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Implementation of the Seismic Design Criteria for DOE-STD-1189-2008, Appendix A

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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This paper will describe the approach taken by two Fluor Hanford projects for implementing of the seismic design criteria from DOE-STD-1189-2008, Appendix A. The existing seismic design criteria and the new seismic design criteria will be described, and an assessment of the primary differences provided. The gaps within the new system of seismic design criteria, which necessitate conduct of portions of work to the existing technical standards pending availability of applicable industry standards, will be discussed. Two Hanford Site projects currently in the Control Decision (CD)-1 phase of design have developed an approach to implementation of the new criteria. Calculations have been performed to determine the seismic design category for one project, based on information available in early CD-1. The potential effects of DOE-STD-1189-2008, Appendix A seismic design criteria on the process of project alternatives analysis will be discussed. Presentation of this work is expected to benefit others in the DOE Complex that may be implementing DOE-STD-1189-2008.

1.0 INTRODUCTION

Fluor Hanford (FH) committed in July of 2007 to pilot implementation of the draft standard DOE-STD-1189-YR, *Integration of Safety into the Design Process*, for two engineering projects currently in the early stages of engineering design. The requirements of DOE-STD-1189-YR for seismic design were not consistent with the FH contract requirements for natural phenomena hazard design, which were based on the technical standards and guidance documents invoked by DOE O 420.1B, *Facility Safety*. FH had to examine the two sets of applicable requirements, and determine a strategy for implementation. This paper describes the new and existing requirements, the differences between those requirements, and the strategy developed by FH for implementation. It should be noted that subsequent to the development of this strategy, the draft standard was approved and issued as DOE-STD-1189-2008.

2.0 REQUIREMENTS

The current requirements for natural phenomena hazard design are contained in DOE O 420.1B, *Facility Safety,* (Attachment 2, Chapter IV, "Natural Phenomena Hazards Mitigation," Section 3, Requirements). The requirements state that:

> *DOE [U.S. Department of Energy] facilities and operations must be analyzed to ensure that structures, systems, and components (SSCs) and personnel will be able to perform their intended safety functions effectively under the effects of NPH. Where no specific requirements are identified, model building codes or national consensus industry standards must be used consistent with intended SSC functions.*

The primary goals of natural phenomenon hazard (NPH) mitigation and specifically seismic design of structures, systems, and components (SSCs), as stated by DOE O 420.1B are:

(a) Confinement of hazardous materials,
(b) Protection of occupants of the facility, as well as members of the public
(c) Continued operation of essential facilities,
(d) Protection of government property.

A footnote to this section invokes DOE G 420.1-2, *Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Nonnuclear Facilities.* This guidance document (as stated) is not intended to establish or invoke any new requirements, but simply to provide guidance in implementing the NPH mitigation requirements of DOE O 420.1B. The language with which DOE G 420.1-2 invokes the series of technical standards on NPH mitigation is as follows:

> *DOE has prepared and is updating the following five supporting standards to implement the NPH requirements of DOE O 420.1; compliance with the most current version of these standards is required in order to provide desired safety at DOE facilities.*
>
> - DOE-STD-1020, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*
> - DOE-STD-1021, *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components*
> - DOE-STD-1022, *Natural Phenomena Hazards Site Characterization Criteria*
> - DOE-STD-1023, *Natural Phenomena Hazards Assessment Criteria*
> - DOE-STD-1024, *Guidelines for Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites.*

A new set of requirements for development of the seismic design basis is provided by DOE-STD-1189-2008, Appendix A, "Safety Systems Design Criteria." These requirements are based on two recently published national standards for seismic design:

- ASCE/SEI 43-05, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities.*

- ANSI/ANS 2.26-2004, *Categorization of Nuclear Facility Structures, Systems and Components for Seismic Design.*

Under DOE-STD-1189, the provisions of ASCE/SEI 43-05 replace the seismic design requirements and performance criteria of DOE-STD-1020-2002. The seismic-related performance categorization guidelines of DOE-STD-1021-93 are replaced by the provisions of American National Standards Institute (ANSI)/American Nuclear Society (ANS) 2.26-2004, as modified by DOE-STD-1189-2008, Appendix A.

