3.6 PROTECTION AGAINST DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING

This section describes the design bases and measures that are taken on Waterford 3 to demonstrate that the systems, components and structures required to safely shutdown and maintain the reactor in a cold shutdown condition, are adequately protected against the effects of blowdown jets, reactive forces, and pipe whip resulting from postulated rupture of piping both inside and outside containment.

The following criteria are used for the protection against dynamic effects associated with postulated pipe rupture:

a) Branch Technical Position APCSB 3-1, Protection Against Postulated Piping Failures in Fluid Systems Outside Containment (3/75),

b) Regulatory Guide 1.46, Protection Against Pipe Whip Inside Containment (5/73): analysis of safety class 1 piping inside the containment,

C) Branch Technical Position MEB 3-1, Postulated Break and Leakage Locations in Fluid System Piping Outside Containment (2/75): analysis of safety classes 2 and 3 piping both inside and outside containment, and

d) Structural Engineering Branch Document B.

→(DRN 06-803, R15)

e) Branch Technical Position MEB 3-1 Rev. 2, Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment (6/87), issued with Generic Letter 87-11, Relaxation in Arbitrary Intermediate Pipe Rupture Requirements: analysis of safety classes 1, 2, and 3 piping.

←(DRN 06-803, R15)

After the pipe break event, the consequences are considered to be the following:

a) pipe whip,

b) jet impingement,

c) compartment pressurization,

d) compartment flooding and

e) high temperature/high humidity environment.

3.6.1 POSTULATED PIPING FAILURES IN FLUID SYSTEMS BOTH INSIDE AND OUTSIDE OF CONTAINMENT

3.6.1.1 Design Basis

The following design bases are considered in determination of the dynamic effects associated with the pipe rupture:

a) The assumptions (e.g. loss of offsite power, single active failure) used in conducting pipe break analyses are listed in Subsection 3.6.1.3.

→(DRN 05-127, R14)

b) The effects of each postulated piping failure will result in offsite consequences within the guidelines of 10CFR50.67.

←(DRN 05-127, R14)

→(DRN 00-1121)

c) The functional capability of systems and equipment required to assure safe shutdown and the ability to maintain a cold shutdown condition after a given break must not be impaired by the pipe whip, jet impingement or environmental conditions resulting from that break.

←(DRN 00-1121)

d) Damage to any structure, either directly caused by the pipe whip, jet impingement or environmental consequences of a given break, or indirectly through failure of an adjacent structure, must not impair the function of any systems or equipment required to assure reactor cold shutdown and the ability to maintain a cold shutdown condition.

e) The effects of a postulated failure, including radiation and environmental conditions should not preclude habitability of the main control room or any location where manual action is required to achieve a cold shutdown condition. The structural integrity of these areas shall be preserved.

f) The design leak-tightness integrity of the primary containment shall be preserved.

Essential systems are those that are to shutdown the reactor and mitigate the consequences of a postulated pipe break, without offsite power. However, depending upon the type and location of a postulated pipe break, certain safety equipment may not be classified as essential for that particular event.

The essential system required for each postulated piping failure are identified below.

A) The following systems or portions of these systems are required to mitigate the consequences of postulated breaks of reactor coolant pressure boundary piping that will result in a loss-of-coolant accident (LOCA).

1) Reactor Protection System

2) Engineered Safety Features Actuation System

3) Safety Injection System

4) Containment Spray System

5) Reactor Coolant System

6) Main Steam and Feedwater Systems (from the steam generator out to the isolation valves)

7) Emergency Feedwater System

8) Class 1E electrical systems, ac and dc (including switchgear, batteries, and distribution systems)

9) diesel generators (including jacket water cooling and lube oil)

10) diesel Fuel Oil Storage and Transfer System

11) Containment Cooling System

12) Hydrogen analyzer and hydrogen recombiner

13) Component Cooling Water System (portions required for operation of other listed systems)

14) Heating, ventilation, and air conditioning systems required for operation of other listed systems and main control room (including Essential Services Chilled Water System)

15) Containment Isolation System

16) Post accident monitoring instruments (see Section 7.5)

17) Radiation monitors

    Containment area radiation monitors (four area monitors in the containment)

18) Shutdown Cooling System (for RCPB breaks less than or equal to 0.5 ft equivalent diameter)

19) Control element assembly drive mechanisms (CEDM) (protection of the CEDMs is required to the extent that the control element assembles will be released for insertion into the core during accident conditions; protection of power and control circuitry is not required)

B) The following systems or portions of these systems are required to mitigate the consequences of postulated breaks of main steam, feedwater or steam generator blowdown piping.

1) Reactor Protection System

2) Engineered Safety Features Actuation System

3) Emergency Feedwater System

4) Safety Injection System

5) Containment Spray System (for breaks inside the containment only)

6) Reactor Coolant System (maintain RCPB)

7) Main Steam and Feedwater System (from the steam generator out to the containment isolation valves)

8) Shutdown Cooling System

9) Class 1E electrical systems, ac and dc (including switchgear, batteries, and distribution systems)

10) diesel generators (including jacket water cooling and lube oil)

11) diesel Fuel Oil Storage and Transfer System

12) Containment Cooling System (for breaks inside the containment only)

13) Component Cooling Water System (portions required for operation of other listed systems)

14) Heating, ventilation, and air conditioning systems required for operation of other listed systems and main control room (including Essential Services Chilled Water System)

15) Instrumentation required for post accident monitoring (see Section 7.5)

16) Control element assembly drive mechanisms (CEDM) (protection of the CEDMs is required to the extent that the control element assemblies will be released for insertion into the core during accident conditions; protection of power and control circuitry is not required)

17) Containment Isolation System

C) Other postulated high energy line breaks not included in listings A) and B) above. These breaks are evaluated on a case-by-case basis to ensure that the design bases a) through f) listed above are met.

Piping isometrics with rupture points indicated are provided in Appendix 3.6A. Appendix 3.6A also identifies those systems or components that are required for plant safety or shutdown and must be protected by a barrier from the effects of the postulated break.

3.6.1.2 Description

Piping systems which, during normal operating conditions, exceed 200° F and/or 275 psig are considered to be high energy. The following systems, or portions of systems, are evaluated as high energy pipelines for pipe rupture:

→(DRN 03-2056, R14)

a) Inside Containment (High Energy)[1]

→(EC-19087, R305)

1) Pressurizer spray and relief lines, and drain lines to the Boron Management System.

←(DRN 03-2056, R14)

2) Chemical and Volume Control System (letdown and charging)

3) Safety Injection System (all portions included in the RCPB)

4) Main Steam System

5) Feedwater System

6) Steam Generator Blowdown System

→(DRN 03-2056, R14; EC-19087, R305)

[1]The design requirements for the affects of postulated breaks in the main coolant loop and surge line piping have been eliminated by leak-before-break considerations. See Section 3.6.3.

←(DRN 03-2056, R14; EC-19087, R305)

b) Outside Containment (High Energy)

1) Main Steam System

2) Feedwater System

3) Steam Generator Blowdown System

4) Chemical and Volume Control System (from containment penetration to the letdown back pressure valve downstream of the letdown heat exchanger and from discharge of charging pump to containment penetration)

Moderate energy systems include those systems where both the following conditions apply during normal operation of the reactor:

a) Maximum operating temperature is 200 F or less, and

b) Maximum operating pressure is 275 psig or less.

A system is also considered moderate energy if the system exceeds 200 F and/or 275 psig less than two percent of the system normal operating time (not including testing).

a) Inside Containment (Moderate Energy)

1) Component Cooling Water System

2) Shutdown Cooling System (downstream of valves 1SI-V1504A and 1SI-VI502B)

3) Containment Spray System

4) Boron Management System

5) Fuel Pool System

6) Safety Injection System drains

b) Outside Containment (Moderate Energy)

1) Component Cooling Water System

2) Fire Protection System

3) Shutdown Cooling System

4) Containment Spray System

5) Essential Services Chilled Water System

6) Sampling System

7) Demineralized Water System

8) Circulating Water System

9) Steam Generator Blowdown System

10) Fuel Pool Cooling System

11) Waste and Boron Management Systems

12) Condensate System

→(DRN 00-1032, R11-A)

13) Diesel Generator Fuel Oil Transfer System

←(DRN 00-1032, R11-A)

14) Potable Water System

15) Chemical and Volume Control System

16) Safety Injection System

17) Emergency Feedwater System (Note: This piping is maintained at the feedwater operating pressure via a 0.25 inch orifice. It has been classified as moderate energy piping since there is essentially no high energy source to cause jet impingement or pipe whip.)

→(DRN 06-291, R14-B)

18) Supplementary Chilled Water

←(DRN 06-291, R14-B)

An analysis of pipe break events postulated in the design was performed to determine the effect on those safety related systems and components that provide protective actions required to mitigate the consequences of the postulated pipe break event.

Whenever the separation inherent in the plant design is shown to assure the functional capability of the essential systems required following a postulated pipe break event, no additional protective measures are required. When necessary, additional protective measures such as those described below are incorporated into the design to assure the functional capability of essential systems following the postulated pipe break event.

a) Separation

The plant arrangement provides separation where practical between redundant safety systems in order to prevent loss of safety function resulting from the dynamic effects of the rupture event. Separation between redundant safety systems with their related auxiliary supporting features, therefore, is the basic protective measure that is incorporated in the design to protect against the dynamic effects of postulated pipe break events.

→(DRN 00-1032, R11-A)

In general, layout of the facility follows a multistep process to ensure adequate separation.

←(DRN 00-1032, R11-A)

1) Safety related systems are located away from most high energy piping.

2) Redundant (e.g., "A" and "B" trains) safety subsystems and components are located in separate compartments.

3) As necessary, specific components are enclosed to retain the redundancy required for those systems that must function as a consequence of specific piping failure events.

b) barriers, shields and Enclosures

Structures required to provide protection against the effects and consequences of the pipe break are evaluated to determine that these structures are designed to accomplish this function. Neither direct nor indirect damage to any structure caused by pipe rupture, jet impingement, missiles or environmental consequences will impair the capability to safely shutdown the plant. Structures providing barrier protection are designed to withstand the pressure, humidity and temperature transients which result from a high energy piping system break plus normal operating loads plus SSE loads. In analyzing seismic Category I structures both inside and outside containment, Structural Engineering Branch Document B is used.

c) Piping Restraint Protection

Where adequate protection does not already exist due to separation, barriers or shields, piping restraints are provided as necessary to meet the functional protection requirements. Restraints are not provided when it can be shown that the broken pipe will not cause unacceptable damage to essential systems or components.

The design criteria for restraints are given in Subsection 3.6.2.3.

Area drawings that show design layout used to protect the essential systems, structures and components are given in Appendix 3.6A.

The effects of steam environment on safety related equipment are discussed in Section 3.11. An analysis of the potential effects of missiles is discussed in Section 3.5.

3.6.1.3 Safety Evaluation

By means of the design features such as separation, barriers, and pipe whip restraints, all of which are discussed in Subsection 3.6.1.2, the effects of pipe break will not damage essential systems to an extent that would impair their functional capability.

Specific design features listed in Subsection 3.6.1.2, used for protecting the essential systems, are identified in Appendix 3.6A.

In conducting the pipe rupture analyses, the following assumptions are used:

a) If the postulated pipe failure results in an automatic separation of the turbine generator from the power grid, then offsite power is assumed to be unavailable.

b) If the postulated pipe failure requires safety system response to the event, the analysis assumes a single active component failure in either the safety systems required to mitigate the consequences of the event or their auxiliary supporting features except as noted in e) below. This single active failure is in addition to the postulated pipe failure and any direct consequences of the piping failure.

c) Operator action to mitigate the consequences of the postulated pipe failure is analyzed for each specific event. The feasibility of initiating operator actions on a timely basis, as well as the accessibility provided to allow the operator actions, is demonstrated.

d) In the analysis of pipe failures, the use of all plant systems, including non-seismic systems, in bringing the plant to a safe shutdown condition, is allowed.

e) Where the postulated piping failure is assumed to occur in one of two or more redundant trains of a dual purpose moderate energy essential system (i.e., one required to operate during normal plant conditions as well as to shutdown the reactor and mitigate the consequences of the piping failure), single failures of components in the other train or trains of that system only are not assumed, provided the system is designed to seismic Category I standards, is powered from both offsite and onsite sources, and is constructed, operated, and inspected to quality assurance, testing, and in-service inspection standards appropriate for nuclear safety systems.

f) An unrestrained whipping pipe is considered capable of

    1) rupturing impacted pipes of smaller nominal pipe sizes, and

    2) developing through-wall leakage cracks in larger nominal pipe sizes with thinner wall thicknesses.

