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Westinghouse

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1.0 INTRODUCTION

1.1 PURPOSE

The current structural design basis for the D.C. Cook Units 1 and 2 Safety Injection (SI) lines, including the 6-inch and 8-inch lines directly attached to the hot leg piping of the reactor coolant system (RCS) as well as the 10-inch and 6-inch lines attached to the accumulator line piping for injection into the cold leg of the RCS, require 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 SI 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 of break will not occur within the SI lines. The evaluations consider that circumferentially oriented flaws cover longitudinal cases.

1.2 SCOPE AND OBJECTIVES

The purpose of this investigation is to demonstrate Leak-Before-Break (LBB) for the D.C. Cook Units 1 and 2 SI lines from the hot leg piping of each loop of the RCS through a check valve and up to an isolation valve, as well as the SI lines from the 10-inch Accumulator lines up to the first check valve. Schematic drawing of the piping systems are shown in Section 3.0, Figure 3-1. The recommendations and criteria proposed in SRP 3.6.3 (References 1-1 and 1-2) 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 based on as-built configuration. Identify the location(s) at which the highest faulted stress occurs.

2. Identify the materials and the material properties.

3. Postulate a through-wall flaw at the governing location(s). 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. Demonstrate that there is a margin of 10 between the calculated leak rate and the leak detection capability.

4. Using maximum faulted loads in the stability analysis, demonstrate that there is a margin of 2 between the leakage size flaw and the critical size flaw.

5. 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.

6. For the material types used in the plant, provide representative material properties.

7. Demonstrate margin on applied load by combining the faulted loads by absolute summation method.

This report provides a fracture mechanics demonstration of SI line piping integrity for D.C. Cook Units 1 and 2 consistent with the NRC's position for exemption from consideration of dynamic effects (Reference 1-3).

It should be noted that the terms "flaw" and "crack" have the same meaning and are used interchangeably. "Governing location" and "critical location" are also used interchangeably throughout the report.

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-0800 Revision 1, March 2007, Standard Review Plan: 3.6.3 Leak-Before-Break Evaluation Procedures.

1-3 Nuclear Regulatory Commission, 10 CFR 50, Modification of General Design Criteria 4 Requirements for Protection Against Dynamic Effects of Postulated Pipe Ruptures, Final Rule, Federal Register/Vol. 52, No. 207/Tuesday, October 27, 1987/Rules and Regulations, pp. 41288-41295.

2.0 OPERATION AND STABILITY OF THE REACTOR COOLANT SYSTEM

2.1 STRESS CORROSION CRACKING

The Westinghouse reactor coolant system (RCS) primary loops and connected Class 1 piping 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 1400 reactor-years, including 16 plants each having over 30 years of operation, 10 other plants each with over 25 years of operation, 11 plants each with over 20 years of operation, and 12 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 (PCSG), established in 1975, addressed cracking in boiling water reactors only.) One of the objectives of the second PCSG was to include a review of the potential for stress corrosion cracking in Pressurized Water Reactors (PWRs). 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."

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, sulfites, 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 is expected to be in the parts per billion (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. Thus during plant operation, the likelihood of stress corrosion cracking is minimized.

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.

Primary Water Stress Corrosion Cracking (PWSCC) occurred in the V. C. Summer reactor vessel hot leg nozzle, Alloy 82/182 weld. It should be noted that this susceptible material is not found at the D.C. Cook Units 1 and 2 SI lines.

2.2 WATER HAMMER

Overall, there is a low potential for water hammer in the RCS and connecting SI lines since they are designed and operated to preclude the voiding condition in normally filled lines. The RCS and connecting SI 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 the control rod positions; pressure is also controlled within a narrow range for steady-state conditions by the pressurizer heaters and pressurizer spray. 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 the connecting auxiliary lines. Preoperational testing and operating experience has verified the Westinghouse approach. The operating transients of the RCS primary piping and connected SI lines are such that no significant water hammer can occur.

2.3 LOW CYCLE AND HIGH CYCLE FATIGUE

The 1967 edition of the B31.1 Code does not contain an explicit piping low cycle fatigue analysis requirement. The B31.1 piping complies with a stress range reduction factor to be applied to the allowable stress as a way to address fatigue from full temperature cycles for thermal expansion stress evaluation. The stress range reduction factor is 1.0 (i.e., no reduction) for equivalent full temperature

cycles less than 7000. For D.C. Cook Units 1 and 2, the equivalent full temperature cycles for the applicable design transients are less than 7000, so no reduction is required.

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 vibration 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 RCP have been found analytically to be very small, between 2 and 3 ksi at the highest. Field measurements on a typical PWR plant indicate vibration stress amplitudes less than 1 ksi. When translated to the connecting SI lines, these stresses would be even lower, well below the fatigue endurance limit for the SI line materials and would result in an applied stress intensity factor below the threshold for fatigue crack growth.

2.4 OTHER POSSIBLE DEGRADATION DURING SERVICE OF THE SI LINES

The SI lines and the associated fittings for the D.C. Cook Nuclear Power Plants are forged product forms, which are not susceptible to toughness degradation due to thermal aging.

The maximum normal operating temperature of the SI piping is about 618°F. This is well below the temperature that would cause any creep damage in stainless steel piping. Cleavage type failures are not a concern for the operating temperatures and the material used in the stainless steel piping of the SI lines.

Wall thinning by erosion and erosion-corrosion effects should not occur in the SI piping due to the low velocity, typically less than 1.0 ft/sec and the stainless steel material, which is highly resistant to these degradation mechanisms. Per NUREG-0691 (Reference 2-2), a study on pipe cracking in PWR piping reported only two incidents of wall thinning in stainless steel pipe and these were not in the SI lines. The cause of wall thinning is related to high water velocity and is therefore clearly not a mechanism that would affect the SI piping.

Brittle fracture for stainless steel material occurs when the operating temperature is about -200°F. SI line operating temperature is higher than 120°F and therefore, brittle fracture is not a concern for the SI lines.

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.

3.0 PIPE GEOMETRY AND LOADING

3.1 CALCULATIONS OF LOADS AND STRESSES

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

$$\sigma = \frac{F}{A} + \frac{M}{Z} \qquad (3\text{-}1)$$

where,

σ	=	stress, psi
F	=	axial load, lbs
M	=	moment, in-lbs
A	=	pipe cross-sectional area, in^2
Z	=	section modulus, in^3

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

$$M = \sqrt{M_x^2 + M_y^2 + M_z^2} \qquad (3\text{-}2)$$

where,

M_x	=	X component of moment, Torsion
M_y	=	Y component of bending moment
M_z	=	Z component of bending moment

The axial load and moments for leak rate predictions and crack stability analyses are computed by the methods to be explained in Sections 3.2 and 3.3.

3.2 LOADS FOR LEAK RATE EVALUATION

The normal operating loads for leak rate predictions are calculated by the following equations:

$$F = F_{DW} + F_{TH} + F_P \qquad (3\text{-}3)$$

$$M_X = (M_X)_{DW} + (M_X)_{TH} \qquad (3\text{-}4)$$

$$M_Y = (M_Y)_{DW} + (M_Y)_{TH} \qquad (3\text{-}5)$$

$$M_Z = (M_Z)_{DW} + (M_Z)_{TH} \qquad (3\text{-}6)$$

The subscripts of the above equations represent the following loading cases:

DW = deadweight

TH = normal thermal expansion

P = load due to internal pressure

This method of combining loads is often referred to as the algebraic sum method (References 3-1 and 3-2). The LBB evaluations do not include moment effects due to pressure loading since the moment loading is significantly dominated by the thermal loads for normal operation and by the seismic loads for faulted events.

The dimensions and normal operating conditions are given in Tables 3-1 and 3-2. The loads based on this method of combination are provided in Tables 3-3 through 3-18 at all the weld locations.

3.3 LOAD COMBINATION FOR CRACK STABILITY ANALYSES

In accordance with Standard Review Plan 3.6.3 (References 3-1 and 3-2), the absolute sum of loading components can be applied which results in higher magnitude of combined loads. If crack stability is demonstrated using these loads, the LBB margin on loads can be reduced from √2 to 1.0. The absolute summation of loads is shown in the following equations:

$$F = |F_{DW}| + |F_{TH}| + |F_P| + |F_{SSEINERTIA}| + |F_{SSEAM}| \quad (3\text{-}7)$$

$$M_X = |(M_X)_{DW}| + |(M_X)_{TH}| + |(M_X)_{SSEINERTIA}| + |(M_X)_{SSEAM}| \quad (3\text{-}8)$$

$$M_Y = |(M_Y)_{DW}| + |(M_Y)_{TH}| + |(M_Y)_{SSEINERTIA}| + |(M_Y)_{SSEAM}| \quad (3\text{-}9)$$

$$M_Z = |(M_Z)_{DW}| + |(M_Z)_{TH}| + |(M_Z)_{SSEINERTIA}| + |(M_Z)_{SSEAM}| \quad (3\text{-}10)$$

where subscript SSEINERTIA refers to safe shutdown earthquake inertia, SSEAM is safe shutdown earthquake anchor motion. It is noted that the D.C. Cook piping analyses consider Design Basis Earthquake (DBE) as the seismic criteria, which is equivalent to Safe Shutdown Earthquake (SSE).

The loads so determined are used in the fracture mechanics evaluations (Section 7.0) to demonstrate the LBB margins at the locations established to be the governing locations. These loads at all the weld locations are given in Tables 3-19 and 3-34.

Notes: For the cold leg SI lines, LBB analysis will not be performed at the locations beyond the first check valve. The cold leg SI line check valve, in conjunction with the 10-inch check valve on the Accumulator line, provides protection against break propagation. Any break beyond the second check valve will not have any effect on the primary loop piping system. Similar justification is considered for the hot leg SI lines, in that LBB analysis will not be performed at the locations beyond the isolation valve. The check valve and isolation valve, in series on the hot leg SI lines, provides protection against break propagation. Any break beyond the isolation valve will not have any effect on the primary loop piping

system. Figure 3-1 illustrates the typical layout of the cold leg and hot leg SI lines, showing segments, for D.C. Cook Units 1 and 2.

3.4 REFERENCES

3-1 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.

3-2 NUREG-0800 Revision 1, March 2007, Standard Review Plan: 3.6.3 Leak-Before-Break Evaluation Procedures.

Table 3-1 Summary of D.C. Cook Unit 1 Piping Geometry and Normal Operating Condition for the Hot Leg and Cold Leg Safety Injection Lines

Loop	Segment	Weld Location Nodes	Outer Diameter (in)	Minimum Wall Thickness (in)	Normal Operating Temperature (°F)	Normal Operating Pressure (psig)
1	SI-CL-I	403F to 402	10.750	0.896	120	2,235
		398	6.625	0.650		
	SI-HL-I	181 to 174	6.625	0.650	618	2,235
	SI-HL-II	170F to 152B	6.625	0.650	120	2,235
	SI-HL-III	148X to 132	8.625	0.731	120	2,235
2	SI-CL-I	400N to 400F	10.750	0.896	120	2,235
		406	6.625	0.650		
	SI-HL-I	511 to 500F	6.625	0.650	618	2,235
	SI-HL-II	500F to 479	6.625	0.650	120	2,235
	SI-HL-III	96X to 78	8.625	0.731	120	2,235
3	SI-CL-I	158F to 158N	10.750	0.896	120	2,235
		152	6.625	0.650		
	SI-HL-I	550 to 536F	6.625	0.650	618	2,235
	SI-HL-II	536F to 516	6.625	0.650	120	2,235
	SI-HL-III	96Y to 78	8.625	0.731	120	2,235
4	SI-CL-I	294X	10.750	0.896	120	2,235
		290 to 284	6.625	0.650		
	SI-HL-I	221 to 214	6.625	0.650	618	2,235
	SI-HL-II	210F to 190	6.625	0.650	120	2,235
	SI-HL-III	148Y to 132	8.625	0.731	120	2,235

Notes:

- Figure 3-1 shows the piping layout and segments.
- Figures 3-2 through 3-7 show the weld locations for each line analyzed.
- Material type is A376 TP316 or A403 WP316.
- Piping in segment SI-CL-I is 10-inch Schedule 140 and 6-inch Schedule 160.
- Piping in segment SI-HL-I and SI-HL-II is 6-inch Schedule 160.
- Piping in segment SI-HL-III is 8-inch Schedule 140.
- The minimum wall thickness is conservatively based at the weld counterbore and not per ASME Code requirement.

