Westinghouse Non-Proprietary Class 3

WCAP-15108-NP-A
Revision 1

Technical Justification for Eliminating Accumulator Lines Rupture as the Structural Design Basis for Point Beach Units 1 and 2 Nuclear Plants

Westinghouse Electric Company LLC

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-15108-NP-A
Revision 1

Technical Justification for Eliminating Accumulator Rupture as the Structural Design Basis for Point Beach Units 1 and 2 Nuclear Plants

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WCAP-15108-NP-A Revision 1 **APPROVED VERSION- TABLE OF CONTENTS**

Note: Sections A, B, C and D are added. Revisions in Section E are identified on page vii.

SECTION A

NRC ACCEPTANCE LETTER

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

November 7, 2000

Mr. Mark Reddemann
Site Vice President
Point Beach Nuclear Plant
Nuclear Management Company, LLC
6610 Nuclear Road
Two Rivers, WI 54241

SUBJECT: POINT BEACH NUCLEAR PLANT, UNITS 1 AND 2 - REVIEW OF LEAK-BEFORE-BREAK EVALUATION FOR THE ACCUMULATOR LINE PIPING AS PROVIDED BY 10 CFR PART 50, APPENDIX A, GDC 4 (TAC NOS. MA7834 AND MA7835)

Dear Mr. Reddemann:

By letters dated December 2, 1999, July 7 and August 16, 2000, the Wisconsin Electric Power Company (WEPCo) submitted a request for the NRC to review and approve the leak-before-break (LBB) evaluation for the Point Beach Nuclear Plant, Units 1 and 2, accumulator line piping. WEPCo was subsequently succeeded by Nuclear Management Company, LLC (NMC), as the licensed operator of Point Beach, Units 1 and 2. By letter dated October 5, 2000, NMC requested the staff continue to process and disposition licensing actions previously docketed and requested by WEPCo. The submittal was made in accordance with the provisions of Title 10 of the *Code of Federal Regulations*, Part 50, Appendix A, General Design Criteria 4, which permits licensees to exclude the dynamic effects associated with postulated pipe ruptures from the facility's licensing basis if "analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping." LBB evaluations utilizing the guidance of NUREG-1061, Volume 3, have been previously approved by the staff as a method for making such a demonstration.

The staff has completed its evaluation of your submittal. The information provided in the original submittal and supplemented by the July 7 and August 16, 2000, responses to the staff's request for additional information was sufficient to permit the staff to independently evaluate the licensee's conclusions. While the detailed results of the staff's evaluation differ with the licensee's, the staff agrees with your conclusion that LBB behavior has been demonstrated for the analyzed portions of the accumulator line piping. Therefore, the staff finds that you may remove consideration of the dynamic effects associated with the postulated rupture of the analyzed portions of the accumulator line piping from the licensing basis of Point Beach, Units 1 and 2.

The safety evaluation that addresses the technical basis for the staff's finding is enclosed.

Sincerely,

Beth A. Wetzel

Beth A. Wetzel, Senior Project Manager, Section 1
Project Directorate III
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket Nos. 50-266 and 50-301

Enclosure: Safety Evaluation

cc w/encl: See next page

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SECTION B

NRC SAFETY EVALUATION REPORT

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION OF THE REQUEST TO APPLY LEAK-BEFORE-BREAK STATUS TO THE ACCUMULATOR LINE PIPING AT POINT BEACH NUCLEAR PLANT, UNITS 1 AND 2

1.0 INTRODUCTION

By letter dated December 2, 1999, as supplemented July 7 and August 16, 2000, the licensee for Point Beach Nuclear Plant, Units 1 and 2, requested that the NRC review and approve their application to remove consideration of the dynamic effects of postulated ruptures of the accumulator line piping from the licensing basis for Point Beach, Units 1 and 2. The licensee's submittal was based on an application of Title 10 of the *Code of Federal Regulations*, Part 50, Appendix A, General Design Criteria (GDC) 4, which states, in part:

> However, dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping.

For the purposes of this demonstration, the licensee submitted a leak-before-break (LBB) analysis prepared by Westinghouse for the subject portions of the accumulator line piping. LBB evaluations developed by the NRC using the analysis methodology contained in NUREG-1061, Volume 3 (Reference 1), have been previously approved by the Commission as demonstration of an extremely low probability of piping system rupture.

2.0 REGULATORY REQUIREMENTS AND STAFF POSITIONS

Nuclear power plant licensees have, in general, been required to consider the dynamic effects that could result from the rupture of sections of high energy piping (fluid systems that during normal plant operations are at a maximum operating temperature in excess of 200 °F and/or a maximum operating pressure in excess of 275 psig). This requirement has been formally included in 10 CFR Part 50, Appendix A, GDC 4, which states, "Structures, systems, and components important to safety....shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit."

As noted in Section 1.0 above, the NRC modified GDC 4 to permit the dynamic effects of some high energy piping ruptures to be excluded from facility licensing bases based upon the demonstration of an extremely low probability of piping system rupture. Consistent with this modification to GDC 4, the NRC accepted the LBB analysis methodology as an acceptable means by which this extremely low probability of piping system rupture could be demonstrated.

ENCLOSURE

The philosophy of LBB behavior for high energy piping systems was developed by the NRC in the early 1980s, used in certain evaluations stemming from Unresolved Safety Issue A-2, "Asymmetric Blowdown Loads on PWR Primary Systems," and then subsequently expanded for application toward resolving issues regarding defined dynamic effects from high energy piping system ruptures.

3.0 LICENSEE'S DETERMINATION

The following discussion contains information supplied by the licensee in its December 2, 1999, submittal. Included in the submittal was the report prepared by Westinghouse (WCAP-15107, "Technical Justification for Eliminating Accumulator Lines Rupture as the Structural Design Basis for Point Beach Units 1 and 2 Nuclear Plants") for the licensee. The following discussion also includes information provided in the licensee's responses, dated July 7 and August 16, 2000, to the NRC staff's request for additional information (RAI), dated June 7, 2000. The figures and tables referred to herein are attached to this safety evaluation.

3.1 Identification of Analyzed Piping and Piping Material Properties

The licensee's submittal identified and analyzed the following sections of high energy piping for LBB behavior verification. The licensee addressed the accumulator lines for each unit from their connections to the cold leg of the main coolant loop and the accumulator to the point of containment penetration. Figures 1 through 4 show the layout for the piping attached to each of the four accumulator tanks at the two units. The piping shown in these figures is 10-inch nominal diameter piping ranging from Schedule 40 (0.340-inch wall thickness) to Schedule 140 (0.896-inch wall thickness).

The accumulator line piping was manufactured from several materials. The piping and fittings of the Point Beach Units 1 and 2 accumulator lines were manufactured from wrought ASME specification SA-376 Type 316 and wrought ASME specification SA-312 Type 304 stainless steel (SS). The welds in this system were fabricated from SS using gas tungsten arc and shielded metal arc welding (SMAW) processes.

For the material properties used in the accumulator line LBB evaluations, Westinghouse used minimum and average room temperature tensile properties based on Certified Materials Test Report (CMTR) data. The minimum and average tensile properties at temperatures of interest (i.e., 105 °F, 547 °F) were calculated using the ratio of the American Society for Mechanical Engineers (ASME) Code, Section III, properties at room temperature to the Code properties at the temperature of interest to scale CMTR-based data. The modulus of elasticity variation with temperature was established based on ASME Code, Section III, values. The minimum tensile properties were used by Westinghouse in the LBB critical flaw size determination, while the average tensile properties were used in the LBB leakage flaw size determination. Additional fracture toughness properties were reported and used to demonstrate flaw stability at the limiting location identified by the licensee.

3.2 General Aspects of the Licensee's LBB Analysis

The analyses provided by the licensee sought to address the following four principal areas that were consistent with the criteria established for LBB analysis acceptability in NUREG-1061, Volume 3: (1) demonstrate that the subject piping is a candidate for LBB analysis by showing that the piping is not particularly susceptible to active degradation mechanisms or atypical loading events; (2) establish the critical through-wall flaw size under which analyzed locations would be expected to fail under normal operation (NOP) plus safe-shutdown earthquake (SSE) loading conditions; (3) establish the leakage behavior of smaller through-wall flaws under NOP loads alone for each location; and (4) evaluate the margin between the critical through-wall flaw size and an appropriate leakage through-wall flaw size and the stability of the through-wall leakage flaw.

3.3 Evaluation of Accumulator Line Piping

The analysis of the accumulator line piping that was submitted to the staff as an attachment to the licensee's December 2, 1999, letter was prepared for the licensee by Westinghouse as report number WCAP-15107. This section summarizes the Westinghouse results for the four subject areas noted in section 3.2 above.

Initially, the licensee's submittal addressed the issue of potential piping degradation mechanisms and atypical loading conditions. Per the discussion of the limitations of LBB analyses in NUREG-1061, Volume 3, the LBB approach should not be considered when operating experience has indicated particular susceptibility to failure from the effects of corrosion, water hammer, or fatigue. The licensee's submittal concluded that pressurized-water reactor accumulator line piping like that at Point Beach, Units 1 and 2, has not been shown to be particularly susceptible to the effects of water hammer, stress corrosion cracking, or erosion-corrosion.

Regarding the potential for fatigue cracking from mechanical and thermal loadings, the licensee and Westinghouse noted that low cycle fatigue considerations were accounted for in the design of this piping system through the fatigue usage factor evaluation to show compliance with the rules of Section III of the ASME Code. Additionally, the licensee and Westinghouse provided an analysis of the growth of postulated surface flaws based on design transient loading conditions and the analysis procedure suggested by Section XI, Appendix A of the ASME Code. Westinghouse showed that for semi-elliptic surface flaws with initial depths of up to one-third of the thickness of the pipe wall, little flaw growth was expected to occur. High-cycle fatigue loads, primarily from pump vibrations, are managed through the monitoring of reactor coolant pump shaft vibration limits and inservice measurements have shown that the magnitude of the stresses associated with these vibrations is very low and below levels at which it would pose a concern.

Next, the Westinghouse analysis evaluated the accumulator line piping by developing the applied stresses under NOP and NOP plus SSE loading and determining the leakage and critical through-wall flaw size for various locations along the piping. In the determination of the applied stresses, the analysis included the tensile and bending stresses resulting from the internal pressure, deadweight, and thermal expansion, with SSE loads included when determining the loads associated with the critical flaw size evaluation. It should, however, be noted that in the original submittal, load combinations in WCAP-15107 did not account for torsional loads on the accumulator line piping for either NOP or NOP plus SSE loading conditions. Loads that were provided in the licensee's August 16, 2000, supplemental letter responding to the NRC staff's RAI did include torsional loads as requested by the NRC staff.

In the load combination, the deadweight, thermal expansion, pressure, and SSE stresses were summed absolutely for the critical flaw size determination. The deadweight, thermal expansion, and pressure stresses were summed algebraically for the leakage flaw size determination. Table 1a summarizes the significant load combination results provided by the licensee and Westinghouse in the December 2, 1999, submittal. Table 1b shows the load combinations submitted by the licensee in its August 16, 2000, supplemental submittal.

For the purposes of LBB analyses, the critical flaw size can be defined as the longest preexisting through-wall flaw that could exist without growing unstably to double-ended pipe rupture under NOP plus SSE stresses. The analysis performed by Westinghouse to establish the critical flaw size at a nodal location was based on the use of a limit-load analysis approach. This approach effectively predicts piping failure based on net section collapse of the cross-section that has been reduced by the through-wall cracked section. In the Westinghouse analysis of the accumulator lines, the SS welds were identified as the limiting material (i.e., the material for which the smallest margin between the critical and leakage flaw size exists). When analyzing SS welds using a limit-load-based approach, an additional factor (the Z-factor) is incorporated to account for the generally lower toughness and lower load carrying capacity of SMAW welds. The Westinghouse analysis applied the Z-factor to increase the applied loads and thus reduce the through-wall flaw size that could be withstood without piping failure. An additional J-R-based analysis was performed for the location identified as limiting by the licensee and Westinghouse to ensure that flaw stability concerns were addressed.

The leakage flaw size for an LBB analysis is defined as the flaw size which, under NOP conditions, would leak 10 times the amount of fluid detectable by the facility's leakage detection system. The factor of 10 is established in the LBB guidance of NUREG-1061, Volume 3, as the safety factor on leakage to account for uncertainties in calculating leakage from a through-wall crack. As noted in Section 5.3.3 of WCAP-15107, the performance of the Point Beach pressure boundary leakage detection system is consistent with the guidelines of Regulatory Guide 1.45, "Reactor Coolant Pressure Boundary Leakage Detection Systems," and is therefore capable of detecting a one-gallon-per-minute (gpm) leak in 1 hour. Therefore, the leakage flaw calculated by Westinghouse at each nodal location was based on a leak rate of 10 gpm under NOP conditions. The leakage analysis performed by Westinghouse was based on the use of a Westinghouse proprietary methodology for calculating single or two-phase flow through cracks in light-water reactor piping.

Table 2 summarizes the limit-load analysis results submitted by the licensee for the locations that were identified to be limiting for the purposes of the accumulator line LBB analyses. For all nodes (except node 165) on the Point Beach, Unit 1, Tank A accumulator line, the margin of 2 on length between the leakage and critical flaws sizes recommended by NUREG-1061, Volume 3, was achieved. The margin reported by the licensee for Point Beach, Unit 1, Tank A, node 165, was 1.87. The more detailed, J-R-based stability analysis performed by Westinghouse demonstrated that a 20.40-inch long flaw at node 165 would be stable under

NOP plus SSE loading conditions and therefore, a margin of 2 also existed for that location. Finally, since all critical flaw analyses used the absolute summation on NOP plus SSE loads, stability analysis of the leakage size flaw under NOP plus SSE conditions with a safety factor on the loads of unity was also demonstrated.

4.0 STAFF EVALUATION

Based on the information provided by the licensee regarding the materials comprising the Point Beach, Units 1 and 2, accumulator line piping and the loads under NOP and NOP plus SSE conditions, the staff independently assessed the compliance of these systems with the LBB criteria established in NUREG-1061, Volume 3. The staff has concluded that the analysis submitted by the licensee, including the additional information supplied in response to the staff's RAI, was sufficient to demonstrate that LBB behavior would be expected from the subject piping. The following sections will focus on the differences between the details of the staff's analysis, conducted per NUREG-1061, Volume 3, and the licensee's analysis.

4.1 Identification of Analyzed Piping and Piping Material Properties

The staff examined the list of materials identified for the accumulator line piping and concluded that the materials of primary interest for the LBB analysis would be the SS welds because of their susceptibility to thermal aging. However, in evaluating the fracture behavior of the SS welds, the stress-strain properties of the surrounding wrought SS piping would also be used, as addressed below. NUREG-1061, Volume 3, specifies particular aspects that should be considered when developing materials property data for LBB analyses. First, data from the testing of the plant-specific piping materials is preferred. However, in the absence of such data, more generic data from the testing of samples having the same material specification may be used. More specifically, it was noted in Appendix A of the NUREG that "[m]aterial resistance to ductile crack extension should be based on a reasonable lower-bound estimate of the material's J-resistance curve," while Section 5.2 of the NUREG stated that the materials data should include "appropriate toughness and tensile data, long-term effects such as thermal aging and other limitations."

Given the above, the staff did not concur with the Westinghouse methodology for evaluating the SS weld materials. Westinghouse's use of a Z-factor modified limit-load approach is consistent with guidance in draft Standard Review Plan, Section 3.6.3 (Reference 2) (published for comment in 1987), on LBB and the technical bases on which some of the flaw evaluation criteria in ASME Code, Section XI, were developed. However, since the mid-to-late 1980s time-frame, additional evidence regarding the effects of thermal aging on SMAW SS pipe welds has been collected. When comparing the J-R data cited as the basis for the flaw evaluation criteria of ASME Code, Section XI, and the Z-factor approach (References 3 and 4), it appears that the thermal aging of SS weld materials may not be adequately accounted for. It is the staff's position that an LBB analysis is significantly different from a flaw evaluation and that the thermal aging of SS weld materials must be explicitly addressed. An additional study from Argonne National Laboratory (Reference 3) was the staff's reference for this information and the staff's characterization of the J-R curve is given in Table 3. The mean minus one standard deviation lower bound J-R curve used by the staff was actually developed by Wilkowski and Ghadiali at Battelle Columbus Laboratory as a fit to unaged SS weld data, but the conclusions of Reference 3 noted that there was little observed change in the fracture toughness behavior with thermal aging for those welds that began with inferior fracture toughness properties. The stress-strain properties of aged SS weld material for this evaluation are also given in Table 3. For the wrought austenitic SS piping, the NRC staff accepted the tensile properties provided by the licensee for use in the NRC staff's analysis.

