DRAFT for Comment

DESIGN SPECIFIC REVIEW STANDARD FOR mPOWER™ iPWRs

3.3.2 EXTREME WIND LOADS (HURRICANE AND TORNADO LOADS)

REVIEW RESPONSIBILITIES

Primary - Organization responsible for structural analysis reviews

Secondary - None

I. AREAS OF REVIEW

The mPower™ integral pressurized water reactor (iPWR) is a small-size reactor inside a below-ground containment. The reactor water storage tank is located inside the containment and a reactor service building sits above the containment structure. The spent fuel pool is below grade and located in the reactor service building. The ultimate heat sink tanks for the reactor water storage tank passive coolers are outside containment and are also enclosed in the reactor service building. This DSRS section specifies the design-basis extreme wind load and its effects and extreme wind-generated missile impact effects for all seismic Category I structures.

All structures, systems, and components (SSCs) important to safety are to be protected from extreme wind loads to ensure compliance with 10 CFR 50, Appendix A, General Design Criterion (GDC) 2 requirements. All safety-related and risk-significant SSCs are subject to extreme wind load protection. An SSC may be classified as:

Safety-related risk-significant
Safety-related nonrisk-significant
Nonsafety-related risk-significant
Nonsafety-related non-risk significant

If the SSC belongs in one of the first three classifications above, the review described in this Design-Specific Review Standard (DSRS) Section 3.3.2 is applied. For the purpose of brevity in this section, the first three categories above will be designated as “safety-related or risk-significant”.

The specific areas of review are as follows:

1. The design parameters applicable to the tornado, including the tornado wind translational and rotational speeds; the tornado-generated atmospheric pressure change; and the spectrum of tornado-generated missiles, including their characteristics, from the standpoint of use in defining the input parameters for the structural design criteria appropriate to account for tornado loads.

2. The procedures that are used to transform tornado parameters into effective loads on structures, including the following:

   A. The transformation of tornado wind into equivalent loads applied to structures, taking into consideration the geometrical configuration and physical characteristics of the structures and the distribution of tornado wind pressure on structures.

   B. The transformation of tornado-generated atmospheric pressure changes into applied loads on structures.

   C. The transformation of tornado-generated missiles, which are impactive dynamic loads, into equivalent loads on structures.

   D. The combination of the above individual loads in a manner that will produce the most adverse total tornado effect on structures.

3. The design hurricane parameters, including maximum wind speed and the spectrum of hurricane-generated missiles, including their characteristics to be used in defining the hurricane loads as part of input to the structural design.

4. The procedure used to transform hurricane parameters into effective loads on structures, including the following:

   A. The transformation of hurricane wind into equivalent pressure loads onto structures, taking into consideration the geometric configuration and physical characteristics of the structures and the distribution of hurricane wind pressure on structures.

   B. The transformation of hurricane-generated missiles induced impactive dynamic loads into equivalent loads on structures.

   C. The combination of the above individual loads in such a manner that will produce the most adverse total hurricane effect on structures.

5. The information provided to demonstrate that failure of any structure or component not designed for both tornado and hurricane loads will not affect the capability of other structures or components to perform necessary safety functions.

6. 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 DSRS section in accordance with DSRS 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 DSRS Section 14.3.

7. 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.

8. Extreme Wind Loads and Associated Missile Impact Effects for mPower™ Applications

   The specific areas of review items 1 through 7 discussed above are generally applicable provided that the unique mPower™ containment configurations and layouts (e.g., below ground containment) as described below are adequately accounted for in the review.)

   The mPower™ integral pressurized water reactor (iPWR) is a small-size reactor inside a below-ground containment. The reactor water storage tank is located inside the containment and a reactor service building sits above the containment structure. The spent fuel pool is below grade and located in the reactor service building. The ultimate heat sink tanks for the reactor water storage tank passive coolers are outside containment and are also enclosed in the reactor service building. This DSRS section provides guidance for determining pertinent design-basis tornado/hurricane loads and associated tornado/hurricane-generated missile impact effects for all seismic Category I structures. Regulatory Guide 1.76, “Design-Bases Tornado and Tornado Missiles for Nuclear Power Plants” and Regulatory Guide 1.221, “Design-Basis Hurricane and Hurricane Missiles for Nuclear Power Plants” provide staff guidance acceptable for use in selecting the design-basis tornado/hurricane and design-basis tornado/hurricane-generated missiles that a nuclear power plant, such as mPower™ should be designed to withstand their effects and, to prevent undue risk to the health and safety of the public.

Review Interfaces

Other DSRS sections interface with this section as follows.

1. The adequacy of the most severe regional and local meteorological data used to specify design basis tornado and design basis hurricane load parameters for SSCs that may be affected by weather phenomena is reviewed in accordance with DSRS Sections 2.3.1 and 2.3.2.