Both ASCE/SEI 43-05 and ANSI/ANS 2.26-2004 indicate that they are intended to be used in conjunction with ANSI 2.27, *Site Characterization Requirements for Natural Phenomena Hazards and Nuclear Materials Facilities Sites,* and ANSI 2.29, *Probabilistic Analysis of Natural Phenomena Hazards for Nuclear Materials Facilities.* However, these standards have not been issued; ANSI 2.27 is available only in draft, and ANSI 2.29 is not available at this time. Therefore, the national standards set for seismic phenomena hazards mitigation are not complete at this time.

The NPH mitigation requirements of DOE O 420.1B indicate that design requirements may be satisfied through implementation of the specific requirements identified in the corresponding guidance document (DOE G 420.1-2) or through the use of model building codes or national consensus industry standards applied in a manner consistent with intended SSC functions. It is assumed that a single coherent system for seismic design, intended to replace that currently established by DOE O 420.1B via DOE G 420.1-2, will eventually be set forth through future revision of DOE-STD-1189-2008. Such a system does not currently exist, pending revision of the associated DOE guides and technical standards, and completion of the outstanding ANSI standards. Therefore, the implementation of DOE-STD-1189-2008 currently requires the use of some existing DOE technical standards, the partial implementation of ANSI/ANS 2.26-2004, and the implementation of the new ASCE/SEI 43-05. The mapping between the existing and proposed requirements is shown in Table 1.

Table 1. Mapping of Existing and Proposed Seismic Design Requirements.

Subject	Existing Requirements	Proposed Requirements
Seismic Design and Evaluation Criteria	DOE-STD-1020-2002	ASCE/SEI 43-05
Seismic Performance Categorization for SSCs	DOE-STD-1021-93	ANSI/ANS 2.26-2004 as modified by DOE-STD-1189
Seismic Site Characterization Criteria	DOE-STD-1022-2002	DOE-STD-1022-2002
Seismic Assessment Criteria	DOE-STD-1023-95	DOE-STD-1023-95
Probabilistic Seismic Hazards Assessment	DOE-STD-1024-92	DOE-STD-1024-92

SSC = structure, system, and component.

It should be noted that the new system of requirements is applicable only to seismic phenomena. New design guidance is not provided for natural phenomena hazards other than seismic.

3.0 COMPARISON OF EXISTING AND NEW REQUIREMENTS

In general, the new guidance established via DOE-STD-1189, Appendix A, provides a system that is equivalent to the existing requirements. The analysis provided below summarizes the differences between the new and existing requirements as related to categorization of SSCs, performance and seismic design categories, seismic response spectra, seismic evaluation and design criteria, and seismic interaction.

3.1 CATEGORIZATION OF STRUCTURES, SYSTEMS, AND COMPONENTS

The existing process for natural phenomena hazards performance categorization is provided by DOE-STD-1021-93. In this process, the performance category for a nuclear facility and associated SSCs is based upon:

- The facility hazard category, established in accordance with DOE-STD-1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*
- Safety classification of SSCs, determined in accordance with DOE-STD-3009-94, *Preparation Guide for U.S. Department of Energy Non-Reactor Nuclear Facility Analysis*
- Identification of SSCs whose failure may adversely affect the general life safety of facility occupants.

The specific criteria provided by DOE-STD-3009-94 and DOE-STD-1021-93 for natural phenomena performance hazards categorization are as follows:

- SSCs are designated PC-3 if the failure of the SSC has adverse release consequences to the public in excess of 25 rem.
- SSCs are designated PC-2 if the SSC has been classified as safety significant for protection of the collocated worker.
- SSCs are designated PC-2 if the failure of the SSC may result in loss of function for any emergency handling, hazard recovery, fire suppression, emergency preparedness, communication, or power system that may be necessary for the health and safety of the facility worker.
- SSCs are designated PC-2 if they are part of a building primarily used for the assembly of more than 300 persons in one room, and if the failure of the SSC could adversely affect the life safety of the occupants.

