LO-0319-64982

March 28, 2019

Docket No. 52-048

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
One White Flint North
11555 Rockville Pike
Rockville, MD 20852-2738

SUBJECT: NuScale Power, LLC Updates to Final Safety Analysis Report, Section 1.6, “Materials Referenced,” Section 3.6, “Protection Against Dynamic Effects Associated with Postulated Rupture of Piping,” and the “Pipe Rupture Hazards Analysis,” TR-0818-61384

REFERENCES:

1. Letter from NuScale Power, LLC to Nuclear Regulatory Commission, “NuScale Power, LLC Submittal of the NuScale Standard Plant Design Certification Application, Revision 2,” dated October 30, 2018 (ML18311A006)
2. Letter from NuScale Power LLC, to Nuclear Regulatory Commission, “NuScale Power, LLC Submittal of ‘Pipe Rupture Hazards Analysis,’ TR-0818-61384, Revision 1,” dated December 20, 2018 (ML1835B400)

During the recent November 20, 2018 and January 14, 2019 public teleconferences with NRC Staff, several inconsistencies were identified between the Final Safety Analysis Report (FSAR) Section 1.6, “Materials Referenced,” Section 3.6, “Protection Against Dynamic Effects Associated with Postulated Rupture of Piping,” and the “Pipe Rupture Hazards Analysis,” TR-0818-61384, Revision 1. NuScale was requested to resolve these inconsistencies with updates to the respective documents, as required.

Enclosure 1 to this letter provides a mark-up of the FSAR pages incorporating revisions to Section 1.6 “Materials Referenced” and Section 3.6, “Protection Against Dynamic Effects Associated with Postulated Rupture of Piping” in redline/strikeout format. NuScale will include these changes as part of a future revision to the NuScale Design Certification Application.

Enclosures 2 and 3 provide a mark-up of the “Pipe Rupture Hazards Analysis” (PRHA) technical report (TR) pages incorporating consistency corrections (as required) in redline/strikeout format. NuScale will include these changes as part of a future revision to the NuScale PRHA technical report. Enclosure 2 contains the proprietary version of the report titled “Pipe Rupture Hazards Ananlysis,” Revision 1. NuScale requests that the proprietary version be withheld from public disclosure in accordance with the requirements of 10 CFR § 2.390. The enclosed affidavit (Enclosure 4) supports this request. Enclosure 3 contains the nonproprietary version of the affected TR pages.

This letter makes no regulatory commitments or revisions to any existing regulatory commitments.

Please feel free to contact Marty Bryan at (541) 452-7172 or at mbryan@nuscalepower.com if you have any questions.

Sincerely,

Zackary W. Rad
Director, Regulatory Affairs
NuScale Power, LLC

Distribution: Samuel Lee, NRC, OWFN-8H12
Gregory Cranston, NRC, OWFN-8H12
Marieliz Vera, NRC, OWFN-8H12

Enclosure 1: Changes to Final Safety Analysis Report Section 1.6, “Materials Referenced” and Section 3.6, “Protection Against Dynamic Effects Associated with Postulated Rupture of Piping”
Enclosure 2: Changes to “Pipe Rupture Hazards Analysis,” TR-0818-61384, proprietary version
Enclosure 3: Changes to “Pipe Rupture Hazards Analysis,” TR-0818-61384, nonproprietary Version
Enclosure 4: Affidavit of Zackary W. Rad, AF-0319-64983

Enclosure 1:

Changes to Final Safety Analysis Report Section 1.6, “Materials Referenced” and Section 3.6, “Protection Against Dynamic Effects Associated with Postulated Rupture of Piping”

RAI 03.08.04-21S2, RAI 03.08.02-6, RAI 13.05.02.01-1S2

Table 1.6-2: NuScale Referenced Technical Reports

Report Number	Title	FSAR Section
TR-0116-20781	Fluence Calculation Methodology and Results	4.3, 5.3
TR-0316-22048	Nuclear Steam Supply System Advanced Sensor Technical Report	7.1, 7.2
TR-0416-48929	NuScale Design of Physical Security Systems	9.5, 13.6, 14.2, 14.3
TR-0516-49084	Containment Analysis Methodology	6.2
TR-0616-49121	NuScale Instrument Setpoint Methodology Technical Report	7.0, 7.2
TR-0716-50424	Combustible Gas Control	3.8, 6.2
TR-0716-50439	Comprehensive Vibration Assessment Program (CVAP) Technical Report TR-0716-50439	3.9, 14.2
TR-0816-49833	Fuel Storage Rack Analysis	3.7, 3.8, 9.1
TR-0816-50796	Loss of Large Areas Due to Explosions and Fires Assessment	20.2
TR-0816-50797	Mitigation Strategies for Extended Loss of AC Power (ELAP) Event	20.1
TR-0816-51127	NuFuel HTP2 Fuel and Control Rod Assembly Designs	4.2
TR-0916-51299	Long-Term Cooling Methodology	5.4, 6.2, 6.3, 15.0
TR-0916-51502	NuScale Power Module Seismic Analysis	3.7, 3.12, 3B
TR-1015-18177	Pressure and Temperature Limits Methodology	5.3
TR-1016-51669	NuScale Power Module Short-Term Transient Analysis	3.8
TR-1116-51962	NuScale Containment Leakage Integrity Assurance	6.2
TR-1116-52065	Effluent Release Methodology Technical Report	11.1, 11.2, 11.3
RP-0215-10815	Concept of Operations	18.7
RP-0316-17614	Human Factors Engineering Operating Experience Review Results Summary Report	18.2
RP-0316-17615	Human Factors Engineering Functional Requirements Analysis and Function Allocation Results Summary Report	18.3
RP-0316-17616	Human Factors Engineering Task Analysis Results Summary Report	18.4
RP-0316-17617	Human Factors Engineering Staffing and Qualifications Results Summary Report	18.5
RP-0316-17618	Human Factors Engineering Treatment of Important Human Actions Results Summary Report	18.6
RP-0316-17619	Human Factors Engineering Human-System Interface Design Results Summary Report	18.7
RP-0516-49116	Control Room Staffing Plan Validation Results	18.5
RP-0914-8534	Human Factors Engineering Program management Plan	18.1
RP-0914-8543	Human Factors Verification and Validation Implementation Plan	18.1
RP-0914-8544	Human Factors Engineering Design Implementation Implementation Plan	18.11
RP-1215-20253	Control Room Staffing Plan Validation Methodology	18.5
TR-1117-57216	NuScale Generic Technical Guidelines	13.5
TR-0917-56119	CNV Ultimate Pressure Integrity	3.8
TR-0918-60894	Comprehensive Vibration Assessment Program Measurement and Inspection Plan Technical Report	3.9, 14.2
TR-0818-61384	Pipe Rupture Hazards Analysis	3.6

Table 1.8-2: Combined License Information Items (Continued)

Item No.	Description of COL Information Item	Section
COL Item 3.6-1:	A COL applicant that references the NuScale Power Plant design certification will complete the routing of piping systems outside of the ~~CNV~~containment vessel and the area under the bioshield, identify the location of high- and moderate-energy lines, and update Table 3.6-1 as necessary. This activity includes the performance of associated final piping stress analyses, design and qualification of associated piping supports, evaluation of subcompartment pressurization effects (if applicable), and completion of the Balance of Plant Pipe Rupture Hazards Analysis, including the design and evaluation of pipe whip/jet impingement mitigation devices as required. This includes an evaluation and disposition of multi-module impacts in common pipe galleries.	3.6
COL Item 3.6-2:	A COL applicant that references the NuScale Power Plant design certification will verify that the pipe rupture hazards analysis (including dynamic and environmental effects) of the high- and moderate-energy lines outside the ~~CNV~~containment vessel (under the bioshield) is applicable. If changes are required, the COL applicant will update the pipe rupture hazards analysis, design additional protection features as necessary, and update Table 3.6-2.	3.6
COL Item 3.6-3:	A COL applicant that references the NuScale Power Plant design certification will perform the pipe rupture hazards analysis (including dynamic and environmental effects) of the high- and moderate-energy lines outside the reactor pool bay ~~and~~ in the Reactor Building (RXB) ~~design appropriate protection features~~and update Table 3.6-2 as appropriate. This includes an evaluation and disposition of multi-module impacts in common pipe galleries, and evaluations regarding subcompartment pressurization. ~~The COL applicant will update Table 3.6-2 as appropriate.~~ The COL applicant will show that the analysis of RXB piping bounds the possible effects of ruptures for the routings of lines outside of the RXB or perform the pipe rupture hazards analysis of the high- and moderate-energy lines outside the buildings.	3.6
COL Item 3.6-4:	Not used.	3.6
COL Item 3.7-1:	A COL applicant that references the NuScale Power Plant design certification will describe the site-specific structures, systems, and components.	3.7
COL Item 3.7-2:	A COL applicant that references the NuScale Power Plant design certification will provide site-specific time histories. In addition to the above criteria for cross correlation coefficients, time step and earthquake duration, strong motion durations, comparison to response spectra and power spectra density, the applicant will also confirm that site-specific ratios V/A and AD/V2 (A, V, D, are peak ground acceleration, ground velocity, and ground displacement, respectively) are consistent with characteristic values for the magnitude and distance of the appropriate controlling events defining the site-specific uniform hazard response spectra.	3.7
COL Item 3.7-3:	A COL applicant that references the NuScale Power Plant design certification will: • develop a site-specific strain compatible soil profile. • confirm that the criterion for the minimum required response spectrum has been satisfied. • determine whether the seismic site characteristics fall within the seismic design parameters such as soil layering assumptions used in the certified design, range of soil parameters, shear wave velocity values, and minimum soil bearing capacity.	3.7
COL Item 3.7-4:	A COL applicant that references the NuScale Power Plant design certification will confirm that nearby structures exposed to a site-specific safe shutdown earthquake will not collapse and adversely affect the Reactor Building or Seismic Category I portion of the Control Building.	3.7
COL Item 3.7-5:	A COL applicant that references the NuScale Power Plant design certification will perform a soil-structure interaction analysis of the Reactor Building and the Control Building using the NuScale SASSI2010 models for those structures. The COL applicant will confirm that the site-specific seismic demands of the standard design for critical structures, systems, and components in Appendix 3B are bounded by the corresponding design certified seismic demands and, if not, the standard design for critical structures, systems, and components will be shown to have appropriate margin or should be appropriately modified to accommodate the site-specific demands. Seismic demands investigated shall include forces, moments, deformations, in-structure response spectra, and seismic stability of the structures.	3.7

3.6 Protection against Dynamic Effects Associated with Postulated Rupture of Piping

RAI 03.06.02-6

This section describes the design bases and measures needed to protect safety-related and essential systems and components inside and outside containment against the effects of postulated pipe rupture. Figure 3.6-1 is a flowchart depicting the steps in the process for evaluation of potential line breaks. The NuScale methodology applicable to identification and assessment of pipe rupture hazards addresses determination of postulated rupture locations, characteristics of ruptures, and assessment of the possible dynamic and external effects of ruptures. Details of the analyses are provided in the Pipe Rupture Hazards Analysis Technical Report (Reference 3.6-21).

RAI 03.06.02-6

Pipe rupture protection is provided according to the requirements of 10 CFR 50, Appendix A, General Design Criterion 4. In the event of a high- or moderate-energy pipe rupture within the NuScale Power Module (NPM), adequate protection is provided so that safety-related and essential structures, systems, and components (SSC) are not unacceptably affected. Essential systems and components are those required to shut down the reactor and mitigate the consequences of the postulated piping rupture. Nonsafety-related systems are not required to be protected from the dynamic and environmental effects associated with the postulated rupture of piping except as necessary to preclude adverse effect on an essential system. In addition, although neither safety-related nor essential, the post-accident monitoring (PAM) functionality provided by various portions of the instrumentation and control (I&C) systems is protected.

RAI 03.06.02-6

The criteria used to evaluate pipe rupture protection are generally consistent with NRC guidelines including those in the Standard Review Plan Section 3.6.1, Section 3.6.2, and Section 3.6.3, NUREG-1061, Vol. 3, and applicable Branch Technical Positions (BTPs), as discussed within this section.

RAI 03.06.02-6

Section 3.6.1 identifies the high- and moderate-energy lines that have a potential to affect safety-related and essential SSC, and describes the approaches used in the NuScale Power Plant design for protection of these SSC. Section 3.6.2 describes the analytical methodology used to determine break locations, identifies postulated breaks, and discusses the consequences of those breaks and the effect on SSC functionality. Section 3.6.3 describes the leak-before-break (LBB) analysis for applicable piping systems inside containment. Section 3.6.4 discusses the analysis of non-LBB high- and moderate-energy piping.

3.6.1 Plant Design for Protection against Postulated Piping Ruptures in Fluid Systems

RAI 03.06.02-6

General Design Criterion (GDC) 4 requires that SSC be 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 (LOCAs). This includes both environmental effects (temperature changes, pressure changes, humidity changes, and flooding) from line breaks and leakage cracks and dynamic effects (blast, pressurization, pipe whip and jet impingement) that may result from high-energy line breaks (HELB~~s~~).

RAI 03.06.02-6

Plant designers are provided with options to address GDC 4 for pipe ruptures. These options are as follows:

RAI 03.06.02-6

- On a limited basis, portions of pipe may be excluded from postulating breaks and cracks provided they meet criteria regarding the design arrangement, stress and fatigue limits, and a high level of inservice inspection (ISI). The criteria for this exclusion are provided in BTP 3-4, "Fluid System Piping in Containment Penetration Areas," Section B.A.(ii).

RAI 03.06.02-6

- Systems that can demonstrate a low probability of rupture prior to the detection of a leak may be excluded from HELB dynamic effect considerations. This is referred to as LBB analysis and is discussed in SRP 3.6.3. LBB is applied to high-energy piping systems having well-characterized loading conditions and load combinations. This method is an acceptable design approach provided that plant design and specific analyses have indicated a low probability of rupture from damage mechanisms such as water hammer, steam hammer, stress corrosion cracking, and fatigue.

