U.S. NUCLEAR REGULATORY COMMISSION

DESIGN-SPECIFIC REVIEW STANDARD FOR mPOWER™ iPWR DESIGN

3.6.2 DETERMINATION OF RUPTURE LOCATIONS AND DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING

REVIEW RESPONSIBILITIES

Primary- Organization responsible for Mechanical Engineering reviews

Secondary- None

I. AREAS OF REVIEW

10 CFR 50, Appendix A, General Design Criterion (GDC) 4 requires, in part, that structures, systems, and components (SSCs) important to safety be designed to accommodate the effects of postulated accidents including appropriate protection against the dynamic effects of postulated pipe ruptures.

All safety-related and risk-significant SSCs are subject to protection against the dynamic effects of postulated pipe ruptures. An SSC may be classified as:

(1) Safety-related risk-significant;
(2) Safety-related nonrisk-significant;
(3) Nonsafety-related risk-significant; or
(4) Nonsafety-related non risk significant.

If the SSC is safety-related or nonsafety-related and risk significant (Categories 1-3, above)(see Review Procedure 2 below), the review described in this Design-Specific Review Standard (DSRS) 3.6.2 is applied. Otherwise, those SSCs are not subject to protection against postulated pipe ruptures.

Information concerning break and crack location criteria and methods of analysis for evaluating the dynamic effects associated with postulated breaks and cracks in high- and moderate-energy fluid system piping, including "field run" piping inside and outside of containment, should be provided in the applicant's safety analysis report (SAR). This information is reviewed by the staff in accordance with this design specific review standard section to confirm that there is appropriate protection of SSCs components relied upon for safe reactor shutdown or to mitigate the consequences of a postulated pipe rupture.

The specific areas of review are as follows:

1. The criteria used to define break and crack locations and configurations.

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2. The analytical methods used to define the forcing functions, including the jet thrust reaction at the postulated pipe break or crack location and jet impingement loadings on adjacent safety-related SSCs.

3. The dynamic analysis methods used to verify the integrity and operability of mechanical components, component supports, and piping systems, including restraints and other protective devices, under postulated pipe rupture loads.

4. The criteria for defining pipe break and crack locations and configurations.

5. The criteria dealing with special features, such as augmented inservice inspection programs or the use of special protective devices such as pipe-whip restraints, including diagrams showing final configurations, locations, and orientations in relation to break locations in each piping system.

6. The acceptability of the analysis results, including jet thrust and impingement forcing functions, and pipe-whip dynamic effects.

7. The design adequacy of systems, components, and component supports to ensure that the intended design functions will not be impaired to an unacceptable level of integrity or operability as a result of pipe-whip or jet impingement loadings.

8. 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 Standard Review Plan (SRP) Section 14.3.

9. 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 staff reviews plant arrangements where separation of high-and moderate-energy systems is the method of protection for essential systems and components outside containment in accordance with SRP Section 3.6.1. The reviewer identifies high-and moderate-energy systems outside containment and the essential systems and components that must be protected from postulated pipe rupture in these high-and moderate-energy systems.

2. The staff reviews for adequacy the loading combinations and other design aspects of protective structures of compartments used to protect essential systems and components in accordance with DSRS Sections 3.8.3 and 3.8.4. The organization responsible for inservice inspection and related design provisions of high-and moderate-energy systems, including those associated with the break exclusion regions, reviews the information in accordance with SRP Section 5.2.4 and DSRS Section 6.6.

3. The staff reviews high-and moderate-energy systems inside containment and the essential systems and components that must be protected from postulated pipe rupture in these high-and moderate-energy systems, such as the emergency core cooling system, in accordance with DSRS Section 6.3.

4. The staff reviews the information described for environmental effects of pipe rupture, such as temperature, humidity, and spray-wetting, with respect to the functional performance of essential electrical equipment and instrumentation, in accordance with DSRS Section 3.11.

5. The staff reviews to verify that piping systems penetrating the containment barrier are designed with acceptable isolation features to maintain containment integrity in accordance with DSRS Section 6.2.4.

