Enclosure 1

Background for Proposed Seismic Interim Staff Guidance

Background

Industry initiated the New Reactor Seismic Issues Resolution Program to work with the U.S. Nuclear Regulatory Commission (NRC) to address technical issues pertaining to the seismic design of new reactors. The NRC Seismic Issues Technical Advisory Group, comprising staff members from the Office of New Reactors, Office of Nuclear Reactor Regulation, Office of Nuclear Regulatory Research, and Office of Nuclear Materials Safety and Safeguards, was a principal interface with industry. In part, the effort was needed to address the estimated high-frequency spectral ground acceleration values at the proposed sites. The issues included (1) implementation of the performance-based approach to determining the ground motion, outlined in American Society of Civil Engineers (ASCE) Standard 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities," and the research work contained in NUREG-6728, "Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-Consistent Ground Motion Spectra Guidelines," (2) implementation of a technique to eliminate those earthquakes in the probabilistic seismic hazard analysis that do not have significant damage potential (i.e., use of the cumulative absolute velocity (CAV) as a filtering technique), (3) determination of a technical basis to truncate lognormal distribution for ground motion at a specified number of standard deviation (epsilon), (4) implementation of the use of ground motion incoherency phenomena on large foundations that reduce high-frequency motions sustained by the structure, and (5) update and validation of existing software packages for soil-structure interaction analysis to include the incoherency functions (i.e., CLASSI/SASSI comparison). The implementation of these topics represents a substantial departure from the deterministic processes used in past designs and, although the concepts are not new, the implementation of these concepts in a design process is novel. Thus, significant effort has been required to develop technical requirements and approaches. Along with the technical approaches, the development of regulatory guidance and processes has also been vital.

Industry and the NRC have had substantial interaction on these issues. One of the principal outcomes of these efforts has been the publication of Regulatory Guide (RG) 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion," issued March 2007 (ADAMS Accession No. ML070310619), which establishes an acceptable regulatory approach to implement the performance-based derivation of site-specific ground motions. This guide includes the use of CAV concepts and addresses the issue of truncation of lognormal distribution for ground motions.

Issues Addressed in this ISG Paper

Since the publication of RG 1.208, technical dialogues have continued on the topics of incoherency and CLASSI/SASSI validation. Since October 2006, the NRC staff and industry have also discussed the regulatory framework and contents of a combined license (COL) or design certification (DC) application to address the high frequency ground motion issue. The NRC developed the umbrella framework to address this issue and incorporated it in Section 3.7.1, "Seismic Design Parameters," of NUREG-0800, "Standard Review Plan for the Review of

Safety Analysis Reports for Nuclear Power Plants," Revision 3, issued March 2007 (hereafter referred to as the SRP). The SRP recognizes that for some sites the site-specific ground motion may exceed the ground motion spectra used in a certified design and defines a progressive, stepwise process to address these exceedances. The process, in part, depends upon the use of incoherency concepts. During the development of the regulatory guidance, it has become clear that some basic definitions and a clear understanding need to be established to implement the above approaches and to fully develop a COL or DC application. Therefore, since December 2006, the interactions between the NRC and industry have focused on technical issues related to the high-frequency response analyses and the other issues as follows:

(1) definitions of various ground motions used in the design and site-specific analyses,

(2) definitions of safe-shutdown earthquakes (SSE) and operating-basis earthquakes (OBE),

(3) clear understanding of ground motions to be used in the certified design portion, site-specific design portion, and operability considerations,

(4) OBE exceedance and location of seismic instrumentation,

(5) development and justification of incoherency functions,

(6) use and validation of CLASSI/SASSI computer codes for incoherency analysis,

(7) scope of the analyses and approaches to be used to address high-frequency responses for structures, systems, and components.

In addition, industry also identified an eighth, emerging issue related to conducting soil testing at a proposed site:

(8) the unavailability of enough soil testing laboratories to test all the site soil samples.

Issues 1, 2, 3, and 4

The implementation of the performance-based approaches and the fact that the spectra used in the certified design are distinct from site-specific spectra introduce significant complications when compared to spectra generated from the various ground motions used for seismic analysis (Issue 1). After discussions at the December 14, 2006, meeting (see the meeting summary, ADAMS Accession No. ML063610506), industry, through the Nuclear Energy Institute, submitted a paper on performance-based spectra definitions and site acceptability standards on February 2, 2007 (ADAMS Accession No. ML070600662). Based on the industry paper and the staff's deliberations in developing RG 1.208 and the SRP, the staff included the definition of various ground motions in RG 1.208 and SRP Section 3.7.1. Enclosure 2 provides these definitions to facilitate further discussions and use in the subsequent positions.

