S. Department of Energy (DOE) monitored retrievable storage installation (MRS). These amendments will update the seismic siting and design criteria, including geologic, seismic, and earthquake engineering considerations in 10 CFR Part 72 regulations. The final rule will allow NRC and its licensees to benefit from experience gained in the licensing of existing facilities and to incorporate rapid advances in earth sciences and earthquake engineering, using probabilistic seismic hazard analysis (PSHA). The proposed rule and the announcement on the availability of the draft Regulatory Guide, DG-3021, were published for public comments on July 22, 2002.

This paper describes the basis for recommending the reference probability that is used in Regulatory Position 3.4 of the Regulatory Guide (RG) 3.73 (draft was the aforementioned DG-3021) to determine the design earthquake ground motion (DE) for ISFSI and MRS facilities. The reference probability is the mean annual probability of exceeding the DE.

This paper is prepared in response to the Staff Requirements Memorandum (SRM) dated November 19, 2001, pertaining to the Modified Rulemaking Plan for changes to the seismological and geological requirements of Part 72, for siting and design of a dry cask ISFSI or MRS (SECY-01-0178). The SRM required the staff to seek public comments on the issue of the appropriate value of the reference probability in the range of 5E-4 and 1E-4, and to provide further analysis to support a specific recommendation.

In certain situations, the Part 72 amendments to the regulations require the use of PSHA methods or suitable sensitivity analyses for specific ISFSI or MRS facilities. In particular, a specific-license applicant for a dry cask storage ISFSI or MRS facility at a site not co-located with a nuclear power plant (NPP), in either the western U.S., or in areas of known seismic activity in the Eastern U.S., must use PSHA or suitable sensitivity analyses, to address uncertainties in determining the DE. For all other specific-license applicants for a dry cask storage ISFSI or MRS facility, the use of PSHA or suitable sensitivity analyses is optional. For instance, the applicant can use the design criteria for the most recent NPP (if applicable), or for locations in the Eastern U.S., a standardized DE described by a response spectrum anchored at 0.25 g (acceleration due to gravity), consistent with current Part 72 regulations.

To select the reference probability, the staff performed analytical studies to evaluate dry cask storage system behavior, and the potential for a cask failure and the subsequent radioactivity release during an earthquake. In addition, the staff reviewed the requirements and guidelines for siting and design of NPPs and other critical facilities contained in NRC RG 1.165; DOE-STD-1020-2002; and the International Building Code - 2000. Finally, the staff considered the public comments received in response to a specific question on an appropriate value of the

reference probability, published with the proposed rule.

Based on the above-mentioned evaluations, the staff has concluded that the risk of a dry cask storage system releasing radioactivity during an earthquake is not significant, and that an ISFSI or MRS facility designed to the reference probability of 5E-4 (2000-year return period[1]) is expected to provide reasonable assurance that public radiological health and safety will be protected.

[1]The mean annual probability of exceedance, p, of an earthquake, is the reciprocal of the return period of the earthquake (i.e., p = 1/T). As an example, consider a site at which the return period for an earthquake is 2000 years. In this case, the mean annual probability of exceedance is 5E-4 (1/2000) or 0.05 percent.

SELECTION OF THE DESIGN EARTHQUAKE GROUND MOTION REFERENCE PROBABILITY

1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) is amending its licensing requirements for dry cask modes of storage of spent nuclear fuel, high-level radioactive waste, and power reactor-related Greater than Class C waste in an independent spent fuel storage installation (ISFSI) or in a U.S. Department of Energy (DOE) monitored retrievable storage installation (MRS). These amendments will update the seismic siting and design criteria, including geologic, seismic, and earthquake engineering considerations in 10 CFR Part 72 regulations. The final rule will allow NRC and its licensees to benefit from experience gained in the licensing of existing facilities and to incorporate the rapid advancements in the earth sciences and earthquake engineering using probabilistic seismic hazard analysis (PSHA). The proposed rule and the announcement on the availability of the draft Regulatory Guide, DG-3021, were published for public comments on July 22, 2002 (Ref. 1).

This paper describes the basis for recommending the reference probability that is used in Regulatory Position 3.4 of Regulatory Guide (RG) 3.73 (Ref. 2, draft was DG-3021) to determine the design earthquake ground motion (DE) for ISFSI and MRS facilities. The reference probability is the mean annual probability of exceeding (MAPE) the DE. Appendix A contains the abbreviations used in this paper.

This paper is prepared in response to the Staff Requirements Memorandum (SRM) dated November 19, 2001 (Ref. 3), pertaining to the Modified Rulemaking Plan for changes to the seismological and geological requirements of Part 72, for siting and design of a dry cask ISFSI or MRS (SECY-01-0178). The SRM required the staff to seek public comments on the issue of the appropriate value of the reference probability in the range of 5E-4 and 1E-4, and to provide further analysis to support a specific recommendation.

2. BACKGROUND

In certain situations, the Part 72 amendments to the regulations require the use of PSHA or suitable sensitivity analyses for specific ISFSI or MRS facilities. In particular, a specific-license applicant for a dry cask storage ISFSI or MRS facility at a site not co-located with a nuclear power plant (NPP), in either the western U.S., or in areas of known seismic activity in the eastern U.S., must use PSHA or suitable sensitivity analyses, to address uncertainties in determining the DE. For all other specific-license applicants for a dry cask storage ISFSI or MRS facility, the use of PSHA or suitable sensitivity analyses is optional. The applicant can use the design criteria for the most recent NPP (if applicable), or for locations in the Eastern U.S., a standardized DE described by a response spectrum anchored at 0.25 g (acceleration due to gravity), consistent with the current Part 72 regulations. The amendments are not applicable to licensees operating an ISFSI under a Part 72 general license anywhere in the U.S.

In the “Statement of Considerations” accompanying the initial Part 72 rulemaking, in 1980 (Ref. 4), NRC recognized that probabilistic techniques are adequate to determine potential seismicity on a regional basis, but these techniques were not adequately developed for application to a specific site. During the past 20 years, PSHA methodology and procedures have now been developed sufficiently for the evaluation of seismic safety of nuclear facilities, and can be applied to the dry cask ISFSI and MRS, using the guidelines of Reference 5.

The NPPs, ISFSIs, and MRS facilities have been designed for earthquake loads, based on considering the greater risk factors for such facilities than for traditional buildings. The current Part 72 regulations for an ISFSI or an MRS facility require that for sites that have been evaluated under the criteria of Appendix A of 10 CFR Part 100, the DE must be equivalent to the safe shutdown earthquake ground motion (SSE) for an NPP. Recently, the seismological and geological siting criteria for an NPP were revised to require the use of PSHA methods or suitable sensitivity analyses, to account for uncertainties in the determining the ground motion used in the seismic design of structures, systems, and components (SSCs) (10 CFR 100.23, and Appendix S to 10 CFR Part 50). In addition, staff/Commission received requests for exemptions to 1o CFR 72.102(f), which requires that the DE for an ISFSI or MRS facility be determined using Appendix A of Part 100. Therefore, there is a need to change Part 72 to allow the use of PSHA and make the earthquake design level commensurate with the risk to public health and safety from an ISFSI or MRS facility.

