U.S. NUCLEAR REGULATORY COMMISSION

DESIGN-SPECIFIC REVIEW STANDARD FOR mPOWER™ iPWR DESIGN

15.9.A THERMAL HYDRAULIC STABILITY (mPower™ iPWR)

REVIEW RESPONSIBILITIES

Primary - Organization responsible for review of transient and accident analyses for mPower™

Secondary - None

I. AREAS OF REVIEW

The specific areas of review are as follows:

1. Coupled neutronic-thermal-hydraulic instabilities, also known as density-wave instabilities, are safety concerns for nuclear reactors. Three recognized modes of density-wave instability are core-wide (when the power and flow of all the core channels oscillate in phase), regional (when the power and flow of half the core channels oscillate out-of-phase with the other half), and single-channel flow instability (when the flow in a single channel oscillates, accompanied by small power oscillations).

2. Instability modes other than density-wave type are possible in reactors and their systems. The most common sources of unstable power oscillations are poorly-tuned control systems or control oscillations caused by partial failures like sticky valves. Other sources of unstable power oscillations are design-dependent. For example, passive natural-circulation reactors may be susceptible to oscillations or loop instabilities during the startup phase or for decay heat removal.

3. Certain instability events can lead to unacceptable consequences to the fuel if the reactor is not shut down on time. Specifically, for the density-wave regional stability mode, the original reactor protection system in boiling water reactors (BWRs) could not guarantee a timely shutdown because the average power range monitor signal averages the positive and negative sides of the power oscillation. Thus, the oscillation amplitude sensed by the average power range monitor is significantly smaller than the actual power oscillation experienced by the channels. Methodologies for resolving BWR core-stability issues presented in General Electric topical report NEDO-31960 and Supplement 1 were approved by the U.S. Nuclear Regulatory Commission (NRC) in Reference 2. These reports provide long-term solutions (LTSs) to BWR stability issues and present methods to support plant system designs that comply with General Design Criteria (GDCs) 10 and 12.

   For the mPower™ iPWR core, if boiling is present in some hot regions, the flow and power distribution will be affected because of the change in reactivity due to void formation. Oscillations can develop, especially out-of-phase oscillations between regions of the core. The possibility of these oscillations and their impact on specified acceptable fuel design limits (SAFDLs) must be evaluated by analysis.

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4. Combined License (COL) Action Items and Certification Requirements and Restrictions. For a design certification (DC) application, the review will also address COL action items and requirements and restrictions (e.g., interface requirements and site parameters).

   For a COL application referencing a DC, a COL applicant must address COL action items (referred to as COL license information in certain DCs) included in the referenced DC. Additionally, a COL applicant must address requirements and restrictions (e.g., interface requirements and site parameters) included in the referenced DC.

Review Interfaces

Other DSRS sections interface with this section as follows:

1. General information on transient and accident analyses is provided in DSRS Section 15.0.

2. Design basis radiological consequence analyses associated with design basis accidents are reviewed under DSRS Section 15.0.3.

3. Determination of the adequacy of the hardware implementation of stability LTS is reviewed under DSRS Sections 7.0-A and 7.2.

4. Determination of stability during anticipated transients without scram events is reviewed under DSRS Section 15.8.

II. ACCEPTANCE CRITERIA

Requirements

Acceptance criteria are based on meeting the relevant requirements of the following Commission regulations:

1. General Design Criterion (GDC) 10, “Reactor Design”, as it relates to reactor coolant system design with appropriate margin so that specified acceptable fuel design limits are not exceeded during normal operations, including anticipated operational occurrences (AOOs).

2. GDC 12, “Suppression of Reactor Power Oscillations,” which requires that oscillations be either not possible or reliably and readily detected and suppressed.

3. GDC 13, “Instrumentation and Control,” which includes requirements for the hardware implementation of stability protection system features (SPSF).

