U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

BRANCH TECHNICAL POSITION 3-4

POSTULATED RUPTURE LOCATIONS IN FLUID SYSTEM PIPING INSIDE AND OUTSIDE CONTAINMENT

REVIEW RESPONSIBILITIES

Primary - Organization responsible for Mechanical Engineering reviews

Secondary - None

A. BACKGROUND

This position on pipe rupture postulation is intended to comply with the requirements of Title 10 of *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 Criteria (GDC) 4, for the design of nuclear power plant structures, systems, and components (SSCs). It is recognized that pipe rupture is a rare event that may only occur under unanticipated conditions, such as those that might be caused by possible design, construction, or operation errors; unanticipated loads; or unanticipated corrosive environments. The staff's observation of actual piping failures has indicated that they generally occur at high stress and fatigue locations, such as at the terminal ends of a piping system at its connection to the nozzles of a component. The criteria of this branch technical position (BTP) are intended to utilize the available piping design information by postulating pipe ruptures at locations having relatively higher potential for failure, such that an adequate and practical level of protection may be achieved. Subject to certain limitations as delineated in Standard Review Plan (SRP) Section 3.6.3, GDC 4 allows dynamic effects associated with postulated pipe ruptures to be excluded from the design basis when analyses reviewed and approved by the Commission

demonstrate that the probability of fluid system piping rupture is extremely low under design basis conditions. These analyses are commonly referred to as "leak-before-break" (LBB) analyses. The application of LBB to piping system design is reviewed in accordance with --- SRP Section 3.6.3.

In 10 CFR Part 50, Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," the staff approves the elimination of the operating basis earthquake (OBE) in the design process of a plant when the OBE ground motion is less than or equal to one-third of the safe shutdown earthquake ground motion.

Furthermore, no replacement earthquake loading should be used to establish the postulated pipe rupture and leakage crack locations once the OBE is eliminated from the design and that the criteria for postulating pipe ruptures and leakage cracks in high- and moderate-energy piping systems should be based on factors attributed only to normal and operational transients. However, for establishing pipe breaks and leakage cracks due to fatigue effects, calculation of the cumulative usage factor should continue to include seismic cyclic effects.

B. BRANCH TECHNICAL POSITION

1. <u>High-Energy Fluid Systems Piping</u>

(i) Fluid Systems Separated From Essential Systems and Components. For the purpose of satisfying the separation provisions of plant arrangement as specified in B.1.a of BTP 3-3, a review of the piping layout and plant arrangement drawings should clearly show that the effects of postulated piping breaks at any location are isolated or are physically remote from essential systems and components.[1] At the designer's option, break locations as determined from 2A(iii) of this BTP may be assumed for this purpose.

(ii) Fluid System Piping in Containment Penetration Areas. Breaks and cracks need not be postulated in those portions of piping from containment wall to and including the inboard or outboard isolation valves, provided that they meet the design criteria of the American Society of Mechanical Engineers (ASME) Boiler and *Pressure Vessel Code* (Code), Section III, Subarticle NE-1120, and the following additional design criteria:

(1) The following design stress and fatigue limits should not be exceeded:

For ASME Code, Section III, Class 1 Piping

(a) The maximum stress range between any two load sets (including the zero load set) should not exceed 2.4S_m and should be calculated□[2] by Eq. (10) in ASME Code, Section III, NB-3653.

If the calculated maximum stress range of Eq. (10) exceeds 2.4S_m, the stress ranges calculated by both Eq. (12) and Eq. (13)

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[1] Essential systems and components are those necessary to shut down the reactor and mitigate the consequences of a postulated pipe rupture without offsite power.

[2] The maximum stress range should be calculated for those loads and conditions for which Level A and Level B stress limits have been specified in the design specification (including the operating basis earthquake, if applicable).

in Paragraph ASME Code, Section III, NB-3653 should meet the limit of $2.4S_m$.

(b) The cumulative usage factor (CUF) should be less than 0.1. The CUF limit of 0.1 can be increased to 0.4 when the effects of environmental assisted fatigue (EAF) are considered in the piping design.