The energy level in a whipping pipe is considered insufficient to rupture an impacted pipe of equal or greater nominal pipe size and equal or heavier wall thickness.

The high energy lines, inside and outside containment, evaluated in the analysis are described in Subsections 3.6.1.1 and 3.6.1.2. The results of these analyses are presented in Appendix 3.6A.

Given the separation criteria in Subsection 3.6.1.2, and the pipe break criteria in Subsection 3.6.2, the effects of high energy pipe breaks are generally not analyzed where it is obvious that all essential systems, components, or structures are physically remote from a break in that piping run.

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

3.6.2.1 Criteria Used to Define Break and Crack Location and Configuration

3.6.2.1.1 High Energy Piping Systems (Inside Containment)

→(DRN 00-1032, R11-A; 03-2056, R14)

This section provides the criteria used to locate the postulated break points for high energy fluid systems inside containment. All current postulated breaks are full flow breaks with a 1 millisecond rise time to full flow area.

The only limited separation breaks that were postulated were in the main coolant loop (MCL) piping. These breaks have been eliminated by LBB (see Subsection 3.6.2.1.1.1(d) and Section 3.6.3). The postulated main coolant loop breaks (MCLBs) were postulated as limited separation breaks in accordance with Subsection 3.6.2.1.1.1 (a), (b) and (c), and were based on the CENPD-168A topical report. The pipe break sizes for these breaks were all the same as CENPD-168A except for the guillotine break at the reactor inlet nozzles. CENPD-168A reported a break flow area at the reactor inlet nozzle of 350 in^2 based on a saddle type pipe whip restraint located inside the penetration tunnel. The Waterford 3 RCS design incorporates a set of pipe lugs integral with the cold leg pipe which mate with a set of restraint structures to effect a flat interface surface at this particular restraint location. The resultant break flow area at the reactor inlet nozzles was 125 in^2. The 125 in^2 break was only used in the analysis of the fuel and reactor internals. All other RCS components were evaluated using CENPD-168A.

←(DRN 00-1032, R11-A)

3.6.2.1.1.1 Reactor Coolant System (RCS) Main Loop Piping and Surge Line

a) Original Criteria for RCS Main Loop Pipe Break Locations

For the Reactor Coolant System main loop piping (ASME Section III, Code Class 1), circumferential type pipe breaks were postulated to occur at all terminal ends. Pipe breaks of the type determined by the methods described in c) below were postulated at all intermediate locations throughout the piping system where the range of primary plus secondary stress intensity exceeded 80 percent of the code allowable or the cumulative usage factor exceeded 0.1 of the code allowable.

Where all intermediate pipe break locations would be considered unlikely because the stresses and cumulative usage factors calculated for a particular run of piping between terminal ends are everywhere less than the stress and fatigue limits stated above, the two intermediate locations of highest cumulative usage factor were chosen as the most likely break locations for piping runs longer than 10 diameters total length, and for piping runs having more than one change in direction throughout the run.

b) RCS Pipe Break Types

Two types of pipe breaks were considered in establishing the design conditions for the RCS main loop piping:

1) Circumferential Breaks

A complete severance of the pipe, perpendicular to the pipe axis that resulted in an instantaneous removal of mechanical internal pipe forces across the break.

←(DRN 03-2056, R14)

2) Longitudinal Break

→(DRN 03-2056, R14)

An elliptical opening in the pipe wall parallel to the pipe axis that had a length of two inside pipe diameters and a maximum flow area of one internal pipe flow area.

c) Criteria for RCS Pipe Break Types

At each postulated intermediate break location, a detailed finite element stress analysis was performed to determine the type of break more likely to occur at that location, based on the following:

1) If the maximum stress range was in the longitudinal direction and it was significantly higher than the circumferential stress range at that point on the cross-section, a circumferential break was postulated as the more likely break at that location.

2) If the maximum stress range was in the circumferential direction and it was significantly higher than the longitudinal stress range at that point on the cross-section, a longitudinal break was postulated as the more likely break at that location. This was oriented around the circumference at the point of maximum circumferential stress range unless the circumferential stress range at all orientations within a portion of the circumference was essentially equal to the maximum, in which case, the longitudinal break was oriented at any point within that portion of the circumference.

d) Current Criteria for Pipe Break Locations Affecting the RCS Design

→(EC-19087, R305)

Due to changes in the regulations, General Design Criterion 4 (Reference 18) was revised to allow the application of Leak Before Break (LBB) criteria. The application of LBB per GDC 4 has eliminated the postulated MCL and pressurizer surge line breaks for purposes of the dynamics effects design basis of the RCS. However, in accordance with NUREG-1061 Volume 3, the non-mechanistic MCLB design basis is maintained for containment design, ECCS performance analysis, and electrical and mechanical environmental qualification.

Following the application of LBB to the MCL and surge line piping, the limiting pipe breaks in the design basis for mechanical (dynamic) effects on the RCS are the remaining primary and secondary side branch line pipe breaks (BLPBs) that interface with the RCS. Of these, the controlling BLPBs with respect to RCS response are breaks in the largest tributary pipes. Break locations in these lines are postulated as discussed in Subsections 3.6.2.1.1.2 and 3.6.2.1.1.3. The BLPBs that affect the RCS design are postulated in the following piping systems. See Section 3.6.3 for a discussion of LBB.

- main steam line
- feedwater line
- safety injection line
- shutdown cooling line

3.6.2.1.1.2 ASME Section III, Code Class 1 Piping (excluding RCS loop and surge piping)

←(DRN 03-2056, R14; EC-19087, R305)

→(DRN 06-803, R15)

Rupture locations have been postulated to occur in any piping run or branch at terminal ends and other intermediate points in accordance with Regulatory Guide 1.46, Protection Against Pipe Whip Inside Containment (May, 1973) and Branch Technical Position MEB 3-1 issued with Generic Letter 87-11, Relaxation in Arbitrary Intermediate Pipe Rupture Requirements. Postulated rupture locations for Class 1 piping are based on the following:

←(DRN 06-803, R15)

a) Terminal points

b) Any intermediate points between terminal ends where the cumulative usage factor exceeds 0.1 (based upon normal and upset plant conditions and OBE).

c) Any intermediate points between terminal ends where the primary plus secondary stress intensities derived on an elastic basis is greater than 2.0 Sm in ferritic and 2.4 Sm in austenitic piping materials (based on normal and upset plant conditions and OBE).

→(DRN 06-803, R15)
←(DRN 06-803, R15)

3.6.2.1.1.3 ASME Section III, Code Classes 2 and 3 Piping

Rupture locations are postulated to occur in any piping or branch run, at terminal ends and intermediate locations as per Branch Technical Position MEB 3-1. Break locations are postulated on the aforementioned piping by the following:

a) At all terminal ends of the run if located adjacent to the protective structure.

→(DRN 00-1032, R11-A; 06-803, R15)
b) At other locations between terminal ends where stresses under normal and upset plant conditions and an OBE event as calculated by Equations 9 and 10 of Paragraph NC-3652 of the ASME Code Section III exceed 0.8 $(1.2\ S_H + S_A)$.
←(DRN 00-1032, R11-A; 06-803, R15)

3.6.2.1.2 High Energy Piping Systems (Outside Containment)

This section discusses the criteria used for location of postulated break points in ASME Section III, Code Classes 2 and 3 high energy fluid systems outside the containment. The postulated rupture points are located as previously discussed in Subsection 3.6.2.1.1.3.

The main steam and feedwater piping located between the outboard isolation valves and Turbine Building interface restraints plus Steam Generator Blowdown System piping from the isolation valves outside containment to the nozzles on the blowdown tank are classified as non-nuclear class piping (ANSI B31.1) but designed to seismic Category I requirements. The design rules with respect to break selection for this section of piping are equivalent to ASME Section III, Code Class 2 requirements. Therefore the criteria for selection of postulated breaks in this section of piping is given in Subsection 3.6.2.1.1.3.

The bypass piping around the feedwater control valves offers no significant restraint to free thermal expansion. The selection of postulated break locations on these sections of piping is as follows:

a) Breaks are postulated at each tee fitting. This results in the equivalent of a longitudinal break in the feedwater run piping and a circumferential break in the bypass piping. The break area equals the flow area of the bypass piping.

b) Intermediate breaks are postulated in the bypass piping at those locations where the summation of Equation 9 and 10 stresses (as calculated by paragraph NC-3652 of ASME Section III) exceed the Equation 9 and 10 stresses of the feedwater run piping where a break is postulated.

3.6.2.1.3 Moderate Energy Piping Systems (Both Inside and Outside Containment)

For ASME Code Class 2, 3 and non-nuclear moderate energy piping systems routed in areas containing no high energy piping, but which are located near components or structures required for safe shutdown, through wall leakage cracks are postulated to occur at any location.

Through wall leakage cracks are postulated in seismic Category I fluid system piping located within, or outside and adjacent to, protective structures, except where the maximum stress range in these portions of Code Class 2 or 3 piping, or non-nuclear piping is less than 0.4 $(1.2S_H + S_A)$. Through wall leakage cracks are postulated in fluid system piping designed to non-seismic standards so as not to result in any loss of capability of essential systems and components to withstand the further effects of any single active component failure and still perform all functions required to shutdown the reactor and mitigate the consequences of the postulated piping failure.

Through wall leakage cracks are not postulated in moderate energy fluid piping systems that are located in the same area as high energy fluid piping systems which have previously determined rupture locations, unless such cracks would result in more limiting environmental conditions.

→ (DRN 00-0958, R12-B)
Through-wall leakage cracks are not postulated in Essential Chilled Water piping sizes 1¼" to 10" NPS when the piping has been supported using the chart method.
← (DRN 00-0958, R12-B)

Leakage cracks in fluid system piping between containment isolation valves is described in Subsection 3.6.2.1.4.

3.6.2.1.4 High and Moderate Energy Piping Between the Containment Isolation Valves

a) <u>High Energy Systems</u>

Breaks are not postulated in those portions of Main Steam and Feedwater piping between the isolation valve and the containment anchor since, in accordance with the requirements of BTP APSCB 3-1, (Paragraph B.2.c) and BTP MEB 3-1, (Paragraph B.l.b), the requirements of ASME Section III, Subarticle NE-1120 and the following additional design requirements are met.

1) All piping is ASME Code Class 2 piping. The following design stresses are not exceeded for ASME Code, Section III, Class 2 piping:

(a) The maximum stresses as calculated by the sum of Equations (9) and (10) in Paragraph NC-3652, ASME Code, Section III, considering normal and upset plant conditions (i.e., sustained loads, occasional loads, and thermal expansion) and an OBE event do not exceed $0.8(1.2S_h + S_A)$.

(b) The maximum stress, as calculated by Equation (9) in Paragraph No. NC-3652 under the loadings resulting from a postulated piping failure of fluid system piping beyond these portions of piping does not exceed $1.8S_h$.

2) To the extent practicable, welded attachments, for pipe supports or other purposes, to these portions of piping are avoided except where detailed stress analyses (by using CYLNOZ), or tests are performed to demonstrate compliance with the limits of item 1) above. Localized stresses which are developed by the welded attachments i.e., trunnions and lugs are combined with the pipe stresses at the various plant operating conditions and remain within the specified ASME Section III allowables as listed in Table 3.9-7. See Tables 3.6-3 and 3.6-4 for a list of welded attachments.

3) The number of circumferential and longitudinal piping welds and branch connections are minimized. Where guard pipes are used, the enclosed portion of fluid system piping is seamless construction.

4) The length of these portions of piping is reduced to the minimum length practical.

5) To the extent practicable, the design of pipe anchors or restraints (e.g., connections to containment penetrations and pipe whip restraints) will not require welding directly to the outer surface of the piping (e.g., flued integrally forged pipe fittings may be used) except where welds are 100 percent volumetrically examinable in service and detailed stress analysis is performed to demonstrate compliance with the limits of item 1) above.

