Summary Report of High-Energy Piping Rupture Analysis

Revision 2

Non-Proprietary

October 2017

REVISION HISTORY

Revision	Date	Page	Description
0	August 2015	All	First Issue
1	July 2017	Page 5	Added the blast effect.
		Page 14	Arranged the form and modified the Table 2-1.
		Page 17	Modified the description of section 4.1.
		Page 18 to 22	Revised the methodology and results for dynamic effect analysis.
		Page 27 to 30	Arranged the form.
		Appendix A	Added the description for intermediate break and revised the results in Table A1-1 thru Table A1-4.
2	October 2017	Abstract, Page3 and 7	Added blast effect
		Page 15	Added abbreviations
		Page 20 to 21	Added the flow chart and methodology to structural evaluation on SSC
		Page 23	Modified the factor in table 4.2-3
		Page A12 to A14	Insert the column for blast wave effect

ABSTRACT

This document summarizes the High-Energy Piping Rupture Analysis for the Advanced Power Reactor 1400 (APR1400). The high-energy piping rupture analysis is performed to implement the 10 Code of Federal Regulations (CFR) Part 50, Appendix A, General Design Criterion (GDC) 4.

This document provides the methodologies and results of safety analyses for dynamic and environmental effects associated with the postulated pipe failures. Evaluations include the effects of a high-energy pipe failure, the consequences of pipe whip, jet impingement, blast effect, subcompartment pressurization, flooding, and environmental qualification.

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Acronyms and Abbreviations

2D	Two Dimensional
3D	Three Dimensional
ACRS	Advisory Committee on Reactor Safeguards
AF	Auxiliary Feedwater
AISC	American Institute of Steel Construction
APR	Advanced Power Reactor
ASME	American Society of Mechanical Engineers
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CVCS	Chemical and Volume Control System
DCD	Design Control Document
DLF	Dynamic Load Factor
DSRS	Design Specific Review Standard
DVI	Direct Vessel Injection
ESBWR	Economic Simplified Boiling Water Reactor
GDC	General Design Criteria
HELB	High Energy Line Break
JI	Jet Impingement
KEPCO	Korea Electric Power Corporation
KHNP	Korea Hydro & Nuclear Power Co., Ltd.
LBB	Leak Before Break
LDS	Leak Detection System
LOCA	Loss-Of-Coolant Accident
LWR	Light Water Reactor
M/E	Mass and Energy
MF	Main Feedwater
MS	Main Steam
MSVH	Main Steam Valve House
NRC	U.S. Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System
PED	Piping Evaluation Diagram
POSRV	Pilot Operated Safety Relief Valve
PSW	Primary Shield Wall
	TS
PW	Pipe Whip
PWR	Pipe Whip Restraint
PZR	Pressurizer
RCGV	Reactor Coolant Gas Vent
RCP	Reactor Coolant Pump
RCPB	Reactor Coolant Pressure Boundary
RCS	Reactor Coolant System
RV	Reactor Vessel
SC	Shutdown Cooling
SG	Steam Generator

SGBD	Steam Generator Blowdown
SI	Safety Injection
SRP	Standard Review Plan
SSC	Structure, System, and Component
TS	Trade Secret
V&V	Verification and Validation

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1 INTRODUCTION

This report summarizes the methodology and the analysis result of high- and moderate-energy pipe ruptures.

The scope of this report is limited to the piping within the reactor containment building and the main steam valve house of the auxiliary building according to the graded approach of APR1400 piping design for DC application.

The pipe rupture locations, dynamic effects and environmental effects due to piping ruptures and protection measures to mitigate the consequences of breaks are described in this report.

2 GENERAL CRITERIA

According to 10 CFR Part 50, Appendix A, General Design Criterion (GDC) 4 (Reference 1), essential structures, systems, and components (SSCs) important to safety are required to be protected from postulated piping failures. The effects of postulated piping failures include dynamic and environmental effects. Dynamic effects include pipe whipping, jet impingement, subcompartment pressurization, and fluid system decompression. Environmental effects include spray wetting, higher temperature, humidity, radiological consequences, and localized flooding.

The criteria used to evaluate the effects of postulated piping failures are generally consistent with U.S. Nuclear Regulatory Commission (NRC) guidelines including those in Standard Review Plan (SRP) Sections 3.6.1, 3.6.2, and 3.6.3 (References 2, 3, and 4), and Branch Technical Positions (BTPs) 3-3 and 3-4 (References 5 and 6).

2.1 Design Basis

Protection of essential equipment is achieved primarily by separation of redundant safe shutdown systems and by separation of high-energy pipelines from safe shutdown systems, which are required to be functional following specific pipe rupture events. Redundancy and separation result in a design that requires very few special protective features (such as pipe whip restraints and jet shields) to provide reasonable assurance of safe shutdown capability following a postulated high-energy line break (HELB).

Most systems and components outside the containment required for safe plant shutdown are located in the auxiliary building. The auxiliary building is divided by a structural wall that serves as a barrier between redundant trains of safe shutdown systems and components. Each half of the auxiliary building is compartmentalized to separate redundant safe shutdown components to the extent practical. High-energy piping systems located in the auxiliary building, which are not required to be functional for safe shutdown, are routed primarily in designated pipe tunnels or in the Main Steam Valve Houses (MSVHs) to provide separation from safe shutdown systems and components.

Systems and components inside the containment, which are required to be functional for safe plant shutdown, are protected from postulated pipe failure dynamic effects primarily by separation and barriers. The secondary shield wall serves as a barrier between the reactor coolant loops and the containment liner. The steam generators (SGs) and pressurizer (PZR) are also enclosed in cavities that provide separation.

A list of high-energy and moderate-energy fluid systems is provided in Table 2-1.

2.1.1 High-Energy Piping Systems

A high-energy pipe failure is postulated in branches or piping runs that are larger than 2.54 cm (1 in) nominal diameter and operate with high-energy fluid during normal plant conditions. Included in this category are fluid systems or portions of fluid systems that, during normal plant conditions, are either in operation or maintained pressurized under conditions where either or both of the following are met:

a. Maximum operating temperature exceeds 93.3 °C (200°F), or

b. Maximum operating pressure exceeds 19.3 kg/cm^2 (275 psig)

2.1.2 Moderate-Energy Piping Systems

A moderate-energy pipe failure is postulated in branches or piping runs that are larger than 2.54 cm (1 in) nominal diameter and operate with moderate-energy fluid during normal plant conditions.

Fluid piping systems that qualify as high energy for only short operational periods are considered moderate-energy systems if the fraction of the time that the system operates within the pressure-temperature conditions specified for high-energy fluid systems is less than 2 percent of the total time the system operates.

Included in this category are fluid systems or portions of fluid systems that, during normal plant conditions, are either in operation or maintained pressurized (above atmospheric pressure) under conditions where both of the following are met:

a. Maximum operating temperature is 93.3 °C (200°F) or less, and

b. Maximum operating pressure is 19.3 kg/cm^2 (275 psig) or less

2.2 Dynamic and Environmental Effects

The dynamic and environmental effects associated with the postulated fluid system piping failures that shall be considered are:

a. Pipe whip and jet impingement

b. High-energy line break for nuclear steam supply system (NSSS) nozzle loads

c. Containment pressurization

d. Subcompartment pressurization

e. Flooding

f. Environmental qualification

In analyzing the effects of a high-energy pipe failure, the consequences of pipe whip, jet impingement, flooding, compartment pressurization, and environmental conditions are considered. In analyzing the effects of a moderate-energy pipe failure, the consequences of flooding and environmental conditions are considered.

2.3 Failure Modes and Effects Analysis

An evaluation of postulated pipe break events is performed to identify the safety-related systems and components that provide protective actions required to mitigate, to acceptable limits, the consequences of the postulated pipe break event.

If the separation inherent in the plant design is shown to provide reasonable assurance of the functional capability of the safety systems required following a postulated pipe break event, no additional protective measures are required for that event. When necessary, additional protective measures are incorporated into the design to provide reasonable assurance of the functional capability of safety systems that are required following a postulated pipe break event.

The following criteria are used in the failure modes and effects analysis to establish the integrity of systems and components necessary for safe reactor shutdown and maintenance of the shutdown condition:

a. Offsite power is assumed to be unavailable if an automatic turbine generator trip or automatic reactor trip is a direct consequence of a postulated piping failure.

b. In addition to the postulated pipe failure and its accompanying effects, a single active component failure is assumed in the systems required to mitigate the consequences of the postulated piping failure except as noted in Item d below.

c. Each high-energy or moderate-energy fluid system pipe failure is considered separately as a single postulated initiating event occurring during normal plant conditions.

d. Where a postulated piping failure is assumed in one of two redundant trains of a system that is required to operate during normal plant conditions as well as to shut down the reactor, single failures that prevent the functioning of the other train or trains of that system are not assumed, provided the system is (1) designed to seismic Category I standards, (2) powered from offsite and onsite sources, and (3) designed, constructed, operated, and inspected to quality assurance, testing, and inservice inspection standards appropriate for nuclear safety systems.

e. All available systems and components, including non-seismic Category I and those actuated by operator actions, may be used to mitigate the consequences of a postulated piping failure. In judging the availability of such systems and components, account is taken of the postulated failure and its direct consequences, such as unit trip and loss of offsite power, and of the assumed single active component failure and its direct consequences.

f. For a postulated pipe failure, the escape of steam, water, and heat from structures enclosing the high-energy fluid containing piping does not preclude:

1) Accessibility to surrounding areas important to the safe control of reactor operations

2) Habitability of the main control room (MCR)

2.4 Safety Evaluation

2.4.1 General

By means of design features such as separation, barriers, pipe whip restraints and jet shields, all of which are described below, the effects of a pipe break would not damage essential systems to the extent that the design function is impaired or the necessary component operability is affected.

Typical measures used for protecting the essential SSCs are described below.

2.4.2 Protection Measures

The design to protect essential SSCs from the effects of postulated pipe break is basically achieved by separation, physical barriers, or piping restraint protection.

2.4.2.1 Separation

The plant arrangement provides separation to the extent practical between redundant safety systems in order to prevent loss of safety function as a result of hazards different from those for which the system is required to function, as well as for the specific event for which the system is required to be functional. Separation between redundant safety systems and associated auxiliary supporting features is the basic protective measure. In general, layout of the facility followed a multistep process to provide reasonable assurance of adequate separation.

a. Safety-related systems are located away from most high-energy piping.

b. Redundant safety systems and subsystems are located in separate compartments.

c. As necessary, components are enclosed to maintain the redundancy required for the systems that must function as a consequence of piping failure events.

2.4.2.2 Barriers and Shields

Protection requirements are met through the protection afforded by the walls, floors, and columns in many cases. Where adequate protection does not exist due to separation, additional barriers, deflectors, or shields are provided as necessary to meet the functional protection requirements. Where compartments, barriers, and structures are required to provide the necessary protection, they are designed to withstand the effects of the postulated failure concurrent with an earthquake event.

2.4.2.3 Piping Restraints

Where adequate protection does not 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 postulated pipe breaks would not cause unacceptable damage to essential systems or components.