(c) The maximum stress, as calculated by Eq. (9) in ASME Code, Section III, NB-3652 under the loadings resulting from a postulated piping failure beyond these portions of piping, should not exceed $2.25S_m$ and $1.8S_y$, except that following a failure outside containment, the pipe between the outboard isolation valve and the first restraint may be permitted higher stresses provided that a plastic hinge is not formed and operability of the valves with such stresses is ensured in accordance with the criteria specified in SRP Section 3.9.3. Primary loads considered in Eq. (9) include those that are deflection-limited by whip restraints.

For ASME Code, Section III, Class 2 Piping

(d) The maximum stress ranges as calculated by the sum of Eqs. (9) and (10) in Paragraph NC-3653, ASME Code, Section III, considering those loads and conditions thereof for which level A and level B stress limits have been specified in the system's design specification (i.e., sustained loads, occasional loads, and thermal expansion), including an OBE event (if applicable), should not exceed $0.8(1.8\ S_h + S_A)$. The S_h and S_A are allowable stresses at maximum (hot) temperature and allowable stress range for thermal expansion, respectively, as defined in Article NC-3600 of the ASME Code, Section III.

(e) The maximum stress, as calculated by ASME Code, Section III, NC-3653, paragraph Eq. (9) under the loadings resulting from a postulated piping failure of fluid system piping beyond these portions of piping, should not exceed $2.25S_h$ and $1.8S_y$.

Primary loads include those which are deflection-limited by whip restraints. The exceptions permitted in Subsection (c) above may also be applied, provided that when the piping between the outboard isolation valve and the restraint is constructed in accordance with the Power Piping Code ANSI B31.1, the piping should either be of seamless construction with full radiography of all circumferential welds or all longitudinal and circumferential welds should be fully radiographed.

(2) Welded attachments, for pipe supports or other purposes, to these portions of piping should be avoided, except where detailed stress analyses, or tests, are performed to demonstrate compliance with the limits of 2.A(ii)(1).

(3) The number of circumferential and longitudinal piping welds and branch connections should be minimized. Where guard pipes are used, the enclosed portion of fluid system piping should be of a seamless construction and without circumferential welds unless specific access provisions are made to permit inservice volumetric examination of the longitudinal and circumferential welds.

(4) The length of these portions of piping should be reduced to the minimum length practical.

(5) Pipe anchors or restraints (e.g., connections to containment penetrations and pipe-whip restraints) should not be designed to need welding directly to the outer surface of the piping (e.g., flued integrally forged pipe fittings may be used), except where such welds are 100 percent volumetrically examinable in service and a detailed stress analysis is performed to demonstrate compliance with the limits of 2.A(ii)(1).

(6) Guard pipes provided for those portions of piping in the containment penetration areas should be constructed in accordance with the criteria of the ASME Code, Section III, Subsection NE, Class MC, where the guard pipe is part of the containment boundary. In addition, the entire guard pipe assembly should be designed to meet the following criteria and tests:

(a) The design pressure and temperature should not be less than the maximum operating pressure and temperature of the enclosed pipe under normal plant conditions.

(b) The Level C stress limits in ASME Code, Section III, NE-3220 should not be exceeded under the loading associated with containment design pressure and temperature in combination with the safe shutdown earthquake.

(c) Guard pipe assemblies should be subjected to a single pressure test at a pressure not less than its design pressure.

(d) Guard pipe assemblies should not prevent the access necessary to conduct the inservice examination specified in 2.A(ii)(7). Inspection ports, if used, should not be located in that portion of the guard pipe through the annulus of dual barrier containment structures.

(7) A 100 percent volumetric inservice examination of all pipe welds should be conducted during each inspection interval as defined in ASME Code, Section XI, IWA-2400.

(iii) Postulation of Pipe Breaks in Areas Other Than Containment Penetration

(1) With the exceptions of those portions of piping identified in 2.A(ii), breaks in Class 1 piping (ASME Code, Section III) should be postulated at the following locations in each piping and branch run:

(a) At terminal ends.[3]

(b) At intermediate locations where the maximum stress range[4] as calculated by Eq. (10) and either Eq. (12) or Eq. (13) exceeds $2.4S_m$.