- SSCs are designated PC-1 in buildings with the potential for human occupancy if the SSC failure may cause fatality or serious injuries to the facility worker, or if failure can be cost-effectively prevented.

The radiological dose-based alternate criteria provided by DOE-STD-1189-2008 are shown in Table 2. These criteria modify the radiological dose-based criteria provided in ANSI/ANS-2.26-2004. Additional criteria provided by ANSI/ANS-2.26-2004 and related to qualitative assessment of the consequences of SSC failure are as follows:

- SSCs are designated seismic design category (SDC) -4 if the radiological or toxicological consequences of SSC failure may result in long-term health effects or fatality for the facility worker.

- SSCs are designated SDC-3 if the radiological or toxicological consequences of SSC failure may require activation of emergency plans to ensure public protection or if there is a potential for long-term health effects for the facility worker.

- SSCs are designated SDC-2 if the consequences of SSC failure may place facility workers at risk of physical injury, or may adversely affect facility emergency operations.

- SSCs are designated SDC-1 if the consequences of SSC failure place facility workers at risk of physical injury not related to radiological or toxicological release.

Table 2. DOE-STD-1189-2008 Requirements for Categorization of Structures, Systems, and Components.

Seismic Design Category	Collocated Worker	Public
SDC-1	Dose < 5 rem	N/A
SDC-2	5 rem < Dose < 100 rem	5 rem < Dose < 25 rem
SDC-3	100 rem < Dose	25 rem < Dose

N/A = not applicable.
SDC = seismic design category.

It should be noted that the radiological dose-based criteria specified by DOE-STD-1189-2008, Appendix A (Table 2) replace the more conservative criteria provided by ANSI/ANS-2.26-2004 (shown in Table 3).

DOE-STD-1189-2008 also modifies the prescribed methodology provided in ANSI/ANS 2.26-2004 for calculation of unmitigated radiological dose consequence to the collocated worker (100 m). These modifications provide a more conservative methodology than that mandated by ANSI/ANS 2.26-2004, by specifying the use of conservative or bounding rather than mean values for the parameters associated with the material release, dispersal, and health consequences.

With respect to categorization of SSCs for protection of the public, the new criteria are more stringent. Requiring the categorization of SSCs as SDC-2 for unmitigated consequences between 5 rem and 25 rem total effective dose equivalent (TEDE) may result in a more robust design, although it is likely that the affected SSCs would be classified under the current requirements as safety-significant for the protection of the collocated worker and, therefore, designated as PC-2.

Table 3. ANSI/ANS-2.26-2004 Guidance for Seismic Design Category Based on Unmitigated Radiological Consequences of Structure, System, or Component Failure.

Seismic Design Category	Worker	Public
SDC-1	Failure of SSCs may place facility workers at risk of physical injury.	N/A
SDC-2	Consequences less than SDC-3; no permanent health effects	Essentially no off-site consequences.
SDC-3	25 rem < Dose < 100 rem	5 rem < Dose < 25 rem
SDC-4	100 rem < Dose < 500 rem	25 rem < Dose < 100 rem
SDC-5	Radiological effects may be likely to result in worker fatality.	100 rem < Dose

N/A = not applicable.
SDC = seismic design category.
SSC = structure, system, and component.

With respect to categorization of SSCs for protection of the collocated worker, the new criteria are significantly more conservative. Under the existing requirements, the highest performance category assigned to any SSC necessary for protection of the collocated worker is PC-2. Under the new requirements, SSCs may be designated as SDC-3 for unmitigated consequences in excess of 100 rem TEDE to the collocated worker. Preliminary hazard assessment work currently in progress for the M-91 Project indicates that this criterion is likely to result in more stringent seismic design requirements for facility SSCs.