2.4.3 Specific Protection Measure

The design criteria define acceptable types of isolation for safety-related elements and for high-energy lines from similar elements of the redundant train. Separation is accomplished by:

a. Routing the redundant trains through separate compartments

b. Physically separating the redundant trains by a specified minimum distance

c. Separating the redundant trains by structural barriers

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2.5 Determination of Break Locations and Configurations

This section describes the design bases for locating breaks and cracks in piping inside and outside containment, the procedure used to define the thrust at the break location, the jet impingement loading criteria, and the dynamic response models.

2.5.1 General Requirements

Postulated pipe ruptures are considered in all plant piping systems and the associated potential for damage to required systems and components is evaluated on the basis of the energy in the system. System piping is classified as high-energy or moderate-energy, and postulated ruptures are classified as circumferential breaks, longitudinal breaks, or through-wall cracks. Each postulated rupture is considered separately as a single postulated initiating event.

For each postulated circumferential and longitudinal break, an evaluation is made of the effects of pipe whip, jet impingement, blast effect, compartment pressurization, environmental conditions, and flooding. For piping systems where LBB is applied, dynamic effects of pipe breaks are not considered. If required to demonstrate safe plant shutdown, an internal fluid system load evaluation is performed on the effects of fluid forces on components within or bounding the fluid system.

2.5.2 Type of Postulated Ruptures

a. Circumferential Pipe Break
   A circumferential break is assumed to result in pipe severance with full separation of the two severed pipe ends unless the extent of separation is limited by consideration of physical means. The break plane area is assumed to be perpendicular to the longitudinal axis of the pipe and is assumed to be the cross-sectional flow area of the pipe at the break location. The break flow area, discharge coefficient, and discharge correlation are substantiated analytically.

b. Longitudinal Pipe Break
   A longitudinal break is assumed to result in a split of the pipe wall along the pipe longitudinal axis but without severance. The break plane area is assumed to be parallel to the longitudinal axis of the pipe and equal to the cross-sectional flow area of the pipe at the break location. The break is assumed to be circular or elliptical (2D × D/2) with its long axis parallel to the longitudinal axis of the pipe where D is the effective inner diameter of the pipe. The discharge coefficient and any other values used for the area or shape associated with a longitudinal break are substantiated analytically.

c. Leakage Crack
   A leakage crack is assumed to be a crack through the pipe wall where the size of the crack and corresponding flow rate are determined by analysis and a leak detection system, as described in Subsection 2.5.5.

d. Through-Wall Crack
   A through-wall crack is assumed to be a circular orifice through the pipe wall of cross-sectional flow area equal to the product of half of the inside pipe diameter and half of the pipe wall thickness.

2.5.3 Postulated Rupture Locations

2.5.3.1 Break Location for High-Energy Fluid System Piping in Areas Other than Containment Penetration

Both circumferential and longitudinal breaks of high-energy piping systems are postulated to occur, but not concurrently, considering the following exceptions:

a. Circumferential breaks are not postulated in piping runs of a nominal diameter equal to or less than 2.54 cm (1 in).

b. Longitudinal breaks are not postulated in piping runs of a nominal diameter less than 10.16 cm (4 in).

c. Longitudinal breaks are not postulated at terminal ends.

A terminal end is defined as an extremity of a piping run that connects to structures, components, or pipe anchor that acts as a rigid constraint to piping motion and thermal expansion. Branch lines connected to main piping runs are considered terminal ends except where the branch run is classified as part of a main run in the stress analysis and is shown to have a significant effect on the main run behavior in accordance with BTP 3-4.

2.5.3.1.1 ASME Section III, Class 1 Piping

With the exceptions of the portions of piping identified in Subsection 2.5.3, breaks in American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Section III, Class 1 (Reference 8) piping are postulated at the following locations in each piping and branch run:

a. At terminal ends

b. At intermediate locations where U exceeds 0.1 or S from Equation (10) plus Equation (12) or (13) exceeds 2.4 S_m

Where, as defined in ASME Section III, Division 1, Paragraph NB-3653:

S = primary-plus-secondary stress-intensity range under the combination of loadings for which either Level A or Level B service limits have been specified, as calculated from Equations (10), (12), and (13)

S_m = allowable stress-intensity value

U = cumulative usage factor

As a result of piping reanalysis due to differences between the design configuration and the as-built configuration, the highest-stress or cumulative usage factor locations may be shifted. However, the initially determined intermediate break locations need not be changed unless one of the following conditions exists:

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

b. A change is required in pipe parameters such as major differences in pipe size, wall thickness, and routing.

2.5.3.1.2 ASME Section III, Class 2, 3, or Seismically Analyzed ASME B31.1 Piping

With the exceptions of the portions of piping identified in Subsection 2.5.3, breaks in ASME Section III, Class 2 and 3, or seismically analyzed ASME B31.1 piping are postulated at the following locations in each piping and branch run:

a. At terminal end

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

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

2) At intermediate locations where the stress S exceeds 0.8 (X + Y)

Where, as defined in ASME Section III, Division 1, Paragraph NC/ND-3653:

S = stresses under the combination of loadings for which either Level A or Level B stress limits have been specified, as calculated from the sum of Equations (9) and (10)

X = Equation (9) service level B allowable stress

Y = Equation (10) allowable stress

As a result of piping reanalysis due to differences between the design configuration and the as-built configuration, the highest-stress locations may be shifted; however, the initially determined intermediate break locations may be used unless a redesign of the piping resulting in a change in pipe parameters (diameter, wall thickness, routing) is required, or the dynamic effects from the new (as-built) intermediate break locations are not mitigated by the original pipe whip restraints and jet shields.

2.5.3.1.3 Non-Seismically Analyzed ASME B31.1 Piping

Safety class systems and piping are seismically analyzed. Most non-safety systems and piping are non-seismically analyzed. Therefore, isolation and separation are required in order to avoid impact to safety-related systems from non-safety-related piping failure effects caused by an earthquake. In cases where it is not possible or practical to isolate the seismic piping, adjacent non-seismic piping is analyzed according to seismic Category II criteria.

For non-seismic piping attached to seismic piping, the dynamic effects of the non-seismic piping are simulated in the modeling of the seismic piping. The attached non-seismic piping up to the analyzed/unanalyzed boundary is designed not to cause a failure of the seismic piping during a seismic event.

The seismically analyzed/unanalyzed boundary is defined as the interface between the safety and non-safety piping and is usually designed with an anchor at that location to avoid causing a failure of the seismic piping during a seismic event. In instance where installation of an anchor is not feasible at the code break interface, the seismic Category I design is extended to the first anchor point.

Breaks are postulated at the following locations in each non-safety-related, ASME B31.1 piping network that is not seismically analyzed.

a. At terminal ends of the pressurized portions of the network

b. At each intermediate location of potential high stress or fatigue, such as pipe fittings, valves, flanges, and welded-on attachments

2.5.3.2 Crack Locations

2.5.3.2.1 Through-Wall Cracks

Through-wall cracks are postulated in all high-energy and moderate-energy piping systems having a nominal diameter greater than 2.54 cm (1 in), except that through-wall cracks are not postulated at locations where:

a. For Class 1 piping, the calculated value of stress range by Equation (10) in ASME Section III, Division 1, NB-3653 is less than 1.2 S_m.

b. For Class 2, Class 3, or seismically analyzed ASME B31.1 (Reference 9) piping, the calculated stress by the sum of Equations (9) and (10) in NC/ND-3653 is less than 0.4 times the sum of the stress limits given in NC/ND-3653.

c. The requirements of Subsection 2.5.3 for piping in containment penetration areas are satisfied.

d. For moderate-energy piping near high-energy piping where a break in high-energy piping is postulated that results in more limiting environmental conditions, the through-wall crack in the moderate-energy piping is not postulated.

e. Through-wall cracks, instead of breaks, are postulated for the piping classified as moderate energy as defined in Subsection 2.1.2 due to its short operational period in the high-energy condition.

For moderate-energy fluid systems in areas other than containment penetration, through-wall cracks are postulated at axial and circumferential locations that result in the most severe environmental consequences.

2.5.3.2.2 Leakage Cracks

A leakage crack is postulated in place of a circumferential break, longitudinal break, or through-wall crack if justified by an analysis performed on the pipeline in accordance with the requirements described in Subsection 2.5.5.

2.5.3.3 Fluid System Piping in Containment Penetration Areas

2.5.3.3.1 High-Energy Piping

Breaks and cracks are not postulated in the piping between the containment wall and the inboard or outboard isolation valves, which is designed in accordance with ASME Section III, NE-1120. Pipe break exclusion design also meets the following additional requirements:

a. The following design stress and fatigue limits are not exceeded:

- For ASME Code, Section III, Class 1 Piping

  There is no ASME Section III, Class 1 piping in containment penetration areas and no applicable following design criteria.

  a) The maximum stress range between any two load sets (including the zero load set) should not exceed 2.4 S_m and should be calculated by Equation (10) in ASME Code, Section III, NB-3653. If the calculated maximum stress range of Equation (10) exceeds 2.4 S_m, the stress ranges calculated by both Equation (12) and Equation (13) in ASME Code, Section III, NB-3653 should meet the limit of 2.4 Sm.

  b) The cumulative usage factor should be less than 0.1.

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

- For ASME Code, Section III, Class 2 Piping

  a) The maximum stress as calculated by the sum of Equations (9) and (10) in Paragraph NC-3653, ASME Section III, considering those loads and conditions thereof for which Level A and Level B stress limits have been specified in the system design specification (i.e., sustained loads, occasional loads, and thermal expansion), excluding earthquake loads, does not exceed 0.8 (1.8 S_h + S_A). The S_h and S_A are allowable stresses at maximum (hot) temperature and allowable stress range for thermal expansion, respectively, as defined in Article NC-3600 of ASME Section III.

  b) The maximum stress, as calculated by Equation (9) in ASME Section III, Paragraph NC-3653, under the loadings resulting from a postulated piping failure of fluid system piping beyond these portions of piping, does not exceed the lesser of 2.25 S_h and 1.8 S_y.

  Primary loads include those that are deflection limited by whip restraints. The exceptions permitted in c) above may also be applied provided that when the piping between the outboard isolation valve and the restraint is constructed in accordance with Power Piping Code ASME B31.1 (see ASB 3-1 B.2.c.[4]), the piping is either of seamless construction with full radiography of all circumferential welds, or all longitudinal and circumferential welds are fully radiographed.

b. Welded attachments for pipe supports or other purposes to these portions of piping are avoided except where detailed stress analyses or tests are performed to demonstrate compliance with the limits of Item a above.

c. The number of circumferential and longitudinal piping welds and branch connections is minimized. Specific access provisions are made to permit in-service volumetric examination of the longitudinal and circumferential welds.

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

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

f. A 100 percent volumetric in-service examination of all pipe welds is conducted during each inspection interval as defined in IWA-2400, ASME Section XI (Reference 10).

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Essential equipment is not concentrated in the break exclusion zone. Essential equipment is protected from the environmental effects of an assumed nonmechanistic longitudinal break of the main steam and feedwater lines. Each assumed nonmechanistic longitudinal break has a cross-sectional area of at least 1 ft^2 is postulated to occur at MSVH where result in the greatest effect on essential equipment.

2.5.3.4 Moderate-Energy Piping

For moderate-energy fluid systems, through-wall cracks are not postulated in those portions of piping from the containment wall to and including the inboard or outboard isolation valves, provided that they meet the requirements of ASME Section III, NE-1120, the stresses calculated by the sum of Equations (9) and (10) of ASME Section III, NC-3653, and do not exceed 0.4 times the sum of the stress limits given in ASME Section III, NC-3653.