The staff and industry discussed Issue 2 at a meeting on March 1, 2007, and industry submitted a draft paper on May 28, 2007 (ADAMS Accession No. ML071660304), providing an outline of industry presentation on SSE and OBE definitions for the meeting on May 31, 2007. Unlike the past designs where the SSE was synonymous with the earthquake used in the design or the so-called design-basis earthquake, the use of two distinct earthquakes in the current situation requires a common understanding in defining unique SSEs and OBEs satisfying both the regulatory requirements of Title 10, Section 100.23, "Geologic and Seismic Siting Criteria," of the *Code of Federal Regulations* (10 CFR 100.23) and Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities." Enclosure 3 outlines the staff positions with respect to the definitions of SSE and OBE. In addition, the industry paper addressed, in part, Issues 3 and 4. Staff and industry discussed these issues in detail at the May 31, 2007, meeting (see the meeting summary, ADAMS Accession No. ML071630037). Enclosure 3 also outlines the staff positions on these three issues. With respect to the definitions, use of the various ground motions, and operability considerations, the staff position reflects the common understanding established at the May 31, 2007, meeting.

<u>Issues 5, 6, and 7</u>

Issue 5 has been the subject of long-standing discussions between staff and industry as it is a key technical issue in implementing an incoherency-based analysis. This issue has involved significant technical developments and unanticipated challenges along the way that have caused the industry delays in completing the studies. Industry has recently provided a critical report to address this and other key issues related to the use of incoherency. This report is entitled "Hard-Rock Coherency Functions Based on the Pinyon Flat Array Data," dated July 5, 2007 (ADAMS Accession No. ML071980104). Based on discussions at the recent meeting of July 23–24, 2007, and past discussions and reviews of reports submitted on the subject, the staff developed guidance on the use of the coherency functions to address the high-frequency issue (as described in Enclosure 4), which relates to Issues 5, 6, and 7. The final report on incoherency is expected in the near future.

Industry has also recently submitted a draft report on CLASSI/SASSI comparison and validation, entitled "Validation of CLASSI and SASSI to Treat Seismic Wave Incoherence in SSI Analysis of Nuclear Power Plant Structures," dated July 9, 2007 (ADAMS Accession No. ML071980151). The staff and industry discussed both of these reports at the July 23–24, 2007, meeting. Again, industry has yet to deliver the final report that will include guidance on the use of these two codes.

Two additional draft reports submitted by the industry also relate to the high-frequency issues, namely (1) "Consideration for NPP Equipment and Structures Subjected to Response Levels Caused by High Frequency Ground Motions," dated March 19, 2007 (ADAMS Accession No. ML071010497), and (2) "Seismic Screening of Components Sensitive to High Frequency Vibratory Motions," dated June 28, 2007 (ADAMS Accession No. ML071930427). Participants discussed the first paper at the March 1, 2007, meeting (see the meeting summary at ADAMS Accession No. ML070930135), and the staff provided its comments at the meeting. This report deals with historical studies, past earthquake experiences, and analytical studies to demonstrate why the effects of high frequencies are limited with respect to structural integrity considerations. This report provides a foundation for the staff position to perform only a scoping analysis rather than a complete analysis of all structures, systems, and components. The second report addresses some of the staff's comments from the March meeting and includes proposed approaches for demonstrating the functional adequacy of components that are sensitive to high-frequency ground motions. Enclosure 4 outlines the staff position on what a COL or DC application should contain to address this issue. The staff will review the technical details, such as the basis for screening sensitive components and different techniques to show adequate performance, during its evaluation in connection with the amendment to the AP1000 design. However, Enclosure 4 clearly defines the needed contents of an application, and the staff articulated these positions at the March and May meetings. In this context, the staff notes that Westinghouse, in its application to amend the AP1000 DC rule, has outlined an approach on the high-frequency issue (see the Westinghouse presentation on Evaluation for High-Frequency Seismic Input, dated April 17, 2007) for addressing structures, systems, and components. The staff will conduct its reviews in the context of the amendment request by Westinghouse when it receives the technical report on the subject, currently scheduled for August 2007.