RAI 03.06.02-6

- For high- and moderate-energy systems that cannot be fully excluded using criteria of BTP 3-4~~,~~ Section B.A.(ii) or LBB, line breaks and leakage cracks are postulated. The criteria for the specific locations for the postulated breaks are provided in BTP 3-4 (e.g., Section B.A.(iii)). In general, locations meeting certain stress, fatigue and design requirements may be excluded and are not required to be postulated to rupture. Other locations, such as terminal ends or high-stress locations, must be postulated to rupture. At break locations, the piping systems are located such that there is no safety-related or essential equipment in the area (i.e., separation), or safety-related and essential SSC are shown to be protected from exposure to break effects or otherwise not unacceptably affected.

RAI 03.06.02-6

The piping systems that must be considered include the ASME Section III Class 1, 2, 3, and ASME B31.1, high-energy and moderate-energy systems located inside and outside of the containment vessel (CNV). Table 3.6-1 identifies the high- and moderate-energy piping systems and associated plant locations. Breaks and leakage cracks need not be postulated in high- and moderate-energy lines that are NPS 1 and smaller.

RAI 03.06.02-6

High-energy lines are evaluated for both line breaks and through-wall leakage cracks. Line breaks include both circumferential (complete rupture around the circumference of the pipe) and longitudinal breaks (rupture of the pipe along its axis). Line breaks are analyzed for dynamic and environmental effects. Through-wall leakage cracks are analyzed for flooding and environmental effects.

RAI 03.06.02-6

- in the Radioactive Waste Building (RWB) (Section 3.6.1.1.5)
- onsite (outside the buildings) (Section 3.6.1.1.6)

RAI 03.06.02-6

Table 3.6-1 identifies the largest piping line size and the highest normal operating pressure and temperature of the fluid system to assign an energy classification. The energy classification and line size do not necessarily correspond to the same region of the fluid system.

While Table 3.6-1 provides a ~~comprehensive~~ listing of the high- and moderate-energy systems outside of the NPM, the piping line size and energy classification may vary from these maximum values at the postulated rupture location. COL Item 3.6-1 requires that the COL applicant confirm the content of Table 3.6-1 following the performance of the balance of plant PRHA, or update it accordingly.

RAI 03.06.02-6

Figure 6.6-1 shows the high- and moderate-energy lines that interface with the CNV. Generally, the portions of these lines from the NPM disconnect flanges up to and including the CNV penetration are considered to be part of the containment system (CNTS). Inside the CNV, the lines are considered to be part of a different system. The main steam and feedwater lines are part of the steam generator system (SGS) inside containment. The chemical and volume control system (CVCS) lines are part of the reactor coolant system (RCS) inside the CNV, and include the ~~reactor cooling system (~~RCS~~)~~ injection, RCS discharage, pressurizer (PZR) spray supply, and reactor pressure vessel (RPV) high point degasification lines. The reactor component cooling water system (RCCWS) supply and return lines are part of the control rod drive system (CRDS) inside the CNV.

RAI 03.06.02-6

The decay heat removal system (DHRS) piping is a high-energy system only associated with the NPM.

RAI 03.06.02-6

The containment flooding and drain system (CFDS) is a single open pipe inside containment that is normally isolated and not pressurized during operation. This line is moderate-energy based on the amount of time in use. This line is identified as the CNTS flooding and drain line both inside and outside the CNV.

RAI 03.06.02-6

Generally, in this Section a particular portion of piping is referred to by its functional name (e.g., main steam, RCCWS~~, etc.~~) regardless of whether that portion is inside the CNV, a part of the CNTS, or outside the NPM.

RAI 03.06.02-6

3.6.1.1.1 Inside the Containment Vessel

RAI 03.06.02-6, RAI 03.06.02-12, RAI 03.06.02-13

The high-energy lines inside the CNV are: main steam, feedwater, RCS injection, RCS discharge, high point degasification, PZR spray supply and DHRS condensate return. There are two moderate-energy lines inside the CNV, the RCCWS supply and return lines and the CFDS line (See Table 3.6-1). The ECCS includes several small hydraulic lines inside containment that run between the ECCS valves, the Trip/Reset valves, and the RCS injection line. These high-energy ECCS lines are excluded from consideration as they are smaller than NPS 1.

RAI 03.06.02-6

3.6.1.1.2 Outside the Containment Vessel (Under the Bioshield)

RAI 03.06.02-6, RAI 03.06.02-12, RAI 03.06.02-13

The high-energy lines (main steam, feedwater, RCS injection, RCS discharge, high point degasification, PZR spray supply and DHRS) and the moderate-energy lines ~~[~~(CRDS, CFDS, and the containment evacuation system (CES))~~]~~ continue outside containment to the NPM disconnect flange (See Table 3.6-1).

RAI 03.06.02-6

The DHRS steam line connects to the MSS line outside containment, immediately upstream of the MSS containment isolation valve and leads to the DHRS condenser and then to the DHRS condensate return lines. Although not normally in use, this entire system is pressurized during NPM operation.

RAI 03.06.02-6

3.6.1.1.3 In the Reactor Building (Outside the Bioshield)

RAI 03.06.02-6

Within the RXB, but outside the area under the bioshield, the high-energy lines include the MSS, FWS, and CVCS lines, and additional high-energy lines associated with the auxiliary boiler and process sampling system (PSS) (See Table 3.6-1). Based on limited operating time, the auxiliary boiler lines are considered moderate-energy. Based on the nominal diameter of the PSS lines, breaks do not need to be postulated.

RAI 03.06.02-6

The high-energy MSS and FWS lines exit the reactor pool through the North and South reactor pool walls, cross a mechanical equipment area (pipe gallery) and exit the RXB.

RAI 03.06.02-6

Once they exit the area under the bioshield, the high-energy CVCS lines run vertically downward in a pipe chase to the CVCS heat exchanger rooms at elevation 50' 0" and associated CVCS rooms at Elevations 24′ 0″ and 35' 6". ~~A break in any of these lines only impacts the function of the CVCS equipment for that module.~~ The pipe chase can be seen on the general arrangement drawings in Section 1.2.

Moderate-energy lines are routed throughout the RXB (See Table 3.6-1).

RAI 03.06.02-6

3.6.1.1.4 In the Control Building

There are no high-energy lines in the CRB. There are three moderate-energy lines: fire protection, chilled water, and potable water (See Table 3.6-1).

RAI 03.06.02-6

3.6.1.1.5 In the Radioactive Waste Building

There are no high-energy lines in the RWB. There are two moderate-energy lines: fire protection and liquid radioactive waste management (See Table 3.6-1).

RAI 03.06.02-6

3.6.1.1.6 Onsite (outside the buildings)

RAI 03.06.02-6

Outside of the RXB and CRB there are three high-energy lines: MSS, FWS, and extraction steam, and multiple moderate-energy lines (See Table 3.6-1).

RAI 03.06.02-6

There is no safety-related or essential equipment in the area outside of the RXB or CRB. Final routing of piping outside of the RXB, CRB, and RWB is the responsibility of the COL applicant.

RAI 03.06.02-6, RAI 03.06.02-15

COL Item 3.6-1: A COL applicant that references the NuScale Power Plant design certification will complete the routing of piping systems outside of the ~~CNV~~containment vessel and the area under the bioshield, identify the location of high- and moderate-energy lines, and update Table 3.6-1 as necessary. This activity includes the performance of associated final piping stress analyses, design and qualification of associated piping supports, evaluation of subcompartment pressurization effects (if applicable), and completion of the Balance of Plant Pipe Rupture Hazards Analysis, including the design and evaluation of pipe whip/jet impingement mitigation devices as required. This includes an evaluation and disposition of multi-module impacts in common pipe galleries.

RAI 03.06.02-6

3.6.1.2 Identification of Safety-Related and Essential Structures, Systems, and Components

RAI 03.06.02-6

By design, the NuScale Power Plant only has a small number of safety-related and essential SSC. These SSC are primarily associated with the NPM, either inside the CNV or mounted on the top of the CNV head.

RAI 03.06.02-6

Shutdown of the reactor requires the following systems be protected from HELB:

- RCS
- module protection system (MPS)
- neutron monitoring system
- SGS
- CVCS
- control rod assembly and the CRDS
- CNTS
- DHRS
- emergency core cooling system (ECCS)
- ultimate heat sink / reactor pool

RAI 03.06.02-6

Of these, only the CNTS, DHRS, ECCS, and ultimate heat sink/reactor pool are needed following reactor shutdown. In addition, PAM functionality for Type B and C variables (there are no Type A variables) is protected.

RAI 03.06.02-6

3.6.1.3 Characteristics of the NuScale Design

RAI 03.06.02-6

The NuScale design is an integral, multi-unit, small modular reactor for which safety is provided by passive features without the need for safety-related electrical power. Because NRC regulatory guidance for HELB is premised on the existing fleet of large light water reactors with reactor coolant loops and active safety features, instances exist where the current NRC pipe rupture guidance is not a direct fit. In many cases, the NRC has not issued a Design-Specific Review Standard to address what is directly applicable for the NuScale design.

RAI 03.06.02-6

Specific examples of relevant design differences are:

- ~~The mass and energy released in a HELB is much less for a NuScale plant than for a large, light-water reactor. For example, taking into account pipe sizes and system fluid conditions, a NuScale main steam line has about one-twenty-fifth of the energy per foot of length.~~
- The response to HELB~~s~~ for a NuScale plant requires neither electric power nor injection of additional cooling water.
- The NPMs are mostly submerged in a large pool of water that serves as the ultimate heat sink and does not require replenishment for design-basis events.

- Design-basis accidents do not require operator actions or re-establishing electric power for long-term cooling.

RAI 03.06.02-6

- Piping is small compared to the large reactors for which regulatory guidance was initially developed.~~Other than the RXB and the reactor pool inventory, SSC outside of the NPM are not required to prevent core damage for design basis events once a reactor trip occurs.~~
- Active safety-related components (~~[~~e.g., ECCS valves, DHRS actuation valves, and containment isolation valves (CIVs))~~]~~ are shown to operate during refueling. As part of the start-up sequence for an NPM, each of the safety-related ECCS, DHRS, and ~~CIVs~~containment isolation valves is~~are~~ repositioned. These system line-up activities provide assurance the safety-related valves are operable.
- The NPM containment is a pressure vessel designed and constructed to ASME Code Section III Class 1 requirements versus a building in conventional LWRs.~~The NPM containment is not a building. It is a pressure vessel designed and fabricated to ASME Code Section III Class 1 requirements.~~
- Piping of the NPM, including secondary system piping, is made of corrosion-resistant stainless steel~~ (Type 304 or 304L)~~.
- MSS and FWS piping inside the containment boundary and under the bioshield is designed to RCS design pressure and temperature.

RAI 03.06.02-6

- MSS and FWS piping inside the CNV meets LBB criteria.
- HELB~~s~~ inside the CNV are limited to NPS 2 piping.
- The length of~~and size of high-energy~~ piping in which breaks must be postulated is minimal and the size of high-energy piping is small compared to current design reactors~~is small compared to large, light-water reactors for which the regulatory guidance was written~~.
- The NPM containment is operated at a vacuum.
- Equipment and piping inside the NPM containment are not covered by insulation. This is important for multiple reasons:

RAI 03.06.02-6

  - Jet impingement does not dislodge insulation that could lead to blockage of long-term-cooling recirculation.
  - Detection of small leakage cracks is not impeded by retention of moisture in insulation.
  - The bare piping is readily inspectable during refueling, because insulation does not need to be removed to observe deposits, discoloration, or other signs of degradation.
  - ~~Potential c~~Corrosive substances (e.g., chlorides) cannot be trapped and held in contact with the piping surface.

RAI 03.06.02-6, RAI 06.02.01.01.A-18S1

- Safety-related and essential components inside the NPM containment are qualified to be functional after exposure to saturated steam at containment design pressure ~~up to 1000~~of at least 1000 psia, requiring designs that are robust.
- The small NPM containment results in congestion that makes difficult the addition of traditional piping restraints and the separation of essential components from break locations~~. Consequently~~, but whipping pipes in turn have a limited range of motion before encountering an obstacle.
- Containment isolation valves are outside of containment. Where two valves in series are required (~~e.g.,~~ i.e., for containment penetrations governed by GDC 55 and 56), both are in a single-piece valve body (i.e., no piping or welds between CIVs, precluding breaks in between). Also, the lines directly connected to the primary system or the containment have only a single piping weld in the area between the containment wall and the CIV.
- The RCS-connected lines (i.e., CVCS), except for the normally isolated RPV high-point degasification line, have check (or excess flow check) valves immediately outside the CIVs to preserve reactor coolant inventory in case of LOCAs outside containment.
- Containment pressure suppression is not required, and there are no sprays that introduce chemical additives.

RAI 03.06.02-6

- During a refueling, the NPM is disconnected from supporting systems by removal of piping spools, transported by crane to a refueling location, and disassembled. This provides access for inspection to portions of the plant not normally accessible.
- Up to 12 NPMs are operating at the same time and in proximity, so the potential for a rupture in a system of one module to affect others is considered.
- The plant main control room is in a separate building that does not contain high energy piping systems.
- Dynamic ~~E~~effects of postulated HELB~~s~~ on multiple modules are evaluated, and protection for PAM capability and reliable DC power is provided by separation in different compartments within the building.

RAI 03.06.02-6

These unique characteristics affect choices about the means to address HELB~~s~~.

3.6.2 Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping

RAI 03.06.02-6

This section describes the criteria and methods used to postulate break and leakage crack locations in high-energy and moderate-energy piping inside and outside containment, the methodology used to define potential blast effects, the thrust at the postulated break location, potential pipe whip, the jet impingement loading on adjacent essential safety-related SSC and subcompartment pressurization resulting from fluid blowdown.

RAI 03.06.02-6

General Design Criterion 4 requires that SSC important to safety both accommodate the effects of, and are compatible with, the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents. In the event of a high-energy or moderate-energy pipe rupture within the plant, GDC 4 requires that adequate protection is provided so that essential SSC are not impacted unacceptably by the adverse effects of ~~postulated piping~~the rupture. Nonsafety-related systems are not required to be protected from the dynamic and environmental effects associated with the postulated rupture of piping. Compliance with GDC 4 is demonstrated through conformance with the criteria of BTP 3-4 as described in Section 3.6.2.1.