6. The staff reviews of the description and results of the probabilistic risk assessment are performed under SRP Section 19.0.

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

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 SSCs important to safety being designed to accommodate the effects of postulated accidents, including appropriate protection against the dynamic effects associated with postulated pipe rupture.

2. Title 10 of *Code of Federal Regulations* (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 design certification is built and will operate in accordance with the design certification, the provisions of the Atomic Energy Act (AEA), and the Commission's rules and 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 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) 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."

With respect to meeting the relevant requirements of GDC 4:

1. Postulated Pipe Rupture Locations Inside Containment. Acceptable criteria to define postulated pipe rupture locations and configurations inside containment are specified in Branch Technical position (BTP) 3-4.

2. Postulated Pipe Rupture Locations Outside Containment. Acceptable criteria to define postulated rupture locations and plant layout considerations for protection against postulated pipe ruptures outside containment are specified in BTP 3-4.

3. Methods of Analysis. Detailed acceptance criteria covering pipe-whip dynamic analysis, including determination of the forcing functions of jet thrust and jet impingement, are included in subsection III, "Review Procedures," of this DSRS section. The general bases and assumptions of the analysis are given in BTP 3-4, Subsection 2.C.

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 4 requires that nuclear power plant SSCs important to safety be designed to accommodate the effects of, and be compatible with, the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents. These SSCs shall be protected against certain dynamic effects, including pipe-whipping and discharging fluids. Such dynamic effects may be excluded from the design basis if the probability of pipe rupture is shown to be extremely low under conditions consistent with the design basis for piping.

2. Meeting the requirements of GDC 4 provides assurance that safety-related SSCs will be protected from dynamic effects of pipe-whip and discharging fluids that could result from expected environmental conditions, thereby ensuring the ability of these SSCs 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. Programmatic Requirements and Guidance - 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. Examples of those programs and associated guidance follows:

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

    B. Quality Assurance Program SRP Sections 17.3 and 17.5 (SRP 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 SRP 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), 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.

3. Review of the effects of postulated pipe ruptures on structures is a primary responsibility under DSRS Section 3.6.2. First it must be determined whether the equipment is needed to perform a safety-related function or a risk-significant function. DSRS Section 3.2.2 and SRP Section 19.3 as related to augmented design standards provide guidance on the identification of the SSCs subject to protection against postulated pipe ruptures. The safety functions of the SSCs in the various plant designs are essentially the same; however, the location and arrangement of the SSCs and the methods used may vary depending upon individual design. The reviewer must evaluate variations in plant designs as individual cases. SSCs that perform safety functions or which by virtue of their failure could affect a safety function adversely should be protected from the effects of postulated pipe ruptures.

4. The staff reviews the criteria for locations and configurations of breaks in high-energy piping and leakage cracks in moderate-energy piping.

   A. The applicant's criteria for determining break and crack locations are reviewed for conformance with the acceptance criteria referenced in Subsection II of this DSRS section.

      Exceptions taken by the applicant to the referenced pipe break location and configuration criteria must be identified and the basis clearly justified so that evaluation is possible. Deviations from approved criteria and the justifications provided are reviewed to determine acceptability.

   B. The following are reviewed to ensure that the pipe break criteria have been properly implemented:

      i. Sketches showing the locations of the resulting postulated pipe ruptures, including identification of longitudinal and circumferential breaks; structural barriers, if any; restraint locations; and the constrained directions in each restraint.

      ii. A summary of the data developed to select postulated break locations, including, for each point, the calculated stress intensity, the calculated cumulative usage factor, and the calculated primary plus secondary stress range as delineated in A. Giambusso letter of December 1972 and J.F. O'Leary letter of July 12, 1973 and BTP 3-4.

5. The staff reviews the analyses of pipe motion caused by the dynamic effects of postulated breaks. These analyses should show that pipe motions will not result in unacceptable impact upon, or overstress of, any safety-related or risk-significant SSCs to the extent that essential functions would be impaired or precluded. The analysis methods used should be adequate to determine the resulting loadings in terms of the kinetic energy or momentum induced by the impact of the whipping pipe, if unrestrained, upon a protective barrier or a component important to safety and to determine the dynamic response of the restraints induced by the impact and rebound, if any, of the ruptured pipe.