With respect to categorization of SSCs for protection of the facility worker, the new criteria are essentially equivalent to, although less prescriptive than, the existing criteria. The specific facility systems specified in the existing criteria that are required to remain operable (emergency handling, hazard recovery, fire suppression, etc.) are interpreted by FH as covered under the general terminology (e.g., failure may place facility workers at risk of physical injury, or may adversely affect facility emergency operations) provided by the new requirements. Criteria pertaining to assembly occupancies, previously provided in the DOE-STD-1021-93, are specified in the IBC.

3.2 PERFORMANCE AND SEISMIC DESIGN CATEGORIES

The existing requirements for seismic design and evaluation are provided by DOE-STD-1020-2002. As defined by the standard, the process of seismic design or evaluation begins with performance categorization in accordance with DOE-STD-1021-93. Five performance categories are specified (PC-0 through PC-4); these categories correspond to the performance requirements for designated SSCs, which define the allowable degree of damage resulting from the seismic event and are related to the required degree of SSC operability during and after the seismic event. Each performance category is also related to a specific probability of exceedence or return period for the design basis earthquake, with high performance category SSCs being required to withstand seismic events having lower probabilities but higher potential ground acceleration.

The new requirements for seismic evaluation and design, as provided by ASCE/SEI 43-05, also begin with a categorization process as defined in ANSI/ANS-2.26-2004. Five seismic design categories are specified (SDC-1 through SDC-5). These categories also correspond to the probability of exceedence or return period for the design basis earthquake, with high seismic design category SSCs being evaluated against seismic events having lower probabilities but higher potential ground acceleration. Within each seismic design category, one of four limit states may be selected based on the safety functions for the SSC of concern as determined through safety analysis. The degree of required performance for SSCs associated with each limit state is provided in ANSI/ANS-2.26-2004, Appendix B, and is summarized below.

- Limit State D: Damage resulting from the seismic event is negligible; building structures retain full strength and stiffness capacities and are safe for occupancy; containment structures remain leak-tight; confinement structures remain operable without assistance of active exhaust; mechanical and electrical SSCs remain essentially elastic and are capable of performing both their normal and safety functions during and after the seismic event.

- Limit State C: Structural and passive SSCs are capable of performing both their normal and safety functions during and after the seismic event; structural components retain full strength and nearly full stiffness; containment structures may sustain minor damage; confinement structures remain operable with the assistance of active exhaust; mechanical or electrical SSCs may experience limited permanent distortion but remain capable of performing both their normal and safety functions during and after the seismic event.

- Limit State B: Structural components retain substantial margin against collapse although repair may be required for continued occupancy and restart of operations; containment structures may experience damage sufficient to result in a slow release of contents if secondary containment is provided, or the release has no adverse consequence and cleanup/repair may be accomplished expediently; confinement structures remain operable with the assistance of active exhaust; mechanical or electrical SSCs may experience moderate permanent distortion if they remain capable of performing their safety functions and are repairable for restoration of normal functional capability.

- Limit State A: Structural components retain some margin against collapse so that egress is not impaired although major repair may be required for continued occupancy; containment structures may fail if secondary containment is provided, the release has no immediate impact to the worker, and spill recovery can be completed with little risk; mechanical or electrical SSCs may undergo large permanent distortion if they remain capable of performing their safety functions. Design to Limit State A is not allowed for confinement systems.

Comparison of the seismic design criteria and associated limit states with the existing performance criteria is presented in Table 4.

Table 4. Comparison of Seismic Design and Performance Categories.

	Limit State			
SDC	**A**	**B**	**C**	**D**
1	PC-1			
2		PC-2		
3			PC-3	
4				
5			PC-4	

PC = performance category.
SDC = seismic design category.

The requirement of DOE-STD-1189-2008 is to default to SDC-3 Limit State D for any Hazard Category 2 nuclear facility in the preconceptual states of design, or until adequate design information exists to document SSC safety classifications and safety functions that would indicate a less conservative seismic design category or limit state.