6) Guard pipes are used for those portions of piping that pass through the containment annulus and whose postulated failure could effect the leaktight integrity of the containment structure or result in pressurization of the containment annulus beyond design limits. They are constructed in accordance with rules of Class MC, Subsection NE of the ASME Code, Section III, where the guard pipe is part of the containment boundary. In addition, the entire guard pipe is designed to meet the following requirements and tests:

   (a) the design pressure and temperature is equal to the maximum operating pressure and temperature of the enclosed process pipe under normal plant conditions,

   (b) the design stress limits of paragraph NE-3131 (c) are not exceeded under the loading associated with design pressure and temperature in combination with the SSE, and

   (c) guard pipe assemblies will be subjected to a single pressure test at a pressure not less than the process pipe design pressure.

As stated above, for main steam and feedwater piping no breaks are postulated in the area of the containment penetrations because the supplemental requirements of BTP APCSB 3-1 paragraph B.2.c and BTP MEB 3-1 paragraph B.1.b, are met. However, to furnish additional protection, a terminal point break is postulated at each piping tee located in this section of piping. This break is equivalent to a longitudinal break of the run and a circumferential break of the branch piping, with a break area equal to the flow of the branch.

b) Moderate Energy Systems

Leakage cracks are not postulated in those portions of Code Class 2 fluid system piping between containment isolation valves provided they meet the requirements of the ASME Code Section III, Subarticle NE-1120, and are designed such that the maximum stress range does not exceed 0.4 $(1.2S_H + S_A)$ for ASME Code, Section III, Code Class 2 piping.

3.6.2.1.5 Types of Breaks and Leakage Cracks in Fluid System Piping

a) Circumferential Pipe Breaks

The following circumferential breaks are postulated in high energy fluid system piping:

1) Circumferential breaks are postulated in fluid system piping and branch runs exceeding a nominal pipe size of one inch, except where the maximum stress range exceeds 0.8 $(1.2\ S_H + S_A)$ but the circumferential stress range is at least 1.5 times the axial stress range.

2) Where break locations are selected without the benefit of stress calculations, breaks are postulated at the piping welds to each fitting, valve, or welded attachment. Alternatively, a single break location at the section of maximum stress range may be selected as determined by detailed stress analyses (e.g., finite element analyses) or tests on a pipe fitting.

3) Circumferential breaks are 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 is 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 is taken into account, as applicable, in the reduction of jet discharge.

5) Pipe whipping is assumed to occur, however the possible motions of whipping pipe are controlled by the piping configuration and the direction of the jet reaction force.

b) Longitudinal Pipe Breaks

The following longitudinal breaks are postulated in high-energy fluid system piping:

1) Longitudinal breaks in fluid system piping and branch runs are postulated in nominal pipe sizes four inches and larger, except where the maximum stress range exceeds 0.8 ($1.2S_H + S_A$) but the axial stress range is at least 1.5 times the circumferential stress range.

2) Longitudinal breaks are not postulated at:

   a) Terminal ends provided the piping at the terminal ends contains no longitudinal pipe welds (if longitudinal welds are used, the requirements of item (1) above apply).

   (b) At intermediate locations where the criterion for a minimum number of break locations must be satisfied.

3) Longitudinal breaks are assumed to result in an axial split without pipe severance. Splits are oriented (but do not occur concurrently) at two diametrically-opposed points on the piping circumference such that the jet reaction causes out-of-plane 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). These two breaks are used for both pipe whip and jet impingement analyses.

4) The dynamic force of the fluid jet discharge is 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 are taken into account, as applicable, in the reduction of jet discharge.

5) Piping movement is 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.

c) Through Wall Leakage Cracks

The following through wall leakage cracks are postulated in moderate energy fluid system piping:

1) Cracks are postulated in moderate energy fluid system piping and branch runs exceeding a nominal pipe size of one inch.

2) Fluid flow from a crack is 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.

3) The flow from the crack is 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 are determined on the basis of a conservatively estimated time period required to effect corrective actions.

3.6.2.2 Analytical Methods To Define Forcing Functions and Response Model

3.6.2.2.1 RCS Main Loop Piping

The pipe halves separate in the amount and directions consistent with the structural characteristics of the pipe halves when acted upon by axial forcing functions equal to:

$$F(t) = p(t)\ (^{\pi}/4)Di^{2} + Fm(t)$$

where:

F(t) = time varying pipe thrust force acting at break
p(t) = time varying system break pressure
Di = inside diameter of pipe
Fm(t)= time varying force due to momentum of escaping fluid.

For a postulated longitudinal break, the pipe responds structurally to a forcing function perpendicular to the axis of the pipe equal to:

$$F(t) = p(t)\ A(t) + Fm(t)$$

where:

A(t) = time varying flow area at break

The analytical methods for determining the time varying forcing functions from the system hydraulic analyses, the break area opening time and magnitude, and typical mathematical models used for the dynamic response analysis, are as presented in Reference 1.

3.6.2.2.2 Main Steam and Feedwater Systems - Inside And Outside Containment

a) Blowdown Analysis

→(DRN 00-1032)

System blowdown reaction force calculations are determined with the use of the PRTHRUST computer program[2] PRTHRUST computes and plots force time history curves of the reaction fluid thrust loads resulting from a circumferential or longitudinal pipe break for subcooled liquid, flashing liquid, and steam systems.

←(DRN 00-1032)

In PRTHRUST, the fluid system is mathematically modeled as an assemblage of control volumes interconnected by flow paths. Characteristics of a control volume include state of the contained fluid and potential energy addition or subtraction. Control volumes are used to model such components as pressure vessels, steam generators, heat exchangers and the piping volumes. Flow paths are used to interconnect control volumes and may include operable control valves, check valves, fills and pumps. A time dependent thermal hydraulic solution is then obtained by integrating a set of differential equations subject to the basic properties of water.

A basic mass and energy balance is performed on each defined volume using the following equations:

$$\frac{dMi}{dt} = \sum_{j=1}^{N} Wij \qquad \text{(Mass Balance)}$$

$$\frac{dU_i}{dt} = \sum_{j=1}^{N} W_{ij}h_{ij} \qquad \text{(Energy Balance)}$$

where:

M_i = total mass in volume i

→(DRN 00-1032)

W_{ij} = flow rate into volume i through junction j

←(DRN 00-1032)

U_i = energy in volume i

h_{ij} = enthalpy of flowing fluid

N = number of junctions in volume i

Through suitable input parameters and mathematical modeling in the program the energy is calculated and used in the volume energy balance. The program also allows actuation of flow control and energy devices to be triggered at a specified time or based on a physical signal such as pressure or flow at a point in the system.

→(DRN 00-1032)

The pressure, P_i,in each volume is determined implicitly by requiring the mass of fluid, M., with internal energy, U_i, to fill the control volume, V. Through the use of enthalpy, h_i,an estimated pressure, and the 1967 ASME steam tables[3], the specific volume of the fluid is calculated and compared to the known specific volume V_i/M_i with the equation:

←(DRN 00-1032)

$$h_i = \frac{U_i}{M_i} + P_i \left(\frac{V_i}{M_i}\right) \qquad \text{(Thermodynamic Pressure)}$$

Through an iterative process, the volume pressure is determined.

Junction flows are calculated from the one dimensional momentum equation:

$$\frac{1}{44\, g_c} \frac{\ell}{A} \frac{dW_j}{dt} = (P_i - P_{i+1}) + \Delta P_p + \int v_j \frac{pdz}{144} - \frac{K_j W_j \left|W_j\right|}{p_j}$$

(Momentum Equation)

Where:

g_c = gravitational conversion constant

$\frac{\ell}{A}$ = junction inertia

W_j = average flow from volume i to volume i+1

$(P_i - P_{i+1})$ = thermodynamic pressure differential across the fluid contained in the flow volume

ΔP_p = pump head

$\int_v pdz$ = gravitational head across fluid column

K_j^j = net friction coefficient including normal friction loss

p_j = fluid density in volume j.

A limiting (choked) mass flow is defined in the program by Moody's two phase choked flow model[4] where maximum mass flow flux is a function of stagnation pressure and enthalpy. The flow through the junction is chosen as the smaller of the inertial flow (momentum equation) or choked flow. Moody's model also defines the static pressure existing at the throat (limiting flow area).

The discharging fluid thrust (reaction force) is calculated based on the momentum equation applied to the control volume in which the break occurs. (Refer to Reference 5, page 18.

→(DRN 00-1032)

$$\sum F = F_R - F_P = \frac{d}{dt} \int_{c.v.} \frac{\rho v\, dV}{g_c} + \oint_{c.s.} \frac{\rho (v\, dA) v}{g_c}$$

←(DRN 00-1032)

where:

F	= sum of external forces
F_R	= reaction blowdown force
F_P	= pressure force
t	= time
ρ	= density
v	= velocity
c.v.	= control volume
V	= volume
A	= area
g_c	= gravitational constant
c.s.	= control surface

Transposing terms results in the simplified equation

$$F_R = F_a + F_m + F_p \qquad \text{(Reaction Force)}$$

where:

→(DRN 00-1032)

$$F_a = \text{acceleration force} = \frac{d}{dt}\int_{c.v.}\frac{pv.dv}{g_c}$$

$$F_m = \text{momentum force} = \oint_{c.s.}\frac{\rho(v.dA)v}{g_c}$$

←(DRN 00-1032)

F_p = pressure force = $A(P_e - P_a)$

P_e = exit pressure

P_a = ambient pressure

The acceleration force, F_a, component is caused by the change in momentum with time and can be approximated by:

→(DRN 00-1032)

$$Fa = 1\Big/2\ell\,\frac{W_{t+\Delta t} - W_t}{tg_c}$$

←(DRN 00-1032)

where:

t = time

Δt = calculation time increment

ℓ = length of control volume

W = mass flow rate

The momentum force, F_m, represents momentum from the control volume and can be approximated by:
→(DRN 00-1032)

$$Fm = \frac{\rho A v^2}{g_c} = \frac{Wv}{g_c}$$

←(DRN 00-1032)
The velocity, v, is the exit velocity from the break as determined from either Moody's model or the momentum equation previously discussed.

The pressure force, F_p, is given by the equation:

$$F_p = A(P_c - P_a)$$

If the limiting flow (choked flow) is established, P_e is determined by Moody's model. If inertial or unchoked flow exists, $P_e = P_a$ and the pressure force term is equal to zero.

The PRTHRUST computer program incorporates the above equations and solves the time-dependent parameters. Reaction force, flow rates, pressures, fluid energy and other pertinent output parameters are listed as functions of time.

The solution of the PRTHRUST and RELAP programs for the time dependent forces, flow rates, etc. employs correlation's developed by F. Moody to establish critical (choked) flow rates of two phase fluids.(4)

As discussed more extensively in Appendix 3.6B (Section 3.1.4 of that Appendix), it is customary to use a multiplier to the Moody tables to more correctly predict the blowdown rates of two phase fluids discharging from vessels and/or piping systems.

Typically, the value of the Moody multiplier used ranges from 0.6 to 1.0. In the latter case one obtains a generally conservative prediction of the flow rate of the two phase fluid.

In completing the forcing functions for pipe rupture, the Moody multiplier of 1.0 has been utilized. Use of this value of the multiplier is the dynamic equivalent to the use in the static formula KPA of a thrust coefficient of 2.0 for subcooled fluid and 1.26 for two phase of saturated fluid, thus meeting the requirements of MEB3-1 and APCSB3-1.
→(DRN 00-1032)
To illustrate the equivalency of the dynamic and static method, the steady blowdown force derived by dynamic analysis of a frictionless system, and a system with friction can be compared with the static formula KPA.

Reproduced on Figure 3.6-20 is the time behavior of the "wave, thrust" and "blowdown thrust" components as defined by Moody(16) as computed by the method by Moody(16) for
←(DRN 00-1032)

→(DRN 00-1032)

different frictional losses within a simple system, utilizing a mass flow rate out of the break predicted by the Moody correlation[4] with a multiplier of 1.0. The total thrust is the sum of the two components. One can readily see that for zero friction the steady blowdown thrust is identical to that predicted by the formula F_T = KPA where K in this instance equals 1.26 since the fluid is saturated steam. For cases with friction, the thrust at steady blowdown will be lower.