In addition, the NRC staff did not concur with the original licensee and Westinghouse position in WCAP-15107 to not include torsional moments in the load summations for determining both the critical and leakage flaw sizes. In discussions with the licensee and Westinghouse regarding this matter, the staff noted that the guidance provided in NUREG-1061, Volume 3, and draft Standard Review Plan 3.6.3 was clear on this subject. In an LBB evaluation, torsional loads shall be included in a square-root-sum-of-the-squares (SRSS) summation with the other bending moments. While assessment in this manner may be conservative, excluding torsional moments from the analysis outright would certainly be non-conservative. Hence, unless an alternate methodology were provided to "more accurately" assess the impact of torsional loads (and assess the fracture toughness of the subject materials under combined Mode I and Mode II loadings), the SRSS summation is necessary to ensure all loads are adequately accounted for. A comparison of the load values given in Table 1a and Table 1b demonstrates that for the accumulator piping, the overall impact of including torsional loads in the analysis is small.

4.2 General Aspects of the Staff's LBB Analysis

The staff's analysis was performed in accordance with the guidance provided in NUREG-1061, Volume 3. Based on the information submitted by the licensee, the staff determined the critical flaw size at potential bounding locations for each piping system using the codes compiled in the NRC's Pipe Fracture Encyclopedia (Reference 5). For the purposes of the staff's evaluation, the list of potential bounding locations was defined by those locations at which materials with low postulated fracture toughness existed in combination with high ratios of SSE-to-NOP stresses. This was because high SSE stresses tend to reduce the allowable critical flaw size, while low NOP stresses increase the size of the leakage flaw. When evaluating pipe welds, the staff used the LBB.ENG3 code developed by Battelle (Reference 6) for that express purpose. The LBB.ENG3 methodology is significantly different from the other codes in Reference 5 and from the licensee's analysis in that LBB.ENG3 explicitly incorporates a J-R-based approach and accounts for the differences in the stress-strain properties of the weld and an adjoining base material when determining the effective energy release from the structure with crack extension. Criteria regarding the applied J exceeding the material J_{IC} and the applied dJ/da exceeding the material's d(J-R)/da were used to identify the critical crack size.

The staff then compared the critical flaw at the bounding location to the leakage flaw which provided 10 gpm of leakage under NOP conditions to determine whether the margin of 2 defined in NUREG-1061, Volume 3, was achieved. The leakage flaw size calculation was carried out using the PICEP (Pipe Crack Evaluation Program), Revision 1, analytic code (Reference 7). The 10 gpm value was defined by noting that the compliance of the Point Beach, Units 1 and 2, containment leakage detection system with the position in Regulatory Guide 1.45 indicates that this system would be able to detect a 1 gpm leak in the course of 1 hour and a factor of 10 is applied to this 1 gpm detection capability to account for thermohydraulic uncertainties in calculating the leakage through small cracks. The stability of the leakage flaw under NOP plus SSE loads was subsequently evaluated to check the final acceptance criteria of NUREG-1061, Volume 3.

4.3 Evaluation of the Point Beach, Units 1 and 2, Residual Heat Removal System Piping

Based on the loadings supplied by the licensee in their August 16, 2000, RAI response and preliminary scoping calculations, the staff concluded that the locations which would be expected to be limiting for the accumulator line piping evaluation would be node 165 in the Unit 1 accumulator Tank 1A line. Since the weld at node 165 existed between two sections of wrought SS piping, the LBB.ENG3 code was used to evaluate the impact of the base material stress-strain properties on each side of the weld. Using base material properties, as submitted by the licensee for 105 °F, the aged SS weld properties cited in Table 3, and the J-R curve based on the information from Wilkowski and Ghaliadi, the staff calculated that the critical flaw size at Point Beach, Unit 1, Tank A, node 165, would be 18.30 inches under NOP plus SSE loading conditions.

The staff then used the PICEP code to evaluate the leakage flaw size for node 165. Using the surface roughness value that the staff has used in previous LBB evaluations of $\varepsilon = 0.003$ inch, the staff determined that 10 gpm of leakage would be expected from a 10.4-inch through-wall flaw. Therefore, the factor of safety between the length of critical and leakage size flaws using this approach would be (18.3/10.4) = 1.76. In previous LBB evaluations, the staff has concluded that margins of slightly less than 2 on the critical-to-leakage flaw size are acceptable provided that a full margin of 10 is maintained on the leakage uncertainty. The NRC staff concluded that for this evaluation, a margin of 1.76 provides adequate assurance that the Point Beach, Units 1 and 2, accumulator line piping will exhibit LBB behavior. Finally, the 10.4-inch leakage flaw was shown to be stable under a combination of NOP plus SSE loads. Therefore, both LBB criteria were demonstrated for the bounding location.

5.0 CONCLUSION

Based on the information and analysis supplied by the licensee, the staff was able to independently assess the LBB status of the analyzed portions of the Point Beach, Units 1 and 2, accumulator line piping. The staff has concluded that, because acceptable margins on leakage and crack size have been demonstrated, these sections of piping will exhibit LBB behavior. Furthermore, the licensee is permitted to credit this conclusion for eliminating the dynamic effects associated with the postulated rupture of these sections of piping from the Point Beach, Units 1 and 2, facility licensing basis, consistent with the provisions of 10 CFR Part 50, Appendix A, GDC 4.

6.0 REFERENCES

[1] NUREG-1061, Volume 3, "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee, Evaluation of Potential for Pipe Breaks," November 1984.

[2] Draft Standard Review Plan, Section 3.6.3, "Leak-Before-Break Evaluation Procedures," Volume 52 of the Federal Register 32626, August 28, 1987.

[3] Gavenda, D.J., et al., "Effects of Thermal Aging on Fracture Toughness and Charpy-Impact Strength of Stainless Steel Pipe Welds," NUREG/CR-6428, ANL-95/47.

[4] EPRI Report NP-4768, "Toughness of Austenitic Stainless Steel Pipe Welds," October 1986.

[5] Pipe Fracture Encyclopedia, produced on CD-ROM by Battelle-Columbus Laboratory for the U.S. Nuclear Regulatory Commission, 1997.

[6] Brust, F. W., et al., "Assessment of Short Through-Wall Circumferential Cracks in Pipes," NUREG/CR-6235, BMI-2179.

[7] ERPI Report NP-3596-SR, Revision 1, "PICEP: Pipe Crack Evaluation Program (Revision 1)," December 1987.

Attachments: 1. Tables 1a, 2, and 3
2. Figures 1 through 4

Principal Contributor: M. Mitchell

Date: November 7, 2000

TABLE 1a:
Point Beach Unit 1 and 2 Accumulator Line Loads for
Licensee-Identified Critical Locations (Not Including Torsional Loads)

Unit / Tank	Node	Pipe Schedule	Normal Operation (NOP) Loads: Deadweight + Thermal + Pressure		NOP + Safe Shutdown Earthquake Loads	
			Axial (lbs)	Moment (in-lbs)	Axial (lbs)	Moment (in-lbs)
Unit 1 Tank A	165	140	47377	22401	49187	204867
Unit 1 Tank A	225	80S	57063	11269	58447	134206
Unit 1 Tank B	5	40	38126	139233	38916	290456
Unit 1 Tank B	310	140	90929	486598	134417	554062
Unit 1 Tank B	340	140	89113	555885	132777	630280
Unit 1 Tank B	380	140	104875	663421	153189	735195

TABLE 1b:
NRC Staff-Selected Point Beach Units 1 and 2 Accumulator Line
Piping Loads (Including Torsional Loads)

Unit / Tank	Node	Pipe Schedule	Normal Operation (NOP) Loads: Deadweight + Thermal + Pressure		NOP + Safe Shutdown Earthquake Loads	
			Axial (lbs)	Moment (in-lbs)	Axial (lbs)	Moment (in-lbs)
Unit 1 Tank A	165	140	47377	23166	49187	217415
Unit 1 Tank A	225	80S	57069	23112	58418	137426
Unit 1 Tank B	340	140	89113	564670	132777	640210
Unit 1 Tank B	380	140	104875	678603	153189	763369

TABLE 2:
Licensee's Results Regarding the Comparison of the Leakage and Critical Flaw Sizes (by Limit Load Analysis) for Limiting Nodes in the Analyzed Portion of the Point Beach Units 1 and 2 Accumulator Lines

Unit / Tank	Node	Critical Flaw Size Based on NOP + SSE Loads	Leakage Flaw Size based on NOP Loads	Margin
Unit 1 Tank A	165	19.05 inches*	10.20 inches	1.87
Unit 1 Tank A	225	17.50 inches	7.40 inches	2.36
Unit 1 Tank B	5	15.12 inches	5.60 inches	2.70
Unit 1 Tank B	310	14.23 inches	4.50 inches	3.16
Unit 1 Tank B	340	12.92 inches	4.35 inches	2.97
Unit 1 Tank B	380	11.94 inches	3.80 inches	3.14

* For node 165, the licensee performed a more detailed, J-R analysis and demonstrated that a flaw of length 20.40 inches would be stable under NOP plus SSE conditions, hence demonstrating a margin of 2 for this node as well.

TABLE 3:
Parameters used in Staff Evaluation of Accumulator Line Node 165,
Point Beach Unit 1, Tank A

Parameter	Value
Young's Modulus	28265 ksi
Yield Strength	64.0 ksi
Ultimate Tensile Strength	87.0 ksi
Sigma-zero	64.0 ksi
Epsilon-zero	0.00226
Ramberg-Osgood Alpha	9.0
Ramberg-Osgood n	9.8
J_{IC}	73.4 KJ / m^2
C	83.5 KJ / m^2 mm
n	0.643

Note: $J = J_{IC} + C(\Delta a)^n$ and a point-by-point representation was converted to English System units after the calculation was completed in metric units.