In a risk-informed, performance-based approach, the earthquake design level of the facility is selected based on the degree of risk associated with the facility. For more than 50 years, this approach has been used in the building codes, such as the Uniform Building Codes (UBC) (Ref. 5); the National Building Codes (Ref. 6); and recently in the International Building Code -2000 (IBC-2000) (Ref. 7). These codes specify the earthquake design levels, considering the adverse consequences in terms of the hazard to human life, and the required performance of the structures. For example, specific seismic design provisions in the IBC-2000 Code are based on a graded approach, considering the function of the building, number of occupants, the post-earthquake requirement to have the facility available for use, etc.), and the hazard to the public from the contents of the building (toxic materials) (Ref. 7, section 1604.5).

3. RISK OF ISFSI/MRS FACILITY

This section discusses why an ISFSI or MRS facility does not have to be designed for NPP criteria, and how annual probability of exceeding the DE (the reference probability) was selected considering the risk of an ISFSI or MRS facility. First, the risk of an ISFSI/MRS facility is compared to an NPP. Second, the consequences of an earthquake and the likelihood of a release of radioactivity at an ISFSI/MRS facility are reviewed. Third, the industry codes for facilities similar to ISFSI or MRS facilities and the public comments are reviewed to select an appropriate reference probability for ISFSI or MRS facilities.

3.1 Comparison to NPP Risk

In the "Statement of Considerations" accompanying the initial Part 72 rulemaking, NRC recognized that the storage of spent fuel is a low-risk operation when compared to an NPP (45 FR 74697; November 12, 1980). Factors that result in lower radiological risk at an ISFSI or MRS, compared with an NPP, include the following:

- In comparison with an NPP, an operating ISFSI or MRS is a relatively simple facility in which the primary activities are waste receipt, handling, and storage. An ISFSI or MRS does not have the variety and complexity of active systems necessary to support an operating NPP. After the spent fuel is in place, an ISFSI or MRS is essentially a static operation.

- During normal operations, the conditions required for the release and dispersal of significant quantities of radioactive materials are not present. There are no components carrying fluids at high temperatures or pressures, during normal operations, nor under design basis accident conditions, to cause the release and dispersal of radioactive materials. This is primarily because of the low heat-generation rate of spent fuel that has undergone more than 1 year of decay before storage in an ISFSI or MRS, and to the low inventory of volatile radioactive materials readily available for release to the environment.

- The long-lived nuclides present in spent fuel are tightly bound in the fuel materials and are not readily dispersible. Short-lived volatile nuclides, such as Iodine-131, are no longer present in aged spent fuel. Furthermore, even if the short-lived nuclides were present during a fuel assembly rupture, the canister surrounding the fuel assemblies would confine these nuclides. Therefore, the Commission believes that the seismically induced radiological risk associated with an ISFSI or MRS is significantly less than the risk associated with an NPP.

3.2 Consequences of an Earthquake

Radiological risks to the public result from a release of radioactive materials and its dispersal to the environment. To protect the public from radiological risk, Part 72 regulations require that the SSCs in an ISFSI or MRS facility be classified as important to safety if they have the function of protecting public health and safety from undue risk and preventing damage to the spent fuel during handling and storage.

3.2.1 Part 72 Requirements

The Dry Cask Storage Systems (DCSS') for ISFSIs or MRS', approved under Part 72 regulations, are typically self-contained, massive, concrete or steel structures, weighing approximately 90000 to 160000 kg (100 to 180 tons) when fully loaded, and are completely passive. The DCSS consists of free-standing vertical casks, or concrete Vault-Module-type storage systems. The spent fuel is contained in a steel sealed canister for both types of storage systems. An ISFSI or MRS facility also includes a Canister Transfer Building (CTB). This reinforced concrete building is considered important to

safety, because the building is used for transferring the canister, containing the spent fuel assemblies, from the cask used to transport the canister from a spent-fuel pool, to the cask used for storage.

The requirements in Part 72 in Subparts E, “Siting Evaluation Factors,” and F, “General Design Criteria,” ensure that the dry cask storage designs are very rugged and robust. The DCSS design dimensions, such as thickness of various members, are governed by radiological shielding, thermal, and potential drop accidents during handling of the cask. Stresses in various cask components from natural phenomena such as earthquakes, tornadoes, floods, etc., are generally less than 5 percent of the design allowables, and do not govern the physical design of the cask. However, because the cask is free-standing, cask stability (sliding and/or overturning) is a significant design parameter. Cask movements are calculated to evaluate the potential for a cask tip-over, and a cask-to-cask impact. The effects of a cask tip-over event on the cask structural integrity are evaluated even if it is demonstrated that a cask tip-over is not probable. If a cask-to-cask impact is likely to occur, the cask structural integrity is evaluated. Applicable requirements for cask structural integrity are contained in 10 CFR 72.122 and 72.212.

3.2.2 DCSS Confirmatory Evaluations/Analyses

To evaluate DCSS behavior during an earthquake on a generic basis, typical storage systems [one a cylindrical cask, HI-STORM 100, the other a concrete module type, NUHOMS] were analyzed for a range of earthquakes (Refs. 8 -11). Site-specific properties at three ISFSI facilities, two on the West coast, and one on the East coast, were considered in the analyses. The analyses were performed for the maximum peak ground acceleration varying from 0.15 g to 1.5 g. The purpose of the studies was to determine the stability of the free-standing DCSS’ during an earthquake.

Based on the results of the analyses, it has been concluded that a free-standing dry storage cask remains stable and will not tip over, or would not slide and impact the adjacent casks during an earthquake with the maximum peak ground acceleration as high as 1.5 g. The maximum earthquake SSE levels for currently licensed NPPs do not exceed 1.0 g. Even though a cask would remain stable and continue to maintain structural integrity for DE levels as high as SSE of an NPP, the current Part 72 requirements of DE, to be the same as SSE, impose unnecessary regulatory burden for the design of other structures of the ISFSI or MRS facility, such as cask pad and the foundation stability, CTB stability, and CTB structural design. Requiring these structures to be designed for SSE does not increase the safety of the facility because the consequences of an earthquake event at an ISFSI or MRS facility are not significant, as discussed earlier.

3.2.3 CTB at ISFSI/MRS Facility

Consequences of a failure of the CTB, during an earthquake magnitude greater than the DE, were analyzed (Ref. 12) to determine if the failure of the crane and the handling system, and resulting drop of the cask and the crane [approximately 16 m (51 feet)], would damage the multi-purpose canister (MPC) of the HI-STORM 100 system. Based on the evaluation, it is concluded that the MPC would not be damaged and release radioactivity to

the environment. Therefore, even if the CTB were to fail during an earthquake, there are no consequences from failure of the building at a dry cask ISFSI or MRS facility (Ref. 12).

Additionally, for the CTB, the probability of the occurrence of an earthquake during the time the cask is being handled is low. This is because the handling building and crane are used for only a fraction of the licensed period of an ISFSI or MRS, and for only a few casks at a time. Moreover, dry cask ISFSIs are expected to handle only sealed casks and not individual fuel assemblies. Therefore, the potential risk of a release of radioactivity caused by failure of the cask handling or crane during an earthquake is small.

Based on the above, the staff has concluded that the DCSS' for an ISFSI or MRS facility are inherently robust structures because of design requirements other than for an earthquake, and for an earthquake of a magnitude equal to the SSE for an NPP, there is relatively low probability of radioactivity release, and thus relatively low probability of adverse consequences from operation of a dry cask ISFSI or MRS facility.