   An unrestrained whipping pipe should be considered capable of causing circumferential and longitudinal breaks, individually, in impacted pipes of smaller nominal pipe size, and of developing through-wall cracks in equal or larger nominal pipe sizes with thinner wall thickness, except where analytical or experimental, or both, data for the expected range of impact energies demonstrate the capability to withstand the impact without rupture.

The staff reviews the applicant's criteria, methods, and procedures used or proposed for dynamic analyses by comparing them to the following criteria. In addition, the analyses are reviewed in accordance with these criteria.

A. Dynamic Analysis Criteria. An analysis of the dynamic response of the pipe run or branch should be performed for each longitudinal and circumferential postulated piping break.

The loading condition of a pipe run or branch, prior to the postulated rupture, in terms of internal pressure, temperature, and inertial effects should be used in the evaluation for postulated breaks. For piping pressurized during operation at power, the initial condition should be the greater of the contained energy at hot standby or at 102% power.

In case of a circumferential rupture, the need for a pipe-whip dynamic analysis may be governed by considerations of the available driving energy.

Dynamic analysis methods used for calculating piping and restraint system responses to the jet thrust developed after the postulated rupture should adequately account for the following effects: (a) mass inertia and stiffness properties of the system, (b) impact and rebound, (c) elastic and inelastic deformation of piping and restraints, and (d) support boundary conditions.

If a crushable material, such as honeycomb, is used, the allowable capacity of crushable material should be limited to 80% of its rated energy dissipating capacity as determined by dynamic testing, at loading rates within $\pm$50% of the specified design loading rate. The rated energy dissipating capacity should be taken as not greater than the area under the load-deflection curve as illustrated in Figure 3.6.2-1. The portion of the curve in which the value of load vs. deflection has departed from the essentially horizontal portion should not be used. Pure tension members should be limited to an allowable strain of 50% of the ultimate uniform strain (X_m) (see Figure 3.6.2-2(a)). Alternatively, the allowable strain value may be determined as the value of strain associated with 50% of the ultimate uniform energy absorption capacity as determined by dynamic testing at loading rates within $\pm$50% of the specified design loading rate (see Figure 3.6.2-2(b)). The method of dynamic analysis used should be capable of determining the inelastic behavior of the piping and restraint system within these design limits.