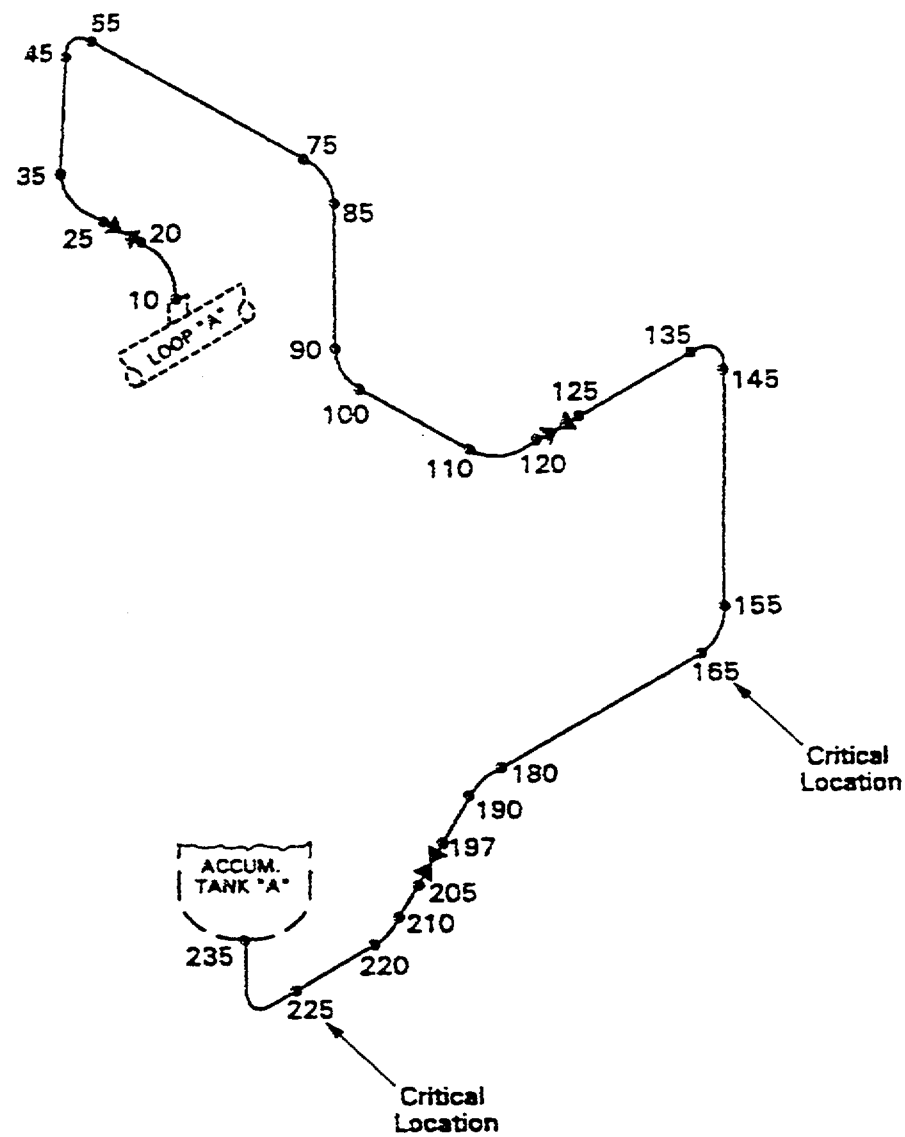

Figure 1 Point Beach Unit 1 Accumulator Line Tank A Layout

ATTACHMENT 2

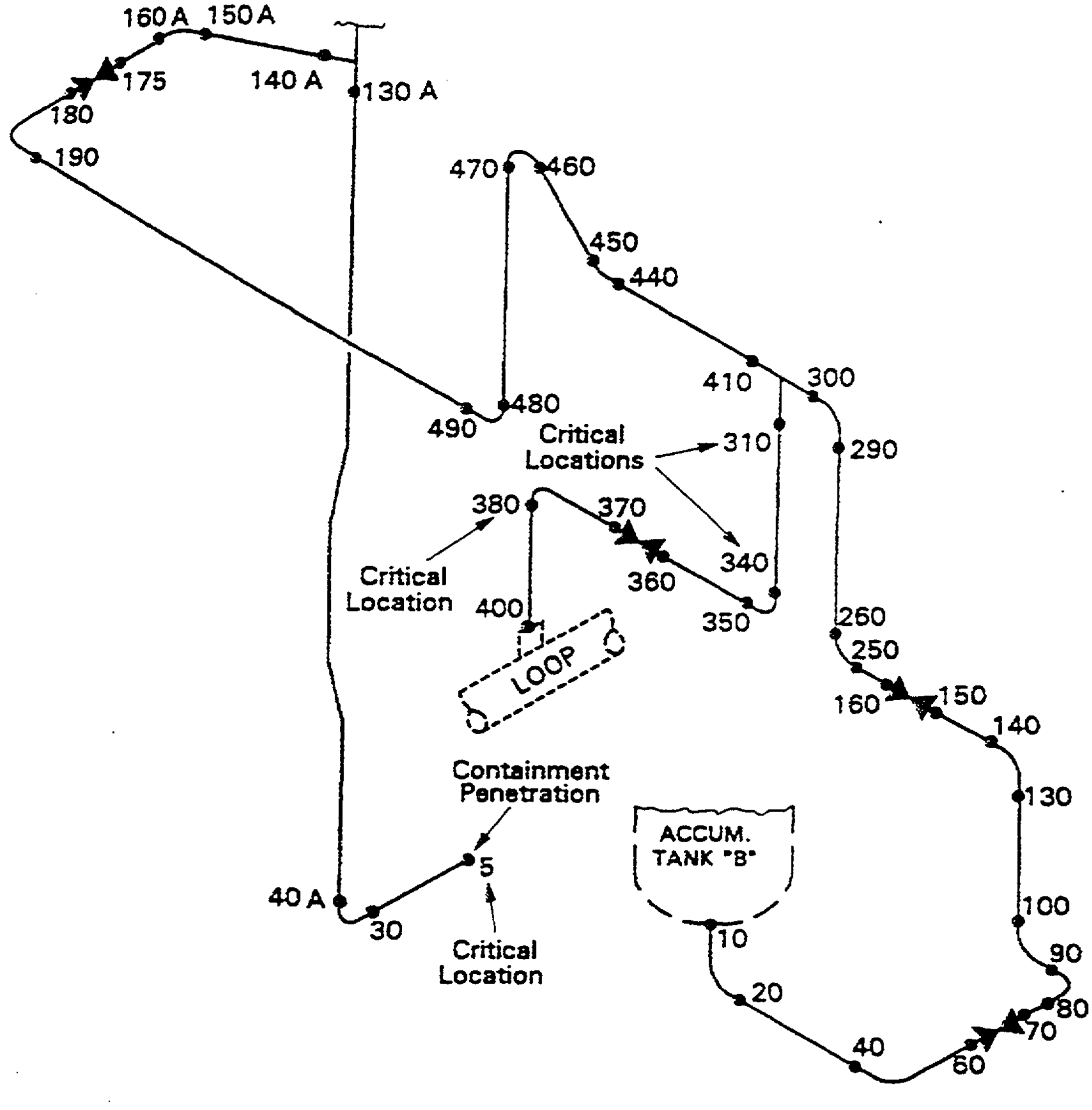

Figure 2 Point Beach Unit 1 Accumulator Line Tank B Layout

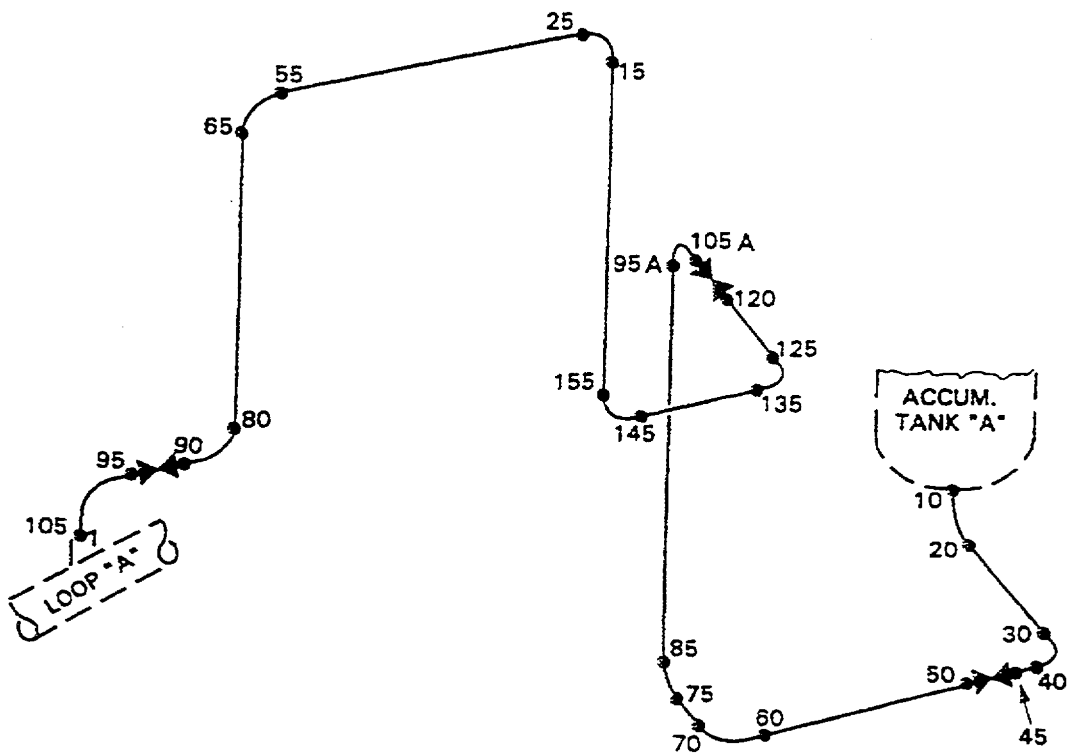

Figure 3 Point Beach Unit 2 Accumulator Line Tank A Layout

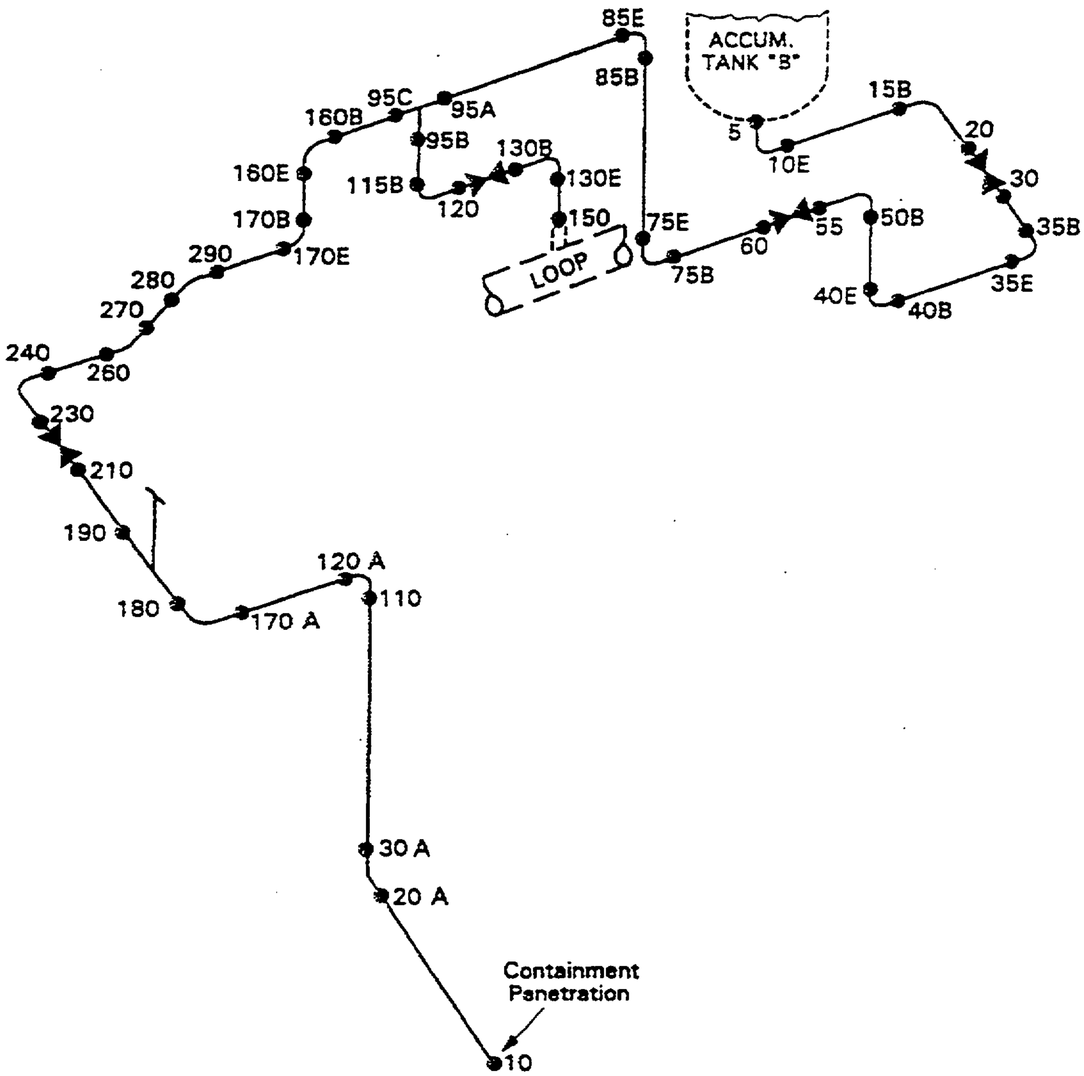

Figure 4 Point Beach Unit 2 Accumulator Line Tank B Layout

SECTION C

NRC RAI LETTER

NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

June 7, 2000

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231 West Michigan Street
Milwaukee, WI 53201

SUBJECT: POINT BEACH NUCLEAR POWER PLANT, UNITS 1 AND 2 - REQUEST FOR ADDITIONAL INFORMATION REGARDING APPLICATION OF LEAK-BEFORE-BREAK METHODOLOGY IN DESIGN-BASIS ANALYSIS OF PIPING SYSTEM (TAC NOS. MA7805, MA7806, MA7834, MA7835, MA7836, AND MA7837)

Dear Mr. Sellman:

By letter dated December 2, 1999, Wisconsin Electric Power Company (the licensee) submitted, for staff's review and approval, an application of leak-before-break methodology in a design-basis analysis to exclude dynamic effects associated with the postulated rupture of certain piping systems, including portions of residual heat removal system piping, surge line piping, and accumulator injection line piping. The enclosed request for additional information has been prepared to clarify issues raised by the staff based on its review of the licensee's December 2, 1999, submittal.

The enclosed request was discussed with Mr. Tom Malanowski and other members of your staff during a conference call on April 28, 2000. A mutually agreeable target date of 30 days from the date of this letter for your response was established. If circumstances result in the need to revise the target date, please contact me at (301) 415-1355 at the earliest opportunity.

Sincerely,

Tae Kim
for
Beth A. Wetzel, Senior Project Manager, Section 1
Project Directorate III
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket Nos. 50-266 and 50-301

Enclosure: Request for Additional Information

cc w/encl: See next page

Point Beach Nuclear Plant, Units 1 and 2

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REQUEST FOR ADDITIONAL INFORMATION
LEAK-BEFORE-BREAK SUBMITTAL
POINT BEACH NUCLEAR PLANT, UNITS 1 AND 2

The staff has completed an initial review of the information provided in Wisconsin Electric Power Company's December 2, 1999, submittal requesting approval of leak-before-break (LBB) status for sections of the Point Beach, Units 1 and 2, residual heat removal (RHR) system piping, surge line piping, and accumulator injection line piping. The following questions are based on the reports from Westinghouse Energy Systems (WCAP-15105, WCAP-15065, and WCAP-15107) enclosures to the December 2, 1999, submittal letter.

Section I: Regarding WCAP-15107 on Accumulator Injection Line Piping LBB

(1) Clarify the information in Table 3-5. It appears that there are two entries for Type 316 stainless steel @ 600 °F. What does each entry signify?

(2) Confirm that the analyses in WCAP-15107 bound all of the nodal locations identified in Figures 3-1 thru 3-4.

(3) In Section 4.1, equation 4-2, the torsional loads (M_x) have been left out of the moment summation. The LBB procedural guidance in NUREG-1061, Volume 3 (see Section 5.4), requires that these loads be conservatively included in the moment summation. It may be that these loads are insignificant in comparison to the other loads on this piping. If so, note that this is the case and provide some bounding value for M_x that would adequately cover all of the nodal locations in this piping system.

Section II: Regarding WCAP-15105 on RHR System Piping LBB

(1) In Section 4.1, equation 4-2, the torsional loads (M_x) have been left out of the moment summation. The LBB procedural guidance in NUREG-1061, Volume 3 (see Section 5.4) requires that these loads be conservatively included in the moment summation. It may be that these loads are insignificant in comparison to the other loads on this piping. If so, note that this is the case and give some bounding value for M_x that would adequately cover all of the nodal locations in this piping system.

(2) Confirm that the analyses in the WCAP bound all of the nodal locations identified in Figures 3-1 and 3-2 and that the LBB approval is intended to apply to all of the depicted piping.

(3) For Tables 4-1 and 4-2, provide the normal (used to determine the leakage flaw size) and faulted (used to determine the critical flaw size) loading conditions (with and without the inclusion of the thermal stratification stresses) for each nodal location in Figures 4-1 and 4-2. It is understood that for some nodal locations, thermal stratification stresses may

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not apply. Therefore, only having a Table 4-1 entry for those locations would be sufficient. If it is not practical to include the loads for every nodal location, provide the appropriate loads for the 10 highest stressed locations. Confirm that the information for the node with the highest ratio of:

> (the loads determining the critical flaw size)-to-(the loads determining the leakage flaw size)

is included in the 10 highest stressed locations.

<u>Section III: Regarding WCAP-15065 on Surge Line Piping LBB</u>

(1) In Section 4.1, equation 4-2, the torsional loads (M_x) have been left out of the moment summation. The LBB procedural guidance in NUREG-1061, Volume 3 (see Section 5.4) requires that these loads be conservatively included in the moment summation. It may be that these loads are insignificant in comparison to the other loads on this piping. If so, note that is the case and give some bounding value for M_x that would adequately cover all of the nodal locations in this piping system.

(2) For Table 4-4, provide the case A through G loading conditions for each nodal location in Figure 4-1. It is understood that for some nodal locations, not all of the loading cases may apply. If it is not practical to include the loads for every nodal location, provide the appropriate loads for the three highest stressed locations. Confirm that the information for the node with the highest ratio of:

> (the loads determined for Case F)-to-(the loads determined for Case B)

is included in the three highest stressed locations.

SECTION D

RAI RESPONSES

Subject: Response to NRC Verbal and written RAI on Point Beach Leak-Before-Break (LBB) Reports - WCAP-15065, WCAP-15105 and WCAP-15107.

We have received a verbal and a written RAI from the NRC staff on the information contained in the Point Beach Leak-Before-Break (LBB) Reports - WCAP-15065, WCAP-15105 and WCAP-15107. RAI responses are included in this letter.

In regard to the Highest Stressed Location (critical location):

LBB analyses for the Point Beach Pressurizer Surge lines, RHR lines and Accumulator lines were performed using the criteria of NUREG1061 Volume 3 and draft SRP 3.6.3 and the analyses were documented in WCAP-15065, WCAP-15105 and WCAP-15107. The criteria of NUREG1061 Volume 3 and draft SRP 3.6.3 requires that the critical location(s) be identified at which the highest faulted stress occurs. Accordingly the loads were provided at the highest faulted stress location(s) in WCAP-15065, WCAP-15105 and WCAP-15107.

However as requested, loads at location(s) other than the critical location(s) are included in this letter for your information. We believe it is not necessary to include these locations in the WCAP reports because failure is more likely to occur at the highest stressed location.

In regard to Torsional Moment:

Torsional moments are not addressed in the analyses, because torsional failure is a different failure Mode (Mode 3) than the opening mode of failure (Mode 1) addressed in the WCAPs . The fracture resistance in torsion is much higher than the fracture resistance in the opening mode. It is technically incorrect to combine Mode 1 and Mode 3 loadings, unless higher toughness is used for the combined loadings. This is consistent with all the LBB analyses performed by Westinghouse.

However as requested, normal (by algebraic summation method) and faulted (by absolute summation method) combined moments (including torsion) are provided in this letter for your information for a location which has the highest combined faulted Moment (M).

Moment (M) is combined as follows:

$$M= (M_1^2+M_2^2+M_3^2)^{0.5}$$

Where M_1 and M_2 are the transverse bending moments and M_3 is the torsional moment.

In regard to Loads for the location(s) at which the highest ratio between the faulted stress over the normal stress occurs:

The highest ratio of the faulted stress to the normal stress may occur at a location(s) [typically with low stress] other than the highest stressed location. All LBB analyses were performed consistent with the criteria of NUREG1061 Volume 3 and draft SRP 3.6.3 and for the highest faulted stress location(s) and not at the location at which the highest ratio of the faulted stress to the normal stress occurs, which typically corresponds to low normal stress.

However as requested, loads at the location (s) where the highest ratio of the faulted stress to normal stress occurs are provided for your information.

In summary we feel that the WCAP reports of the Point Beach Units 1 and 2 Pressurizer Surge lines, RHR lines and Accumulator lines LBB analyses have complied with both the intent and specific requirements of NUREG1061 Volume 3 and draft SRP 3.6.3. The data in this letter is provided for your information.

Section I: Regarding WCAP-15107 on Accumulator Injection Line Piping LBB

Question I-1:
Provide Tables 5-1, 5-2 and 7-1 in a non-proprietary and Table 5-3 in a proprietary form

Response I-1: The information is provided below. Flaw size, J_{IC} and J applied values in Table 5-3 are kept as proprietary, information within the proprietary bracket is not shown below and they are the same as given in WCAP-15107.

Table 5-1 Leakage Flaw Size

Node	Temperature (°F)	Crack Length (in) (for 10 gpm leakage)
380	547	3.80
340	547	4.35
310	105	4.50
165	105	10.20
5	105	5.60
225	105	7.40

Table 5-2 Summary of Critical Flaw Size

Node	Temperature (°F)	Critical Flaw Size (in.)
380	547	11.94
340	547	12.92
310	105	14.23
165	105	19.05
5	105	15.12
225	105	17.50

Table 5-3 Stability Result for Node 165 Based on J-Integral Evaluation

Node Point	Flaw Size (in.)	J_{IC} (in-lb/in^2)	J Applied (in-lb/in^2)
165	[		]^{a,c,e}

Table 7-1 Leakage Flaw Sizes, Critical Flaw Sizes and Margins			
Node Point	Critical Flaw Sizes (in)	Leakage Flaw Sizes (in)	Margins
380	11.94	3.80	3.1
340	12.92	4.35	3.0
310	14.23	4.50	3.2
165	20.40	10.20	>2.0[1]
5	15.12	5.60	2.7
225	17.50	7.40	2.4

[1] Based on J-integral approach.

Question I-2:
Clarify the information in Table 3-5. It appears that there are two entries for Type 316 stainless steel @ 600 °F. What does each entry signify?

Response I-2:
Two entries for Type 316 stainless steel @ 600 °F are provided, one for the minimum value and other for the maximum value. These values are based on the tests performed by Westinghouse and the values are taken from WCAP-9558 Revision 2.

Question I-3:
Confirm that the analyses in WCAP-15107 bound all of the nodal locations identified in Figures 3-1 thru 3-4.

Response I-3:
We confirm that that the analyses in WCAP-15107 bound all of the nodal locations identified in Figures 3-1 thru 3-4.

Question I-4:
In Section 4.1 equation 4-2, the torsional loads (M_x) have been left out of the moment summation. The LBB procedural guidance in NUREG-1061, Volume 3 (see Section 5.4), requires that these loads be conservatively included in the moment summation. It may be that these loads are insignificant in comparison to the other loads on this piping. If so, note that this is the case and provide some bounding value for M_x that would adequately cover all of the nodal locations in this piping system.

Response I-4:
Due to the complexity of the piping layout, torsional moment at a given location may or may not be insignificant in comparison to the other load component at the same location on this piping system. We have combined torsion with bending moments at all the locations and found that the highest combined faulted moment (M) occurs at Node 380. Therefore, loads (including torsion) at Node 380 are provided below. It can be noted that Node 380 is also one of the highest stressed locations for which LBB analyses were performed.

