19 November 2010

To: J. N. McKamy Manager, US DOE NCSP
From: C. M. Hopper Chair, US DOE NCSP CSSG CMH

In response to Tasking 2010-01, a subgroup of the Criticality Safety Support Group (CSSG) was organized to draft a position white paper regarding *Balanced Technical Approaches for Addressing Potential Seismically Induced Criticality Accidents in New Facility Design.*

The drafting team consisted of the following CSSG members:

David Heinrichs, Writing Team Lead
Richard E. Anderson
Bradley Embrey (NA-1 Ex-officio)
Thomas P. McLaughlin
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R. Michael Westfall (Emeritus)
Robert E. Wilson

The draft white paper was reviewed by the entire CSSG and several independent subject matter experts. Minor comments were incorporated into the final version of the paper that is attached to this memo. This version represents a consensus position by the entire CSSG.

Cc: CSSG Members
A. N. Ellis
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CSSG Response to Tasking 2010-01
Balanced Technical Approaches for
Addressing Potential Seismically Induced Criticality Accidents
in New Facility Design
19 November 2010

Executive Summary

The Criticality Safety Support Group (CSSG) was directed in Tasking 2010-01 to develop a white paper on the use of balanced technical approaches for addressing potential seismically induced criticality accidents in new nuclear facility design (see Attachment 1). This white paper addresses this tasking by providing a thorough review of regulatory compliance issues and by providing recommendations for the application of a graded approach using sound practical judgment regarding risk and cost-benefit considerations.

Generally, it is recommended that criticality safety engineers participate in all stages of the design process, including the conceptual design phase, to ensure proper hazard categorization of the facility based on radiological risks and to ensure the assignment of the appropriate seismic design criteria and limit states to structures, systems and components important for the prevention of criticality accidents.

Specifically, and consistent with the recent CSSG response to tasking 2010-02, it is concluded that criticality accidents are expected to be worker safety issues and not pose significant risks to co-located workers or the public. Thus, Seismic Design Criteria (SDC) 1 is appropriate for structures and equipment important to criticality accident prevention. Also, it is recommended that emergency plans and procedures associated with earthquakes address personnel evacuation. This could prevent large expenditures that might otherwise be spent on making a criticality accident alarm system seismically tolerant.

Hazard Categorization

Early in the design process, DOE O 413.3A, Change 1, and DOE-STD-1189, require development of a Conceptual Safety Design Report that: (a) identifies and analyzes the primary facility hazards – including criticality hazards; (b) identifies and analyzes facility design basis accidents – including the design basis earthquake (DBE); (c) determines the preliminary seismic design category for the facility; (d) determines the safety class and safety significant structures, systems, and components (SSC); and (e) establishes the preliminary hazard categorization of the facility.

The CSSG Response to Tasking 2010-02 provides detailed guidance on the "Role of Criticality Safety in Facility Hazard Categorization". That CSSG guidance concludes that facilities with credible criticality accident risks should be classified no greater than Hazard Category 3 based on the localized radiological consequences of actual and realistically postulated criticality accidents. In particular, the CSSG Response to Tasking 2010-02 documents that historical criticality accidents and reasonably postulated potential accidents are highly likely to produce doses at 100 meters that are less than

0.5 rad and doses to the public that are negligible. These consequences for the postulated accidents do not take into consideration radiation shielding present in facility construction or process equipment that would further reduce radiological consequences. Therefore, the appropriate seismic design category for the facility for criticality safety is SDC-1 with no facility-level safety class or safety significant SSCs based on the criteria of DOE-STD-1189, Appendix A, §A.2.1, "Public Protection Criteria", and §A.2.2, "Collocated Worker Protection Criteria", respectively.

If dose assessment in or near specific facility structures is desired, guidance on criticality accident sources term and radiation dose estimations are available in American National Standard ANSI/ANS-8.23, Nuclear Criticality Accident Emergency Planning and Response.

<u>Seismic Design Criteria, Performance Goals and Limit States</u>

The primary guidance documents for assessing any seismic event – including criticality accidents induced by an earthquake – in new facility design are DOE-STD-1189, ANSI/ANS-2.26, ASCE/SEI 7-05 and ASCE/SEI 43-05. These standards provide a graded approach in the form of seismic design criteria, performance goals and limit states (LS).

The seismic design criteria are based on total effective dose equivalent (TEDE) consequences to the public and collocated workers as shown in Table 1. Collocated workers are defined in DOE-STD-1189 as workers 100 meters distant from the criticality accident (i.e., "the release point") or from the building perimeter.

Table 1. Seismic Design Criteria (SDC)

Unmitigated Consequence of SSC Failure from a Seismic Event		
Category	Collocated Worker at 100 m	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

The target performance goal for each SDC, shown in Table 2, is the mean annual probability of exceedance of the specified limit state of structures and equipment due to the design seismic event. The corresponding qualitative likelihood based on the criteria of DOE-STD-3009 is also provided in the table.