Table 3-2 Summary of D.C. Cook Unit 2 Piping Geometry and Normal Operating Condition for the Hot Leg and Cold Leg Safety Injection Lines

Loop	Segment	Weld Location Nodes	Outer Diameter (in)	Minimum Wall Thickness (in)	Normal Operating	
					Temperature (°F)	Pressure (psig)
1	SI-CL-I	402F to 402N	10.750	0.896	120	2,235
		400 to 388	6.625	0.650		
	SI-HL-I	181 to 174	6.625	0.650	618	2,235
	SI-HL-II	170F to 150	6.625	0.650	120	2,235
	SI-HL-III	148X to 132	8.625	0.731	120	2,235
2	SI-CL-I	400N to 400F	10.750	0.896	120	2,235
		404 to 412	6.625	0.650		
	SI-HL-I	511 to 500F	6.625	0.650	618	2,235
	SI-HL-II	500F to 479	6.625	0.650	120	2,235
	SI-HL-III	96X to 78	8.625	0.731	120	2,235
3	SI-CL-I	158F to 158N	10.750	0.896	120	2,235
		156 to 146	6.625	0.650		
	SI-HL-I	550 to 536F	6.625	0.650	618	2,235
	SI-HL-II	536F to 516	6.625	0.650	120	2,235
	SI-HL-III	96Y to 78	8.625	0.731	120	2,235
4	SI-CL-I	294X	10.750	0.896	120	2,235
		288F to 284	6.625	0.650		
	SI-HL-I	221 to 214	6.625	0.650	618	2,235
	SI-HL-II	210F to 188	6.625	0.650	120	2,235
	SI-HL-III	148Y to 132	8.625	0.731	120	2,235

Notes:
- Figure 3-1 shows the piping layout and segments.
- Figures 3-2 through 3-7 show the weld locations for each line analyzed.
- Material type is A376 TP316 or A403 WP316.
- Piping in segment SI-CL-I is 10-inch Schedule 140 and 6-inch Schedule 160.
- Piping in segment SI-HL-I and SI-HL-II is 6-inch Schedule 160.
- Piping in segment SI-HL-III is 8-inch Schedule 140.
- The minimum wall thickness is conservatively based at the weld counterbore and not per ASME Code requirement.

Table 3-3 Summary of D.C. Cook Unit 1 Normal Loads and Stresses for SI Line to Loop 1 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
403F	141,396	52,841	5,937
402	141,558	41,557	5,764
398	49,122	39,885	6,427

Notes: See Figure 3-2 for piping layout.
Axial force includes pressure.

Table 3-4 Summary of D.C. Cook Unit 1 Normal Loads and Stresses for SI Line to Loop 2 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
400N	140,202	54,708	5,924
400F	140,013	42,332	5,721
406	48,909	40,039	6,419

Notes: See Figure 3-2 for piping layout.
Axial force includes pressure.

Table 3-5 Summary of D.C. Cook Unit 1 Normal Loads and Stresses for SI Line to Loop 3 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
158F	141,219	58,379	6,019
158N	141,329	46,611	5,836
152	50,225	43,494	6,735

Notes: See Figure 3-2 for piping layout.
Axial force includes pressure.

Table 3-6 Summary of D.C. Cook Unit 1 Normal Loads and Stresses for SI Line to Loop 4 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
294X	141,911	59,081	6,055
290	50,808	55,526	7,506
288N	49,051	46,049	6,792
286F	50,410	29,948	5,935
284	50,922	12,978	4,956

Notes: See Figure 3-2 for piping layout.
Axial force includes pressure.

Table 3-7 Summary of D.C. Cook Unit 1 Normal Loads and Stresses for SI Line to Loop 1 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
181	50,846	94,977	9,882
178	49,473	83,849	9,100
174	50,106	51,130	7,184
170F	51,158	44,914	6,897
170N	49,871	36,695	6,297
168F	50,007	52,202	7,241
168N	51,138	64,111	8,050
164F	51,138	100,358	10,230
164N	50,487	94,363	9,816
162F	51,093	106,682	10,607
162N	48,405	106,295	10,363
156F	49,749	6,579	4,475
155	49,319	6,918	4,460
154N	50,310	7,588	4,582
152	50,310	16,016	5,089
148X	90,587	17,215	5,518
148T	90,133	11,489	5,320
146F	90,116	12,102	5,337
146N	89,976	14,162	5,392
144F	89,976	16,083	5,450
144N	89,867	16,886	5,468
142F	89,867	15,280	5,420
142N	89,613	16,092	5,430
136	91,242	18,199	5,584
132	89,109	30,612	5,842

Notes: See Figure 3-3 for piping layout.
Axial force includes pressure.

Table 3-8 Summary of D.C. Cook Unit 1 Normal Loads and Stresses for SI Line to Loop 2 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
511	50,779	98,601	10,095
509	49,495	86,161	9,241
504	50,083	51,618	7,212
500F	51,380	52,265	7,357
500N	49,855	42,744	6,659
498F	50,031	63,717	7,935
498N	51,386	78,002	8,906
494F	51,386	120,520	11,463
494N	50,543	112,699	10,923
492F	51,113	107,055	10,631
492N	48,679	117,568	11,063
490F	48,645	127,090	11,633
490N	48,168	126,369	11,551
484F	49,722	8,962	4,616
484N	50,290	6,341	4,505
482F	50,290	6,073	4,489
480F	49,429	10,833	4,705
480N	49,282	17,127	5,071
479	50,295	21,906	5,442
96X	90,572	22,310	5,672
96T	89,974	19,859	5,564
94F	89,964	20,053	5,570
94N	90,187	19,593	5,568
H07-299	90,187	17,307	5,499
88F	89,948	13,021	5,356
88N	89,777	12,367	5,327
86F	89,777	11,782	5,309
86N	90,335	10,566	5,303
84F	89,908	16,337	5,454
78	90,000	18,279	5,518

Notes: See Figure 3-4 for piping layout.
Axial force includes pressure.

Table 3-9 Summary of D.C. Cook Unit 1 Normal Loads and Stresses for SI Line to Loop 3 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
550	50,974	75,780	8,738
546	50,363	64,590	8,015
540	50,362	34,384	6,198
536F	51,348	49,662	7,198
536N	49,829	39,890	6,485
534F	50,050	63,896	7,948
534N	51,239	76,634	8,811
530F	51,239	120,089	11,425
530N	50,543	114,398	11,026
528F	48,473	76,582	8,581
528N	48,721	82,989	8,987
526F	48,635	121,526	11,298
526N	51,345	120,857	11,480
520F	49,660	10,642	4,712
518F	49,896	9,780	4,680
518N	50,417	10,999	4,796
516	50,417	12,374	4,879
96Y	90,693	12,578	5,384
96T	89,974	19,859	5,564
94F	89,964	20,053	5,570
94N	90,187	19,593	5,568
H07-299	90,187	17,307	5,499
88F	89,948	13,021	5,356
88N	89,777	12,367	5,327
86F	89,777	11,782	5,309
86N	90,335	10,566	5,303
84F	89,908	16,337	5,454
78	90,000	18,279	5,518

Notes: See Figure 3-4 for piping layout.
Axial force includes pressure.

Table 3-10 Summary of D.C. Cook Unit 1 Normal Loads and Stresses for SI Line to Loop 4 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
221	50,888	83,729	9,209
218	49,409	73,134	8,451
214	49,409	41,948	6,575
210F	51,111	43,187	6,789
210N	49,869	34,989	6,194
208F	50,010	50,262	7,124
208N	51,062	61,527	7,888
204F	51,062	99,383	10,165
204N	50,493	94,367	9,817
202F	51,044	83,671	9,218
202N	48,794	90,867	9,467
200F	48,747	102,708	10,175
200N	51,117	99,185	10,158
194F	49,616	7,782	4,537
192F	49,410	9,608	4,630
191	50,488	11,173	4,812
190	50,488	18,415	5,248
148Y	90,764	19,399	5,594
148T	90,133	11,489	5,320
146F	90,116	12,102	5,337
146N	89,976	14,162	5,392
144F	89,976	16,083	5,450
144N	89,867	16,886	5,468
142F	89,867	15,280	5,420
142N	89,613	16,092	5,430
136	91,242	18,199	5,584
132	89,109	30,612	5,842

Notes: See Figure 3-3 for piping layout.
Axial force includes pressure.

Table 3-11 Summary of D.C. Cook Unit 2 Normal Loads and Stresses for SI Line to Loop 1 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
402F	141,460	36,939	5,688
402N	141,520	29,875	5,578
400	50,417	29,028	5,880
398F	49,160	38,047	6,320
396F	49,408	41,113	6,524
396N	50,417	44,269	6,797
392F	50,417	57,042	7,565
392N	49,438	53,217	7,255
390F	50,139	57,111	7,547
388	49,331	61,933	7,770

Notes: See Figure 3-5 for piping layout.
Axial force includes pressure.

Table 3-12 Summary of D.C. Cook Unit 2 Normal Loads and Stresses for SI Line to Loop 2 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
400N	140,052	55,872	5,937
400F	139,916	46,864	5,789
404	48,812	44,641	6,688
408N	48,813	75,277	8,531
408F	50,287	70,037	8,336
410N	49,290	66,775	8,058
412	50,380	73,888	8,576

Notes: See Figure 3-5 for piping layout.
Axial force includes pressure.

Table 3-13 Summary of D.C. Cook Unit 2 Normal Loads and Stresses for SI Line to Loop 3 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
158F	141,301	53,876	5,950
158N	141,375	43,159	5,783
156	50,271	41,688	6,630
150F	49,306	50,062	7,054
150N	49,549	45,600	6,806
148F	50,028	43,022	6,690
146	49,131	46,729	6,840

Notes: See Figure 3-5 for piping layout.
Axial force includes pressure.

Table 3-14 Summary of D.C. Cook Unit 2 Normal Loads and Stresses for SI Line to Loop 4 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
294X	141,974	71,479	6,253
288F	50,872	65,276	8,098
288N	48,564	53,459	7,198
286F	50,897	36,806	6,388
284	50,947	16,019	5,141

Notes: See Figure 3-5 for piping layout.
Axial force includes pressure.

Table 3-15 Summary of D.C. Cook Unit 2 Normal Loads and Stresses for SI Line to Loop 1 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
181	51,407	117,539	11,285
178	50,122	103,745	10,350
174	50,123	56,258	7,494
170F	51,130	47,551	7,053
170N	49,891	39,773	6,484
168F	49,987	50,593	7,142
168N	51,100	61,397	7,883
164F	48,477	98,095	9,876
164N	50,492	92,512	9,705
162F	51,098	104,394	10,469
162N	51,142	103,701	10,431
156F	49,722	6,027	4,440
155	49,348	7,126	4,475
154N	50,285	7,805	4,593
150	50,285	16,340	5,106
148X	90,561	16,827	5,505
148T	90,071	11,259	5,309
146F	90,054	11,939	5,329
146N	89,936	14,095	5,388
144F	89,936	16,188	5,451
144N	89,821	16,818	5,464
142F	89,821	16,610	5,458
142N	89,561	17,940	5,484
138F	88,013	15,678	5,330
132	89,077	31,253	5,860

Notes: See Figure 3-6 for piping layout.
Axial force includes pressure.

Table 3-16 Summary of D.C. Cook Unit 2 Normal Loads and Stresses for SI Line to Loop 2 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
511	51,173	114,587	11,089
509	50,116	100,647	10,163
504	49,458	53,095	7,249
500F	51,388	52,236	7,356
500N	49,830	43,232	6,687
498F	50,049	64,943	8,010
498N	51,380	78,882	8,958
494F	51,380	120,987	11,491
494N	50,555	113,270	10,959
492F	51,124	106,824	10,618
492N	50,858	117,484	11,237
490F	48,660	127,460	11,657
490N	48,165	127,132	11,597
484F	49,722	8,637	4,597
484N	50,276	6,088	4,489
482F	50,276	5,914	4,478
480F	49,469	10,444	4,685
480N	49,296	16,302	5,023
479	50,281	20,151	5,335
96X	90,558	20,439	5,614
96T	89,894	19,177	5,539
94F	89,885	19,530	5,550
94N	90,238	19,017	5,553
90F	90,238	18,921	5,551
88F	90,144	11,703	5,327
88N	89,910	10,609	5,281
86F	89,910	10,418	5,275
86N	90,180	10,042	5,279
H06-299	89,852	13,396	5,362
78	90,205	14,979	5,429

Notes: See Figure 3-7 for piping layout.
Axial force includes pressure.