←(DRN 00-1032)

The peak of the thrust force corresponds in this instance to the force predicted by KPA, but with a thrust coefficient corresponding to the values given on Figure 3.6-21 (from Reference 17).

b) Pipe Whip Response Analysis

→(DRN 00-1032)

Analysis performed on the piping/restraint systems (main steam and feedwater) is conducted with the use of computer programs PIPERUP[6] and RAP[7]. PIPERUP analyses include all system nonlinearities and connectivity in addition to a nonlinear representation of restraints. It is used to determine the whip potential of the main steam and feedwater piping systems inside and outside containment.

←(DRN 00-1032)

RAP, which models segments of a piping system as a single degree of freedom system, is primarily used to determine the effects of material property variations in the pipe whip restraints. In addition, an energy balance analysis is performed to determine the consequences of unrestrained pipe whips in the Turbine Building.

c) Pipe Whip Analysis Using PIPERUP

The PIPERUP computer program performs dynamic, nonlinear, elastic plastic analysis of three dimensional piping systems subjected to concentrated static or time history forcing functions. These forces result from fluid jet thrust at the location of a postulated longitudinal or circumferential rupture of high energy piping. The program calculates support reactions, internal forces, moments, and system deflections as a function of time. In addition, strains in each section of pipe which have exceeded the yield criterion are also identified.

PIPERUP is an adaptation of the finite element method to the requirements of pipe rupture analyses. The continuous piping is mathematically modeled as an assembly of weightless structural members connecting discrete nodal points. Nodal points are placed in such a manner as to isolate particular types of piping elements, such as straight runs of pipe, valves, elbows, etc, for which force deformation characteristics may be determined. Nodal points are also placed at all discontinuities, such as piping restraints, branch lines, and changes in cross section. Weight of the system including distributed weight of the piping and concentrated weights (valves, etc) is lumped at selected mass points. An incremental procedure is used to account for the nonlinear deformation and elastic-plastic effect of the pipe and restraints. Typical mathematical models of the main steam and feedwater piping are shown in Figures 3.6-1 through 3.6-6.

→(DRN 00-1032)

The method used in the program to account for the change in piping stiffness during elastic deformation is to represent each member connecting two nodes by three sub-elements in parallel, whose total stiffness equals the elastic stiffness of the pipe. Upon transition from the elastic to the linear strain hardening region, one of the three sub-elements is defined to have a sum stiffness equal to the strain hardening stiffness of the pipe. At the second transition the process is repeated, leaving a single sub-element with a smaller stiffness. Prediction of plastic collapse is based on detection of excessive deflection.

←(DRN 00-1032)

In situations where stress reversal and unloading occurs, an isotropic strain hardening model is used; i.e., unloading is always parallel to the elastic line.

Pipe restraints are modeled in PIPERUP with an initial gap and a trilinear stiffness curve. Again, the first stiffness represents linear elastic behavior, the second stiffness models linear strain hardening, and the third stiffness models perfectly plastic behavior (Figure 3.6-7).

The program uses stiffness and mass proportional damping as follows:

C = (DAMPM) x (M) + (DAMPK) x (K)

where:

C = viscous damping matrices

M = mass matrices

K = stiffness matrices

DAMPM & DAMPK = input constants determining the degree of damping

These constants can be related to critical damping of the system by the following equation:

$$\lambda = \frac{\mathrm{DAMPM}}{2\omega_i} + \mathrm{DAMPK}\ \frac{\omega_i}{2}$$

where:

λ = is the fraction of critical damping

ω_i = natural angular frequency of node i

→(DRN 00-1032)

Inspection of this equation will reveal that DAMPM and DAMPK can be adjusted to meet a given damping criteria, assume two percent of critical, at any two desired frequencies, and that a (conservatively) lower damping value would result between these frequencies. In addition, the effect of DAMPM is greater at lower frequencies and the effect of DAMPK is greater at higher frequencies. Experience has shown that for many piping systems the greatest piping response is in the lower frequencies and optimum solution stability is obtained by specifying sufficient damping for these frequencies.

←(DRN 00-1032)

d) Upper and Lower Bound Material properties

As discussed below, pipe whip analyses are typically performed utilizing both upper and lower bounds of the range of piping stress strain properties. Table 1-6 of Reference 8 is used to determine Young's Modulus as a function of temperature. The lower bound yield stress utilized was determined from Reference 7 (Table I-2.1), while the lower bound ultimate stress was determined from Reference 9. Ultimate strain, defined as that strain at which maximum stress occurs, is taken as 16 percent, based on stress-strain curves for low carbon steel tested at high strain rates as discussed in Reference 10.

Maximum strain for lower bound is taken as 50 percent of normal ultimate strain.

Consideration was given to variations in stress strain properties encountered in piping materials. The particular properties used in an analysis will influence both the prediction of pipe whip and the values calculated for impact force on piping restraints. It has been found that the statistical "lower bound" of the pipe's stress strain curve will provide the weakest and most flexible piping system possible, and is conservative for the prediction of pipe whip. The statistical "upper bound" of the piping stress strain curve may in some cases result in maximum restraint loads and in other cases may not. Therefore, for each rupture location selected for pipe whip analysis, a judgmental evaluation is made to determine whether "upper bound", or "lower bound", or both pipe material properties should be utilized.

The mechanism utilized for selection of analysis cases and the input data for these cases are presented in break location evaluation summaries. At each postulated break location the break type and direction is specified.

e) Pipe Whip Analyses Using RAP

The RAP program performs a time step integration solution of the dynamic equilibrium equation for a mass (the pipe) subjected to a force time history (the blowdown force) impacting a bilinear strain hardening viscous-damped spring (the restraint). The solution makes use of kinematic relationships between accelerations, velocities and displacements at the beginning and end of each time step to reduce the second order differential equation of motion to a form-which may be solved algebraically over the time increment (References 11 and 12).

The incremental equilibrium equation for the system shown in Figure 3.6-8 is the following:

$$M\,\Delta X + C\,\Delta X + K\,\Delta X = \Delta F \qquad (1)$$

where:

M = effective mass of pipe

C = viscous damping coefficient

K = restraint stiffness

F = applied blowdown force

X = displacement

Δ = an increment of the succeeding quantity

→(DRN 00-1032)

. = Superscript indicating derivative with respect to time

←(DRN 00-1032)

In addition, if the acceleration of the mass is assumed to change linearly over a time step, the following relationships can be written:

→(DRN 00-1032)

$$\Delta \ddot{X}_{N+1} = \frac{6}{DT^2}\,\Delta X_{N+1} - \frac{6}{DT}\,\dot{X}_N - 3\ddot{X}_N \qquad (2)$$

$$\Delta \dot{X}_{N+1} = \frac{3}{DT}\,\Delta X_{N+1} - 3\dot{X}_N - \frac{DT}{2}\,\dot{X}_N \qquad (3)$$

←(DRN 00-1032)

where the subscript "N" represents a quantity taken at the "Nth" time step and DT is the length of the time step. If Equations (2) and (3) are substituted into Equation (1), the result is

→(DRN 00-1032)

$$\left\{\frac{6M}{DT^2} + \frac{3C}{DT} + K\right\} AX_{N+1} = \Delta F + \left\{\frac{6M}{DT} + 3C\right\}\dot{X}_N + \left\{3M + \frac{DT(C)}{2}\right\}\ddot{X}_N$$

which can be solved for ΔX_{N+1}, since $\dot{X}_N$ and $\ddot{X}_N$ are known initial conditions at the beginning of the time step. Having ΔX_{N+1}, Equations (2) and (3) can be used to determine the change in acceleration and velocity during the time increment. At each step during the incremental process, the status of the restraint is checked to determine whether it is detached, elastically loading, plastically loading or elastically unloading, and appropriate changes are made to the initial gap, yield deflection and restraint stiffness.

←(DRN 00-1032)

The restraint loads are considered conservative since the energy adsorption capability of the piping system and the damping in the system are neglected.

3.6.2.2.3 Analytical Methods to, Define Forcing Functions And Response Model For All High Energy Systems (except Main Steam, Feedwater and Reactor Coolant Loops) - Inside and Outside Containment

The methods utilized to define the forcing functions and response model for all high energy systems (except main steam, feedwater and reactor coolant loops), both inside and outside containment meet the requirements of MEB 3-1 and APCSB 3-1 and are discussed in detail in Appendix 3.6B.

Normal operating conditions at 100% power were assumed in developing the forcing functions for these high energy systems.

3.6.2.3 Dynamic Analysis Methods to Verify Integrity and Operability

3.6.2.3.1 RCS Main Loop Piping and Components

→(DRN 03-2056, R14)

The analytical methods used to determine the reaction loads on RCS main loop piping and components due to postulated MCLBs are as presented in Reference 1. Since the MCLBs have been eliminated by LBB, the effect on the RCS of BLPBs under power uprate conditions has been evaluated. The resultant loads on piping and components are included in the design specifications for combination with other appropriate Faulted Condition loadings.

→(EC-19087, R305)

The results of the piping dynamic analyses due to MCLBs also included the reaction loads on RCS pipe whip restraints. The results for BLPBs under power uprate conditions demonstrate that BLPBs do not cause the main coolant loop pipes to engage the existing RCS pipe whip restraints. The pressurizer surge line has also been removed as a possible break location under LBB.

←(DRN 03-2056, R14; EC-19087, R305)

3.6.2.3.2 High Energy Piping Dynamic Analysis

Pipe breaks are postulated in high energy piping in accordance with the criteria in Subsection 3.6.2.1. The analyses for determining the dynamic effects of pipe break are performed using the techniques discussed in Subsection 3.6.2.2.3. Descriptions of the applicable measures to protect against pipe whip and blowdown jet impingement forces are given in Subsection 3.6.1.2.

3.6.2.3.3 Pipe Whip Restraint Design Criteria

a) Design Bases

The pipe break locations and orientation are determined in accordance with Subsection 3.6.2.1. For each postulated pipe break, the possible effects of the break are investigated and, if necessary (per Subsection 3.6.1.2), restraints are provided to prevent pipe whip. Functional requirements are discussed in listing b) below:

b) Functional Requirements

The pipe whip restraints for the RCS main loop piping are designed such that there will be no unacceptable deformation of the RCS piping. Other high energy pipe whip restraints are designed to ensure that the pipe whip will be eliminated or minimized. On the other hand, the restraints are designed to permit the predicted thermal and seismic movements of the pipes.

c) Design Parameters

After the pipe restraint locations are identified, the following design parameters are determined:

1) Jet thrust force

2) Pipe seismic displacements

3) Pipe thermal displacements

4) Pipe insulation thickness

5) Maximum allowable pipe travel

The jet thrust force and maximum allowable pipe travel are used in the analysis process.

Insulation and seismic and thermal movements are used in determining the minimum gap between the restraint and pipe surfaces.

Typical sketches of the various pipe whip restraints to be used are shown in Figures 3.6-9 to 3.6-11.

The design loading combination considered for the design of pipe whip restraints, which are within ASME Code allowables is as follows:

Load Combination	Dead Weight of Restraint + Pipe Rupture Load + Jet Impingement (if applicable) + SSE

3.6.2.3.4 Jet Impingement

The geometry of the jet stream, its pressure distribution and the temperature distribution, depend on the properties of the discharged fluid, the surrounding medium, and the fluid conditions at the exit plane, i.e., choked or unchoked flow.

Two types of breaks and three kinds of jet development are considered. For jets emerging out of breaks where the flow is unchoked (typically nonflashing water) the theory of free submerged jets applies(14). For choked flow at the exit plane (typically flashing water and/or wet steam) the jet streams are based on work by F.J. Moody(13).

a) Guillotine break jet development: This break is perpendicular to the pipe axis with complete severance and lateral separation of at least one pipe diameter between the two ends. This results in the development. of two free and clear jets whose shape is dependent on the fluid phase (see Figures 3.6-12 and 3.6-14).

b) Guillotine break with limited separation jet development: This special case of a jet development is due to the relative position of the two pipe ends. For this kind of jet development, dynamic analysis must prove that with respect to each other, the pipe ends remain within the following bounds:

→(DRN 06-913, R15)

axial separation	≤ 0.5 inside diameter
lateral separation	≤ 0.5 inside diameter
area of break	≤ twice the pipe flow cross-sectional area

←(DRN 06-913, R15)

→(EC-29816, R306)

The jet which develops from this case is shown in Figure 3.6-13. This type of jet will have a lower impingement pressure then the jets described in items a) and c) at equal distances from the break plane because the jet area perpendicular to the pipe centerline is much larger. This type of jet development was utilized only for RCS loop breaks. With the elimination of main loop RCS breaks based on leak-before-break (see Section 3.6.3) and the corresponding elimination of the restraint requirements for whip restraints on the main loop RCS, limited separation breaks are no longer applicable for the RCS. Pipe end separation for these cases is defined in Reference 1.