3.3 Selection of an Appropriate Reference Probability

To select an appropriate reasonable value of the MAPE of an earthquake (the reference probability), or a mean return period, for a dry cask ISFSI or MRS facility, the staff reviewed the current guidelines contained in DOE-STD-1020-2002 (Ref. 13); the IBC-2000 Code (Ref. 7); RG 1.165 for an NPP (Ref. 14), and considered the public comments received in response to the specific question accompanying the proposed rule (Ref. 1).

3.3.1 DOE Design Standard

DOE requires the safety-significant or important-to-safety SSCs to be classified into one of four performance categories (PCs), based on the performance requirements (Ref. 13). The four categories are PC-1 through PC-4. The PC-1 category is for an SSC or a building/structure with potential human occupancy, the failure of which may cause a fatality or serious injuries to workers. The PC-2 category is for an SSC performing emergency functions to preserve the health and safety of workers, and is a part of a building used for assembly of more than 300 persons in one room. The PC-3 category is for an SSC whose failure would result in adverse release consequences less than the unmitigated release associated with a large-reactor severe accident. The PC-4 category is for an SSC whose failure would result in off-site release consequences greater than or equal to the unmitigated release associated with a large-reactor severe accident.

The PC-3 category is generally used for SSCs that handle significant amounts of hazardous materials. Based on the DOE classification of SSCs, the dry cask ISFSIs can be classified as PC-3 SSCs. For PC-3 SSCs, the design seismic hazard exceedance is 4E-4 (2500-years return period), except for sites which are near tectonic plate boundaries. For PC-3 SSCs at these sites, the design seismic hazard exceedance probability is 1E-3 (1000-years return period). The seismic hazard exceedance probability of 4E-4 is equivalent to a 2 percent probability of exceedance in 50 years. Design forces for these structures are multiplied by a Scale Factor of 0.9 (page A-6 of Attachment A) to bring the earthquake design levels to approximately 2000-year return period, specified in the earlier

DOE-STD-1020-94. The "Foreword" of DOE-STD-1020-2002 (Page A-2 of Attachment A), explains the change in the return period as follows:

> "It is not the intent of this revision to alter the methodology for evaluating PC-3 facilities, nor to increase the performance goal of PC-3 facilities, by increasing [the] return period for the PC-3 from a 2000-year earthquake to a 2500-year earthquake. Rather, the intention is more for convenience to provide a linkage from the NEHRP maps and DOE Standards."

It can be seen from Figure 1 that the Scale Factor of 0.9 used for the DOE PC-3 facilities would be equivalent to an approximately 2000-year return period earthquake for a facility located in New York City, and an approximately 1700-years return period for a facility located in the San Francisco area. Therefore, it can be concluded that the DOE design basis earthquake for PC-3 category structures similar to a dry cask ISFSI or MRS facility is an approximately 2000-year return period earthquake.

In summary, DOE facilities typical of ISFSIs and MRS' are designed to seismic criteria lower than the NPP design criteria, and the use of a reference probability of 5E-4 (2000-year return period for the design of an ISFSI or MRS facility DE, would be consistent with that used in DOE-STD-1020, for similar-type facilities.

3.3.2 IBC- 2000

The IBC-2000 (Ref. 7) seismic requirements are based on the 1997 edition of the NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures (Ref. 15). A graded approach is used in specifying the design levels of earthquakes, based on the degree of risk and the potential for human loss caused by failure of a structure from an earthquake. The requirements are intended to minimize the hazard to life for all buildings, increase the expected performance of higher-occupancy buildings, as compared to ordinary buildings, and improve the capability of essential facilities, such as hospitals, and infrastructure required for national defense etc., to function during and after an earthquake. For essential facilities, it is expected that damage from DE would not be so severe as to prevent continued occupancy and function of the facility. For ground motion greater than the design levels, the intent is that there would be a low likelihood of structural collapse.

The IBC-2000 defines the maximum considered earthquake (MCE) ground motion, as a collapse-level earthquake with a 2 percent probability of exceedance in 50 years. This is equivalent to an annual probability of exceedance of 4E-4 (2500-year return period). The design earthquake spectral acceleration, which is equivalent to the DE for an ISFSI or MRS facility, is specified in the IBC-2000 as two-thirds of the MCE spectral response acceleration. The purpose of specifying the MCE instead of the DE was to provide an approximately uniform margin against collapse of structures located in the Western United States (WUS) and the Eastern United States.

The earlier UBCs specified a DE at a 10 percent probability of exceedance in 50 years (an approximately 500-year return period). Because of the differences in the shapes of the seismic hazard curves of the Eastern United States and the WUS, the buildings located in

the Eastern and the WUS would have different safety margins in their ability to survive a greater-level earthquake ground motion. Considering the margin of safety of 1.5 inherent in recent and current U. S. seismic design practice (Ref. 16) and using the Hazard Curves for the Eastern United States (New York City), and the WUS (San Francisco), as shown in Figure 2, it can be seen that a building in New York City designed using the 500-year earthquake return period ground motion can survive an earthquake with a return period of approximately 830 years, whereas the same building in San Francisco can survive an earthquake of return period of approximately 1670-years. Thus, there was a disparity in the seismic risk levels for the WUS and Eastern United States. A study (Ref. 17) discusses this in detail. The IBC-2000, which replaced the earlier UBCs, corrects this disparity by specifying the collapse-level earthquake MCE and requires the DE to be determined using the margin of safety of 1.5. Thus, the IBC-2000 provides for a uniform margin against collapse, but not a uniform probability of the ground motion.

To account for the degree of consequences and grading the risk to public health and safety, the IBC-2000 requires the DE to be multiplied by a seismic factor that varies from 1.00 to 1.5. The seismic factor increases with the importance of the facility, based on the nature of occupancy and the degree of adverse consequences (Table 1604.5 of Ref. 7, included as Attachment B to this report). A dry cask ISFSI or MRS facility is a passive-storage facility that does not require continuous operation, and thus represents a low hazard to human life in case of failure. Therefore, it is appropriate to use the Seismic Factor of 1.00 for a dry cask ISFSI or MRS facility, consistent with IBC-2000 Category IV buildings.

Based on the evaluation described above, the IBC-2000 would require the DE for the dry cask ISFSI or MRS facility to be equivalent to a 909-year return period for a facility located in San Francisco, CA, and a 1430-year return period for a facility located in New York City (Figure 3). The DE included in the RG (Ref. 2) is equivalent to a 2000-year return period, which exceeds the IBC-2000 Code requirement of a 1300-year return period.

3.3.3 CTB Capacity

The CTB at an ISFSI or MRS facility is designed using the load combinations, the acceptance criteria, and the design code, which are the same as for NPP safety-related seismic Category I buildings. Considering the margin of safety of 1.5 inherent in recent and current U. S. seismic design practice (Ref. 16) and using the Hazard Curves (at 0.1-second Spectral Acceleration) for New York City, in the Eastern United States, and San Francisco, in the WUS (Figure 4), it can be seen that a building structure designed for DE with a return period of 2000 years (0.1-second Spectral Acceleration, varying from 0.5 g to 1.3 g), as proposed in the regulatory amendments, has a capacity to withstand an earthquake with a return period of 4000-years in New York City, and 25000-years in San Francisco, CA, without collapse (0.1-second Spectral Acceleration, varying from 0.75 g to 3.15 g). The difference in these estimates between the Eastern United States and the WUS is caused by differences in seismic hazard curves.