3.6.2.1 Criteria Used to Define Break and Crack Location and Configuration

RAI 03.06.02-6

Branch Technical Position 3-4 provides guidance on the selection of the break locations within a piping system. The types of breaks postulated in high-energy lines include circumferential breaks in fluid system piping greater than 1 inch NPS; longitudinal breaks in fluid system piping that is 4-inch NPS and greater, and leakage cracks in fluid system piping greater than 1-inch NPS. Leakage cracks are also postulated in moderate-energy lines.

RAI 03.06.02-6, RAI 03.06.02-8

The pipe break criteria of BTP 3-4 include~~s~~ the requirement that breaks be postulated at terminal ends. The~~refore, the~~ definition of a terminal end, consistent with BTP 3-4, is the extremity of a piping run that connects to structures, components (e.g., vessels, pumps, valves), or pipe anchors that act as rigid constraints to piping motion and thermal expansion. A branch connection on a main piping run is a terminal end for the branch run, except where the branch run is classified as part of a main run in the stress analysis or is shown to have a significant effect on the main run behavior. In piping runs that are maintained pressurized during normal plant conditions for a portion of the run (i.e., up to the first normally closed valve), a terminal end is the piping connection to this closed valve.

RAI 03.06.02-6

General Design Criterion 4 allows dynamic effects associated with postulated pipe ruptures to be excluded from the design basis when analyses demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping. This is referred to as LBB analyses. This is discussed in Section 3.6.3. Similarly, breaks and leakage cracks may be excluded within the containment penetration area if criteria of BTP 3-4 B.A.(ii) are met.

3.6.2.1.1 Pipe Breaks Inside the Containment Vessel

RAI 03.06.02-6

The CIVs are outside the containment. A break inside the CNV does not lead to containment bypass. Therefore, there is no containment penetration area inside the CNV and BTP 3-4 B.A.(ii) does not apply. Due to the tight configuration and the concentration of safety-related and essential SSC inside the CNV, dynamic effects of pipe breaks are assessed for specific locations. The following strategies are employed for HELBs~~s~~ inside containment:

RAI 03.06.02-6

- The main steam and feedwater lines meet the criteria for LBB (see Section 3.6.3). Therefore, circumferential and longitudinal breaks are not postulated for dynamic effects for the MSS and FWS lines inside containment.

RAI 03.06.02-6

- The RCS injection, RCS discharge, PZR spray supply, and high-point degasification lines inside containment are NPS 2, Schedule 160, ASME Class 1 stainless steel pipes. Due to their size, longitudinal breaks are not postulated. Circumferential breaks are postulated in accordance with BTP 3-4 Section B.A.(iii)(1). Breaks in Class 1 high-energy piping systems are postulated at the following locations:

RAI 03.06.02-8

  a) terminal ends (defined in Section 3.6.2.1)

RAI 03.06.02-6

  b) intermediate locations where the maximum stress range exceeds 2.4 S_m as calculated by equation (10) and either equation (12) or (13) of NB-3653 of Section III of the ASME Boiler and Pressure Vessel Code.

RAI 03.06.02-6

  c) intermediate locations where the cumulative usage factor exceeds 0.1, unless environmentally assisted fatigue is considered in which case the cumulative usage factor exceeds 0.4.

RAI 03.06.02-6

- The DHRS condensate lines inside containment run from each feedwater line, just upstream of the feed plenum, to the containment upper cylindrical shell penetration. These lines are NPS 2 ASME Class 2. Due to their size, longitudinal breaks are not postulated. Circumferential breaks are postulated in accordance with BTP 3-4 Section B.A.(iii)(2). Breaks in Class 2 high energy piping systems are postulated at the following locations:

RAI 03.06.02-8

a) terminal ends (defined in Section 3.6.2.1)

RAI 03.06.02-6

b) at intermediate locations where stresses are calculated by the sum of equations (9) and (10) in NC-3653 of Section III of the ASME Boiler and Pressure Vessel Code to exceed 0.8 times the sum of the stress limits given in NC/ND-3653.

RAI 03.06.02-6, RAI 03.06.02-12, RAI 03.06.02-13

The RCCWS and CFDS lines are moderate-energy. Moderate-energy lines are subject only to through-wall leakage cracks and the resultant environmental consequences of localized flooding and increased temperature, pressure, and humidity (Section 3.6.1.2). The environmental effects of postulated moderate-energy leakage cracks are bounded by the accident conditions inside the CNV. As a result, leakage cracks are not evaluated further for the RCCWS and CFDS lines inside containment.

RAI 03.06.02-6

Final stress analysis is performed concurrent with fabrication of the first NPM. The postulated break locations based upon the current analysis are listed in Table 3.6-2.

RAI 03.06.02-6

ITAAC A07, Pipe Break Hazards Protective Features Verification, was established to confirm that the final pipe rupture hazards analysis demonstrates the acceptability of the dynamic and environmental effects associated with postulated ruptures in high-energy and moderate-energy piping systems within the NPM.

RAI 03.06.02-6

3.6.2.1.2 Pipe Breaks Outside the Containment Vessel (under the bioshield)

RAI 03.06.02-6

The CIVs for the RCS injection, RCS discharge, PZR spray supply, and RPV high-point degasification lines are each dual, independent valves in a single body that is welded directly to an Alloy 690 safe-end that is welded to the respective nozzle on the CNV head. These lines, except for the normally isolated RPV high-point degasification line, also have a check (injection and spray) or excess flow check (discharge) valve welded directly to the CIV. The feedwater system CIV is similar, except there is a single isolation valve (in accordance with GDC 57) with a check valve as the outboard valve in the single piece body.

RAI 03.06.02-6

The MSS lines each have a single CIV. Between the CNV safe end~~nozzle~~ and the valve body are two tee fittings to which the DHRS steam lines attach.

RAI 03.06.02-6

Outboard of the valves in each of these lines is a short piping segment welded to a flange used to connect the refueling pipe spools to the module.

RAI 03.06.02-6

The containment isolation valves are outside the containment. The containment penetration area is defined by regulatory guidance as the run of piping from the inside CIV to the outside CIV. This definition is not directly applicable to NuScale. Instead, NuScale has omitted piping inside the CNV, but includes the above described valves. In other words, the NuScale containment penetration area is limited to the section from the CNV safe-end-to-valve (or tee) weld out to and including the piping weld to the outermost of the CIV or check/excess flow check valve.

RAI 03.06.02-6

For welds in the containment penetration area, provisions of BTP 3-4 Section B.A.(ii) have been applied to preclude the need for breaks to be postulated, because they meet the design criteria of the Section III of the ASME Boiler and Pressure Vessel Code, Subarticle NE-1120 and the following seven criteria:

RAI 03.06.02-6

1) The ASME Class 1 piping (i.e., the four CVCS lines) is designed to satisfy the following stress and fatigue limits:

    a) The maximum stress range between any two load sets (including the zero load set) calculated by equation (10) in Section III of the ASME Boiler and Pressure Vessel Code, NB-3653 does not exceed 2.4 S_m.

       Or, 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 Section III of the ASME Boiler and Pressure Vessel Code, NB-3653 meet the limit of 2.4 S_m.

RAI 03.06.02-6

    b) The cumulative usage factor is less than 0.1 unless environmentally assisted fatigue is considered in which case the cumulative usage factor is less than 0.4.

    c) The maximum stress, as calculated by equation (9) in Section III of the ASME Boiler and Pressure Vessel Code, NB-3652 under the loadings resulting from a postulated piping rupture beyond these portions of piping, does not exceed 2.25 S_m and 1.8 S_y.

RAI 03.06.02-6

   The ASME Class 2 main steam and ~~F~~feedwater piping from the safe end~~containment~~ to the ~~first isolation valve~~weld outboard of the body holding the CIV and check valve is designed to satisfy the following stress limits:

    a) The maximum stress ranges as calculated by the sum of equations (9) and (10) in Paragraph NC-3653, Section III of the ASME Boiler and Pressure Vessel Code, do not exceed 0.8(1.8 S_h + S_A).

    b) The maximum stress, as calculated by Section III of the ASME Boiler and Pressure Vessel Code, paragraph NC-3653 equation (9) under the loadings resulting from a postulated piping rupture of fluid system piping beyond these portions of piping, does not exceed 2.25 S_h and 1.8 S_y.

2) There are no welded attachments for pipe supports.

RAI 03.06.02-6

3) There is a minimum number of circumferential and no longitudinal welds in these lines in the containment penetration area.

RAI 03.06.02-6

4) The length of the piping is the minimum practical (the total containment penetration piping length for 12 NPMs is less than a typical large pressurized water reactor).

5) There are no pipe anchors or restraints.

6) Guard pipes are not used.

RAI 03.06.02-6

7) The piping welds are included in the ISI program as described in Section 6.6, and the NPS 2 welds including and inboard of those of the pipe to outer nozzle welds of the check and excess flow check valves and CIVs are 100 percent volumetrically inspected, in addition to surface inspections as required by the ASME Boiler and Pressure Vessel Code Section XI.

RAI 03.06.02-6

Outboard of the containment isolation valves and check/excess flow check valves, the CVCS NPS 2, Schedule 160, RCS discharge, RCS injection, PZR spray supply, and high point degasification lines are ASME Class 3 lines to the first spool piece used to disconnect the NPM from the permanent piping. The spool piece and subsequent piping are also ASME Class 3 to the junction of an additional valve (or check valve) in each line, and subsequently become ASME B31.1 after that last valve. At the first spool piece breakaway flange, the four lines become part of the CVCS. Remaining piping under the bioshield, including the refueling pipe spools, is designed to comply with BTP 3-4 Rev. 2 Paragraph B.A.(iii)~~Breaks in these lines are postulated in accordance with BTP 3-4 Section B.A.(iii)(2)~~ to preclude breaks at intermediate locations by limiting~~where~~ stresses calculated by the sum of equations (9) and (10) in NC/ND-3653 of Section III of the ASME Boiler and Pressure Vessel Code to not exceed 0.8 times the sum of the stress limits given in NC/ ND-3653.

RAI 03.06.02-6

Final stress analysis is performed concurrent with fabrication of the first NPM. Based on designing to meet the criteria from BTP 3-4, no breaks in the NPM bay outside the CNV (under the bioshield) are postulated. However, nonmechanistic breaks in MSS and FWS lines in the containment penetration area and leakage cracks are considered.~~There are no postulated break locations based upon the current analysis.~~

RAI 03.06.02-6

~~Due to the unique nature of the DHRS piping, these lines are specifically discussed in Section 3.6.2.7.~~

Decay Heat Removal System Lines

RAI 03.06.02-6

The DHRS is a closed loop system outside of the CNV that is entirely associated with a single NPM. Each NPM has two independent DHRS trains. Each train is associated with an independent steam generator (SG). The only active components in the DHRS are the DHRS actuation valves. The DHRS also relies on the MSS and FWS containment isolation valves to provide a closed loop system when it is activated. The DHRS is used to respond to transients including HELB outside containment. It is not used for normal shutdown, though the DHRS actuation valves are opened to allow slight circulation during wet layup of the SG. There is no flow through the DHRS system during normal operation. The DHRS is attached to the MSS line between the CNV and the MSS CIV. This portion of DHRS has two parallel actuation valves that are normally closed. These two lines join into a single line that supplies the passive condenser. Each DHRS condenser is attached to the outside of the CNV. The condenser is designed as an ASME Class 2 component. A NPS 2 line exits the bottom of each DHRS condenser and penetrates the CNV. This line connects to the feedwater system inside containment. During operation, the DHRS is pressurized from the feedwater line. See Section 5.4.3 for additional discussion about the DHRS.

Breaks are not postulated in the DHRS piping outside containment in accordance with in BTP 3-4, B.A.(ii). Subject to certain design provisions, NRC guidance allows breaks associated with high-energy fluid systems piping in containment penetration areas to be excluded from the design basis. Though the DHRS piping extends beyond what would traditionally be considered a containment penetration area, this approach is chosen because the DHRS cannot be isolated from the CNV as there are no isolation valves.

RAI 03.06.02-6

Breaks are not postulated in this segment of piping because it meets the design criteria for break exclusion in a containment penetration area (see Section 3.6.2.1.2). Although the DHRS condenser is manufactured from piping products, it is considered a major component and not a piping system; thus breaks are not postulated.

RAI 03.06.02-6, RAI 03.06.02-15

COL Item 3.6-2: A COL applicant that references the NuScale Power Plant design certification will verify that the pipe rupture hazards analysis (including dynamic and environmental effects) of the high- and moderate-energy lines outside the ~~CNV~~containment vessel (under the bioshield) is applicable. If changes are required, the COL applicant will update the pipe rupture hazards analysis, design additional protection features as necessary, and update Table 3.6-2.

RAI 03.06.02-13S1

3.6.2.1.2.1 Non-mechanistic Secondary Line Breaks in Containment Penetration Area

RAI 03.06.02-13S1

BTP 3-3 B.1 (a)(1) specifies:

RAI 03.06.02-13S1

"Even though portions of the main steam and feedwater lines meet the break exclusion requirements of item 2.A(ii) of BTP 3-4, they should be separated from essential equipment. Designers are cautioned to avoid concentrating essential equipment in the break exclusion zone. Essential equipment must be protected from the environmental effects of an assumed non-mechanistic longitudinal break of the main steam and feedwater lines. Each assumed non-mechanistic longitudinal break should have a cross sectional area of at least one square foot and should be postulated to occur at a location that has the greatest effect on essential equipment."

RAI 03.06.02-13S1

For the NuScale design, the following considerations apply:

- MSS and FWS piping is the largest, high energy piping near the containment boundary
- The lines have a single CIV outside containment in accordance with GDC 57 for lines closed inside containment
- MSS and FWS piping is usually made of less corrosion resistant material than used for the NuScale design. MSS and FWS piping in many pressurized water reactors is carbon or low alloy steel, which has greater susceptibility to degradation than stainless steel.