Table 3-17 Summary of D.C. Cook Unit 2 Normal Loads and Stresses for SI Line to Loop 3 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
550	51,346	88,378	9,526
546	49,230	75,253	8,563
540	50,346	32,159	6,063
536F	51,368	48,905	7,154
536N	49,832	38,947	6,429
534F	50,047	64,236	7,968
534N	51,267	77,430	8,861
530F	51,267	121,932	11,538
530N	50,545	116,043	11,125
528F	48,469	78,623	8,704
528N	48,736	85,323	9,129
526F	48,650	123,071	11,392
526N	51,367	122,526	11,582
520F	49,593	10,438	4,695
518F	49,627	10,029	4,673
518N	50,453	12,290	4,876
516	50,453	14,469	5,008
96Y	90,730	14,827	5,454
96T	89,894	19,177	5,539
94F	89,885	19,530	5,550
94N	90,238	19,017	5,553
90F	90,238	18,921	5,551
88F	90,144	11,703	5,327
88N	89,910	10,609	5,281
86F	89,910	10,418	5,275
86N	90,180	10,042	5,279
H06-299	89,852	13,396	5,362
78	90,205	14,979	5,429

Notes: See Figure 3-7 for piping layout.
Axial force includes pressure.

Table 3-18 Summary of D.C. Cook Unit 2 Normal Loads and Stresses for SI Line to Loop 4 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
221	51,356	93,826	9,855
218	49,415	80,624	8,902
214	50,163	37,535	6,371
210F	51,132	44,426	6,865
210N	49,855	35,917	6,249
208F	50,023	50,461	7,137
208N	51,087	62,028	7,920
204F	51,087	101,028	10,266
204N	50,509	95,889	9,910
202F	51,074	89,179	9,552
202N	50,762	96,683	9,978
200F	48,750	104,373	10,276
200N	51,139	100,307	10,227
194F	49,973	7,815	4,568
192F	49,411	9,623	4,631
192N	50,492	11,124	4,810
188	50,492	19,368	5,305
148Y	90,769	19,842	5,608
148T	90,071	11,259	5,309
146F	90,054	11,939	5,329
146N	89,936	14,095	5,388
144F	89,936	16,188	5,451
144N	89,821	16,818	5,464
142F	89,821	16,610	5,458
142N	89,561	17,940	5,484
138F	88,013	15,678	5,330
132	89,077	31,253	5,860

Notes: See Figure 3-6 for piping layout.
Axial force includes pressure.

Table 3-19 Summary of D.C. Cook Unit 1 Faulted Loads and Stresses for SI Line to Loop 1 Cold Leg			
Weld Location Node	**Axial Force (lbf)**	**Moment (in-lbf)**	**Total Stress (psi)**
403F	141,892	179,151	7,956
402	142,077	164,448	7,730
398	50,921	157,807	13,668

Notes: See Figure 3-2 for piping layout.
Axial force includes pressure.

Table 3-20 Summary of D.C. Cook Unit 1 Faulted Loads and Stresses for SI Line to Loop 2 Cold Leg			
Weld Location Node	**Axial Force (lbf)**	**Moment (in-lbf)**	**Total Stress (psi)**
400N	142,223	183,518	8,037
400F	142,400	168,062	7,799
406	51,240	162,347	13,967

Notes: See Figure 3-2 for piping layout.
Axial force includes pressure.

Table 3-21 Summary of D.C. Cook Unit 1 Faulted Loads and Stresses for SI Line to Loop 3 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
158F	142,168	235,243	8,854
158N	141,990	203,960	8,353
152	50,834	190,576	15,632

Notes: See Figure 3-2 for piping layout.
Axial force includes pressure.

Table 3-22 Summary of D.C. Cook Unit 1 Faulted Loads and Stresses for SI Line to Loop 4 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
294X	142,497	109,287	6,871
290	51,391	106,093	10,596
288N	51,085	96,236	9,978
286F	50,951	80,705	9,032
284	51,863	67,914	8,338

Notes: See Figure 3-2 for piping layout.
Axial force includes pressure.

Table 3-23 Summary of D.C. Cook Unit 1 Faulted Loads and Stresses for SI Line to Loop 1 Hot Leg			
Weld Location Node	**Axial Force (lbf)**	**Moment (in-lbf)**	**Total Stress (psi)**
181	51,396	236,587	18,445
178	50,955	222,790	17,579
174	50,901	172,702	14,562
170F	51,911	97,101	10,097
170N	50,774	83,873	9,209
168F	50,374	92,879	9,717
168N	51,636	99,827	10,239
164F	51,341	119,428	11,394
164N	50,828	116,217	11,158
162F	51,471	154,640	13,522
162N	51,525	154,330	13,508
156F	51,419	41,947	6,740
155	51,330	56,352	7,599
154N	52,302	52,526	7,448
152	52,292	75,804	8,848
148X	92,558	86,547	7,726
148T	93,990	86,014	7,789
146F	93,965	88,645	7,867
146N	93,348	111,220	8,517
144F	93,343	152,278	9,760
144N	94,240	172,198	10,413
142F	94,225	173,692	10,457
142N	92,710	141,507	9,399
136	93,358	106,468	8,374
132	92,704	115,447	8,609

Notes: See Figure 3-3 for piping layout.
Axial force includes pressure.

Table 3-24 Summary of D.C. Cook Unit 1 Faulted Loads and Stresses for SI Line to Loop 2 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
511	51,358	242,447	18,795
509	50,971	231,313	18,093
504	50,923	178,790	14,930
500F	52,122	104,804	10,578
500N	50,891	89,945	9,583
498F	50,514	103,751	10,383
498N	51,897	114,808	11,161
494F	51,542	138,845	12,578
494N	50,899	134,131	12,242
492F	51,488	150,114	13,251
492N	51,462	159,665	13,824
490F	51,499	171,561	14,542
490N	51,767	174,832	14,761
484F	50,071	16,290	5,086
484N	51,033	19,495	5,357
482F	51,027	20,548	5,420
480F	50,330	21,314	5,409
480N	51,000	28,613	5,903
479	51,000	36,092	6,353
96X	91,269	36,826	6,150
96T	92,202	113,064	8,510
94F	92,191	115,326	8,577
94N	91,208	102,308	8,129
H07-299	91,188	81,280	7,491
88F	92,120	91,964	7,866
88N	91,706	88,649	7,743
86F	91,639	97,989	8,022
86N	91,654	86,656	7,680
84F	92,846	46,951	6,543
78	90,958	64,533	6,971

Notes: See Figure 3-4 for piping layout.
Axial force includes pressure.

Table 3-25 Summary of D.C. Cook Unit 1 Faulted Loads and Stresses for SI Line to Loop 3 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
550	51,593	240,235	18,681
546	51,229	216,269	17,209
540	51,171	171,146	14,491
536F	52,217	107,015	10,719
536N	50,921	92,504	9,740
534F	50,543	111,613	10,858
534N	51,836	120,710	11,511
530F	51,504	143,183	12,836
530N	50,962	141,958	12,718
528F	51,599	115,786	11,196
528N	51,309	127,870	11,899
526F	51,407	177,463	14,890
526N	51,769	182,247	15,207
520F	52,118	23,588	5,693
518F	50,567	19,945	5,346
518N	51,113	45,145	6,907
516	51,105	75,601	8,738
96Y	91,376	81,843	7,519
96T	92,202	113,064	8,510
94F	92,191	115,326	8,577
94N	91,208	102,308	8,129
H07-299	91,188	81,280	7,491
88F	92,120	91,964	7,866
88N	91,706	88,649	7,743
86F	91,639	97,989	8,022
86N	91,654	86,656	7,680
84F	92,846	46,951	6,543
78	90,958	64,533	6,971

Notes: See Figure 3-4 for piping layout.
Axial force includes pressure.

Table 3-26 Summary of D.C. Cook Unit 1 Faulted Loads and Stresses for SI Line to Loop 4 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
221	51,468	234,437	18,322
218	51,041	217,436	17,264
214	50,987	168,947	14,343
210F	51,905	98,298	10,169
210N	50,801	85,362	9,300
208F	50,401	94,785	9,834
208N	51,598	101,127	10,314
204F	51,292	121,062	11,488
204N	50,872	119,443	11,356
202F	51,478	128,025	11,922
202N	51,288	139,402	12,591
200F	51,339	152,541	13,385
200N	51,491	154,903	13,540
194F	51,721	16,930	5,260
192F	51,387	28,263	5,914
191	51,749	41,533	6,742
190	51,739	94,322	9,916
148Y	92,006	106,550	8,301
148T	93,990	86,014	7,789
146F	93,965	88,645	7,867
146N	93,348	111,220	8,517
144F	93,343	152,278	9,760
144N	94,240	172,198	10,413
142F	94,225	173,692	10,457
142N	92,710	141,507	9,399
136	93,358	106,468	8,374
132	92,704	115,447	8,609

Notes: See Figure 3-3 for piping layout.
Axial force includes pressure.

Table 3-27 Summary of D.C. Cook Unit 2 Faulted Loads and Stresses for SI Line to Loop 1 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
402F	142,272	186,610	8,088
402N	142,122	167,777	7,784
400	50,990	164,003	14,046
398F	50,906	79,898	8,980
396F	51,057	78,610	8,915
396N	50,900	77,904	8,860
392F	50,865	103,989	10,426
392N	50,509	103,782	10,384
390F	50,781	108,618	10,697
388	51,047	114,834	11,093

Notes: See Figure 3-5 for piping layout.
Axial force includes pressure.

Table 3-28 Summary of D.C. Cook Unit 2 Faulted Loads and Stresses for SI Line to Loop 2 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
400N	142,665	229,125	8,776
400F	142,671	201,525	8,339
404	51,524	189,824	15,643
408N	51,372	130,827	12,082
408F	50,718	129,303	11,937
410N	50,961	129,945	11,995
412	51,306	135,107	12,334

Notes: See Figure 3-5 for piping layout.
Axial force includes pressure.

Table 3-29 Summary of D.C. Cook Unit 2 Faulted Loads and Stresses for SI Line to Loop 3 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
158F	142,515	276,095	9,514
158N	142,214	243,066	8,980
156	51,090	235,969	18,383
150F	50,972	117,263	11,233
150N	50,679	117,315	11,212
148F	50,575	124,252	11,621
146	51,246	129,438	11,988

Notes: See Figure 3-5 for piping layout.
Axial force includes pressure.

Table 3-30 Summary of D.C. Cook Unit 2 Faulted Loads and Stresses for SI Line to Loop 4 Cold Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
294X	142,710	126,196	7,147
288F	51,609	118,683	11,371
288N	51,812	107,590	10,720
286F	51,674	90,266	9,667
284	52,214	67,672	8,352

Notes: See Figure 3-5 for piping layout.
Axial force includes pressure.

Table 3-31 Summary of D.C. Cook Unit 2 Faulted Loads and Stresses for SI Line to Loop 1 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
181	52,192	288,856	21,654
178	51,311	268,518	20,359
174	51,016	193,759	15,838
170F	51,981	109,528	10,851
170N	50,749	95,873	9,928
168F	50,334	99,233	10,096
168N	51,639	103,828	10,480
164F	51,274	123,698	11,645
164N	50,892	120,666	11,431
162F	51,535	168,720	14,374
162N	51,559	168,758	14,379
156F	51,289	37,504	6,462
155	51,170	49,694	7,185
154N	51,925	46,119	7,032
150	51,915	74,882	8,761
148X	92,182	79,741	7,499
148T	93,376	68,413	7,222
146F	93,353	69,602	7,257
146N	93,009	85,005	7,704
144F	93,001	121,875	8,820
144N	93,838	139,550	9,402
142F	93,820	149,270	9,695
142N	92,168	123,274	8,817
138F	93,185	88,104	7,808
132	92,707	106,504	8,339

Notes: See Figure 3-6 for piping layout.
Axial force includes pressure.