4. GDC 20, “Protection System Functions,” which requires the reactor protection system to initiate automatic action so SAFDLs are not exceeded for conditions that result in unstable power oscillations.

5. GDC 29, “Protection against Anticipated Operational Occurrences,” which requires that SPSFs be designed for an extremely high probability of accomplishing safety functions.

DSRS Acceptance Criteria

Specific DSRS acceptance criteria acceptable to meet the relevant requirements of the NRC's regulations identified above are set forth below. The DSRS is not a substitute for the NRC's regulations, and compliance with it is not required. Identifying the differences between this DSRS section and the design features, analytical techniques, and procedural measures proposed for the facility, and discussing how the proposed alternative provides an acceptable method of complying with the regulations that underlie the DSRS acceptance criteria, is sufficient to meet the intent of 10 CFR 52.47(a)(9), "Contents of applications; technical information." The same approach may be used to meet the requirements of 10 CFR 52.79(a)(41) for COL applications.

1. To meet requirements of GDC 12, the reactor core and its systems should be designed with sufficient margin to be free of undamped oscillations and other thermal-hydraulic instabilities for all conditions of steady-state operation and for anticipated operational occurrences (AOOs).

2. If potential oscillations cannot be eliminated, design proposals should detect and suppress them reliably and readily.

3. A reactor is considered stable if it satisfies one of the following criteria:

   A. The calculated decay ratio (DR) for all three common stability modes (core-wide, regional, and channel) satisfies the relationship DR < (1 -σ), where σ is the uncertainty of the calculation. The staff reviews and approves both the calculation methodology and its uncertainty. The value of σ is typically 0.2, but is methodology-dependent. This value includes the code uncertainty and some degree of variability of the input parameters.

   B. Use of an approved correlation to estimate the stability of the regional stability mode based on calculated core-wide and channel DRs is permitted. One example is the FABLE/BYPSS Stability Criteria reviewed and approved by staff and documented in NEDO-31960.

4. An acceptable SPFS methodology to satisfy GDC 12 reduces the operating domain by defining an exclusion region where the reactor is not allowed to operate. The exclusion region, defined by the area in the operating map where stability criteria are not met, should be enforced automatically with an approved SPSF. In addition to the exclusion region, the SPSF defines a larger buffer region enforced with administrative controls. The buffer region minimizes challenges to the reactor protection system.

5. An alternative acceptable SPSF methodology to satisfy GDC 12 will readily detect and suppress unstable power oscillations by scramming the reactor before SAFDLs are violated. An approved D&S SPSF should be implemented. SAFDL requirements are specified in DSRS Section 4.2, "Fuel System Design," and DSRS Section 4.4, "Thermal and Hydraulic Design."

6. Detect and Suppress SPSFs rely on calculations of the reduction in critical power ratio margin for oscillations of a given amplitude. The response to these D&S hardware oscillations should be modeled by a series of likely oscillation-amplitude contours and randomly failed power instruments.

7. All SPSF implementations should have backup options in case the licensing solution is declared inoperable. Technical specifications should require that the primary licensing solution be restored in a relatively short period (no longer than 120 days). Backup

options in effect for short periods may rely on administrative controls and manual operator actions only if operator actions required to prevent SAFDL exceedences can be accomplished within the two minutes allowed for operator action in the demonstration calculations. Backup solution exclusion regions should be confirmed for specific cycles and specified in the core operating limits report (COLR).

8. A number of SPSFs has been reviewed and approved by the staff for BWRs. These are known as the stability long term solutions (LTS). As reactor and fuel designs evolve, the industry may propose new SPSFs. The following criteria judge the acceptability of new SPSFs and facilitate meeting the requirements of GDC 20:

   A. The SPSF should protect against SAFDL violations automatically.

   B. The SPSF should demonstrate by analysis that either (i) the probability of instabilities in the allowed operating region is sufficiently small or (ii) unstable power oscillations can be detected and suppressed readily without SAFDL violations. The SPSF may use a combination of both demonstrations for different instability modes.