RAI 03.06.02-13S1

Analyzing for non-mechanistic ruptures provides assurance that multiple essential SSCs are capable of withstanding the effects of a limited piping failure should one occur. In the NuScale plant, the dual CIVs are located outside the containment and exposed to the same environmental conditions, which makes protection against unexpected ruptures particularly important. However, the NuScale design has the following characteristics that make non-mechanistic ruptures low risk:

RAI 03.06.02-13S1

- The essential SSCs in vicinity of MSS and FWS piping in the containment penetration area are CIVs, DHRS valves, and instrumentation cables and sensors.
- Unlike some safety-related valves in other plant designs that use motor-operators, the NuScale CIVs are hydraulically held open against pneumatic pressure from an accumulator and shut upon a loss of power or a failure of the hydraulic line. The DHRS actuation valves similarly fail open.
- Failure of MSS and FWS piping is unlikely because:
  - Piping in the containment penetration area is made of stainless steel.
  - The physical length of MSS and FWS piping in the containment penetration area is zero (i.e., there are only valves and fittings).
  - MSS and FWS piping has a design pressure and temperature of 2100 psia and 625 degrees F, respectively, equivalent to the RCS piping.

RAI 03.06.02-13S1

The flow area of 1 ft^2 specified in BTP 3-3 for a non-mechanistic, longitudinal break is disproportionately large for a small modular reactor with small pipe sizes. NuScale MSS piping is NPS 12 Schedule 120 and FWS piping is NPS 4 and NPS 5 Schedule 120 in the containment penetration area. For those piping sizes, a 1 ft^2 flow area exceeds the area for a full circumferential rupture, which is physically unrealistic.

RAI 03.06.02-13S1

For the NuScale design, non-mechanistic breaks of MSS and FWS piping in the containment penetration area are evaluated, after consideration of the design differences from larger LWR plants. Comparing the typical PWR pipe MSS flow area to that of NuScale (NPS 30 to 38 vs NPS 12) yields a ratio of one-eighth to one twelfth. On this basis, NuScale analyzes for environmental effects of an MSS non-mechanistic break with an area of 12 in^2, versus 1 ft^2 (144 in^2). The non-mechanistic FWS break size applied for the NuScale design (NPS 4 and NPS 5) is 5.87 in^2.

RAI 03.06.02-13S1

The volume under the bioshield is small; roughly a cube 20 feet on a side. Therefore, even though only leakage cracks are required to be considered outside the containment penetration area, analysis is performed for a 12 in^2 MSS break at the highest point of the pipe run, resulting in a conservative pressure and temperature profile over time for environmental qualification and bounding breaks occurring in any section of the piping under the bioshield.

RAI 03.06.02-13S1

3.6.2.1.2.2 Break Exclusion

RAI 03.06.02-13S1

BTP 3-4 B.A.(iii) identifies specific criteria for which ruptures need not be considered from the containment wall to and including the inboard or outboard isolation valves (usually referred to as the containment penetration area "break exclusion zone"). The concept was necessary due to constraints on ability to cope with breaks between the CIVs. Should a break occur between the CIVs followed by a single failure of a CIV, then containment bypass could occur. To preclude bypass, criteria were developed to ensure that the probability of a piping failure was sufficiently low to make it implausible.

RAI 03.06.02-13S1

The NuScale plant has both CIVs in a single valve body. There are no break locations between the valves. However, the weld between the valve body and the CNV safe end is equivalent to those to which break exclusion applies. Therefore, NuScale has extended this boundary outside the CNV to include:

RAI 03.06.02-13S1

- The outboard weld at the CIV
- The outboard check or excess flow check valve nozzle weld in pressurizer spray, injection, and discharge lines
- DHRS piping welds outside the CNV

RAI 03.06.02-13S1

Accordingly, the guidance of BTP 3-4 B.A.(ii) is used in piping design to ensure that breaks and leakage cracks can be excluded in the containment penetration area. BTP 3-3 non-mechanistic breaks of MSS and FWS piping are also addressed. The remaining high energy piping under the bioshield applies BTP 3-4 B.A.(iii) for ruptures and (v) for leakage cracks. Figure 3.6-33 is a representation (not all lines shown) of application of the BTP 3-4 guidance on break location and size, as applied in the NPM bay and the RXB.

RAI 03.06.02-13S1

The length of piping and number of welds inside the NuScale CNV is limited. For the NuScale design, no primary or secondary piping other than about 160 feet of DHRS piping is within the break exclusion zone outside containment. The design pressure and temperature of MSS, FWS, and DHRS piping in the break exclusion zone is the same as for the RCS.

RAI 03.06.02-13S1

Break exclusion is not applied to any of the piping in the RXB outside of the bioshield.

RAI 03.06.02-13S1

3.6.2.1.2.3 Leakage Cracks

RAI 03.06.02-13S1

Leakage cracks are excluded in containment penetration areas where the criteria of BTP 3-4 B.A.(ii) are satisfied.

For areas outside the containment penetration area, per BTP 3-4 Paragraph B.A.(v), leakage cracks are postulated unless specific criteria are met. For Class 2 piping, the acceptance criterion is for the calculated stress to not exceed 0.4 times the sum of stress limits given in Subarticles NC/ND-3635. BTP 3.4 B.C.(iii) specifies postulating leakage cracks with a flow area of one-half of a pipe diameter by one half pipe wall thickness in piping in the vicinity of essential SSCs, regardless of system.

RAI 03.06.02-6

3.6.2.1.3 Pipe Breaks in the Reactor Building (outside the Bioshield)

RAI 03.06.02-6

Within the NPM, there are a ~~large~~ number of essential SSC that require protection and relatively small amounts of piping. Therefore, postulated pipe break locations within the NPM or in close proximity to the NPM (i.e., under the bioshield) are specifically addressed by analysis, as discussed in Section 3.6.1.3.

RAI 03.06.02-6

Beyond the NPM, there are fewer SSC that require protection and a large amount of high- and moderate-energy piping (See Table 3.6-1). The SSC that require protection are evaluated for effects of line breaks or are separated within compartments of the RXB from areas that contain piping. In addition, the building structure necessary to support the modules and to maintain the integrity of the pool (i.e., the ultimate heat sink) is evaluated.

RAI 03.06.02-6

Piping arrangements in the RXB have not been finalized yet. It is appropriate, therefore, for evaluation of potential rupture locations beyond the reactor pool bay wall, to identify the bounding dynamic effects of postulated breaks and then to determine if protection is required. The approach is to evaluate:

RAI 03.06.02-6

- blast, unconstrained pipe whip, and jet impingement caused by rupture of a main steam pipe.
- subcompartment pressurization, spray wetting, flooding, and other adverse environmental effects caused by main steam or CVCS breaks that are potentially limiting where they might occur in the building.
- multi-module impacts in common pipe galleries.

RAI 03.06.02-6

A break in a high-energy MSS or FWS line in the RXB (outside of the ~~CNV and above the NPM under the~~ bioshield) could potentially cause breaks or leakage cracks in smaller diameter or pipe schedule lines of other NPMs, introducing an additional transient in a second NPM. Therefore, ~~Reactor Building~~RXB MSS and FWS pipes must be arranged, and/or pipe whip restraints must be provided to prevent a collateral rupture, or pipe whip impact analysis must be performed to show that a collateral rupture does not occur. However, the effects of an MSS or FWS break are assumed to cause an MSS bypass line rupture in an adjacent module in order to determine bounding dynamic effects and to ensure that the RXB structure is adequate for beyond design basis interactions between adjoining modules. Once piping arrangements are finalized, the need for pipe whip restraints and barriers may be determined to avoid multi-module effects. This is addressed by the COL applicant as part of COL Item 3.6-3.

RAI 03.06.02-6

The CVCS lines in the RXB (outside ~~of the CNV and above the NPM under~~ the bioshield) are not co-located with essential SSC, with the exception of the RXB itself. Therefore, dynamic effects are addressed on a bounding basis and individual break locations are not specified. For flooding and environmental effects, as discussed in Sections 3.4 and 3.11 respectively, breaks are postulated to occur anywhere on the line.

RAI 03.06.02-6, RAI 03.06.02-15

COL Item 3.6-3: A COL applicant that references the NuScale Power Plant design certification will perform the pipe rupture hazards analysis (including dynamic and environmental effects) of the high- and moderate-energy lines outside the reactor pool bay in the leakage cracks should be postulated at axial and circumferential locations that result in the most severe environmental consequences (per BTP 3-4 B(iii)(2)).

- Fluid flow from a leakage crack should be based on a circular opening of area equal to that of a rectangle one-half pipe diameter in length and one-half pipe wall thickness in width. The flow from a leakage crack should be assumed to result in an environment that wets the unprotected components within the compartment with consequent flooding in the compartment and communicating compartments. Flooding effects should be determined on the basis of a conservatively estimated time period necessary to effect corrective actions.

RAI 03.06.02-6

3.6.2.2 Effects of High- ~~and Moderate~~ Energy Line Breaks

RAI 03.06.02-6

In accordance with SRP Section 3.6.2, the dynamic ~~and environmental~~ effects of postulated high-energy line break are evaluated using the methodology as described in this section.

RAI 03.06.02-6

3.6.2.2.1 Blast Effects

RAI 03.06.02-6

The potential for a blast wave to occur depends on the surrounding environment. Key factors include the timing of the break and the initial system thermodynamic conditions. The timing of opening of the break and the initial, intact system thermodynamic conditions also are key factors. Although pipe rupture times of less than a millisecond are unlikely, break opening time is assumed to be instantaneous, maximizing blast formation. The formation and effects of a blast wave caused by an HELB is evaluated using three-dimensional computational fluid dynamics (CFD) modeling that reflects the postulated break characteristics and NuScale plant geometry. The analysis is performed using ANSYS CFX.

The acceptability of using CFX for this purpose was demonstrated by performing verification and validation using eight test problems that exercised different capabilities of the code.

RAI 03.06.02-6

Key observations from this blast wave modeling are:

- A blast wave is weakly formed if the surrounding environment is at low pressure (less than 1 psia), as is the case inside the CNV. Buildup of pressure as blowdown progresses is not relevant, because the blast wave is a prompt and short-lived phenomenon.
- The severity of a blast depends on the amount of fluid that can escape within approximately one millisecond of break onset because the blast wave forms within that time.

In summary, three-dimensional CFD analysis of blast wave formation in the CNV and RXB is performed using modeling assumptions that bound the pressurization effects that occur for HELB~~s~~ in the plant. Blast wave force time histories are calculated for nearby SSC. The results show:

- Peak forces are low and bounded by the jet thrust forces that subsequently develop. The values are low because NuScale HELB~~s~~ are relatively small diameter and deposit only a small amount of mass and energy in the time it takes for a blast wave to form. The forces inside the CNV are low because the initial low ambient pressure does not support formation of a significant blast wave.
- The forces of the passing shock wave are of very short duration.

RAI 03.06.02-6

Therefore, effects of HELB-induced blast waves in the NuScale plant are considered negligible. No damage to surrounding SSC occurs because these loads are small and brief.

RAI 03.06.02-6

3.6.2.2.2 Pipe Whip

RAI 03.06.02-6

The methodology for pipe whip includes determination of whether a pipe has sufficient energy to whip, whether a whipping pipe can actually contact a safety-significant target, whether the target is sufficiently robust to withstand the impact (qualitatively or by dynamic analysis), and evaluation of the consequences of an impact should the previous steps not obviate the possibility of damage.

RAI 03.06.02-6

The thrust force caused by release of fluid from a circumferential break of a high-energy piping system may cause the piping to rotate about a plastic hinge-point (e.g., pipe restraint, pipe anchor point) and possibly impact nearby SSC.

RAI 03.06.02-6

Inside the CNV, the largest pipe size subject to HELB conditions is NPS 2 and target SSC are robust [e.g., reactor vent valves (RVVs)]. High-energy piping systems larger than NPS 2 have been qualified for LBB inside the CNV. Outside the CNV, under the bioshield, piping satisfies the criteria of BTP 3-4 B.A.(ii) or (iii) to conclude that no breaks occur and that piping does not need to be evaluated for whip. However, nonmechanistic breaks of MSS and FWS lines and leakage cracks are considered. In the RXB outside the bioshield, MSS, FWS, and CVCS lines are subject to a postulated HELB, but there are only a limited number of SSC requiring protection. Also, Auxiliary Boiler System (ABS) line leakage cracks are evaluated.

RAI 03.06.02-6

The following considerations apply to evaluation of pipe whip:

For effects on concrete, MSS breaks are limiting and are assumed to occur within 2 L/D of a wall, with no reduction in jet pressure with distance from the break. The maximum force of the jet and its maximum pressure is that at the break exit, or 103,000 lbf and 630 psia, which is well within the minimum 5000 psi compressive strength of the concrete making up the five-foot thick wall. In addition, the effect of erosion is negligible.

RAI 03.06.02-6

An overview of the NuScale resistance to jet impingement is:

- The damage potential of the smaller-scale NuScale piping is reduced compared to large reactors:
  - Based on plant operating conditions and size of piping, thrust loads for NuScale line breaks are a fraction of those encountered in large LWRs (e.g., a NuScale 12-inch MSS line has about five percent of the total thrust force of a 38-inch MSS line break).
  - Main steam system HELB occurrence is limited to the RXB, because MSS breaks inside the CNV and under the bioshield are eliminated by LBB and break exclusion, respectively. Considering MSS steam density, flow rate driven by the system to ambient differential pressure, and the full break single-ended flow area, the NuScale MSS HELB mass and energy transfer is approximately five percent of that in other large LWRs.

- Jet reaction load and, if within the ZOI, potential jet impingement load is included in load combinations in accordance with FSAR Section 3.9 and Section 3.12.

RAI 03.06.02-6

- Damage to insulation on piping is not a concern:
  - In the CNV, no pipe or component thermal insulation is used.
  - ~~In the NPM bay~~Under the bioshield, no ruptures are postulated.
  - In the NPM outside the pool area, dislodged insulation has no effect on long-term NPM cooling.

RAI 03.06.02-6

Thus, allowable impingement pressure on SSC is considerably higher than that in large pressurized water reactors where insulation stripping is relevant.

RAI 03.06.02-6

- The maximum load imposed by the impinging jet is that of the thrust force of the broken pipe at the break exit.
  - Because only NPS 2 RCS pipes are locations of postulated breaks in the CNV, the load is limited to the maximum operating pressure times the flow area times the thrust coefficient (1.26 for steam and two-phase jets). The total load imposed by the jet is approximately 5220 lbf.