(c) At intermediate locations where the cumulative usage factor exceeds 0.1.

As a result of piping reanalysis, the highest stress locations may be shifted; however, the initially determined intermediate break locations need not be changed unless one of the following conditions exists:

(i) The dynamic effects from the new (as-built) intermediate break locations are not mitigated by the original pipe-whip restraints and jet shields.

(ii) A change is necessary in pipe parameters such as major differences in pipe size, wall thickness, and routing.

(2) With the exceptions of those portions of piping identified in 2A(ii), breaks in Class 2 and 3 piping (ASME Code, Section III) should be postulated at the following locations in those portions of each piping and branch run:

(a) At terminal ends.

(b) At intermediate locations selected by one of the following criteria:

(i) At each pipe fitting (e.g., elbow, tee, cross, flange, and nonstandard fitting), welded attachment, and valve. Or, where the piping contains no fittings, welded attachments, or valves, at one location at each extreme of the piping run adjacent to the protective structure.

(ii) At each location where stresses are calculated□[5] by the sum of Eqs. (9) and (10) in NC/ND-3653 of ASME Code, Section III, to exceed 0.8 times the sum of the stress limits given in NC/ND-3653.

As a result of piping reanalysis, due to differences between the design configuration and the as-built configuration, the highest stress locations may be shifted; however, the

[3] This term is defined as the extremities of piping runs that connect to structures, components (e.g., vessels, pumps, valves), or pipe anchors that act as rigid constraints to piping motion and thermal expansion. A branch connection to a main piping run is a terminal end of the branch run, except where the branch run is classified as part of a main run in the stress analysis and is shown to have a significant effect on the main run behavior. In piping runs that are maintained pressurized during normal plant conditions for only a portion of the run (i.e., up to the first normally closed valve), a terminal end of such a run is the piping connection to this closed valve.

[4] See Footnote 2.
[5] See Footnote 2.

initially determined intermediate break locations may be used unless redesign of the piping resulting in a change in pipe parameters (diameter, wall thickness, routing) is necessary, or the dynamic effects from the new (as-built) intermediate break locations are not mitigated by the original pipe-whip restraints and jet shields.

(3) Breaks in seismically analyzed non-ASME Class piping are postulated according to the same criteria as for ASME Class 2 and 3 piping above.[6]

(4) The following is applicable to (1), (2), and (3) of this section:

If a structure separates a high-energy line from an essential component, that separating structure should be designed to withstand the consequences of the pipe break in the high-energy line that produces the greatest effect at the structure, irrespective of the fact that the criteria identified in 2.A(iii) might not need such a break location to be postulated.

(5) Safety-related equipment should be environmentally qualified in accordance with SRP Section 3.11. Appropriate pipe ruptures and leakage cracks (whichever controls) should be included in the design bases for environmental qualification of electrical and mechanical equipment both inside and outside the containment.

(iv) The designer should identify each piping run it considered in order to postulate the break locations pursuant to 2.A(iii) above. In complex systems such as those containing arrangements of headers and parallel piping running between headers, the designer should identify and include all such piping within a designated run in order to postulate the number of breaks pursuant to these criteria.

(v) With the exceptions of those portions of piping identified in 2.A(ii), leakage cracks should be postulated as follows:

(1) For ASME Code, Section III, Class 1 piping, at axial locations where the calculated stress range[7] by Eq. (10) in NB-3653 exceeds $1.2S_m$.

(2) For ASME Code, Section III, Class 2 and 3 or nonsafety-class (not ASME Class 1, 2, or 3) piping, at axial locations where the calculated stress[8] by the sum of Eqs. (9) and (10) in NC/ND-3653 exceeds 0.4 times the sum of the stress limits given in NC/ND-3653.

(3) Nonsafety-class piping that has not been evaluated to obtain stress information should have leakage cracks postulated at axial locations that produce the most severe environmental effects.