Loads at the location with the highest combined faulted moment (M)

		Normal		Faulted	
Node	Location	Axial Force (lb)	Moment (M) (in-lbs)	Axial Force (lb)	Moment (M) (in-lbs)
380	Unit 1 Tank B	104875	678603	153189	763369

He following additional information was provided based on a verbal request.

Normal (by algebraic summation method) and faulted (by absolute summation method) combined moment, M (including torsion) are provided for the locations requested by the NRC. Normal and faulted axial forces are also included.

Moment, M is combined as follows:

$$M = (M_1^2 + M_2^2 + M_3^2)^{0.5}$$

Where M_1 and M_2 are the transverse bending moments and M_3 is the torsional moment.

		Normal		Faulted	
Node	Location	Axial Force (lb)	Moment (M) (in-lbs)	Axial Force (lb)	Moment (M) (in-lbs)
10	Unit 1 Tank A	129657	231985	130884	360123
110	Unit 1 Tank A	110047	34191	112158	267360
165	Unit 1 Tank A	47377	23166	49187	217415
225	Unit 1 Tank A	57069	23112	58418	137426
5	Unit 1 Tank B	37747	139237	38537	291400
175	Unit 1 Tank B	38738	60255	40850	196545
310	Unit 1 Tank B	90929	496610	134417	565332
340	Unit 1 Tank B	89113	564670	132777	640210
380	Unit 1 Tank B	104875	678603	153189	763369
400	Unit 1 Tank B	104382	630326	153682	756637

SECTION E

WCAP-15108-NP-A Revision 1 Text

WCAP-15108-NP-A
Revision 1

Technical Justification for Eliminating Accumulator Rupture as the Structural Design Basis for Point Beach Units 1 and 2 Nuclear Plants

D. C. Bhowmick
C. K. Ng
A. T. Paterson

June 2001

Verified: J. F. Petsche
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Added page vii. Revised cover page, page 1-2, Table 5-1, Table 5-2, Table 5-3 and Table 7-1. A bar in the column on the right identifies the revisions.

1 INTRODUCTION

1.1 BACKGROUND

The current structural design basis for the accumulator lines requires postulating non-mechanistic circumferential and longitudinal pipe breaks. This results in additional plant hardware (e.g. pipe whip restraints and jet shields) which would mitigate the dynamic consequences of the pipe breaks. It is, therefore, highly desirable to be realistic in the postulation of pipe breaks for the accumulator lines. Presented in this report are the descriptions of a mechanistic pipe break evaluation method and the analytical results that can be used for establishing that a circumferential type break will not occur within the accumulator lines. The evaluations considering circumferentially oriented flaws cover longitudinal cases.

1.2 SCOPE AND OBJECTIVE

The purpose of this investigation is to demonstrate leak-before-break for the accumulator lines. The scope of this work covers the accumulator lines from the cold leg to the accumulator tanks and the connecting 10-inch lines to the containment penetration. Schematic drawings of the piping system are shown in Section 3.0. The recommendations and criteria proposed in SRP 3.6.3 (Reference 1-1) are used in this evaluation. The criteria and the resulting steps of the evaluation procedure can be briefly summarized as follows:

1. Calculate the applied loads. Identify the location at which the highest stress occurs.

2. Identify the materials and the material properties.

3. Postulate a surface flaw at the governing location. Determine fatigue crack growth. Show that a through-wall crack will not result.

4. Postulate a through-wall flaw at the governing location. The size of the flaw should be large enough so that the leakage is assured of detection with margin using the installed leak detection equipment when the pipe is subjected to normal operating loads. A margin of 10 is demonstrated between the calculated leak rate and the leak detection capability.

5. Using maximum faulted loads, demonstrate that there is a margin of at least 2 between the leakage size flaw and the critical size flaw.

6. Review the operating history to ascertain that operating experience has indicated no particular susceptibility to failure from the effects of corrosion, water hammer or low and high cycle fatigue.

7. For the materials types used in the plants provide representative material properties.

The leak rate is calculated for the normal operating condition. The leak rate prediction model used in this evaluation is an [isentropic equilibrium model by Fauske-Henry with Griffith modification which adds the frictional pressure drop upstream of the choked exit plane]^{a,c,e}. The crack opening area required for calculating the leak rates is obtained by subjecting the postulated through-wall flaw to normal operating loads (Reference 1-2). Surface roughness is accounted for in determining the leak rate through the postulated flaw.

The computer codes used in this evaluation for leak rate and fracture mechanics calculations have been validated (bench marked).

1.3 REFERENCES

1-1 Standard Review Plan; public comments solicited; 3.6.3 Leak-Before-Break Evaluation Procedures; Federal Register/Vol. 52, No. 167/Friday, August 28, 1987/Notices, pp. 32626-32633.

1-2 NUREG/CR-3464, 1983, "The Application of Fracture Proof Design Methods Using Tearing Instability Theory to Nuclear Piping Postulating Circumferential Through Wall Cracks."

2 OPERATION AND STABILITY OF THE ACCUMULATOR LINES AND THE REACTOR COOLANT SYSTEM

2.1 STRESS CORROSION CRACKING

The Westinghouse reactor coolant system primary loop and connecting Class 1 lines have an operating history that demonstrates the inherent operating stability characteristics of the design. This includes a low susceptibility to cracking failure from the effects of corrosion (e.g., intergranular stress corrosion cracking, IGSCC). This operating history totals over 900 reactor-years, including five plants each having over 20 years of operation and 15 other plants each with over 15 years of operation.

In 1978, the United States Nuclear Regulatory Commission (USNRC) formed the second Pipe Crack Study Group. (The first Pipe Crack Study Group established in 1975 addressed cracking in boiling water reactors only.) One of the objectives of the second Pipe Crack Study Group (PCSG) was to include a review of the potential for stress corrosion cracking in Pressurized Water Reactors (PWR's). The results of the study performed by the PCSG were presented in NUREG-0531 (Reference 2-1) entitled "Investigation and Evaluation of Stress Corrosion Cracking in Piping of Light Water Reactor Plants." In that report the PCSG stated:

> "The PCSG has determined that the potential for stress-corrosion cracking in PWR primary system piping is extremely low because the ingredients that produce IGSCC are not all present. The use of hydrazine additives and a hydrogen overpressure limit the oxygen in the coolant to very low levels. Other impurities that might cause stress-corrosion cracking, such as halides or caustic, are also rigidly controlled. Only for brief periods during reactor shutdown when the coolant is exposed to the air and during the subsequent startup are conditions even marginally capable of producing stress-corrosion cracking in the primary systems of PWRs.
>
> Operating experience in PWRs supports this determination. To date, no stress-corrosion cracking has been reported in the primary piping or safe ends of any PWR."

During 1979, several instances of cracking in PWR feedwater piping led to the establishment of the third PCSG. The investigations of the PCSG reported in NUREG-0691 (Reference 2-2) further confirmed that no occurrences of IGSCC have been reported for PWR primary coolant systems.

As stated above, for the Westinghouse plants there is no history of cracking failure in the reactor coolant system loop or connecting Class 1 piping. The discussion below further qualifies the PCSG's findings.

For stress corrosion cracking (SCC) to occur in piping, the following three conditions must exist simultaneously: high tensile stresses, susceptible material, and a corrosive environment. Since some residual stresses and some degree of material susceptibility exist in any stainless steel piping, the potential for stress corrosion is minimized by properly selecting a material immune to SCC as well as preventing the occurrence of a corrosive environment. The material specifications consider compatibility with the system's operating environment (both internal and external) as well as other material in the system, applicable ASME Code rules, fracture toughness, welding, fabrication, and processing.

The elements of a water environment known to increase the susceptibility of austenitic stainless steel to stress corrosion are: oxygen, fluorides, chlorides, hydroxides, hydrogen peroxide, and reduced forms of sulfur (e.g., sulfides, sulfides, and thionates). Strict pipe cleaning standards prior to operation and careful control of water chemistry during plant operation are used to prevent the occurrence of a corrosive environment. Prior to being put into service, the piping is cleaned internally and externally. During flushes and preoperational testing, water chemistry is controlled in accordance with written specifications. Requirements on chlorides, fluorides, conductivity, and pH are included in the acceptance criteria for the piping.

During plant operation, the reactor coolant water chemistry is monitored and maintained within very specific limits. Contaminant concentrations are kept below the thresholds known to be conducive to stress corrosion cracking with the major water chemistry control standards being included in the plant operating procedures as a condition for plant operation. For example, during normal power operation, oxygen concentration in the RCS and connecting Class 1 lines is expected to be in the ppb range by controlling charging flow chemistry and maintaining hydrogen in the reactor coolant at specified concentrations. Halogen concentrations are also stringently controlled by maintaining concentrations of chlorides and fluorides within the specified limits. This is assured by controlling charging flow chemistry. Thus during plant operation, the likelihood of stress corrosion cracking is minimized.

2.2 WATER HAMMER

Overall, there is a low potential for water hammer in the RCS and connecting accumulator lines since they are designed and operated to preclude the voiding condition in normally filled lines. The RCS and connecting accumulator lines including piping and components, are designed for normal, upset, emergency, and faulted condition transients. The design requirements are conservative relative to both the number of transients and their severity. Relief valve actuation and the associated hydraulic transients following valve opening are considered in the system design. Other valve and pump actuations are relatively slow transients with no significant effect on the system dynamic loads. To ensure dynamic system stability, reactor coolant parameters are stringently controlled. Temperature during normal operation is maintained within a narrow range by control rod position; pressure is controlled by pressurizer heaters and pressurizer spray also within a narrow range for steady-state conditions. The flow characteristics of the system remain constant during a fuel cycle because the only governing parameters, namely system resistance and the reactor coolant pump characteristics are controlled in the design process. Additionally, Westinghouse has instrumented typical reactor coolant systems to verify the flow and vibration characteristics of the system and connecting accumulator lines. Preoperational testing and operating experience have verified the Westinghouse approach. The operating transients of the RCS primary piping and connected accumulator lines are such that no significant water hammer can occur.

2.3 LOW CYCLE AND HIGH CYCLE FATIGUE

Low cycle fatigue considerations are accounted for in the design of the piping system through the fatigue usage factor evaluation to show compliance with the rules of Section III of the ASME Code. A further assessment of the low cycle fatigue loading is discussed in Section 6.0 as part of this study in the form of a fatigue crack growth analysis.

Pump vibrations during operation would result in high cycle fatigue loads in the piping system. During operation, an alarm signals the exceedance of the RC pump shaft vibration limits. Field measurements have been made on the reactor coolant loop piping in a number of plants during hot functional testing. Stresses in the elbow below the RC pump have been found to be very small, between 2 and 3 ksi at the highest. Field measurements on typical PWR plants indicate vibration amplitudes less than 1 ksi. When translated to the connecting accumulator line, these stresses would be even lower, well below the fatigue endurance limit for the accumulator line material and would result in an applied stress intensity factor below the threshold for fatigue crack growth.

2.4 POTENTIAL DEGRADATION DURING SERVICE

There has never been any service cracking or wall thinning identified in accumulator lines of Westinghouse PWR design. Sources of such degradation are mitigated by the design, construction, inspection, and operation of the accumulator lines.

Wall thinning by erosion and erosion-corrosion effects will not occur in the accumulator lines due to the low velocity, typically less than 10 ft/sec and the material, austenitic stainless steel, which is highly resistant to these degradation mechanisms. Per NUREG-0691 [Reference 2-2], a study of pipe cracking in PWR piping, only two incidents of wall thinning in stainless steel pipe were reported. One incident was related to the accumulator system. However, this occurred in the pump recirculation path which has higher flow velocity and is more susceptible to other contributing factors such as cavitation, than the accumulator piping near the primary loop. Therefore, wall thinning is not a significant concern in the portion of the system being addressed in this evaluation.

The Point Beach Units 1 and 2 accumulator lines piping and associated fittings are forged product forms which are not susceptible to toughness degradation due to thermal aging.

The maximum normal operating temperature of the accumulator piping is about 600°F. This is well below the temperature which would cause any creep damage in stainless steel piping.

2.5 REFERENCES

2-1 Investigation and Evaluation of Stress-Corrosion Cracking in Piping of Light Water Reactor Plants, NUREG-0531, U.S. Nuclear Regulatory Commission, February 1979.

2-2 Investigation and Evaluation of Cracking Incidents in Piping in Pressurized Water Reactors, NUREG-0691, U.S. Nuclear Regulatory Commission, September 1980.

3 MATERIAL CHARACTERIZATION

3.1 PIPE AND WELD MATERIALS

The pipe materials of the accumulator lines for the Point Beach Units 1 and 2 Nuclear Plants are A376/TP316 and A312/TP304. This is a wrought product form of the type used for the primary loop piping of several PWR plants. The accumulator lines system does not include any cast pipes or cast fittings. The welding processes used are gas tungsten arc (GTAW) and shielded metal arc (SMAW). Figures 3-1 and 3-2 show the schematic layouts of the accumulator lines and identify the weld locations by node points.

In the following sections the tensile properties of the materials are presented for use in the leak-before-break analyses.

3.2 MATERIAL PROPERTIES

Industry data were used as a basis for determining tensile properties. The room temperature mechanical properties of the accumulator lines material were obtained from the Certified Materials Test Reports and are given in Tables 3-1 and 3-2. The representative minimum and average tensile properties were established (see Table 3-2). The material properties at temperatures (105°F and 547°F) are required for the leak rate and stability analyses. The minimum and average tensile properties were calculated by using the ratio of the ASME Code Section III (Reference 3-1) properties at the temperatures of interest stated above. Table 3-3 shows the tensile properties at various temperatures. The modulus of elasticity values were established at various temperatures from the ASME Code Section III (see Table 3-4). In the leak-before-break evaluation, the representative minimum properties at temperature were used for the flaw stability evaluations and the representative average properties were used for the leak rate predictions. The minimum ultimate stresses were used for stability analyses. These properties are summarized in Table 3-3.

3.3 FRACTURE TOUGHNESS PROPERTIES

Series of fracture toughness tests on SA376TP316 pipe material and welds are reported in References 3-2 and 3-3. These data are summarized in Table 3-5. [

]a,c,e

3.4 REFERENCES

3-1 ASME Boiler and Pressure Vessel Code Section III, "Rules for Construction of Nuclear Power Plant Components; Division 1, Appendices," 1989 Edition, July 1, 1989.

3-2 S. S. Palusamy, "Tensile and Toughness Properties of Primary Piping Weld Metal for Use in Mechanistic Fracture Evaluation," WCAP-9787, May 1981 (Westinghouse Proprietary Class 2).

3-3 S. S. Palusamy, et. al., "Mechanistic Fracture Evaluation of Reactor Coolant Pipe Containing a Postulated Circumferential Through-Wall Crack," WCAP-9558, Rev. 2, May 1982, (Westinghouse Proprietary Class 2).

Table 3-1 Room Temperature Mechanical Properties of the Accumulator Lines Materials			
Plant	**Material**	**Yield Strength (psi)**	**Ultimate Strength (psi)**
A	A376/TP316	46800	93800
	A376/TP316	48000	86400
	A376/TP316	45600	87900
	A376/TP316	41300	83200
	A376/TP316	38600	82600
	A376/TP316	44900	84000
B	A376/TP316	59100	84900
	A376/TP316	52100	87400
	A376/TP316	51900	85400
	A376/TP316	48400	84900
	A376/TP316	59100	84900
	A376/TP316	47400	81100
	A376/TP316	47400	81100
	A376/TP316	59100	84900
	A376/TP316	48400	84900
	A376/TP316	48400	84900
	A376/TP316	59100	84900
	A376/TP316	45200	87600
	A376/TP316	51900	85400
	A376/TP316	59100	84900
	A376/TP316	59100	84900
	A376/TP316	59100	84900
	A376/TP316	45200	87600
	A376/TP316	48400	84900
	A376/TP316	47400	81100
	A376/TP316	45200	87600

Table 3-1 Room Temperature Mechanical Properties of the Accumulator Lines Materials (Cont.)

Plant	Material	Yield Strength (psi)	Ultimate Strength (psi)
B	A376/TP316	51900	85400
	A376/TP316	47400	81100
	A376/TP316	47400	81100
	A376/TP316	47400	81100
	A376/TP316	59100	84900
	A376/TP316	59100	84900
	A376/TP316	51900	85400
	A376/TP316	52100	87400
	A376/TP316	47400	81100
	A376/TP316	59100	84900
	A376/TP316	47400	81100
	A376/TP316	51900	85400
	A376/TP316	59100	84900
	A376/TP316	59100	84900
	A376/TP316	48400	84900
	A376/TP316	52100	87400
	A376/TP316	59100	84900
	A376/TP316	47400	81100
	A376/TP316	39200	84200
	A376/TP316	42200	84900
	A376/TP316	39200	84200
	A376/TP316	52100	87400
	A376/TP316	52100	87400
	A376/TP316	52100	87400
	A376/TP316	45200	87600

Table 3-1 Room Temperature Mechanical Properties of the Accumulator Lines Materials (Cont.)