2.5.4 Postulated Rupture Configurations

2.5.4.1 Break Configurations

Where break locations are postulated without the benefit of a stress calculation, breaks are assumed to occur at the piping welds to each fitting, valve, or welded attachment. Detailed stress analyses of the piping system are performed to determine intermediate, break locations based on the criteria in Subsection 2.5.3.1.

Circumferential breaks are postulated in fluid system piping and branch runs as specified in Subsection 2.5.3.1. Instrument lines with tubing size of 2.54 cm (1 in) and less nominal pipe are designed to meet the provisions of NRC Regulatory Guide (RG) 1.11 (Reference 11).

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. The break plane area (A_e) is assumed perpendicular to the longitudinal axis of the pipe, and is assumed to be the cross-sectional flow area of the pipe at the break location. The break flow area, discharge coefficient, and discharge correlation are substantiated analytically.

Longitudinal breaks in fluid system piping and branch runs are postulated as specified in Subsection 2.5.3.1. A longitudinal break results in an axial split without severance. The split is assumed to be oriented at any point about the circumference of the pipe, or alternatively at the point of highest stress as justified by detailed stress analyses. The break plane area (A_e) is assumed parallel to the longitudinal axis of the pipe and equal to the cross-sectional flow area of the pipe at the break location. The break is assumed to be circular or elliptical (2D × D/2) with its long axis parallel to the axis of the pipe.

2.5.4.2 Crack Configurations

Through-wall cracks are postulated at those axial locations specified in Subsection 2.5.3.2. For high-energy piping, through-wall cracks are postulated to be in those circumferential locations that result in the most severe environmental consequences. The flow from the crack is assumed to wet all unprotected components within the compartment with consequent flooding in the compartment and communicating compartments.

Fluid flow from a leakage crack is based on a circular orifice with a cross-sectional area equal to that of a rectangle of one-half the pipe inside diameter in length and one-half the pipe wall thickness in width.

2.5.4.3 Guard Pipe Assembly Design Criteria

Guard pipes are not used in any containment penetrations of high-energy piping.

2.5.5 Piping Within Leak-Before-Break Criteria

According to 10 CFR Part 50, Appendix A, GDC 4, the exclusion of dynamic effects due to a pipe rupture from the design basis is allowed when the analyses demonstrate that the probability of pipe rupture is extremely low under conditions satisfied by the design basis such as normal operation, thermal transients, and seismic events in the process of approval and review.

LBB analysis is used to eliminate from the structural design basis the dynamic effects of double-ended guillotine breaks and equivalent longitudinal breaks for an applicable piping system.

This section describes how the piping system meets the LBB criteria in accordance with SRP 3.6.3 and demonstrates that the probability of pipe rupture is extremely low. The steps below are followed to carry out the LBB analyses.

a. Evaluate the potential failure mechanism

b. Perform the LBB analysis using the piping evaluation diagram (PED)

The method of PEDs allows for the evaluation of the piping system in advance of the final piping analysis, incorporating LBB considerations into the piping design. The LBB methodology is demonstrated for the following piping systems:

a. Reactor coolant loop (RCL) piping, hot and cold legs

b. Surge line

c. Direct-vessel injection (DVI) line (main run inside containment)

d. Shutdown cooling (SC) line (main run inside containment)

The points considered for applicability of LBB are:

a. Requirements for the potential failure mechanism – level of susceptibility to failure from erosion, erosion/corrosion, erosion/cavitation, water hammer, creep fatigue, corrosion resistance, indirect causes, cleavage-type failure, fatigue cracking, and thermal aging.

b. Requirements for the fracture mechanics analyses – leak detection capability, pipe material properties and geometries, and loads including normal operation, seismic and stratified flow, where applicable.

The LBB evaluation is consistent with the requirements set forth in SRP 3.6.3 and NUREG-1061, Volume 3 (Reference 7) as described in DCD Tier 2, Subsection 3.6.3. As per Regulatory Guide 1.45 (Reference 17), the detectable leakage rate requirement of the leak detection system is 3.785 L/min (1.0 gpm) or less. The leakage crack subjected to the crack stability analyses must leak at a rate 10 times the capability of the leak detection system (LDS) unless otherwise justified.

The LBB evaluations are based on a leak detection capability of 1.89 L/min (0.5 gpm) for APR1400 LDS, and a safety margin 10. The PICEP program (Reference 18) is used to calculate the flow for a crack length and loading. J-T method is used for the generation of PED in LBB analysis.

2.6 Essential Structures, Systems, and Components

Essential systems and components to be protected against the consequences of piping ruptures are those that are needed to safely shut down the reactor or mitigate the consequences of a pipe break for a given postulated piping failure. The systems that are required for safe shutdown or to support safe shutdown for a given pipe failure are described in DCD Tier 2, Section 3.2 and Table 3.2-1.

Table 2-1 High- and Moderate-Energy Fluid Systems

System (1)(2)	High Energy	Moderate Energy
Reactor Coolant System	○	
Reactor Coolant Gas Vent System	○	
Safety Injection System	○	
Shutdown Cooling System	○	
Chemical and Volume Control System	○	
Steam Generator Blowdown System(3)	○	
Component Cooling System		○
Spent Fuel Pool Cooling and Cleanup System		○
Process and Effluent Radiation Monitoring and Sampling System		○
Process and Post-Accident Sampling System		○
Containment Spray System		○
Essential Service Water System		○
Main Steam System	○	
Condensate and Feedwater System	○	
Auxiliary Feedwater System (5)	○	
Auxiliary Steam System	○	
Emergency Diesel Generator System(4)	○	
Fire Protection System		○
Equipment and Floor Drainage System		○
Essential Chilled Water System		○
Plant Chilled Water System		○
Compressed Air System		○

(1) Systems classified as high-energy are either totally or partially high-energy. If portions of system are high-energy, it is classified as high-energy system. The portions of high-energy piping are identified in Figures A1-1 through A1-11.
(2) Systems or portions of systems outside the containment building and auxiliary building are excluded from this table.
(3) Wet layup recirculation system is classified as a moderate-energy system.
(4) Subsystems other than an EDG engine starting air system are classified as moderate-energy systems.
(5) Subsystems other than an auxiliary feedwater pump turbine subsystem are classified as moderate-energy systems.

3 ANALYSIS METHOD TO DEFINE FORCING FUNCTIONS AND RESPONSE MODELS

This section describes the specific analytical methods and results due to high- and moderate-energy pipe ruptures.

3.1 Leak-Before-Break Applied Piping

There are no forcing functions or response models for the piping qualified for LBB.

3.2 Analytical Methods to Define Forcing Functions and Response Models for Piping Not Applied to Leak-Before-Break

3.2.1 Steady-State Jet Discharge Force

The dynamic force of the fluid jet discharge from either a postulated circumferential or longitudinal break is based on a circular break area equal to the cross-sectional flow area of the pipe at the break location and on a calculated fluid pressure multiplied by an analytically determined thrust coefficient, as determined for a circumferential break at the same location.

Flow limiters, positive displacement pump-controlled flow, and the absence of energy reservoirs are taken into account, as applicable, in the reduction of jet discharge.

Piping movement is assumed to occur in the direction of the jet reaction, unless limited by structural members or piping restraints. Blowdown thrust force (F_{thrust}) is determined by multiplication of three parameters (i.e., appropriately calculated thrust coefficient considering the fluid conditions, piping internal pressure, and cross-sectional area at the break location). For the realistic calculation, P_aA acting on the outside of the pipe may be subtracted from the thrust force acting on the inside of the pipe. The initial conditions used are the higher operating condition, either 102 percent power or hot standby condition in accordance with SRP 3.6.2 Section III.4.A.

$$F_{thrust} = (C_T\, P_o - P_a)\, A$$

At first, initial, intermediate, and final thrust coefficients are calculated.

$$F_{ini} = 1.0\, P_o\, A, \text{ or } F_{ini} = (1.0\, P_o - P_a)\, A$$

$$F_{inter} = C_{TI}\, P_o\, A, \text{ or } F_{inter} = (C_{TI}\, P_o - P_a)\, A$$

$$F_{final} = C_{TS}\, P_o\, A, \text{ or } F_{final} = (C_{TS}\, P_o - P_a)\, A$$

Where:
- C_T = thrust coefficient
- C_{TI} = intermediate thrust coefficient
- C_{TS} =steady-state thrust coefficient
- D = pipe inside diameter based on the average or nominal pipe wall thickness
- P_o = initial fluid pressure in source or pipe
- P_a = atmospheric pressure
- A = pipe flow area

This methodology is based on the simplified methods described in ANSI/ANS 58.2-1988 (Reference 12) and pipe thrust and jet loads (Reference 13).

3.2.2 Time-Dependent Break Forcing Function

RELAP5/MOD3.3 (Reference 14) is used to estimate the hydrodynamic transient load of the piping system. The code is a best-estimate system code suitable for the analysis of all transients and postulated accidents in light water reactor (LWR) systems, including both large- and small-break loss-of-coolant accidents (LOCAs) as well as the full range of operational transients. The one-dimensional RELAP5/MOD3.3 code is based on a nonhomogeneous and nonequilibrium model for the two-phase system.

This code is also used to analyze rapid transients such as pipe breaks and valve quick opening and some thermal-hydraulic parameters of the results such as velocity, density, and pressure are extracted for generation of hydrodynamic loads on the piping system.

The blowdown hydraulic loads on primary loop components are computed from the equation:

$$F = 144A\left(\left(P - 14.7\right) + \frac{\dot{m}^2}{\rho g A_m^2 144}\right)$$

Where:
- F = force (lbf)
- A = area of aperture (ft^2)
- P = pressure of system (psia)
- $\dot{m}$ = mass flow rate (lbm/s)
- ρ = density (lbm/ft^3)
- g = gravitational constant (32.174 ft-lbm/lb-s^2)
- A_m = mass flow area (ft^2)

4 DYNAMIC EFFECTS ANALYSIS

Break location for the analysis of dynamic effects are determined based on the criteria in Section 2.5. The results are summarized in Appendix A.

4.1 Containment Pressurization

A containment response analyses to a postulated LOCA and secondary system pipe rupture are performed to demonstrate containment structural integrity. The APR1400 uses a simplified and distinct GOTHIC containment model to calculate the containment pressure and temperature transients in response to the mass and energy release through the break following a LOCA and secondary system pipe rupture. The containment design pressure is determined from the calculation results of the limiting case among the analyzed accidents with appropriate pressure margin.

All the assumptions, initial conditions and specific sub-models used in the GOTHIC containment model are biased to maximize the containment peak pressure. A detailed description of the containment analysis methodology and calculation is provided in DCD Tier 2, Subsection 6.2.1.1.3 and Appendices A through G of the Technical Report APR1400-Z-A-NR-14007-P (Reference 19).

