

# Proposed - For Interim Use and Comment



## U.S. NUCLEAR REGULATORY COMMISSION DESIGN-SPECIFIC REVIEW STANDARD FOR mPOWER™ iPWR DESIGN

### 3.5.3 BARRIER DESIGN PROCEDURES

#### REVIEW RESPONSIBILITIES

**Primary** - Organization responsible for structural analysis reviews

**Secondary** - None

#### I. AREAS OF REVIEW

The following areas are related to procedures utilized in the design of seismic Category I structures, shields, and barriers to withstand the effects of missile impact. These areas are reviewed to ensure conformance with Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, Appendix A, General Design Criterion (GDC) 2 and 4.

The specific areas of review are as follows:

1. Procedures utilized for the prediction of local damage in the impacted area. This includes estimation of the depth of penetration and, in case of concrete barriers, the potential for generation of secondary missiles by spalling or scabbing effects.
2. Procedures utilized for the prediction of the overall response of the barrier or portions thereof due to the missile impact. This includes assumptions on acceptable ductility ratios where elasto-plastic behavior is relied upon, and procedures for estimation of forces, moments, and shears induced in the barrier by the impact force of the missile.
3. The adequacy of missiles' parameters cited in support of the applicant's conclusions concerning their suitability for the plant and the effects of missiles on structures, systems, and components (SSCs). The staff also reviews the missiles' parameters as an integral part of structural analysis.
4. 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 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.
5. 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. The adequacy of missile parameters cited in support of the applicant's conclusions concerning their suitability for the plant are reviewed in accordance with DSRS Sections 3.5.1.1, 3.5.1.2, 3.5.1.4, 3.5.1.5, and 3.5.1.6.
2. The adequacy of turbine missile parameters cited in support of the applicant's conclusions concerning their suitability for the plant are reviewed in accordance with DSRS Section 3.5.1.3.
3. The review of the SSCs to be protected from externally-generated missiles includes all plant site safety-related SSCs or risk-significant non-safety-related SSCs. These SSCs are listed in DSRS Section 3.2.2.
4. The review of the risk significance of SSCs 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.

The design of structures, shields, and barriers shall be such that these can withstand the effects of environmental and natural phenomena to be in conformance with requirements of GDC 2 and 4.

The relevant requirements are as follows:

1. GDC 2 requires that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, tornados, hurricanes, floods, tsunamis, and seiches without loss of capability to perform their safety functions. 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. GDC 4 requires that SSCs important to safety 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.
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 facility that incorporates the design certification has been constructed and will be operated in conformity with the design certification, the provisions of the Atomic Energy Act (AEA), and the Commission's rules and 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 combined license, the provisions of the AEA, and the Commission's rules and regulations.

#### DSRS Acceptance Criteria

Specific DSRS acceptance criteria acceptable to meet the relevant requirements of the U.S. Nuclear Regulatory Commission's (NRC's) regulations identified above are as follows for 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."

#### For Local Damage Prediction

##### A. Concrete

Sufficient thickness of concrete should be provided to prevent perforation, spalling, or scabbing of the barriers in the event of missile impact.

Empirical equations used in the modified National Defense Research Council (NDRC) formula recommended in "A Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects," by R.P. Kennedy, Nuclear Engineering and Design, 1976, Pages 187-188 are available to estimate missile penetration into concrete. These equations should be used to determine the required barrier thicknesses for both cases of tornado and hurricane. Minimum acceptable concrete barrier thicknesses for preventing local scabbing against tornado generated missiles for tornado spectrum shown in Table 2 of Regulatory Guide (RG) 1.76 should be computed. In the case of hurricane missiles, the same modified NDRC formula may be used to compute the minimum barrier thickness. For guidance related to hurricane generated missile velocity required for the computation, refer to Table 2 in RG 1.221, as applicable.

Barrier thicknesses less than those calculated using modified NDRC formula for tornado and hurricane missiles may be used, provided that sufficient justification (including test data) is presented by applicant or licensee to support them. These justifications will be reviewed on a case-by-case basis.

Other types of missiles are specified in DSRS Sections 3.5.1.1 through 3.5.1.6.

For turbine missile barriers, penetration and scabbing predictions should be based on empirical equations such as the modified NDRC formula or the results of a valid test program.