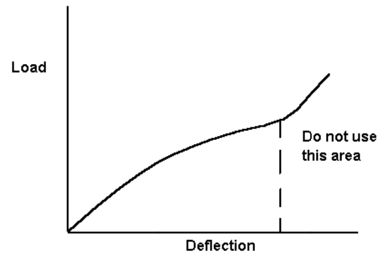

Figure 3.6.2-1 Rated energy dissipating capacity

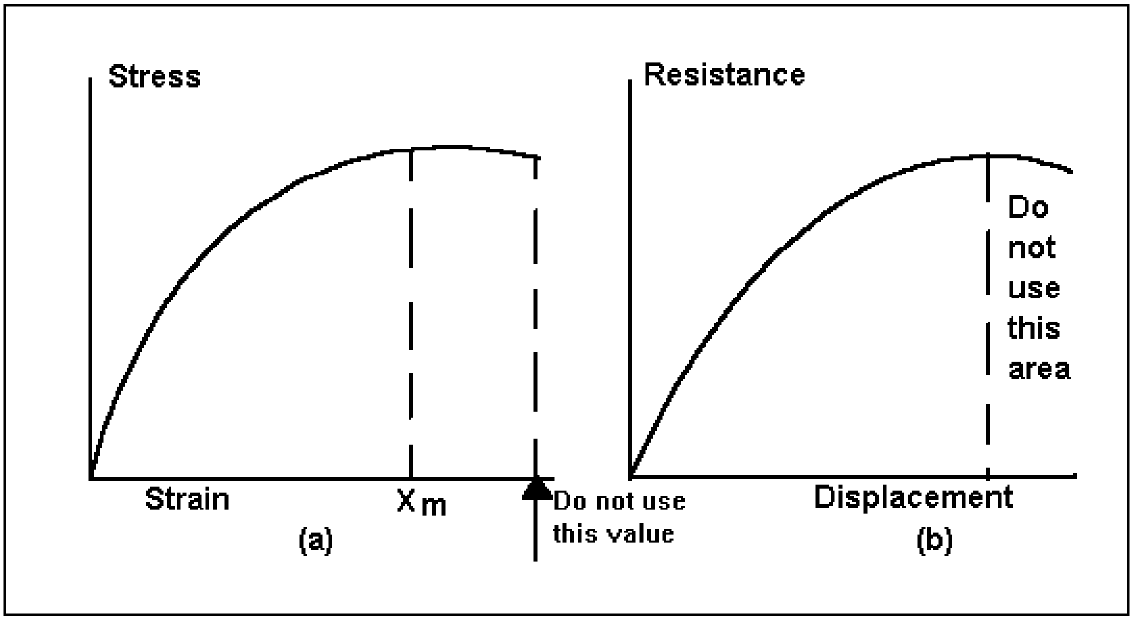

Figure 3.6.2-2 Limitations on pure tension members

A 10% increase of minimum specified design yield strength (S_y) may be used in the analysis to account for strain rate effects.

Dynamic analysis methods and procedures presented should include:

i. A representative mathematical model of the piping system or piping and restraint system.

ii. The analytical method of solution selected.

iii. Solutions for the most severe responses among the piping breaks analyzed.

iv. Solutions with demonstrable accuracy or justifiable conservatism.

The extent of mathematical modeling and analysis should be governed by the method of analysis selected.

B. Dynamic Analysis Models for Piping Systems. Analysis should be conducted of the postulated ruptured pipe and pipe-whip restraint system response to the fluid dynamic force.

Acceptable models for the analysis of American Society of Mechanical Engineers (ASME) Class 1, 2, and 3 piping systems and other nonsafety-class high-energy piping systems include the following:

i. Lumped Parameter Analysis Model: Lumped mass points are interconnected by springs to take into account inertia and stiffness properties of the system, and time histories of responses are computed by numerical integration, taking into account clearances at restraints and inelastic effects. In the calculation, the maximum possible initial clearance should be used to account for the most adverse dynamic effects of pipe-whip.

ii. Energy Balance Analysis Model: Kinetic energy generated during the first quarter cycle movement of the rupture pipe and imparted to the piping and restraint system through impact is converted into equivalent strain energy. In the calculation, the maximum possible initial clearance at restraints should be used to account for the most adverse dynamic effects of pipe-whip. Deformations of the pipe and the restraint should be compatible with the level of absorbed energy. The energy absorbed by the pipe deformation may be deducted from the total energy imparted to the system. For applications where pipe rebound may occur upon impact on the restraint, an amplification factor of 1.1 should be used to establish the magnitude of the forcing function in order to determine the maximum reaction force of the restraint beyond the first quarter cycle of response. Amplification factors other than 1.1 may be used if justified by more detailed dynamic analysis.

iii. Static Analysis Model: The jet thrust force is represented by a conservatively amplified static loading, and the ruptured system is analyzed statically. An amplification factor can be used to establish the magnitude of the forcing function. However, the factor should be based on a conservative value obtained by comparison with factors derived from detailed dynamic analyses performed on comparable systems.

iv. Other models may be considered if justified.