3.3.4 NPP Design

For the siting of an NPP, RG 1.165 recommends the reference probability of 1E-5, as the

"median" annual probability of exceeding the SSE. The "median" annual probability of exceedance of 1E-5 is approximately equal to a "mean" annual probability of exceedance of 1E-4 (10,000 years return period) for the SSE, at sites in the Eastern United States (Ref. 18). Because the uncertainty associated with the seismic hazard evaluations at sites in the WUS is less than at Eastern United States sites, "mean" values normally are closer to "median" values at the WUS sites. Thus, choosing a "mean" annual probability of exceedance of 1E-4 would be consistent with the "mean" hazard level associated with the "mean" hazard levels of nuclear power plants in the Eastern United States, but choosing a "median" annual probability of exceedance of 1E-5 would not be. Based on the recent work in NUREG/CR-6728 (Ref. 19), the staff has determined that the use of a "mean" annual probability of exceedance for the reference probability of the seismic hazard is an appropriate method for the design of an ISFSI or MRS facility.

3.3.5 Public Comments

There were seven public comments on an appropriate reference probability for DE. Four of the comments from the nuclear industry and DOE, strongly endorse the referenced probability of 5E-4, whereas two comments (State of Utah and the California Energy Commission) appear to imply that, as a minimum, NRC should use the reference probability of 4E-4, consistent with the IBC-2000. One comment from the State of Nevada suggests that 10 CFR 100.23 should be adopted in its entirety, including conforming the DE to the SSE criteria.

The discussions in sections 3.1 and 3.3.1 through 3.3.5 provide the bases for the DE reference probability of 5E-4. It also demonstrates that the DE reference probability is reasonable, considering the relative risks of an ISFSI or MRS facility and an NPP, and is consistent with the design-level ground motions specified by the codes for similar facilities.

3.4 Summary

1. Based on the fact that the risk from an earthquake at a dry cask ISFSI or MRS facility is lower than at an NPP, the reference probability for such a facility should be higher than the reference probability of 1E-4 for an NPP. In other words, the design-mean-earthquake return period for such a facility should be less than 10000 years.

2. The reference probability of 5E-4 (2000-year return period), for an ISFSI or MRS facility DE, is consistent with that used in DOE-STD-1020, for similar-type facilities.

3. The IBC-2000 requires the buildings, similar to a dry cask ISFSI or MRS facility, to be designed for earthquakes for a return period varying from 500 to 1300 years. Therefore, the recommended reference probability of 5E-4 (2000-year return period) provides more stringent seismic design criteria than the IBC-2000 seismic design requirements.

Requirements of the DOE-STD-1020-2002, IBC-2000, and ISFSI or MRS facility for DE are compared in Figure 5.

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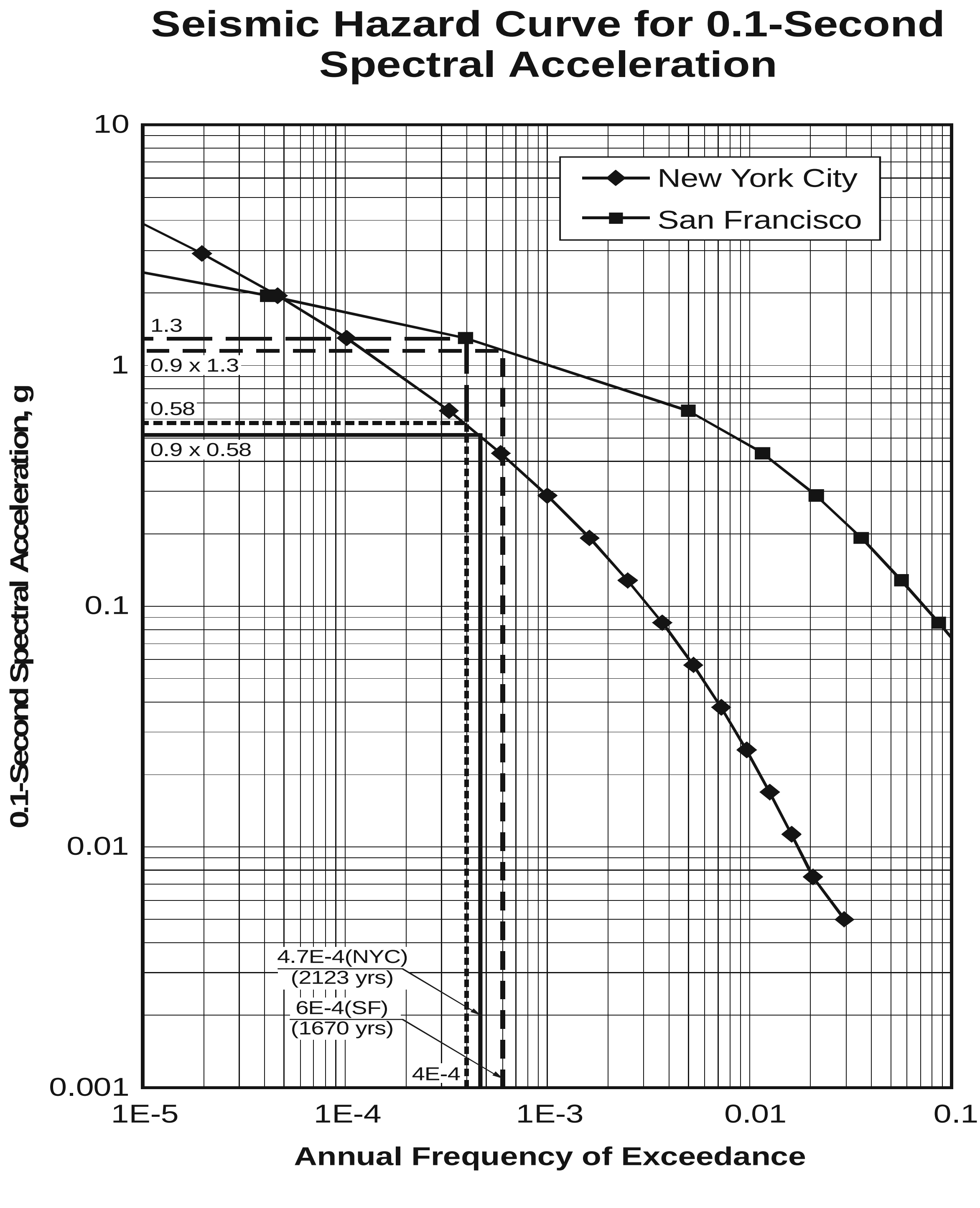

