U.S. NUCLEAR REGULATORY COMMISSION

DESIGN-SPECIFIC REVIEW STANDARD for NuScale SMR DESIGN

10.2.3 TURBINE ROTOR INTEGRITY

REVIEW RESPONSIBILITIES

Primary - Organization responsible for the review of materials engineering issues related to flaw evaluation and welding

Secondary - None

I. AREAS OF REVIEW

General Design Criterion (GDC) 4, "Environmental and Dynamic Effects Design Bases," of Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, requires, in part, that structures, systems, and components (SSCs) important to safety be appropriately protected against environmental and dynamic effects, including the effects of missiles, that may result from equipment failure. Because turbine rotors have large masses and rotate at relatively high speeds during normal reactor operation, failure of a rotor may cause excessive vibration of the turbine rotor assembly and result in the generation of high-energy missiles that could affect safety-related and risk-significant SSCs. Measures taken by the applicant to ensure turbine rotor integrity and reduce the probability of turbine rotor failure must satisfy the relevant requirements of GDC 4.

The low-pressure turbine rotor assembly may consist of a rotor shaft with shrunk-on disks or a one-piece rotor using either an integral forging or welded design. Low-pressure rotors are subject to relatively high stresses caused by thermal gradients, the interference fit, and centrifugal forces. The low-pressure turbine operates at lower temperatures than the high-pressure turbine. Thus, it is particularly important that the low-pressure rotor be made of a tough material. The use of suitable design, materials, fabrication techniques, coating processes, and nondestructive examinations during the fabrication process, as well as inservice inspection, can greatly reduce the probability of a turbine rotor failure.

The turbine rotor is a nonsafety component that could affect safety-related and risk-significant SSCs. The purpose of this section of the design-specific review standard (DSRS) is to review and evaluate the information submitted by the applicant to ensure turbine rotor integrity and a low probability of turbine rotor failure with the generation of missiles that could affect safety-related and risk-significant SSCs. It should be noted that plants that use barriers to protect <u>all</u> essential SSCs specified below and in DSRS Section 3.5.1.3, "Turbine Missiles," would not have to rely on the turbine missile generation probabilities, including turbine rotor integrity discussed in this section. The review of missile barriers will be reviewed in DSRS Section 3.5.1.3.

All safety-related and regulatory treatment of nonsafety systems category "B" (RTNSS B) SSCs are subject to missile protection.

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The NuScale application will include the classification of SSCs, a list of risk-significant SSCs, and a list of RTNSS equipment. Based on this information, the staff will review it according to NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants” (SRP), Section 3.2.2, “System Quality Group Classifications”; SRP Section 17.4, “Reliability Assurance Program”; and SRP Section 19.3, “Regulatory Treatment of Non-Safety Systems (RTNSS) for Passive Advanced Light Water Reactors,” to confirm the determination of safety-related and risk-significant SSCs.

The specific areas of review are as follows:

1. Materials Selection. The materials properties, including descriptions of the procedures used to minimize flaws and improve fracture toughness, are reviewed to establish that sufficient information is provided to evaluate the adequacy of the low-pressure rotor materials. Included in this information are the following:

   A. a discussion of the ductile-brittle transition temperatures (fracture appearance transition temperature of nil-ductility transition (NDT) temperature) of the materials and the tests and standards used to determine them

   B. the Charpy V-notch (C_v) test program used to establish minimum upper-shelf energies of the rotor materials

   C. the fracture toughness test program used to establish the minimum upper-shelf toughness of the rotor materials

2. Fracture Toughness. The fracture toughness of the materials and the materials tests or correlations of Charpy and tensile data to toughness properties are reviewed to establish that the turbine rotor materials exhibit adequate fracture toughness at a normal operating temperature and during startup.

3. Pre-service Inspection. The Preservice Inspection Program information is reviewed to verify the following:

   A. The rotor forgings are rough machined with minimum excess stock before heat treatment.

   B. Visual and surface inspections are performed on all finished machined surfaces.

   C. A 100-percent volumetric (ultrasonic) examination is performed.

   D. Before welding or brazing, all surfaces prepared for welding will be surface examined.

   E. After welding or brazing, all surfaces exposed to steam during turbine operation will be surface examined, giving particular attention to stress risers and welds.

   F. Welds will be ultrasonically examined in the radial and radial-tangential sound beam directions.

4. Turbine Rotor Design. The low-pressure turbine rotor design information, including allowable stresses, temperature distributions, and design overspeed considerations, is reviewed.