C. Dynamic Analysis Models for Jet Thrust Justified.

i. The time-dependent function representing the thrust force caused by jet flow from a postulated pipe break or crack should include the combined effects of the following: the thrust pulse resulting from the sudden pressure drop at the initial moment of pipe rupture; the thrust transient resulting from wave propagation and reflection; and the blowdown thrust resulting from buildup of the discharge flow rate, which may reach steady state if there is a fluid energy reservoir having sufficient capacity to develop a steady jet for a significant interval. Alternatively, a steady state jet thrust function may be used, as outlined in subsection III.2.C(iv), below.

ii. A rise time not exceeding one millisecond should be used for the initial pulse, unless a combined crack propagation time and break opening time greater than one millisecond can be substantiated by experimental data or analytical theory based on dynamic structural response.

iii. The time variation of the jet thrust forcing function should be related to the pressure, enthalpy, and volume of fluid in the upstream reservoir and the capability of the reservoir to supply a high energy flow stream to the break area for a significant interval. The shape of the transient function may be modified by considering the break area and the system flow conditions, the piping friction losses, the flow directional changes, and the application of flow-limiting devices.

iv. The jet thrust force may be represented by a steady state function if the energy balance model or the static model is used in the subsequent pipe motion analysis. In either case, a step function amplified as indicated in subsection III.2.B(ii) or III.2.B(iii), above, is acceptable. The function should have a magnitude not less than

$$T = KpA$$

where

p = system pressure prior to pipe break,
A = pipe break area, and
K = thrust coefficient.

To be acceptable, K values should not be less than 1.26 for steam, saturated water, or stream-water mixtures or 2.0 for subcooled, nonflashing water.

6. The following assumptions in modeling jet impingement forces are consistent with the guidance in the American National Standard Institute (ANSI)/American Nuclear Society (ANS) Standard 58.2-1988 currently used by industry. The ANSI/ANS 58.2 Standard has been accepted by the NRC. However, based on recent comments from the Advisory Committee on Reactor Safeguards (ACRS) (V. Ransom and G. Wallis), it appears that some assumptions related to jet expansion modeling in the ANSI/ANS 58.2 Standard may lead to nonconservative assessments of the jet impingement loads of postulated pipe breaks on neighboring SSCs. The NRC staff is currently assessing the technical adequacy of the information pertaining to dynamic analyses models for jet thrust force and jet impingement load that are included in this DSRS Section and ANSI/ANS 58.2. Pending completion of this effort, the NRC staff will review analyses of the jet impingement forces on a case by case basis. These analyses should show that jet impingement loadings on nearby safety related SSCs will not impair or preclude their essential functions. More details related to the potential non-conservatism of ANSI/ANS 58.2 Standard issue are discussed in Appendix A of this DSRS.

The assumptions are as follows:

A. The jet area expands uniformly at a half angle, not exceeding 10 degrees.

B. The impinging jet proceeds along a straight path.

C. The total impingement force acting on any cross-sectional area of the jet is time and distance invariant, with a total magnitude equivalent to the jet thrust force as defined in subsection III.2.C(iv), above.

D. The impingement force is uniformly distributed across the cross-sectional area of the jet, and only the portion intercepted by the target is considered.

E. The break opening may be assumed to be a circular orifice of cross-sectional flow area equal to the effective flow area of the break.

F. Jet expansion within a zone of five pipe diameters from the break location is acceptable if substantiated by a valid analysis or testing, i.e., Moody's expansion model (F.J. Moody). However, jet expansion is applicable to steam or water-steam mixtures only and should not be applied to cases of saturated water or subcooled water blowdown.

7. Analyses of pipe-break dynamic effects on mechanical components and supports should include the effects of both internal reactor pressure vessel asymmetric pressurization loads and expanded asymmetric compartment pressurization loads, as appropriate, as discussed for pressurized water reactor (PWR) primary systems in NUREG-0609.

8. 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, 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 safety evaluation report. The reviewer also states the bases for those conclusions.

The staff concludes that the applicant has postulated pipe ruptures appropriately, has designed SSCs to accommodate and protect against the associated dynamic effects, and, therefore, has met the relevant requirements of GDC 4. This conclusion is based on the following:

1. The applicant has appropriately identified/postulated proposed pipe rupture locations, and the design of piping restraints and measures to deal with the subsequent dynamic effects of pipe-whip and jet impingement provide adequate protection for the integrity and functionality of the safety-related SSCs.

