U.S. NUCLEAR REGULATORY COMMISSION

DESIGN-SPECIFIC REVIEW STANDARD FOR mPOWER^{TM} iPWR DESIGN

6.2.1.2 SUBCOMPARTMENT ANALYSIS

REVIEW RESPONSIBILITIES

Primary - Organization responsible for the review of containment integrity

Secondary - None

The responsible organization reviews the information presented by the applicant in the safety analysis report (SAR) concerning the determination of the design differential pressure values for containment subcompartments. A subcompartment is defined as any fully or partially enclosed volume within the primary containment that houses high-energy piping and would limit the flow of fluid to the main containment volume in the event of a pipe rupture within the volume. This is referred to as an internal compartment in General Design Criterion (GDC) 50 of Appendix A to Title 10 of the *Code of Federal Regulations* (CFR), Part 50. A short-term pressure pulse would exist inside a containment subcompartment following a pipe rupture within the volume. This pressure transient would produce a pressure differential across the walls of the subcompartment which would generally reach a maximum value within the first second after blowdown begins. The magnitude of this maximum value is a function of several parameters, which include blowdown mass and energy release rates, subcompartment volume, vent area, and vent flow behavior. A transient differential pressure response analysis should be provided for each subcompartment or group of subcompartments that meets the above definition.

I. <u>AREAS OF REVIEW</u>

Babcock & Wilcox Nuclear Energy mPower™ is an integral pressurized-water reactor with the reactor, steam generator, pressurizer, and control rod drives all located in a single pressure vessel. The mPower™ reactor containment is a free-standing carbon steel structure that is located below grade level.

The specific areas of review are as follows:

1. <u>Nodalization Schemes</u>: The basis for the nodalization within each subcompartment is reviewed.

2. <u>Initial Thermodynamic Conditions</u>: The initial thermodynamic conditions within each subcompartment are reviewed to ensure the selection of values that maximize the resultant differential pressure.

3. <u>Vent FlowPath and Distribution of Mass and Energy Released</u>: The nature of each vent flowpath considered, the distribution of the mass and energy released, and the extent of entrainment assumed in the vent flow mixture is reviewed. The review may also include an analysis of the dynamic characteristics of components, such as doors, blowout

panels, or sand plugs that must open or be removed to provide a vent flowpath, as well as the methods and results of component tests performed to demonstrate the validity of these analyses. The analytical procedure used to determine the loss coefficients and inertia terms (L/A, m^{-1} (ft^{-1})) for each vent flowpath used to predict the vent mass flow rates is also reviewed.

4. Design Pressure: The design pressure chosen for each subcompartment is reviewed.

5. Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC): For design certification (DC) and combined license (COL) reviews, the staff reviews the applicant's proposed ITAAC associated with the structures, systems, and components (SSCs) related to this design-specific review standard (DSRS) section in accordance with Standard Review Plan (SRP) Section 14.3, "Inspections, Tests, Analyses, and Acceptance Criteria." The staff recognizes that the review of ITAAC cannot be completed until after the rest of this portion of the application has been reviewed against acceptance criteria contained in this DSRS section. Furthermore, the staff reviews the ITAAC to ensure that all SSCs in this area of review are identified and addressed as appropriate in accordance with SRP Section 14.3.

6. COL Action Items and Certification Requirements and Restrictions: For a 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 SRP and DSRS sections interface with this section as follows:

1. Review of the various types and aspects of the containment design are identified in DSRS Section 6.2.1.

2. Review of the break locations and dynamic effects of postulated pipe ruptures and the mechanical design of movable and stationary devices provided for vent flow control in containment subcompartments are performed under DSRS Section 3.6.2.

3. Review of the structural design of movable and stationary devices provided for vent flow control in containment subcompartments is performed under SRP Section 3.8.3.

4. Determination of SSC risk significance is performed under SRP Section 19.0.

II. ACCEPTANCE CRITERIA

Requirements

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

1. GDC 4, as it relates to the design of containment internal compartments to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents (LOCAs). The containment internal compartments shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit.

2. GDC 50, as it relates to the design of the containment internal compartments to ensure that the reactor containment structure, including access openings, penetrations, and the containment heat removal system are designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from any LOCA.

3. 10 CFR 52.47(b)(1), which requires that a DC application contain the proposed ITAAC that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a plant that incorporates the DC is built and will operate in accordance with the DC, the provisions of the Atomic Energy Act (AEA), and the U.S. Nuclear Regulatory Commission’s (NRC's) regulations.

4. 10 CFR 52.80(a), which requires that a COL application contain the proposed inspections, tests, and analyses, including those applicable to emergency planning, that the licensee shall perform, and the acceptance criteria that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, the facility has been constructed and will operate in conformity with the COL, the provisions of the AEA, and the NRC's regulations.