←(EC-29816, R306)

c) Longitudinal break jet development: This break is an axial split of circular or elliptical shape whose break area is equivalent to the effective cross-sectional flow area of the pipe at the break location. The resultant jet development is dependent on the fluid phase (see Figures 3.6-12 and 3.6-14).

Only two non-concurrent jets are assumed at longitudinal break locations, both for analyzing jet effects and for the design of pipe whip restraints. These jets will be diametrically opposed and cause the worst out of plane bending.

The jet impingement force on a target is then calculated from:

$$F = \frac{F_j}{A_j} \quad A_x \, G \, (DLF)$$

where:

→(DRN 00-1032, R11-A)

DLF = dynamic load factor

←(DRN 00-1032, R11-A)

A_x = impacted area of the target (sq. ft.)

G = geometric shape factor

A_j. = cross sectional area of jet at the target distance from break plane (sq. ft.)

F_i = total jet impingement force at the break plane (lbf.)

The jet stream for wet steam and saturated water will be divided into three regions, as indicated in Figure 3.6-12. In region 1, the jet opens up with a half-angle of 45 degrees for a distance of five D, where D is the inside diameter of the broken pipe. Region 2 extends uniformly from five D to approximately 25.5 D, at which points region 3 begins as a cone whose apex at the break plane has a half-angle of 10 degrees. Region 3 extends from 25.5 D to the end of the jet.

For region 1:

$F_{j.} = KPA$ where: K = 2.0
P = operating fluid pressure
A = cross-sectional flow area

For regions 2 & 3:

$F_j = KP_{sat}A$ where: K = 1.26

→(DRN 00-1032, R11-A)

P_{sat} = saturation pressure @ operation fluid temperature

←(DRN 00-1032, R11-A)

A = cross-sectional flow area

The jet streams developed by dry steam and nonflashing water are indicated in Figure 3.6-14. For these two types of fluids:

$F_j = KPA$ where: K = 1.26 for dry steam or 2.0 for nonflashing water
P = operating pressure
A = cross-sectional flow area

Fluid	Apex Angle
Dry Steam	22 degrees
Nonflashing Water	10 degrees

For guillotine breaks which have limited separation (see Figure 3.6-13):

→(DRN 00-1032, R11-A)

Steam of Quality >99 Percent (For all regions, from r=o to r=∞)

$F_{j.} = KPA_o$ where: K = 1.26
p = operating pressure
A_o = break area

←(DRN 00-1032, R11-A)

Flashing Fluids and Steam-Water mixtures (Quality <99 percent)

→(DRN 06-913, R15)

In the initial asymptotic region, from r=o to r=r ^{jet}

←(DRN 06-913, R15)

→(DRN 00-1032, R11-A)

$F_j = KPA_o$ where: K = 2.0
P = operating pressure
A_o = break area

→(DRN 06-913, R15)

In the subsequent asymptotic region, from $r = r^{jet}$ to $r = \infty$

$F_j = KP_{sat}A$ where: K = 1.26

←(DRN 06-913, R15)

P_{sat} = saturation pressure @ operating fluid temperature

←(DRN 00-1032, R11-A)

A = break area

These jet streams are then analyzed to determine what components are being hit. Those pieces of equipment which are essential for the safety of the plant are then either qualified with the jet loading or are protected from the jet impingement forces by the methods described in Subsection 3.6.1.2.

The design loading combinations and allowable stress limits for essential components which fall under the ASME Code are as follows:

Load Combination	Plant Operating Condition	Allowable Stress
→(DRN 00-1032, R11-A)		
Normal Operating + SSE + Jet Impingement	Faulted	≤ 3 Sm (safety class 1) ≤ 2.4 Sh (safety classes 2 and 3)
←(DRN 00-1032, R11-A)		

where: Sm = design stress intensity (NB-3600 of ASME III)

Sh = allowable stress at maximum (hot) temperature (NC-3600 of ASME III)

→(DRN 00-1032, R11-A)

All other essential components (e.g., conduit, junction boxes, instrumentation cabinets) with jet impingement loads are evaluated on a case basis. For results of the jet impingement analysis, see Appendix 3.6A.

←(DRN 00-1032, R11-A)

3.6.2.4 Guard Pipe Assembly Design Criteria

Guard pipes are supplied for Types I, III, IV, V, VI and certain modified Type II piping penetration assemblies as discussed in Subsection 3.8.2. The guard pipe on the Type I penetration is inside of and separate from the containment nozzle. The guard pipes for the other types of penetrations are welded to the containment nozzle.

In the event of a process line rupture or pipe whip, the guard pipe will protect the rest of the penetration assembly and other penetrations in the near proximity from steam impingement, jet forces, or deflection while directing the released fluids into the containment. Moment limiting restraints are shown on pipe rupture figures given in Appendix 3.6A.

On Type I penetrations, the guard pipe serves to limit pressurization of the annulus. On Types IV, V, and VI penetrations, the guard pipe serves to provide an extension of the containment. The guard pipe for Type III and certain modified Type II penetrations serves both as an extension of the containment and to prevent overpressurization of the annulus.

The entire penetration assembly is designed to meet the requirements of ASME, Boiler and Pressure Vessel Code, Section III, Subarticle NE-1120, Winter 1973 addenda.

The penetration assemblies are designed to meet the load combinations as indicated on Figures 3.6-15 through 3.6-19. The pressures, temperatures and design loads are given in Table 3.6-1.

The pipe weight load stress, (w), is 1.5 ksi for all penetrations except for the fuel transfer tube where dead weight loads are used.

The stuck carriage load for the fuel transfer tube (Cs) is 20 kips. Seismic load due to the interaction with the piping system (EP) consist of the following components:

	Operating Basis Earthquake (OBE)	Safe Shutdown Earthquake (SSE)
Axial Load	EPA	EPA'
Transverse Load	EPT	EPT'
Bending Moment	EPM	EPM'
→(DRN 00-1032)		
Torsional Moment	EPTO	EPTO
←(DRN 00-1032)		

Seismic loads associated with the fuel transfer tube are based on the following conditions due to the penetration interaction with the building structures:

OBE load of .25 g horizontal and .25 g vertical

SSE load of .40 g horizontal and .30 g vertical

The horizontal and vertical loads are considered as acting simultaneously.

The pipe rupture loads (PR) consist of the following components:

Axial Load	PRA
Transverse Load	PRT
Bending Moment	PRM
→(DRN 00-1032)	
Torsional Moment -	PRTO
←(DRN 00-1032)	

The jet impingement loads (J) consist of the following components:

Impinging Force on Guard Pipe	JGT
Bending Moment on Process Pipe	JPM
Transverse Load on Process pipe	JPT

The thermal loads transmitted from the piping (T) consist of the following components:

Axial Load	TA
Transverse Load	TT
Bending Moment	TM
→(DRN 00-1032)	
Torsional Moment -	TTO
←(DRN 00-1032)	

The tornado load (Z), acting on the portion of the penetration assembly located outside, is a 2.5 psi up-lift load.

The explosion load (D) is a function of the projected area of the penetration verses time.

All process piping in the penetrations is constructed of seamless piping except the piping in HVAC penetrations 10 and 11 which is welded (note, these penetrations convey air only and are not high energy). The process pipe is designed for the various pressures, temperatures, and loads due to all operating conditions associated with the piping system. Those loads are summarized in Figure 3.8-3. Table 3.6-2 contains a list of the material used for the process lines with their respective allowable stress levels.

The flued head for all Type I, II and III piping penetrations is fabricated from a one piece forging. The flued head is designed to withstand the various pressures, temperatures and loads that are expected.

Type I penetration assemblies have, as an integral part of the flued head, trunnions which serve as an anchor and are supported by the Reactor Auxiliary Building, so as not to impose undue stresses on the containment vessel. The trunnion serves as an anchor against the forces and moments generated by the piping configuration.

The bellows expansion joints serve two general functions. They provide for the passage of process pipes into the containment while maintaining a leak tight seal between them and they absorb relative movements (thermal and/or seismic) between the containment vessel, shield Building and/or the process piping.

Bellows assemblies located between the containment vessel and the flued head are designated as primary bellows. Those bellows assemblies located between the shield wall and the flued head are designated as secondary bellows.

The primary bellows assemblies are designed to withstand the containment pressure and temperature after a loss of coolant accident. The secondary bellows assemblies are designed for a five psig differential pressure at a temperature of 180 F. The bellows are designed to withstand a 40 year lifetime total of 7000 cycles of expansion and compression due to maximum operating conditions and an additional 200 cycles of design seismic movements.

The fuel transfer tube assembly bellows, inside the Fuel Handling Building is under water during normal refueling conditions and shall be subject to a 33 ft. head of water.

Sections 6.6 and 16.4 discuss in-service inspection requirements for penetrations.

3.6.2.5 Material to be Submitted for the Operating License Review

3.6.2.5.1 RCS Main Loop Piping

➔(DRN 03-2056, R14)

This subsection presents a summary of the dynamic analyses applicable to the RCS main loop piping and component supports that determine the loadings resulting from postulated pipe breaks.

a) Implementation of the stress survey criteria in Subsection 3.6.2.1.1.1 resulted in the postulation of a MCLB location at the terminal ends of each leg of the RCS main loop piping and at two of the three intermediate elbows in each of the pump suctions legs. The plant operating condition transients that were used in these stress analyses are as presented in Reference 1. Implementation of the detailed finite-element stress analysis criteria in Subsection 3.6.2.1.1.1 resulted in the postulation of a longitudinal type pipe break at each elbow break location, oriented with +/-90 degrees circumferentially from the crotch of the elbow. Detailed results are presented in Reference 1.

➔(EC-19087, R305)

The subsequent elimination of MCLBs via LBB resulted in the postulation and evaluation of the effect of BLPBs under power uprate conditions. The tributary piping in which pipe breaks were postulated are listed in Subsection 3.6.2.1.1.1 (d). The pressurizer surge line was subsequently eliminated as a potential pipe break location under LBB.

🡐(EC-19087, R305)

b) The design basis MCLB sizes, with the exception discussed in Subsection 3.6.2.1.1, are as presented in Reference 1. These break sizes were based upon implementation of Reference 1 methodology for the set of pipe whip restraints used in Waterford 3.

All postulated BLPBs evaluated were full area breaks with a flow area rise time of 1 millisecond.

c) The time varying forcing functions that were used for MCLBs and the time varying responses of the RCS main loop piping are as presented in Figure 16, 25, and 27 through 30 of Reference 1.

For BLPBs analyses, forcing functions representing thrust and jet impingement loads were conservatively characterized as attaining full load in 1 millisecond, thereafter maintaining full load while the time varying blowdown event was completed.

d) The resultant reaction forces at all affected RCS main loop components and supports were included in the respective design specifications. Issuance of the final stress report certifying design adequacy with all Code requirements assured acceptability of the loadings resulting from postulated pipe breaks.

Addenda to all stress reports were prepared, certifying continued design adequacy of RCS components for power uprate to 3716 MWt.

e) Stress levels within the RCS main loop piping are as presented in Chapter 3.4 of Reference 1 for various plant operating conditions.

🡐(DRN 03-2056, R14)

➔(EC-8433, R307)

As part of replacing the steam generators that was performed during RF18, each of the four RCS cold leg "B" and "C" series pipe stops were modified and the shim packs from upper, middle and lower elevation RCP structural stops for all four RCPs were permanently removed in order to delete their pipe rupture restraint function. With the application of Leak-Before-Break (LBB), the RCS piping rupture restraint

🡐(EC-8433, R307)

→(EC-8433, R307)
function of these supports is no longer required. These as-modified RCS piping rupture restraints have been evaluated to remain unloaded from the dynamic effects of postulated branch line pipe breaks.
←(EC-8433, R307)

3.6.2.5.2 Non-NSSS Piping

The results of the analyses performed on piping systems are contained in Appendix 3.6A.
→(DRN 03-2056, R14; EC-19087, R305)

3.6.3 LEAK-BEFORE-BREAK EVALUATION

This section describes the Leak-Before-Break (LBB) analysis for the main coolant loop (MCL) piping, hot and cold legs and pressurizer surge line. LBB analysis is used to eliminate from the structural design bases the dynamic effects of double-ended guillotine breaks and equivalent longitudinal breaks.