The issue of the high-frequency response is likely to vary in terms of scope and the extent to which exceedances may have to be addressed for different designs and different sites. In general, the issue is more likely to affect hard-rock sites. With respect to different designs, the AP1000 approach is discussed above. The response spectral shape used in the ongoing review of the ESBWR DC contains a high-frequency amplification region in recognition of the anticipated high-frequency ground motion at sites in the eastern and central United States. The DC applications are yet to be submitted for the U.S. Evolutionary Power Reactor (USEPR) and U.S. Advanced Pressurized Water Reactors (USAPWR). The staff guidance on this issue and the progressive review process outlined in SRP 3.7.1 allows for situations arising out of a mismatch between the certified design and the site-specific demand. Incorporation of the positions outlined in this paper should facilitate completion of the applications currently under preparation by the industry.

Issue 8

Industry initially discussed Issue (8) at the March meeting and subsequently submitted a draft white paper, entitled "Testing of Dynamic Soil Properties for Nuclear Power Plant COL Applications," dated May 25, 2007 (ADAMS Accession No. ML071660306), for discussion at the May 31, 2007, meeting. The staff provided its comments on the draft report at the meeting and documented them in a letter dated July 19, 2007. Enclosure 5 provides these comments. The staff finds the industry's strategy to deal with this issue acceptable, provided the considerations stated in Enclosure 5 are fully addressed.

Summary

The staff positions outlined in Enclosures 3, 4, and 5 focus on the content of an application so that a prospective applicant can proceed with completing analyses to fully develop an application. The NRC has completed its efforts to close the first three issues discussed in the opening paragraph of this enclosure through issuance of RG 1.208 and SRP Section 3.7.1. The staff will pay special attention in its acceptance review to issues such as soil testing to identify potential future scheduling delays because of insufficient information or anticipated additional reviews. The staff also emphasized these concerns in its summary of the May 31, 2007, meeting. The staff will continue to work with the New Reactor Seismic Issue Resolution program to finalize the ongoing studies.

<u>Enclosure 2</u>

Ground Motion Definitions

Certified Seismic Design Response Spectra (CSDRS)—Site-independent seismic design response spectra that have been approved under Subpart B, "Standard Design Certifications," of Title 10, Part 52, "Early Site Permits: Standard Design Certifications; and Combined Licenses for Nuclear Power Plants," of the *Code of Federal Regulations* (10 CFR Part 52) as the seismic design response spectra for an approved certified standard design nuclear power plant.

Ground Motion Response Spectra (GMRS)—Site-specific ground motion response spectra characterized by horizontal and vertical response spectra determined as free-field motions on the ground surface or as free-field outcrop motions on the uppermost in-situ competent material using performance-based procedures.[1]

Foundation Input Response Spectra (FIRS)—When the site-specific GMRS and the CSDRS are determined at different elevations, the site-specific GMRS need to be transferred to the base elevations of each seismic Category I foundation. These site-specific GMRS at the foundation levels are referred to as FIRS and are derived as free-field outcrop spectra.

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[1] When the GMRS are determined as free-field outcrop motions on the uppermost in-situ competent material, the site response analysis includes only the effects of the materials below this elevation. Note that the soil/rock material located above the outcrop elevation should be removed from the analytic soil column during site response evaluations. However, the effects of confinement caused by these materials should be included in the evaluation of the modulus reduction and damping relations for materials below the outcrop elevation to properly incorporate these effects in developing site amplification functions.

Enclosure 3

Staff Guidance/Positions on the Definitions of Safe-Shutdown and Operating-Basis Earthquakes, Use of Various Ground Motions, and Operating-Basis Earthquake Exceedance

1. Definition of Safe-Shutdown Earthquake

The safe-shutdown earthquake (SSE) for the site is the ground motion response spectra (GMRS), which also satisfies the minimum requirement of paragraph IV(a)(1)(i) of Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," to Title 10, Part 50, "Domestic Licensing of Production and Utilization Facilities," of the *Code of Federal Regulations* (10 CFR Part 50) or is modified to meet this requirement.

Section 3 below outlines the uses of certified seismic design response spectra (CSDRS) and GMRS for an application referring to a certified design.

2. Definition of Operating-Basis Earthquake

To satisfy the requirements of paragraph IV(a)(2)(A) of Appendix S to 10 CFR Part 50, for applications that involve the use of a certified design, the operating-basis earthquake (OBE) ground motion is defined as follows:

(i) For the certified design portion of the plant, the OBE ground motion is one-third of the CSDRS.