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[6] Note that, in addition, breaks in nonseismic (i.e., non-Category I) piping should be taken into account as described in Section II.2.k, "Interaction of Other Piping with Category I Piping," of SRP Section 3.9.2.
[7] See Footnote 2.
[8] See Footnote 2.

2. Moderate-Energy Fluid System Piping

(i) Fluid Systems Separated from Essential Systems and Components. For the purpose of satisfying the separation provisions of plant arrangement as specified in B.1.a of BTP 3-3, a review of the piping layout and plant arrangement drawings should clearly show that the effects of through-wall leakage cracks at any location in piping designed to seismic and nonseismic standards are isolated or physically remote from essential systems and components.

(ii) Fluid System Piping in Containment Penetration Areas. Leakage cracks need not be postulated in those portions of piping from containment wall to and including the inboard or outboard isolation valves, provided 1) they meet the criteria of the ASME Code, Section III, NE-1120, and 2) the stresses calculated[9] by the sum of Eqs. (9) and (10) in ASME Code, Section III, NC-3653 do not exceed 0.4 times the sum of the stress limits given in NC-3653.

(iii) Fluid Systems in Areas Other Than Containment Penetration.

(1) Leakage cracks should be postulated in piping located adjacent to structures, systems, or components important to safety, except:

(a) Where excluded by 2.B(ii) or 2.B(iv),

(b) For ASME Code, Section III, Class 1 piping, where the stress range calculated[10] by Eq. (10) in NB-3653 is less than $1.2S_{m,}$ and

(c) For ASME Code, Section III, Class 2 or 3 and nonsafety-class piping, where the stresses calculated[11] by the sum of Eqs. (9) and (10) in NC/HD-3653 are less than 0.4 times the sum of the stress limits given in NC/ND-3653.

(2) Leakage cracks, unless the piping system is excluded by 2.B(iii)(1), should be postulated at axial and circumferential locations that result in the most severe environmental consequences.

(3) Leakage cracks should be postulated in fluid system piping designed to nonseismic standards as necessary to satisfy B.3.d of BTP 3-3.

(iv) Moderate-Energy Fluid Systems in Proximity to High-Energy Fluid Systems. Leakage cracks need not be postulated in moderate-energy fluid system piping located in an area in which a break in high-energy fluid system piping is postulated, provided such leakage cracks would not result in more limiting environmental conditions than the high-energy piping break. Where a postulated leakage crack in the moderate-energy fluid system piping results in more limiting environmental conditions than the break in proximate high-energy fluid system piping, the provisions of 2.B(iii) should be applied.

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[9] See Footnote 2.
[10] See Footnote 2.
[11] See Footnote 2.

(v) Fluid Systems Qualifying as High-Energy or Moderate-Energy Systems. Through-wall leakage cracks instead of breaks may be postulated in the piping of those fluid systems[12] that qualify as high-energy fluid systems for only a short operational period but qualify as moderate-energy fluid systems for the major operational period.

3. Type of Breaks and Leakage Cracks in Fluid System Piping

(i) Circumferential Pipe Breaks

The following circumferential breaks should be postulated individually in high-energy fluid system piping at the locations specified in 2.A of this BTP:

(1) Circumferential breaks should be postulated in fluid system piping and branch runs exceeding a nominal pipe size of 1 inch, except where the maximum stress range[13] exceeds the limits specified in 2.A(iii)(1) and 2A(iii)(2), and the circumferential stress range is at least 1.5 times the axial stress range. Instrument lines, as well as 1 inch and less nominal pipe or tubing size, should meet the provisions of Regulatory Guide (RG) 1.11, "Instrument Lines Penetrating Primary Reactor Containment (Safety Guide 11)."

(2) Where break locations are selected without the benefit of stress calculations, breaks should be postulated at the piping welds to each fitting, valve, or welded attachment.

(3) Circumferential breaks should be assumed to result in pipe severance and separation amounting to at least a one-diameter lateral displacement of the ruptured piping sections unless physically limited by piping restraints, structural members, or piping stiffness as may be demonstrated by inelastic limit analysis (e.g., a plastic hinge in the piping is not developed under loading).