3.6.3.1 Applicability of Leak-Before-Break

MCL and pressurizer surge line piping systems for which LBB is demonstrated are first shown to meet the applicability requirements for NUREG-1061, Volume 3 (Reference 19). The current NRC accepted guidance for application of leak-before-break is contained in Standard Review Plan (SRP) 3.6.3 (Reference 25) which was used for elimination of the pressurizer surge line dynamic protection. Specifically, the points considered for applicability for LBB are:
←(EC-19087, R305)

1. Regulatory requirements – level of susceptibility of failure from erosion, erosion/corrosion, corrosion/cavitation, waterhammer, creep fatigue, corrosion resistance, indirect causes, cleavage type failure, and fatigue cracking.

→(EC-19087, R305)

2. Technical requirements – pipe properties, normal operation, and seismic load levels. Topical Report CEN-367-A (Reference 20) describes the applicability of LBB for the Waterford 3 main loop piping. WCAP-17187-P (Reference 24) provides the analytical basis for eliminating the dynamic protection of the pressurizer surge line under LBB.

3.6.3.2 Leak Detection

In order to apply the LBB concept to eliminate consideration of breaks in the RCS piping, leakage detection systems must be capable of detecting RCS leakage before it approaches the leakage rate associated with a critical-sized crack. There are two major aspects to leak rate detection that are based on crack detection in addition to the crack opening size: leak detection capability and flow rate correlation for leakage through a crack.

3.6.3.2.1 Leak Detection System

Waterford 3 has an installed leakage detection system that meets the requirements of Regulatory Guide 1.45 (Reference 21). The determination of acceptability for the RCS leakage detection system for the pressurizer surge line LBB analysis was based on Revision 1 of Regulatory Guide 1.45 (Reference 23). Section 5.2.5 describes the leak detection systems in detail.

3.6.3.2.2 Flow Rate Correlation

The flow rate correlation for leakage through a given crack size cannot be predicted precisely. Variables such as surface roughness of the side walls of the crack, the nonparallel relationship of the side walls due to the elongated crack shape, and possibly zigzag tearing of the material during crack formation, all introduce uncertainties in defining an exact flow rate correlation. References 20 and 24 describes the flow rate correlation in detail.
←(EC-19087, R305)

3.6.3.3 Material Properties

The main loop piping material is SA516Gr70. All hot and cold leg pipe-to-pipe welds and pipe-to-reactor vessel and steam generator safe ends are carbon steel welds. The pump case is 304 stainless steel, causing the pipe to pump safe end weld to be a bimetallic weld. The detailed analyses of cracks in pipe welds require consideration of the properties of the pipe and weld materials. Section 7.1 of Reference 20 describes the material properties applicable to the LBB evaluation.

←(DRN 03-2056, R14)

→(DRN 03-2056, R14; EC-19087, R305)

The Waterford 3 surge line piping system is fabricated from Schedule 160 pipe made of cast austenitic stainless steel (CASS) SA-351 CF8M material. The weld processes used to fabricate the surge line are a combination of Gas Tungsten Arc Welding (GTAW) and Shielded Metal Arc Welding (SMAW). The safe-ends are welded to the hot leg surge nozzle and pressurizer surge nozzle containing Alloy 82/182 metal. The Alloy 82/182 welds have been mitigated by structural weld overlays (SWOLs) using Alloy 52M weld material. Section 4 of Reference 24 provides details of the material property evaluation performed for the surge line.

3.6.3.4 Leakage Crack Length Determination

Hypothetical through-wall cracks must open significantly to allow detection by normal leakage monitoring under normal full power loading. The method for determining the appropriate leakage crack length is described in References 20 and 24.

3.6.3.5 Stability Evaluations

The stability evaluations, including determination of crack size and detail J-integral calculation, are described in References 20 and 24.

3.6.3.6 Results

The evaluations performed confirm that the bases for the LBB acceptance criteria are satisfied by the as-built design and materials of the MCL and surge line piping system. References 20 and 22 identify the acceptability of applications of LBB to the Waterford 3 main loop piping. References 24 and 26 provide the acceptability of applications of LBB to the Waterford 3 pressurizer surge line.

3.6.3.6.1 Applicability of LBB under Extended Power Uprate to 3716 MWt

Compliance with all LBB criteria for eliminating MCLBs was found to be unaffected by Waterford 3 power uprate to 3716 MWt. Piping load revisions were found to be within the envelope loads employed in the CEN-367-A evaluation, and the criteria with respect to materials, stress corrosion, water hammer and fatigue of the main loop piping, as well as leak detection, are unaffected by power uprate. Therefore, the evaluations of the Reference 20 are applicable for Waterford 3 with power uprate to 3716 MWt. The pressurizer surge line LBB analysis was performed after the power uprate and applied updated power uprate loadings under 3716 MWt as reported in Reference 24.

Following the application of LBB to exclude the dynamic (mechanical) effects of MCL and surge line breaks, the next limiting set of pipe breaks with respect to dynamic effects on the RCS consists of the remaining primary and secondary side branch line pipe breaks (BLPBs) interfacing with the RCS. Of these, the controlling breaks with respect to RCS response are breaks in the largest tributary pipes. Breaks in these pipelines are postulated and evaluated under power uprate conditions. The RCS is evaluated for BLPBs under power uprate conditions in the following pipelines:

a) main steam line
b) feedwater line
c) safety injection line
d) shutdown cooling line

←(DRN 03-2056, R14; EC-19087, R305)

SECTION 3.6: REFERENCES

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3- C.A. Meyer, et. al., "1967 ASME Steam Tables - Thermodynamic and Transport Propert1Es of Steam", New York: ASME, 1967.

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→(DRN 03-2056, R14)

18- General Design Criterion 4, “Environmental and Missile Design Bases”.

19- NUREG 1061, Volume 3 “Evaluation of Potential for Pipe Breaks”, November 1984.

←DRN 03-2056, R14)

→(DRN 03-2056, R14)

20- Topical CEN-367-A, Revision 000, “Leak-Before-Break Evaluation of Primary Coolant Loop Piping in Combustion Engineering Designed Nuclear Steam Supply Systems”, prepared for the C-E Owners’ Group, February 1991.

21- USNRC Regulatory Guide 1.45 “Reactor Coolant Pressure Boundary Leakage Detection Systems”, May 1973.

22- SER-055, Revision 000, “Acceptance for Referencing of Topical Report CEN-367, ‘Leak-Before-Break Evaluation of Primary Coolant Loop Piping in Combustion Engineering Designed Nuclear Steam Supply Systems’”, J.E. Richardson (NRC) to E.C. Sterling III, dated October 30, 1990, with Enclosure 1 (Safety Evaluation by NRC).

←(DRN 03-2056, R14)

→(EC-19087, R305)

23- Regulatory Guide 1.45, Revision 1, “Guidance on Monitoring and Responding to Reactor Coolant System Leakage” (May 2008).

24- WCAP-17817-P, “Technical Justification for Eliminating Pressurizer Surge Line Rupture as the Structural Design Basis for Waterford Steam Electric Station, Unit 3 Using Leak-Before-Break Methodology” (February 2010).

25- NUREG-0800, Standard Review Plan, Section 3.6.3, “Leak-Before-Break Evaluation Procedures”, Revision 1 (March 2007).

26- Waterford License Amendment 232, “Approval of Leak-Before-Break of the Pressurizer Surge Line”, dated February 28, 2011.

←(EC-19087, R305)

TABLE 3.6-1 (Sheet 1 of 2) Revision 11-A (02/02)

GUARD PIPE ASSEMBLY DESIGN CRITERIA

P_C	- Containment Pressure, Ambient; 14.7 psia (0 psig)
T_C	- Containment Temperature, Ambient; 120 F
P_{CL}	- Containment Pressure After LOCA: 44 psig
T_{CL}	- Containment Temperature After LLOCA, 263 F
P_D	- Process Line Design Pressure; As Required
T_D	- Process Line Design Temperature; As Required
P_O	- Process Line Maximum Operating Pressure; As Required
T_O	- Process Line Maximum Operating Temperature; As Required
P_G	- Guard Pipe Internal Pressure, Ambient; 14.7 psia (0 psig)
T_G	- Guard Pipe Internal Temperature, Ambient; 120 F
P_{GL}	- Guard Pipe Internal Pressure After LOCA; 263 F (Containment Design Internal Temp)
T_{GL}	- Guard Pipe Internal Temperature After LOCA; 263 F (Containment Design Internal Temp)
→(DRN 00-1032)	
P_{GR}	- Guard Pipe Internal Pressure After Rupture of Process Pipe Inside the Penetration; Equal to P_o
T_{GR}	- Guard Pipe Internal Temperature After Rupture of Process Pipe Inside the Penetration; Equal to T_o
←(DRN 00-1032)	
P_A	- Annulus Pressure, Normal; -8.0 in. WG
T_A	- Annulus Temperature, Normal; 120 F Max
P_{AL}	- Annulus Pressure After LOCA; @ t = 5 minutes, 13.6 psia @ t = 60 minutes, 14.6 psia
T_{AL}	- Annulus Temperature After LOCA; @ t = 5 minutes, 120 F @ t = 60 minutes, 180 F
T_{AB}	- Reactor Auxiliary Building Ambient Temperature; 50 F to 120 F
P_{AB}	- Reactor Auxiliary Building Ambient Pressure Range; -2.0 to +2.0 in. WG
T_{FB}	- Fuel Handling Building Ambient Temperature; 50 F to 120 F

TABLE 3.6-1 (2 of 2)

GUARD PIPE ASSEMBLY DESIGN CRITERIA

P_{FB} - Fuel Handling Building Ambient Pressure Range; -2.0 to +2.0 in. WG

T_{OS} - Outside Ambient Temperature; 0 to 102 F

P_{OS} - Outside Pressure, Normal 14.7 psia (0 psig)

Z - Outside Pressure, Tornado 2.5 psi uplift

P_W - Waterhead, Refueling Cavity/Refueling Canal 33 ft.

T_W - Refueling Cavity/Refueling Canal Water Temp. 135 F

Note:

Containment Leakage Rate Test Pressure = 44 psig

TABLE 3.6-2

MATERIAL USED FOR PROCESS LINES
WITHIN GUARD PIPE

Penetration No.	Material	Allowable Stress Level lb_f/sq. in.
1, 2, 3, 4	SA-106 Gr C	17500
5, 6, 8, 9, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 31, 45, 46, 47, 48, 52, 60, 61, 63, 68	SA-106 Gr B	15000
7, 42, 50, 51, 53 54, 59, 65, 66, 67	SA-312 TP 304 (seamless)	17800
27, 34, 35, 43, 49, 62	SA-312 TP 304 (seamless)	16600
26, 28, 36, 37, 38, 39, 40, 41, 44, 55, 56, 57, 58, 69, 70	SA-312 TP 304 (seamless)	15900
29, 30	SA-312 TP 304	15600
10, 11, 25	SA-155 KCF-70 CL 1	17500
25	SA-358 CL1 TP 316	18800
32,33	SA-376 TP 304	16600

TABLE 3.6-3

TRUNNION WELDED ATTACHMENTS BETWEEN CONTAINMENT ISOLATION VALVES

PENETRATION NUMBER	LINE NUMBER	HANGER MARK NUMBER	CALCULATION NUMBER	POINT NUMBER
1	2-MS-40-163A 2-MS-40-5A 2-MS-40-164A	MSRR-241, 242, 243, 244	1030	1701, 2101, 2599, 2801
2	2-MS-40-165B 2-MS-40-34B 2-MS-40-166B	MSRR-247, 248, 249, 250	1030	1985, 2021, 2065
17	2-CC-8-8-88A1	CCRR-1522, 1500, 1519	2687	1761, 189, 183
20	2-CC-8-157A2	CCRR-1506	2683	831
21	2-CC-8-158B1	CCRR-1377, 1509	2692	45, 358
22	2-CC-8-91B1	CCRR-1369	2691	14
34A, B	2-CS-10-12A	CSSH-311, 289, 385, 314	1065, 1029-6	4365, 434, 417, 4101
35A, B	2-CS-10-12B	CSRR-356, CSA-384	1029-4, 1073	3061, 3
36	2-SI-8-113RL1A	SIRR-391, SISH-406	1029-1	195, 1951
37	2-SI-8-122RL1B	SISH-405	1029-1	1021
38	2-SI-8-130RL2A	SISR-961, SISH-147, SIRR-939	1029-2	1752, 175, 1745
39	2-SI-8-138RL2B	SIRR-969	1029-2	1225
55	2-SI-3-115RL1A	SIRR-408, 410	1056-5	2039
56	2-SI-3-124RL1B	SIRR-381, 380, SISR-848	1056-1	1801
57	2-SI-3-132RL2A	SISH-126, SIRR-929	1056-3	1431, 1311
60	2-FP-3-44	FPRR-253	2702-2	32
69	2-SI-3-204	SIRR-1052, 1049, 1048	2593	542, 5631, 5311
70	2-SI-3-208	SIRR-1057, 1423, SISH-1108	2592	510, 16, 1400