4.2 Jet Impingement Accounting of Non-Conservatism of ANSI 58.2

4.2.1 Background

ANSI/ANS 58.2 has been used for estimating jet plume geometries and loads based on the fluid conditions internal and external to the piping, and has been accepted by the NRC. The Advisory Committee on Reactor Safeguards (ACRS) has given the NRC comments that some assumptions related to jet expansion modeling in the ANSI/ANS 58.2 standard may lead to non-conservative assessments of the jet impingement loads of postulated pipe breaks on neighboring SSCs. The ACRS also stated that initial blast waves are unaccounted for in the standard. The NRC determined that the ANSI/ANS 58.2 Standard is no longer universally acceptable for modeling jet expansion in nuclear power plants. The NRC noted the ACRS recommendation and potential non-conservatisms in the Standard Review Plan (SRP) Section 3.6.2, Revision 2, Section III.3 (Reference 3).

The NRC requires evaluation on these non-conservatisms for APR1400 design. In accordance with this requirement, a report that addresses the non-conservatism in the ANSI/ANS 58.2 model will be submitted.

As noted in SRP 3.6.2, Section III.3, following interactions with the ACRS on the jet models described in ANSI/ANS 58.2, the NRC determined that there were potential non-conservatisms in these models. Pending completion of general guidance on this topic from the NRC, the staff is reviewing analyses of the jet impingement forces on a case-by-case basis. Therefore, the DCD should address the potential non-conservatisms of the ANSI/ANS 58.2 model for blast wave effects, jet plume expansion and zone of influence, pressure distribution within the jet plume, and jet dynamic loading including potential feedback amplification and resonance effects.

The NRC developed Design-Specific Review Standard (DSRS) 3.6.2, Appendix A for the mPower™ review. That draft guidance is available and is the starting point for the APR1400 analysis. If a bounding analysis is presented for the APR1400 design, the applicable issues in Appendix A are addressed. If an issue is thought not to be applicable to the APR1400 design, the basis will be described.

4.2.2 Methodology Summary

Key issues required in the SRP 3.6.2 and DSRS 3.6.2, Appendix A (Reference 20) are:

a. Blast wave effect

b. Jet plume expansion and zone of influence

c. Distribution of pressure within the jet plume

d. Feedback amplification/resonance effect

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Figure 4.2-1 Flow Chart of Methodology to Assess Shock Wave Effect on SSC

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4.2.3 Results

Detailed description for methodology and calculations of the jet impingement and blast wave load are presented in High Energy Line Break Jet Impingement Technical Report APR1400-E-N-NR-17001-P (Reference 24). The blast pressure due to a postulated pipe break of steam jet is summarized in Table 4.2-1 thru Table 4.2.3. Jet impingement loads on essential target and protection features are listed in Table A1-4 of Appendix A.

Table 4.2-1 Blast pressure for Main Steam Line Nozzle Break

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Table 4.2-2 Blast pressure for Main Steam Penetration Break

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Table 4.2-3 Blast pressure for Steam Generator Blowdown Break

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4.3 Pipe Whipping Analysis of Unrestricted Pipes

4.3.1 Analysis method of whipping load

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4.3.2 Results

The analysis results of pipe whipping loads impacted on the SSCs are summarized in Table A1-3 of Appendix A.

4.4 Pipe Whip Restraints

The types of pipe whip restraints and the analytical methods for design are provided in this section.

When required, pipe whip restraints are provided to protect the essential SSCs important to safety against the effects of pipe whipping during a postulated pipe break that can not be eliminated from the design basis by LBB evaluation. The design of pipe whip restraints is governed not only by the pipe break blowdown thrust, but also by functional requirements, deformation limitations, properties of whipping pipe, and the capacity of the support structure. The restraint is designed for the impact force induced by the maximum possible initial gap between the whip restraint and the process pipe.

The impact energy is usually too high for an elastic restraint system or support structure to be absorbed. Therefore, energy-absorbing restraints are designed using the energy balance approach (impact energy + external work = internal energy of pipe restraint system).

4.4.1 Pipe Whip Restraint Components

Pipe whip restraints typically consist of the components listed below.

a. Energy-absorbing members
   Members that absorb energy by significant plastic deformations under the influence of impacting pipes (pipe whip). The crushable honeycomb material is not considered as the material of pipe whip restraint of APR1400.

b. Non-energy-absorbing members
   Components that form a direct link between the pipe and the structure.

c. Structural attachments
   Fasteners that provide the method of attaching connecting members to the structure (e.g., welds, bolts).

d. Support structure
   Steel and concrete support structures that ultimately carry the restraint load. Design criteria are specified in DCD Tier 2, Subsections 3.8.3 and 3.8.4.

4.4.2 Design Loads for Pipe Whip Restraints

A clearance between a pipe whip restraint and pipe is provided for thermal movement of pipe during normal operation and used as the maximum possible initial gap at dynamic analysis. If a break occurs, the restraints or anchors nearest the break point prevent unlimited movement of the pipe at the point of break. In the absence of analytical justification, a dynamic load factor (DLF) of 2.0 is applied in determining a restraint loading to consider the dynamic nature of the piping thrust load. Elasto-plastic pipe and whip restraint material properties may be considered as applicable. The effect of rapid strain rate of material properties is considered in accordance with ANSI/ANS 58.2-1988. A 10 percent increase in yield strength is used to account for strain rate effects.

In general, the loading that may result from a piping break is determined using either a dynamic blowdown or a conservative static blowdown analysis. The two methods that are used for analyzing the interaction effects between a whipping pipe and a restraint are the energy balance method and equivalent static method.

The energy balance method is based on the principle of conservation of energy. The kinetic energy of the whipping pipe generated during the first quarter-cycle of movement is assumed to be converted into equivalent strain energy, which is distributed to the pipe or the whip restraint.

An equivalent static analysis model is used for rigid rupture restraints. In order to obtain the design load for a rigid restraint, the following equation is used:

$F = 2 \times 1.1 \times F_B = 2.2\ F_B$

Where:
F = design load
F_B = maximum blowdown force

The DLF is taken as 2.0 and rebound effects are accounted for by a factor of 1.1.

4.4.3 Allowable Stresses

The strain of energy-absorbing members is limited to 50 percent of the ASTM-specified minimum elongation. The yield stress for energy-absorbing members is equal to using a dynamic yield stress (F_{yd}) that is 1.1 times the static yield stress (F_{ys}) specified by ASTM.

The allowable stresses for non-energy-absorbing members, structural attachments, and support steel structures are specified in American Institute of Steel Construction (AISC) N690. In evaluating allowable stresses, dynamic yield stress (F_{yd}) is used for dynamic loads and static yield stress (F_{ys}) for static loads.

4.4.4 Design Criteria

The unique features in the design of pipe whip restraint components relative to the structural steel design are geared to the loads used and the allowable stresses. These are as follows:

a. Energy-absorbing members are designed for the restraint reaction and the corresponding deflection established according to size and material of pipe, and the blowdown force delineated in Section 4.4.2.

b. Non-energy-absorbing members, structural attachments, and the support structure are designed for the design load delineated in Subsection 4.4.2.

4.4.5 Material

The materials used for pipe whip restraint components are as follows:

a. For energy-absorbing members: ASTM A193 Grade B7

b. For other members: ASTM A500 Grade B, ASTM A572 Grade 50, ASTM A36

4.5 High-Energy Line Break Load for NSSS Nozzle Loads

4.5.1 Background

Breaks of the MS and FW economizer lines connected to the SG are enough to affect the integrity of the whole NSSS piping system.

The force-time history loads of the SG nozzles under the conditions of pipe breaks of MS and FW economizer lines inside the reactor containment building are provided for the NSSS designer to ensure the integrity of the NSSS piping system.

4.5.2 Methodology Summary

The forces on the SG nozzles are calculated. The pipe breaks are postulated at the following locations:

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4.5.3 Results

In the case of the MS line break, the nozzle loading for subsystems other than 9MS103 is not described. The nozzle loading on 9MS104 (Quadrant 1A) is mirror-imaged to 9MS103 (Quadrant 1B) with respect to the x-axis (plant north-south axis). In addition, the nozzle loading on 9MS101 (Quadrant 2B) and 9MS102 (Quadrant 2A) is mirror-imaged to 9MS104 (Quadrant 1A) and 9MS103 (Quadrant 1B) with respect to the z-axis (plant east-west axis), respectively.

In the case of the FW economizer break, the nozzle loading for the subsystem, 9FW102, is not described. The nozzle loading on 9FW102 is mirror-imaged to 9FW101 with respect to the z-axis (plant north-south axis).

The SG nozzle load of the MS line penetration break at 0 percent power is shown in Figure 4.5-3. The SG nozzle 1B load of FW economizer SG nozzle 1A break is shown in Figure 4.5-4.

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Figure 4.5-1 ANSYS Model for MS Line Break

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Figure 4.5-2 ANSYS Model for FW Line Break

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Figure 4.5-3 Reaction Force on Steam Outlet Nozzle

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Figure 4.5-4 Reaction Force on FW Economizer Nozzle 1B

4.6 Subcompartment Pressurization

4.6.1 Background

The design and licensing of nuclear power plants requires that the subcompartments and components be analyzed for pressure effects. The analyses include short-term pressure transient to which the subcompartments will be exposed as a result of the postulated line breaks. The subcompartment pressurization analysis is performed to determine localized pressure distributions and the asymmetric pressure loading analysis is conducted to determine the design requirements of structures, components, and component supports due to the transient distribution of pressure on the surface of the structure, equipment, or component.

4.6.2 Methodology

A subcompartment is any fully or partially enclosed volume within the nuclear power plant that is influenced by the pressure developed due to a postulated high-energy line break. Following a postulated high-energy line break, local transient differential pressure loading will occur on subcompartments and subcompartments can be pressurized due to the break effluent buildup and flow between subcompartments.

For subcompartment pressurization analysis, the nodalization schemes for each subcompartment should be chosen so that there is no substantial pressure gradient within a node. With regard to modeling for computational code, nodal parameters should be conservatively selected. To maximize the resultant differential pressure, the initial atmospheric conditions within a subcompartment are assumed to be the maximum allowable temperature, minimum absolute pressure, and zero percent relative humidity according to SRP Subsection 6.2.1.2. Assumptions with regard to mass and energy release are biased to maximize the subcompartment pressure. The vent flow behavior through the flowpath within the nodes is based on a homogeneous mixture in thermal equilibrium, with the assumption of 100 percent water entrainment. Currently acceptable vent critical flow correlations are the “frictionless Moody” with a multiplier of 0.6 for water-steam mixtures, and the thermal homogeneous equilibrium model for air-steam-water mixtures. The COMPARE-MOD1A is used to perform the short-term subcompartment pressure transient analysis and the generated results are used in determining the design values.

4.6.3 Results

Subcompartment structures within the containment building are designed to withstand the transient differential pressures loads resulting from a postulated pipe break. Vent paths in each subcompartment are used in depressuization to keep the differential pressures below the design value. The RCS piping, reactor vessel, and steam generator inside the containment are designed not to threaten containment integrity due to asymmetric loads.

The design features for subcompartments are described in APR1400 DCD Tier 2, Subsection 6.2.1.2.2 and the information for subcompartments and postulated pipe breaks is tabulated in Tier 2, Table 6.2.1-25.

For the steam generator subcompartment, the pressure loadings on building structures and the distribution of pressure loadings in time across NSSS components are calculated following the line breaks, such as feedwater economizer nozzle break, feedwater downcomer nozzle break, and SG blowdown nozzle break. The node and vent path descriptions are tabulated in Tier 2, Tables 6.2.1-26 and 6.2.1-31.