2. The adequacy of the design-basis tornado and hurricane-generated missile spectrum is reviewed in according with DSRS Section 3.5.1.4.

The specific acceptance criteria and review procedures are contained in the reference DSRS sections.

The adequacy of procedures used to determine tornado-generated atmospheric pressure change effects on partially enclosed structures are reviewed on a case-by-case basis.

II. ACCEPTANCE CRITERIA

Requirements

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. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the DSRS acceptance criteria and evaluate how the proposed alternatives to the DSRS acceptance criteria provide acceptable methods of compliance with the NRC regulations.

1. 10 CFR 50, Appendix A, GDC 2 requires that SSCs important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornados, hurricanes, tsunami, floods, and seiches without loss of capability to perform their safety functions as it relates to natural phenomena. The design bases for these SSCs shall reflect appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena.

2. 10 CFR 52.47(b)(1), which requires that a DC application contain the proposed inspections, tests, analyses, and acceptance criteria (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 design certification is built and will operate in accordance with the design certification, the provisions of the Atomic Energy Act, and the NRC's regulations;

3. 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 combined license, the provisions of the Atomic Energy Act, and the NRC's regulations.

SRP 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. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the DSRS acceptance criteria and evaluate how the proposed alternatives to the DSRS acceptance criteria provide acceptable methods of compliance with the NRC regulations.

1. The GDC 2 requirement that SSCs important to safety be designed to withstand the effects of the most severe of the natural phenomena that have been historically reported for the site and surrounding area is accounted for by considering the extreme environmental loads associated with the design-basis tornadoes and design-basis hurricanes specified in RG 1.76 and RG 1.221, respectively.

2. The acceptance criteria for the design basis tornado parameters (including maximum wind speed, translational speed, rotational speed, and atmospheric pressure change)

and the design basis hurricane parameters and the bases for determining these parameters are defined in DSRS Sections 2.3.1 and 2.3.2. Acceptance criteria for the spectrum of tornado and hurricane-generated missiles and their characteristics, as well as the bases for determining these parameters, are defined in DSRS Section 3.5.1.4. These parameters should serve as basic input to the review and evaluation for structural design. For mPower™ plants, the containment is below the grade level, but there are other structures above ground for which tornado and hurricane loads and their associated missile impact effects need to be defined. In particular, this includes assessing the effects of tornado/hurricane wind on the reactor service building and the enclosed ultimate heat sink tanks for the in-containment reactor water storage tank passive coolers. Since the spent fuel pool is below grade and located in the reactor service building and the ultimate heat sink tanks for the reactor water storage tank passive coolers are outside containment and are also enclosed in the reactor service building, the tornado/hurricane wind loads and tornado/hurricane missile impact induced dynamic vibratory effects, including spent fuel pool water sloshing effect, should be adequately accounted for in the design of spent fuel pools, ultimate heat sink tanks as well as other affected seismic Category I SSCs consistent with the provisions of DSRS Sections 3.3, 3.7 and 3.8. Other structures are also defined as those buildings that house Power Conversion System (PCS), Radiation Waste (both liquid and gaseous), Feedwater, Main Steam, Diesel Generators, and other systems and components that may be determined to be important to safety due to risk significance as established by a risk-informed and performance-based technical analysis complemented by design-specific PRA information when available.

3. The acceptance criteria for procedures used to transform tornado parameters into equivalent loads on structures are as follows:

   A. <u>Tornado Characteristics and Effects</u>

      Tornados are characterized, in Table 1 of Regulatory Guide (RG) 1.76 for the contiguous United States into three geographical regions and by (1) maximum wind speed, (2) translational speed, (3) maximum rotational speed, (4) radius of maximum rotational speed, (5) pressure drop, and (6) rate of pressure drop for each of the three regions. Tornado effects are subdivided into three groups:

      i. Tornado wind effects caused by the direct action of air flow on structures,

      ii. Atmospheric pressure change effects caused by the differential pressure between the interior and exterior of a structure during the passage of a tornado, and

      iii. Tornado-generated missile impact effects.

      Tornado effects considered in design should include combinations of tornado wind effects, atmospheric pressure change effects, and tornado-generated missile impact effects.