Plant	Material	Yield Strength (psi)	Ultimate Strength (psi)
B	A376/TP316	52100	87400
	A376/TP316	51900	85400
	A376/TP316	48400	84900
C	A376/TP316	43300	85600
	A376/TP316	42700	88200
	A376/TP316	38100	82600
	A376/TP316	43300	85600
	A376/TP316	42700	88200
	A376/TP316	38100	82600
	A376/TP316	40100	83000
	A376/TP316	38100	82600
	A376/TP316	43300	87800
	A376/TP316	44100	88600
	A376/TP316	40100	83000
	A376/TP316	40500	84600
	A376/TP316	44500	81400
	A376/TP316	50250	87400
	A376/TP316	42400	84900
	A376/TP316	42100	89000
	A376/TP316	39700	86200
	A376/TP316	44500	81400
	A376/TP316	44500	81400
D	A376/TP316	42700	88200
	A376/TP316	38100	82600
	A376/TP316	42700	88200
	A376/TP316	38100	82600

Table 3-1 Room Temperature Mechanical Properties of the Accumulator Lines Materials (Cont.)			
Plant	Material	Yield Strength (psi)	Ultimate Strength (psi)
D	A376/TP316	42700	88200
	A376/TP316	46700	92600
	A376/TP316	42700	88200
	A376/TP316	42050	82500
	A376/TP316	44600	85100
	A376/TP316	49100	81200
	A376/TP316	41150	80900
	A376/TP316	49100	81200
	A376/TP316	41150	80900
	A376/TP316	42100	82900
	A376/TP316	51400	91050
	A376/TP316	42050	82500
	A376/TP316	41150	80900
	A376/TP316	49100	81200
	A376/TP316	40100	83000
	A376/TP316	40100	83000
	A376/TP316	40100	83000
	A376/TP316	41100	98400
	A376/TP316	39300	84200
	A376/TP316	41150	80900
	A376/TP316	45150	86600
	A376/TP316	41050	79600
	A376/TP316	41150	80900
	A376/TP316	41050	79600
	A376/TP316	41650	78550
	A376/TP316	41050	79600

Table 3-2 Room Temperature Mechanical Properties of the Accumulator Lines Materials			
Plant	Material	Yield Strength (psi)	Ultimate Strength (psi)
A	A312/TP304	40200	84400
B	A312/TP304	48430	82190
	A312/TP304	48430	82190
	A312/TP304	53460	83000
	A312/TP304	48340	82190
	A312/TP304	53460	83000
	A312/TP304	46300	82190
	A312/TP304	48430	82190
	A312/TP304	48430	82190
	A312/TP304	48430	82190
	A312/TP304	48430	82190
	A312/TP304	48430	82190
	A312/TP304	48430	82190
	A312/TP304	48430	82190
	A312/TP304	48430	82190
C	A312/TP304L	38100	82700
D	A312/TP304	45000	89000
	A312/TP304	43400	82200
	A312/TP304	42800	81800
	A312/TP304	42200	83300
	A312/TP304	43700	82600
	A312/TP304	45000	90000
	A312/TP304	41200	83500
	A312/TP304	41400	82500
	A312/TP304	46300	86500

Table 3-2 Room Temperature Mechanical Properties of the Accumulator Lines Materials (Cont.)

Plant	Material	Yield Strength (psi)	Ultimate Strength (psi)
D	A312/TP304	47000	89900
	A312/TP304	40100	79500
	A312/TP304	41600	83200

Table 3-3 Representative Tensile Properties				
Material	Temperature (°F)	Minimum Yield (psi)	Average Yield (psi)	Minimum Ultimate (psi)
A376/TP316	Room	38,100	46,700	78,550
A376/TP316	105	37,833	46,372	78,550
A376/TP316	547	24,616	30,172	75,199
A312/TP304	Room	38,100	45,852	79,500
A312/TP304	105	37,783	45,470	79,288

Table 3-4 Modulus of Elasticity (E)	
Temperature (°F)	E (ksi)
Room	28,300
105	28,265
547	25,570

Table 3-5 Fracture Toughness Properties			
Material	Test Temp. (°F)	J_{IC} (in-lb/in^2)	T_{mat}
SA376TP316	600	[	]^{a,c,e}
SA376TP316	600	[	]^{a,c,e}
Weld[2]	600	[	]^{a,c,e}

1. The maximum J measured was in excess of [ ]^{a,c,e}.
2. Lowest value from 6 J-R curves. Five SMAW welds and one SAW weld.