(ii) For the safety-related noncertified design portion of the plant, the OBE ground motion is one-third of the design motion response spectra, as stipulated in the design certification conditions specified in design control document (DCD).

(iii) The spectrum ordinate criterion to be used in conjunction with Regulatory Guide 1.166, "Pre-Earthquake Planning and Immediate Nuclear Power Plant Operator Postearthquake Actions," issued March 1997, is the lowest of (i) and (ii).

3. Use of Various Ground Motions

The stipulations in the DCD of a certified design govern the use of the CSDRS and GMRS (terminology used in currently certified designs is site-specific SSE).

For the certified design portion of the plant, the CSDRS is the design basis and must be maintained as the design basis. The use of any alternative ground motion would require an exemption or amendment.

The GMRS is the ground motion for certain features as stipulated in the DCD of a certified design. For example, the DCD of most certified designs specify the use of site-specific SSE (GMRS) ground motion for slope stability and liquefaction analyses.

The use of GMRS is acceptable to demonstrate plant safety/operability for the as-found condition. However, the condition must be restored to meet the original design basis and the design criteria.

4. Seismic Instrumentation and OBE Exceedance

To meet the requirements of paragraphs IV(3) and IV(4) of Appendix S to 10 CFR Part 50, the staff has provided guidance in Regulatory Guide 1.12, "Nuclear Power Plant Instrumentation for Earthquakes," Revision 2, issued March 1997, and Regulatory Guide 1.166, "Pre-Earthquake Planning and Immediate Nuclear Power Plant Operator Postearthquake Actions," issued March 1997. The staff will conduct a case-by-case review if a COL applicant proposes an alternative instrumentation plan, locations, or other deviations from the two regulatory guides.

Enclosure 4

Staff Guidance/Positions on Addressing High-Frequency Ground Motion Evaluations

When the ground motion response spectra (GMRS) (or foundation input response spectra (FIRS)) exceed the certified seismic design response spectra (CSDRS) (or associated foundation level spectra), the staff will follow the review process outlined in Section 3.7.1 of NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (hereafter referred to as the SRP). These exceedances are expected in the high-frequency range. The staff positions/guidance to conduct the "high-frequency ground motion analysis" are grouped into five categories—(1) use of computer codes for incoherency problems, (2) coherency functions (CFs) to be used in the analysis, (3) evaluation of structures, systems, and components (SSCs), (4) evaluation of high-frequency sensitive components, and (5) interface requirements and proposed inspections, tests, analysis, and acceptance criteria (ITAAC). The SRP process is progressive and can stop when it is clear that the design demands resulting from the GRMS are bounded by CSDRS demands for SSCs.

The use of incoherency concepts in review of the seismic analysis is new and evolving. The following staff guidance/positions are based on review of the information provided by the industry as discussed in Enclosure 1. Final reports on the incoherency functions and CLASSI/SASSI validations are due in the near future. Furthermore, the staff is currently reviewing Revision 16 of the AP1000 certified design and the economic simplified boiling-water reactor (ESBWR) design certification applications. Given this situation, the staff guidance/position consists of two categories—(1) specific positions needed to conduct high-frequency response analysis and (2) guidance on the scope of evaluations to be performed and included in an application.

1. Use of Computer Codes for Incoherency Analysis

1.1 The use of CLASSI and SASSI incoherency approaches, embodied in the codes CLASSIinco-SRSS, SASSI-SRSS, and SASSI-Simulation, are considered acceptable for treatment of random phasing effects, provided it is demonstrated that the code used is properly implemented for a particular application taking into account site and foundation conditions.

1.2 Use of any other code should be validated through the approaches and benchmarks given in the industry report entitled, "Validation of CLASSI and SASSI to Treat Seismic Wave Incoherence in SSI Analysis of Nuclear Power Plant Structures," dated July 9, 2007.[2] Review of the validation will provide a basis for determining the acceptability of the alternative code.

2. Coherency Functions

The staff accepts the use of the proposed horizontal and vertical CFs, as detailed in the Electric Power Research Institute report entitled, "Hard-Rock Coherency Functions Based on the Pinyon Flat Array Data," dated July 5, 2007 (ADAMS Accession No. ML071980104).

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[2] The final version of this report is in preparation.

Since the incorporation of the incoherency effects increases the rotational motions (rocking and torsional), the transfer functions for these motions will be provided when incoherency is included in the soil-structure interaction (SSI) analyses.