Table 2. Target Performance Goal for SDC

SDC	Target Performance Goal	Qualitative Likelihood
1	$< 1 \times 10^{-3}$ yr^{-1}	Unlikely
2	$< 4 \times 10^{-4}$ yr^{-1}	Unlikely
3	$\sim 1 \times 10^{-4}$ yr^{-1}	Unlikely/Extremely Unlikely
4	$\sim 4 \times 10^{-5}$ yr^{-1}	Extremely Unlikely
5	$\sim 1 \times 10^{-5}$ yr^{-1}	Extremely Unlikely

Note that the target performance goal frequency (for facility structures and equipment) is different than the frequency of the design basis earthquake (DBE), which is specified as a 2500-year return (mean) event for SDC-1, SDC-2, SDC-3 and SDC-4. The principal difference being that the design methods are specified by the U.S. Geological Survey, International Building Code, and ASCE/SEI 7-05 for SDC-1 and SDC-2; and, ASCE/SEI 43-05, ANSI/ANS-2.26, ANSI/ANS-2.27 and ANSI/ANS-2.29 for SDC-4. For SDC-5, the DBE is a 10,000-year (mean) event using the same design methods as SDC-4.

The limit states provided in Table 3 are deformation limits to be credited in safety analyses, including criticality safety evaluations, for the response of facility structures or equipment to the design basis earthquake. In criticality safety evaluations, such seismic-induced deformation should be considered the "credible abnormal conditions" for compliance with American National Standard ANSI/ANS-8.1-1998, Nuclear Criticality Safety in Operations with Fissionable Material Outside Reactors, §4.1.2, "Process Analysis".

Table 3. Structural Deformation Limit States

LS	Structural Deformation Limits	Damage
A	Large permanent distortion, short of collapse	Significant damage
B	Moderate permanent distortion	Generally repairable damage
C	Limited permanent distortion	Minimal damage
D	Essentially elastic behavior	No damage

Together, the SDC, design basis earthquake, target performance goal, and limit state establish the design and construction practices to be applied to facility SSCs. In the case of SDC-1 and SDC-2, the seismic design criteria are provided in ASCE/SEI 7-05; whereas ASCE/SEI 43-05 applies to SDC-3, SDC-4 and SDC-5.

The limit state to address equipment-distortion related criticality concerns will be no worse than limit state B in most cases. The structures or vessels specified as safety significant SSCs would be selected from the control set identified in the nuclear criticality safety evaluation (NCSE) and the documented safety analysis for each accident of concern. The SSC safety function described in the safety basis documentation would prevent fissile material from reaching the critical state. SSCs may suffer some loss of stiffness and strength in a seismic event, but still maintain the ability to provide the safety function described in the safety basis. The design team should carefully consider the increased cost of a more conservative design before specifying criteria beyond limit state B.

Equipment distortion/breakage leading to a potential criticality accident would primarily involve vessels that contain larger volumes and fissile masses in liquid forms or possibly large quantity vault storage. For example, fissile-bearing liquid leaking from pipes and process vessels could potentially flow into a sump or other unfavorable geometry location. Usually this is readily foreseen as a possibility and precluded with relatively inexpensive measures involving the application of neutron absorbers. Criticality concerns associated with loss of container spacing in vault storage subsequent to a seismic event are also often readily precluded by either seismic qualification of the shelving arrangement or by fissile density measures associated with container fissile mass limits and sizes.

Due to the expected, very limited consequences of a seismically induced criticality accident, safety class SSCs for protection of the public and safety significant SSCs for protection of the collocated worker are not expected to be identified in hazard analysis documentation addressing the criticality hazard. However, hazard analysis, including NCSEs, may identify SSCs as called out in DOE-STD-3007-2007 for specific aspects of defense-in-depth and worker safety.

Cost-Benefit Considerations

Participation of criticality safety engineers in the safety design strategy ensures criticality safety issues are addressed through all stages of the design process and included in the development of key safety documentation. Significant cost savings may be realized though the appropriate assignment of seismic design criteria and limit states such as assigning limit state A for equipment that may be assumed to fail (no performance criteria credited in a criticality safety evaluation) or considering moderate (limit state B) or limited distortion (limit state C) based on crediting realism in the criticality safety evaluation rather than requiring no damage (limit state D) for reasons of convenience to the analyst. In any case, credited performance based on limited damage should be clearly identified in NCSEs as key assumptions per DOE-STD-3007-2007.

When evaluating the cost of implementing different limit states, consideration must be given to the risk reduction provided by the SSC. In particular, if the fissile material can be shown to remain in the subcritical state subsequent to a seismic event then assigning the least costly limit state, A, is appropriate. Applying increasingly stringent seismic design requirements beyond those derived from applying the DOE-STD-1189 process, should not be pursued without a comprehensive assessment documenting cost versus benefit.

DOE O 420.1B, Change 1, requires facilities or sites with hazardous materials to "have instrumentation or other means to detect and record the occurrence and severity of seismic events". Such instrumentation, if equipped with an immediate evacuation alarm or procedurally coupled with emergency evacuation procedures, would obviate the need for (costly) seismic tolerance of an installed criticality accident alarm system (CAAS). If a seismic instrument is credited with performing the immediate evacuation function, the Criticality Safety Program Description Document should describe compliance with ANSI/ANS-8.3, §5.3, "Seismic Tolerance". Guidance on responding to a criticality accident including re-entry following an accident is provided in ANSI/ANS-8.23-2007.

