U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

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

Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion (GDC) 4, "Environmental and Dynamic Effects Design Bases," 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.

Safety-related SSCs and regulatory treatment of nonsafety system (RTNSS) Category B (RTNSS "B") SSCs , as defined and reviewed in Standard Review Plan (SRP) Section 19.3, "Regulatory Treatment of Nonsafety Systems for Passive Advanced Light Water Reactors," and discussed in Review Procedure 2 below, are reviewed in this SRP section. Nonsafety-related SSCs that are not RTNSS "B" are not required to have protection against postulated pipe ruptures under the scope of this SRP section. 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 SRP 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.

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 implementation of 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 SRP 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 SRP 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.

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 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, "Plant Design for Protection Against Postulated Piping Failures in Fluid Systems." 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. If an applicant proposes to use leak-before-break technology to exclude the dynamic effects of postulated pipe ruptures from the design basis of plant SSCs, the staff will review the applicant's design and analyses in accordance with SRP Section 3.6.3, "Leak-Before-Break Evaluation Procedures."

3. 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 SRP Sections 3.8.3, "Concrete and Steel Internal Structures of Steel or Concrete Containments," and 3.8.4, "Other Seismic Category I Structures." 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 Sections 5.2.4, "Reactor Coolant Pressure Boundary Inservice Inspection and Testing," and 6.6, "Inservice Inspection and Testing of Class 2 and 3 Components."

4. 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 SRP Section 6.3, "Emergency Core Cooling System."

5. 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 SRP Section 3.11, "Environmental Qualification of Mechanical and Electrical Equipment."

6. The staff reviews the information described for containment isolation features to verify that piping systems penetrating the containment barrier are designed with acceptable isolation features to maintain containment integrity in accordance with SRP Section 6.2.4, "Containment Isolation System."

7. The identification and evaluation of nonsafety-related risk-significant SSCs is reviewed in accordance with the guidance in SRP Chapters 17, "Quality Assurance," and 19, "Severe Accidents," and DC/COL-ISG-018 concerning quality assurance (QA) and reliability assurance.

The specific acceptance criteria and review procedures are contained in the referenced SRP 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 and environmental 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 DC is built and will operate in accordance with the DC, the provisions of the Atomic Energy Act (AEA), and the Commission's rules and regulations;

3. Regulations in 10 CFR 52.80(a), "Contents of Applications; Additional Technical Information," which require 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.

SRP Acceptance Criteria

Specific SRP acceptance criteria acceptable to meet the relevant requirements of the NRC regulations identified above are as follows for review described in this SRP section. The SRP is not a substitute for the NRC's regulations, and compliance with it is not required. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the SRP acceptance criteria and evaluate how the proposed alternatives to the SRP acceptance criteria provide acceptable methods of compliance with the NRC regulations.

With respect to meeting the relevant requirements of GDC 4:

1. Postulated Pipe Rupture Locations Inside Containment. Acceptable criteria to identify postulated pipe rupture locations and configurations inside containment are specified in Branch Technical position (BTP) 3-4, "Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment."

2. Postulated Pipe Rupture Locations Outside Containment. Acceptable criteria to identify 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 SRP section.

Technical Rationale

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

1. Compliance with GDC 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 when analyses reviewed and approved by the Commission demonstreate that 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 and the RTNSS "B" 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 SRP 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), 10 CFR 52.47(a)(21), and 10 CFR 52.47(a) (22), and 10 CFR 52.79(a)(17), 10 CFR 52.79(a)(20) and 10 CFR 52.79(a)(37), for DC or COL applications submitted under 10 CFR Part 52, , "Licenses, Certifications, and Approvals for Nuclear Power Plants," 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 10 CFR 50.34(f)(1)(xii), 10 CFR 50.34(f)(2)(ix), and 10 CFR 50.34(f)(3)(v) for a DC application, and except paragraphs 10 CFR 50.34 (f)(1)(xii), 10 CFR 50.34(f)(2)(ix), 10 CFR 50.34(f)(2)(xxv), and 10 CFR 50.34 (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.