5. Inservice Inspection. Descriptions of the baseline and inservice phases of the Inservice Inspection Program, including types of inspections, areas to be inspected, frequencies of inspection, and acceptance criteria, are reviewed.

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 SSCs related to this DSRS section, in accordance with 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.

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 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 DSRS section as follows:

1. The review of turbine missile probability analysis and protection against turbine missiles is performed under DSRS Section 3.5.1.3, using the guidance in Regulatory Guide (RG) 1.115, "Protection Against Turbine Missiles," Revision 2.

2. The review of the probabilistic risk assessment is performed under SRP Section 19.0, "Probabilistic Risk Assessment and Severe Accident Evaluation for New Reactors," for the potential risk significance of SSCs.

II. ACCEPTANCE CRITERIA

Requirements

Acceptance criteria are based on meeting the relevant requirements of the following U.S. Nuclear Regulatory Commission (NRC) regulations:

1. GDC 4, as it relates to SSCs important to safety being appropriately protected against environmental and dynamic effects, including the effects of missiles that may result from equipment failure

2. 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 DC has been constructed and will be operated in conformity with the DC, the provisions of the Atomic Energy Act (AEA), 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 COL, the provisions of the AEA, and the NRC's regulations

DSRS Acceptance Criteria

Specific DSRS acceptance criteria that 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. As an alternative, and as described in more detail below, an applicant may identify the differences between a DSRS section and the design features (DC and COL applications only), analytical techniques, and procedural measures proposed in an application and discuss how the proposed alternative provides an acceptable method of complying with the NRC regulations that underlie the DSRS acceptance criteria.

1. Materials Selection. The turbine forged or welded rotor should be made from a material and by a process that tends to minimize flaw occurrence and maximize fracture toughness properties, such as a nickel-chromium-molybdenum-vanadium alloy processed by vacuum melting or vacuum degassing. The material should be examined and tested to meet the following criteria:

   A. Chemical analysis should be performed for each forging. Elements that have a deleterious effect on toughness, such as sulfur and phosphorus, should be controlled to low levels.

   B. The 50-percent fracture appearance transition temperature (FATT), as obtained from Charpy tests performed in accordance with the specification ASTM A370, should be no higher than -18 degrees Celsius (C) (0 degrees Fahrenheit (F)) for low-pressure turbine rotors. The NDT temperature obtained in accordance with specification ASTM E208 may be used in lieu of FATT. NDT temperatures should be no higher than -35 degrees C (-30 degrees F).

   C. The C_v energy at the minimum operating temperature of each low-pressure rotor in the tangential direction should be at least 8.3 kilogram/meters (kg/m) (60 poundforce/foot (ft-lb)). A minimum of three C_v specimens should be tested, in accordance with specification ASTM A370.

2. Fracture Toughness. The low-pressure turbine disk forged or welded rotor fracture toughness properties are acceptable if the following criteria are met.

   The ratio of the fracture toughness (K_{Ic}) of the rotor material to the maximum tangential stress at speeds from normal to design overspeed should be at least 10 $\sqrt{mm}$ (2 $\sqrt{in}$), at minimum operating temperature. Bore stress calculations should include components due to centrifugal loads, interference fit, and thermal gradients. Sufficient warmup time should be specified in the turbine operating instructions to ensure that toughness will be adequate to prevent brittle fracture during startup. Fracture toughness properties can be obtained by any of the following methods:

A. Testing of the actual material of the turbine rotor is to establish the K_{Ic} value at normal operating temperature.

B. Testing of the actual material of the turbine rotor with an instrumented Charpy machine and a fatigue precracked specimen is to establish the K_{Ic} (dynamic) value at the normal operating temperature. If this method is used, K_{Ic} (dynamic) shall be used in lieu of K_{Ic} (static) in meeting the toughness criteria above.

C. Estimating K_{Ic} values at various temperatures from conventional Charpy and tensile data on the rotor material uses methods presented by J. A. Begley and W. A. Logsdon, in Scientific Paper 71-1E7-AMSLRF-P1. This method of obtaining K_{Ic} should be used only on materials that exhibit a well-defined Charpy energy and fracture appearance transition curve and are strain-rate insensitive. The staff should review the test data and the calculated toughness curve submitted by the applicant.

D. Estimating "lower-bound" values of K_{Ic} at various temperatures use the equivalent energy concept developed by F. J. Witt and T. R. Mager, in ORNL-TM-3894. The staff should review the load-displacement data from the compact tension specimens and the calculated toughness data submitted by the applicant.