   C. If the licensing basis option is declared inoperable the SPSF should provide a backup option that may implement manual or administrative actions only if operator actions required to prevent SAFDLs can be accomplished within the two minutes allowed for operator action in the demonstration calculations.

   D. The SPSF option should include generic technical specifications that address:

      i. The methodology for setpoint and region calculation and documentation of the setpoint on a cycle-specific basis (e.g., COLR).

      ii. Operability and surveillance requirements for the licensing basis option.

      iii. A time limit (120 days maximum) for operation under the backup option.

9. To meet requirements of GDC 13, stability-related instrumentation functionality should be demonstrated by analysis. Hardware implementation should follow DSRS Section 7.2.

10. In addition to the density-wave instability modes, the applicant should ensure that the plant is free from other instability modes that could violate SAFDLs (e.g., startup or control system instabilities) or that oscillations can be detected and suppressed readily. Note: Some instability modes may be acceptable with no potential for SAFDL violation, (e.g., bi-stable flow or small-flow oscillations during low-pressure startup).

Technical Rationale

The technical rationale for application of these requirements to reviewing this DSRS section is discussed in the following paragraphs:

1. GDC 12 states, “The reactor core and associated coolant, control, and protection systems shall be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed.” GDC 12, therefore, sets two types of generic LTS requirements:

A. Exclusion region solutions that reduce the operating domain by defining an exclusion region where the reactor is not allowed to operate, and

B. D&S solutions that scram the reactor if oscillations develop.

2. For plants with D&S solutions, unstable power oscillations are AOOs. GDC 20 requires effective reactor protection system protection against SAFDLs for AOOs. Thus, the success criteria for protection system actuation during unstable power oscillations are avoidance of boiling transition and other criteria specified in DSRS Sections 4.2 and 4.4 even though during short events fuel damage may not occur.

3. The SPSF protection should be automatic. Manual and administrative actions are acceptable as backup systems when the primary licensed SPSF is declared inoperable for a period of up to 120 days. Manual actions are acceptable for a short time if only a small probability of an instability that would challenge SAFDLs can be shown in reasonable operator action times. If this small probability cannot be demonstrated, there should be an automatic backup.

4. There is a third acceptance option for instability modes other than density-wave stability. Criteria in this DSRS specify that the GDC 12 intent is that the reactor may be designed to operate with any such oscillations if they cannot violate SAFDLs.

III. REVIEW PROCEDURES

These review procedures are based on the identified DSRS acceptance criteria. For deviations from these acceptance criteria, the staff should review the applicant's evaluation of how the proposed alternatives provide an acceptable method of complying with the relevant NRC requirements identified in Subsection II. The reviewer will select material from the procedures described below, as may be appropriate for a particular case.

The evaluation of compliance with acceptance criteria may be based on referenced approved designs, analyses, and/or assessments including topical reports, standard design approvals, and designs of systems previously reviewed and approved by the staff. If there is any aspect of a design not identical to the referenced design, an evaluation should address the differences and the conclusions on such differences should be included in the safety evaluation report (SER).

1. Programmatic Requirements - In accordance with the guidance in NUREG-0800 "Introduction," Part 2 as applied to this DSRS Section, the staff will review the programs proposed by the applicant to satisfy the following programmatic requirements. If any of the proposed programs satisfies the acceptance criteria described in Subsection II, it can be used to augment or replace some of the review procedures. It should be noted that the wording of "to augment or replace" applies to nonsafety-related risk-significant structures, systems, and components (SSCs), but "to replace" applies to nonsafety-related nonrisk-significant SSCs according to the "graded approach" discussion in NUREG-0800 "Introduction," Part 2. Commission regulations and policy mandate programs applicable to SSCs that include:

   A. Maintenance Rule Standard Review Plan (SRP) Section 17.6 (DSRS Section 13.4, Table 13.4, Item 17, RG 1.160, "Monitoring the Effectiveness of Maintenance at Nuclear Power Plants." and RG 1.182; "Assessing and Managing Risk Before Maintenance Activities at Nuclear Power Plants".