2. Review of the effects of postulated pipe ruptures on structures is a primary responsibility under SRP Section 3.6.2, “Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping.” First it must be determined whether the equipment is needed to perform a safety-related function or a risk-significant function. SRP Section 3.2.2, “System Quality Group Classification,” 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-related functions or the risk-significant 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.

3. 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 SRP section.

      i. 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 BTP 3-4.

4. 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 RTNSS “B” 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 percent 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 percent of its rated energy dissipating capacity as determined by dynamic testing, at loading rates within $\pm$50 percent 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. Pure tension members should be limited to an allowable strain of 50 percent 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 percent of the ultimate uniform energy absorption capacity as determined by dynamic testing at loading rates within $\pm$50 percent 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.

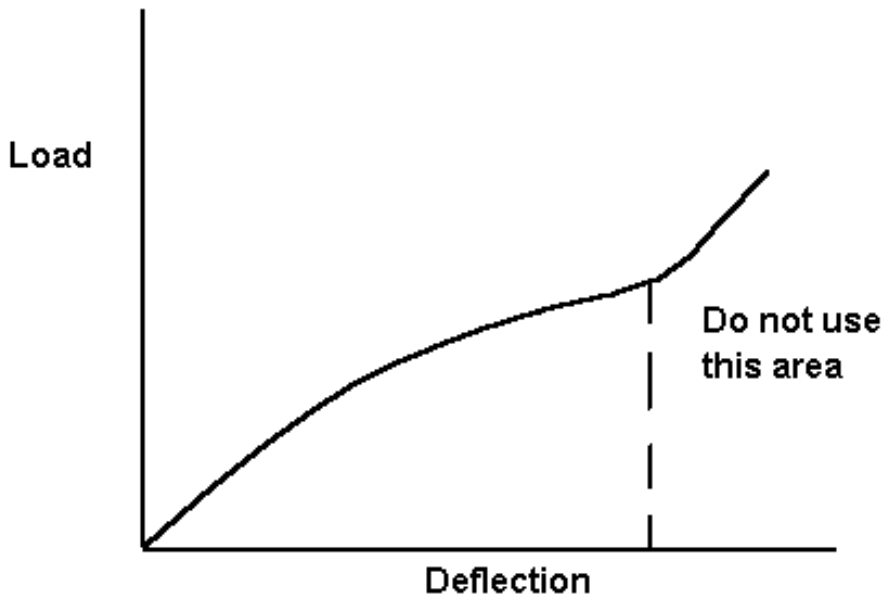

Figure 3.6.2-1 Rated energy dissipating capacity

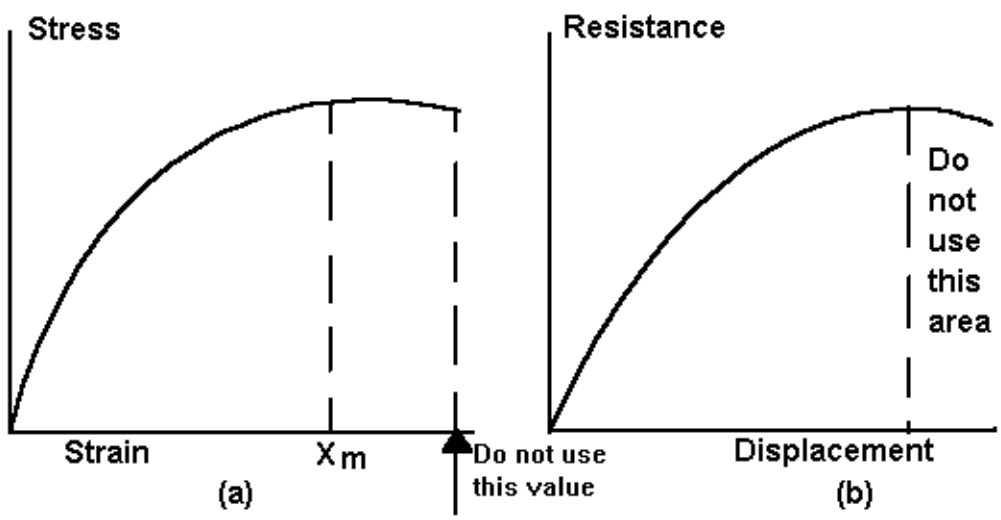

Figure 3.6.2-2 Limitations on pure tension members

A 10 percent 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 dynamic analytical method 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 dynamic 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 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.5.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.5.B(ii) or III.5.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 steam-water mixtures or 2.0 for subcooled, nonflashing water.