3. Preservice Inspection. The applicant's Preservice Inspection Program is acceptable if it meets the following criteria:

A. Forged or welded rotors should be rough machined before heat treatment.

B. Each finished forged or welded rotor should be subjected to 100-percent volumetric (ultrasonic), surface, and visual examinations using procedures and acceptance criteria equivalent to those specified for Class 1 components in ASME Boiler and Pressure Vessel Code (ASME Code) Sections III and V. Before welding or brazing, all surfaces prepared for welding or brazing should be surface examined. After welding or brazing, all surfaces exposed to steam during turbine operation should be surface examined, giving particular attention to stress risers and welds. Welds should be ultrasonically examined in the radial and radial-tangential sound beam directions.

C. Finished machined bores, keyways, and drilled holes should be subjected to magnetic particle or liquid penetrant examination. No flaw indications in keyway or hole regions are allowed.

D. Each turbine rotor assembly should be spin tested at 5 percent above the maximum speed anticipated during a turbine trip following a loss of full load.

4. Turbine Rotor Design. The turbine assembly should be designed to withstand normal conditions, anticipated transients, and accidents resulting in a turbine trip without a loss of structural integrity. The design of the turbine assembly should meet the following criteria:

   A. The design overspeed of the turbine should be 5 percent above the highest anticipated speed resulting from a loss of load. The staff should review the basis for the assumed design overspeed.

   B. The combined stresses of low-pressure turbine rotor at design overspeed due to centrifugal forces, interference fit, and thermal gradients should not exceed 75 percent of the minimum specified yield strength of the material, or 75 percent of the measured yield strength in the weak direction of the materials, if appropriate tensile tests have been performed on the actual rotor material.

   C. The turbine shaft bearings should be able to withstand any combination of the normal operating loads, anticipated transients, and accidents resulting in a turbine trip.

   D. The natural critical frequencies of the turbine shaft assemblies between zero speed and 20 percent overspeed should be controlled in the design and operation stages so as to cause no distress to the unit during operation.

   E. The turbine rotor design should facilitate inservice inspection of all high-stress regions, including bores and keyways, without the need for removing the disks from the shaft.

5. Inservice Inspection. The applicant's Inservice Inspection Program is acceptable if it meets the following criteria:

   The Inservice Inspection Program for the steam turbine assembly should provide assurance that rotor flaws that might lead to brittle failure of a rotor at speeds up to design speed will be detected. The inservice inspection and maintenance programs for the turbine assembly should comply with the manufacturer's recommendations.

   Inservice inspection and maintenance activities may be performed during plant shutdown coinciding with the inservice inspection schedule, as required by ASME Code Section XI, and should include complete inspection of all significant turbine components, such as couplings, coupling bolts, turbine shafts, low-pressure turbine blades, low-pressure rotors, and high-pressure rotors. This inspection should consist of visual, surface, and volumetric examinations.

6. In 10 CFR 52.47(b)(1), the NRC 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 DC has been constructed and will be operated in conformity with the DC, the provisions of the AEA, and the NRC's regulations.

Technical Rationale

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

1. Compliance with GDC 4 requires in part that SSCs important to safety be designed to accommodate the effects of, and be compatible with, environmental conditions associated with normal operations, maintenance, testing, and postulated accidents, including loss-of-coolant accidents. These SSCs shall be appropriately protected against dynamic effects, including missiles caused by equipment failures.

   GDC 4 applies to this DSRS section, because the turbine is a potential source of high-energy missiles that could compromise the function of safety-related plant components. Protection from these missiles is provided by placing specific requirements on turbines relative to materials, fabrication, inspections during fabrication, and inservice inspections, thus ensuring that the failure of a turbine will be highly unlikely. It should be noted that plants that use barriers to protect all essential SSCs in DSRS Section 3.5.1.3 would not have to rely on the turbine missile generation probabilities, including turbine rotor integrity discussed in this section. This DSRS section applies to those essential SSCs not protected by barriers. The review of missile barriers will be discussed in DSRS Section 3.5.1.3.

   Meeting the requirements of GDC 4 provides assurance that the turbine will not be a source of missiles that could damage SSCs. Compliance with GDC 4 therefore decreases the potential for release of fission products to the environment, which could lead to offsite doses in excess of the reference values cited in 10 CFR Part 100.

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.

Following these review procedures, the acceptability of the turbine rotor design may be determined based on reviewing the corresponding information in the technical submittal and identifying programmatic requirements, such as ITAAC, that provide reasonable assurance the turbine rotor material properties, design, fabrication, installation, and preservice and inservice inspection and testing requirements will satisfy the acceptance criteria in Subsection II.