For the pressurizer subcompartment, pilot-operated safety relief valve (POSRV) nozzle break and main spray nozzle break are assumed as the potential sources of pressurization in the pressurizer subcompartment. The node and vent path descriptions are tabulated in Tier 2, Tables 6.2.1-27 and 6.2.1-32.

For the pressurizer spray valve room, a postulated break in the pressurizer spray piping is regarded as the potential source of pressurization in pressurizer spray valve room. The node and vent path descriptions are tabulated in Tier 2, Tables 6.2.1-28 and 6.2.1-33.

For the regenerative heat exchanger, letdown heat exchanger, and letdown heat exchanger valve room, the chemical and volume control system (CVCS) letdown line break is considered as a potential source of pressurization. The node and vent path descriptions are tabulated in Tier 2, Tables 6.2.1-29, 6.2.1-30, 6.2.1-34, and 6.2.1-35.

Tier 2, Figures 6.2.1-26 through 6.2.1-31 show the pressure responses for each subcompartment.

With regard to the subcompartment analysis for a 0.09m^2 (1 ft^2) break within the pipe break exclusion zone, the additional pressurization analysis is performed and the design differential pressure, (5.0 psid,) is determined. **TS**

5 ENVIRONMENTAL EFFECTS ANALYSIS

5.1 Flooding

5.1.1 Background

According to 10 CFR Part 50, Appendix A, GDC 4, SSCs important to safety are designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents.

5.1.2 Methodology

The internal flooding analyses for the postulated piping breaks in high-energy lines or cracks of moderate-energy lines are performed on a floor-by-floor and room-by-room basis so that the ruptures result in most severe environmental effects on essential SSCs important to safety. For flooding analysis, the single worst-case piping rupture for non-seismically analyzed piping is assumed for each analyzed area. Also, only one break at a time is postulated for non-seismic Category I or II piping as the result of a seismic event in the internal flooding analysis. The discharge volume through the ruptured area is calculated in accordance with the formula given in ANSI/ANS 56.10-1987, Section 3 (Reference 25). The released steam flow rate is conservatively assumed to be completely condensed to result in a higher flood level. The discharge flow rate from a high-energy line break is obtained by one of the following critical flow correlations.

a. Moody model for two-phase mixture and saturated steam conditions

b. Henry-Fauske Model for subcooled liquid

5.1.3 Results

The reactor containment building is not designed to provide divisional separation but it allows flooding sources to flow to the lowest level of the building through the floor openings and stairwells. The worst-case flooding event of the reactor containment building is a double-ended discharge leg LOCA with the minimum SI pump flow, because it results in maximum break flow to the reactor containment building as a flooding source. Discharged water first fills up the volume below elevation El. 100 ft 0 inch and then spreads the volume above the ground level of the reactor containment building. Water released by a LOCA is collected in the in-containment refueling water storage tank (IRWST) through the floor opening. It then flows back to the reactor coolant system or is sprayed into the containment and recirculated. The flood water level is determined as 0.61 m (2 ft) above El. 100 ft 0 in. The maximum flood level of containment does not affect safety-related equipment. There are no submerged SSCs required for safe shutdown.

The auxiliary building is designed to provide physical separation to prevent spreading of fluids to the areas housing safety-related equipment and components. The worst case of flooding in the auxiliary building is the water source in the IRWST. The total water volume of the IRWST is 2,540 m^3 (89,715 ft^3) and the floodable area in the four quadrants (A, B, C, and D) is 1,168 m^2 (12,577 ft^2), 1,176 m^2 (12,664 ft^2), 1,232 m^2 (13,263 ft^2), and 1,232 m^2 (13,263 ft^2), respectively. Based on these values, the maximum water level is 2.74 m (9 ft) with some margin. The released water volume is contained within the affected quadrant.

The cross-sectional area of the break for the main steam and feedwater line within the break exclusion zone is considered as 0.09 m^2 (1.0 ft^2), as defined in Standard Review Plan, Branch Technical Position 3-3 (Reference 5). A rupture of a feedwater system line is the worst case of flooding in the main steam valve house. In addition, a main feedwater pump is assumed to operate at the maximum flow rate. An emergency flood relief path is installed to drain out at each room. The potential flood level of main steam valve house is 1.82 m (6 ft) above El. 137 ft 6 in and the maximum flood level of the area does not affect safety-related equipment.

The detailed flooding analysis results of reactor containment building and auxiliary building are described in DCD Tier 2, Subsection 3.4.1.5.

5.2 Pressure and Temperature for Environmental Qualification

5.2.1 Background

The design and licensing of nuclear power plants requires that subcompartments be analyzed for temperature effects. The analysis includes determination of long-term temperature transients resulting from a postulated pipe break, 0.09 m^2 (1.0 ft^2), in a main steam line within the break exclusion area, as defined in Standard Review Plan, Branch Technical Position 3-3 pressure and temperature analysis due to high-energy line breaks in other rooms except for MSVH are not performed, because piping design in those rooms are not the DC application scope of APR1400. The purpose of this analysis is to generate the envelope curve for the environmental qualification pressure and temperature analysis due to high energy line breaks in other.

5.2.2 Methodology

[ ] TS

5.2.3 Results

The envelope curve for the environmental qualification due to a postulated pipe break, 0.09 m^2 (1.0 ft^2), in a main steam line within the break exclusion area is determined using the proper temperature margin. The environmental parameter and envelope curve description is tabulated in Category M (Main Steam Line Break) in Tier 2, Table 3.11-2.

6 REFERENCES

1. 10 Code of Federal Regulations Part 50, “Domestic Licensing of Production and Utilization Facilities,” U.S. Nuclear Regulatory Commission.

2. Standard Review Plan 3.6.1, “Plant Design for Protection Against Postulated Piping Failures in Fluid Systems Outside Containment,” Rev. 3, U.S. Nuclear Regulatory Commission, March 2007.

3. Standard Review Plan 3.6.2, “Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping,” Rev. 3, U.S. Nuclear Regulatory Commission, December 2016.

4. Standard Review Plan 3.6.3, “Leak-Before-Break Evaluation Procedures,” Rev. 1, U.S. Nuclear Regulatory Commission, March 2007.

5. Standard Review Plan BTP 3-3, “Protection Against Postulated Piping Failures in Fluid Systems Outside Containment,” Rev. 3, U.S. Nuclear Regulatory Commission, March 2007.

6. Standard Review Plan BTP 3-4, “Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment,” Rev. 2, U.S. Nuclear Regulatory Commission, March 2007.

7. NUREG-1061, Vol. 3, “Evaluation of Potential for Pipe Breaks,” U.S. Nuclear Regulatory Commission, November 1984.

8. ASME Boiler and Pressure Vessel Code, Section III, Division 1, “Rules for Construction of Nuclear Facility Components,” American Society of Mechanical Engineers, 2004.

9. ASME, “Code for Pressure Piping, Power Piping,” ASME B31.1, American Society of Mechanical Engineers, 2010 Edition.

10. ASME, “Inservice Inspection of Nuclear Power Plants,” ASME Section XI, American Society of Mechanical Engineers.

11. NRC RG 1.11, “Instrument Lines Penetrating Primary Containment,” U.S. Nuclear Regulatory Commission, March 1971.

12. ANSI/ANS 58.2, “American National Standard Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture,” 1988.

13. R. T. Lahey, Jr., and F. J. Moody, “Pipe Thrust and Jet Loads,” The Thermal Hydraulics of a Boiling Water Nuclear Reactor, Subsection 9.2.3, pp. 375-409, Published by American Nuclear Society, Prepared by the Division of Technical Information, United States Energy Research and Development Administration, 1977.

14. NUREG/CR-5535, “RELAP5/MOD3.3 Code Manual,” Volume I, U.S. Nuclear Regulatory Commission, March 2003.

15. NUREG/CR-2781, “Evaluation of Water Hammer Events in Light Water Reactor Plants,” U.S. Nuclear Regulatory Commission, July 1982.

16. NUREG/CR-2059, "Compilation of Data Concerning Known and Suspected Water Hammer Events in Nuclear Power Plants, CY 1969-May 1981," U.S. Nuclear Regulatory Commission, May 1982.

17. NRC RG 1.45, "Reactor Coolant Pressure Boundary Leakage Detection Systems," U.S. Nuclear Regulatory Commission, May 1973.

18. EPRI NP-3596-SR, PICEP, "Pipe Crack Evaluation Program," August 1984.

19. APR1400-Z-A-NR-14007-P, "LOCA Mass and Energy Release Methodology," Rev. 0, KEPCO& KHNP, November 2014.

20. DSRS for mPOWER™ iPWR Design BTP 3-4, "Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment," Rev. 0, U.S. Nuclear Regulatory Commission, May 2013.

21. ASME V&V 20-2009, "Standard for Verification and Validation in Computational Fluids Dynamics and Heat Transfer," American Society of Mechanical Engineers, 2009.

22. MUAP-10022-NP, "Evaluation on Jet Impingement Issues Associated with Postulated Pipe Rupture," Rev. 2, Mitsubishi Heavy Industries, Ltd., 2012.

23. NEDO-33440, Appendix A, "CFD Modeling of Blast Wave Propagation During an ESBWR Feedwater Line Break (TR 0000-0102-6265-R0)," Rev 2, GEH, March 2010.

24. APR1400-E-N-NR-17001-P, "APR1400 High Energy Line Break Jet Impingement," Rev. 0, KEPCO& KHNP, June 2017.

25. ANSI/ANS 56.10-1987, "Subcompartment Pressure and Temperature Transient Analysis in Light Water Reactors," American Nuclear Society, 1988.

APPENDIX A

Location of High-Energy Line Break

1. LOCATION OF HIGH-ENERGY LINE BREAK

The portions of high-energy piping of nominal diameter over than 25.4 mm (1 in) and break location for each system are identified in Figure A1-1 through Figure A1-11. Piping applied leak-before-break criteria are also identified in these figures. High-energy line break locations are described in Table A1-1.

Table A1-1 and Table A1-2 show terminal end break locations. There are no intermediate break locations of the piping system taken to the graded approach as a result of stress analysis and cumulative usage factor analysis for ASME Code, Section III, Class 1 piping.

For ASME Code, Section III, Class 2 and 3 piping, main steam and main feedwater piping which are applied to graded approach are located in the break exclusion area from the containment penetration anchors to the MSVH penetration anchors beyond the isolation valves.

The pipe whip load and jet impingement load on essential target are summarized in Table A1-3 and Table A1-4.

For moderate-energy fluid systems in areas other than containment penetrations, through-wall cracks are postulated at axial and circumferential locations that result in the most severe environmental consequences.