B. Tornado Wind Effects

Procedures delineated in American Society of Civil Engineers/ Structural Engineering Institute (ASCE/SEI) 7-05, "Minimum Design Loads for Buildings and Other Structures" are acceptable for transforming tornado wind speed into pressure-induced forces applied to structures. In particular, the following shall apply:

i. The maximum velocity pressure, q_z, should be based on the applicable maximum tornado wind speed, V, using the following equation from ASCE/SEI 7-05, Section 6.5.10:

$$q_z = 0.00256\ K_z K_{zt} K_d V^2 I\ (\text{lb/ft}^2)$$

where:

K_z = velocity pressure exposure coefficient evaluated at height, z, as defined in ASCE/SEI 7-05, Table 6-3, but not less than 0.87
K_{zt} = topographic factor equal to 1.0
K_d = wind directionality factor equal to 1.0
V = maximum tornado wind speed (mi/h)
I = importance factor equal to 1.15

The maximum tornado wind speed, V, is the resultant of the maximum rotational speed and the translational speed of the tornado.

ii. Wind speed is assumed not to vary with the height above ground.

iii. Design tornado wind loads should be determined in accordance with the following sections in ASCE/SEI 7-05, as applicable.

(1) 6.5.12 Design Loads on Enclosed and Partially Enclosed Buildings
(2) 6.5.13 Design Wind Loads on Open Buildings with Monoslope, Pitched, or Troughed Roofs
(3) 6.5.14 Design Wind Loads on Solid Freestanding Walls and Solid Signs
(4) 6.5.15 Design Wind Loads on Other Structures

C. Atmospheric Pressure Change Effects

RG 1.76 provides guidance for determining the pressure drop and the rate of pressure drop caused by the passage of a tornado. "Wind Effects on Structures: Fundamentals and Applications to Design," (Third Edition, John Wiley and Sons, Inc., New York, 1996.) by E. Simiu and R. H. Scanlan, provides methods for

determining loads on structures due to atmospheric pressure changes during the passage of a tornado.

For a structure that is completely open subjected to a tornado, the internal and external pressures on the structure equalize rapidly during the passage of the tornado. Therefore, the atmospheric pressure change between the interior and the exterior of that structure approaches zero.

For a structure that is enclosed (unvented structure), the internal pressure remains equal to the atmospheric pressure before the passage of a tornado. The atmospheric pressure outside the structure changes during the passage of a tornado, which creates pressure differences between the interior and the exterior of that structure, and these differential pressures produce outward acting loads on the roof and walls of the enclosed structure.

For a structure that is partially enclosed (vented structure), the determination of loads on the structure due to atmospheric pressure changes during the passage of a tornado is more complicated. If venting is adopted as a way to reduce the atmospheric pressure change effect on a structure, the review will be performed on a case-by-case basis.

D. Tornado-Generated Missile Impact Effects

Tornado-generated missile characteristics and the design-basis tornado missile spectrum are provided in RG 1.76. The acceptance criteria for transforming tornado-generated missile impact into equivalent static loads on structures are delineated in DSRS Section 3.5.3, subsection II.

E. Combined Tornado Effects

After tornado-generated wind effects, W_w, atmospheric pressure change effects, W_p, and missile impact effects, W_m, are determined, the combination thereof should then be established in a conservative manner for structures. An acceptable method of combining these effects and establishing the total tornado load on a structure is as follows:

$$W_t = W_p \qquad \text{Eq. 1}$$

$$W_t = W_w + 0.5\, W_p + W_m \qquad \text{Eq. 2}$$

where:

W_t = total tornado load
W_w = load from tornado wind effect
W_p = load from tornado atmospheric pressure change effect
W_m = load from tornado missile impact effect

F. Hurricane Characteristics and Effects

Hurricanes are characterized in RG 1.221 for the contiguous United States

(except for the Pacific coast). Hurricane effects are subdivided into two groups:

i. Hurricane wind effects caused by the direct action of air flow on structures, and
ii. Hurricane-generated missile impact effects.

Hurricane effects considered in design should include combinations of hurricane wind effects and hurricane-generated missile impact effects.

G. Hurricane Wind Effects

Procedures delineated in ASCE/SEI 7-05 similar to that for tornado wind effect described in Subsection B are acceptable for transforming hurricane wind speed into pressure-induced forces applied to structures.

H. Hurricane-Generated Missile Impact Effects

Hurricane-generated missile characteristics and the design-basis hurricane missile spectrum are provided in RG 1.221. The acceptance criteria for transforming hurricane-generated missile impact into equivalent static loads on structures are delineated in DSRS Section 3.5.3, subsection II.

I. Combined Hurricane Effects

After hurricane-generated wind effects, Wwh, and missile impact effects, Wmh, are determined, the combination thereof should then be established in a conservative manner for structures. An acceptable method of combining these effects and establishing the total hurricane load on a structure is as follows:

$$W_{th} = W_{wh} + W_{mh} \qquad \text{Eq. 3}$$

where:

W_{th} = total hurricane load
W_{wh} = load from hurricane wind effect
W_{mh} = load from hurricane missile impact effect

4. The information provided to demonstrate that failure of any structure or component not designed for tornado and hurricane loads will not affect the capability of other SSCs to perform necessary safety functions, is acceptable if found in accordance with either of the following:

A. The postulated failure or collapse of structures and components not designed for tornado and hurricane loads, including missiles, can be shown not to result in any structural or other damage to safety-related structures, systems, or components.