2. The applicant's provisions for protection against dynamic effects associated with pipe ruptures of the reactor coolant pressure boundary (RCPB) inside containment and the resulting discharging fluid provide adequate assurance that design basis loss-of-coolant accidents will not be aggravated by sequential failures important to safety-related piping, and emergency core cooling system performance will not be degraded by such dynamic effects.

3. The applicant's proposed piping and restraint arrangement and applicable design considerations for high- and moderate-energy fluid systems inside and outside of containment, including the RCPB, provide adequate assurance that the safety-related or risk significant SSCs that are in close proximity to the postulated pipe rupture will be appropriately protected. The proposed design appropriately mitigates the consequences of pipe ruptures so that the reactor can be safely shut down and maintained in a safe shutdown condition in the event of a postulated rupture of a high- or moderate-energy piping system inside or outside of containment.

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^{TM}-specific design certification (DC), or combined license (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^{TM} 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^{TM} -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 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 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 4, "Environmental and Dynamic Effects Design Bases."

2. 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants."

3. Letter from A. Giambusso, December 1972, Attachment, "General Information Required for Consideration of the Effects of a Piping System Break Outside Containment," Appendix B to BTP 3-3.

4. Letter from J. F. O'Leary, July 12, 1973, and attachment entitled, "Criteria for Determination of Postulated Break and Leakage Locations in High and Moderate Energy Fluid Piping Systems Outside of Containment Structures," Appendix C to BTP 3-3.

5. BTP 3-3, "Protection Against Postulated Piping Failures in Fluid Systems Outside Containment."

6. American National Standards Institute/American Nuclear Society, "Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture," LaGrange, IL: American Nuclear Society, ANSI/ANS 58.2-1988, 1988 Edition.

7. Ransom, V., "Comments on GSI-191 Models for Debris Generation," September 14, 2004, ADAMS ML050830341, ML051320338.

8. Wallis, G., "The ANSI/ANS Standard 58.2-1988: Two Phase Jet Model," September 14, 2004, ADAMS ML050830344.

9. F. J. Moody, "Prediction of Blowdown and Jet Thrust Forces," ASME Paper 69 HT-31, August 6, 1969.

10. NUREG-0609, "Asymmetric Blowdown Loads on PWR Primary Systems" (resolution of Generic Task Action Plan A-2).

11. ASME, "Power Piping," B31.1-2004, New York, NY: American Society of Mechanical Engineers, 2004.

APPENDIX A

POTENTIAL NONCONSERVATISM OF ANSI/ANS 58.2 STANDARD'S JET MODELING

The objectives of this appendix are to describe potential non-conservatisms in ANSI/ANS 58.2 Standard's jet modeling. It also describes how the staff performs its review of this issue for new reactor design certification applications. As stated in Section III.3 of DSRS 3.6.2, the staff is reviewing this issue on a case by case basis.

Discussion of Issues

Prior to 2008, the nuclear industry commonly used the ANSI/ANS Standard 58.2-1988 (Reference 6) for estimating jet plume geometries and impingement loads based on the fluid conditions internal and external to the piping. However, following interactions with the ACRS on the jet models described in ANSI/ANS 58.2 by ACRS the staff determined that there were potential non-conservatisms in these models with respect to the (a) strength, (b) zone of influence, and (c) space and time-varying nature of the loading effects of postulated pipe ruptures on neighboring structures, systems, and components (SSCs).

Blast Waves

In the event of a high pressure pipe rupture, the first significant fluid load on surrounding SSCs would be induced by a blast wave. A spherically expanding blast wave is reasonably approximated to be a short duration transient and analyzed independently of any subsequent jet formation. However, the expansion of blast waves in an enclosed space is not purely spherical, and reflections and amplifications may need to also be accounted for. Blast waves are not considered in the ANSI/ANS 58.2 Standard for evaluating the dynamic effects associated with the postulated pipe rupture.