B. Quality Assurance Program SRP Sections 17.3 and 17.5 (DSRS Section 13.4, Table 13.4, Item 16).

C. Technical Specifications (DSRS Section 16.0 and SRP Section 16.1) – including brackets value for DC and COL. Brackets are used to identify information or characteristics that are plant specific or are based on preliminary design information.

D. Reliability Assurance Program (SRP Section 17.4).

E. Initial Plant Test Program (RG 1.68, "Initial Test Programs for Water-Cooled Nuclear Power Plants, "DSRS Section 14.2, and DSRS Section 13.4, Table 13.4, Item 19).

F. Inspections, tests, analyses, and acceptance criteria (DSRS Chapter 14).

2. In accordance with 10 CFR 52.47(a)(8),(21), and (22), for new reactor license applications submitted under Part 52, the applicant is required to (1) address the proposed technical resolution of unresolved safety issues and medium- and high-priority generic safety issues that are identified in the version of NUREG-0933 current on the date 6 months before application and that are technically relevant to the design; (2) demonstrate how the operating experience insights have been incorporated into the plant design; and, (3) provide information necessary to demonstrate compliance with any technically relevant portions of the Three Mile Island requirements set forth in 10 CFR 50.34(f), except paragraphs (f)(1)(xii), (f)(2)(ix), and (f)(3)(v). Reference: 10 CFR 52.47(a)(21), 10 CFR 52.47(a)(22) , and 10 CFR 52.47(a)(8), respectively. These cross-cutting review areas should be addressed by the reviewer for each technical subsection and relevant conclusions documented in the corresponding SER section.

The reviewer evaluates the applicant's SAR information on thermal-hydraulic stability concerns during normal operations and anticipated operational occurrences for compliance with specific acceptance criteria listed in subsection II of this DSRS section. Specifically:

1. The reviewer verifies whether the reactor and its systems facilitate automatic protective action either to prevent thermal-hydraulic instabilities or to make certain that specified acceptable fuel design limits are not exceeded in thermal hydraulic instabilities in accordance with an approved SPSF methodology.

2. The reviewer verifies whether the reactor and its subsystems are free from instabilities other than density-wave instability (e.g., startup or control system instabilities) or whether those instability modes have insignificant effects on SAFDLs.

3. The reviewer verifies whether technical specifications satisfy acceptance criteria listed in subsection II of this DSRS section.

4. The reviewer verifies whether all analysis methodologies including treatment of uncertainties in the submission have been reviewed and approved by staff. In cases when an approved methodology is not available, the staff may accept the use of other methodologies based on the results of audits or preliminary reviews.

5. The reviewer evaluates the need for staff-confirming calculations if design changes deviate significantly from established practice.

6. For review of a DC application, the reviewer should follow the above procedures to verify that the design, including requirements and restrictions (e.g., interface requirements and site parameters), set forth in the final safety analysis report (FSAR) meets the acceptance criteria. DCs have referred to the FSAR as the design control document (DCD). The reviewer should also consider the appropriateness of identified COL action items. The reviewer may identify additional COL action items; however, to ensure these COL action items are addressed during a COL application, they should be added to the DC FSAR.

For review of a COL application, the scope of the review is dependent on whether the COL applicant references a DC, an early site permit or other NRC approvals (e.g., manufacturing license, site suitability report or topical report).

IV. EVALUATION FINDINGS

The reviewer verifies that the applicant has provided sufficient information and that the staff's technical review and analysis, as augmented by the application of programmatic requirements in accordance with the staff's technical review approach in the DSRS Introduction, support conclusions of the following type to be included in the staff's safety evaluation report. The reviewer also states the bases for those conclusions.