TABLE 3.6-4 (Revision 309 06/16)

SHEAR LUG WELDED ATTACHMENTS BETWEEN CONTAINMENT ISOLATION VALVES

PENETRATION NUMBER	LINE NUMBER	HANGER MARK NUMBER	CALCULATION NUMBER	POINT NUMBER
→(LBDCR 14-026, R309)				
3	2-FW-20-12A	FWSH-4, 9, FWRR-5	1031	700, 120, 9
4	2FW-20-14B	FWSH-16, FWSR-21	1032	9110, 9060
←(LBDCR 14-026, R309)				
15	2CC-8-158B2	CCRR-1513	2693	121
16	2CC-8-91B2	CCRR-652	2500	9100
18	2-CC-8-157A1	CCRR-1352, 1358	2685	22, 34
20	2CC-8-157A2	CCRR-1325, 1328	2683	9605, 103
21	2CC-8-158B1	CCRR-1382	2692	53
34A, B	2CS-10-12A	CSSH-312	1065	417
40	2SI-14-18B	SIRR-1335	1020	305
41	2SI-14-18A	SIRR-1123	1024	2905
61	2FP-3-47	FPRR-244	2709-1	8
59	2SI-2-80A/B	SISR-1125	1134	2351
19	2CC-8-88A2	CCRR-1333, 1338, 1507	2684	73, 86, 681
71	2DW-1-1/2-78	DWRR-136	2729	8

TABLE 3.6-5 (Sheet 1 of 10) Revision 15 (03/07)

CALCULATED STRESSES IN ASME CODE CLASS 1 PIPING SYSTEMS

→(DRN 99-2063, R11)

Break No.	Calc No.	Point No.	* Sn	* Ke	3Sm	* CUF	Material	* Primary Stress Intensity	* Peak Stress
Pressurizer Spray (Figures) 3.6A-38, -38a, -38b									
R-HRC-16A/B-1	* 2606	278 (Ter. End)	39,848	1.0000	50,421	0.0000	A-376 TP304H	7,515	58,091
R-HRC-16A/B-2	* 2606	272	20,946	1.000	50,421	0.0000	A-376 TP304H	7,563	23,081
R-HRC-14A-7	* 2606	280	19,962	1.0000	50,421	0.0000	A-376 TP304H	8,408	21,373
R-HRC-12A-8	* 2606	282	25,545	1.0000	50,421	0.0000	A-376 TP304H	8,329	45,574
R-HRC-12A-9	* 2606	305 (Ter. End)	21,509	1.0000	50,421	0.0000	A-376 TP304H	6,401	37,883
R-HRC-15B-3	* 2606	323	21,688	1.0000	50,421	0.0000	A-376 TP304H	9,378	23,102
R-HRC-15B-4	* 2606	325	26,073	1.0000	50,421	0.0000	A-376 TP304H	8,224	46,895
→(DRN 06-883, R15)									
R-HRC-13B-5	* 2606	327	(see latest stress analysis calculation)				A-376 TP304H	7,159	
←(DRN 06-883, R15)									
R-HRC-13B-6	* 2606	353	24,796	1.0000	50,421	0.0000	A-376 TP304H	6,920	46,100
CVCS - Letdown (Figure 3.6A-27)									
R-HRC-43A/B-1	1206	48 (Ter. End)	38,096	1.0000	50,520	0.0000	A-376 TP304H	5,727	46,636
R-HRC-49RL2B-2	1206	49	14,035	1.0000	50,520	0.0000	A-376 TP304H	5,995	23,750

* NOTE: Stress intensities, cumulative usage factors, and the primary and secondary stress ranges at the break location(s) represents a historic summary of data developed to select postulated break locations. The postulated break locations and configurations are current. However, the supporting data should not be used as a reference for the state of stress at the subject locations. For the current state of stress in the piping system, refer to the pipe stress analysis calculations.

←(DRN 99-2063, R11)

TABLE 3.6-5 (Sheet 2 of 10) Revision 15 (03/07)

CALCULATED STRESSES IN ASME CODE CLASS 1 PIPING SYSTEMS

→(DRN 99-2063, R11)

Break No.	Calc No.	Point No.	* Sn	* Ke	3Sm	* CUF	Material	* Primary Stress Intensity	* Peak Stress
R-HCH-58A/B-4	1206	17	57,304	1.448	50,520	0.0017	A-376 TP304H	5,881	97,482
R-HCH-59A/B-4	1206	1 (Ter. End)	20,714	1.000	50,520	0.0000	A-376 TP304H	12,295	35,377
CVCS - Charging (Figures 3.6A-36 and -36C									
R-HCH-56A/B-23	1271-2	180	31,841	1.0000	53,019	0.0000	A-376 TP304H	8,941	49,057
R-HCH-57A/B-22	1271-2	182	42,016	1.0000	56,100	0.0002	A-376 TP304H	8,686	66,948
→(DRN 06-883, R15)									
R-HCH-57A/B-21	1271-2	183	(see latest stress analysis calculation)				A-376 TP304H	5,986	
←(DRN 06-883, R15)									
R-HRC-55A-/B-20	1271-2	185	38,413	1.000	50,751	0.0000	A-376 TP304H	5,490	60,4983
R-HRC-55A/B-10	1271-2	2370	18,018	1.000	50,751	0.0000	A-376 TP304H	5,401	19,588
→(DRN 06-883, R15)									
R-HRC-55A/B-11	1271-2	250	(see latest stress analysis calculation)				A-376 TP304H	11,628	
←(DRN 06-883, R15)									
R-HRC-55A/B-12	1271-2	402	38,108	1.0000	53,019	0.0068	A-376 TP304H	13,269	88,340
Safety Injection - Tank 2B (Figures 3.6A - 17 and -18									
→(DRN 06-883, R15)									
R-HRC-40-4	1133	49 (Ter. End)	(see latest stress analysis calculation)				A-376 TP304H		
R-HRC-40-11	1133	31	(see latest stress analysis calculation)				A-376 TP304H	8,373	
←(DRN 06-883, R15)									
R-HSI-143-6	1133	29	43,398	1.0000	54,150	0.0007	A-376 TP304H	7,683	68,030

* NOTE: Stress intensities, cumulative usage factors, and the primary and secondary stress ranges at the break location(s) represents a historic summary of data developed to select postulated break locations. The postulated break locations and configurations are current. However, the supporting data should not be used as a reference for the state of stress at the subject locations. For the current state of stress in the piping system, refer to the pipe stress analysis calculations.

←(DRN 99-2063, R11)

TABLE 3.6-5 (Sheet 3 of 10) Revision 15 (03/07)

CALCULATED STRESSES IN ASME CODE CLASS 1 PIPING SYSTEMS

→(DRN 99-2063, R11)

Break No.	Calc No.	Point No.	* Sn	* Ke	3Sm	* CUF	Material	* Primary Stress Intensity	* Peak Stress
R-HSI-144-5	1133	64	41,119	1.000	54,150	0.0008	A-376 TP304H	7,826	63,536
R-HSI-144-4	1133	66	42,008	1.000	56,100	0.0003	A-376 TP304h	8,215	65,137
R-HSI-144-3	1133	68	42,385	1.000	56,100	0.0005	A-376 TP304H	7,280	65,816
R-HSI-145-2	1133	70	11,145	1.0000	60,000	0.0000	A-376 TP304H	3,092	17,389
R-HSI-145-1	1133	9001 (Ter. End)	7,626	1.0000	60,0000	0.0000	A-376 TP304H	3,910	11,690
→(DRN 06-883, R15)									
←(DRN 06-883, R15)									
R-HSI-137-20	5560	572 (Ter. End)	Class 2, Load Set Point not in calculation						
R-HSI-149-19	5560	554 (Ter. End)	Class 2, Load Set Point not in calculation						
Safety Injection - Tank 1A (Figures 3.6A - 11, -12 and -13)									
→(DRN 06-883, R15)									
R-HRC-37-5	1132	532 (Ter. End)	(see latest stress analysis calculation)				A-376 TP304H		
←(DRN 06-883, R15)									
R-HRC-37-2	1132	528	42,286	1.0000	50,421	0.0000	A-376 TP304H	12,760	44,245
R-HRC-37-10	1132	516	49,429	1.0000	50,421	0.0029	A-376 TP304H	8,153	75,599
R-HSI-119-31	1132	5141	48,848	1.0000	54,150	0.0013	A-376 TP304H	8,411	75,803
R-HSI-119-29	1132	533	20,101	1.0000	54,150	0.0000	A-376 TP304H	7,105	29,616

* NOTE: Stress intensities, cumulative usage factors, and the primary and secondary stress ranges at the break location(s) represents a historic summary of data developed to select postulated break locations. The postulated break locations and configurations are current. However, the supporting data should not be used as a reference for the state of stress at the subject locations. For the current state of stress in the piping system, refer to the pipe stress analysis calculations.

←(DRN 99-2063, R11)

CALCULATED STRESSES IN ASME CODE CLASS 1 PIPING SYSTEMS

→(DRN 99-2063, R11)

Break No.	Calc No.	Point No.	* Sn	* Ke	3Sm	* CUF	Material	* Primary Stress Intensity	* Peak Stress
R-HSI-119-28	1132	535	41,630	1.0000	54,150	0.0008	A-376 TP304H	7,326	64,456
R-HSI-120-27	1132	5375	27,572	1.0000	56,100	0.0000	A-376 TP304H	13,431	28,391
R-HSI-120-26	1132	539	32,286	1.0000	56,100	0.0000	A-376 TP304H	7,005	47,722
R-HSI-121-25	1132	541	11,350	1.0000	60,000	0.0000	A-376 TP304H	2,341	17,757
R-HSI-1221-24	1132	9001 (Ter. End)	Class 2, Load Set Point not in calculation						
R-HSI-118-33	1132	479 (Ter. End)	54,901	1.0000	56,100	0.0000	A-376 TP304H	8,630	84,821
R-HSI-117-34	1132	492 (Ter. End)	31,877	1.0000	56,100	0.0000	A-376 TP304H	6,790	47,874
R-HSI-94-46	5561	555 (Ter. End)	Class 2, Load Set Pooint not in calculation						
R-HSI-153-10	5562	53 (Ter. End)	Class 2, Load Set Point not in calculation						
R-HSI-142-8	1133	405 (Ter. End)	51,498	1.000	56,100	0.0007	A-376 TP304H	8,856	78,695
R-HSI-141-9	1133	422 (Ter. End)	31,198	1.0000	56,100	0.0000	A-376 TP304H	6,922	46,849
Safety Injection - Tank 1B (Figures 3.6A-14, -15 and -16)									
→(DRN 06-883, R15) R-HRC-38-6	1131	531 (Ter. End)	(see latest stress analysis calculation)				A-376 TP304H		
R-HSI-125-21	1131	2112	(see latest stress analysis calculation)				A-376 TP304H	7,849	

←(DRN 06-883, R15)

* NOTE: Stress intensities, cumulative usage factors, and the primary and secondary stress ranges at the break location(s) represents a historic summary of data developed to select postulated break locations. The postulated break locations and configurations are current. However, the supporting data should not be used as a reference for the state of stress at the subject locations. For the current state of stress in the piping system, refer to the pipe stress analysis calculations.