With respect to performance and design categorization, the new criteria mandate a more stringent initial categorization; Limit State D requires design that survives the event with essentially elastic behavior. The performance of additional analysis to determine and justify the level of functionality actually required for an SSC to meet its designated safety function has the potential to result in the design of selected SSCs to less stringent criteria than mandated under the existing system.

3.3 SEISMIC RESPONSE SPECTRA

The existing process requires the development of a site-specific seismic hazard curve and design response spectra in accordance with DOE-STD-1022-94 for SSCs designated as PC-3 or PC-4. For developed areas of existing DOE sites, seismic hazard curves and design response spectra should be defined in approved documentation. Under the existing set of requirements, seismic design spectra developed for PC-3 SSCs are based on a return period of 2,000 years or an annual probability of exceedence of 5E-04.

The new requirements for seismic evaluation and design are provided by ASCE/SEI 43-05. As defined by the standard, the process of seismic design or evaluation begins with the definition of appropriate design response spectra and development of seismic hazard curves for the site of interest. The following industry standards are referenced:

- ANSI 2.27, *Site Characterization Requirements for Natural Phenomena Hazards and Nuclear Materials Facilities Sites*
- ANSI 2.29, *Probabilistic Analysis of Natural Phenomena Hazards for Nuclear Materials Facilities.*

These standards are assumed to be intended to replace the guidance currently provided in DOE-STD-1022-94, DOE-STD-1023-95, and DOE-STD-1024-92. Both ANSI standards are still in development and, therefore, not available for use. However, the requirements of ASCE/SEI 43-05 for development of seismic design spectra for SDC-3 SSCs are based on a return period of 2,500 years or an annual probability of exceedence of 4E-04.

For SSCs designated as SDC-1 or SDC-2, both the new requirements (ASCE/SEI 43-05) and the existing requirements (DOE-STD-1020-2002) require design to be based on the IBC.

3.4 SEISMIC EVALUATION AND DESIGN CRITERIA

A Seismic Design Implications Working Group was convened by the DOE to investigate the implications of adopting ASCE/SEI 43-05 and ANSI/ANS-2.26-2004 (SDIWG 2007). With regards to seismic design, the working group concluded that the implementation of ASCE/SEI 43-05 allows a finer gradation in seismic design criteria to address situations that do not conveniently correspond to an existing Performance Category. The existing system is judged by the working group to produce unnecessarily conservative seismic design in some cases; under the new requirements, the seismic ruggedness of an SSC may be tailored to its safety function. While the elimination of unnecessary conservatism can be construed to reduce the level of protection provided, the tailoring of seismic design to safety function can also be argued to ensure an adequate level of worker and public protection.

The Working Group also emphasizes that the existing provisions for relief in evaluation of existing facilities are not duplicated in ASCE-SEI 43-05 and ANSI/ANS-2.26-2004. Specifically, the requirements of DOE-STD-1020-2002 allow the use of a 1,000-year return period for seismic evaluation and design for existing facilities. No such relief is provided in the new standards; major modifications to existing facilities will be required to be designed and evaluated to the criteria as specified for new facilities, with facility upgrade as necessary to meet those criteria. This will have the effect of eliminating existing facilities from consideration for the siting of new nuclear activities, due to an inability to demonstrate or upgrade to seismic adequacy.

An evaluation conducted by Brookhaven National Laboratory (NUREG/CR-77569-2007, *Evaluation of the Seismic Design Criteria in ASCE/SEI Standard 43-05 for Application to Nuclear Power Plants*) concludes that the requirements of ASCE/SEI 43-05 are conservative with respect to customary building code requirements for critical facilities, and provide acceptable levels of protection against severe low-probability seismic events. The methodology provided by ASCE/SEI 43-05 is concluded to be comparable to the seismic design approach presented by DOE-STD-1020-2002 for critical facilities identified as SDC-3, -4, or -5.