1. Selected Programs and Guidance—In accordance with the guidance in NUREG–0800, "Introduction – Part 2: Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: Light-Water Small Modular Reactor Edition" (NUREG-0800, Intro Part 2), as applied to this DSRS Section, the staff will review the information proposed by the applicant to evaluate whether it meets the acceptance criteria described in Subsection II of this DSRS. As noted in NUREG-0800, Intro Part 2, the NRC requirements that must be met by an SSC do not change under the small modular reactor (SMR) framework. Using the graded approach described in NUREG-0800, Intro Part 2, the NRC staff may determine that, for certain SSCs, the applicant's basis for compliance with other selected NRC requirements may help demonstrate satisfaction of the applicable acceptance criteria for that SSC in lieu of detailed independent analyses.

The design-basis capabilities of specific SSCs would be verified, where applicable, as part of completing the applicable ITAAC. The use of the selected programs to augment or replace traditional review procedures is shown in Figure 1 of NUREG-0800, Intro Part 2. Examples of such programs that may be relevant to the graded approach for these SSCs include:

- 10 CFR Part 50, Appendix A, GDC, Overall Requirements, Criteria 1–5
- 10 CFR Part 50, Appendix B, Quality Assurance (QA) Program
- 10 CFR 50.49, Environmental Qualification of Electrical Equipment (EQ) Program
- 10 CFR 50.55a, Code Design, Inservice Inspection, and Inservice Testing (ISI/IST) Programs
- 10 CFR 50.65, Maintenance Rule requirements
- Reliability Assurance Program (RAP)
- 10 CFR 50.36, “Technical Specifications”
- Availability Controls for SSCs Subject to Regulatory Treatment of Nonsafety Systems (RTNSS)
- Initial Test Program (ITP)
- Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC)

This list of examples is not intended to be all inclusive. It is the responsibility of the technical reviewers to determine whether the information in the application, including the degree to which the applicant seeks to rely on such selected programs and guidance, demonstrates that all acceptance criteria have been met to support the safety finding for a particular SSC.

2. In accordance with 10 CFR 52.47(a)(8), (21), and (22), and 10 CFR 52.79(a)(17), (20), and (37), for DC or COL applications submitted under 10 CFR 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, “Resolution of Generic Safety Issues,” 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), for a DC application, and except paragraphs (f)(1)(xii), (f)(2)(ix), (f)(2)(xxv), and (f)(3)(v),for a COL application. 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. Materials Selection. The materials properties and the procedures used to minimize flaws and improve fracture toughness, as described by the applicant, should be reviewed and compared with the requirements of Subsection II.1 of this DSRS section. If a new material that is not used in prior licensed cases is used, the applicant's selection of materials should be reviewed and evaluated to establish its acceptability. Such an evaluation should be based on the acceptance criteria of Subsection II of this DSRS section.

4. Fracture Toughness. The fracture toughness properties of the low-pressure turbine disk or forged or welded rotor material, including specimen test data, where applicable, should be reviewed and compared with the requirements of Subsection II.2 of this DSRS section. The applicant is permitted to use any of the three alternative test methods identified in Subsection II.2 of this DSRS section to derive the fracture toughness of the rotor materials.

5. Preservice Inspection. The Preservice Inspection Program, including finish machining, ultrasonic inspection, surface inspection, visual inspection, and spin testing, should be reviewed and compared with the requirements of Subsection II.3 of this DSRS section. The extent to which the ultrasonic inspections and the acceptance criteria in the final safety analysis report (FSAR) agree with ASME Code Section III, NB-2530 for plate materials or NB-2540 for forgings, should be reviewed.

6. Turbine Rotor Design. The design and stress analysis procedures used for the low-pressure turbine disks or forged or welded rotors that should be reviewed include the following information.

   A. load combinations and allowable stresses at normal operating speed

   B. design overspeed and the basis for selecting design overspeed

   C. load combinations and allowable stresses at design overspeed

   The SAR data should be evaluated and compared with Subsection II.4 of this DSRS section.

7. Inservice Inspection. The inservice inspection and maintenance programs described by the applicant, including areas to be inspected, methods of inspection, frequency of inspection, and acceptance criteria, should be reviewed and compared with the criteria of Subsection II.5 of this DSRS section.

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 FSAR meets the acceptance criteria. DCs have referred to the FSAR as the design control document. 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, SRP Section 14.3 should be followed for the review of ITAAC. The ITAAC review 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 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 SER. The reviewer also states the bases for those conclusions.