Legend

▬▬▬▬▬▬	High-Energy Line Inside Containment
■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■	LBB Application Piping
[XXXX]	Subsystem Number
●	Break Location

Table A1-1 High-Energy Line and Break Location (1/6)

Subsystem	Room Number	High-Energy Line	Break Location	
9RC101	136C02	RCS cold leg (RC003AD30) – PZR spray nozzle	Terminal End	Figure A1-1 (1 and 2 of 2)
9RC101	136C02	RCS cold leg (RC003AB30) – PZR spray nozzle	Terminal End	Figure A1-1 (1 and 2 of 2)
9RC101	136C02	Charging side regenerative HX outlet – PZR spray line connection	Terminal End	Figure A1-1 (2 of 2)
-	136C02	PZR – PZR spray line connection (V200/V201)	Terminal End	Figure A1-1 (2 of 2)
-	136C02	PZR – PZR spray line connection (V202/V203)	Terminal End	Figure A1-1 (2 of 2)
9RC103	100C02B	RCS cold leg (RC002AD30) – RCS drain line (RC008AD2)	Terminal End	Figure A1-1 (1 of 2)
9RC104	100C02A	RCS cold leg (RC002AA30) – RCS drain line (RC008AA2)	Terminal End	Figure A1-1 (1 of 2)
9RC105	100C02A	RCS cold leg (RC002AC30) – RCS drain line (RC008AC2)	Terminal End	Figure A1-1 (1 of 2)
9RC105	100C02A	RCS drain line letdown line (RC10A2) – Regenerative HX letdown line inlet nozzle	Terminal End	Figure A1-1 (1 of 2)
9RC106	100C02B	RCS cold leg (RC002AB30) – RCS drain line (RC008AB2)	Terminal End	Figure A1-1 (1 of 2)
9RG101	156C01	RCS gas vent system POSRV inlet vent line – Vent line isolation valve (V412/413)	Terminal End	Figure A1-1 (2 of 2) / Figure A1-2
9SI101	136C01A	SI tank (1A) vent line nozzle (SI009AA12) – RCS DVI nozzle (RC005AA12)	Terminal End	Figure A1-3 (2 of 2) / Figure A1-1 (1 of 2)
9SI102	136C01B	SI tank (1B) vent line nozzle (SI009AB12) – RCS DVI nozzle (RC005AD12)	Terminal End	Figure A1-3 (1 of 2) / Figure A1-1 (1 of 2)

Table A1-1 High-Energy Line and Break Location (2/6)

Subsystem	Room Number	High-Energy Line	Break Location	
9SI103	136C01B	SI tank (1C) vent line nozzle (SI009AC12) – RCS DVI nozzle (RC005AB12)	Terminal End	Figure A1-1 (1 of 2) / Figure A1-3 (2 of 2)
9SI104	136C01A	SI tank (1D) vent line nozzle (SI009AD12) – RCS DVI nozzle (RC005AC12)	Terminal End	Figure A1-1 (1 of 2) / Figure A1-3 (1 of 2)
9SI105	100C02A	RCS hot leg (RC001AA42) – Shutdown cooling line isolation valve inside containment (V653)	Terminal End	Figure A1-1 (1 of 2) / Figure A1-3 (2 of 2)
9SI105	100C02A	RCS hot leg injection line at containment penetration (PC0123) – Shutdown cooling line connection (RC004AA16)	Terminal End	Figure A1-3 (2 of 2)
9SI106	100C02B	RCS hot leg (RC001AB42) – Shutdown cooling line isolation valve inside containment (V654)	Terminal End	Figure A1-1 (1 of 2) Figure A1-3 (1 of 2)
9SI106	100C02B	RCS hot leg injection line at containment penetration (PC0123) – Shutdown cooling line connection (RC004AB16)	Terminal End	Figure A1-1 (1 of 2)
9SI106	100C02B	Shutdown cooling line connection (RC004AB16) – RCS drain line isolation valve (V216)	Terminal End	Figure A1-1 (1 of 2)
9SI611	136C01A	SI tank (1A) drain line (SI025BA2) connection –RCS drain line isolation valve (V641)	Terminal End	Figure A1-3 (2 of 2)
9SI612	136C01B	SI tank (1B) drain line (SI025BB2) connection –RCS drain line isolation valve (V621)	Terminal End	Figure A1-3 (2 of 2)
9SI613	136C01B	SI tank (1C) drain line (SI025BC2) connection –RCS drain line isolation valve (V631)	Terminal End	Figure A1-3 (2 of 2)
9SI614	136C01A	SI tank (1D) drain line (SI025BD2) connection –RCS drain line isolation valve (V611)	Terminal End	Figure A1-3 (2 of 2)

Table A1-1 High-Energy Line and Break Location (3/6)

Subsystem	Room Number	High-Energy Line	Break Location	
9SI619	156C01	SI tank (1A) atmosphere vent line (SI047AA2) connection – Atmosphere vent valve (V241)	Terminal End	Figure A1-3 (2 of 2)
9SI620	156C01	SI tank (1B) atmosphere vent line (SI047AB2) connection – Atmosphere vent valve (V221)	Terminal End	Figure A1-3 (2 of 2)
9SI621	156C01	SI tank (1C) atmosphere vent line (SI047AC2) connection – Atmosphere vent valve (V231)	Terminal End	Figure A1-3 (2 of 2)
9SI622	156C01	SI tank (1D) atmosphere vent line (SI047AD2) connection – Atmosphere vent valve (V211)	Terminal End	Figure A1-3 (2 of 2)
9CV101	100C02B	Regenerative HX charging line outlet nozzle – RCS cold leg (RC003AA30) charging nozzle	Terminal End	Figure A1-4 (1 of 2) / Figure A1-1 (1 of 2)
9CV102	100C02B	Charging line at containment penetration (PC230) – Regenerative HX charging line inlet nozzle	Terminal End	Figure A1-4 (1 of 2)
9CV106	100C02B	Regenerative HX letdown line outlet nozzle – Letdown HX letdown line inlet nozzle / isolation valve inside containment (V363)	Terminal End	Figure A1-4 (1 of 2)
9CV107	100C02B	Letdown HX letdown line outlet nozzle – Letdown line at containment penetration (PC402)	Terminal End	Figure A1-4 (1 of 2)
9CV622	114C01A	RCP seal water line at containment penetration (PC304) – 2”x1” reducer	Terminal End	Figure A1-4 (2 of 2)
9SD101	100C02A 136C01A	SG1 wet layup nozzle – Wet layup isolation valve (V1119)	Terminal End	Figure A1-5
9SD102	100C02B 136C01B	SG2 wet layup nozzle – Wet layup isolation valve (V1120)	Terminal End	Figure A1-5
9SD103	100C02A	SG1 blowdown line nozzle – Blowdown line at containment penetration (PC911)	Terminal End	Figure A1-5
9SD104	100C02B	SG2 blowdown line nozzle – Blowdown line at containment penetration (PC921)	Terminal End	Figure A1-5

Table A1-1 High-Energy Line and Break Location (4/6)

Subsystem	Room Number	High-Energy Line	Break Location	
9SD215	137A31C	Blowdown line at containment penetration (PC911) – Blowdown flash tank compartment wall	Terminal End	Figure A1-5
9SD216	137A31D	Blowdown line at containment penetration (PC921) – Blowdown flash tank compartment wall	Terminal End	Figure A1-5
9MS101	136C01B 100C02B	SG2 steam vent nozzle – SG2 main steam line at containment penetration (PC621)	Terminal End	Figure A1-6
9MS269	137A31D	SG2 main steam line at containment penetration (PC621) – SG2 main steam valve house anchor wall penetration	Terminal End	Figure A1-6
9MS288	137A31D	Main steam line (9M269) condensate drain line nozzle – Main steam valve house anchor wall penetration	Terminal End	Figure A1-6
9MS102	156C01 136C01B	SG2 steam vent nozzle – SG2 main steam line at containment penetration (PC622)	Terminal End	Figure A1-6
9MS270	137A31D	SG2 main steam line at containment penetration (PC622) – SG2 main steam valve house anchor wall penetration	Terminal End	Figure A1-6
9MS287	137A31D	Main steam line (9M270) condensate drain line nozzle – Main steam valve house anchor wall penetration	Terminal End	Figure A1-6
9MS275	137A31D	SG2 aux-feedwater pump turbine steam line connection – pipe layout area boundary wall	Terminal End	Figure A1-6
9MS103	136C01A 100C02A	SG1 steam vent nozzle – SG1 main steam line at containment penetration (PC612)	Terminal End	Figure A1-6
9MS271	137A31C	SG1 main steam line at containment penetration (PC612) – SG1 main steam valve house anchor wall penetration	Terminal End	Figure A1-6
9MS286	137A31C	Main steam line (9M271) condensate drain line nozzle – Main steam valve house anchor wall penetration	Terminal End	Figure A1-6
9MS273	137A31C	SG1 aux-feedwater pump turbine steam line connection – pipe layout area boundary wall	Terminal End	Figure A1-6

Table A1-1 High-Energy Line and Break Location (5/6)

Subsystem	Room Number	High-Energy Line	Break Location	
9MS104	136C01A 100C02A	SG1 steam vent nozzle – SG1 main steam line at containment penetration (PC611)	Terminal End	Figure A1-6
9MS272	137A31C	SG1 main steam line at containment penetration (PC611) – SG1 main steam valve house anchor wall penetration	Terminal End	Figure A1-6
9MS285	137A31C	Main steam line (9M272) condensate drain line nozzle – Main steam valve house anchor wall penetration	Terminal End	Figure A1-6
9FW209	137A31C	SG1 economizer main steam valve house anchor wall – Economizer line at containment penetration (PC511)	Terminal End	Figure A1-7 (1 of 1)
9FW101	136C01A	Economizer line at containment penetration (PC511) – SG1 economizer injection nozzle	Terminal End	Figure A1-7 (1 of 1)
9FW603	100C02A	SG1 secondary drain line (FW066AA2) nozzle – Drain line isolation valve (V2122)	Terminal End	Figure A1-7 (1 of 1)
9FW627	100C02A	SG1 secondary drain line (FW066AB2) nozzle – Drain line isolation valve (V2123)	Terminal End	Figure A1-7 (1 of 1)
9FW219	137A31C	SG1 downcomer main steam valve house anchor wall – SG1 downcomer at containment penetration (PC512)	Terminal End	Figure A1-7 (1 of 1)
9AF101	136C01A	SG1 downcomer at containment penetration (PC512) / aux-feedwater check valve (V1008A/V1007A) – SG1 downcomer injection nozzle	Terminal End	Figure A1-7 (1 of 1) / Figure A1-8 (1 of 1)
9FW210	137A31D	SG2 economizer main steam valve house anchor wall – Economizer line at containment penetration (PC521)	Terminal End	Figure A1-7 (1 of 1)
9FW102	136C01B	Economizer line at containment penetration (PC521) – SG2 economizer injection nozzle	Terminal End	Figure A1-7 (1 of 1)
9FW602	100C02B	SG2 secondary drain line (FW066AC2) nozzle – Drain line isolation valve (V2124)	Terminal End	Figure A1-7 (1 of 1)
9FW628	100C02B	SG2 secondary drain line (FW066AD2) nozzle –Drain line isolation valve (V2125)	Terminal End	Figure A1-7 (1 of 1)

Table A1-1 High-Energy Line and Break Location (6/6)

Subsystem	Room Number	High-Energy Line	Break Location	
9FW220	137A31D	SG2 downcomer main steam valve house anchor wall – SG2 downcomer at containment penetration (PC522)	Terminal End	Figure A1-7 (1 of 1)
9AF102	136C01B	SG2 downcomer at containment penetration (PC522) / aux-feedwater check valve (V1008B/V1007B) – SG2 downcomer injection nozzle	Terminal End	Figure A1-7 (1 of 1) Figure A1-8 (1 of 1)

Table A1-2 System-Specific High-Energy Line Break Protection (1/7)