Figure 1 DOE-STD-1020-2002 DE for PC-3 SSCs

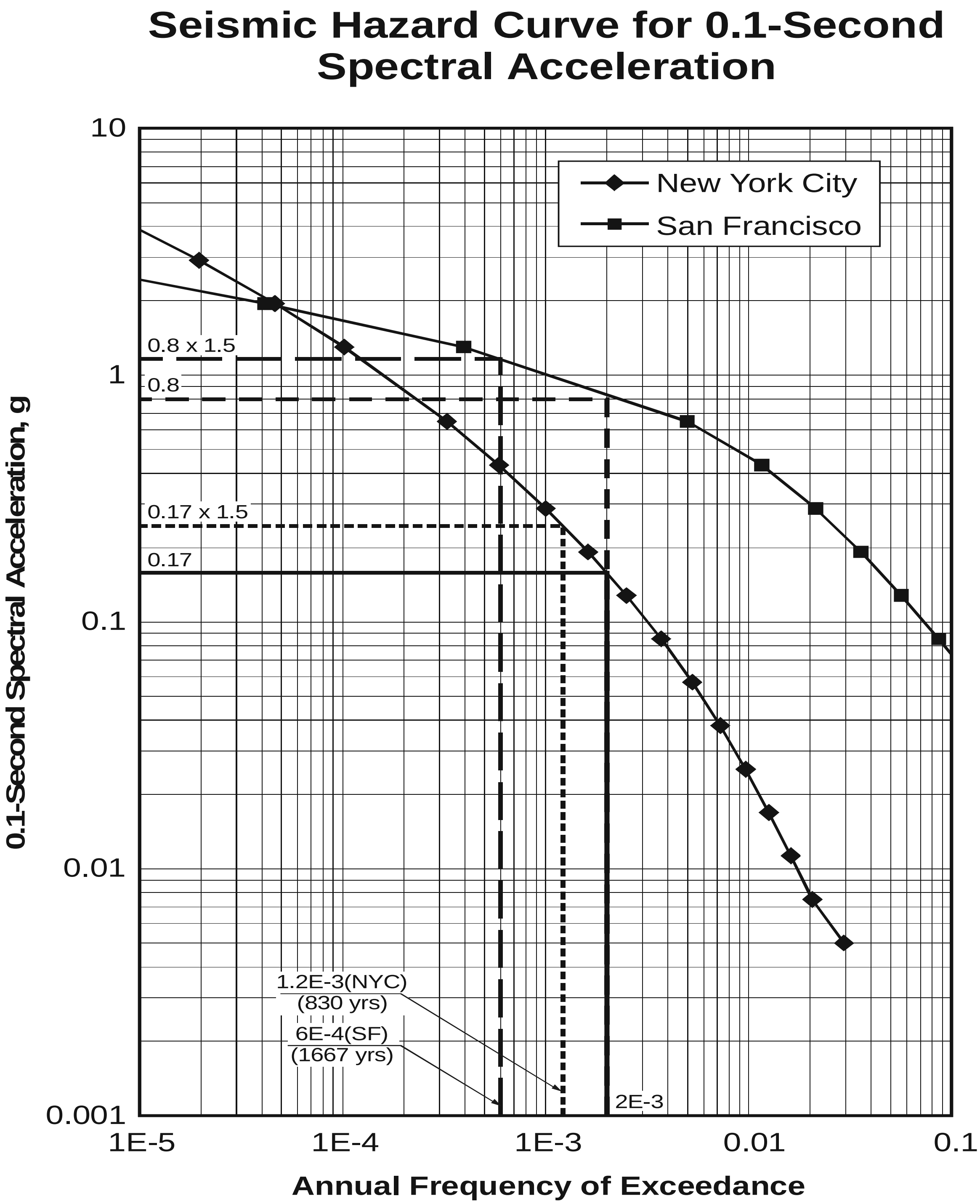

Figure 2 Capacity of Buildings Designed to Earlier UBCs (prior to IBC-2000)