RAI 03.06.02-6

  - The applied load is adjusted by a target shape factor (e.g., 0.576 for a jet striking a cylinder normal to its axis) and by the cosine of the angle from perpendicular for the intersection of the jet and the target surface. These two adjustments reduce the imposed load to below 2000 lbf, or approximately two times the weight of a reactor recirculation valve.
  - Finally, the jet rapidly traverses the zone of influence (ZOI) caused by whip of the broken pipe, moving more than 100 ft/sec within a few degrees of motion. The RVVs are not directly in line with a location in which a whipping pipe could come to rest and are, therefore, exposed to the jet only transiently. The RVVs are approximately a foot in diameter, meaning that they are within the jet for a maximum of 0.01 of a second. Exposing a 1000 lbm, thick-walled, metal component to 2000 lbf for 0.01 of a second or less is a negligible load that can be omitted from load combinations that include dead weight and seismic accelerations of over 10 g.

RAI 03.06.02-6, RAI 06.02.01.01.A-18S1

- The impingement damage threshold of 190 psi is a sufficient measure of the structural integrity of components, but does not confirm functionality. Essential components inside the CNV are qualified for a CNV design condition of ~~1000~~at least 1000 psia saturated steam. This exceeds the 190 psi impingement acceptance threshold of 190 psia by a factor of more than five and is sufficient basis to consider functionality after jet impingement to be demonstrated.
- Jet impingement on concrete is neither a pressure load nor an erosion concern.

RAI 03.06.02-6

Having addressed the resistance of the NuScale design to jet impingement damage, the HELB jet conditions must be determined. Three categories of jets are considered:

1) Liquid jets

2) Two-phase jets

3) Steam jets

RAI 03.06.02-6

As discussed for other effects, jet behavior and effects differ for the three areas of the plant:

- Inside the CNV: breaks are limited to NPS 2 RCS-connected and DHRS piping because the SGS piping meets LBB. Only a degasification line break is steam, however, the reverse flow from a pressurizer spray line break almost immediately turns to steam. Other breaks such as DHRS, the injection line, or spray line forward flow are two-phase.
- Under the bioshield: piping satisfies criteria that no postulated breaks occur.

- In the RXB, outside the bioshield: piping arrangements are not finalized, so break locations and jet directions are assumed to be throughout in the rooms containing high-energy piping. The piping is limited to NPS 12 and 4 MSS, NPS 6 FWS, and NPS 2 to 3 CVCS piping at various pressures and temperatures (see Table 3.6-1 and Table 3.6-4). Main steam system jets are steam only, whereas FWS and CVCS breaks are two-phase.

RAI 03.06.02-6

The concern for jet impingement that underlies regulatory guidance is the stripping of insulation with subsequent sump blockage as described in GSI-191. As noted above, the impingement damage threshold for NuScale is greater than 190 psig.

RAI 03.06.02-6

Liquid jets

RAI 03.06.02-6

Liquid jets are assumed to not expand (i.e., the cross section of the pipe rupture is maintained) and to not droop with distance (i.e., travel straight until impeded). Additionally, a 2.0 thrust coefficient is used for dynamic loading. The only areas subject to liquid jets are in the RXB where CVCS lower temperature, high-pressure piping is present. The essential SSCs in this area are the CVCS demineralized water makeup valves and RXB structure (liquid jets are considered to have less potential to damage concrete structure than steam jets, which are shown to be acceptable).~~There are no essential SSC in these areas and the liquid jets are considered to have less potential to damage concrete structures than steam jets, which were shown to be acceptable, as discussed previously.~~

RAI 03.06.02-6

Two-phase jets

RAI 03.06.02-6

Two-phase jets are assessed using the methodology of NUREG/CR-2913 (Reference 3.6-19). A bounding approach is taken by identifying criteria for jet formation in order to avoid the need to analyze individual break locations in the CNV and RXB.

RAI 03.06.02-6

- In the CNV

RAI 03.06.02-6

Although the low operating pressure of the CNV is a variation from the experimental and analytical basis of NUREG/CR-2913, the low ambient pressure results in faster expansion of the jet and is conservative when estimating loading.

RAI 03.06.02-6

Only RCS-connected NPS 2 pipe breaks are evaluated (DHRS system pressure and temperature are lower at postulated break locations). The inputs needed for the NUREG/CR-2913 methodology are the system static thermodynamic conditions, as shown in Table 3.6-4.

RAI 03.06.02-6

Following the methodology, the relevant graph of Appendix A of NUREG/CR-2913 is selected to obtain target pressure and total force on the target for appropriate values of P_0, ΔT_0, or X_0, and distance to the target in L/D. For the CVCS breaks in the CNV, the thermodynamic conditions are 48 degrees K subcooling and 67 bar. The appropriate graph is Figure A.39, which shows pressures at specific points downstream in L/D and radially from the jet centerline in r/D. At the origin of the plot is the jet centerline at the break exit plane, and the shaded area at the lower left is the jet core (the region that has not yet begun to interact with the environment and in which fluid striking a target would experience full recovery of the fluid stagnation pressure). The letters A through D refer to the key for pressure (letters E and beyond for pressures above 10 bar are not plotted because they exist only near the jet core). For example, a letter B indicates pressure is 2.5 bar at 4 L/D and 1.5 r/D.

RAI 03.06.02-6

The jet core is the region immediately downstream of a break in which the target pressure is the full stagnation pressure. Reference 3.6-17, Section 3.3.1.1 states that this region is significant only for jets involving subcooled stagnation conditions. Figure A.39 of NUREG/CR-2913 shows that the jet core dissipates within 2 L/D or about 3.4 inches for a thermodynamic condition similar to a chemical volume and control system HELB. This is viewed as conservative. Reference 3.6-13 Section 3.5.3.B notes that Sandia (Reference 2.6.19) emphasizes the pipe exit core. The persistence of the core is attributed by Sandia to the time it takes for external pressure to penetrate the jet, and that the core length will always be longer than 0.5 D for subcooled and saturated water jets. Reference 3.6-13 notes, however, that test data is not consistent with the Sandia model, with only one or two test data sets exhibiting something like a liquid core while most data contradict the presence of a liquid core. Reference 3.6-13 concludes "If a liquid core exists, it seems to be much smaller than indicated by Sandia."

At 2.5 L/D and 1 r/D, the single D point is a pressure of 10 bar (145 psig), below the ~~low~~ NuScale damage threshold of 190 psig. Within 4 L/D or about 6.8 inches, the jet peak pressure has dropped to below 5.0 bar (72.5 psig). The A points representing 1.0 bar correspond to the edge of the jet. The jet persists beyond 7.5 L/D, which is indicative of the concern for fibrous insulation damage at pressures of 4 psig out to a 10 L/D penetration distance. For NuScale's design, pressures at about 2 L/D are low enough to cause no damage to the hard components.

RAI 03.06.02-6

Although the ~~graph~~NUREG/CR-2913 figure can be used to determine the ZOI, the ZOI in the CNV is assumed to be in the forward-facing hemisphere because of the greater spreading angle in the low-pressure CNV and possible pipe whip.

RAI 03.06.02-6

- In the RXB

RAI 03.06.02-6

Similarly, for chemical and volume control system HELB~~s~~ in the RXB, the generic approach of a universal ZOI allows for breaks at locations determined once pipe routing is finalized and for pipe whip. Based on the discussion that follows for steam jets, CVCS pressure loading, as shown in Figure A.39 of NUREG/CR-2913, is not damaging.

RAI 03.06.02-6

Steam Jets

RAI 03.06.02-6

- In the CNV

For breaks inside the CNV, expansion of the jet into the low-pressure surroundings results in different behavior than is experienced for HELB~~s~~. Wider jet spreading (a half-angle exceeding 60 degrees) is expected to occur, because the initially low air density of the CNV removes most of the resistance to jet expansion. The wider jet expands the ZOI, but substantially reduces the pressure and the penetration length, because the mass and energy of the jet are widely dispersed. Although pressure within the CNV increases with time, the pre-existing wide expansion of the jet persists because the jet is already established.

RAI 03.06.02-6

~~For a circumferential break with limited separation (not just a crack), ANSI/ANS 58.2 provides a complicated method to determine the three regions of jet expansion. For Region 3 (beyond the asymptotic plane, at which jet static pressure approaches ambient pressure), a 10 degree half-angle is specified. For simplicity, 10 degrees is assumed for the entire jet length, which is an underestimate of the expansion when determining drop off of pressure with distance. The pressure in the downstream jet depends on this angle, thermodynamic conditions in the pipe, and the separation of the pipe ends. ANSI/ANS 58.2 specifies that assumed separation of pipe ends be limited to one-half the pipe inner diameter. For NPS 2 CVCS piping, the maximum separation~~ ~~W_f~~ ~~is 0.844 in. In this case, the pressure drops off with distance in accordance with the increasing circumference of the jet and also with the widening of the disk from its initial value of~~ ~~W_f~~ ~~at the pipe surface. The 10-degree half-angle expansion results in a drop off in pressure imposed on more distant targets exposed to the jet, such that pressure is below 190 psia beyond four inches from the pipe outer wall. Regulatory guidance that the ZOI is assumed to extend to a diameter of 25 times~~ ~~W_f~~ ~~(i.e., 21 in.) and also to 25~~

~~times W_f axially centered on the break is therefore not appropriate for the NuScale design.~~

RAI 03.06.02-6

For simplicity and because there are no rigid restraints at postulated break locations to constrain separation, circumferential breaks are assumed to be full separation. For circumferential breaks with full separation, it is assumed that an essential system or component is within the ZOI if it is located within the forward-facing hemisphere based on the original pipe orientation.

RAI 03.06.02-6

A~~s noted for the limited separation case, a~~pplying the break exit pressure over this ZOI is an overestimation of the possible jet impingement loading. Therefore, the steam and two-phase jet pressure is assumed to decrease with distance proportional to the area of a jet that expands at a 30-degree half-angle to five pipe diameters and then at 10 degrees beyond that. A half-angle of 30 degrees is less than identified in the ANSI/ANS 58.2 Standard and in other jet analyses for expansion into surroundings at normal atmospheric pressure. Thus, the jet pressure is below the 190 psi threshold for component damage at 2.2 L/D (3.65 in.). Although the NRC has challenged the general applicability of the ANSI/ANS Standard 58.2 spreading model, a half-angle of approximately 45 degrees or more is usually used. As the jet spreads more rapidly into the low-density CNV atmosphere, a 30-degree assumption is sufficiently conservative to bound actual jet impingement pressures due to local variation within the jet.

As noted, the jet core is only significant for subcooled jets. Reference 3.6-19 Section 3.6 discusses the core length L_c as ½D, one half of the pipe diameter for saturated stagnation conditions. It also notes that the length L_c depends on the time it takes a pressure wave to travel from the outer edge of the nozzle (i.e., break) to the jet center. Figure 4.3 of Reference 3.6-19 shows that for zero degrees subcooling L_c=½D. Thus, even if a jet core existed for a steam jet, its influence would be dissipated within ½D, which is too close for a jet impingement force to be of concern compared to pipe whip impact.

RAI 03.06.02-6

- In the RXB

RAI 03.06.02-6

~~There are a limited number of target SSC in the RXB. Included are structural walls of the RXB itself.~~ Jet core length is not relevant for RXB breaks because full exit plane pressure is assumed. The distance between a break and a target SSC is not defined because RXB piping arrangements have not yet been finalized. To verify suitability of the design of the RXB, bounding HELB scenarios have been identified.

RAI 03.06.02-6

The MSS lines are larger and contain more energy than other potential jet sources in the RXB. Demonstrating passing performance for MSS breaks provides confidence that final HELB analysis results are bounded. Therefore, a conservative approach is taken in which the jet impingement pressure is assumed to be the same as that at the break exit (i.e., no reduction for spreading with distance). For a main steam system HELB, the break exit pressure is 500 psia. Applying the thrust coefficient C_T of 1.26 yields a jet impingement pressure of 630 psi, or about one-eighth of the minimum compressive strength of the concrete and less than the previously discussed erosion that testing demonstrated is acceptable.

RAI 03.06.02-6

Jet impingement for HELB~~s~~ in the NuScale plant is therefore not a source of concern because of the lesser jet energies associated with the smaller size piping, and because of the high impingement pressure damage threshold associated with not needing to protect against insulation being dislodged.

RAI 03.06.02-6

3.6.2.2.4 Dynamic Amplification and Resonance of Impingement Jet

RAI 03.06.02-6

Based upon concerns raised by the ACRS in 2004, the NRC identified (SRP Section 3.6.2) that unsteadiness in free jets, especially supersonic jets, tends to propagate in the shear layer (i.e., the region with a large velocity gradient near the boundary of the jet) and induce time-varying oscillatory loads on obstacles in the flow path. The ACRS concern was that pressures and densities vary nonmonotonically with distance along the axis of a typical supersonic jet, feeding and interacting with shear layer unsteadiness. In addition, for a typical supersonic jet, interaction with obstructions could lead to backward-propagating transient shock and expansion waves that cause further unsteadiness in downstream shear layers.

RAI 03.06.02-6

The concern was that synchronization of the transient waves with the shear layer vortices emanating from the jet break could lead to amplification of the jet pressures and forces (a form of resonance) that is not considered in ANSI/ANS 58.2. Should the dynamic response of the neighboring structure also synchronize with the jet loading time scales, further amplification of the loading occurs, including at the source of the jet. General observations by investigators were that strong discrete frequency loads occur when the impingement surface is within 10 diameters of the jet opening, and that when resonance within the jet does occur, amplification of impingement loads might result.

RAI 03.06.02-6

The basis for this concern was research into such amplification of loads that occur in the interaction of the jet issuing from vertical and short take-off and landing aircraft and certain industrial gas jet applications. It causes vibration and fatigue damage to aircraft parts, jet deflectors, parts cleaned with gas jets, etc. This phenomenon has been studied extensively, with considerable work performed to mitigate its effects.

RAI 03.06.02-6

Experiments simulating HELB~~s~~ routinely evince random oscillations, but not resonance. For dynamic amplification and resonance to occur, a number of criteria must be met. These criteria are based on the research referenced in SRP Section 3.6.2 and similar work that identified the physical phenomena leading to resonance. These processes require a stable, axisymmetric jet impinging at a fixed distance perpendicular to a large, flat surface. The processes at work during a HELB have fundamental differences from those that occur in a jet with dry, noncondensable gas issuing from a smooth, fixed nozzle. These physical differences involve instability of the discharge, irregular discharge geometry, phase changes that suppress pressure changes, misalignment of jet and impingement target surface preventing establishment of a feedback loop, lack of an appropriately flat surface within a sufficiently close distance, and etc. If one of these criteria is not met, a resonance is implausible. In a HELB in the NuScale plant, none of the criteria is satisfied, precluding the formation of a resonance.