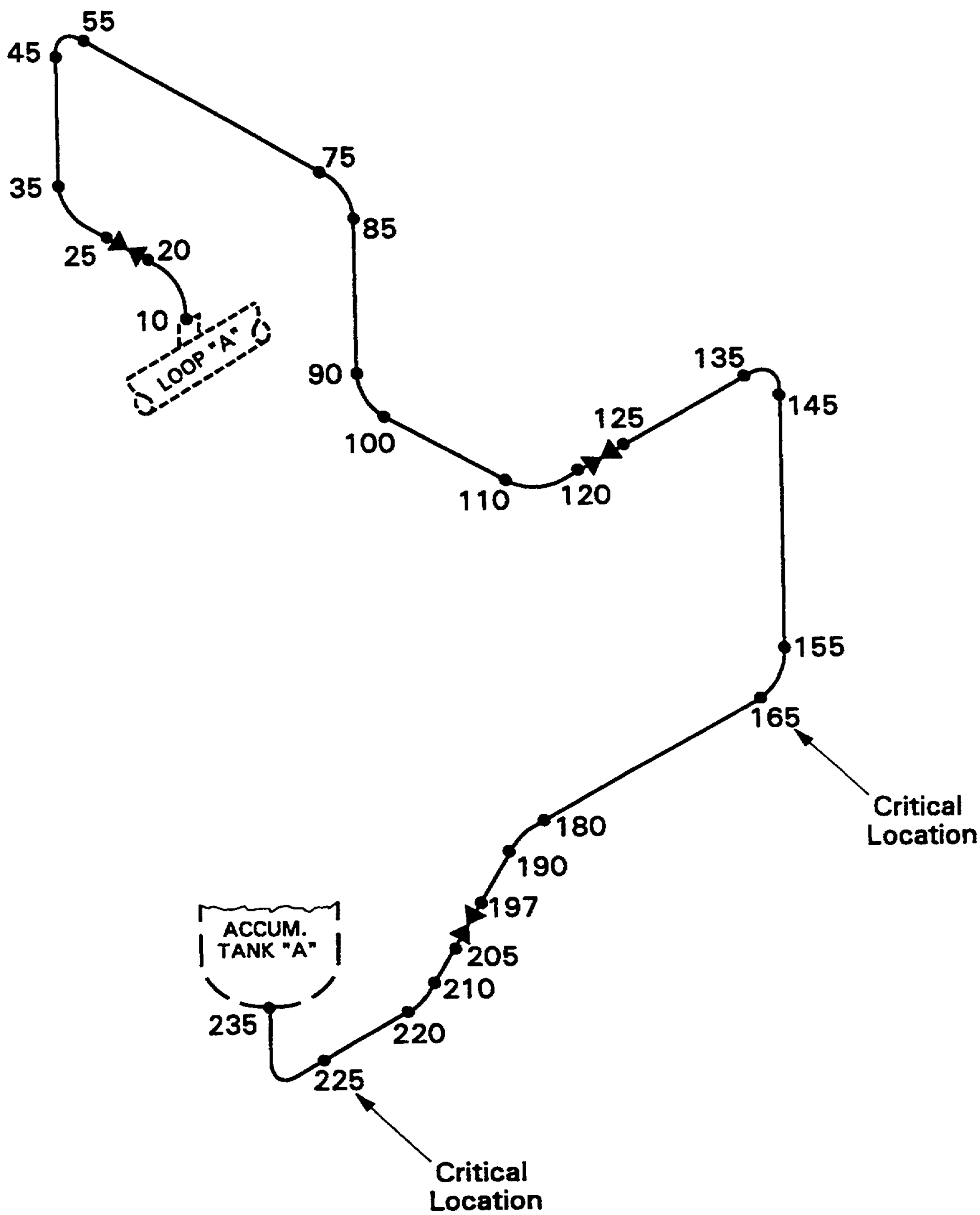

Figure 3-1 Point Beach Unit 1 Accumulator Line Tank A Layout

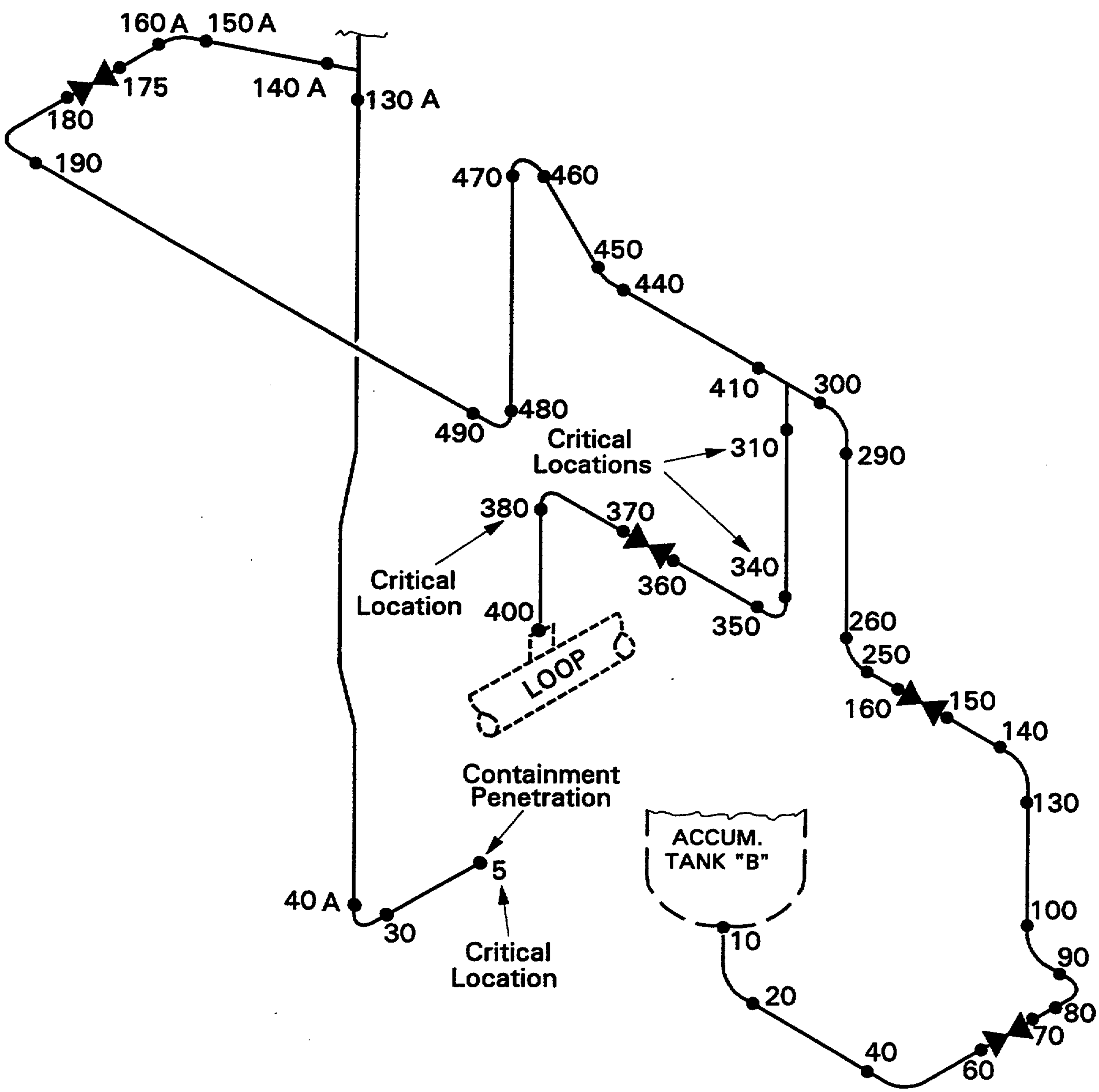

Figure 3-2 Point Beach Unit 1 Accumulator Line Tank B Layout

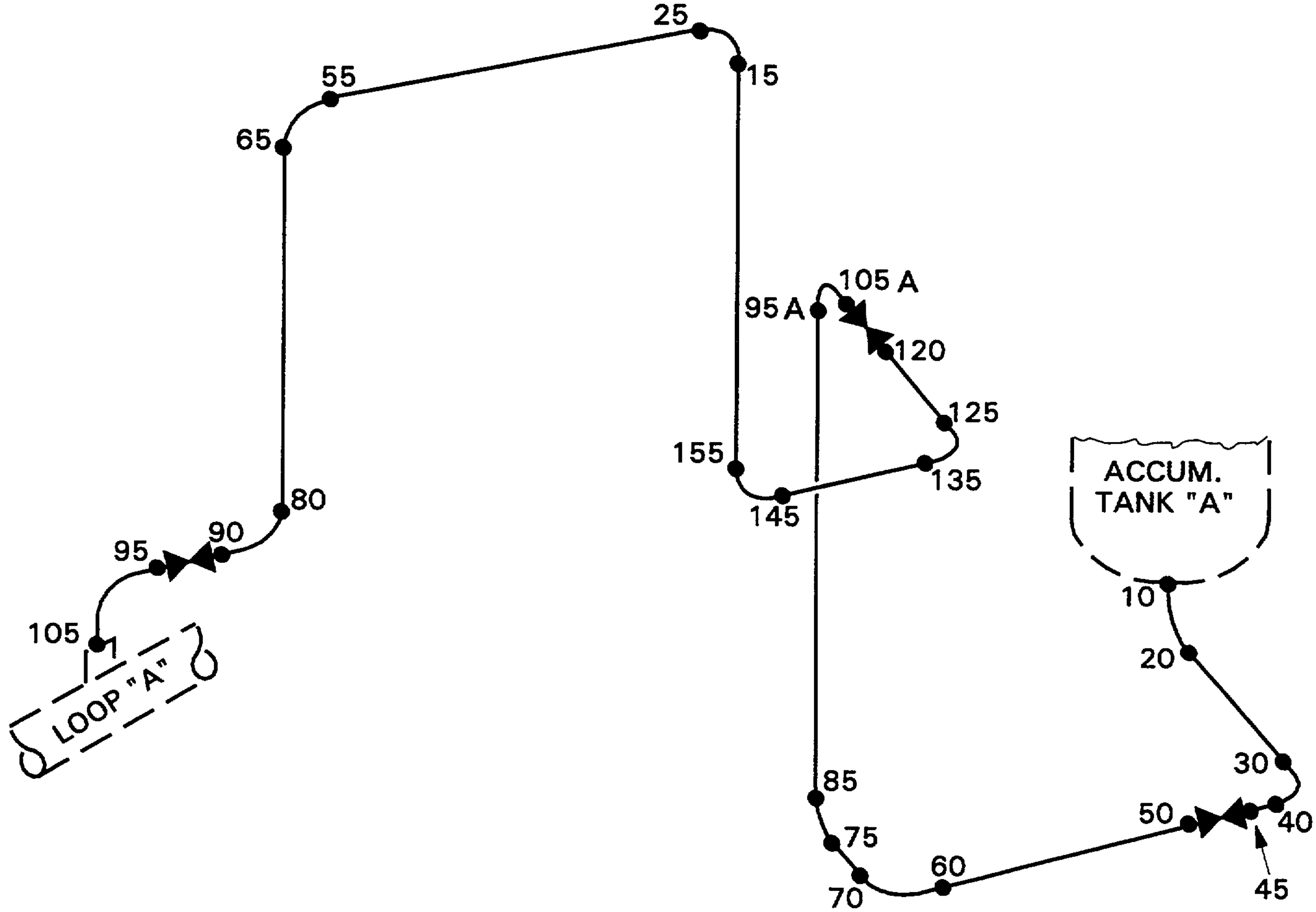

Figure 3-3 Point Beach Unit 2 Accumulator Line Tank A Layout

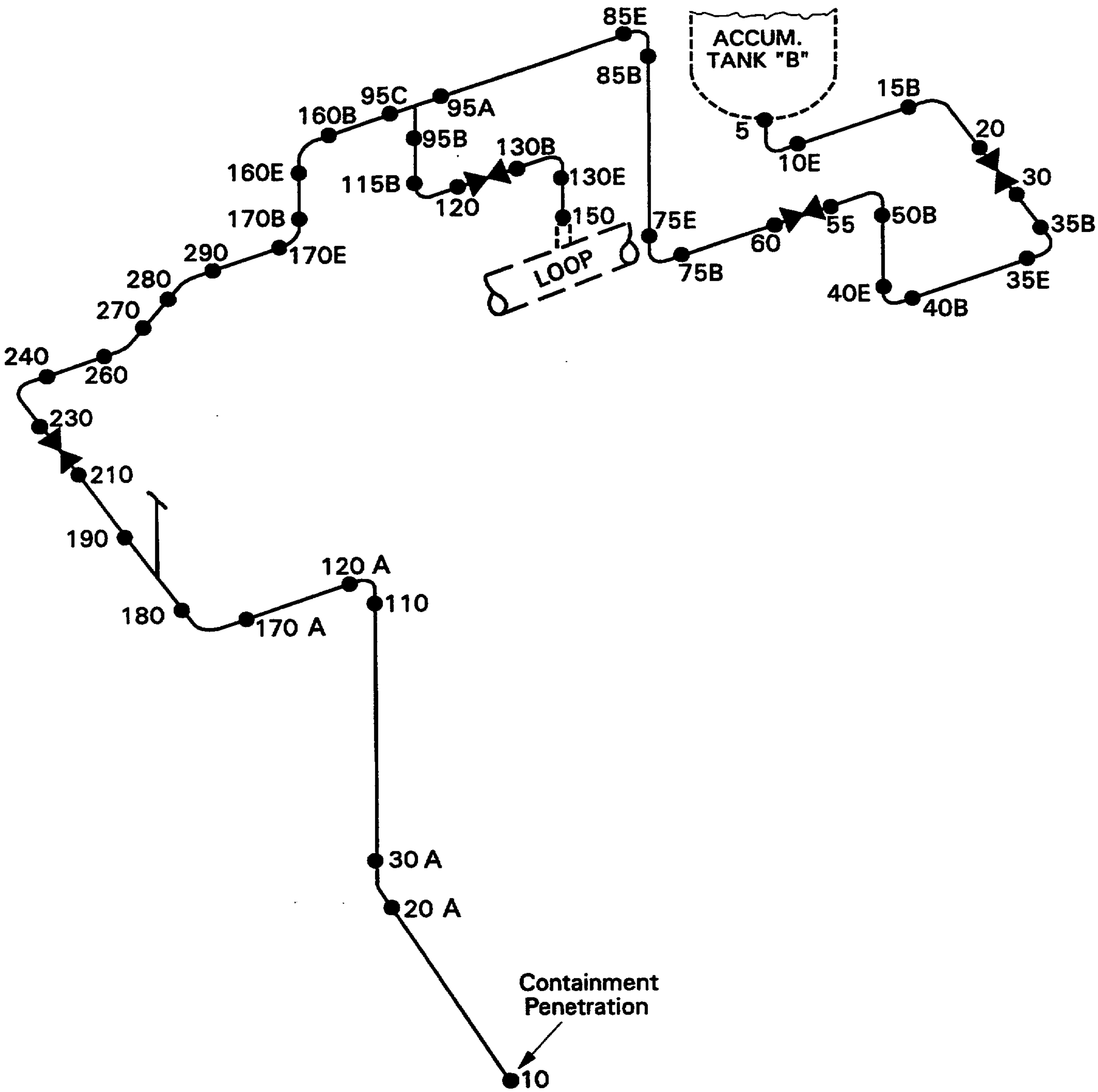

Figure 3-4 Point Beach Unit 2 Accumulator Line Tank B Layout

4 LOADS FOR FRACTURE MECHANICS ANALYSIS

4.1 NATURE OF THE LOADS

Figure 3-1 shows schematic layout of the accumulator lines for Point Beach Unit 1 and identifies the weld locations by node points. Figure 3-2 shows schematic layout of the accumulator lines for Point Beach Unit 2 and identifies the weld locations by node points.

The stresses due to axial loads and bending moments were calculated by the following equation:

$$\sigma = \frac{F}{A} + \frac{M}{Z} \tag{4-1}$$

where,

σ	=	stress
F	=	axial load
M	=	bending moment
A	=	metal cross-sectional area
Z	=	section modulus

The bending moments for the desired loading combinations were calculated by the following equation:

$$M_B = \left(M_Y^2 + M_Z^2\right)^{0.5} \tag{4-2}$$

where,

M_B	=	bending moment for required loading
M_Y	=	Y component of bending moment
M_Z	=	Z component of bending moment

The axial load and bending moments for crack stability analysis and leak rate predictions are computed by the methods to be explained in Sections 4.1 and 4.2 which follow.

4.2 LOADS FOR CRACK STABILITY ANALYSIS

The faulted loads for the crack stability analysis were calculated by the absolute sum method as follows:

$$F = |F_{DW}| + |F_{TH}| + |F_p| + |F_{SSE}| \tag{4-3}$$

$$M_Y = |M_{YDW}| + |M_{Y\,TH}| + |M_{Y\,SSE}| \tag{4-4}$$

$$M_Z = |M_{ZDW}| + |M_{Z\,TH}| + |M_{Z\,SSE}| \tag{4-5}$$

where

DW	=	Deadweight
TH	=	Normal thermal load
P	=	Load due to internal pressure
SSE	=	SSE loading including seismic anchor motion

4.3 LOADS FOR LEAK RATE EVALUATION

The normal operating loads for leak rate predictions were calculated by the algebraic sum method as follows:

$$F = F_{DW} + F_{TH} + F_P \tag{4-6}$$

$$M_Y = (M_Y)_{DW} + (M_Y)_{TH} \tag{4-7}$$

$$M_Z = (M_Z)_{DW} + (M_Z)_{TH} \tag{4-8}$$

The parameters and subscripts are the same as those explained in Section 4.2.

4.4 SUMMARY OF LOADS AND GEOMETRY FOR THE ACCUMULATOR LINES

The load combinations were evaluated at the various weld locations. Normal loads were determined using the algebraic sum method whereas faulted loads were combined using the absolute sum method. Tables 4-1 to 4-4 show normal loads and stresses for Point Beach Units 1 and 2 accumulator lines. Pipe outer diameter and minimum wall thickness are also shown in these tables. Tables 4-5 to 4-8 show the faulted loads and stresses for Point Beach Units 1 and 2 accumulator lines.

4.5 GOVERNING LOCATIONS FOR THE ACCUMULATOR LINES

Figures 3-1 to 3-4 show schematic layouts of the accumulator lines for Point Beach Units 1 and 2 and identify the weld locations.

All the welds at Point Beach accumulator lines are fabricated using the GTAW and SMAW procedures.

The governing locations were established on the basis of the pipe schedules, types of material, operating temperature, operating pressure, and the highest faulted stresses for welds. All four lines for Point Beach Units 1 and 2 were investigated and the following governing locations were identified. These governing locations enveloped all four accumulator lines for Point Beach Units 1 and 2 for the LBB analyses.

Material	Pipe (10") Schedule	Temperature (°F)	Pressure (psia)	Node Point	Tank	Unit
A376/TP316	140	547	2035	380	B	1
A376/TP316	140	547	1745	340	B	1
A376/TP316	140	105	1745	310	B	1
A376/TP316	140	105	750	165	A	1
A312/TP304	40	105	480	5	B	1
A312/TP304	80S	105	750	225	A	1

The governing locations have been indicated in the layout sketches 3-1 and 3-2.

Table 4-1 Summary of Normal Loads and Stresses for Unit 1 Accumulator Line Tank A					
Node Point[1] (Location)	Outside Diameter (in)	Min. Wall Thickness (in)	Axial[2] (lbs)	Bending Moment (in-lbs)	Total Stress (psi)
10	10.75	0.896	129722	239895	8479
20	10.75	0.896	129809	108339	6398
25	10.75	0.896	111529	199960	7190
35	10.75	0.896	110949	127095	6015
45	10.75	0.896	111765	178666	6862
55	10.75	0.896	108480	262788	8076
75	10.75	0.896	108482	158407	6422
85	10.75	0.896	110881	135348	6144
90	10.75	0.896	109692	267446	8193
100	10.75	0.896	108482	321078	8999
110	10.75	0.896	110044	22102	4319
120	10.75	0.896	109905	49251	4744
125	10.75	0.896	47181	60327	2657
135	10.75	0.896	47181	20588	2028
145	10.75	0.896	45621	41136	2297
155	10.75	0.896	44190	28712	2049
165	10.75	0.896	47377	22401	2064
180	10.75	0.896	47377	3807	1769
190	10.75	0.896	47377	14206	1934
197	10.75	0.896	47378	5638	1798
205	10.75	0.458	57064	35137	4815
210	10.75	0.458	57064	30003	4674
220	10.75	0.458	57063	16072	4293
225	10.75	0.458	57063	11269	4162
235	10.75	0.458	57907	30578	4747

[1] See Figure 3-1

[2] Includes Pressure

Table 4-2 Summary of Normal Loads and Stresses for Unit 1 Accumulator Line Tank B					
Node Point[1] (Location)	Outside Diameter (in)	Min. Wall Thickness (in)	Axial [2] (lbs)	Bending Moment (in-lbs)	Total Stress (psi)
10	10.75	0.458	56906	12719	4191
20	10.75	0.458	57650	24995	4577
40	10.75	0.458	57650	27032	4633
60	10.75	0.458	56924	21480	4432
70	10.75	0.896	47237	32649	2221
80	10.75	0.896	47237	28590	2157
90	10.75	0.896	46593	22536	2038
100	10.75	0.896	43301	49002	2338
130	10.75	0.896	45729	85180	2999
140	10.75	0.896	46594	77283	2905
150	10.75	0.896	46593	31482	2179
160	10.75	0.896	109317	37594	4539
250	10.75	0.896	111700	114257	5839
260	10.75	0.896	124160	312480	9428
290	10.75	0.896	125787	266062	8752
300	10.75	0.896	111700	305011	8861
310	10.75	0.896	90929	486598	10988
340	10.75	0.896	89113	555885	12020
350	10.75	0.896	105932	289593	8408
360	10.75	0.896	105935	243830	7684
370	10.75	0.896	124207	338061	9835
380	10.75	0.896	104875	663421	14292
400	10.75	0.896	104382	613951	13491
410	10.75	0.896	115773	408438	10646
440	10.75	0.896	115771	150208	6555

Table 4-2 Summary of Normal Loads and Stresses for Unit 1 Accumulator Line Tank B (Cont.)

Node Point[1] (Location)	Outside Diameter (in)	Min. Wall Thickness (in)	Axial [2] (lbs)	Bending Moment (in-lbs)	Total Stress (psi)
450	10.75	0.896	113025	59320	5017
460	10.75	0.896	113025	113157	5869
470	10.75	0.896	117015	246248	8122
480	10.75	0.896	116402	117204	6055
490	10.75	0.896	115771	128947	6219
5	10.75	0.340	38126	139233	8392
30	10.75	0.340	38126	26969	4390
40A	10.75	0.340	37879	32029	4548
130A	10.75	0.340	39954	21909	4374
140A	10.75	0.340	38763	7744	3762
150A	10.75	0.340	38763	10553	3862
160A	10.75	0.340	38738	12241	3920
175	10.75	0.340	38738	59006	5587
180	10.75	0.896	110512	34301	4530
190	10.75	0.896	109673	48490	4724

[1] See Figure 3-2
[2] Includes Pressure

Table 4-3 Summary of Normal Loads and Stresses for Unit 2 Accumulator Line Tank A					
Node Point[1] (Location)	Outside Diameter (in)	Min. Wall Thickness (in)	Axial[2] (lbs)	Bending Moment (in-lbs)	Total Stress (psi)
15	10.75	0.896	112372	121769	5982
25	10.75	0.896	112543	51753	4879
55	10.75	0.896	112542	207715	7350
65	10.75	0.896	111910	172360	6767
80	10.75	0.896	110985	295038	8677
90	10.75	0.896	112543	153026	6484
95	10.75	0.896	130823	169971	7411
105	10.75	0.896	131087	375601	10678
10	10.75	0.540	55598	9468	3435
20	10.75	0.540	54586	4815	3266
30	10.75	0.540	54586	30075	3866
40	10.75	0.540	54688	28253	3828
45	10.75	0.540	54767	41412	4145
50	10.75	0.896	46961	16547	1956
60	10.75	0.896	46964	14971	1931
70	10.75	0.896	47774	7347	1840
75	10.75	0.896	47774	13050	1930
85	10.75	0.896	47579	15365	1960
95A	10.75	0.896	44209	76471	2806
105A	10.75	0.896	46785	39538	2314
120	10.75	0.896	109508	16833	4217
125	10.75	0.896	109508	34653	4499
135	10.75	0.896	109687	15755	4206
145	10.75	0.896	109687	29866	4430
155	10.75	0.896	109812	48744	4733

[1] See Figure 3-3

[2] Includes Pressure

Table 4-4 Summary of Normal Loads and Stresses for Unit 2 Accumulator Line Tank B					
Node Point[1] (Location)	Outside Diameter (in)	Min. Wall Thickness (in)	Axial[2] (lbs)	Bending Moment (in-lbs)	Total Stress (psi)
5	10.75	0.540	55812	6078	3367
10E	10.75	0.540	55688	27665	3872
15B	10.75	0.540	55688	27271	3863
20	10.75	0.540	54989	19695	3642
30	10.75	0.896	47187	9786	1857
35B	10.75	0.896	47187	18661	1998
35E	10.75	0.896	46673	24345	2069
40B	10.75	0.896	46673	61654	2660
40E	10.75	0.896	46867	60432	2648
50B	10.75	0.896	49121	59757	2718
55	10.75	0.896	46673	38229	2289
60	10.75	0.896	109396	11015	4120
75B	10.75	0.896	109396	23109	4312
75E	10.75	0.896	110766	10910	4168
85B	10.75	0.896	110232	6309	4076
85E	10.75	0.896	109450	20575	4274
95A	10.75	0.896	109450	48273	4713
95C	10.75	0.896	109217	66680	4996
95B	10.75	0.896	111729	19488	4339
115B	10.75	0.896	109751	20050	4276
120	10.75	0.896	109771	16712	4224
130B	10.75	0.896	128052	17575	4897
130E	10.75	0.896	126237	42389	5225
150	10.75	0.896	125793	34358	5082
160B	10.75	0.896	109217	15192	4180
160E	10.75	0.896	109910	3376	4018
170B	10.75	0.896	109116	49764	4724
170E	10.75	0.896	109217	45555	4661

Table 4-4 Summary of Normal Loads and Stresses for Unit 2 Accumulator Line Tank B (Cont.)					
Node Point[1] (Location)	Outside Diameter (in)	Min. Wall Thickness (in)	Axial[2] (lbs)	Bending Moment (in-lbs)	Total Stress (psi)
10	10.75	0.340	38139	24884	4317
20A	10.75	0.340	38139	7506	3698
30A	10.75	0.340	38174	6633	3670
110	10.75	0.340	40255	26647	4570
120A	10.75	0.340	38299	10723	3827
170A	10.75	0.340	38298	29847	4508
180	10.75	0.340	38233	7035	3689
190	10.75	0.340	38004	26996	4380
210	10.75	0.340	38004	79385	6248
230	10.75	0.896	109777	47737	4716
240	10.75	0.896	109879	36733	4545
260	10.75	0.896	109880	16343	4222
270	10.75	0.896	109756	21136	4294
280	10.75	0.896	109756	22954	4323
290	10.75	0.896	109880	22746	4324

[1] See Figure 3-4

[2] Includes Pressure

Table 4-5 Summary of Faulted Loads and Stresses for Unit 1 Accumulator Line Tank A			
Node Point[1] (Location)	Axial[2] (lbs)	Bending Moment (in-lbs)	Total Stress (psi)
10	130974	363407	10481
20	130421	173460	7452
25	112065	205756	7302
35	114169	198930	7269
45	114783	235168	7866
55	111844	281936	8500
75	111816	168126	6696
85	111945	153402	6468
90	113190	343729	9528
100	112166	371202	9926
110	112202	266622	8271
120	111919	235527	7768
125	49215	192461	4824
135	49273	155759	4245
145	50257	194135	4888
155	51806	144321	4155
165	49187	204867	5019
180	48905	82785	3075
190	49041	124016	3733
197	49056	117009	3623
205	59012	103190	6808
210	59022	83571	6272
220	58443	74845	5994
225	58447	134206	7619
235	59091	72295	5968

[1] See Figure 3-1
[2] Includes Pressure

Table 4-6 Summary of Faulted Loads and Stresses for Unit 1 Accumulator Line Tank B			
Node Point[1] (Location)	Axial[2] (lbs)	Bending Moment (in-lbs)	Total Stress (psi)
10	57962	28905	4705
20	58892	97556	6646
40	58890	72449	5959
60	58420	58304	5540
70	48253	64001	2754
80	48253	65516	2778
90	48547	87418	3136
100	52175	89536	3300
130	49735	124124	3760
140	48436	124170	3714
150	48437	117316	3606
160	111163	113102	5801
250	112436	188033	7034
260	126436	443045	11579
290	126809	310631	9495
300	112224	339086	9419
310	134417	554062	13625
340	132777	630280	14773
350	114590	326916	9312
360	114591	278768	8549
370	132959	365779	10590
380	153189	735195	17172
400	153682	728202	17079
410	116161	462515	11517
440	116293	173824	6948
450	114159	81532	5409
460	114221	143108	6387

Table 4-6 Summary of Faulted Loads and Stresses for Unit 1 Accumulator Line Tank B (Cont.)			
Node Point[1] (Location)	**Axial[2] (lbs)**	**Bending Moment (in-lbs)**	**Total Stress (psi)**
470	117603	280863	8691
480	117274	234550	7946
490	116637	196023	7312
5	38916	290456	13854
30	38926	68093	5928
40A	39405	67617	5954
130A	41594	97792	7227
140A	40405	68051	6060
150A	40441	78605	6439
160A	40828	82421	6610
175	40850	192745	10545
180	112720	203536	7290
190	111801	241359	7856