Jet Plume Expansion and Zone of Influence

In the characterization of supersonic jets given by the ANSI/ANS 58.2 Standard, some physically incorrect assumptions underlie the approximating methodology. The model of the supersonic jet itself is given in Figures C-1 and C-2 of the ANSI/ANS 58.2 Standard. The standard assumes that a jet issuing from a high pressure pipe break will always spread with a fixed 45 degree angle up to an asymptotic plane and subsequently spread at a constant 10 degree angle. The characteristics of the jet, however, are not universal. Initial jet spreading rates are highly dependent on the ratio of the total conditions of the source flow to the ambient conditions. Subsequent spreading rates depend, at a given axial position, on the ratio of the static pressure in the outermost jet flow region to the ambient static pressure.

In the ANSI/ANS 58.2 Standard, the asymptotic plane is described as the point at which the jet begins to interact with the surrounding environment. This has been interpreted to mean that the jet is subsonic downstream of the asymptotic plane. Experts have demonstrated (References 7 and 8) that, supersonic or not, the jet is highly dependent on the conditions in the surrounding medium and, at a given distance from the issuing break, will spread or contract at a rate depending on the local jet conditions relative to the surrounding fluid pressure.

Supersonic jet behavior can persist over distances from the break that are far longer than those estimated by the standard, extending the zone of influence of the jet and the number of SSCs that could be impacted by a supersonic jet. For example, tests in the Seimens-KWU facility in Karlstein, Germany showed that significant damage from steam jets can occur as far as 25 pipe diameters from a rupture.[1]

Distribution of Pressure within the Jet Plume

The ANSI/ANS 58.2 Standard's formulas for the spatial distribution of pressure through a jet cross-section are incorrect for certain locations. The ANSI/ANS 58.2 Standard's assumes that the pressure within a jet cross section is maximum at the jet centerline; far from the break, however, the pressure variation is quite different, often peaking near the outer edges of the jet. Applying the ANSI/ANS 58.2 Standard's formulas could lead to non-conservative pressures away from the jet centerline.

Jet Dynamic Loading including Potential Feedback Amplification and Resonance Effects

Furthermore, unsteadiness in free jets, especially supersonic jets, tends to propagate in the shear layer and induce time-varying oscillatory loads on obstacles in the flow path. Pressures and densities vary nonmonotonically with distance along the axis of a typical supersonic jet, feeding and interacting with shear layer unsteadiness. In addition, for a typical supersonic jet, interaction with obstructions will lead to backward-propagating transient shock and expansion waves that will cause further unsteadiness in downstream shear layers.

In some cases, synchronization of the transient waves with the shear layer vortices emanating from the jet break can lead to significant amplification of the jet pressures and forces (a form of resonance) that is not considered in the ANSI/ANS 58.2 standard. Should the dynamic response of the neighboring structure also synchronize with the jet loading time scales, further amplification of the loading can occur, including that at the source of the jet.[2] Some general observations by past investigators are that strong discrete frequency loads are observed when the impingement surface is within 10 diameters of the jet opening, and that when resonance within the jet occurs, significant amplification of impingement loads can result[3].

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[1] Knowledge Base for Emergency Core Cooling System Recirculation Reliability, February 1996, Issued by the NEA/CSNI, http://www.nea.fr/html/nsd/docs/1995/csni-r1995-11.pdf.

[2] These feedback phenomena have been described for aircraft that use jets to lift off and land vertically (see, for example Ho, C.M., and Nosseir, N.S., Dynamics of an impinging jet. Part 1, The feedback phenomenon, Journal of Fluid Mechanics, Vol. 105, pp.119-142, 1981).

[3] For example, Ho and Nosseir show a factor of 2-3 increase in pressure fluctuations at the frequency of the resonance, but this has not been shown to be a limiting value

Implications for NRC Staff Reviews

Given that alternate standards are not yet available to address the topics described above, the staff reviews each new reactor design certification application concerning its dynamic jet load modeling on a case by case basis.

As described in this DSRS section, the applicant develops a methodology to address the dynamic effects of postulated high energy line breaks and submits it as part of the application. The staff reviews each design certification document (DCD) to verify the adequacy of the modeling for dynamic jet loads including the blast wave effects for their specific piping system design condition (including source and exterior fluid temperature and pressure, and pipe size) and plant design configuration (including spatial interactions between the postulated pipe breaks and neighboring SSCs).