Table 3-32 Summary of D.C. Cook Unit 2 Faulted Loads and Stresses for SI Line to Loop 2 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
511	51,890	280,839	21,148
509	51,237	263,700	20,063
504	51,021	188,612	15,529
500F	52,210	110,594	10,934
500N	50,890	95,640	9,926
498F	50,493	109,017	10,698
498N	51,934	118,607	11,393
494F	51,560	142,341	12,790
494N	50,933	137,653	12,456
492F	51,525	153,238	13,442
492N	51,479	166,255	14,222
490F	51,545	180,534	15,086
490N	51,808	185,315	15,395
484F	50,180	15,866	5,069
484N	51,096	19,658	5,372
482F	51,078	21,432	5,478
480F	50,292	22,414	5,472
480N	51,043	29,615	5,967
479	51,043	37,398	6,435
96X	91,315	38,171	6,193
96T	92,030	124,115	8,835
94F	92,019	125,845	8,886
94N	91,273	111,297	8,405
90F	91,261	72,981	7,244
88F	93,068	88,978	7,828
88N	91,869	88,845	7,758
86F	91,827	107,406	8,318
86N	92,520	105,222	8,290
H06-299	92,489	52,818	6,701
78	91,008	67,429	7,062

Notes: See Figure 3-7 for piping layout.
Axial force includes pressure.

Table 3-33 Summary of D.C. Cook Unit 2 Faulted Loads and Stresses for SI Line to Loop 3 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
550	52,154	262,513	20,067
546	51,453	236,528	18,446
540	51,238	171,927	14,543
536F	52,250	112,160	11,031
536N	50,888	97,253	10,023
534F	50,488	116,111	11,124
534N	51,878	124,720	11,756
530F	51,540	148,615	13,166
530N	50,985	146,608	12,999
528F	51,647	125,244	11,769
528N	51,382	138,602	12,550
526F	51,479	188,600	15,566
526N	51,806	194,538	15,950
520F	52,308	24,770	5,779
518F	50,194	18,533	5,231
518N	51,068	45,104	6,901
516	51,063	79,207	8,952
96Y	91,336	85,935	7,640
96T	92,030	124,115	8,835
94F	92,019	125,845	8,886
94N	91,273	111,297	8,405
90F	91,261	72,981	7,244
88F	93,068	88,978	7,828
88N	91,869	88,845	7,758
86F	91,827	107,406	8,318
86N	92,520	105,222	8,290
H06-299	92,489	52,818	6,701
78	91,008	67,429	7,062

Notes: See Figure 3-7 for piping layout.
Axial force includes pressure.

Table 3-34 Summary of D.C. Cook Unit 2 Faulted Loads and Stresses for SI Line to Loop 4 Hot Leg

Weld Location Node	Axial Force (lbf)	Moment (in-lbf)	Total Stress (psi)
221	52,162	258,524	19,828
218	51,335	238,590	18,561
214	51,066	169,236	14,367
210F	51,969	103,092	10,463
210N	50,837	89,464	9,550
208F	50,436	96,334	9,930
208N	51,657	102,815	10,420
204F	51,333	124,048	11,671
204N	50,912	122,433	11,539
202F	51,529	138,325	12,546
202N	51,304	149,320	13,189
200F	51,377	156,054	13,600
200N	51,542	157,825	13,720
194F	51,444	18,730	5,345
192F	51,062	23,137	5,579
192N	51,531	33,933	6,267
188	51,520	85,439	9,364
148Y	91,787	90,431	7,801
148T	93,376	68,413	7,222
146F	93,353	69,602	7,257
146N	93,009	85,005	7,704
144F	93,001	121,875	8,820
144N	93,838	139,550	9,402
142F	93,820	149,270	9,695
142N	92,168	123,274	8,817
138F	93,185	88,104	7,808
132	92,707	106,504	8,339

Notes: See Figure 3-6 for piping layout.
Axial force includes pressure.

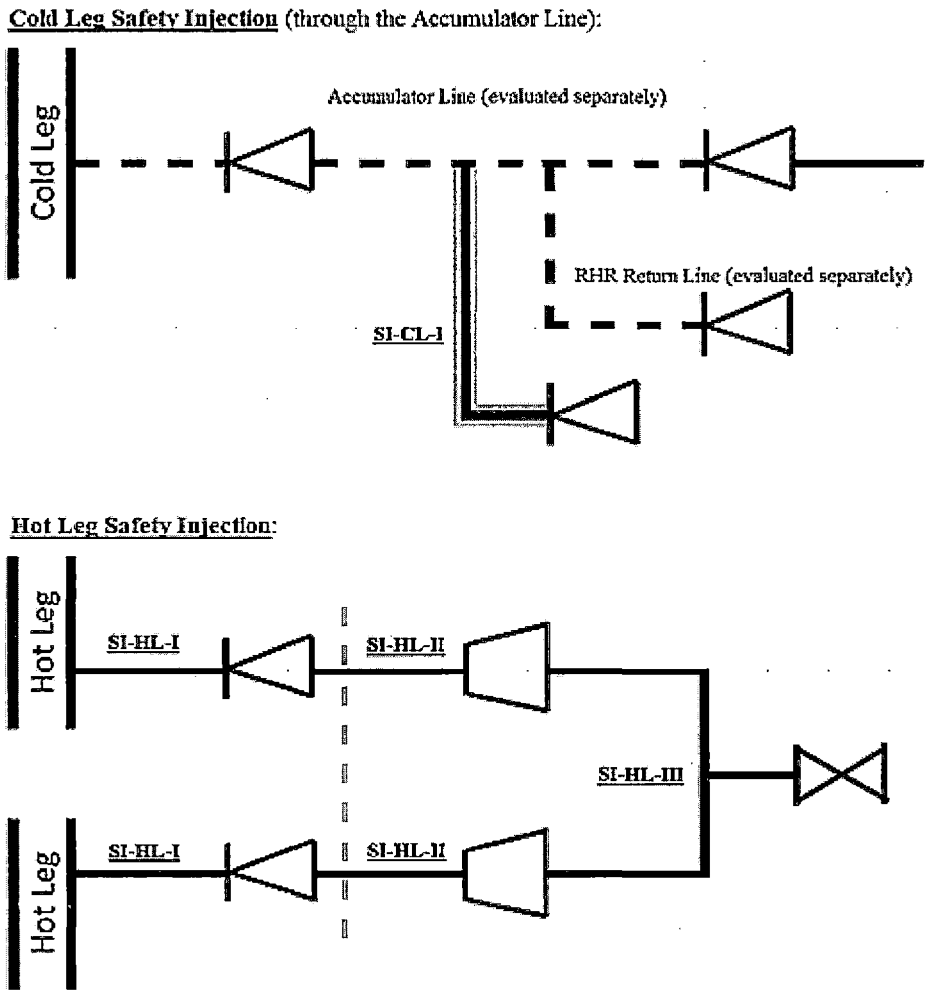

Figure 3-1 D.C. Cook Units 1 and 2 Typical Piping Layout for SI lines

(Note: division between evaluation segments SI-HL-I and SI-HL-II occurs shortly beyond the check valves, where the temperature transition occurs, as defined in the piping analyses)

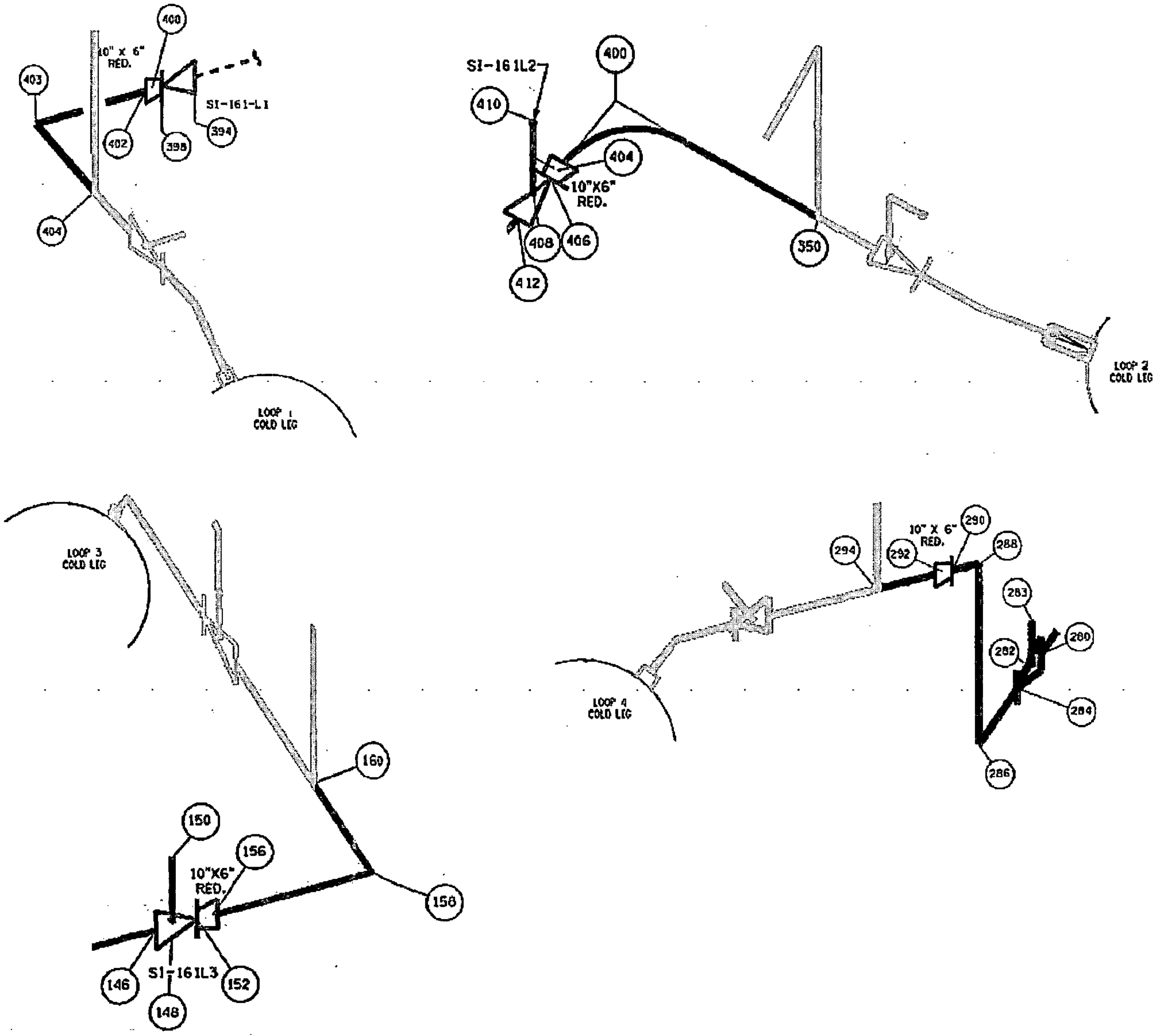

Figure 3-2 D.C. Cook Unit 1 Cold Leg SI Line Layout Showing Weld Locations with Node Points – Loops 1 through 4

(Note: gray lines represent the Accumulator lines which are evaluated in a separate report)