RAI 03.06.02-6

Specifically, each of the following characteristics of postulated HELB~~s~~ in a NuScale plant is sufficient to ensure a resonance does not occur.

RAI 03.06.02-6

- A whipping pipe either 1) comes to rest against an object that intercepts a portion of the jet and distorts its axisymmetry or 2) flutters, causing a variation in the jet impingement angle and separation that prevents establishing synchronization of the transient waves.
- The break exit is distorted because of tearing as the break opens, which eliminates axisymmetry.
- Jets in the CNV dissipate in a short distance. The plant geometry precludes the end of a break coming within 2 L/D of a suitable impingement surface. Beyond that distance, the jet has weakened too much for amplification to be a problem, even if it does occur.

RAI 03.06.02-6

- No suitable (i.e., even, flat) impingement surfaces exist within the CNV. Relevant SSC are curved, which redirects reflected acoustic energy away from the break exit.
- The presence of a steam/water mixture in the jet acts to dampen pressure oscillations, preventing amplification.
- Splashing from the jet (and the jet from the opposite end of the break) interferes with the stability of the jet.

RAI 03.06.02-6

a zero design gap is required. In these cases, the pipe whip restraint is included in the piping analysis and designed to the requirements of pipe support structures for all loads except pipe break, and designed to the requirements of pipe whip restraints when pipe break loads are included.

RAI 03.06.02-3

- In general, the pipe whip restraints do not prevent access required to conduct inservice inspection examination of piping welds. When the location of the restraint makes the piping welds inaccessible for inservice inspection, a portion of the restraint is designed to be removable to provide accessibility.

RAI 03.06.02-3

- Analysis of pipe whip restraints

RAI 03.06.02-3

  – Is either dynamic or conservative static.

RAI 03.06.02-3

  – Static analysis includes

RAI 03.06.02-3

    - dynamic load factor of 2.0 to account for the initial pulse thrust force, unless a lower value is analytically justified

RAI 03.06.02-3

    - potential increase by a factor of 1.1 in loading due to rebound.

RAI 03.06.02-3

  – Loading combination includes dead weight, seismic, and the jet thrust reaction force

RAI 03.06.02-3

  – The criteria for analysis and design of pipe whip restraints for postulated pipe break effects are consistent with the guidelines in ANSI/ANS 58.2-1988.

RAI 03.06.02-3

  – Design is based on energy absorption principles by considering the elastic-plastic, strain-hardening behavior of the materials used.

RAI 03.06.02-3

  – Non-energy absorbing portions of the pipe whip restraints are designed to the requirements of AISC N690 Code.

RAI 03.06.02-3

  – Except in cases where calculations are performed to determine if a plastic hinge is formed, the energy absorbed by the ruptured pipe is assumed to be zero. That is, the thrust force developed goes directly into moving the broken pipe and is not reduced by the force required to bend the pipe.

RAI 03.06.02-3

  – In that a HELB is an accident (i.e., infrequent) event, pipe whip restraints are single use: allowed to deform provided the whipping pipe is restrained throughout the blowdown. Where structural members of a restraint are designed for elastic response, a dynamic increase factor is used.

RAI 03.06.02-3

- Allowable strain in a pipe whip restraint is dependent on the type of restraint.

RAI 03.06.02-3

- Stainless steel U-bar – this one-dimensional restraint consists of one or more U-shaped, upset-threaded rods or strips of stainless steel looped around the pipe but not in contact with the pipe. This allows unimpeded pipe motion during seismic and thermal movement of the pipe. At rupture, the pipe moves against the U-bars, absorbing the kinetic energy of pipe motion by yielding plastically.

RAI 03.06.02-3

- Structural steel – this two-dimensional restraint is a stainless steel frame encircling the pipe that does not restrict pipe motion for normal operation or earthquakes. Should a rupture occur, the pipe motion brings it into contact with the frame, absorbing the kinetic energy of the pipe by deforming plastically.

RAI 03.06.02-3

- Crushable material – if used, the allowable energy absorption of the material is 80 percent of its capacity based on dynamic testing performed at equivalent temperatures and at loading rates of ±50 percent of that determined by analysis.

RAI 03.06.02-3

Note that a wall penetration may also serve as a two-dimensional pipe whip restraint, provided the wall has sufficient strength to resist the pipe load.

RAI 03.06.02-3

- Material properties are consistent with applicable code values, with strain-rate stress limits 10 percent above code or specification values, consistent with NRC guidance (SRP 3.6.2, III.2.A).

RAI 03.06.02-3

3.6.2.3.1.2 Pipe Whip Barriers

RAI 03.06.02-3

Standard Review Plan 3.6.2 identifies that an unrestrained, whipping pipe need not be assumed to cause ruptures or through-wall cracks in pipes of equal or larger NPS with equal or greater wall thickness. By extrapolation, a structure, system, or component made of metal of equivalent or better yield strength, equal or larger diameter, and equal or greater wall thickness does not only not leak or crack but also obstructs further travel of the whipping pipe, protecting SSC farther away from being struck.

The pipe whip load must be considered for inclusion in SSC load combinations to verify that the barrier is not displaced by pipe whip impact. For any structures added to serve as a barrier (or jet impingement shield), Seismic Category 1 loading is analyzed to confirm the structure does not fail and cause damage.

RAI 03.06.02-3

3.6.2.3.1.3 Jet Impingement Shields

RAI 03.06.02-3

NRC guidance does not have specific criteria for judging suitability of an SSC as a jet shield. Regarding impingement effects, if the following criteria are met, then the SSC is judged capable of serving as a shield without further evaluation:

RAI 03.06.02-3

- The diameter and wall thickness of the shield meet the criteria for a pipe whip barrier with a size equal or greater than that of the broken pipe.

RAI 03.06.02-3

- The barrier is of sufficient area and positioned to subtend a solid angle from the pipe break opening (considering potential pipe whip) that covers the essential SSC to be protected.

RAI 03.06.02-3

- The barrier is solid (without openings) to the extent that no direct line of sight exists from the break opening to the essential SSC. This criterion allows for some indirect passage of spray through an opening, but environmental qualification for pressurization and flooding demonstrates functionality. The possibility of pipe whip affecting the location of the pipe break exit must be considered.

3.6.2.4 Guard Pipe Assembly Design Criteria

RAI 03.06.02-6

Guard pipes are not used.

3.6.2.5 Analytical Methods to Define Forcing Functions and Response Models

RAI 03.06.02-6

See Section 3.6.2.2.

3.6.2.6 Dynamic Analysis Methods to Verify Integrity and Operability

RAI 03.06.02-6

See Section 3.6.2.2.

3.6.2.7 Implementation of Criteria Dealing with Special Features

RAI 03.06.02-6

See Section 3.6.2.1.2.

~~**Decay Heat Removal System Lines**~~

~~RAI 03.06.02-6~~

~~The DHRS is a closed loop system outside of the CNV that is entirely associated with a single NPM. Each NPM has two independent DHRS trains. Each train is associated with an independent steam generator (SG). The only active components in the DHRS are the DHRS actuation valves. The DHRS also relies on the MSS and FWS containment isolation valves to provide a closed loop system when it is activated. The DHRS is used to respond to transients including HELB outside containment. It is not used for normal shutdown, though the DHRS actuation valves are opened to allow slight circulation during wet layup of the SG. There is no flow through the DHRS system during normal operation. The DHRS is attached to the MSS line between the CNV and the MSS CIV. This portion of DHRS has two parallel actuation valves that are normally closed. These two lines join into a single line that supplies the passive condenser. Each DHRS condenser is permanently attached to the outside of the CNV at approximately the 50' level. The condenser is designed an ASME Class 2 component. A NPS 2 line exits the bottom of each DHRS condenser and penetrates the CNV. This line connects to the feedwater system inside containment. During operation, the DHRS is pressurized from the feedwater line. See Section 5.4.3 for additional discussion about the DHRS.~~

~~Breaks are not postulated in the DHRS piping outside containment in accordance with in BTP 3-4, B.A.(ii). Subject to certain design provisions, NRC guidance allows breaks associated with high-energy fluid systems piping in containment penetration areas to be excluded from the design basis. Though the DHRS piping extends beyond what would traditionally be considered a containment penetration area, this approach is chosen because the DHRS cannot be isolated from the CNV as there are no isolation valves.~~

~~RAI 03.06.02-6~~

~~Breaks are not postulated in this segment of piping because it meets the design criteria for break exclusion in a containment penetration area (see Section 3.6.2.1.2). Although the DHRS condenser is manufactured from piping products, it is considered a major component and not a piping system, thus breaks are not postulated.~~

RAI 03.06.02-6, RAI 03.06.02-17, RAI 03.06.02-17S2

Connection of Reactor Vent Valves and Reactor Recirculation Valves to the Reactor Vessel

RAI 03.06.02-17S5

~~In the NuScale design, each of three RVVs and each of two reactor recirculation valves bolt directly to reactor vessel nozzles. These five bolted-flange connections are classified as break exclusion areas. Because this break exclusion area does not include a~~

~~physical piping length, a majority of the BTP 3-4 B.A.(ii) criteria do not apply. However, similar to the augmented ISI requirements given for piping welds in BTP 3-4 B.A.(ii), augmented ISI requirements are specified for the bolts of these flanged connections to ensure they are inspected at least once per interval (Section 3.13.2).~~In the NuScale design, each of three RVVs and two RRVs bolt directly to the reactor vessel. These five bolted-flange connections are classified as break exclusion areas. Because this configuration does not include a physical piping length, a majority of the BTP 3-4 B.A (ii) criteria do not apply. However, these BTP 3-4 B.A (ii) criteria generically involve design stress and fatigue limits and in-service inspection (ISI) guidelines, which are addressed for these bolted connections below.

RAI 03.06.02-17S5

Additionally, discussion is provided regarding threaded fastener design and leakage detection, to demonstrate that the probability of gross rupture is extremely low. The leakage detection systems along with in-service inspections provide assurance that potential failure mechanisms are detected before the onset of a catastrophic failure involving the fasteners of the bolted flange connections for the RRVs and RVVs, and therefore, that a break at this location need not be postulated.

RAI 03.06.02-17S5

Design Stress and Fatigue Limits

RAI 03.06.02-17S5

BTP 3-4 B.A(ii)(1) specifies more conservative stress and fatigue limits for ASME Class 1 piping in containment penetration areas than those required for piping by ASME Code, Section III, NB-3653. The bases for these more conservative limits include a desire to limit the stresses resulting from service loads (excluding those due to peak stresses) to within the material yield strength (i.e., elastic strains), and a concern that the cumulative usage factor calculation account for the possibility of a faulty design or improperly controlled fabrication, installation errors, and unexpected modes of operation, vibration, and other structural degradation mechanisms.

RAI 03.06.02-17S5

The RVV and RRV bolted connections are not classified as piping by their design specifications, and instead are classified as components designed to the rules of NB-3200. For the RVV and RRV bolt material (SB-637 UNS N07718), the design criteria given in NB-3230 for bolting provides greater margin against yielding due to service loads than do the rules of NB-3653 for typical piping system materials, even when considering the more restrictive limits of BTP 3-4 B.A(ii)(1). Therefore, the imposition of more conservative stress limits are not justified.

RAI 03.06.02-17S5

Additional limits on CUF are not justified because the risk of a faulty design and fabrication and installation errors for a flanged connection is low compared to that of a piping system. The possible degradation mechanisms applicable to Class 1 piping systems do not apply to the ECCS valve bolts. These considerations are addressed further below.

RAI 03.06.02-17S5

Where break locations are selected without the benefit of stress calculations, breaks are postulated at the piping welds to each fitting, valve, or welded attachment. Breaks in non-ASME Class piping are addressed in Section 3.6.2.1.8~~Section 3.6.2.1.3~~. Additionally, in accordance with BTP 3-4, Part B, Item A(iii)(4), if a structure is credited with separating a high-energy line from an essential SSC, that separating structure is designed to withstand the consequences of the pipe break in the high-energy line which produces the greatest effect on the structure, irrespective of the fact that the criteria described in BTP 3-4, Part B, Items A(iii)(1) through (3) might not require the postulation of a break at that location.

3.6.4.2 NuScale Power Module Piping System Parameters

Table 3.6-4 lists the NuScale NPM piping along with the respective design and operating conditions. High-energy piping systems (i.e., CVCS, MSS, FWS, and DHRS) are evaluated for HELB both inside and outside the CNV. Although the DHRS condenser is manufactured from piping products, and analyzed to ASME Code, Class 2 piping rules, it is nonetheless considered a major component and not a piping system, thus breaks are not postulated.

Moderate-energy piping systems (i.e., RCCWS, CFDS and CES) are exempt from HELB and are not addressed further herein.

3.6.4.3 NuScale Power Module Piping Material

The high-energy piping systems are manufactured using ASME SA-312, dual-certified TP304/TP304L stainless steel, with the properties shown in Table 3.6-5, which are taken from ASME Section II, Materials. Dual-certified TP304/TP304L SS maintains the low-carbon content of the TP304L SS grade and exhibits the higher strength associated with the straight grade of TP304 SS. Thus, Table 3.6-5 uses the strength properties from the straight TP304 SS grade at design temperature of 650 degrees F shown in Table 3.6-4. Note that S_A in Table 3.6-5 is calculated with a 1.0 stress range reduction factor, f.

3.6.5 References

RAI 03.06.02-6

3.6-1 Electric Power Research Institute, "An Engineering Approach for Elastic-Plastic Fracture Analysis," EPRI NP-1931, Palo Alto, CA, 1981.

RAI 03.06.02-6

3.6-2 Electric Power Research Institute, "Advances in Elastic-Plastic Fracture Analysis," EPRI NP-3607, Palo Alto, CA, 1984.

RAI 03.06.02-6

3.6-3 Electric Power Research Institute, "Elastic-Plastic Fracture Analysis of Through-Wall and Surface Flaws in Cylinders," EPRI NP-5596, Palo Alto, CA, 1988.