In previous reviews, applicants did not fully address the potential non-conservatisms described above, necessitating requests for additional information (RAIs). The staff asked questions related to the potential non-conservatisms described above, including omitting blast wave effects, assuming uniform jet plume expansion, simplifying the spatial pressure distribution within the jet plume, and ignoring the jet dynamic loading and structural dynamic response (e.g., potential feedback amplification of blowdown forces and jet resonance effects). Each applicant was requested to explain what analysis and/or testing has been used to substantiate its the jet expansion and jet loading modeling for their specific piping system design conditions and plant design configuration as described in the respective DCD. Most of the information on how other applicants addressed the concerns is proprietary. High level summaries, however, are in the DCDs and the staff's safety evaluation reports (SERs) and may be used for guidance on future applications.

Staff Review Process

The following paragraphs summarize the staff's review process for assessing the adequacy of the applicants' dynamic jet modeling, including blast wave effects, for new reactor design certification applications.

The staff assesses the applicant's procedures to be used to analyze all loads induced on neighboring SSCs or jet shields by postulated pipe ruptures, along with the dynamic structural analyses of the SSCs. These loads include blast waves emanating from sudden pipe breaks, as well as the static and the dynamic oscillatory jet impingement forces on the SSCs and/or shields throughout the blowdown process (until all source fluid is exhausted). The staff reviews the applicant's criteria for when and how these loads need to be considered and determined to be conservative. For example, the staff has accepted consideration of oscillatory jet loading for SSCs within 10 pipe diameters of two-phase jets and 25 pipe diameters of steam jets. The state of a jet plume fluid often changes during a blowdown process as the pressure and temperature ratios between source and exterior fluid changes. The jet plume geometry also changes during blowdown, with a wide expansion at high pressure ratios (source pressure/external pressure) and a smaller expansion at lower pressure ratios. The staff determines that the applicant's proposed methodologies conservatively capture all SSCs that might be impacted by the varying jet plume areas and fluid states throughout blowdown.

The staff also determines that the applicant's methodologies used to assess the loads capture the worst-case static and oscillatory loads that may occur for all possible loading directions, including situations in which instabilities and coupling to acoustic wave reflections lead to amplifications of oscillatory loads, particularly in impinging jets close to nearby SSCs. These amplifications occur at discrete frequencies associated with the diameter of the pipe break, the jet flow velocity, and the distance between the jet source and impingement surface.

The staff determines that the applicant's methodologies capture conservatively the effects of any reflections of both blast waves and jets within enclosed regions. The blast wave and jet impingement loads may be based on upper bounds inferred from measurements, from detailed simulations such as computational fluid dynamics , or from worst-case assessments of the source conditions. The staff determines the suitability of the selected method for the proposed design. The staff also reviews the application to ensure that the applicant has established conservatism through convergence studies (when numerical methods are used), comparison to rigorous measurement data, or by bounding approaches based on fundamental hydrodynamic and thermodynamic laws.

The applicant's structural analyses should include both static and dynamic analyses and be of sufficient fidelity to capture the motion and stresses within SSCs in the proposed plant design. Dynamic analyses of SSCs may generally use a structural damping coefficient of no greater than 1 percent, with higher damping specifications substantiated by rigorous testing data. The staff also reviews the application to verify that the applicant's procedure for addressing the uncertainties in the frequencies of structural resonances, as well as within oscillatory loads, is specified and evaluated to demonstrate that worst-case coupling between loads and structural response is assessed. Any bias errors in the loading and structural evaluation procedures must be properly accounted for. Moreover, the staff determines that the applicant's resulting structure responses for all the applicable SSCs are within the allowable stress limit specified in acceptable codes and standards to which the applicant has committed. Finally, the staff reviews representative examples provided by the applicant which demonstrates the applicability of the overall end-to-end assessment procedures to the proposed design.

The staff intends to provide general guidance for modeling dynamic jet effects in the future. Developing the supporting data requires further research and testing; therefore, for the near term, the staff will continue to review on a case-by-case basis as described above.