3. Evaluation of Structures, Systems, and Components

3.1 Information will be provided to demonstrate that the SSI and structural models are of adequate refinement to assure that the high-frequency components of the horizontal and vertical GMRS/FIRS of interest are properly transmitted through both segments of the computational model. The range of high frequency of interest and its basis will be provided. Any subsequent in-structure response spectra (IRS) developed using this model should then reflect the propagation of these high frequencies through the different levels of the structure.

3.2 The procedure used to generate the IRS will follow the procedure used in the certified design.[3] Use of a single set of soil properties for certain sites or other deviations from the procedure may be appropriate, if adequate justifications are provided.

3.3 Information should be provided to demonstrate that the model captures the increased rotational and torsional components that would result from the inclusion of incoherency in the analysis.

3.4 If the comparison of the GRMS/FIRS-based IRS still exceeds the CSDRS-based IRS, the further evaluations of SSCs are performed on a sampling basis.

3.4.1 Provide selection screening criteria and their basis for SSCs (e.g., piping), such as safety significance, location in the vicinity of the high-frequency response, potential high effects of rotational components, and high support forces.

3.4.2 Describe the evaluation methodologies (including selection of failure modes) used for the assessment of selected SSCs and their basis. Provide the basis for comparison parameters (e.g., shear, overturning moment, support forces, valve locations, nozzles).

3.4.3 Provide the results of evaluations/comparisons and the disposition if the GMRS/FIRS-based design demand exceeds the CSDRS-based demand.

4. Evaluation of High-Frequency Sensitive Components

These evaluations are performed if the comparison of the GRMS/FIRS-based IRS still exceeds the CSDRS-based IRS. These evaluations are in addition to the CSDRS-based seismic qualification program as stipulated in an approved certified design. The purpose of high-frequency evaluations is to demonstrate safety functionality of a sensitive component.

4.1 Provide criteria and basis for determining components with potential high-frequency sensitivity.

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3 The procedures used in the certified designs are based on SRP Sections 3.7.2 and 3.7.3.

4.2 Provide procedures used and their bases to derive motion at the location of a component to be evaluated.

4.3 Provide details and basis for any screening procedures or test procedures used. Provide the details and basis of acceptance criteria to demonstrate functionality.

4.4 Provide the results from the application of item 4.3 above and the disposition of components that do not meet the acceptance criteria.

5. Interface Requirements and Proposed Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC)

5.1 An application referencing a certified design should provide information to demonstrate compliance with the interface requirements as it pertains to the issue of high-frequency ground motion analysis.

5.2 The application should provide inspections, tests, analyses, and the associated acceptance criteria, as necessary, for the high-frequency ground motion analysis.

Enclosure 5

Staff Comments on the Industry Draft White Paper on "Testing of Dynamic Soil Properties for Nuclear Power Plant COL Applications" and Guidance on Information for Review

The white paper summarizes regulatory requirements and the U.S. Nuclear Regulatory Commission (NRC) staff positions in the relevant guidance documents regarding the soil dynamic tests, specifically, the resonant column/torsional shear (RC/TS) testing. The RC/TS testing yields soil modulus reduction and damping curves, which are critical data for site response calculation. The paper also proposes a protocol to accommodate as many combined license applications as possible while considering the limited testing facilities available.

The NRC staff reviewed the paper and found that this protocol could provide a strategy to deal with the shortage of soil dynamic testing facilities. However, the paper also left some key questions to be answered and key terminologies to be defined. The staff also expects industry to address the following five questions in its application:

(1) Define a soil site quantitatively in terms of soil dynamic properties (e.g., shear wave velocity and/or shear wave velocity gradient) to make it clear what kind of soil/rock needs to have RC/TS testing. Furthermore, define hard rock, firm rock, competent rock, and deep soil, which the paper refers to frequently with respect to the same criteria.

(2) Identify the criteria to be used to determine the initial number of testing samples.

(3) Elaborate on the randomization processes to be used to demonstrate that limited initial sample testing will cover the variation when more sample testing results are available or, if a bounding analysis is used, the choices of the appropriate margin or bounding factor.

(4) Describe the measures to be taken to incorporate the final results. If the final testing results prove that the initial testing results did not provide sufficient safety margins for site-specific soil dynamic properties, explain the potential impact on relevant calculations that are based on limited sample testing.

(5) If possible, include a case study using limited soil sample testing to characterize the soil dynamic properties.