Sub system	Break Number	Configu ration [1)]	Break Location	Protection of Essential Target	
Reactor Coolant System (Not applied for Leak-Before-Break): Terminal End Break					
	BT-RC-01	C	Figure A1-1 (2 of 2)	PW [2)]	No PW occurs because of geometric configuration (limited movement of the broken pipe end).
	BT-RC-02			JI [3)]	No essential target
	BT-RC-03				
	BT-RC-04				
9RC101	BT-RC-05	C	Figure A1-1 (2 of 2)	PW	Pressurizer compartment wall (WCE11-02) (designed to withstand PW impact load)
				JI	Top of pressurizer (designed to withstand JI load)
	BT-RC-06	C	Figure A1-1 (1 of 2)	PW	No essential target
				JI	RCS discharge leg (designed to withstand JI load)
	BT-RC-07	C	Figure A1-1 (1 of 2)	PW	Steel structure (2CS101) (designed to withstand PW impact load)
				JI	RCS discharge leg (RC003AB30) (designed to withstand JI load)
9RC104	BT-RC-08	C	Figure A1-1 (1of 2)	PW	RCP 01A concrete pedestal, EL.100' floor (SCE41-01) (designed to withstand PW
				JI	RCS suction leg (RC002AA30) (designed to withstand JI load)
9RC106	BT-RC-09	C	Figure A1-1 (1 of 2)	PW	RCP 02B concrete pedestal, EL.100' floor (SCE11-01) (designed to withstand PW
				JI	RCS suction leg (RC002AB30) (designed to withstand JI load)
9RC105	BT-RC-10	C	Figure A1-1 (1 of 2)	PW	RCP 01B concrete pedestal, EL.100' floor (SCE31-01) (designed to withstand PW
				JI	RCS suction leg (RC002AC30) (designed to withstand JI load)
9RC103	BT-RC-11	C	Figure A1-1 (1 of 2)	PW	RCP 02B concrete pedestal, EL.100' floor (SCE21-01) (designed to withstand PW
				JI	RCS suction leg (RC002AD30) (designed to withstand JI load)

Notes:

1) C and L stand for circumferential and longitudinal breaks, respectively.
2) Pipe whip
3) Jet impingement

Table A1-2 System-Specific High-Energy Line Break Protection (2/7)

Sub system	Break Number	Configu ration	Break Location	Protection of Essential Target	
Reactor Coolant System (Not applied for Leak-Before-Break): Terminal End Break					
9SI105	BT-RC-12	C	Figure A1-1 (1 of 2)	PW	Steel structure (3CS421) (designed to withstand PW impact load)
				JI	Shutdown cooling line (RC004AA16) (designed to withstand JI load)
9SI106	BT-RC-13	C	Figure A1-1 (1 of 2)	PW	Steel structure (3CS221) (designed to withstand PW impact load)
				JI	Shutdown cooling line (RC004AB16) (designed to withstand JI load)
	BT-RC-14	C	Figure A1-1 (1 of 2)	PW	EL.100’ floor (SCE21-01) (designed to withstand PW impact load)
				JI	Shutdown cooling line (RC004AB16) (designed to withstand JI load)
9CV101	BT-RC-15	C	Figure A1-1 (1 of 2)	PW	Hot leg injection line (SI010EC4) (designed to withstand PW
				JI	RCP cold leg (RC003AA30), (designed to withstand JI load)
Safety Injection / Shutdown Cooling System (Not applied for Leak-Before-Break): Terminal End Break					
9SI619	BT-SI-01	C	Figure A1-3 (2 of 2)	PW	No PW occurs (not enough reserved energy to move the broken pipe end).
				JI	No essential target
9SI620	BT-SI-02	C	Figure A1-3 (1 of 2)	PW	No PW occurs (not enough reserved energy to move the broken pipe end).
				JI	No essential target
9SI621	BT-SI-03	C	Figure A1-3 (2 of 2)	PW	No PW occurs (not enough reserved energy to move the broken pipe end).
				JI	No essential target
9SI622	BT-SI-04	C	Figure A1-3 (1 of 2)	PW	No PW occurs (not enough reserved energy to move the broken pipe end).
				JI	No essential target
9SI611	BT-SI-05	C	Figure A1-3 (2 of 2)	PW	EL.136’-6” floor (SCH41-01) (designed to withstand PW impact load)
				JI	EL.136’ -6” floor (SCH41-01) (designed to withstand JI load)
9SI612	BT-SI-06	C	Figure A1-3 (1 of 2)	PW	EL.136’-6” floor (SCH21-01) (designed to withstand PW impact load)
				JI	EL.136’-6” floor (SCH21-01) (designed to withstand JI load)
9SI613	BT-SI-07	C	Figure A1-3 (2 of 2)	PW	EL.136’-6” floor (SCH11-01) (designed to withstand PW impact load)
				JI	EL.136’-6” floor (SCH11-01) (designed to withstand JI load)

Table A1-2 System specific High-Energy Line Break Protection (3/7)

Sub system	Break Number	Configuration	Break Location	Protection of Essential Target	
9SI614	BT-SI-08	C	Figure A1-3 (1 of 2)	PW	EL.136'-6" floor (SCH31-01) (designed to withstand PW impact load)
				JI	EL.136'-6" floor (SCH31-01) (designed to withstand JI load)
Chemical and Volume Control System (Not applied for Leak-Before-Break): Terminal End Break					
9RC105	BT-CV-01	C	Figure A1-4 (1 of 2)	PW	Regenerative heat exchanger room floor (SCE31-01) (designed to withstand PW impact load)
				JI	Regenerative heat exchanger (designed to withstand JI load)
9CV106	BT-CV-02	C	Figure A1-4 (1 of 2)	PW	Regenerative heat exchanger room floor (SCE31-01) (designed to withstand PW impact load)
				JI	Regenerative heat exchanger (designed to withstand JI load)
9CV102	BT-CV-03	C	Figure A1-4 (1 of 2)	PW	Regenerative heat exchanger room wall (WCM11-03) (designed to withstand PW
				JI	Regenerative heat exchanger (designed to withstand JI load)
9CV101	BT-CV-04	C	Figure A1-4 (1 of 2)	PW	Regenerative heat exchanger Floor (SCE31-01) (designed to withstand PW impact load)
				JI	Regenerative heat exchanger (designed to withstand JI load)
9CV106	BT-CV-05	C	Figure A1-4 (1 of 2)	PW	Letdown heat exchanger room wall (WCE11-01) (designed to withstand PW
				JI	Letdown heat exchanger, letdown heat exchanger room wall (WCE11-01) (designed to withstand JI load)
9CV107	BT-CV-06	C	Figure A1-4 (1 of 2)	PW	Letdown heat exchanger room wall (WCM11-01), CC line (CC094A8) (designed to withstand PW impact load)
				JI	Letdown heat exchanger, letdown heat exchanger room floor (SCH11-01) (designed to withstand JI load)

Table A1-2 System-Specific High-Energy Line Break Protection (4/7)

Sub system	Break Number	Configuration	Break Location	Protection of Essential Target	
	BT-CV-07	C	Figure A1-4 (1 of 2)	PW	No PW occurs (impacted piping (SI008EB12) has larger nominal size and thickness than whipping pipe).
				JI	Containment wall, containment penetration (PC0402) (designed to withstand JI load)
Chemical and Volume Control System (Not applied for Leak-Before-Break): Terminal End Break					
9CV102	BT-CV-08	C	Figure A1-4 (1 of 2)	PW	IRWST venting opening (designed to withstand PW impact load)
				JI	Containment wall, containment penetration (PC0230) (designed to withstand JI load)
9CV622	BT-CV-09	C	Figure A1-4 (2 of 2)	PW	No essential target
				JI	Containment wall, containment penetration (PC0304) (designed to withstand JI load)
9CV101	BT-CV-10	C	Figure A1-4 (1 of 2)	PW	No PW occurs because of geometric configuration (broken pipe is restrained by wall).
				JI	No essential target
Steam Generator Blowdown System (Not applied for Leak-Before-Break): Terminal End Break					
9SD103	BT-SD-01	C	Figure A1-5 (1 of 1)	PW	PWR (HSD103-001W) required to protect RCP01A
				JI	SG1 (designed to withstand JI load)
				Blast	RCP #1A (designed to withstand blast load)
	BT-SD-02	C	Figure A1-5 (1 of 1)	PW	PWR (HSD103-002W) required to protect RCP01B
				JI	SG1 (designed to withstand JI load)
				Blast	RCP #1B (designed to withstand blast load)
9SD104	BT-SD-03	C	Figure A1-5 (1 of 1)	PW	PWR (HSD104-001W) required to protect RCP02A
				JI	SG2 (designed to withstand JI load)
				Blast	RCP #2A (designed to withstand blast load)
	BT-SD-04	C	Figure A1-5 (1 of 1)	PW	PWR (HSD104-002W) required to protect RCP02B
				JI	RCP02B, SG2 (designed to withstand JI load)
				Blast	RCP #2B (designed to withstand blast load)
9SD103	BT-SD-05	C	Figure A1-5 (1 of 1)	PW	PWR (HSD103-003W) required to protect containment liner and to restraint nozzle load due to PW
				JI	Containment Penetration(PC0911) (designed to withstand JI load)
				Blast	No essential target other than Containment Penetration(PC0911) (bounded by JI load)

9SD104	BT-SD-06	C	Figure A1-5 (1 of 1)	PW	PWR (HSD104-003W) required to protect containment liner and to restrain nozzle load due to PW
				JI	Containment Penetration(PC0921) (designed to withstand JI load)
				Blast	No essential target other than Containment Penetration(PC0921) (bounded by JI load)
9SD101	BT-SD-07	C	Figure A1-5 (1 of 1)	PW	Secondary shield wall (WCE21-01) (designed to withstand PW impact load).
				JI	Secondary shield wall (WCE21-01) (designed to withstand JI load)
				Blast	Secondary shield wall (WCE21-01) (designed to withstand blast load)
9SD102	BT-SD-08	C	Figure A1-5 (1 of 1)	PW	Secondary shield wall (WCE11-01) (designed to withstand PW impact load).
				JI	Secondary shield wall (WCE11-01) (designed to withstand JI load)
				Blast	Secondary shield wall (WCE11-01) (designed to withstand blast load)

Table A1-2 System-Specific High-Energy Line Break Protection (5/7)