The staff concludes that the plant design adequately addresses stability issues and satisfies GDC 10, 12, 13, 20, and 29, Appendix A, 10 CFR Part 50, and Generic Letter 94-02. This conclusion is based on the following findings:

1. The applicant's plant design includes a stability LTS implementation that either prevents density-wave instabilities or can readily detect and suppress the oscillations.

2. The applicant has provided or referred to information and/or analyses that demonstrate that the plant design is free of other instability modes or that such instability modes cannot violate SAFDLs.

3. All calculation methodologies and referenced information have been reviewed and previously approved by the staff.

4. The applicant has provided technical specifications that address the stability LTS implementation, including setpoint generation, surveillance, and operability requirements. Setpoints and exclusion regions, if applicable, are defined in the COLR.

5. Hardware implementation of the LTS has been reviewed and satisfies DSRS Section 7.2. 6. For DC and COL reviews, the findings will also summarize the staff's evaluation of requirements and restrictions (e.g., interface requirements and site parameters) and COL action items relevant to this DSRS section.

V. IMPLEMENTATION

The staff will use this DSRS section in performing safety evaluations of mPower™-specific design certification, or combined license, applications submitted by applicants pursuant to 10 CFR Part 52. The staff will use the method described herein to evaluate conformance with Commission regulations.

Because of the numerous design differences between the mPower™ and large light-water nuclear reactor power plants, and in accordance with the direction given by the Commission in SRM- COMGBJ-10-0004/COMGEA-10-0001, "Use of Risk Insights to Enhance the Safety

Focus of Small Modular Reactor Reviews," dated August 31, 2010 (ML102510405), to develop risk-informed licensing review plans for each of the small modular reactor reviews including the associated pre-application activities, the staff has developed the content of this DSRS section as an alternative method for mPower™ -specific DC, or COL submitted pursuant to 10 CFR Par 52 to comply with 10 CFR 52.47(a)(9), "Contents of applications; technical information."

This regulation states, in part, that the application must contain "an evaluation of the standard plant design against the SRP revision in effect six months before the docket date of the application." The content of this DSRS section has been accepted as an alternative method for complying with 10 CFR 52.47(a)(9) as long as the mPower™ DCD FSAR does not deviate significantly from the design assumptions made by the NRC staff while preparing this DSRS section. The application must identify and describe all differences between the standard plant design and this DSRS section, and discuss how the proposed alternative provides an acceptable method of complying with the regulations that underlie the DSRS acceptance criteria. If the design assumptions in the DC application deviate significantly from the DSRS, the staff will use the SRP as specified in 10 CFR 52.47(a)(9). Alternatively, the staff may supplement the DSRS section by adding appropriate criteria in order to address new design assumptions. The same approach may be used to meet the requirements of 10 CFR 52.79(a)(41), and COL applications.

VI. REFERENCES

1. Generic Letter 94-02, "Long-Term Solutions and Upgrade of Interim Operating Recommendations for Thermal-Hydraulic Instabilities in Boiling Water Reactors," March 5, 1996.

2. A. C. Thadani, "Acceptance for Referencing of Topical Reports NEDO-31960 and NEDO-31960 Supplement 1, BWR Owners Group Long-Term Stability Solutions Licensing Methodology," U.S. Nuclear Regulatory Commission, July 12, 1993.

3. NEDO-31960, "BWR Owners Group Long-Term Stability Solutions Licensing Methodology," General Electric Company, May 1991.

4. NEDO-31960 Supplement 1, "BWR Owners Group Long-Term Stability Solutions Licensing Methodology," General Electric Company, March 1992.

5. NEDO-32465A, "BWR Owners Group Reactor Stability Detect and Suppress Solutions Licensing Basis Methodology for Reload Applications," GE Nuclear Energy, August 1996.

6. NEDC-33075P, Revision 5, "General Electric Boiling Water Reactor Detect and Suppress Solution-Confirmation Density," GE Nuclear Energy, November 2005.