## B. Steel

The results of tests conducted by the Stanford Research Institute (SRI) on the penetration of missiles into steel plates are summarized in "U.S. Reactor Containment Technology" (ORNL/NSIC-5, Vol.1, Chapter 6, Oak Ridge National Laboratory, 1965) by W.B. Cottrell and A.W. Savolainen. The equations presented in the aforementioned document are acceptable to determine the penetration of missiles into steel plates. Other equations such as the Ballistic Research Laboratory formula described in, "Reactor Safeguards," by C. R. Russell, published by MacMillan, New York, 1962, may be used, provided the results are either comparable to those obtained by using the aforementioned "U.S. Reactor Containment Technology" method or are validated by penetration tests.

## C. Composite Sections

For composite or multi-element barriers, procedures for prediction of local damage are acceptable if the residual velocity of the missile perforating the first element is considered as the striking velocity for the next element. For determining this residual velocity, the equations presented in "Ballistic Perforation Dynamics," Journal of Applied Mechanics, Transactions of the ASME, Vol. 30, Series E, No. 3, September 1963 by R. F. Recht and T. W. Ipson, are acceptable when the first barrier of a multi-element missile barrier is steel. When the first barrier is concrete, procedures used are reviewed on a case-by-case basis.

## 2. For Overall Damage Prediction

The response of a structure or barrier to missile impact depends largely on the location of impact (e.g., midspan of a slab or near a support), on the dynamic properties of the target and missile, and on the kinetic energy of the missile. In general, the assumption of plastic collisions is acceptable, where all of the missile's initial momentum is transferred to the target and only a portion of its kinetic energy is absorbed as strain energy within the target. However, where elastic impacts are expected, the additional momentum transferred to the target by missile rebound should be considered in the analyses.

After it has been demonstrated that the missile will not penetrate the barrier, an equivalent static load concentrated at the impact area should then be determined, from which the structural response, in conjunction with other design loads, can be evaluated using conventional design methods. An acceptable procedure for such an analysis, where the impact is assumed to be plastic, is presented in "Impact Effect of Fragments Striking Structural Elements," Holmes and Narver, Inc., Revised November 1973 by R. A. Williamson and R. R. Alvy. Other procedures may be used, with adequate justification, provided the results obtained are comparable to that of the above reference.

Maximum allowable ductility ratios for steel and reinforced concrete barriers, in the above analysis, are given in American National Standard Institute/ American Institute of Steel Construction (ANSI/AISC) N690-1994 including supplement 2 (2004), American National Standard Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities (1994) and in RG 1.142, respectively.

## 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. Compliance with GDC 2, "Design Bases for Protection Against Natural Phenomena," requires that SSCs important to safety shall be designed to withstand the effects of natural phenomena without loss of capability to perform their safety functions. The design bases for such SSCs must include consideration of the importance of their safety functions, and the effects of accident conditions and natural phenomena.

The staff's criteria for the design of missile barriers provide for protecting SSCs from missiles generated by natural phenomena and other events. The criteria consider natural phenomena that occur concurrently with accident conditions.

Meeting the requirements of GDC 2 provides a level of assurance that SSCs important to safety will be designed to withstand missile and accident effects caused by natural phenomena and thus will be capable of performing its intended safety function.

2. Compliance with GDC 4, "Environmental and Dynamic Effects Design Bases," requires SSCs important to safety be designed to accommodate the effects of, and be compatible with, environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents. Ensuring the adequacy of such SSCs includes protecting against 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.

DSRS Section 3.5.3 includes the staff's criteria for providing adequate barriers design to resist missiles, pipe whipping, and the discharging fluids in order to protect structures, systems, and components important to safety. These criteria are based on sound engineering principles, experience, and test results.

Meeting the requirements of GDC 4 by providing a barrier against the effects of missiles, pipe whipping, and discharging fluids provides a level of assurance that structures, systems, and components important to safety will be capable of performing their intended safety function under environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, include loss-of-coolant accidents.

### 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. In accordance with 10 CFR 52.47(a)(8),(21), and (22), and 10 CFR 52.79(a)(17) and (20), 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 which are identified in the version of NUREG-0933 current on the date up to 6 months before the docket date of the

application and which 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.