3.5 SEISMIC INTERACTION

The existing requirements of DOE-STD-1021-93 specifically address the potential for interaction of SSCs in a seismic event, in which the failure of one SSC impacts the functionality of another. In general, failure of an SSC (the source) is not allowed to result in failure of an SSC (the target) with a higher performance category. The standard provides detailed criteria for revision of performance category for source SSCs based on the performance category of the target SSC and the potential for interaction. The existing requirements are shown in Table 5 for PC-3 and PC-2 target SSCs.

Table 5. System Interaction Effects on Performance Categorization.

Target SSC Performance Category	Source SSC Performance Category	Potential for Interaction	Revised Source SSC Performance Category
PC-3	PC-2	High	PC-3
		Low	PC-2
	PC-1	High	PC-3
		Low	PC-1
PC-2	PC-1	High	PC-2
		Low	PC-1

PC = performance category.
SSC = structure, system, and component.

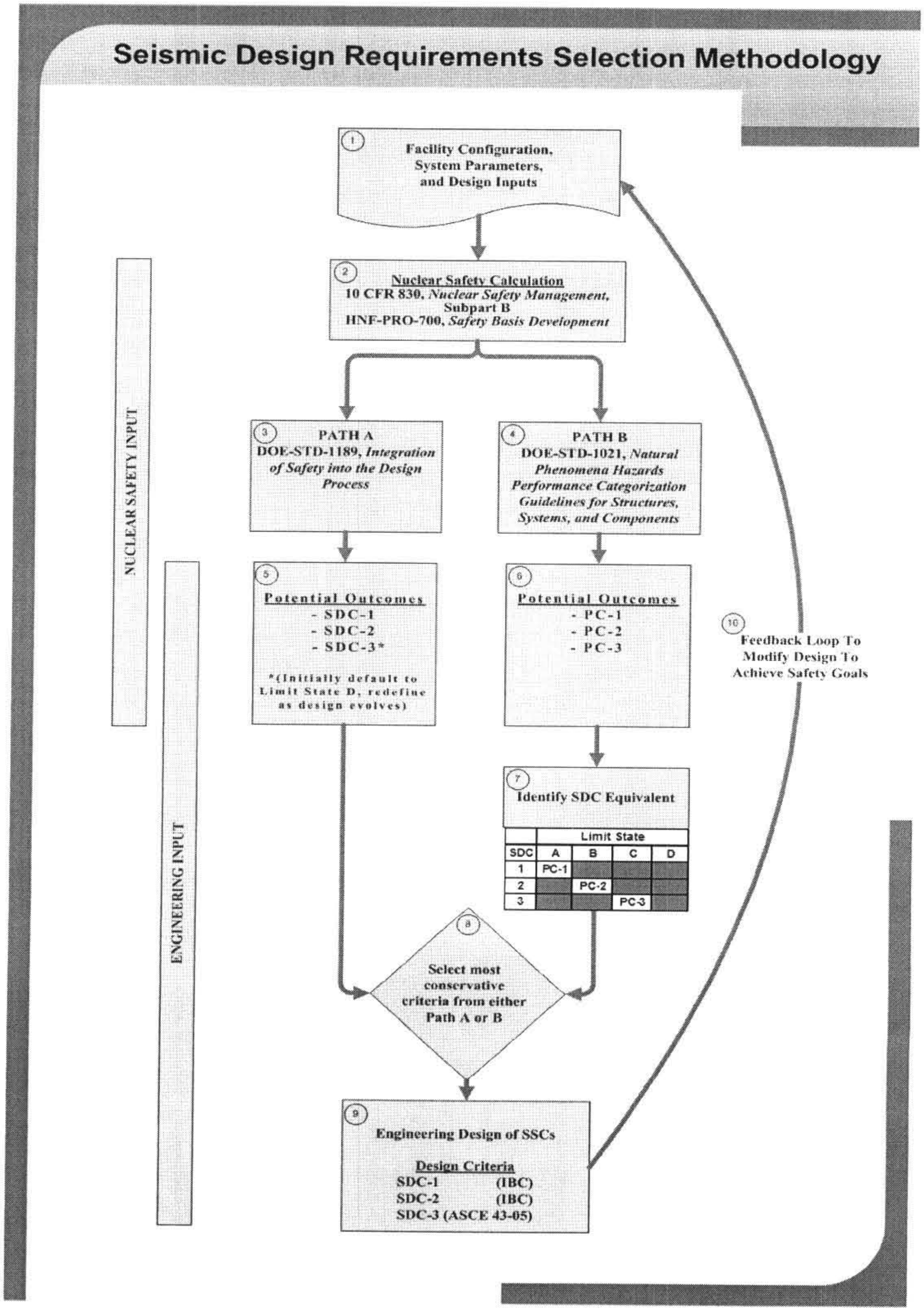
According to the new requirements of ANSI/ANS 2.26-2004, system interaction is to be addressed by upgrading the source SSC to the extent necessary to preclude its adverse interaction with the target SSC, via a change in seismic design category, limit state, or both. Unlike the existing requirements, an assessment of the potential for interaction is not included in this methodology.