DSRS Acceptance Criteria

Specific DSRS acceptance criteria acceptable to meet the relevant requirements of the NRC’s regulations identified above are as follows for the review described in this DSRS section. 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.”

1. Nodalization Schemes. Subcompartment nodalization schemes should be chosen so that there is no substantial pressure gradient within a node. A sensitivity study which includes increasing the number of nodes until the peak calculated pressures converge to small resultant changes should be used to verify the nodalization scheme. The guidelines of Section 3.2 of NUREG-0609 (Reference 1) should be followed and a nodalization sensitivity study should be performed, which should include the consideration of spatial pressure variations (e.g., pressure variations circumferentially, axially, and radially within the subcompartment). These variations are used to calculate the transient forces and moments acting on components.

2. Initial Thermodynamic Conditions. The initial atmospheric conditions within a subcompartment should maximize the resultant differential pressure. An acceptable model would assume air at the maximum allowable temperature, minimum absolute pressure, and zero percent relative humidity. If the assumed initial atmospheric conditions differ from this model, the selected values should be justified by the applicant.

   Another acceptable model that may be used for a restricted class of subcompartments involves simplifying the air model outlined above. In this case, the initial atmosphere within the subcompartment is modeled as a homogeneous water-steam mixture with an average density equivalent to the dry air model. This approach should be limited to subcompartments that have choked flow within the vents because the adequacy of this simplified model for subcompartments having primarily subsonic flow through the vents has not been established.

3. Vent FlowPath and Distribution of Mass and Energy Released. Assumptions with regard to the distribution of mass and energy release should be biased towards maximizing the subcompartment pressure. The vent flow behavior through all flowpaths within the nodalized compartment model should be based on a homogeneous mixture in thermal equilibrium, with the assumption of 100-percent water entrainment. In addition, the selected vent critical flow correlation should be conservative with respect to available experimental data. Currently acceptable vent critical flow correlations are the frictionless Moody (Reference 2), with a multiplier of 0.6 for water-steam mixtures, and the thermal homogeneous equilibrium model for air-steam-water mixtures.

   If vent flowpaths are used that are not immediately available at the time of pipe rupture, the following criteria apply:

   A. The vent area and resistance as a function of time after the break should be based on a dynamic analysis of the subcompartment pressure response to pipe ruptures.

   B. The validity of the analysis should be supported by experimental data, or a testing program should be proposed at the construction permit or DC stage that will support this analysis.

   C. To meet the requirements of GDC 4, the safety analysis should consider the effects of missiles that may be generated during the transient.

4. Design Pressure. For the review of a construction permit (CP) preliminary safety analysis report (PSAR) or a factor of 1.4 should be applied to the peak differential pressure which is calculated in a manner acceptable to the reviewer for the

subcompartment structure, and the enclosed components for use in the design of the structure and the component supports. For the review of the operating license (OL) final safety analysis report (FSAR), DC or COL FSAR, the peak calculated differential pressure should not exceed the design pressure. It is expected that the peak calculated differential pressure will not be substantially different from that of the CP. However, improvements in the analytical models or changes in the as-built subcompartment may affect the available margin.

Technical Rationale

The technical rationale for application of these acceptance criteria to the areas of review addressed by this DSRS section is discussed in the following paragraphs:

1. GDC 4 allows the dynamic effects associated with postulated pipe ruptures in nuclear power units to be excluded from the design-basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design-basis for the piping.

   Demonstration of extremely low probability pipe rupture requires fracture mechanics analysis to evaluate the stability of postulated through-wall flaws in piping and the ability to detect leakage through a flaw before the flaw grows to an unstable size. The concept underlying such analysis is referred to as "leak-before-break" (LBB). Although LBB technology allows applicants to eliminate consideration of local dynamic effects of postulated pipe ruptures in the design-basis of an SSC, the staff will continue to require consideration of the global effects of postulated pipe ruptures for the design of subcompartment enclosures because the global effects provide a convenient and conservative design envelope. Containment subcompartments contain high-energy piping that, if ruptured, could cause collapse of the subcompartment, generation of missiles, and creation of harsh local environmental conditions. Meeting the requirements of GDC 4 will help to maintain the structural integrity of containment subcompartments and protect the containment structure and systems from the effects of a high-energy line break.

2. GDC 50 requires that the containment structure and associated heat removal system be designed to accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from a LOCA. Because a LOCA is the most severe challenge expected, the design of the containment and its subcompartments must be able to withstand such an accident. Providing sufficient design margin will assure that the design can withstand all postulated accidents regardless of unanticipated factors. Meeting the requirements of GDC 50 will help to maintain the structural integrity of containment subcompartments and protect the containment structure and systems from the effects of a subcompartment high-energy line break.