> The applicant has met the requirements of GDC 4 of Appendix A to 10 CFR Part 50 with respect to the use of materials with acceptable fracture toughness and elevated temperature properties, adequate design, and the requirements for preservice and inservice inspections. The applicant has described a program for ensuring the integrity of low-pressure turbine rotors by the use of suitable materials of adequate fracture toughness, conservative design practices, and preservice and inservice inspections. These provisions provide reasonable assurance that the probability of failure with missile generation is low during normal operation, including transients up to design overspeed.

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 regulations in 10 CFR 52.17(a)(1)(xii), 10 CFR 52.47(a)(9), and 10 CFR 52.79(a)(41) establish requirements for applications for ESPs, DCs, and COLs, respectively. These regulations require the application to include an evaluation of the site (ESP), standard plant design (DC), or facility (COL) against the SRP revision in effect 6 months before the docket date of the application. While the SRP provides generic guidance, the staff developed the SRP guidance based on the staff's experience in reviewing applications for construction permits and operating licenses for large light-water nuclear power reactors. The proposed SMR designs, however, differ significantly from large light-water nuclear power plant designs.

In view of the differences between the designs of SMRs and the designs of large light-water power reactors, the Commission issued Staff Requirements Memorandum (SRM)-COMGBJ-10-0004/COMGEA-10-0001, "Use of Risk Insights To Enhance Safety Focus of Small Modular Reactor Reviews," dated August 31, 2010. In the SRM, the Commission directed the staff to develop risk-informed licensing review plans for each of the SMR design reviews, including plans for the associated preapplication activities. Accordingly, the staff has developed the content of the DSRS as an alternative method for evaluating a NuScale-specific application submitted pursuant to 10 CFR Part 52, and the staff has determined that each application may address the DSRS in lieu of addressing the SRP, with specified exceptions.

These exceptions include particular review areas in which the DSRS directs reviewers to consult the SRP and others in which the SRP is used for the review. If an applicant chooses to address the DSRS, the application should identify and describe all differences between the design features (DC and COL applications only), analytical techniques, and procedural measures proposed in an application and the guidance of the applicable DSRS section (or SRP section, as specified in the DSRS), and discuss how the proposed alternative provides an acceptable method of complying with the regulations that underlie the DSRS acceptance criteria.

The staff has accepted the content of the DSRS as an alternative method for evaluating whether an application complies with NRC regulations for NuScale SMR applications, provided that the application does not deviate significantly from the design and siting assumptions made by the NRC staff while preparing the DSRS. If the design or siting assumptions in a NuScale application deviate significantly from the design and siting assumptions the staff used in preparing the DSRS, the staff will use the more general guidance in the SRP, as specified in 10 CFR 52.17(a)(1)(xii), 10 CFR 52.47(a)(9), or 10 CFR 52.79(a)(41), depending on the type of application. Alternatively, the staff may supplement the DSRS section by adding appropriate criteria to address new design or siting assumptions.

VI. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and Missile Dynamic Effects Design Bases."

2. Regulatory Guide 1.115, "Protection Against Turbine Missiles," Revision 2, January 2012.

3. ASME Boiler and Pressure Vessel Code, Sections III, V, and XI, American Society of Mechanical Engineers.

4. ASTM E208, "Standard Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels," Annual Book of ASTM Standards, Part 31, American Society for Testing Materials.

5. ASTM A370, "Standard Test Methods and Definitions for Mechanical Testing of Steel Products," Annual Book of ASTM Standards, Parts 1, 2, 3, 4, or 31, American Society for Testing Materials.

6. J. A. Begley and W. A. Logsdon, "Correlation of Fracture Toughness and Charpy Properties for Rotor Steels," Scientific Paper 71-1E7-MSLRF-P1, Westinghouse Research Laboratories, Pittsburgh, PA, July 26, 1971.

7. F. J. Witt and T. R. Mager, "A Procedure For Determining Bounding Values On Fracture Toughness K_{Ic} At Any Temperature," ORNL-TM-3894, Oak Ridge National Laboratory, October 1972.

8. 10 CFR 50.49, "Environmental Qualification of Electric Equipment Important to Safety for Nuclear Power Plants."

9. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants."

10. NRC Staff Requirements Memorandum SRM-COMGBJ-10-0004/COMGEA-10-0001, “Use of Risk Insights To Enhance the Safety Focus of Small Modular Reactor Reviews,” August 31, 2010.

11. NUREG–0933, “Resolution of Generic Safety Issues.”

12. 10 CFR Part 52, “Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants.”

13. 10 CFR Part 50, Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.”