5. The following assumptions in modeling jet impingement forces are consistent, in part, 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), 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 SRP 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 nonconservatism of ANSI/ANS 58.2 Standard issue are discussed in Appendix A of this SRP.

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.5.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 (Moody, 1969). 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.

6. 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, “Asymmetric Blowdown Loads on PWR Primary Systems.”

7. 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 SER. 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 SRP 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 SRP section in performing safety evaluations of DC applications, COL applications, and license applications submitted by applicants pursuant to 10 CFR Part 50, or 10 CFR Part 52. The staff will use the method described herein to evaluate conformance with Commission regulations.

NRC regulations state, in part, that the DC, COL, or ESP application must contain an evaluation (of the design, facility, or site, respectively) against the SRP revision in effect 6 months before the docket date of the application. The content of this SRP section has been accepted as an alternative method for complying with those regulations (10 CFR 52.47(a)(9), 10 CFR 52.79(a)(41), or 10 CFR 52.17(a)(1)(xii), as applicable) as long as the DCD/FSAR does not deviate significantly from the design/facility/site assumptions made by the NRC staff while preparing this SRP section. The plants for which construction permit applications were tendered before July 1, 1973, may use design criteria for protection against postulated pipe ruptures outside containment as described in the A. Giambosso letter of December 1972 (Appendix B to BTP 3-3). The J. F. O'Leary letter of July 12, 1973 (BTP 3-3, Appendix C) emphasizes design criteria for protection against postulated pipe ruptures outside containment via plant arrangement and layouts utilizing the concept of physical separation to the extent practical for those plants for which construction permit applications were tendered after July 1, 1973, and before July 1, 1975.

For a DC application, the application must identify and describe all differences between the standard plant design and this SRP section, and discuss how the proposed alternative provides an acceptable method of complying with the regulations that underlie the SRP acceptance criteria. If the design assumptions in the DC application deviate significantly from the SRP, the staff will use the SRP as specified in 10 CFR 52.47(a)(9). Alternatively, the staff may supplement the SRP section by adding appropriate criteria 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 or 10 CFR 52.17(a)(1)(xii) for ESP applications.

VI. REFERENCES

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

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

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

4. Ransom, V., "Comments on GSI-191 Models for Debris Generation," September 14, 2004, ADAMS Accession No. ML050830341, and No. ML051320338.

5. U.S. *Code of Federal Regulations*, "Domestic Licensing of Production and Utilization," Part 50, Chapter 1, Title 10, "Energy," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion 4, "Environmental and Dynamic Effects Design Bases."

6. U.S. *Code Of Federal Regulations*, "Reactor Site Criteria," Part 100, Chapter 1, Title 10, "Energy," Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants."

7. U.S. Nuclear Regulatory Commission, "Protection against Postulated Piping Failures in Fluid Systems Outside Containment," BTP 3-3.

8. U.S. Nuclear Regulatory Commission, “Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment,” BTP 3-4.

9. U.S. Nuclear Regulatory Commission, “Asymmetric Blowdown Loads on PWR Primary Systems,” (resolution of Generic Task Action Plan A-2), NUREG-0609.

10. U.S. Nuclear Regulatory Commission, “Monitoring the Effectiveness of Maintenance at Nuclear Power Plants,” Regulatory Guide 1.160, ADAMS Accession No. ML13210A432

11. Wallis, G., “The ANSI/ANS Standard 58.2-1988: Two Phase Jet Model,” September 15, 2004, ADAMS Accession No. ML050830344.