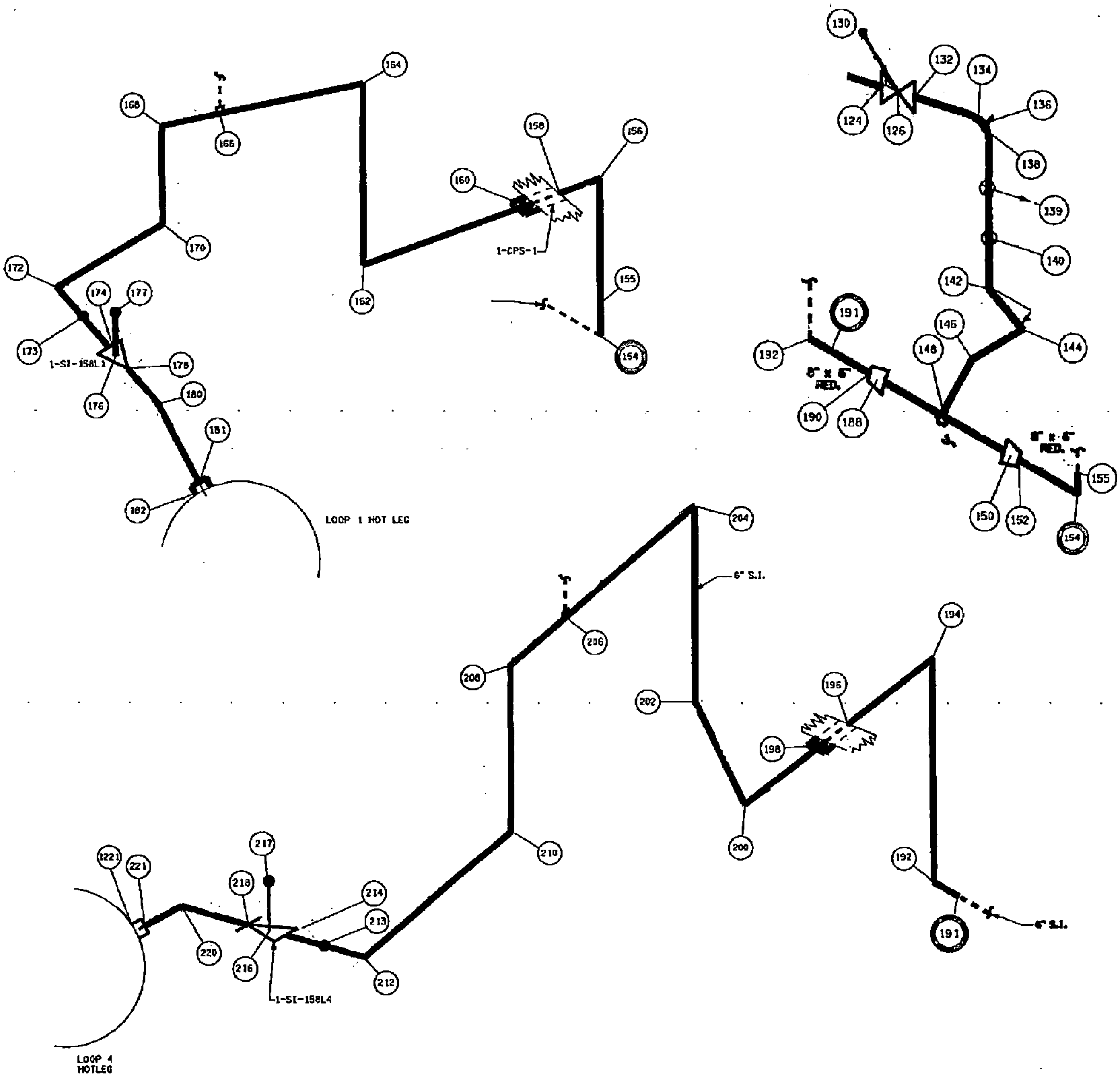

Figure 3-3 D.C. Cook Unit 1 Hot Leg SI Line Layout Showing Weld Locations with Node Points – Loops 1 and 4

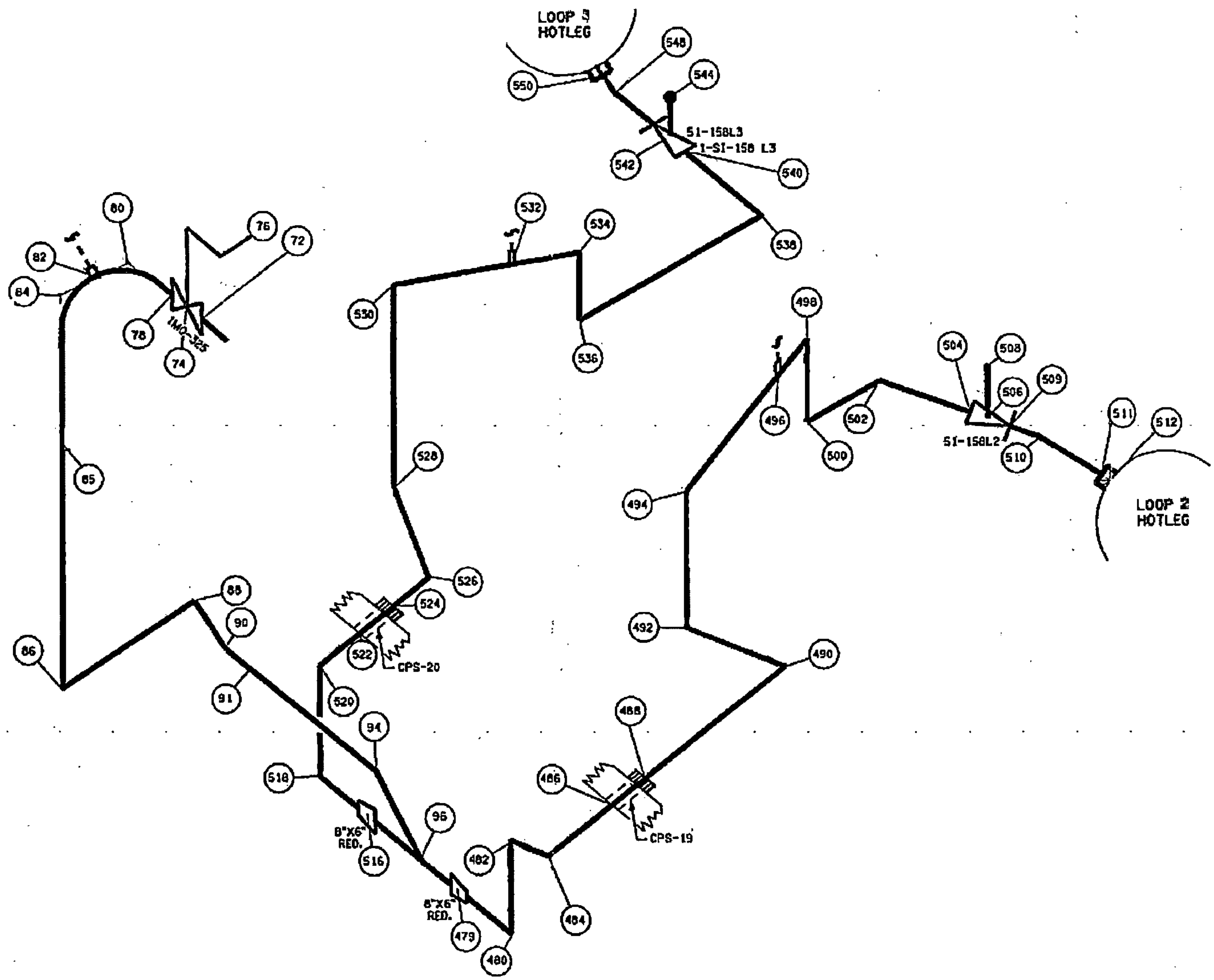

Figure 3-4 D.C. Cook Unit 1 Hot Leg SI Line Layout Showing Weld Locations with Node Points – Loops 2 and 3

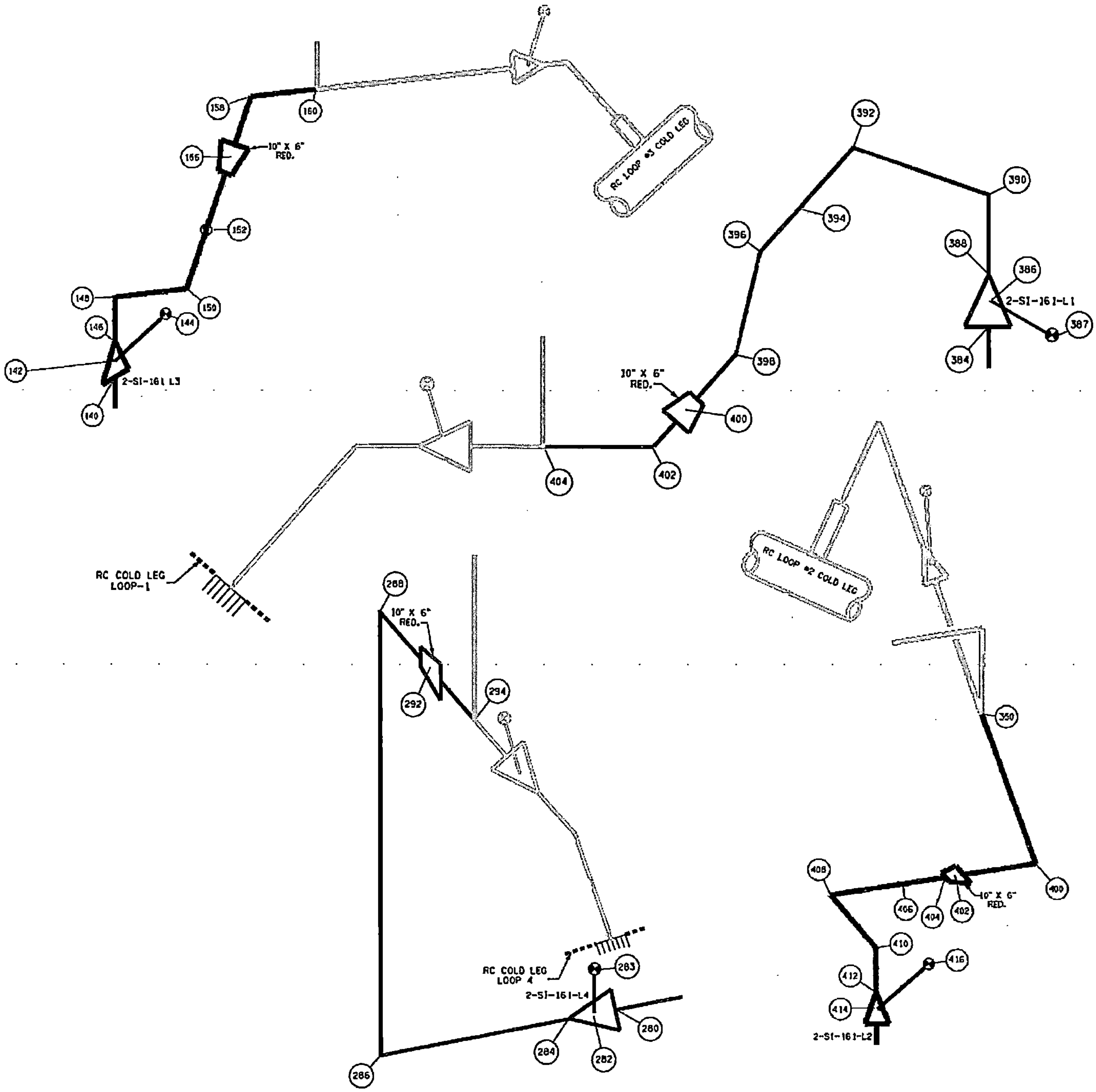

Figure 3-5 D.C. Cook Unit 2 Cold Leg SI Line Layout Showing Weld Locations with Node Points – Loops 1 through 4

(Note: gray lines represent the Accumulator lines which are evaluated in a separate report)