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.

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 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, SRP Section 17.6 (DSRS Section 13.4, Table 13.4, Item 17, Regulatory Guide (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. ITAAC (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). These cross-cutting review areas should be addressed by the reviewer for each technical subsection and relevant conclusions documented in the corresponding safety evaluation report (SER) section.

3. <u>Nodalization Schemes</u>. The reviewer evaluates the nodalization of each subcompartment to determine the adequacy of the calculational model. As necessary, the reviewer performs iterative nodalization studies for subcompartments to confirm that the model includes sufficient nodes.

4. <u>Initial Thermodynamic Conditions</u>. The reviewer compares the initial subcompartment air pressure, temperature, and humidity conditions to the criteria in Subsection II of this DSRS section to confirm that conservative conditions were selected.

5. Vent Flowpath and Distribution of Mass and Energy Released. The reviewer determines the adequacy of the information in the SAR regarding subcompartment volumes, vent areas, vent resistances, and inertia terms. If a subcompartment must rely on doors, blowout panels, or equivalent devices to increase vent areas, or unique flow-limiting devices to control vent flows, the reviewer evaluates the analysis and testing programs that substantiate their use. The review of the mechanical and structural design of such flow control devices will be performed under DSRS Section 3.6.2 and SRP Section 3.8.3.

   The reviewer evaluates the bases, correlations, and computer codes used to predict subsonic and sonic vent flow behavior and the capability of the code to model compressible and incompressible flow. The bases should include comparisons of the correlations to both experimental data and recognized alternate correlations that have been accepted by the staff.

   The reviewer may perform a confirmatory analysis of the blowdown mass and energy profiles within a subcompartment. The analysis is done using thermal-hydraulics computer codes that are acceptable to the responsible reviewing organization for the subject application. The purpose of the analysis is to confirm the predictions of the mass and energy release rates appearing in the SAR and to verify that the analysis considered an appropriate break location and size, including LBB considerations.

6. Design Pressure. For a CP PSAR, OL, DC, or COL FSAR, the reviewer ascertains that the subcompartment design procedures include appropriate margins above the calculated values, as given in Subsection II. Using the nodalization of each subcompartment as specified in the SAR, the reviewer performs analyses using one of several available computer programs to determine the adequacy of the calculated peak differential pressure. The computer program used will depend upon the subcompartment under review and the flow regime.

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 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 DCD.

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 (ESP) or other NRC approvals (e.g., manufacturing license, site suitability report or topical report).

For review of both DC and COL applications, SRP Section 14.3 should be followed for the review of ITAAC. The review of ITAAC cannot be completed until after the completion of this section.

IV. EVALUATION FINDINGS

The reviewer verifies that the applicant has provided sufficient information and that the review and calculations (if applicable) support conclusions of the following type to be included in the staff's SER. The reviewer also states the bases for those conclusions.

The evaluation findings will follow the format provided in DSRS Section 6.2.1 and conclude that the applicant followed the DSRS acceptance criteria identified above [or identified deviations from the DSRS acceptance criteria with appropriate justification] and meet GDCs 4 and 50, as they relate to the design of the containment subcompartments.

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.

In addition, to the extent that the review is not discussed in other SER sections, the findings will summarize the staff's evaluation of the ITAAC, including design acceptance criteria, as applicable.

V. IMPLEMENTATION

The staff will use this DSRS section in performing safety evaluations of mPower™-specific DC, COL, or ESP 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 (Agencywide Documents Access and Management System Accession No. 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, COL, or ESP applications submitted pursuant to 10 CFR Part 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 Standard Review Plan (SRP) revision in effect 6 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 revise the DSRS section in order to address new design assumptions. The same approach may be used to meet the requirements of 10 CFR 52.17 (a)(1)(xii) and 10 CFR 52.79 (a)(41), for ESP and COL applications, respectively.

VI. REFERENCES

1. RG 1.68, “Initial Test Programs for Water-Cooled Nuclear Power Plants.”

2. RG 1.160, “Monitoring the Effectiveness of Maintenance at Nuclear Power Plants.”

3. RG 1.182, “Assessing and Managing Risk Before Maintenance Activities at Nuclear Power Plants.”

4. RG 1.206, “Combined License Applications for Nuclear Power Plants (LWR Edition).”

5. RG 1.215, “Guidance for ITAAC Closure Under 10 CFR Part 52.”

6. NUREG-0609, “Asymmetric Blowdown Loads on PWR Primary Systems,” January 1981.

7. F. J. Moody, Maximum Flow Rate of a Single Component, Two-Phase Mixture, Jour. of Heat Transfer, Trans. Am. Soc. of Mechanical Engineers, Vol. 87, No. 1, February 1965.