[1] See Figure 3-2
[2] Includes Pressure

Table 4-7 Summary of Faulted Loads and Stresses for Unit 2 Accumulator Line Tank A

Node Point[1] (Location)	Axial[2] (lbs)	Bending Moment (in-lbs)	Total Stress (psi)
15	115138	172296	6882
25	113761	102309	5724
55	112972	250380	8041
65	112674	215843	7483
80	112077	328719	9250
90	113273	184798	7013
95	131549	196416	7856
105	132539	406142	11214
10	55732	21878	3737
20	56552	9242	3484
30	56546	52619	4514
40	55749	45183	4292
45	56330	63088	4750
50	48102	44159	2435
60	48100	46954	2479
70	48184	46629	2477
75	48142	49302	2517
85	48466	45034	2462
95A	50734	97858	3380
105A	48198	64771	2765
120	111132	35953	4578
125	111132	52077	4834
135	111027	55037	4877
145	111025	98378	5563
155	113026	111954	5850

[1] See Figure 3-3
[2] Includes Pressure

Table 4-8 Summary of Faulted Loads and Stresses for Unit 2 Accumulator Line Tank B			
Node Point[1] (Location)	Axial[2] (lbs)	Bending Moment (in-lbs)	Total Stress (psi)
5	56791	30590	4005
10E	56886	172349	7377
15B	57006	106287	5815
20	57566	87081	5392
30	48867	97878	3313
35B	48619	115248	3579
35E	48281	85482	3096
40B	48115	149499	4104
40E	49506	160045	4321
50B	51159	147907	4188
55	48799	163509	4350
60	111526	138769	6221
75B	111512	219099	7493
75E	113121	163860	6676
85B	110784	17052	4266
85E	110630	29947	4465
95A	110651	112719	5777
95C	110988	109551	5739
95B	113643	74133	5273
115B	111653	55219	4902
120	110391	24529	4370
130B	128682	30970	5132
130E	130609	70156	5822
150	131054	93390	6207
160B	111042	48351	4771
160E	111443	40172	4656
170B	112021	136803	6208

Table 4-8 Summary of Faulted Loads and Stresses for Unit 2 Accumulator Line Tank B (Cont.)			
Node Point[1] (Location)	**Axial[2] (lbs)**	**Bending Moment (in-lbs)**	**Total Stress (psi)**
170E	111133	62714	5002
10	38739	120778	7789
20A	38739	30499	4571
30A	39340	40938	4997
110	40873	79585	6513
120A	39479	47516	5244
170A	38994	86396	6587
180	38795	58957	5591
190	39770	144117	8714
210	39704	134735	8374
230	111513	162753	6600
240	111985	167405	6691
260	111986	91629	5491
270	112446	98490	5616
280	112450	99541	5633
290	111980	82096	5340

[1] See Figure 3-4

[2] Includes Pressure

5 FRACTURE MECHANICS EVALUATION

5.1 GLOBAL FAILURE MECHANISM

Determination of the conditions which lead to failure in stainless steel should be done with plastic fracture methodology because of the large amount of deformation accompanying fracture. One method for predicting the failure of ductile material is the [ ]^{a,c,e} method, based on traditional plastic limit load concepts, but accounting for [ ]^{a,c,e} and taking into account the presence of a flaw. The flawed component is predicted to fail when the remaining net section reaches a stress level at which a plastic hinge is formed. The stress level at which this occurs is termed as the flow stress. [ ]^{a,c,e} This methodology has been shown to be applicable to ductile piping through a large number of experiments and is used here to predict the critical flaw size in the pressurizer accumulator lines. The failure criterion has been obtained by requiring equilibrium of the section containing the flaw (Figure 5-1) when loads are applied. The detailed development is provided in Appendix A for a through-wall circumferential flaw in a pipe section with internal pressure, axial force, and imposed bending moments. The limit moment for such a pipe is given by:

[ ]^{a,c,e} (5-1)

where:

[ ]^{a,c,e} (5-2)

The analytical model described above accurately accounts for the internal pressure as well as imposed axial force as they affect the limit moment. Good agreement was found between the analytical predictions and the experimental results (Reference 5-1). Flaw stability evaluations, using this analytical model, are presented in Section 5.4.

5.2 LOCAL FAILURE MECHANISM

The local mechanism of failure is primarily dominated by the crack tip behavior in terms of crack-tip blunting, initiation, extension and finally crack instability. The local stability will be assumed if the crack does not initiate at all. It has been accepted that the initiation toughness measured in terms of J_{IC} from a J-integral resistance curve is a material parameter defining the crack initiation. If, for a given load, the calculated J-integral value is shown to be less than the J_{IC} of the material, then the crack will not initiate. Stability analysis using this approach is performed for selected location.

5.3 LEAK RATE PREDICTIONS

Fracture mechanics analysis shows that postulated through-wall cracks in the accumulator lines would remain stable and would not cause a gross failure of this component. However, if such a through-wall crack did exist, it would be desirable to detect the leakage such that the plant could be brought to a safe shutdown condition. The purpose of this section is to discuss the method which will be used to predict the flow through such a postulated crack and present the leak rate calculation results for through-wall circumferential cracks.

5.3.1 General Considerations

The flow of hot pressurized water through an opening to a lower back pressure (causing choking) is taken into account. For long channels where the ratio of the channel length, L, to hydraulic diameter, D_H, (L/D_H) is greater than [ ]^{a,c,e}, both [ ]^{a,c,e} must be considered. In this situation the flow can be described as being single-phase through the channel until the local pressure equals the saturation pressure of the fluid. At this point, the flow begins to flash and choking occurs. Pressure losses due to momentum changes will dominate for [ ]^{a,c,e}. However, for large L/D_H values, the friction pressure drop will become important and must be considered along with the momentum losses due to flashing.

5.3.2 Calculational Method

In using the [

]^{a,c,e}.

The flow rate through a crack was calculated in the following manner. Figure 5-2 from Reference 5-2 was used to estimate the critical pressure, Pc, for the primary loop enthalpy condition and an assumed flow. Once Pc was found for a given mass flow, the [ ]^{a,c,e} was found from Figure 5-3 taken from Reference 5-2. For all cases considered, since [ ]^{a,c,e}. Therefore, this method will yield the two-phase pressure drop due to momentum effects as illustrated in

Figure 5-4. Now using the assumed flow rate, G, the frictional pressure drop can be calculated using

$$\Delta P_f = \left[\qquad\qquad \right]^{a,c,e} \tag{5-3}$$

where the friction factor f was determined using the [ ]^{a,c,e}. The crack relative roughness, e, was obtained from fatigue crack data on stainless steel samples. The relative roughness value used in these calculations was [ ]^{a,c,e} RMS.

The frictional pressure drop using Equation 5-3 was then calculated for the assumed flow and added to the [ ]^{a,c,e} to obtain the total pressure drop from the system under consideration to the atmosphere. Thus,

$$\text{Absolute Pressure} - 14.7 = [\qquad\qquad]^{a,c,e} \tag{5-4}$$

for a given assumed flow G. If the right-hand side of Equation 5-4 does not agree with the pressure difference between the piping under consideration and the atmosphere, then the procedure is repeated until Equation 5-4 is satisfied to within an acceptable tolerance and this results in the flow value through the crack.

For the locations at the lower temperatures, the leak rate is calculated by using the simple orifice type flow formula given by [

]^{a,c,e}

5.3.3 Leak Rate Calculations

Leak rate calculations were performed as a function of postulated through-wall crack length for the critical locations previously identified. The crack opening area was estimated using the method of Reference 5-3 and the leak rates were calculated using the calculational methods described above. The leak rates were calculated using the normal operating loads at the governing locations identified in Section 4.0. The crack lengths yielding a leak rate of 10 gpm (10 times the leak detection capability of 1.0 gpm) for critical locations at the Point Beach Nuclear Plants accumulator lines are shown in Table 5-1.

The Point Beach plants have an RCS pressure boundary leak detection system which is consistent with the guidelines of Regulatory Guide 1.45 for detecting leakage of 1 gpm in one hour.

5.4 STABILITY EVALUATION

A typical segment of the pipe under maximum loads of axial force F and bending moment M is schematically illustrated in Figure 5-5. In order to calculate the critical flaw size, plots of the limit moment versus crack length are generated as shown in Figures 5-6 to 5-11. The critical flaw size corresponds to the intersection of this curve and the maximum load line. The critical flaw size is calculated using the lower bound base metal tensile properties established in Section 3.0.

The welds at the governing location are GTAW and SMAW. Therefore, the "Z" factor correction for the SMAW weld was applied (Reference 5-5) as follows:

$$Z = 1.15\,[1 + 0.013\,(\text{O.D.} - 4)]\ \text{(for SMAW)} \qquad (5\text{-}6)$$

where OD is the outer diameter in inches. Substituting OD = 10.75 inches, the Z factor was calculated to be 1.25 for SMAW. The applied loads were increased by the Z factors and the plots of limit load versus crack length were generated as shown in Figures 5-6 to 5-11. Table 5-2 shows the summary of critical flaw sizes.

Additionally elastic-plastic fracture mechanics (EPFM) J-integral analysis for through-wall circumferential crack in a cylinder is performed for node 165 using the procedure in the EPRI Fracture Mechanics Handbook (Reference 5-6). Table 5-3 shows the results of this analysis.

5.5 REFERENCES

5-1 Kanninen, M. F. et al., "Mechanical Fracture Predictions for Sensitized Stainless Steel Piping with Circumferential Cracks" EPRI NP-192, September 1976.

5-2 [

]a,c,e

5-3 Tada, H., "The Effects of Shell Corrections on Stress Intensity Factors and the Crack Opening Area of Circumferential and a Longitudinal Through-Crack in a Pipe," Section II-1, NUREG/CR-3464, September 1983.

5-4 Crane, D.P., "Handbook of Hydraulic Resistance Coefficient."

5-5 Standard Review Plan; Public Comment Solicited; 3.6.3 Leak-Before-Break Evaluation Procedures; Federal Register/Vol. 52, No. 167/Friday, August 28, 1987/Notices, pp. 32626-32633.

5-6 Kumar, V., German, M.D. and Shih, C. P., "An Engineering Approach for Elastic-Plastic Fracture Analysis," EPRI Report NP-1931, Project 1237-1, Electric Power Research Institute, July 1981.

Table 5-1 Leakage Flaw Size		
Node Point	Temperature (°F)	Crack Length (in.) (for 10 gpm leakage)
380	547	3.80
340	547	4.35
310	105	4.50
165	105	10.20
5	105	5.60
225	105	7.40

Table 5-2 Summary of Critical Flaw Size		
Node Point	Temperature (°F)	Critical Flaw Size (in)
380	547	11.94
340	547	12.92
310	105	14.23
165	105	19.05
5	105	15.12
225	105	17.50

Table 5-3 Stability Result for Node 165 Based on J-Integral Evaluation			
Node	Flaw Size (in)	J_{IC} (in-lb/in^2)	J Applied (in-lb/in^2)
165	[		] a,c,e

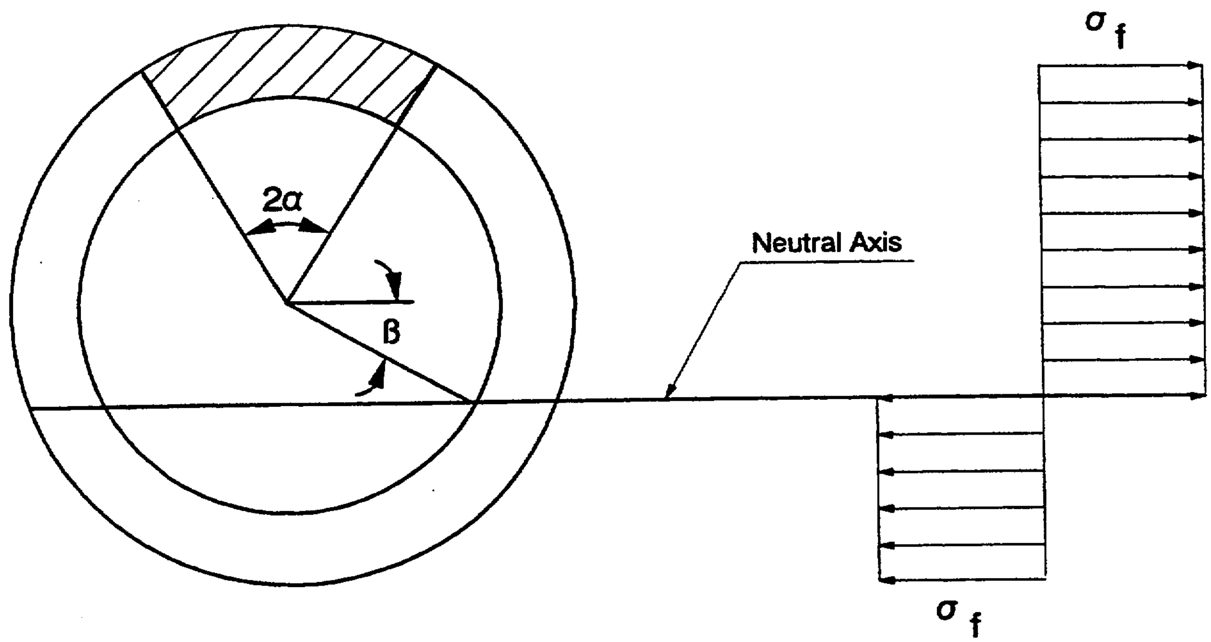

Figure 5-1 Fully Plastic Stress Distribution

a,c,e

Figure 5-2 Analytical Predications of Critical Flow Rates of Steam-Water Mixtures