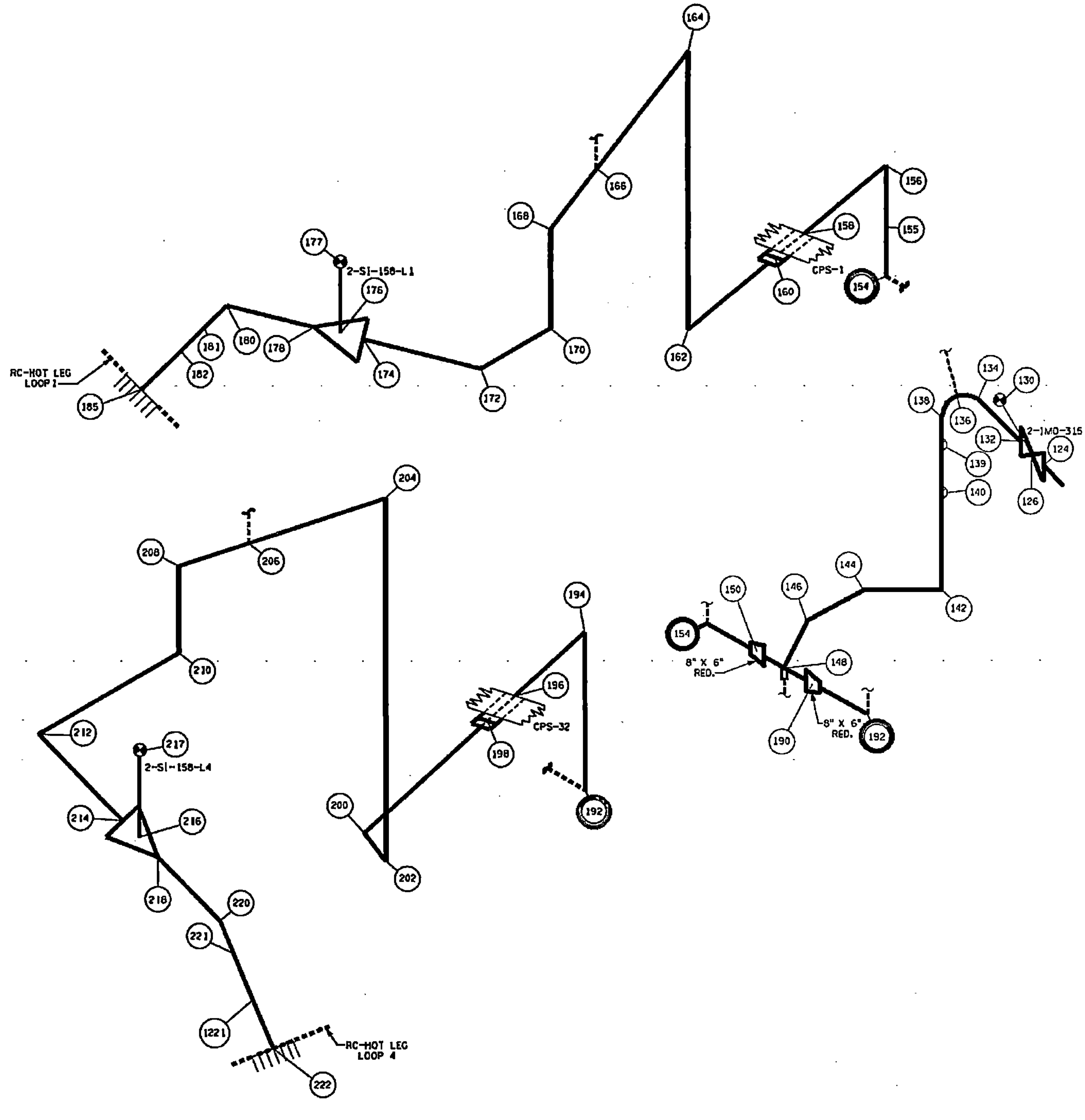

Figure 3-6 D.C. Cook Unit 2 Hot Leg SI Line Layout Showing Weld Locations with Node Points – Loops 1 and 4

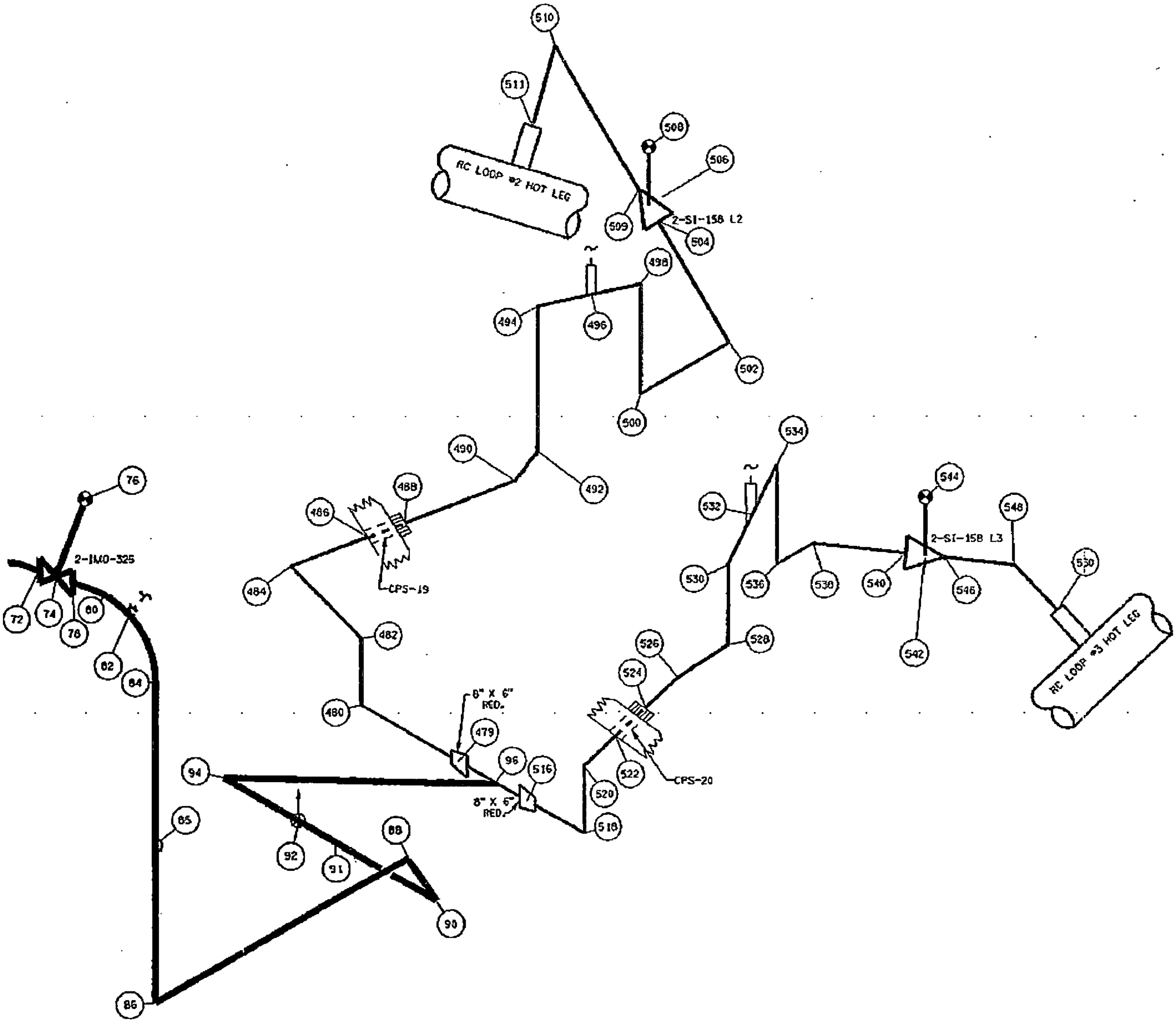

Figure 3-7 D.C. Cook Unit 2 Hot Leg SI Line Layout Showing Weld Locations with Node Points – Loops 2 and 3

4.0 MATERIAL CHARACTERIZATION

4.1 SI LINE PIPE MATERIAL AND WELD PROCESS

The material type of the SI lines for D.C. Cook Units 1 and 2 is either A376 TP316 for seamless pipes or A403 WP 316 for fittings. This is a wrought product of the type used for the piping in several PWR plants. The welding processes used are Shielded Metal Arc Weld (SMAW) and Submerged Arc Weld (SAW).

In the following sections the tensile properties of the materials are presented for use in the Leak-Before-Break analyses.

4.2 TENSILE PROPERTIES

Certified Materials Test Reports (CMTRs) with mechanical properties were not readily available for the D.C. Cook Units 1 and 2 SI lines. Therefore, ASME Code mechanical properties were used to establish the tensile properties for the Leak-Before-Break analyses.

For the A376 TP316 (seamless pipe) and A403 WP316 (wrought fittings) material types, the representative properties at operating temperatures are established from the tensile properties given by Section II of the 2007 ASME Boiler and Pressure Vessel Code. Code tensile properties at temperatures for the operating conditions considered in this LBB analysis were obtained by linear interpolation of tensile properties provided in the Code.

Material modulus of elasticity was also interpolated from ASME Code values for the operating temperatures considered, and Poisson's ratio was taken as 0.3. The yield strengths, ultimate strengths, and elastic moduli for the pipe material at applicable operating temperatures are tabulated in Table 4-1.

4.3 REFERENCE

4-1 ASME Boiler and Pressure Vessel Code Section II, 2007 Edition through 2008 Addenda.

Table 4-1 Material Properties for Operating Temperature Conditions on D.C. Cook Units 1 and 2 SI Lines

Segment	Operating Temperature (°F)	Ultimate Strength (psi)	Yield Strength (psi)	Elastic Modulus (psi)
SI-HL-I	618	71,800	18,756	25,210,000
SI-CL-I SI-HL-II SI-HL-III	120	75,000	28,960	27,992,308

5.0 CRITICAL LOCATIONS

5.1 CRITICAL LOCATIONS

The Leak-Before-Break (LBB) evaluation margins are to be demonstrated for the critical locations (governing locations). Such locations are established based on the loads (Section 3.3) and the material properties established in Section 4.2. These locations are defined below for the D.C. Cook SI lines.

Critical Locations for the SI lines:

All the welds in the SI lines are fabricated using the Shielded Metal Arc Weld (SMAW) or Submerged Arc Weld (SAW) processes. The pipe material type is A376 TP316 or A403 WP316. The governing locations were established on the basis of the pipe geometry, welding process, material type, operating temperature, operating pressure, and the highest faulted stresses at the welds.

Table 5-1 shows the highest faulted stress and the corresponding weld location node for each welding process type in each segment of the hot leg and cold leg SI lines, enveloping both D.C. Cook Units 1 and 2. Definition of the piping segments and the corresponding operating pressure and temperature parameters are from Table 3-1, Table 3-2, and Figure 3-1. Figures 5-1 through 5-4 show the locations of the critical welds.

The weld naming convention used in this report is as follows:

> *<analysis node number>*_U*<Unit 1 or 2>*L*<Loop 1/2/3/4>*
> "L14" indicates the piping where SI lines from Loop 1 and Loop 4 have joined together.

Table 5-1 Critical Analysis Location for Leak-Before-Break of D.C. Cook Units 1 and 2 SI Lines

Segment	Pipe Size	Welding Process	Operating Pressure (psig)	Operating Temperature (°F)	Maximum Faulted Stress (psi)	Weld Location Node
SI-CL-I	10-inch	SAW	2,235	120	9,514	158F_U2L3
	6-inch	SMAW	2,235	120	18,383	156_U2L3
		SAW	2,235	120	12,082	408N_U2L2
SI-HL-I	6-inch	SMAW	2,235	618	21,654	181_U2L1
		SAW	2,235	618	11,031	536F_U2L3
SI-HL-II	6-inch	SMAW	2,235	120	15,950	526N_U2L3
		SAW	2,235	120	15,566	526F_U2L3
SI-HL-III	8-inch	SMAW	2,235	120	9,399	142N_U1L14
		SAW	2,235	120	10,457	142F_U1L14