3.6-4 U.S. Nuclear Regulatory Commission, "Analysis of Experiments on Stainless Steel Flux Welds," NUREG/CR-4878, April 1987.

RAI 03.06.02-6

3.6-5 Not Used.

RAI 03.06.02-6

3.6-6 Electric Power Research Institute, "Crack-Opening Area Calculations for Circumferential Through-Wall Pipe Cracks," EPRI NP-5959-SR, Palo Alto, CA, 1988.

3.6-7 U.S. Nuclear Regulatory Commission, "Evaluation and Refinement of Leak-Rate Estimation Models," NUREG/CR-5128, June 1994.

RAI 03.06.02-6

3.6-8 Henry, R. E., "The Two-Phase Critical Discharge of Initially Saturated or Subcooled Liquid," *Nuclear Science and Engineering*. (1970): 41:336-342.

RAI 03.06.02-6

3.6-9 Henry, R.E. and H.K. Fauske, H. K., "Two-Phase Critical Flow at Low Qualities, Part I: Experimental," *Nuclear Science and Engineering*. (1970): 41:79-91.

RAI 03.06.02-6

3.6-10 U.S. Nuclear Regulatory Commission, "Probabilistic Pipe Fracture Evaluations for Leak-Rate Detection Applications," NUREG/CR-6004, April 1995.

RAI 03.06.02-6

3.6-11 Not used.

RAI 03.06.02-6

3.6-12 Not used.

RAI 03.06.02-6

3.6-13 Marklund, Jan-Erik, Studsvik Energiteknik AB, “Evaluation of Free Jet and Jet Impingement Tests with Hot Water and Steam,” Studsvik/NR-85/54, May 21 1985.~~Not Used.~~

RAI 03.06.02-6

3.6-14 Chattopadhyay, J., "Improved J and COD Estimation by GE/EPRI Method in Elastic to Fully Plastic Transition Zone," *Engineering Fracture Mechanics*. (2006): 73:14:1959-1979.

RAI 03.06.02-6

3.6-15 American National Standards Institute/American Nuclear Society, "Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture," ANSI/ANS-58.2-1988, LaGrange Park, IL.

RAI 03.06.02-6

3.6-16 U.S. Nuclear Regulatory Commission, “Boiling Water Reactor ECCS Suction Strainer Performance Issue No. 7 - ZOI Adjustment for Air Jet Testing,” BWROG Meeting, July 20, 2011, Agencywide Document Access and Management System (ADAMS) Accession No. ML11203A432.

RAI 03.06.02-6

Table 3.6-1: High- and Moderate-Energy Fluid System Piping (Continued)

System Name	Individual Line Names	Line size (NPS)	High- or Moderate-Energy
UWS	Utility water system	36	Moderate

Notes:

(1) Based on operating parameters that exceed 200 degrees F or 275 psig for less than 2 percent of the time the system is in operation, or that exceed 200 degrees F or 275 psig for less than 1 percent of the plant operation time.

(2) Based on the nominal diameter of the lines, breaks do not need to be postulated in PSS lines.

(3) The High point vent can be considered moderate-energy, but is conservatively evaluated as high-energy.

(4) The ~~nozzle~~safe end-to-valve welds for the 2-inch CVCS lines outside the CNV are NPS4. NPS4 applies only to the single weld.

(5) Hydraulic calculations have not been completed to determine system piping sizes.

RAI 03.06.02-6, RAI 03.06.02-14S1, RAI 06.02.01.01.A-18S1

Table 3.6-4: NuScale Power Module Piping Systems Design and Operating Parameters

Process System (NuScale System)	ASME Code	NPS Size	Design		Operating(4)	
			Press. (psia)	Temp. (°F)	Press. (psia)	Temp. (°F)
CVCS (RCS)	Class 1	2	2100	650	1870(2)	625(2)
CVCS (CNTS, CVCS)	Class 3(1)	2(1)	2100	650	1870(2)	625(2)
MSS (steam generator system, CNTS)	Class 2	8 & 12	2100	650	500	585
FWS (steam generator system, CNTS)	Class 2	4 & 5	2100	650	550	300
DHRS	Class 2	2 & 6	2100	650	1400	635(3)
RCCWS (CRDS)	Class 2	2	165	200	80	121
RCCWS (CNTS)	Class 2	4	1050~~00~~	550	80	121
CFDS (CNTS-inside CNV)	Class 2	2	165	300	85	100
CFDS (CNTS-outside CNV)	Class 2	4	1050~~00~~	550	85	100
CES (CNTS)	Class 2	4	1050~~00~~	550	0.037	100

Notes

(1) The weld between the CIV and the safe-end is NPS 4 SCH 160 and is designated as a Class 1 piping weld

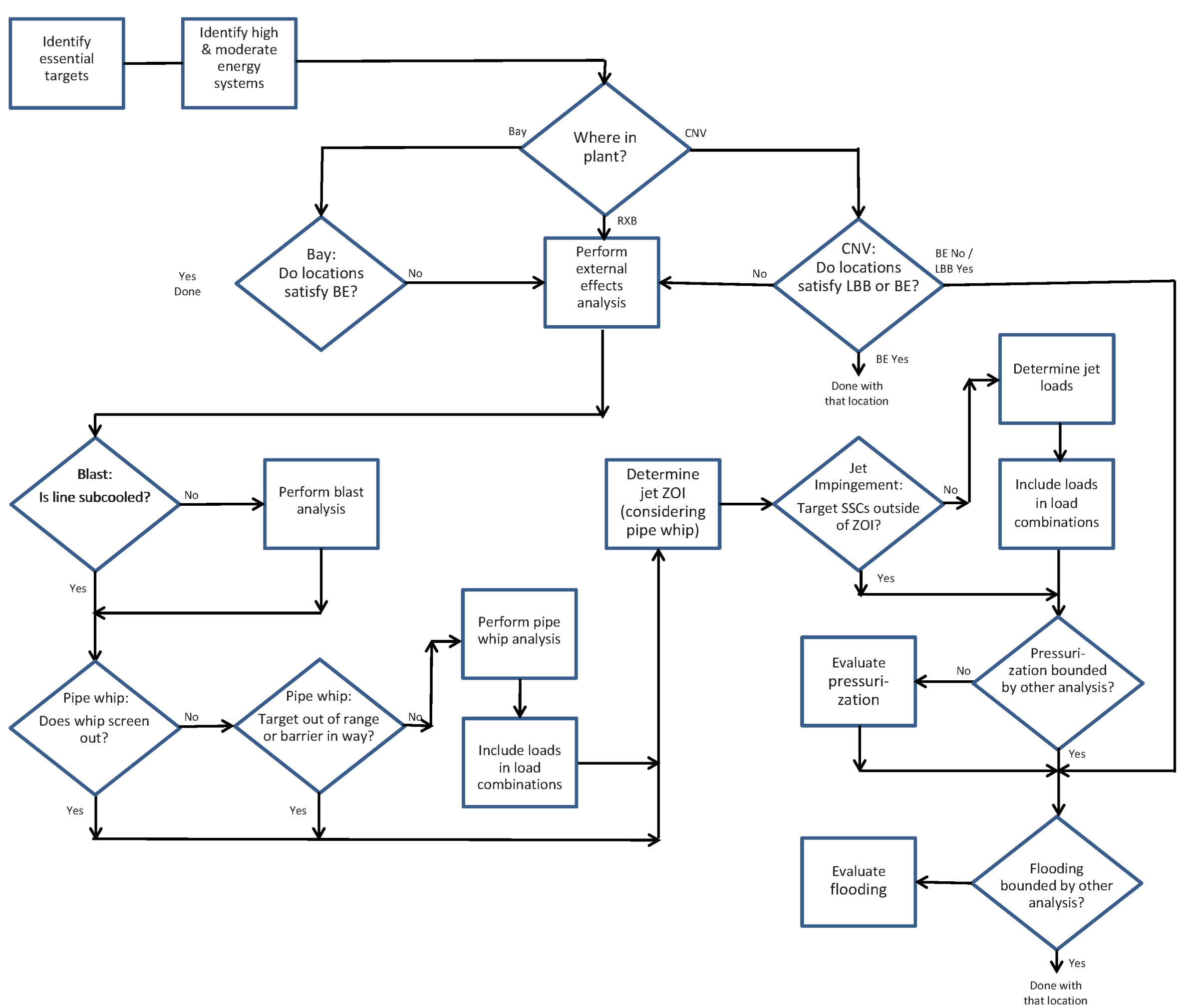
(2) Represents the highest normal operating pressure for the injection line and highest normal operating temperature for the RPV high point degasification line.

(3) Conservatively represents the highest normal operating temperature for the steam portion (i.e., NPS 6 portion) of the DHRS.

(4) The initial conditions are ~~based on full-power operation rather than on~~selected to bound system conditions for any power level, 102 percent thermal power and hot standby operation, for which the NuScale equivalent is referred to as hot shutdown. During hot shutdown, MSS pressure and temperature are approximately 300 psia and 420 degrees ~~º~~F, respectively, and primary pressure and temperature are approximately 1850 psia and 420 degrees~~º~~ F, respectively.

RAI 10.03-4

Figure 3.6-1: Flowchart of methodology for evaluation of line breaks~~Not Used~~



Enclosure 2:

Changes to “Pipe Rupture Hazards Analysis,” TR-0818-61384, proprietary version

Enclosure 3:

Changes to “Pipe Rupture Hazards Analysis,” TR-0818-61384, nonproprietary version

NuScale Power, LLC
1100 NE Circle Blvd., Suite 200 Corvallis, Oregon 97330 Office 541.360-0500 Fax 541.207.3928
www.nuscalepower.com

NuScale approach: Inside the CNV, each of the postulated locations is shown to be acceptable on at least one of the following bases, in order of preference:

1. The piping has insufficient energy to whip (see Appendix C.4.1).
2. The length of whipping pipe is insufficient to reach essential SSC.
3. The whipping pipe is blocked by a barrier, which is a robust component (e.g., RPV, CNV) or wall, from reaching an essential SSC.
4. The essential structure, system or conponent is justified as being sufficiently robust to withstand the impact without loss of function.
5. The number of redundant components is such that the damage caused by pipe whip combined with a single active failure does not cause a loss of an essential function.
6. Dynamic structural analysis of the impact force on a given essential structure, system, or component.

Unless impact effects are clear (e.g., breaking a power cable de-energizes a component), damage caused by an HELB is assumed to fail a component in a way that does not allow the essential function to occur.

Any safety-related or essential components within reach of a whipping pipe are evaluated for need for a pipe whip restraint, pipe whip barrier, or qualification for pipe whip impact. Because piping arrangements within the RXB are not finalized, protection of components for pipe whip will be addressed by the COL applicant in accordance with COL items 3.6-1 and 3.6-3.

For the NPM bay area, because break exclusion eliminates the need to postulate HELBs, pipe whip is not relevant.

For integrity of the RXB concrete structure, an estimate is made of the kinetic energy of the whipping pipe, to be applied over a limited contact area using the methodology described for missile impact in Appendix C.

Regarding multimodule effects, only the impact of {{

}}2(a),(c) Pipe whip and jet reaction loads must be considered in load combinations in accordance with FSAR Section 3.9 and Section 3.12.

temperatures and at loading rates of ±50 percent of that determined by analysis.

Note that a wall penetration may also serve as a two-dimensional pipe whip restraint, provided the wall has sufficient strength to resist the pipe load.

- Material properties are consistent with applicable code values, with strain-rate stress limits 10 percent above code or specification values, consistent with NRC guidance (SRP 3.6.2).

3.5.1.1 Pipe Whip Barriers

Standard Review Plan 3.6.2 identifies that an unrestrained, whipping pipe need not be assumed to cause ruptures or through-wall cracks in pipes of equal or larger NPS with equal or greater wall thickness. By extrapolation, a structure, system, or component made of metal of equivalent or better yield strength, equal or larger diameter, and equal or greater wall thickness does not only not leak or crack but also obstructs further travel of the whipping pipe, protecting SSC farther away from being struck.

Table 3-5 provides a comparison of potential whipping pipes and the SSC credited to act as barriers. The numbers in { } brackets are the factor by which the barrier diameter ("pipe size") and wall thickness exceed that of the whipping pipe, where a minimum value of 1.0 for both satisfies the SRP 3.6.2 guidance for pipe-on-pipe impact not causing a crack or rupture. Therefore, the SSC listed in Table 3-5 are considered to serve as pipe whip barriers without further evaluation. ~~Unless shown to be negligible, t~~The pipe whip load must be considered for inclusion in SSC load combinations to verify that the barrier is not displaced by pipe whip impact. For any structures added to serve as a barrier (or jet impingement shield), Seismic Category 1 loading is analyzed to confirm the structure does not fail and cause damage.

Concrete floors, walls, and ceilings can also serve as pipe whip barriers but require a more quantitative approach as described in Section 3.9.5 and Appendix C.

3.5.1.2 Jet Impingement Shields

NRC guidance does not have specific criteria for judging suitability of a structure, system, or component as a jet shield. Regarding impingement effects, if the following criteria are met, then the structure, system, or component is judged capable of serving as a shield:

- The diameter and wall thickness of the shield meet the criteria for a pipe whip barrier with a size equal or greater than that of the broken pipe.
- The barrier is of sufficient area and positioned to subtend a solid angle from the pipe break opening (considering potential pipe whip) that covers the structure, system, or component to be protected.
- The barrier is solid (without openings) to the extent that no direct line of sight exists from the break opening to the structure, system, or component. This criterion allows for some indirect passage of spray through an opening, but environmental qualification

Schedule 160 pipe has an inner diameter of 1.687 inches. For steam discharge, the jet ZOI is limited to about 2.2 diameters, or less than 4 inches (see Appendix E).

- For some pipe break locations inside the CNV, large structures limit the range and direction of a whipping pipe or jet. Examples are the RPV, CNV, and SGS piping.

3.8.1.1 In the NuScale Power Module Bay

With the exception of nonmechanistic breaks, no HELBs occur in the NPM bay area based on high-energy lines satisfying criteria of BTP 3.4 for excluding breaks. Thus, only environmental qualification effects need evaluation.