B. Safety-related structures are designed to resist the effects of the postulated structural failure, collapse, or generation of missiles from structures and components not designed for tornado and hurricane loads.

Technical Rationale

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

1. Compliance with GDC 2 requires that nuclear power plant SSCs and important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their intended safety functions.

2. The acceptance criteria outlined above include references to industry standards and data for evaluating tornado and hurricane loads on structures. These standards and data have been reviewed by the staff and found to be acceptable.

3. Meeting the requirements of GDC 2 provides assurance that and SSCs important to safety and subject to tornado and hurricane effects will be designed to withstand the extreme loads from the design basis tornado and design basis hurricane without loss of capability to perform their intended safety functions.

III. REVIEW PROCEDURES

The reviewer will select material from the procedures described below, as may be appropriate for a particular case.

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. Site-related parameters described in Review Interfaces, subsection 1, are reviewed in accordance with DSRS Sections 2.3.1 and 2.3.2. The spectrum and characteristics of tornado and hurricane missiles described in Review Interfaces, subsection 2, are reviewed in accordance with DSRS Section 3.5.1.4. Tornado-generated atmospheric pressure change effects for partially enclosed structures described in Review Interfaces, are reviewed on a case-by-case basis.

2. After the acceptability of the site-related parameters is established, the reviewer proceeds to review the structural aspects of tornado and hurricane design in the following manner:

   A. The procedures used by the applicant to transform tornado and hurricane wind effects into design loads for structures are reviewed and compared with the procedures delineated in ASCE/SEI 7-05 and, in particular, with the acceptance criteria delineated in this DSRS Acceptance Criteria, subsection 3.B and 3.G..

   B. The procedures used by the applicant to transform tornado-generated atmospheric pressure change effects into design loads for open and enclosed

structures are reviewed and compared with the procedures described in this DSRS Acceptance Criteria, subsection 3.C. The procedures used by the applicant to transform tornado-generated atmospheric pressure change effects into loads for partially enclosed structures are reviewed on a case-by-case basis.

C. The review procedures for missiles generated by tornadoes and hurricanes are described in SRP Section 3.5.1.4. The review procedures for design of missile barriers are described in DSRS Section 3.5.3.

3. The information provided to demonstrate that failure of any structure or component not designed for tornado and hurricane loads will not affect the capability of other SSCs to perform necessary safety functions is reviewed.

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

   For review of both DC and COL applications, DSRS 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 safety evaluation report. The reviewer also states the bases for those conclusions.

The applicant has met the requirements of GDC 2 with respect to the capability of structures to withstand design-basis tornado and design-basis hurricane wind effects, tornado-generated atmospheric pressure change effects, and tornado and hurricane-generated missile impact effects so that their design reflects:

1. Appropriate consideration for the most severe tornado and hurricane recorded for the site with an appropriate margin;

2. Appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena; and
3. The importance of the safety function to be performed.

The applicant has designed the plant structures with sufficient margin to prevent structural damage during the design-basis tornado and design-basis hurricane loadings predicted for the site so that the requirements in item 1 listed above are met. In addition, the design of seismic Category I structures, as required in item 2 listed above, has included load combinations of the extreme environmental loads resulting from the design-basis tornado and the design-basis hurricane and the loads resulting from normal and accident conditions.

The procedures used to determine the loadings on structures induced by the design-basis tornado and the design-basis hurricane specified for the plant are acceptable because these procedures have been used in the design of conventional structures and proven to provide a conservative basis which together with other engineering design considerations ensures that the structures can withstand such environmental forces.

The use of these procedures provides reasonable assurance that in the event of a design-basis tornado or design-basis hurricane, the structural integrity of the plant structures that have to be designed for tornadoes and hurricanes will not be impaired and, in consequence, safety-related systems and components located within these structures will be adequately protected and may be expected to perform necessary safety functions as required, thus satisfying the requirement in item 3 listed above.

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 design certification (DC), combined license (COL), or early site permit (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 (ML102510405), to develop risk-informed licensing review plans for each of the small modular reactor (SMR) 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. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."
2. American Society of Civil Engineers/Structural Engineering Institute. *"Minimum Design Loads for Buildings and Other Structures,"* ASCE/SEI 7-05, American Society of Civil Engineers, Reston, Virginia, 2006.
3. E. Simiu and R. H. Scanlan, "Wind Effects on Structures: Fundamentals and Applications to Design," John Wiley and Sons, Inc., Third Edition, New York, NY, 1996.
4. Regulatory Guide 1.76, Revision 1, "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants," March 2007.
5. Regulatory Guide 1.221, Revision 0,"Design-Basis Hurricane and Hurricane Missiles for Nuclear Power Plants," October 2011.