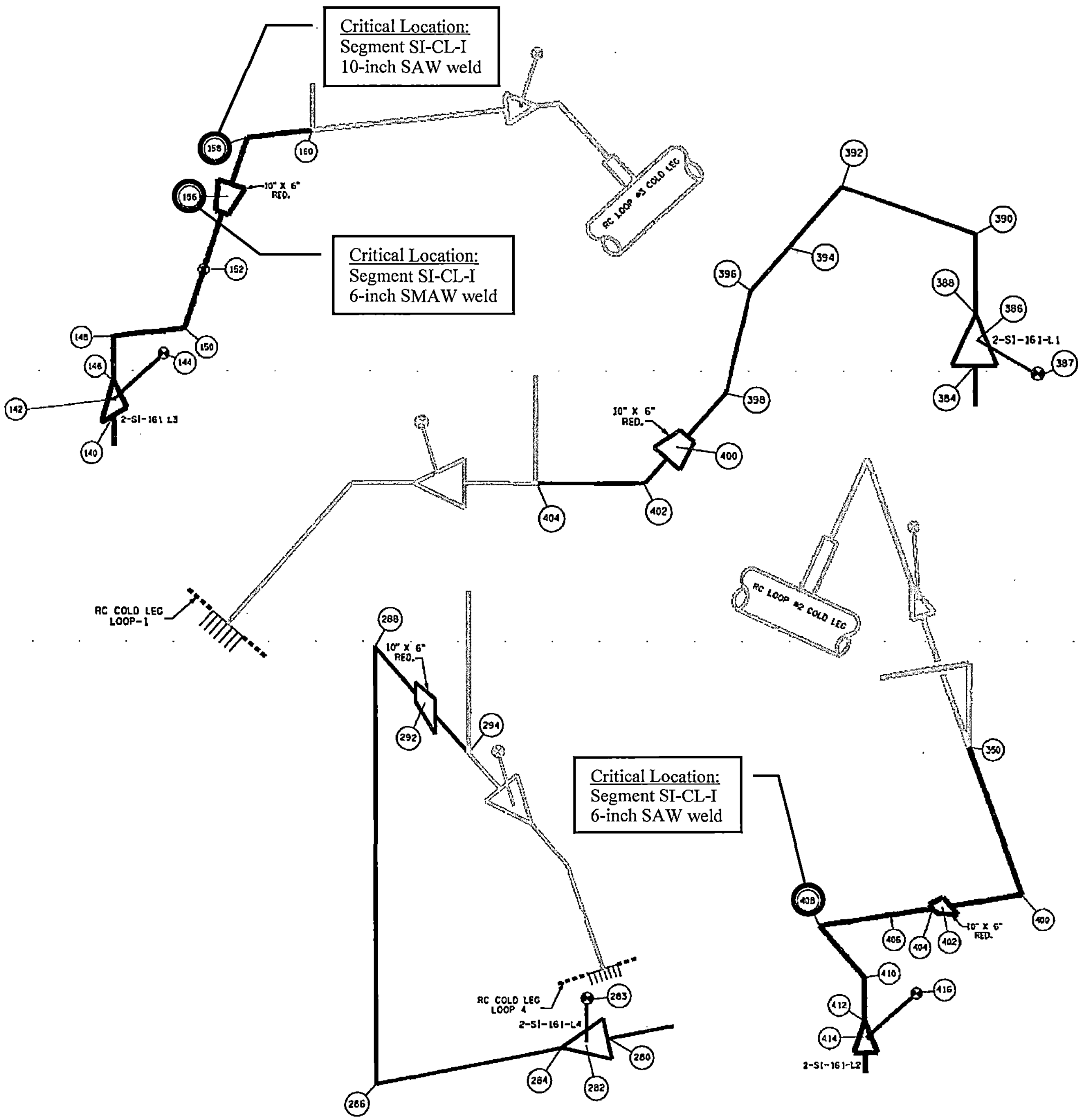

Figure 5-1 D.C. Cook Unit 2 Cold Leg SI Line Critical Weld Locations

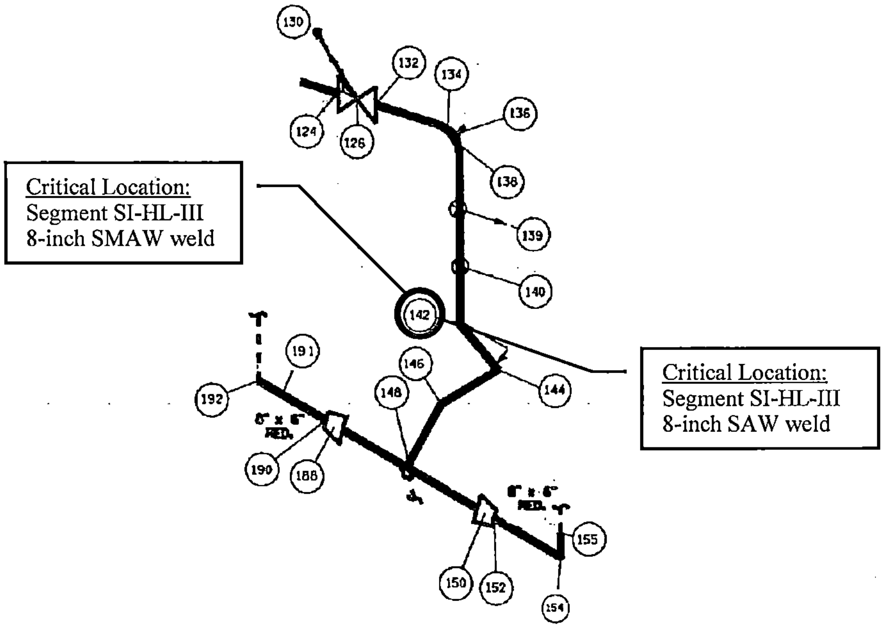

Figure 5-2 D.C. Cook Unit 1 Hot Leg SI Line Loops 1 and 4 Critical Weld Locations

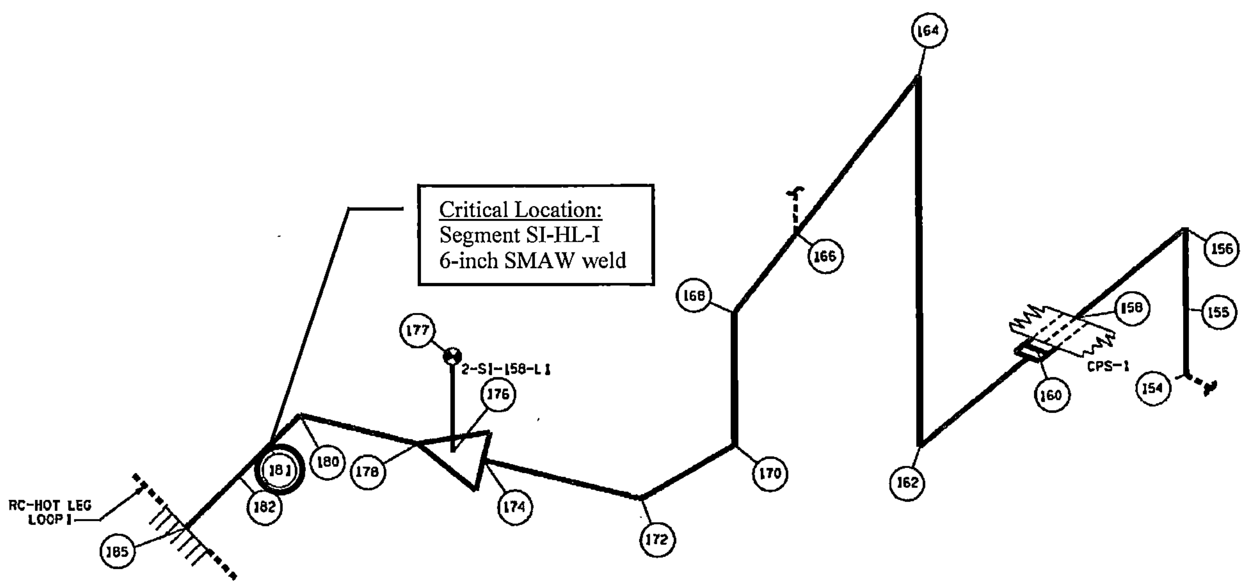

Figure 5-3 D.C. Cook Unit 2 Hot Leg SI Line Loop 1 Critical Weld Locations

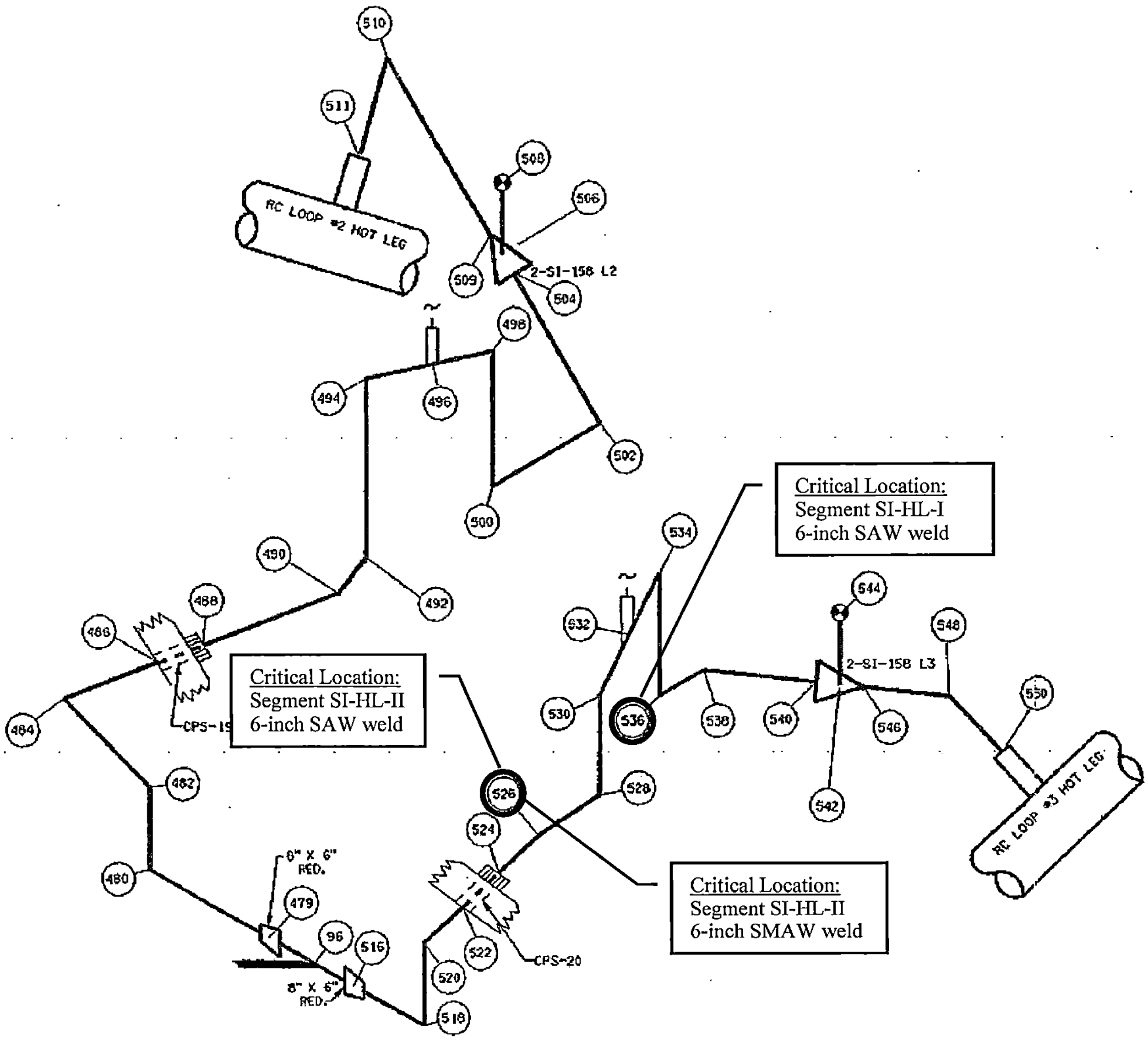

Figure 5-4 D.C. Cook Unit 2 Hot Leg SI Line Loop 3 Critical Weld Locations

6.0 LEAK RATE PREDICTIONS

6.1 INTRODUCTION

The purpose of this section is to discuss the method which is used to predict the flow through postulated through-wall cracks and present the leak rate calculation results for through-wall circumferential cracks.

6.2 GENERAL CONSIDERATIONS

The flow of hot pressurized water through an opening to a lower back pressure causes flashing which can result in choking. 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

6.3 CALCULATION METHOD

The basic method used in the leak rate calculations is the method developed by [

]a,c,e

The flow rate through a crack was calculated in the following manner. Figure 6-1 (from Reference 6-2) was used to estimate the critical pressure, P_c, for the SI line enthalpy condition and an assumed flow. Once P_c was found for a given mass flow, the [ ]a,c,e was found from Figure 6-2 (taken from Reference 6-2). For all cases considered, [ ]a,c,e therefore, this method will yield the two-phase pressure drop due to momentum effects as illustrated in Figure 6-3, where P_o is the operating pressure. Now using the assumed flow rate, G, the frictional pressure drop can be calculated using

$$\Delta P_f = \left[\qquad \right]^{a,c,e} \qquad (6\text{-}1)$$

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

The frictional pressure drop using Equation 6-1 is then calculated for the assumed flow rate and added to the [ ]a,c,e to obtain the total pressure drop from the primary system to the atmosphere.

That is, for the SI lines:

Absolute Pressure - 14.7 = [ ]^{a,c,e} (6-2)

for a given assumed flow rate G. If the right-hand side of Equation 6-2 does not agree with the pressure difference between the SI line and the atmosphere, then the procedure is repeated until Equation 6-2 is satisfied to within an acceptable tolerance which in turn leads to a flow rate value for a given crack size.