(4) The dynamic force of the jet discharge at the break location should be based on the effective cross-sectional flow area of the pipe and on a calculated fluid pressure as modified by an analytically or experimentally determined thrust coefficient. Limited pipe displacement at the break location, line restrictions, flow limiters, positive pump-controlled flow, and the absence of energy reservoirs may be taken into account, as applicable, in the reduction of jet discharge.

(5) Pipe whipping should be assumed to occur in the plane defined by the piping geometry and configuration and to initiate pipe movement in the direction of the jet reaction.

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[12] The operational period is considered "short" if the fraction of time that the system operates within the pressure-temperature conditions specified for high-energy fluid systems is about 2 percent of the time that the system operates as a moderate-energy fluid system (e.g., systems such as the reactor decay heat removal system qualify as moderate-energy fluid systems; however, systems such as auxiliary feedwater systems operated during pressurized-water reactor (PWR) reactor startup, hot standby, or shutdown qualify as high-energy fluid systems).

[13] See Footnote 2.

(ii) Longitudinal Pipe Breaks

The following longitudinal breaks should be postulated in high-energy fluid system piping at the locations of the circumferential breaks specified in 3(i):

(1) Longitudinal breaks in fluid system piping and branch runs should be postulated in nominal pipe sizes 4-inch and larger, except where the maximum stress range[14] exceeds the limits specified in 2.A(iii)(1) and 2.A(iii)(2), and the axial stress range is at least 1.5 times the circumferential stress range.

(2) Longitudinal breaks need not be postulated at terminal ends.

(3) Longitudinal breaks should be assumed to result in an axial split without pipe severance. Splits should be oriented (but not concurrently) at two diametrically opposed points on the piping circumference such that the jet reactions cause out-of-plant bending of the piping configuration. Alternatively, a single split may be assumed at the section of highest tensile stress as determined by detailed stress analysis (e.g., finite element analysis).

(4) The dynamic force of the fluid jet discharge should be based on a circular or elliptical (2D x 1/2D) break area equal to the effective cross-sectional flow area of the pipe at the break location and on a calculated fluid pressure modified by an analytically or experimentally determined thrust coefficient as determined for a circumferential break at the same location. Line restrictions, flow limiters, positive pump-controlled flow, and the absence of energy reservoirs may be taken into account, as applicable, in the reduction of jet discharge.

(5) Piping movement should be assumed to occur in the direction of the jet reaction unless limited by structural members, piping restraints, or piping stiffness as demonstrated by inelastic limit analysis.

(iii) Leakage Cracks

Leakage cracks should be postulated at those axial locations specified in 2.A(v) for high-energy fluid system piping and in those piping systems not excluded in 2.B(iii)(1) for moderate-energy fluid system piping.

(1) Leakage cracks need not be postulated in 1-inch and smaller piping.

(2) For high-energy fluid system piping, the leakage cracks should be postulated to be in those circumferential locations that result in the most severe environmental consequences. For moderate-energy fluid system piping, see 2.B(iii)(2).

[14] See Footnote 2.

(3) Fluid flow from a leakage crack should be based on a circular opening of area equal to that of a rectangle one-half pipe diameter in length and one-half pipe wall thickness in width.

(4) The flow from the leakage crack should be assumed to result in an environment that wets all unprotected components within the compartment, with consequent flooding in the compartment and communicating compartments. Flooding effects should be determined on the basis of a conservatively estimated time period necessary to effect corrective actions.

C. REFERENCES

1. American Society of Mechanical Engineers, ASME Code, Section III, “Rules for Construction on Nuclear Power Plant Components,” and ASME Code, Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components.”

2. 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.”

3. U.S. Code of Federal Regulations, “Domestic Licensing of Production and Utilization,” Part 50, Chapter 1, Title 10, “Energy,” Appendix S, “Earthquake Engineering Criteria for Nuclear Power Plants.”

4. U.S. Nuclear Regulatory Commission, “Instrument Lines Penetrating Primary Reactor Containment (Safety Guide 11),” Regulatory Guide 1.11.