←(DRN 99-2063, R11)

TABLE 3.6-5 (Sheet 5 of 10) Revision 307 (07/13)

CALCULATED STRESSES IN ASME CODE CLASS 1 PIPING SYSTEMS

→(DRN 99-2063, R11)

Break No.	Calc No.	Point No.	* Sn	* Ke	3Sm	* CUF	Material	* Primary Stress Intensity	* Peak Stress
→(EC-8439, R307)									
←(EC-8439, R307)									
R-HRC-38-8	1131	525	46,462	1.0000	50,421	0.0011	A-376 TP304H	10,515	70,150
R-HSI-127-18	1131	5230	37,895	1.0000	54,150	0.0000	A-376 TP304H	8,422	58,126
R-HSI-127-16	1131	5325	22,753	1.0000	54,150	0.0000	A-376 TP304H	8,639	34,390
R-HSI-128-15	1131	533	44,548	1.0000	54,150	0.0008	A-376 TP304H	8,563	69,709
R-HSI-128-14	1131	535	30,798	1.0000	56,100	0.0000	A-376 TP304H	9,273	45,042
R-HSI-128-13	1131	5351	32,948	1.0000	56,100	0.0000	A-376 TP304H	9,949	48,914
R-HSI-129-12	1131	5353	15,683	1.0000	60,000	0.0000	A-376 TP304H	5,490	25,556
R-HSI-129-11	1131	5431 (Ter. End)	14,956	1.0000	60,000	0.0000	A-376 TP304H	8,077	14,956
R-HSI-125-23	1131	509 (Ter. End)	27,913	1.0000	56,100	0.0000	A-376 TP304H	5,908	40,936
R-HSI-126-22	1131	207 (Ter. End)	63,967	1.467	56,100	0.0000	A-376 TP304H	9,871	101,140
CVCS - Charging (Figures 3.6A-31, -33, -34, -35 and -36)									
R-HCH-55A/B-5	1271-1	1 (Ter. End)	14,998	1.0000	53,019	0.0000		10,942	28,252

* NOTE: Stress intensities, cumulative usage factors, and the primary and secondary stress ranges at the break location(s) represents a historic summary of data developed to select postulated break locations. The postulated break locations and configurations are current. However, the supporting data should not be used as a reference for the state of stress at the subject locations. For the current state of stress in the piping system, refer to the pipe stress analysis calculations.

←(DRN 99-2063, R11)

CALCULATED STRESSES IN ASME CODE CLASS 1 PIPING SYSTEMS

→ (DRN 99-2063)

Break No.	Calc No.	Point No.	* Sn	* Ke	3Sm	* CUF	Material	* Primary Stress Intensity	* Peak Stress
R-HCH-56A-7	1271-1	21	19,081	1.0000	53,010	0.0000		8,740	26,088
R-HCH-57A-7	1271-1	23	67,192	1.891	53,019	0.0080		6,056	112,184
R-HCH-77A-8	1271-1	99	16,577	1.0000	53,019	0.0000		6,118	21,581
R-HCH-77A-9	1271-1	101	61,951	1.562	53,019	0.0060		6,766	101,522
R-HCH-78A-10	1271-1	102	62,394	1.589	53,019	0.0237		5,430	102,319
R-HCH-78A-11	1271-1	104	62,801	1.615	53,019	0.0252		5,458	103,052
R-HCH-57A-12	1271-1	30	68,786	1.991	53,019	0.0099		5,671	115,054
R-HRC-41RL1-13	1271-1	32	68,355	1.964	53,019	0.0098		5,822	114,277
R-HRC-41RL1-15	1271-1	93 (Ter. End)	25,683	1.0000	53,019	0.0000		6,029	48,202
R-HCH-56B-16	1271-2	111	32,041	1.0000	53,019	0.0000		8,779	49,416
R-HCH-57B-17	1271-2	113	80,368	2.719	53,019	0.0157	A-376 TP304H	10,583	135,900
R-HCH-57B-18	1271-2	114	78,752	2.618	53,019	0.0150	A-376 TP304H	9,910	132,992
R-HRC-42RL2-19	1271-2	116	74,516	2.352	53,019	0.0143	A-376 TP304H	8,006	125,368
R-HRC-42RL2-25	1271-2	177 (Ter. End)	32,678	1.0000	53,019	0.0000	A-376 TP304H	5,516	37,366
Safety Injection - Tank 2A (Figures 3.6A-8, -9 and -10)									
R-HRC-39-7	1135	34 (Ter. End)	29,563	1.0000	50,421	0.0000	A-376 TP304H	16,921	30,895

* NOTE: Stress intensities, cumulative usage factors, and the primary and secondary stress ranges at the break location(s) represents a historic summary of data developed to select postulated break locations. The postulated break locations and configurations are current. However, the supporting data should not be used as a reference for the state of stress at the subject locations. For the current state of stress in the piping system, refer to the pipe stress analysis calculations.

← (DRN 99-2063)

TABLE 3.6-5 (Sheet 7 of 10) Revision 307 (07/13)

CALCULATED STRESSES IN ASME CODE CLASS 1 PIPING SYSTEMS

→(DRN 99-2063, R11)

Break No.	Calc No.	Point No.	* Sn	* Ke	3Sm	* CUF	Material	* Primary Stress Intensity	* Peak Stress
Safety Injection - Tank 2A (Figures 3.6A-8, -9 and -10									
R-HRC-39-3	1135	26	29,591	1.0000	50,421	0.0000	A-376 TP-304H	14,565	31,550
→(EC-8439, R307)									
←(EC-8439, R307)									
R-HSI-136-39	1135	9	46,295	1.0000	54,150	0.0015	A-376 TP-304H	8,980	72,848
R-HSI-136-38	1135	7	28,386	1.0000	56,100	0.0000	A-376 TP-304H	10,004	40,614
R-HSI-136-37	1135	6	27,527	1.0000	56,100	0.0000	A-376 TP-304H	9,884	39,068
R-HSI-137-36	1135	4	10,116	1.0000	60,000	0.0000	A-376 TP-304H	4,328	15,536
R-HSI-137-35	1135	9001 (Ter. End)	Class 2, Load Set Point not in calculation					4,859	
R-HSI-135-40	1135	12	Class 2, Load Set Point not in calculation						
R-HSI-38-42	1135	134	Class 2, Load Set Point not in calculation						
R-HSI-133-44	1135	85 (Ter. End)	30,699	1.0000	56,100	0.0000	A-376 TP-304H	7,057	45,950
R-HSI-134-43	1135	70 (Ter. End)	55,811	1.0000	56,100	0.0015	A-376 TP-304H	8,477	86,459

* NOTE: Stress intensities, cumulative usage factors, and the primary and secondary stress ranges at the break location(s) represents a historic summary of data developed to select postulated break locations. The postulated break locations and configurations are current. However, the supporting data should not be used as a reference for the state of stress at the subject locations. For the current state of stress in the piping system, refer to the pipe stress analysis calculations.

←(DRN 99-2063, R11)

TABLE 3.6-5 (Sheet 8 of 10) Revision 307 (07/13)

CALCULATED STRESSES IN ASME CODE CLASS 1 PIPING SYSTEMS

→(DRN 99-2063, R11)

Break No.	Calc No.	Point No.	* Sn	* Ke	3Sm	* CUF	Material	* Primary Stress Intensity	* Peak Stress
R-HSI-152-45	5563	121 (Ter. End)	Class 2, Load Set Point not in calculation						
Safety Injection - Reactor Building (Figures 3.6A-19, -20 and -21									
R-HSI-215-29	1020	907 (Ter. End)	31,866	1.000	56,100	0.0000	A-376 TP-304H	5,874	47,518
R-HSI-215-28	1020	9460 (Ter. End)	46,864	1.000	56,100	0.0112	A-376 TP-304H	13,302	125,353
R-HSI-215-27	1020	9290	26,945	1.000	56,100	0.0000	A-376 TP-304H	9,088	51,715
R-HSI-215-25	1020	933	43,422	1.000	56,100	0.0000	A-376 TP-304H	7,931	67,598
R-HSI-215-25	1020	939	35,257	1.000	49,002	0.0000	A-376 TP-304H	11,517	72,662
R-HSI-146B-23	1020	26 (Ter. End)	24,352	1.000	51,093	0.0000	A-376 TP-304H	8,888	33,005
R-HSI-146B-21	1020	24	23,257	1.000	49,002	0.0000	A-376 TP-304H	7,833	31,034
R-HRC-44RL1-20	1020	22	34,354	1.000	49,002	0.0000	A-376 TP-304H	20,258	47,817
→(EC-8439, R307)									
←(EC-8439, R307)									
→(DRN 06-883, R15)									
R-HRC-44RL1-17	1020	1 (Ter. End)	(see latest stress analysis calculation)				A-376 TP304H		
←(DRN 06-883, R15)									

* NOTE: Stress intensities, cumulative usage factors, and the primary and secondary stress ranges at the break location(s) represents a historic summary of data developed to select postulated break locations. The postulated break locations and configurations are current. However, the supporting data should not be used as a reference for the state of stress at the subject locations. For the current state of stress in the piping system, refer to the pipe stress analysis calculations.

←(DRN 99-2063, R11)

TABLE 3.6-5 (Sheet 9 of 10) Revision 307 (07/13)

CALCULATED STRESSES IN ASME CODE CLASS 1 PIPING SYSTEMS

→(DRN 99-2063, R11)

Break No.	Calc No.	Point No.	* Sn	* Ke	3Sm	* CUF	Material	* Primary Stress Intensity	* Peak Stress
Safety Injection - Reactor Building (Figures 3.6A-22, through -26)									
R-HSI-214-15	1024	615 (Ter. End)	49,996	1.000	56,100	0.0009	A-376 TP-304H	5,822	80,212
R-HSI-214-9	1024	600	27,898	1.000	56,100	0.0000	A-376 TP-304H	9,716	54,182
R-HSI-214-8	1024	814 (Ter. End)	59,846	1.223	56,100	0.0009	A-376 TP-304H	12,420	98,695
R-HSI-214-11	1024	8210	39,138	1.000	49,002	0.0000	A-376 TP-304H	6,739	59,887
R-HSI-214-12	1024	825	18,647	1.000	49,002	0.0000	A-376 TP-304H	11,948	31,139
R-HSI-146A-1	1024	24 (Ter. End)	26,126	1.000	51,093	0.0000	A-376 TP-304H	8,015	36,198
R-HSI-146A-3	1020	22	23,783	1.0000	51,093	0.0000	A-376 TP-304H	7,302	31,981
R-HRC-45RL2-4	1024	195	25,262	1.0000	49,002	0.0000	A-376 TP-304H	18,533	35,207
→(EC-8439, R307)									
←(EC-8439, R307)									
R-HRC-45RL2-6	1024	2 (Ter. End)	23,140	1.000	49,002	0.0000	A-376 TP-304H	7,231	34,282
Pressure Relief - Reactor Building, (Figure 3.6A-37)									
R-HRC-18B-1	1163	48 (Ter. End)	22,884	1.000	48,144	0.0009	A-376 TP-304H	10,489	33,938

* NOTE: Stress intensities, cumulative usage factors, and the primary and secondary stress ranges at the break location(s) represents a historic summary of data developed to select postulated break locations. The postulated break locations and configurations are current. However, the supporting data should not be used as a reference for the state of stress at the subject locations. For the current state of stress in the piping system, refer to the pipe stress analysis calculations.

←(DRN 99-2063, R11)

TABLE 3.6-5 (Sheet 10 of 10) Revision 11 (05/01)

CALCULATED STRESSES IN ASME CODE CLASS 1 PIPING SYSTEMS

→ (DRN 99-2063)

Break No.	Calc No.	Point No.	* Sn	* Ke	3Sm	* CUF	Material	* Primary Stress Intensity	* Peak Stress
R-HRC-18B-2	1163	44 (Ter. End)	57,152	1.624	48,144	0.0000	A-376 TP-304H	9,417	92,312
R-HRC-18A-8	1163	28 (Ter. End)	28,975	1.000	48,144	0.0000	A-376 TP-304H	13,539	42,472
R-HRC-18A-9	1163	24 (Ter. End)	79,287	3.156	48,144	0.0000	A-376 TP-304H	10,477	132,154

* NOTE: Stress intensities, cumulative usage factors, and the primary and secondary stress ranges at the break location(s) represents a historic summary of data developed to select postulated break locations. The postulated break locations and configurations are current. However, the supporting data should not be used as a reference for the state of stress at the subject locations. For the current state of stress in the piping system, refer to the pipe stress analysis calculations.

← (DRN 99-2063)