3.8.1.2 In the Reactor Building

Separation by placement in different subcompartments and redundancy are the degrees of separation considered. Although not essential components, PAM and DC power cables are routed in areas separated from high-energy lines by structural or shield walls.

3.9 Analysis Methodology

Figure 3-1 is a flow chart of the process for identifying postulated rupture locations and vulnerable essential and safety-related targets through assessing the relevance and consequences of possible external effects.

- Essential targets are identified (see Section 3.2).
- High- and moderate-energy systems are identified.
- Each of the three regions of the plant (the CNV, the NPM bay under the bioshield, and the RXB) is considered separately.
- If potential HELB locations satisfy break exclusion (in CNV or NPM bay) or LBB (MSS and FWS piping in CNV) acceptance criteria, then consideration of HELB dynamic effects is avoided.
- For postulated breaks of piping containing steam, the potential for creation of a blast wave is assessed (see Section 3.9.3).
- Availability of energy sufficient to cause pipe whip is evaluated (see Appendix C).
- If pipe whip is possible, then the vulnerability of essential SSC to being hit is determined based on direction of pipe whip and distance.
- If pipe whip impact is possible, the consequences of the impact are assessed. Pipe whip load is included in load combinations in accordance with FSAR Section 3.9 and Section 3.12. Note that pipe whip load does not coexist with peak pressurization load.
- Jet ZOI is defined to determine if any essential SSC are within it (see Appendix E).
- For essential SSC within the ZOI, the jet impingement effects are assessed (see Appendix E).
- Jet reaction load and, if within the ZOI, potential jet impingement load, is included in load combinations in accordance with FSAR Section 3.9 and Section 3.12.

3.9.5.2 Impingement Pressure

The maximum force applied to an impingement target is determined using Eq. 3-1.

The only breaks inside the CNV are NPS 2 CVCS and DHRS lines. The limiting break in the RXB is an MSS line. The pressures for these two breaks at the break exit plane are as shown in Table 3-7 and include a factor of 1.26 for the thrust coefficient C_T. These values are upper limits for the downstream pressures for real breaks where pressure across the jet drops off as the jet expands and velocity of the jet is reduced by occurrence of turbulence leading to irreversible conversion of kinetic energy to heat. The isentropic expansion of steam jets is discussed in Appendix E.

Table 3-7 Break exit plane parameters

	CVCS Break*	MSS Break
Inner diameter (inches)	{{	
Intact system pressure (psia)		
Intact system temperature (degrees F)		
Break exit plane pressure (includes C_T of 1.26)(psia)		
Break exit plane area (inches^2)		
Maximum impingement force (lbf)		}}2(a),(c)

* DHRS breaks are assumed equivalent although internal pressure is only about 500 psia

3.9.6 Jet Zone of Influence

Two~~hree~~ types of breaks are considered per regulatory guidance: ~~1)~~ circumferential breaks with full axial or sideways separation of pipe ends~~, 2) circumferential breaks with limited separation,~~ and ~~3)~~ longitudinal breaks. NuScale assumes circumferential breaks are full separation because of the absence of rigid restraints near postulated break locations. In addition, there are three thermodynamic blowdown conditions: 1) liquid, 2) two-phase, and 3) steam that have different behavior, as described in Appendix E.

High-energy line breaks are under-expanded when they issue from the end of the break, because the pipe section immediately upstream confines the flow radially. High-energy line breaks expand rapidly into the surrounding medium, with the expansion limited by jet momentum and increasing pressure at the boundary of the jet with the surrounding medium. In the limit, for a slow leak, the discharged fluid disperses uniformly in all directions. The expansion has the effect of reducing the jet pressure at a target below that at the break exit. ANSI/ANS 58.2 provides guidance on this expansion, but the NRC has expressed concern that this guidance is not generally applicable (see SRP Section 3.6.2).

Considerable effort has gone into evaluating the jet plume appropriate for HELBs. ANSI/ANS 58.2 presents the modified Moody model in which the conical jet expands at a 45-degree half-angle for a downstream distance of 5 L/D_E and at 10 degrees from there on. Some evaluations recommend a hemispherical or even a spherical ZOI. If the wider ZOI is considered in analysis, the drop off of pressure with distance is faster.

4.2 Blast Effects

Blast effects results are based on three-dimensional CFD analysis discussed in Appendix F.

4.2.1 In the Containment Vessel

Because only NPS 2 lines are postulated to break, the mass and energy release feeding the blast formation is small. Only the degasification line has the potential for forming a blast, because the other CVCS lines contain subcooled liquid. The magnitude of the blast wave pressures is low, and the maximum force imposed on any component is limited to 6,000 lbf. In addition, the load is of very short duration, a few milliseconds and ~~does not need to be included in load combinations~~is considered insignificant.

4.2.2 In the NPM Bay under the Bioshield

Not applicable.

4.2.3 In the Reactor Building

Breaks are postulated in MSS lines at three locations in a pipe gallery. Only MSS lines have a potential for forming a blast, because the other CVCS lines contain subcooled liquid. The maximum force on any component is less than 10,000 lbf. Although a force of 103,000 lbf on the pool wall was calculated, it is distributed over a surface area with a radius of about 100 inches, yielding a momentary overpressure of less than 15 psig. No damage occurs as a result~~, and the shortness of the loading eliminates the need to consider it in load combinations~~. In addition, the load is of very short duration, a few milliseconds, and is considered insignificant.

4.3 Pipe Whip

Results of pipe whip evaluations are detailed in Appendix C.

4.3.1 In the Containment Vessel

Pipe whip for breaks at the RPV and CNV terminals ends has been evaluated. The nozzle/safe end end does not whip. For the piping end, the motion of the pipe is such that no safety-related or essential SSC are impacted. Even if an impact did occur, the SSC are of heavy wall construction so that they neither leak nor crack. There is one exception: the ECCS trip/reset line. If a whipping pipe strikes a trip/reset line, the line is severed, causing it to vent. This has the same effect as opening the trip valve and allows the ECCS main valve to open once the IAB clears. As the response to the HELB is ECCS initiation, the severance of a trip/reset line has no effect on response to the event.

4.3.2 In the NPM Bay under the Bioshield

Not applicable.

Appendix E. Jet Impingement

As discussed in Appendix B, jets issuing from pipe breaks in the NuScale plant are not susceptible to dynamic amplification or resonance. However, target SSC potentially in the path of postulated breaks must be assessed for the load imparted by the jet. Three categories of jets are considered:

1. liquid jets
2. two-phase jets
3. steam jets

As for other effects, jet behavior and effects differ for the three areas of the plant:

- Inside the CNV: breaks are limited to NPS 2 RCS-connected and DHRS piping because SGS piping meets LBB. Only a degasification line break is initially steam, but spray line break reverse flow almost immediately turns to steam. Other breaks such as injection line or spray line forward flow are two-phase.

- In the NPM bay under the bioshield: no postulated breaks occur (nonmechanistic breaks do not involve pipe whip) because piping is designed to satisfy break exclusion criteria of BTP 3-4 Paragraph B.A.(ii) and (iii).

- In the RXB: piping arrangements are not finalized, so break locations and jet directions must be assumed to be anywhere in the rooms containing high-energy piping. The piping is limited to NPS 12 and 4 main steam system, NPS 6 feedwater system, and NPS 2 to 3 chemical volume and control system piping at various pressures and temperatures. Main steam system jets are steam only, whereas FWS and CVCS breaks are two-phase jets, and sections of CVCS could be susceptible to breaks leading to liquid jets.

The concern for jet impingement that underlies regulatory guidance is the stripping of insulation with subsequent sump blockage (GSI-191). In the NuScale plant, there is no piping insulation inside the CNV and stripping of insulation outside the CNV has no deleterious safety effects. This raises the impingement damage threshold from four psig to more than 190 psig (NUREG/CR-6808), based on the impingement pressures for which metal insulation sheathing has been found to not be damaged during testing.

E.1.1 Total Force

The total force by the jet (adjusted for thrust coefficient) cannot exceed that at the break exit plane, which is {{ }}2(a),(c) for CVCS and MSS, respectively (Table 3-7).

E.1.2 Liquid jets

Liquid jets are assumed to not expand (i.e., the cross section of the pipe rupture is maintained) and to not droop with distance (i.e., travels straight until impeded). The only areas subject to liquid jets are in the RXB where CVCS low temperature, high pressure piping is present. The essential SSCs in this area are the CVCS demineralized water

Table E-1 Deleted~~CVCS jet impingement pressure versus. distance for limited separation in CNV~~

~~Distance r from Pipe Axis (inch)~~	~~Distance from Pipe Outer Wall (inch)~~	~~Jet Width for 10º Half-angle (inch)~~	~~Jet Area (inches²)~~	~~Pressure at r (psia)▲~~	~~% of Pressure at Pipe Inner Wall~~
~~0.84*~~	~~N/A~~	~~0.84~~	~~4.5~~	~~{{~~	
~~1.19**~~	~~0.00~~	~~0.84~~	~~6.3~~		
~~2~~	~~0.81~~	~~1.13~~	~~14~~		
~~3~~	~~1.81~~	~~1.48~~	~~28~~		
~~4~~	~~2.81~~	~~1.84~~	~~46~~		
~~5~~	~~3.81~~	~~2.19~~	~~69~~		
~~12~~	~~10.8~~	~~4.66~~	~~351~~		~~}}2(a),(c)~~

~~* Inner diameter~~
~~** Outer diameter~~
~~▲Includes 1.26 thrust coefficient C_T~~

{{ }}2(a),(c) Eq. E-4

$$A_j = D_j^2 * \frac{\pi}{4}$$ Eq. E-5

$$P_j = C_T * P_o * \frac{A_E}{A_j}$$ Eq. E-6

where,

D_j = Jet diameter at distance L/D_E (inches),

L/D_E = Distance of nearest point on impingement surface in L/D (unitless),

D_E = Inside diameter of break exit (inches),

A_j = Total cross-sectional area of the jet at the target SSC (inches^2),

P_j = Applied jet pressure at nearest target surface,

C_T = Thrust coefficient (unitless),

P_o = Internal system pressure (psia)[20], and

[20] In accordance with SRP 3.6.2, jet thrust load is based on operating pressure and temperature.

Enclosure 4:

Affidavit of Zackary W. Rad, AF-0319-64983

NuScale Power, LLC

AFFIDAVIT of Zackary W. Rad

I, Zackary W. Rad, state as follows:

(1) I am the Director of Regulatory Affairs of NuScale Power, LLC (NuScale), and as such, I have been specifically delegated the function of reviewing the information described in this Affidavit that NuScale seeks to have withheld from public disclosure, and am authorized to apply for its withholding on behalf of NuScale

(2) I am knowledgeable of the criteria and procedures used by NuScale in designating information as a trade secret, privileged, or as confidential commercial or financial information. This request to withhold information from public disclosure is driven by one or more of the following:

(a) The information requested to be withheld reveals distinguishing aspects of a process (or component, structure, tool, method, etc.) whose use by NuScale competitors, without a license from NuScale, would constitute a competitive economic disadvantage to NuScale.

(b) The information requested to be withheld consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), and the application of the data secures a competitive economic advantage, as described more fully in paragraph 3 of this Affidavit.

(c) Use by a competitor of the information requested to be withheld would reduce the competitor's expenditure of resources, or improve its competitive position, in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

(d) The information requested to be withheld reveals cost or price information, production capabilities, budget levels, or commercial strategies of NuScale.

(e) The information requested to be withheld consists of patentable ideas.

(3) Public disclosure of the information sought to be withheld is likely to cause substantial harm to NuScale's competitive position and foreclose or reduce the availability of profit-making opportunities. The accompanying attachment reveals distinguishing aspects about the methodology by which NuScale develops its pipe rupture hazards analysis (PHRA).

NuScale has performed significant research and evaluation to develop a basis for this PHRA methodology and has invested significant resources, including the expenditure of a considerable sum of money.

The precise financial value of the information is difficult to quantify, but it is a key element of the design basis for a NuScale plant and, therefore, has substantial value to NuScale.

If the information were disclosed to the public, NuScale's competitors would have access to the information without purchasing the right to use it or having been required to undertake a similar expenditure of resources. Such disclosure would constitute a misappropriation of NuScale's intellectual property, and would deprive NuScale of the opportunity to exercise its competitive advantage to seek an adequate return on its investment.

(4) The information sought to be withheld is in the enclosure entitled "Pipe Rupture Hazard Analysis." The enclosure contains the designation "Proprietary" at the top of each page containing proprietary information. The information considered by NuScale to be proprietary is identified within double braces, "{{ }}" in the document.

(5) The basis for proposing that the information be withheld is that NuScale treats the information as a trade secret, privileged, or as confidential commercial or financial information. NuScale relies upon

the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC § 552(b)(4), as well as exemptions applicable to the NRC under 10 CFR §§ 2.390(a)(4) and 9.17(a)(4).

(6) Pursuant to the provisions set forth in 10 CFR § 2.390(b)(4), the following is provided for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld:

(a) The information sought to be withheld is owned and has been held in confidence by NuScale.

(b) The information is of a sort customarily held in confidence by NuScale and, to the best of my knowledge and belief, consistently has been held in confidence by NuScale. The procedure for approval of external release of such information typically requires review by the staff manager, project manager, chief technology officer or other equivalent authority, or the manager of the cognizant marketing function (or his delegate), for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside NuScale are limited to regulatory bodies, customers and potential customers and their agents, suppliers, licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or contractual agreements to maintain confidentiality.

(c) The information is being transmitted to and received by the NRC in confidence.

(d) No public disclosure of the information has been made, and it is not available in public sources. All disclosures to third parties, including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or contractual agreements that provide for maintenance of the information in confidence.

(e) Public disclosure of the information is likely to cause substantial harm to the competitive position of NuScale, taking into account the value of the information to NuScale, the amount of effort and money expended by NuScale in developing the information, and the difficulty others would have in acquiring or duplicating the information. The information sought to be withheld is part of NuScale's technology that provides NuScale with a competitive advantage over other firms in the industry. NuScale has invested significant human and financial capital in developing this technology and NuScale believes it would be difficult for others to duplicate the technology without access to the information sought to be withheld.

I declare under penalty of perjury that the foregoing is true and correct. Executed on March 28, 2019

Zackary W. Rad