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

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.

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 Standard Review Plan (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:

Revision 2 - March 2007

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 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 structures, systems, and components (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. 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.

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 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 Sections 5.2.4 and 6.6.

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.

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.

6. 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 SRP Section 6.2.4.

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 dynamic effects associated with postulated pipe rupture.

2. 10 CFR 52.47(b)(1), which requires that a DC application contain the proposed inspections, tests, analyses, and acceptance criteria (ITAAC) that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a plant that incorporates the design certification is built and will operate in accordance with the design certification, the provisions of the Atomic Energy Act, and the NRC's regulations;

3. 10 CFR 52.80(a), which requires that a COL application contain the proposed inspections, tests, and analyses, including those applicable to emergency planning, that the licensee shall perform, and the acceptance criteria that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, the facility has been constructed and will operate in conformity with the combined license, the provisions of the Atomic Energy Act, and the NRC's regulations.

SRP Acceptance Criteria

Specific SRP acceptance criteria acceptable to meet the relevant requirements of the NRC's regulations identified above are as follows for the 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 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 SRP 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 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 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 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. The staff reviews the criteria for locations and configurations of breaks in high-energy piping and leakage cracks in moderate-energy piping.

   A. At the Construction Permit (CP) stage, 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.

      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. At the OL stage, 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.

2. 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 SSCs important to safety 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.

At the CP stage, the staff reviews the applicant's criteria, methods, and procedures used or proposed for dynamic analyses by comparing them to the following criteria. At the OL stage, 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 ±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 ±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.

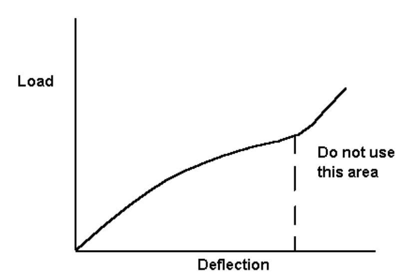

Figure 3.6.2-1 Rated energy dissipating capacity

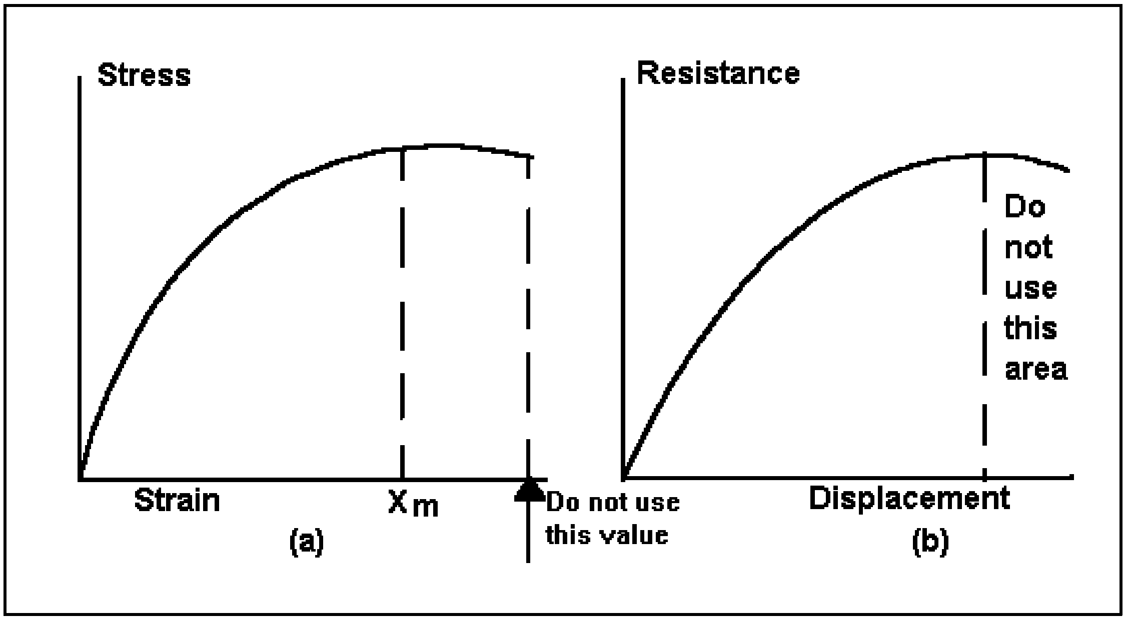

Figure 3.6.2-2 Limitations on pure tension members

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 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.

3. 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 58.2-1998 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 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.

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.

4. 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..

5. For review of a DC application, the reviewer should follow the above procedures to verify that the design, including requirements and restrictions (e.g., interface requirements and site parameters), set forth in the final safety analysis report (FSAR) meets the acceptance criteria. 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 SSCs important to safety 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 and license applications submitted by applicants pursuant to 10 CFR Part 50 or 10 CFR Part 52. Except when the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the staff will use the method described herein to evaluate conformance with Commission regulations.

The provisions of this SRP section apply to reviews of applications submitted six months or more after the date of issuance of this SRP section, unless superseded by a later revision.

For protection against postulated pipe ruptures outside containment, all applicants should demonstrate conformance to criteria as described in BTP 3-4. 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. The J.F. O'Leary letter of July 12, 1973 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.

VI. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 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. Branch Technical Position 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.

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

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

10. American Society of Mechanical Engineers, “Power Piping,” B31.1-2004, New York, NY: American Society of Mechanical Engineers, 2004.