APPENDIX A

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

The objectives of this appendix are to describe potential nonconservatisms in American National Standard Institute (ANSI)/American Nuclear Society (ANS) 58.2 Standard's jet modeling (Ref. 1). It also describes how the staff performs its review of this issue for new reactor design certification applications. As stated in Section III.6 of Standard Review Plan (SRP) 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 for estimating jet plume geometries and impingement loads based on the fluid conditions internal and external to the piping. However, following interactions with the Advisory Committee on Reactor Safeguards (ACRS) on the jet models described in ANSI/ANS 58.2 by ACRS the staff determined that there were potential nonconservatisms 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. As discussed in References 2 and 3, 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

Appendix C and Appendix D of ANSI/ANS Standard 58.2 describe the assumptions used for defining the special pressure distribution within a jet cross section for various jet conditions. It assumes a uniform pressure distribution over the cross section of a nonexpanding jet. For an expanding jet, the standard assumes variable (not uniform) pressure over the cross section of the expanding jet. In developing the formulas for the spatial distribution of pressure through an expanding jet cross section, the standard generally assumes that the pressure within a jet cross section is maximum at the jet centerline. However, this assumption is valid near the break, but far from the break, the pressure variation is quite different, often peaking near the outer edges of the jet. Therefore, applying the standard's formulas could lead to nonconservative 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.

Moreover, 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].

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.

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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.

As described in this SRP 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 of new reactor design certification applications, the staff noted that 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 nonconservatisms 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 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 oscillatory loads need to be considered and determined to be conservative. For example, the staff has accepted the oscillatory jet loading to be considered for SSCs within 10 pipe diameters of two-phase jets and 25 pipe diameters of steam jets. Beyond these distances, the oscillatory jet force is negligible and therefore, does not need to be considered by the applicant. 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 are 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.

References

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

2. Ransom, V., "Comments on GSI-191 Models for Debris Generation," September 14, 2004, ADAMS Accession No. ML050830341, and No. ML051320338

3. Wallis, G., "The ANSI/ANS Standard 58.2-1988: Two Phase Jet Model," September 14, 2004, ADAMS Accession No. ML050830344.

SRP Section 3.6.2
Description of Changes

Section 3.6.2, "Determination Of Rupture Locations And Dynamic Effects Associated With The Postulated Rupture Of Piping"

This section has been updated to reflect the applicability of regulatory treatment of non-safety systems (RTNSS) category "B" structures, systems, and components in the review of the dynamic effects associated with postulated pipe rupture, consistent with SRP Section 19.3, and to address potential non-conservatism of ANSI/ANS 58.2 Standard's Jet Modeling.

In addition to the changes itemized below, editorial changes were made throughout for clarity, consistency, and applicability. Changes incorporated into Revision 3 include:

I. AREAS OF REVIEW

- Applicability of this SRP section to various classifications of SSCs was clarified.
- A pointer to SRP Chapters 17 and 19 for the review of probabilistic risk assessment and quality was added for clarity.

II. ACCEPTANCE CRITERIA

- Details were added to the requirements of GDC 4 as it pertains to the effects of postulated accidents including environmental effects.
- Technical Rationale was updated to include RTNSS-B SSCs.

III. REVIEW PROCEDURES

- Procedures addressing the requirements of 10 CFR 52.47(a), 52.79(a), and 50.34(f) were added for clarity, and to address operating experience requirements.
- Procedures to determine review responsibilities as identified in the reviews in SRP Sections 3.2.2 and 19.3 were added, including changes to address the review of risk-significant SSCs.
- A reference to the Appendix A discussion on potential non-conservatism of ANSI/ANS 58.2 was added.

IV. EVALUATION FINDINGS

- Section was updated to address the review of risk-significant SSCs.

V. IMPLEMENTATION

- Section was updated to more directly address implementation for DC and COL applications.
- A minor correction was made to the applicability of this SRP section based on the docketing date of the application.

VII. REFERENCES

- References were updated in concert with changes referenced above.

APPENDIX A

- A new appendix was added to elaborate on a potential non-conservatism of ANSI/ANS 58.2 Standard's Jet Modeling, which had previously been mentioned in the SRP.