Conclusions

Criticality safety engineers should participate throughout all facility design stages to ensure appropriate hazard categorization of the facility, generally Hazard Category 3 or less, based on the guidance provided in the CSSG Response to Tasking 2010-02. The corresponding seismic design criterion for structures and equipment important to criticality safety would be SDC-1.

The principal role of the criticality safety engineer throughout the design process is to identify SSCs for defense-in-depth and worker safety based on their function credited in criticality safety evaluations following an earthquake. The purpose of a CAAS is to provide an immediate evacuation alarm to protect facility workers. Additional, often very large, costs associated with the seismic tolerance of criticality accident alarm systems may be avoided if emergency evacuation is provided by seismic instrumentation or earthquake evacuation procedures.

Criticality safety engineers are encouraged to work closely with structural analysts to consider possible cost savings by suggesting innovative and inexpensive preventive measures such that seismic damage does not result in a criticality accident. This would permit limit states A, B and C and not require designing to the "no damage" limit state D.

References

1. ANSI/ANS-2.26-2004, Categorization of Nuclear Facility Structures, Systems
2. ANSI/ANS-2.27-2008, Criteria for Investigations of Nuclear Facility Sites for Seismic Hazard Assessments
3. ANSI/ANS-2.29-2008, Probabilistic Seismic Hazard Analysis
4. ANSI/ANS-8.3-1997, Criticality Accident Alarm Systems
5. ANSI/ANS-8.23-2007, Nuclear Criticality Accident Emergency Planning and Response
6. ASCE/SEI 7-05, Minimum Design Loads for Buildings and Other Structures
7. ASCE/SEI 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities
8. CSSG Response to Tasking 2010-02, Role of Criticality Safety in Facility Hazard Categorization
9. DOE O 413.3A, Change 1, Program and Project Management for the Acquisition of Captial Assets
10. DOE O 420.1B, Change 1, Facility Safety
11. DOE-STD-1189-2008, Integration of Safety into Design Process
12. DOE-STD-3007-2007, Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Nonreactor Nuclear Facilities
13. DOE-STD-3009, Change 3, Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses
14. International Building Code, International Code Council, Falls Church, Virginia

Attachment 1

CSSG TASKING 2010-01

Date Issued: April 23, 2010

Task Title:

Balanced Technical Approaches for Addressing Potential Seismically Induced Criticality Accidents in New Facility Design

Task Statement:

The CSSG is directed to develop a white paper on the use of balanced technical approaches for addressing the potential consequences of seismically-induced criticality accidents within the context of regulatory seismic design requirements for non-reactor nuclear facilities. The objective of the white paper is to provide guidance for technical approaches during new facility design phases to assessing criticality accident risk relative to seismic initiated events that balances the need to prevent potential criticality accidents with cost, regulatory compliance, and relative impact of a criticality accident in light of the overall consequence of the initiating event. The approach should include an evaluation of the extent to which seismic design criteria specified by DOE should be applied to facilities based solely on criticality safety risk. The CSSG is encouraged to indicate how the criticality safety philosophy inherent in the ANSI/ANS-8 Nuclear Criticality Safety Standards should influence the development of criticality controls in design of new facilities and how such an approach fits into the overall regulatory framework for new facility design. Hazards and risks that are to be addressed include:

- Potential process and operations equipment distortion that could lead to the potential for a criticality accident
- Loss of material separation and/or containment to the facility and/or environment resulting in the potential for a criticality accident
- Presence of employees during the seismic event, evacuation, and mustering
- Anticipated radiation exposures to employees, public, and the environment in the event of a seismically induced criticality accident
- Generalized cost-benefit evaluation on the use of seismically-qualified SSCs only to meet regulatory requirements without any significant risk reduction

Resources:

The CSSG Deputy Chair will form writing and review teams composed of CSSG members. Contractor CSSG members of the teams will use their FY10 NCSP CSSG support funding; DOE CSSG members of the teams will provide funding from their site offices. CSSG emeritus members may be included in the teams on a voluntary basis. In addition, staff members from the office of the NNSA Chief of Defense Nuclear Safety (CDNS), Brad Embrey, and the NNSA Engineering and Analysis Division, Andrew (Andy) F. Delapaz, shall participate on the team as ad hoc CSSG members on the writing team.

Task Deliverables:

CSSG Chair briefs the NCSP Manager on the proposed technical approaches and also highlights any emergent issues requiring disposition by the NCSP Manager on or before May 28, 2010.

Draft white paper issued to the entire CSSG for comments by June 25, 2010.
CSSG members submit comments on the draft white paper to the writing team lead by July 9, 2010.

Writing team addresses all comments from the CSSG and incorporates any comments that are accepted by August 6.

CSSG chair briefs the NCSP Manager on the comment resolution and the major recommendations of the writing team by August 20.

The writing team lead will submit the white paper to the CSSG Chair for transmittal to the NCSP Manager.

Task Due Date: August 27, 2010