Sub system	Break Number	Configu ration	Break Location Figure No	Protection of Essential Target	
Main Steam System (Not applied for Leak-Before-Break): Terminal End Break					
9MS104 9MS272	BT-MS-01	C	Figure A1-6 (1 of 1)	PW	PWR (HMS104-001W) installed (to protect containment wall (liner plate))
				JI	Top of SG1 (designed to withstand JI load)
				Blast	SG1 (designed to withstand blast load)
	BT-MS-02	C	Figure A1-6 (1 of 1)	PW	PWR(HMS104-002W) installed (to protect feedwater pipe, SG1 nozzle)
				JI	Containment penetration (PC0611) (designed to withstand JI load)
				Blast	FW006 (impulse loading only), CS011,CS003 (out of graded approach scope)
9MS103 9MS271	BT-MS-03	C	Figure A1-6 (1 of 1)	PW	PWR(HMS103-001W) installed (to protect containment wall(liner plate))
				JI	Top of SG1 (designed to withstand JI load)
				Blast	SG1 (designed to withstand blast load)
	BT-MS-04	C	Figure A1-6 (1 of 1)	PW	PWR(HMS103-002W) installed (to protect feedwater pipe, SG1 nozzle)
				JI	Containment penetration (PC612) (designed to withstand JI load)
				Blast	FW006 (impulse loading only), CS011,CS003 (out of graded approach scope)
9MS102 9MS270	BT-MS-05	C	Figure A1-6 (1 of 1)	PW	PWR (HMS102-001W) installed (to protect containment wall (liner plate))
				JI	Top of SG2 (designed to withstand JI load)
				Blast	SG2 (designed to withstand blast load)
	BT-MS-06	C	Figure A1-6 (1 of 1)	PW	PWR (HMS102-002W) installed (to protect feedwater pipe (FW045AB14), SG2 nozzle)
				JI	Containment penetration (PC622) (designed to withstand JI load)
				Blast	FW006 (impulse loading only), CS011,CS003 (out of graded approach scope)

Table A1-2 System specific High-Energy Line Break Protection (6/7)

Sub system	Break Number	Configu ration	Break Location Figure No	Protection of Essential Target	
Main Steam System (Not applicable Leak-Before-Break): Terminal End Break					
9MS101 9MS269	BT-MS-07	C	Figure A1-6 (1 of 1)	PW	PWR (HMS101-001W) installed (to protect containment wall (liner
				JI	Top of SG2 (designed to withstand JI load)
				Blast	SG2 (designed to withstand blast load)
	BT-MS-08	C	Figure A1-6 (1 of 1)	PW	PWR (HMS101-002W) installed (to protect feedwater pipe, SG2 nozzle)
				JI	Containment penetration (PC621) (designed to withstand JI load)
				Blast	FW006 (impulse loading only), CS011,CS003 (out of graded approach
Feedwater System (Not applied for Leak-Before-Break): Terminal End Break					
9FW101 9FW209	BT-FW-01	C	Figure A1-7 (1 of 1)	PW	PWR (HFW101-001W) installed to minimize load to SG1 nozzle
				JI	Containment penetration (PC0511) (designed to withstand JI load)
9FW102 9FW210	BT-FW-02	C	Figure A1-7 (1 of 1)	PW	PWR (HFW102-001W) installed to minimize load to SG2 nozzle
				JI	Containment penetration (PC0521) (designed to withstand JI load)
9FW101	BT-FW-03	C	Figure A1-7 (1 of 1)	PW	Secondary shield wall (WCE41-01) (designed to withstand PW impact load)
				JI	Secondary shield wall (WCE41-01), SG1 (designed to withstand JI load)
9FW101	BT-FW-04	C	Figure A1-7 (1 of 1)	PW	Secondary shield wall (WCE21-01) (designed to withstand PW impact load)
				JI	Secondary shield wall (WCE21-01), SG2 (designed to withstand JI load)
9FW101	BT-FW-05	C	Figure A1-7 (1 of 1)	PW	Secondary shield wall (WCE31-01) (designed to withstand PW impact load)
				JI	Secondary shield wall (WCE31-01), SG1 (designed to withstand JI load)

Table A1-2 System-Specific High-Energy Line Break Protection (7/7)

Sub system	Break Number	Configu ration	Break Location Figure No	Protection of Essential Target	
Feedwater System (Not applied for Leak-Before-Break): Terminal End Break					
9FW101	BT-FW-06	C	Figure A1-7 (1 of 1)	PW	PWR (HFW102-002W) installed to minimize load to pressurizer spray piping, RC007C4
				JI	Secondary shield wall (WCE11-01), SG2 (designed to withstand JI load)
9AF101 9FW219	BT-FW-07	C	Figure A1-7 (1 of 1)	PW	PWR (HAF101-001W) required to minimize load to SG1 nozzle
				JI	Containment penetration (PC0512), PWR (HAF101-001W) (designed to withstand JI load)
9AF102 9FW220	BT-FW-08	C	Figure A1-7 (1 of 1)	PW	PWR (HFW102-001W) required to minimize load to SG1 nozzle
				JI	Containment penetration (PC0522), PWR (HAF102-001W) (designed to withstand JI load)
9AF101	BT-FW-09	C	Figure A1-7 (1 of 1)	PW	Secondary shield wall (WCE21-01) (designed to withstand PW load)
				JI	Secondary shield wall (WCE21-01), SG1 (designed to withstand JI load)
9AF102	BT-FW-10	C	Figure A1-7 (1 of 1)	PW	Secondary shield wall (WCE11-01) (designed to withstand PW load)
				JI	Secondary shield wall (WCE11-01), SG2 (designed to withstand JI load)
9FW601	BT-FW-11	C	Figure A1-7 (1 of 1)	PW	Steel structure (3CS502) (designed to withstand PW load)
				JI	No essential target
9FW627	BT-FW-12	C	Figure A1-7 (1 of 1)	PW	No essential target
				JI	No essential target
9FW602	BT-FW-13	C	Figure A1-7 (1 of 1)	PW	No essential target
				JI	No essential target
9FW628	BT-FW-14	C	Figure A1-7 (1 of 1)	PW	Steel structure (3CS501) (designed to withstand PW load)
				JI	No essential target

Table A1-3 Pipe Whip Load on Essential Target (1/5)

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Table A1-3 Pipe Whip Load on Essential Target (2/5)

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Table A1-3 Pipe Whip Load on Essential Target (3/5)

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Table A1-3 Pipe Whip Load on Essential Target (4/5)

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Table A1-3 Pipe Whip Load on Essential Target (5/5)

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Table A1-4 Jet Impingement Load on Essential Target (1/6)

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Table A1-4 Jet Impingement Load on Essential Target (2/6)

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Table A1-4 Jet Impingement Load on Essential Target (3/6)

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Table A1-4 Jet Impingement Load on Essential Target (4/6)

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Table A1-4 Jet Impingement Load on Essential Target (5/6)

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Table A1-4 Jet Impingement Load on Essential Target (6/6)

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Figure A1-1 High-Energy Piping Portion and Break Location for Reactor Coolant System (1/2)

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Figure A1-1 High-Energy Piping Portion and Break Location for Reactor Coolant System (2/2)

TS

Figure A1-2 High-Energy Piping Portion and Break Location for Reactor Coolant Gas Vent System (1/1)

TS

Figure A1-3 High-Energy Piping Portion and Break Location for Safety Injection and Shutdown Cooling System (1/2)

TS

Figure A1-3 High-Energy Piping Portion and Break Location for Safety Injection and Shutdown Cooling System (2/2)

TS

Figure A1-4 High-Energy Piping Portion and Break Location for Chemical and Volume Control System (1/2)

TS

Figure A1-4 High-Energy Piping Portion and Break Location for Chemical and Volume Control System (2/2)

TS

Figure A1-5 High-Energy Piping Portion and Break Location for Steam Generator Blowdown System (1/1)

TS

Figure A1-6 High-Energy Piping Portion and Break Location for Main Steam System (1/1)

TS

Figure A1-7 High-Energy Piping Portion and Break Location for Feedwater System (1/1)

TS

Figure A1-8 High-Energy Piping Portion and Break Location for Auxiliary Feedwater System (1/1)

TS

Figure A2-1 High Energy Line Isometric Drawing for Reactor Coolant System (1/9)

TS

Figure A2-1 High Energy Line Isometric Drawing for Reactor Coolant System (2/9)

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Figure A2-1 High Energy Line Isometric Drawing for Reactor Coolant System (3/9)

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Figure A2-1 High Energy Line Isometric Drawing for Reactor Coolant System (4/9)

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Figure A2-1 High Energy Line Isometric Drawing for Reactor Coolant System (5/9)

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Figure A2-1 High Energy Line Isometric Drawing for Reactor Coolant System (6/9)

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Figure A2-1 High Energy Line Isometric Drawing for Reactor Coolant System (7/9)

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Figure A2-1 High Energy Line Isometric Drawing for Reactor Coolant System (8/9)

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Figure A2-1 High Energy Line Isometric Drawing for Reactor Coolant System (9/9)

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Figure A2-2 High Energy Line Isometric Drawing for Safety Injection System (1/4)

TS

Figure A2-2 High Energy Line Isometric Drawing for Safety Injection System (2/4)

TS

Figure A2-2 High Energy Line Isometric Drawing for Safety Injection System (3/4)

TS

Figure A2-2 High Energy Line Isometric Drawing for Safety Injection System (4/4)

TS

Figure A2-3 High Energy Line Isometric Drawing for Chemical Volume Control System (1/3)

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Figure A2-3 High Energy Line Isometric Drawing for Chemical Volume Control System (2/3)

TS

Figure A2-3 High Energy Line Isometric Drawing for Chemical Volume Control System (3/3)

TS

Figure A2-4 High Energy Line Isometric Drawing for Steam Generator Blowdown System (1/8)

TS

Figure A2-4 High Energy Line Isometric Drawing for Steam Generator Blowdown System (2/8)

TS

Figure A2-4 High Energy Line Isometric Drawing for Steam Generator Blowdown System (3/8)

TS

Figure A2-4 High Energy Line Isometric Drawing for Steam Generator Blowdown System (4/8)

TS

Figure A2-4 High Energy Line Isometric Drawing for Steam Generator Blowdown System (5/8)

TS

Figure A2-4 High Energy Line Isometric Drawing for Steam Generator Blowdown System (6/8)

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Figure A2-4 High Energy Line Isometric Drawing for Steam Generator Blowdown System (7/8)

TS

Figure A2-4 High Energy Line Isometric Drawing for Steam Generator Blowdown System (8/8)

TS

igure A2-5 High Energy Line Isometric Drawing for Main Steam System (1/8)

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Figure A2-5 High Energy Line Isometric Drawing for Main Steam System (2/8)

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Figure A2-5 High Energy Line Isometric Drawing for Main Steam System (3/8)

TS

Figure A2-5 High Energy Line Isometric Drawing for Main Steam System (4/8)

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Figure A2-5 High Energy Line Isometric Drawing for Main Steam System (5/8)

TS

Figure A2-5 High Energy Line Isometric Drawing for Main Steam System (6/8)

TS

Figure A2-5 High Energy Line Isometric Drawing for Main Steam System (7/8)

TS

Figure A2-5 High Energy Line Isometric Drawing for Main Steam System (8/8)

TS

Figure A2-6 High Energy Line Isometric Drawing for Feedwater System (1/10)

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Figure A2-6 High Energy Line Isometric Drawing for Feedwater System (2/10)

TS

Figure A2-6 High Energy Line Isometric Drawing for Feedwater System (3/10)

TS

Figure A2-6 High Energy Line Isometric Drawing for Feedwater System (4/10)

TS

Figure A2-67 High Energy Line Isometric Drawing for Feedwater System (5/10)

TS

Figure A2-6 High Energy Line Isometric Drawing for Feedwater System (6/10)

TS

Figure A2-6 High Energy Line Isometric Drawing for Feedwater System (7/10)

TS

Figure A2-6 High Energy Line Isometric Drawing for Feedwater System (8/10)

TS

Figure A2-6 High Energy Line Isometric Drawing for Feedwater System (9/10)

TS

Figure A2-6 High Energy Line Isometric Drawing for Feedwater System (10/10)