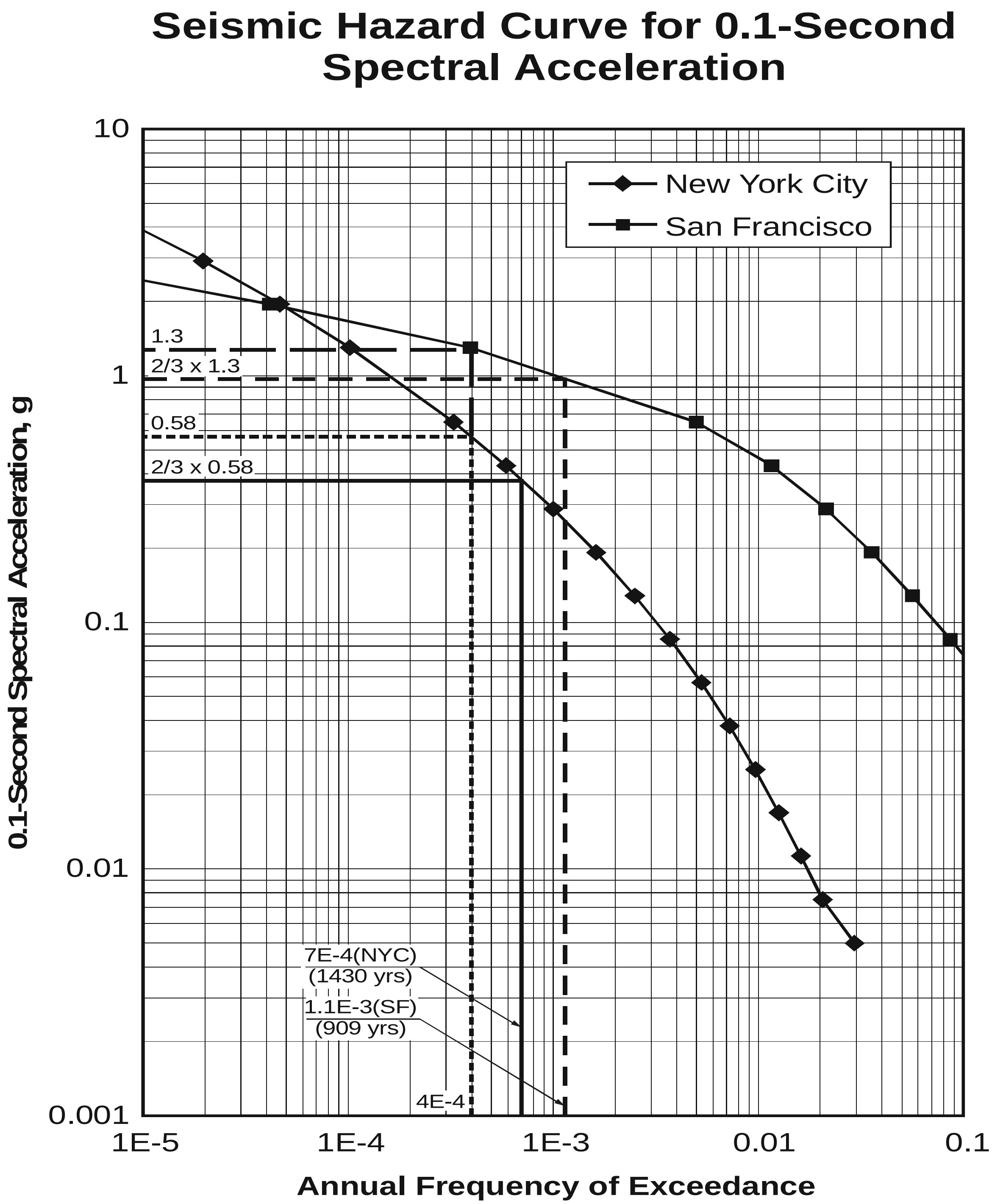

Figure 3 IBC-2000 DE

Seismic Hazard Curve for 0.1-Second Spectral Acceleration

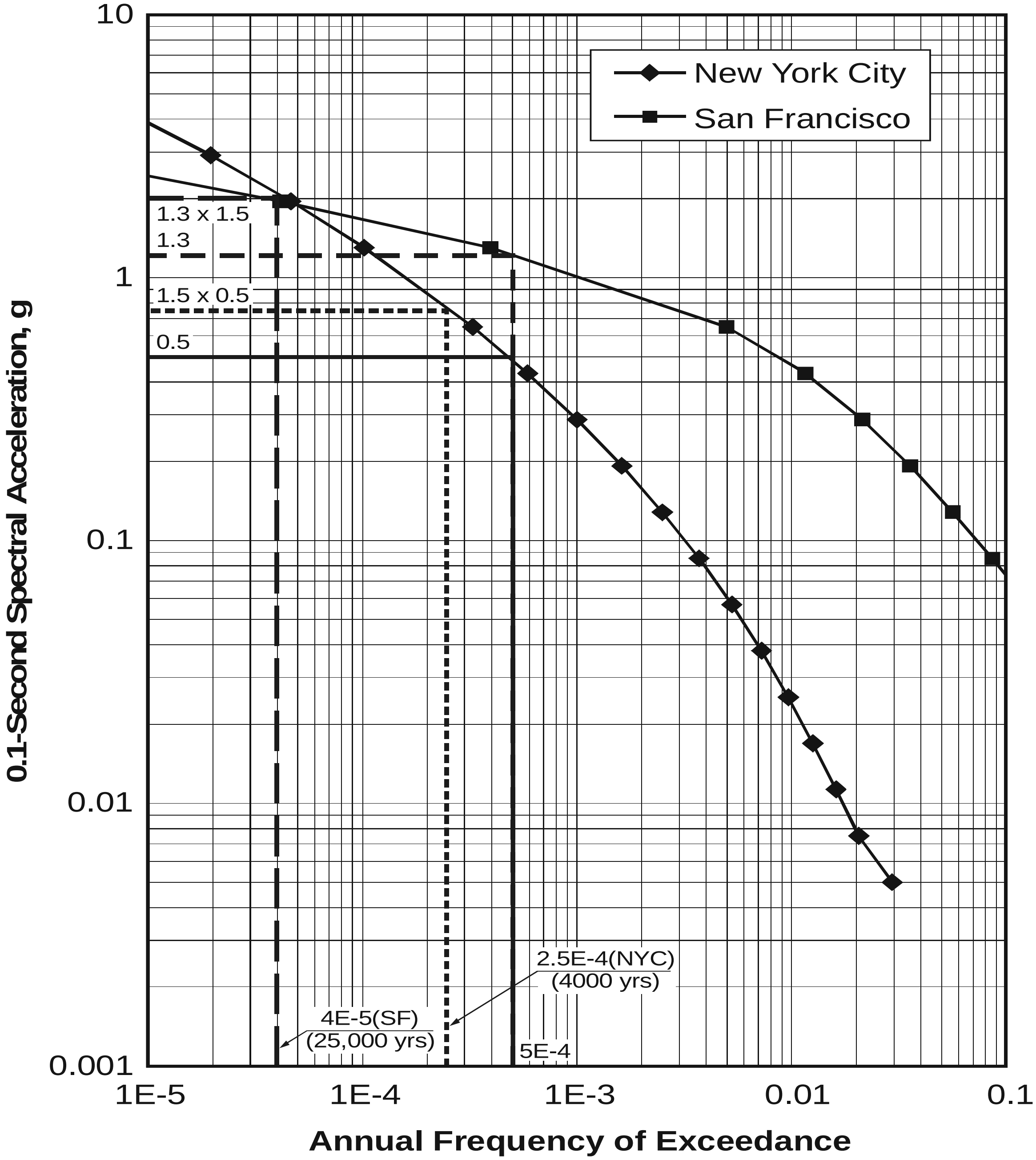

Figure 4 Capacity of Buildings Designed for DE at Reference Probability

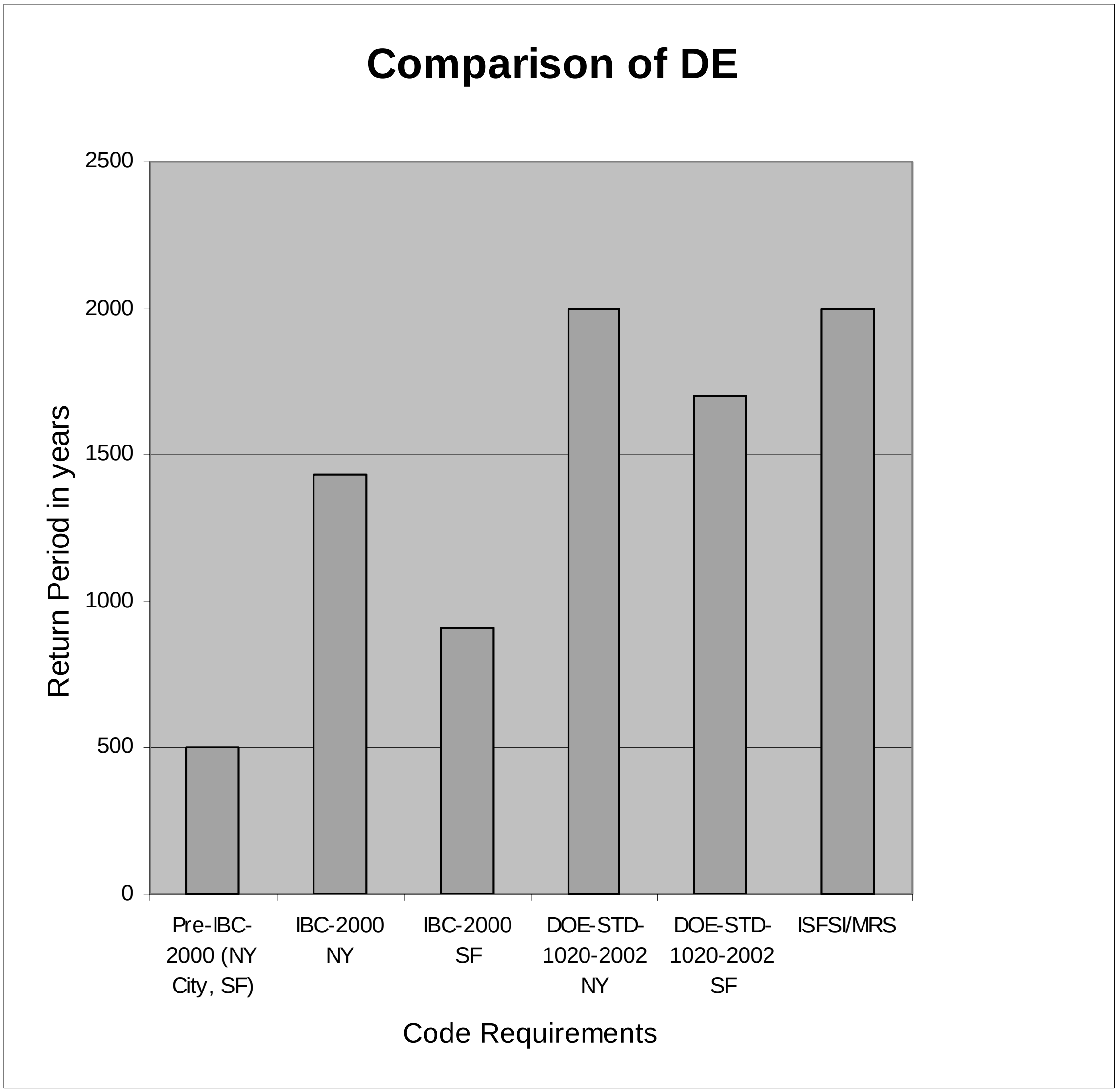

Figure 5 Comparison of DE

ABBREVIATIONS

CEUS	Central and Eastern United States
CTB	Canister Transfer Building
DCSS	Dry Cask Storage System
DE	Design Earthquake Ground Motion
DG	Draft Regulatory Guide
DOE	Department of Energy
g	Acceleration due to gravity
IBC-2000	International Building Code -2000
ISFSI	Independent Spent Fuel Storage Installation
MAPE	Mean Annual Probability of Exceedance
MCE	Maximum Considered Earthquake
MPC	Multi-purpose Canister
MRS	Monitored Retrievable Storage Installation
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
PCs	Performance Categories
PSHA	Probabilistic Seismic Hazard Analysis
RG	Regulatory Guide
SRM	Staff Requirements Memorandum
SSC	Structures, Systems and Components
SSE	Safe Shutdown Earthquake Ground Motion
UBC	Uniform Building Code
WUS	Western United States

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TS

NOT MEASUREMENT SENSITIVE

DOE-STD-1020-2002
January 2002

Superseding
DOE-STD-1020-94
April 1994

DOE STANDARD

NATURAL PHENOMENA HAZARDS DESIGN AND EVALUATION CRITERIA FOR DEPARTMENT OF ENERGY FACILITIES

U.S. Department of Energy
Washington, D.C. 20585

AREA NPHZ

Foreword

This revision provides information to help meet the requirements of 10 CFR Part 830, "Nuclear Safety Management," (for Nuclear Facilities), DOE 0 420.1 and its associated Guides, accounting for cancellation of DOE 0 6430. 1 A and updating this standard to most current references. This standard has also been brought up-to-date to match the requirements of current model building codes such as IBC 2000 and current industry standards.

Since the publication of DOE-STD-1020-94 several new documents have been published which made the seismic design standards of DOE-1020-94 outdated.

- The 1997 NEHRP *Recommended Provisions for Seismic Regulations for New Buildings and Other Structures Parts I and 2* introduced new seismic maps for evaluating the seismic hazard.

- The three model building codes UBC, BOCA, and SBCCI were replaced by the *International Building Code* (IBC 2000), which adopted the 1997 NEBPP seismic provisions.

- DOE Order 420.1 and the associated guide, DOE G 420.1-2, were approved and adopted the use of IBC 2000 for PC- I and PC-2 facilities.

Since DOE-STD- 1020-94 adopted the LJBC for the seismic design and evaluation of PC- I and PC-2 structures, it was necessary to accommodate the use of the IBC 2000 instead of the UBC for DOE facilities. The seismic hazard in the IBC 2000 is provided by maps that define the seismic hazard in terms of the Maximum Considered Earthquake (MCE) ground motions. Except for locations on or near very active known faults, the maps contain accelerations that are associated with a 2500-year return period earthquake. The ground motions associated with MCE ground motions as modified by the site conditions are used for the design and evaluation of PC- I and PC-2 structures in this revised DOE standard. The graded approach is maintained by applying a 2/3 factor for PC- I facilities, and a factor of unity for PC-2 facilities. At the same time PC-3 design ground motions have been adjusted from a 2,000 year return period to a 2,500 year return period.

This differs from DOE-STD-1020-94 where different return periods of 500, 1000, 2000 (1000)[1], and 10,000 (5000)[1] years were used for PC-1, PC-2, PC-3, and PC-4, respectively. Also, specific performance goals were established for each performance category (PC- I thru PC-4). These performance goals (in terms of a mean annual probability of failure) were based on a combination of the seismic hazard exceedance levels and accounting for the level of conservatism used in the design/evaluation. In this revised standard the performance goals for PC- I and PC-2 facilities are not explicitly calculated but are consistent with those of the IBC