Although the interaction-related requirements of ANSI/ANS 2.26-2004 are less prescriptive than those provided by DOE-STD-1021-93, they are judged to provide an equivalent level of protection. Although the level of SSC upgrade required under ANSI/ANS 2.26-2004 may not equal that required under DOE-STD-1021-93, analysis will be required to justify the adequacy of the upgrade to prevent adverse interaction.

4.0 DUAL REQUIREMENT PATH METHODOLOGY

For the projects of concern, FH is in the position of having committed to implement a set of requirements that conflicts with the current contract requirements. If implementation of the new requirements clearly provided a more conservative seismic design in all cases, the issue of contract compliance would still be problematic. However, implementation of the new requirements does not clearly provide a more conservative design in all cases. Therefore, FH has proposed a dual-path methodology, crafted to result in conservative seismic design categorization and design products. This methodology is also designed to streamline the engineering design process, by avoiding performance of design work to dual sets of requirements, and by eliminating the need for justification of the conservative quality of design product. Figure 1 is a graphical depiction of the dual-path methodology that has been developed.

Figure 1. Seismic Design Requirements Selection Methodology



In this methodology, engineering design information feeds into the hazard analysis process provided by DOE-STD-1189-2008. Hazard and accident analysis are performed in accordance with the existing site infrastructure and procedures; safety classification of candidate engineered controls is performed in accordance with DOE-STD-3009-94. The results of this process are compared with the performance criteria set forth in DOE-STD-1021-93, to determine the performance category. The resulting performance category (PC-1, -2, or -3) is translated into an equivalent SDC and Limit State combination.

In the path split based on the new requirements, consequence calculations for the design basis seismic event are modified in accordance with the methodology provided in DOE-STD-1189-2008, Appendix A, which mandates an alternate dispersion coefficient for calculation of the dose consequence to the collocated worker. The resulting dose consequence is compared with the criteria provided by ANSI/ANS 2.26-2004, as modified by DOE-STD-1189-2008, Appendix A, to determine the appropriate SDC. Limit States are assigned based on the SSC safety function, if adequately understood, or in accordance with the default criteria of DOE-STD-1189-2008.

This methodology provides a definition of seismic performance and design requirements in terms of an SDC, regardless of the method used to derive the requirements. This allowed the engineering design team to work in accordance with ASCE/SEI 43-05 for all facility design efforts.

The process is iterative in nature; the results of engineering design feed back into the hazard analysis process, and additional hazard and accident analysis may result in the specification of additional engineered controls. An enhanced understanding of the facility design and process may result in the ability to downgrade existing controls. As the feedback loop shown in Figure 1 is repeated, the same methodology is applied in each iteration to ensure the conservatism of seismic design. While this methodology results in an additional nuclear safety burden during design, it is anticipated to preclude the need for engineering design rework or justification regardless of the timeline for inclusion of new requirements in the FH contract.

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