2. For the prediction of local damage, the equations proposed by the applicant for estimation of missile penetration are reviewed in the following manner:
  - A. For missile penetration in concrete, the reviewer verifies that the applicant has used the empirical formulas such as the modified NDRC formula or valid test results. The reviewer also verifies that the applicant has provided sufficient barrier thickness to prevent perforation and to prevent spalling or scabbing when protection from spalling or scabbing is considered necessary.
  - B. For missile penetration in steel, the reviewer verifies that the applicant has used the SRI equations as referred to in Subsection II.1(B) of this DSRS. If other equations are selected, adequate justification of the applicability and validity of such equations are reviewed to ensure that the results are comparable to those obtained from the aforementioned SRI equations.
  - C. For missile penetration in composite or multi-element barriers, the reviewer verifies that the applicant has used the criteria delineated in Section II Acceptance Criteria, "DSRS Acceptance Criteria" subsection 1.C of this DSRS. If other criteria are proposed, the justification provided is reviewed to ensure that such equations give results which are comparable to those in "DSRS Acceptance Criteria" subsection 1.C.
3. For the prediction of overall damage and response of the barrier, the reviewer verifies that the applicant has used the criteria delineated in Subsection II.2 of this DSRS. If other criteria are selected, the applicant's justification is reviewed to ensure that the results obtained are at least equivalent to those obtained by using method delineated in Subsection II.2.
4. Refer to DSRS Section 3.5.1.3, "Turbine Missiles," for additional information regarding the protection of SSCs from the effects of turbine missiles.
5. 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. 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).

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 staff concludes that the barrier design is acceptable and meets the requirements of GDC 2 and 4 with respect to the capabilities of the structures, shields, and barriers to ensure that SSCs important to safety are designed to withstand the effects of natural phenomena (tornado/hurricane missiles) and environmental effects including the effects of missiles, pipe whipping, and discharging fluids. This conclusion is based on the following:

The procedures utilized to determine the effects and loadings on seismic Category I structures and missile shields and barriers induced by design basis missiles selected for the plant are acceptable since these procedures provide an adequate basis for engineering design to ensure that the structures or barriers are adequately resistant to and will withstand the effects of such forces.

The use of these procedures provides reasonable assurance that in the event of design basis missiles striking seismic Category I structures or other missile shields and barriers, the structural integrity of the structures, shields, and barriers will not be impaired or degraded to an extent that will result in a loss of required protection. Seismic Category I SSCs protected by these barriers are, therefore, adequately protected against the effects of missiles and will perform their intended safety functions. Conformance with these procedures is an acceptable basis for satisfying, in part, the requirements of GDC 2 and 4.

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, or COL, 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 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 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™ design control document 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) for COL applications.

## VI. REFERENCES

1. 10 CFR Part 50, Appendix A, GDC 2, "Design Bases for Protection against Natural Phenomena."
2. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and Dynamic Effects Design Bases."
3. R. P. Kennedy, "A Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects," Nuclear Engineering and Design. Volume 37, Number 2. 183-203. 1976.
4. W. B. Cottrell and A. W. Savolainen, "U.S. Reactor Containment Technology," ORNL NSIC-5, Ridge National Laboratory, Oak Ridge, TN: Volume 1, Chapter 6. 1965.
5. C. R. Russell, "Reactor Safeguards," New York: MacMillan. 1962.
6. R. F. Recht and T. W. Ipson, "Ballistic Perforation Dynamics," ASME Journal of Applied Mechanics. Volume. 30, Series E, Number 3. September 1963.
7. R. A. Williamson and R. R. Alvy, "Impact Effect of Fragments Striking Structural Elements," Holmes and Narver, Inc: Anaheim, CA. 1973.
8. RG 1.76 "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants."
9. American Institute of Steel Construction. Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities. ANSI/AISC N690. American Institute of Steel Construction: Chicago, IL. 1994.
10. RG 1.142, "Safety-Related Concrete Structures for Nuclear Power Plants (Other Than Reactor Vessels and Containments)."
11. RG 1.221, "Design Basis Hurricane and Hurricane Missiles for Nuclear Power Plants,"