1 Numbers in parenthesis are for locations near tectonic plate boundaries.

2000 for Seismic Use Group I and IR, respectively[2]. For PC-3 SSCS there is no change to the performance goal when compared to the previous version of this standard. This was accomplished by making a slight adjustment to the PC-3 scale factor. Thus, it is not the intent of this revision to alter the methodology for evaluating PC-3 facilities nor to increase the performance goal of PC-3 facilities by increasing return period for the PC-3 DBE from a 2000-year earthquake to a 2500-year earthquake. Rather, the intention is more for convenience to provide a linkage from the NEBRP maps and DOE Standards. All PC-3 SSCs which have been evaluated for compliance with the previous version of this standard do not require any re-evaluation considering that the PC-3 level of performance has not changed.

Major revisions to DOE-STD-1020-94 were not attempted because of ongoing efforts to develop an ASCE standard for seismic design criteria for Nuclear Facilities. Referring the design of PC-1 and PC-2 facilities to building codes (such as the IBC 2000) is consistent with design criteria in the proposed ASCE standard.

Some of the major impacts of the above changes are identified below:

1. Use of IBC 2000, International Building Code for PC- I to be designed as Seismic Use Group I and PC-2 to be designed as Seismic Use Group III.
2. Use of seismic hazard exceedance probability of $4x\ 10^{-4}$ in place of $5x\ 10^{-5}$ in current STD for PC-3 facilities.
3. Use of wind advisory for design of SSCs for straight wind referenced in DOE G 420.1-2. In addition tornados wind speeds should be based on the tornado hazards methodology of LLNL (Ref. 3-14). For steel structures, guidance per SAC (see Chapter 1) should be followed based on Northridge experience. For existing buildings evaluation and upgrades, RP-6 is minimum criteria. In addition, the references in Chapter I have been updated for current use.

There is an established hierarchy in the set of documents that specify NPH requirements. In this hierarchy, 10 CFR Part 830 (for Nuclear Facilities only) has the highest authority followed by DOE 0 420.1 and the associated Guides DOE G 420. 1-1 and DOE G 420.1-2. The four NPH standards (DOE-STDS-1020, 1021, 1022, 1023) are the last set of documents in this hierarchy. In the event of conflicts in the information provided, the document of higher authority should be utilized (e.g., the definitions provided in the Guides should be utilized even though corresponding definitions are provided in the NPH standards).

The Department of Energy (DOE) has issued DOE 0 420.1 which establishes policy for its facilities in the event of natural phenomena hazards (NPH) along with associated NPH mitigation requirements. This DOE Standard gives design and evaluation criteria for NPH effects as guidance for implementing the NPH mitigation requirements of DOE 0 420.1 and the associated Guides. These are intended to be consistent design and evaluation criteria for

[2] Refer to the 1997 NEHRP Provisions for a description of the performance goals associated with Seismic Use Groups.

protection against natural phenomena hazards at DOF, sites throughout the United States. The goal of these criteria is to assure that DOF, facilities can withstand the effects of natural phenomena such as earthquakes, extreme winds, tornadoes, and flooding. These criteria apply to the design of new facilities and the evaluation of existing facilities. They may also be used for modification and upgrading of existing facilities as appropriate. It is recognized that it is likely not cost-effective to upgrade existing facilities which do not meet these criteria by a small margin. Hence, flexibility in the criteria for existing facilities is provided by permitting limited relief from the criteria for new design. The intended audience is primarily the civil/structural or mechanical engineers farnfliar with building code methods who are conducting the design or evaluation of DOF, facilities.