a,c,e

Figure 5-3 [ ]a,c,e Pressure Ratio as a Function of L/D

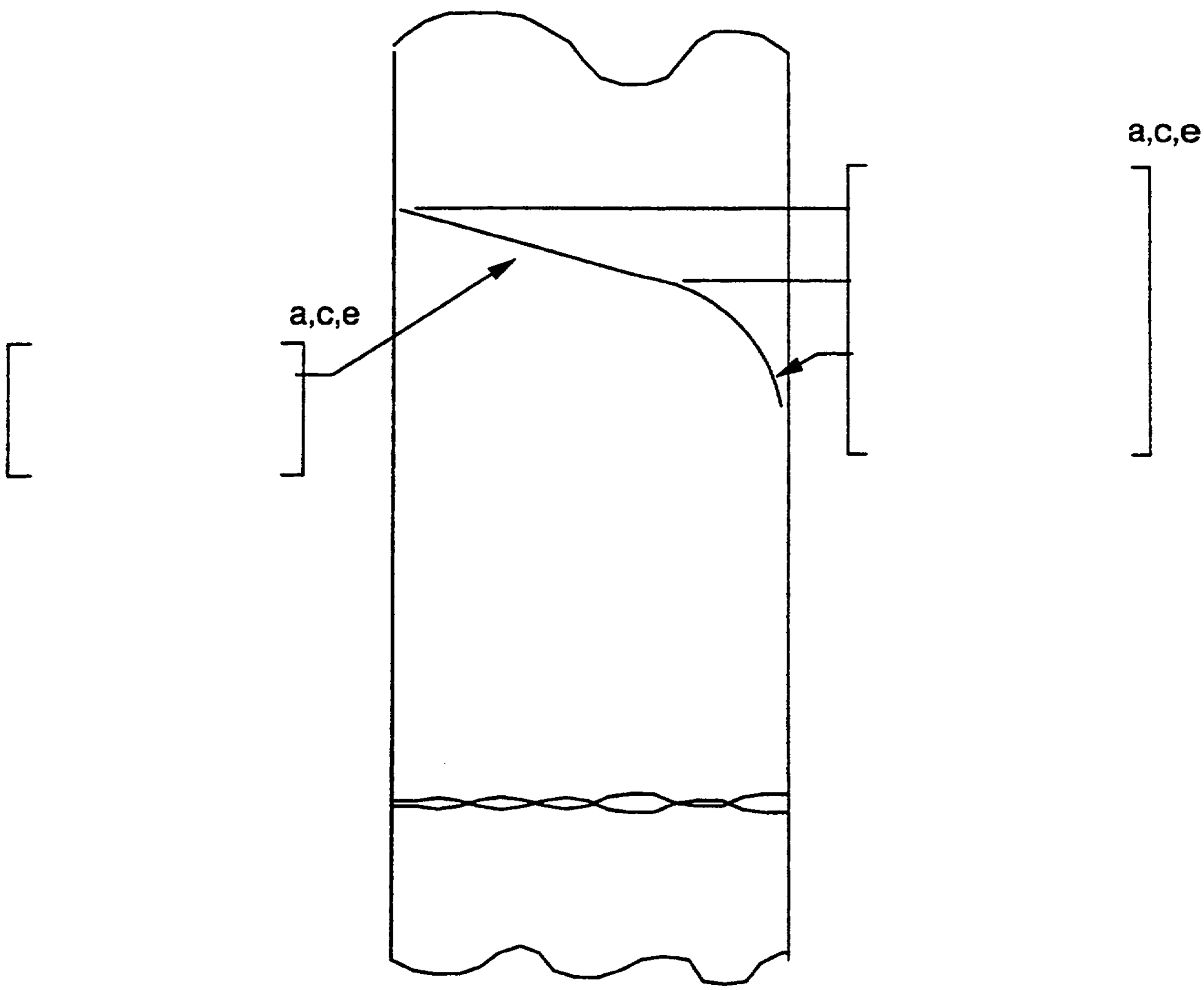

Figure 5-4 Idealized Pressure Drop Profile Through a Postulated Crack

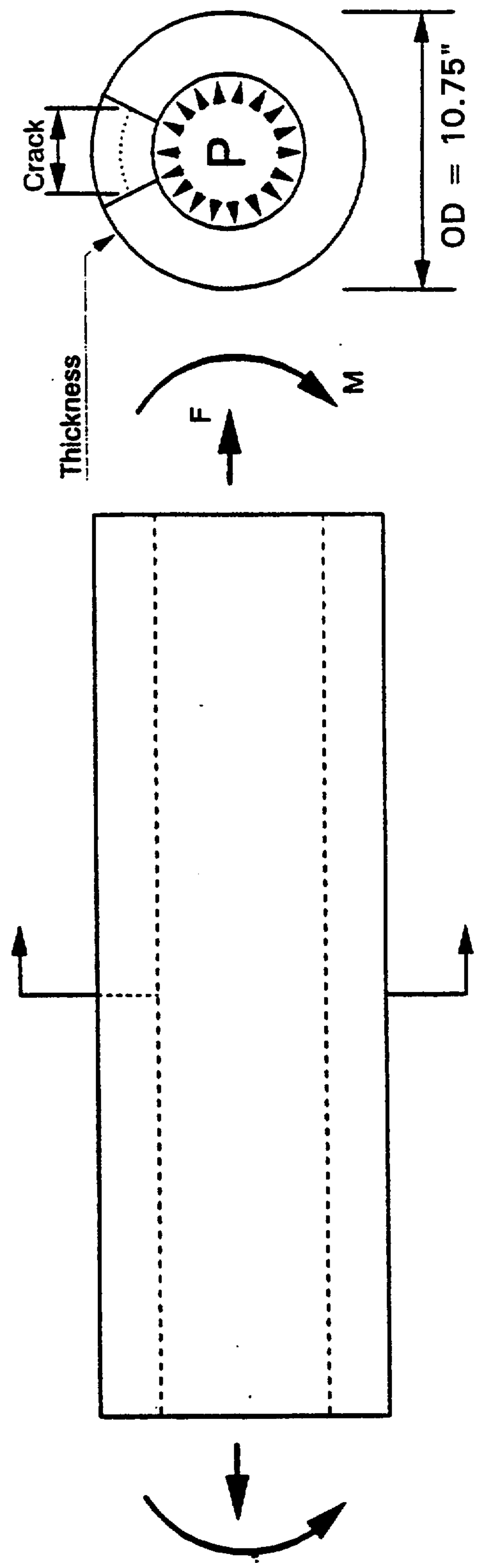

Figure 5-5 Loads Acting on the Model at the Governing Locations

a,c,e

LIMIT MOMENT (in-kips)

FLAW LENGTH (inches)

OD = 10.75 in. σ_y = 24.62 ksi F = 153.19 kips

t = 0.896 in. σ_u = 75.19 ksi M = 735.20 in-kips

A376TP316 with SMAW weld

Figure 5-6 Critical Flaw Size Prediction for Node 380

a,c,e

LIMIT MOMENT (in-kips)

FLAW LENGTH (inches)

OD = 10.75 in. σ_y = 24.62 ksi F = 132.78 kips

t = 0.896 in. σ_u = 75.19 ksi M = 630.28 in-kips

A376TP316 with SMAW weld

Figure 5-7 Critical Flaw Size Prediction for Node 340

a,c,e

LIMIT MOMENT (in-kips)

FLAW LENGTH (inches)

OD = 10.75 in. σ_y = 37.83 ksi F = 134.42 kips

t = 0.896 in. σ_u = 78.55 ksi M = 554.06 in-kips

A376TP316 with SMAW weld

Figure 5-8 Critical Flaw Size Prediction for Node 310

a,c,e

LIMIT MOMENT (in-kips)

FLAW LENGTH (inches)

OD = 10.75 in. σ_y = 37.83 ksi F = 49.19 kips

t = 0.896 in. σ_u = 78.55 ksi M = 204.87 in-kips

A376TP316 with SMAW weld

Figure 5-9 Critical Flaw Size Prediction for Node 165

a,c,e

LIMIT MOMENT (in-kips)

FLAW LENGTH (inches)

OD = 10.75 in. σ_y = 37.78 ksi F = 38.92 kips

t = 0.340 in. σ_u = 79.29 ksi M = 290.46 in-kips

A312TP304 with SMAW weld

Figure 5-10 Critical Flaw Size Prediction for Node 5

a,c,e

LIMIT MOMENT (in-kips)

FLAW LENGTH (inches)

OD = 10.75 in. σ_y = 37.78 ksi F = 58.45 kips

t = 0.458 in. σ_u = 79.29 ksi M = 134.21 in-kips

A312TP304 with SMAW weld

Figure 5-11 Critical Flaw Size Prediction for Node 225

6 ASSESSMENT OF FATIGUE CRACK GROWTH CONSIDERATION

6.1 INTRODUCTION

The fatigue crack growth on the Point Beach Units 1 and 2 accumulator lines was determined by comparison with a generic fatigue crack growth analysis of a similar piping system. The details of the generic fatigue crack growth analysis are presented below. By comparing all parameters critical to the fatigue crack growth analysis, between Point Beach and generic, it was concluded that the generic analysis would envelop the fatigue crack growth of the Point Beach Units 1 and 2 accumulator lines.

Due to similarities in Westinghouse PWR designs, it was possible to perform a generic fatigue crack growth calculation which would be applicable to many projects. A comparison was made of stresses and number of cycles, material, geometry, and types of discontinuities.

Geometry was identical between the Point Beach Units 1 and 2 pipe and the generic of 10 inch schedule 140. Both generic and Point Beach had the same materials for the piping, A376-TP316 austenitic stainless steel at the critical location. The nozzle material is also same SA182-F316 for the generic case and Point Beach. Both generic and Point Beach stresses and number of cycles are similar.

6.2 FATIGUE CRACK GROWTH ANALYSIS

The fatigue crack growth analysis was performed to determine the effect of the design thermal transients. The analysis was performed for the critical cross section identified in Figure 6-1. A range of crack depths was postulated, and each was subjected to the thermal transients, which included pressure and moment.

6.3 ANALYSIS PROCEDURE

The fatigue crack growth analyses presented herein were conducted in the same manner as suggested by Section XI, Appendix A of the ASME Boiler and Pressure Vessel Code. The analysis procedure involves assuming an initial flaw exists at some point and predicting the growth of that flaw due to an imposed series of stress transients. The growth of a crack per loading cycle is dependent on the range of applied stress intensity factor ΔK_I, by the following:

$$\frac{da}{dN} = Co\Delta K_I{}^N \qquad (6\text{-}1)$$

where "Co" and the exponent "n" are material properties, and ΔK_I is defined later. For inert environments these material properties are constants, but for some water environments they are dependent on the level of mean stress present during the cycle. This can be accounted for by adjusting the value of "Co" and "n" by a function of the ratio of minimum to maximum stress for any given transient, as will be discussed later. Fatigue crack growth properties of stainless steel in a pressurized water environment have been used in the analysis.

The input required for a fatigue crack growth analysis is basically the information necessary to calculate the parameter ΔK_I, which depends on crack and structure geometry and the range of applied stresses in the area where the crack exists. Once ΔK_I is calculated, the growth due to that particular cycle can be calculated by equation (6-1). This increment of growth is then added to the original crack size, the ΔK_I adjusted, and the analysis proceeds to the next transient. The procedure is continued in this manner until all the transients have been analyzed.

The crack tip stress intensity factors (K_I) to be used in the crack growth analysis were calculated using an expression which applies for a semi-elliptic surface flaw in a cylindrical geometry (Reference 6-1).

The stress intensity factor expression was taken from Reference 6-1 and was calculated using the actual stress profiles at the critical section. The maximum and minimum stress profiles corresponding to each transient were input, and each profile was fit by a third order polynomial:

$$\sigma(x) = A_0 + A_1 \frac{x}{t} + A_2\left(\frac{x}{t}\right)^2 + A_3\left(\frac{x}{t}\right)^3 \qquad (6\text{-}2)$$

The stress intensity factor $K_I(\phi)$ was calculated at the deepest point of the crack using the following expression:

$$K_I(f) = \Big[\qquad \Big]^{a,c,e} \qquad (6\text{-}3)$$

where ϕ = angular location along crack ($\phi = 0$ is deepest point of crack)

H_0, H_1, H_2, H_3 are magnification factors obtained from reference 6-1

A_0, A_1, A_2, A_3 are coefficients from the fit of equation (6-2)

t = section thickness

a = crack depth

$$Q^{1/2} = \int_0^{\pi/2} \left(\cos^2\phi + a^2/c^2 \sin^2\phi\right)^{1/2} d\phi$$

C = half crack length

Calculation of the fatigue crack growth for each cycle was then carried out using the reference fatigue crack growth rate law determined from consideration of the available data for stainless steel in a pressurized water environment. This law allows for the effect of mean stress or R ratio (K_{Imin}/K_{Imax}) on the growth rates.

The reference crack growth law for stainless steel in a pressurized water environment was taken from a collection of data (Reference 6-2) since no code curve is available, and it is defined by the following equation:

$$\frac{da}{dN} = \left[\qquad\qquad\qquad \right]^{a,c,e} \tag{6-4}$$

where

$$K_{eff} = (K_{Imax})\,(1\text{-}R)^{1/2}$$

$$R = \frac{K_{Imin}}{K_{Imax}}$$

$\frac{da}{dN}$ = crack growth rate in micro-inches/cycle

6.4 RESULTS

Fatigue crack growth analyses were carried out for the critical cross section. Analysis was completed for a range of postulated flaw sizes oriented circumferentially, and the results are presented in Table 6-1. The postulated flaws are assumed to be six times as long as they are deep. Even for the largest postulated flaw of 0.300 inch which is about 30 percent of the wall thickness, the result shows that the flaw growth through the wall will not occur during the 40 year design life of the plant. These results also confirm operating plant experience.

6.5 REFERENCES

6-1 McGowan, J. J. and Raymund, M., "Stress Intensity Factor Solutions for Internal Longitudinal Semi-Elliptical Surface Flaws in a Cylinder Under Arbitrary Loadings," Fracture Mechanics ASTM STP 677, 1979, pp. 365-380.

6-2 Bamford, W. H., "Fatigue Crack Growth of Stainless Steel Reactor Coolant Piping in a Pressurized Water Reactor Environment," ASME Trans. Journal of Pressure Vessel Technology, February 1979.

Table 6-1 Accumulator Line Fatigue Crack Growth Results				
Initial Crack Depth (in)	Crack Depth After Year			
	10	20	30	40
[				
				]a,c,e

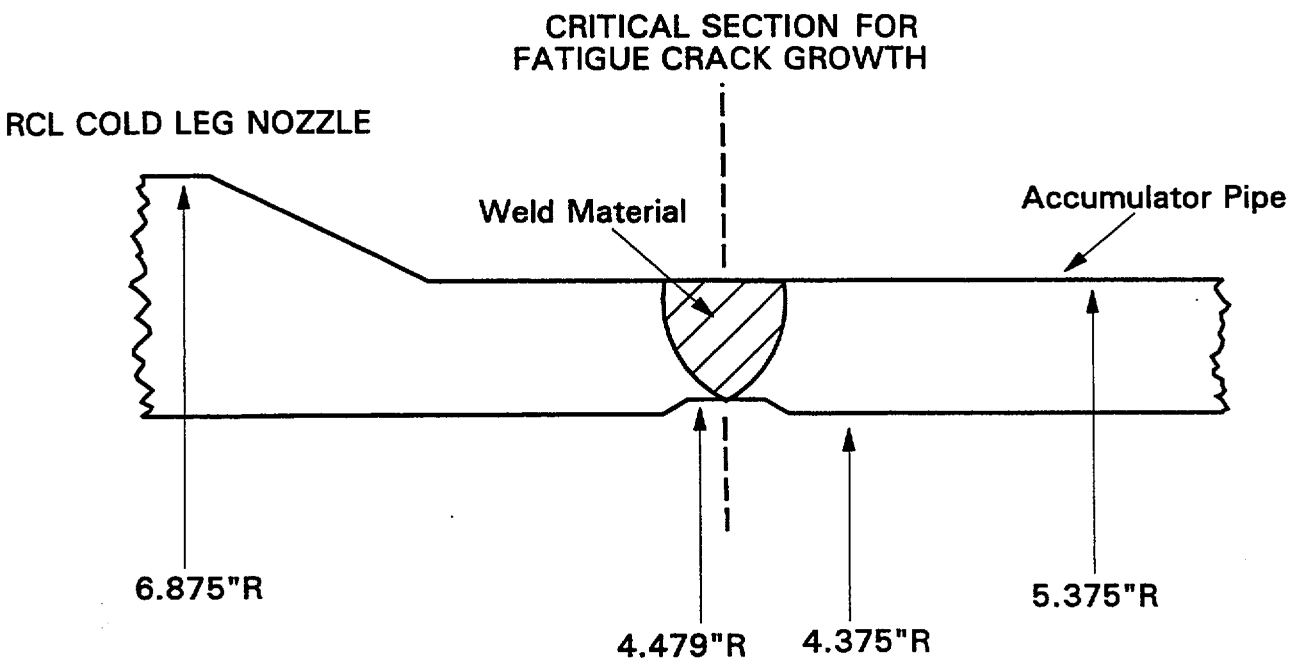

Figure 6-1 Schematic of Accumulator Line At RCL Cold Leg Nozzle Weld Location

7 ASSESSMENT OF MARGINS

In the preceding sections, the leak rate calculations, fracture mechanics analysis and fatigue crack growth assessment were performed. Margins at the critical locations are summarized below:

In Section 5.4 using the SRP 3.6.3 approach (i.e., "Z" factor approach), the "critical" flaw sizes at the governing locations are calculated. Stability analysis is also performed by J-integral approach at node point 165 for a critical flaw size of 2 times the 10 gpm leakage flaw size. In Section 5.3 the crack lengths yielding a leak rate of 10 gpm (10 times the leak detection capability of 1.0 gpm) for the critical locations are calculated.

The leakage flaw sizes, the instability (critical) flaw sizes, and margins are shown in Table 7-1. The margins on leak rate, the margin on flaw size, and the margin on loads are satisfied.

In this evaluation, the leak-before-break methodology is applied conservatively. The conservatisms used in the evaluation are summarized in Table 7-2.

Table 7-1 Leakage Flaw Sizes, Critical Flaw Sizes and Margins			
Node	Critical Flaw Size (in)	Leakage Flaw Size (in)	Margin
380	11.94	3.80	3.1
340	12.92	4.35	3.0
310	14.23	4.50	3.2
165	20.40	10.20	>2.0[1]
5	15.12	5.60	2.7
225	17.50	7.40	2.4

1. Based on J-integral approach.

Table 7-2 LBB Conservatisms
Factor of 10 on Leak Rate
Factor of 2 on Leakage Flaw for all Locations
Algebraic Sum of Loads for Leakage
Absolute Sum of Loads for Stability
Average Material Properties for Leakage
Minimum Material Properties for Stability

8 CONCLUSIONS

This report justifies the elimination of accumulator lines pipe breaks as the structural design basis for Point Beach Units 1 and 2 Nuclear Plants as follows:

a. Stress corrosion cracking is precluded by use of fracture resistant materials in the piping system and controls on reactor coolant chemistry, temperature, pressure, and flow during normal operation.

b. Water hammer should not occur in the RCS piping (primary loop and the attached class 1 auxiliary lines) because of system design, testing, and operational considerations.

c. The effects of low and high cycle fatigue on the integrity of the accumulator lines were evaluated and shown acceptable. The effects of thermal cycling stratification were evaluated and shown acceptable.

d. Ample margin exists between the leak rate of small stable flaws and the capability of Point Beach Units 1 and 2 reactor coolant system pressure boundary leakage detection system.

e. Ample margin exists between the small stable flaw sizes of item d and the critical flaw size.

The postulated reference flaw will be stable because of the ample margins in d, e and will leak at a detectable rate which will assure a safe plant shutdown.

Based on the above, it is concluded that accumulator lines breaks should not be considered in the structural design basis of Point Beach Units 1 and 2 Nuclear Plants.

APPENDIX A - LIMIT MOMENT

[

]a,c,e

a,

Figure A-1 Pipe With A Through-Wall Crack In Bending