The design and evaluation criteria presented herein control the level of conservatism introduced in the design/evaluation process such that earthquake, wind, and flood hazards are treated on a consistent basis. These criteria also employ a graded approach to ensure that the level of conservatism and rigor in design/evaluation is appropriate for facility characteristics such as importance, hazards to people on and off site, and threat to the environment. For each natural phenomena hazard covered, these criteria consist of the following:

1. Performance Categories and target performance goals as specified in the Appendices B and C of this standard.

2. Specified probability levels from which natural phenomena hazard loading on structures, equipment, and systems is developed.

3. Design and evaluation procedures to evaluate response to NPH loads and criteria to assess whether or not computed response is permissible.

Table 2-1 Seismic Performance Categories and Seismic Hazard Exceedance Levels

Performance Category	Mean Seismic Hazard Exceedance Levels, PH	Remarks
0	No Requirements	
1	Follow IBC 2000 in its Entirety*	Use IBC 2000 Seismic Use Group I Criteria-2/3 MCI, Ground Motion
2	Follow IBC 2000 in its Entirety*	Use IBC 2000 Seismic Use Group III Criteria 2/3 MCI, Ground Motion with Importance Factor of 1.5
3	4×10^{-4} (1×10^{-3})[1]	Establish DBE Per DOE-STD-1023 Analysis Per DOE-Std. 1020
4	1×10^{-4} (2×10^{-4})[1]	Establish DBE Per DOE-STD-1023 Analysis Per DOE-Std. 1020

* Based on Maximum Considered Earthquake (MCE) Ground Motion - generally 2% Exceedance Probability in 50 years from the seismic hazard maps, modified to account for site effects. $P_H = 4 \times 10^{-4}$

[1] For sites such as LLNL, SNL-Livermore, SLAC, LJ3NL, and ETEC, which are near tectonic plate boundaries.

Performance Category 2 and lower SSCs may be designed or evaluated using the approaches specified in IBC 2000 seismic provisions. Common cause effects and interaction effects per DOE- STD-1021 should be taken into account. However, for Performance Category 3 or higher, the seismic evaluation must be performed by a dynamic analysis approach. A dynamic analysis approach requires that:

1. The input to the SSC model be defined by either a design response spectrum, or a compatible time history input motion.

2. The important natural frequencies of the SSC be estimated, or the peak of the design response spectrum be used as input. Multi-mode effects must be considered.

contribution from seismic anchor motion. To determine response of SSCs which use Fμ > 1, the maximum spectral acceleration should be used for fundamental periods lower than the period at which the maximum spectral amplification occurs (See Figure 2-4). For higher modes, the actual spectral accelerations should be used.

Calculate the inelastic seismic demand element forces, DSI, as

$$D_{SI} = SF*DS/F\mu \qquad (2\text{-}1)$$

where: Fμ = Inelastic energy absorption factor from Table 2-3 for the appropriate structural system and elements having adequate ductile detailing

SF = Scale factor related to Performance Category
= 1.25 for PC-4
= 0.9 for PC-3

Variable scale factors, based on the slope of site-specific hazard curves are discussed in Appendix C, to result in improved achievement of performance goals. Site specific scale factors for low seisn-iicity sites should be quantified to ensure that use of
S.F = 0.9 is adequately conservative. SF is applied for evaluation of structures, systems, and components. At this time, Fμ values are not provided for systems and components. It is recognized that many systems and components exhibit ductile behavior for which Fμ values greater than unity would be appropriate (see Section C.4.4.2). Low Fμ values in Table 2-3 are intentionally specified to avoid brittle failure modes.

- Evaluate the total inelastic-factored demand D_{TI} as the sum of D_{SI} and D_{NS} (the best-estimate of all non-seismic demands expected to occur concurrently with the DBE).

$$D_{TI} = D_{NS} + D_{SI}, \qquad (2\text{-}2)$$

- Evaluate capacities of elements, C_c, from code ultimate or yield values

Reinforced Concrete

Use IBC 2000, ACI 318 & ACI-349

Steel

Use IBC 2000 and AISC

TABLE 1604.5 FROM
THE INTERNATIONAL BUILDING CODE - 2000

TABLE 1604.5
CLASSIFICATION OF BUILDINGS AND OTHER STRUCTURES FOR IMPORTANCE FACTORS

CATEGORY[a]	NATURE OF OCCUPANCY	SEISMIC FACTOR I_E	SNOW FACTOR I_S	WIND FACTOR I_W
I	Buildings and other structures except those listed in Categories II, III and IV	1.00	1.0	1.00
II	Buildings and other structures that represent a substantial hazard to human life in the event of failure including, but not limited to: • Buildings and other structures where more than 300 people congregate in one area • Buildings and other structures with elementary school, secondary school or day-care facilities with capacity greater than 250 • Buildings and other structures with a capacity greater than 500 for colleges or adult education facilities • Health care facilities with a capacity of 50 or more resident patients but not having surgery or emergency treatment facilities • Jails and detention facilities • Any other occupancy with an occupant load greater than 5,000 • Power-generating stations, water treatment for potable water, waste water treatment facilities and other public utility facilities not included in Category III • Buildings and other structures not included in Category III containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released	1.25	1.1	1.15
III	Buildings and other structures designated as essential facilities including, but not limited to: • Hospitals and other health care facilities having surgery or emergency treatment facilities • Fire, rescue and police stations and emergency vehicle garages • Designated earthquake, hurricane or other emergency shelters • Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response • Power-generating stations and other public utility facilities required as emergency back-up facilities for Category III structures • Structures containing highly toxic materials as defined by Section 307 where the quantity of the material exceeds the exempt amounts of Table 307.7(2) • Aviation control towers, air traffic control centers and emergency aircraft hangars • Buildings and other structures having critical national defense functions • Water treatment facilities required to maintain water pressure for fire suppression	1.50	1.2	1.15
IV	Buildings and other structures that represent a low hazard to human life in the event of failure including, but not limited to: • Agricultural facilities • Certain temporary facilities • Minor storage facilities	1.00	0.8	0.87[b]

a. "Category" is equivalent to "Seismic Use Group" for the purposes of Section 1616.2.
b. In hurricane-prone regions with V >100 miles per hour, I_W shall be 0.77.

structures and portions thereof shall resist the most critical effects from the following combinations of factored loads:

$1.4D$ **(Formula 16-1)**
$1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$ **(Formula 16-2)**
$1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (f_1L \text{ or } 0.8W)$ **(Formula 16-3)**
$1.2D + 1.6W + f_1L + 0.5(L_r \text{ or } S \text{ or } R)$ **(Formula 16-4)**
$1.2D + 1.0E + f_1L + f_2S$ **(Formula 16-5)**
$0.9D + (1.0E \text{ or } 1.6W)$ **(Formula 16-6)**

where:

f_1 = 1.0 for floors in places of public assembly, for live loads in excess of 100 pounds per square foot (4.79 kN/m²), and for parking garage live load.
= 0.5 for other live loads.

B-1

ATTACHMENT B

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