For the single phase cases with lower temperature, leakage rate is calculated by the following equation (Reference 6-4) with the crack opening area obtained by the method from Reference 6-3.

$$Q = A\,(2g\Delta P/k\rho)^{0.5} \quad ft^3/sec; \qquad (6\text{-}3)$$

where, ΔP = pressure difference between stagnation and back pressure (lb/ft^2), g = acceleration of gravity (ft/sec^2), ρ = fluid density at atmospheric pressure (lb/ft^3), k = friction loss including passage loss, inlet and outlet of the through-wall crack, A = crack opening area (ft^2).

6.4 LEAK RATE CALCULATIONS

Leak rate calculations were made as a function of crack length at the governing locations previously identified in Section 5.1. The normal operating loads of Table 3-3 through Table 3-10 (for Unit 1), and Table 3-11 through Table 3-18 (for Unit 2), were applied in these calculations. The crack opening areas were estimated using the method of Reference 6-3 and the leak rates were calculated using the formulation described above. The material properties of Section 4.2 (see Table 4-1) were used for these calculations.

The flaw sizes to yield a leak rate of 8 gpm were calculated at the governing locations and are given in Table 6-1 for D.C. Cook Units 1 and 2. The flaw sizes, so determined, are called leakage flaw sizes.

The D.C. Cook Units 1 and 2 RCS pressure boundary leak detection system meets the intent of Regulatory Guide 1.45 and meets a leak detection capability of 0.8 gpm. Thus, to satisfy the margin of 10 on the leak rate, the flaw sizes (leakage flaw sizes) are determined which yield a leak rate of 8 gpm.

6.5 REFERENCES

6-1 [

]a,c,e

6-2 M. M. El-Wakil, "Nuclear Heat Transport, International Textbook Company," New York, N.Y, 1971.

6-3 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.

6-4 Crane, D. P., "Handbook of Hydraulic Resistance Coefficient," Flow of Fluids through Valves, Fittings, and Pipe by the Engineering Division of Crane, 1981, Technical Paper No. 410.

Table 6-1 Flaw Sizes Yielding a Leak Rate of 8 gpm for the D.C. Cook Units 1 and 2 SI lines

Segment	Pipe Size	Welding Process	Weld Location Node	Leakage Flaw Size (in)
SI-CL-I	10-inch	SAW	158F_U2L3	5.25
	6-inch	SMAW	156_U2L3	4.14
		SAW	408N_U2L2	3.66
SI-HL-I	6-inch	SMAW	181_U2L1	2.93
		SAW	536F_U2L3	3.96
SI-HL-II	6-inch	SMAW	526N_U2L3	3.06
		SAW	526F_U2L3	3.10
SI-HL-III	8-inch	SMAW	142N_U1L14	5.00
		SAW	142F_U1L14	5.01

a,c,e

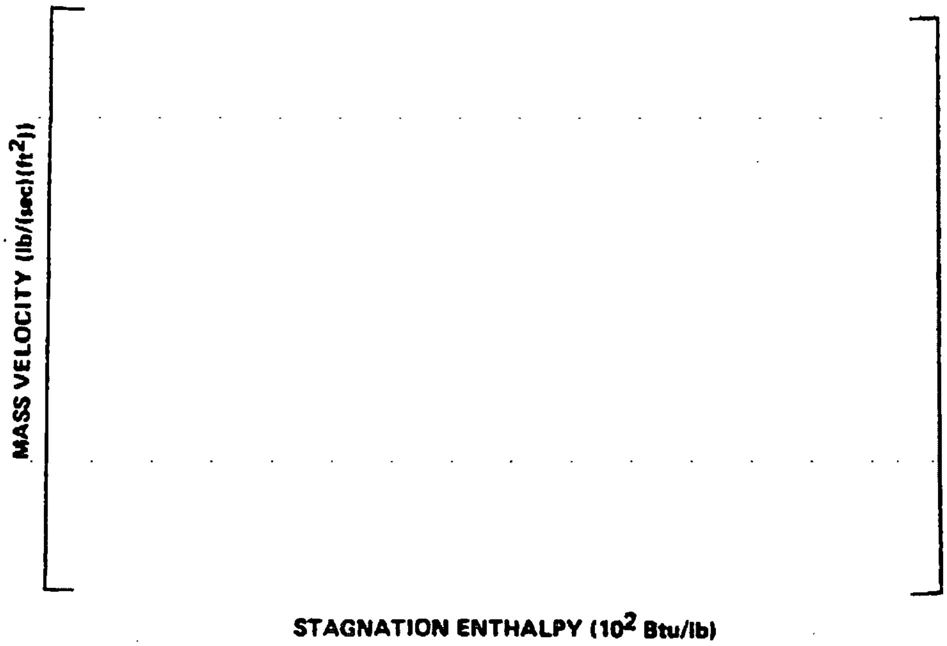

Figure 6-1 Analytical Predictions of Critical Flow Rates of Steam-Water Mixtures

a,c,e

CRITICAL PRESSURE RATIO (p_c/p_o)

LENGTH/DIAMETER RATIO (L/D)

Figure 6-2 [ ][a,c,e] Pressure Ratio as a Function of L/D

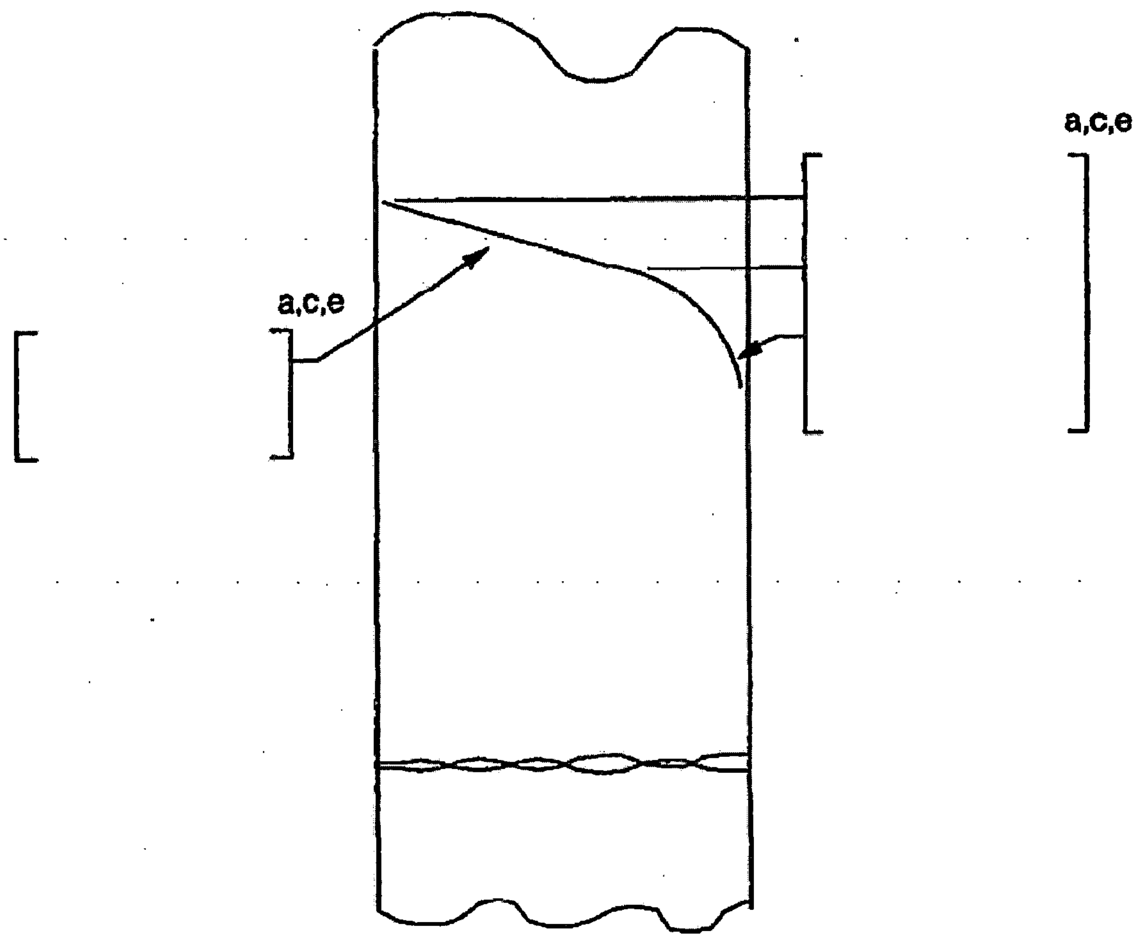

Figure 6-3 Idealized Pressure Drop Profile Through a Postulated Crack

7.0 FRACTURE MECHANICS EVALUATION

7.1 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 plastic instability method, based on traditional plastic limit load concepts, but accounting for strain hardening and taking into account the presence of a flaw. The flawed pipe 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. The flow stress is generally taken as the average of the yield and ultimate tensile strength of the material at the temperature of interest. This methodology has been shown to be applicable to ductile piping through a large number of experiments and will be used here to predict the critical flaw size in the SI line piping. The failure criterion has been obtained by requiring equilibrium of the section containing the flaw (Figure 7-1) when loads are applied. The detailed development is provided in Appendix A for a through-wall circumferential flaw in a pipe with internal pressure, axial force, and imposed bending moments. The limit moment for such a pipe is given by:

[ ]a,c,e

where:

[

]a,c,e

The analytical model described above accurately accounts for the piping 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 7-1). For application of the limit load methodology, the material, including consideration of the configuration, must have a sufficient ductility and ductile tearing resistance to sustain the limit load.

7.2 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 cracks 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 a selected location.

7.3 RESULTS OF CRACK STABILITY EVALUATION

A stability analysis based on limit load was performed. Shop welds and field welds for the SI lines of D.C. Cook Units 1 and 2 utilize the SMAW or SAW weld processes. The "Z" correction factor (References 7-2 and 7-3) are as follows:

$$Z = 1.15\ [1.0 + 0.013\ (OD\text{-}4)]\ \text{for SMAW}$$

$$Z = 1.30\ [1.0 + 0.010\ (OD\text{-}4)]\ \text{for SAW}$$

where OD is the outer diameter of the pipe in inches.

The Z-factors for the SMAW and SAW were calculated for the critical locations, using the pipe outer diameter (OD) for each respective segment of the SI lines. The applied faulted loads of Table 3-19 through Table 3-26 (for Unit 1) and Table 3-27 through Table 3-34 (for Unit 2) were increased by the Z factor and critical flaw size was calculated by flaw stability under the respective loading conditions for each governing location. Table 7-1 summarizes the results of the stability analyses based on limit load for the governing locations on D.C. Cook Units 1 and 2. The associated leakage flaw sizes (from Table 6-1) are also presented in the same table.

Additionally, elastic-plastic fracture mechanics (EPFM) J-integral analysis for through-wall circumferential crack in a cylinder is performed for select locations using the procedure in the EPRI Fracture Mechanics Handbook (Reference 7-4). Table 7-1 shows the results of this analysis.

7.4 REFERENCES

7-1 Kanninen, M. F., et. al., "Mechanical Fracture Predictions for Sensitized Stainless Steel Piping with Circumferential Cracks," EPRI NP-192, September 1976.

7-2 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.

7-3 NUREG-0800 Revision 1, March 2007, Standard Review Plan: 3.6.3 Leak-Before-Break Evaluation Procedures.

7-4 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 7-1 Flaw Stability Results for the D.C. Cook Units 1 and 2 SI Lines Based on Limit Load and EPFM

Segment	Pipe Size	Welding Process	Weld Location Node	Critical Flaw Size (in)	Leakage Flaw Size (in)
SI-CL-I	10-inch	SAW	158F_U2L3	14.47	5.25
	6-inch	SMAW	156_U2L3	8.28(1)	4.14
		SAW	408N_U2L2	8.46	3.66
SI-HL-I	6-inch	SMAW	181_U2L1	6.31	2.93
		SAW	536F_U2L3	8.22	3.96
SI-HL-II	6-inch	SMAW	526N_U2L3	8.03	3.06
		SAW	526F_U2L3	7.67	3.10
SI-HL-III	8-inch	SMAW	142N_U1L14	12.20	5.00
		SAW	142F_U1L14	11.36	5.01

Note:

[1]Based on the methodology in Section 7.2

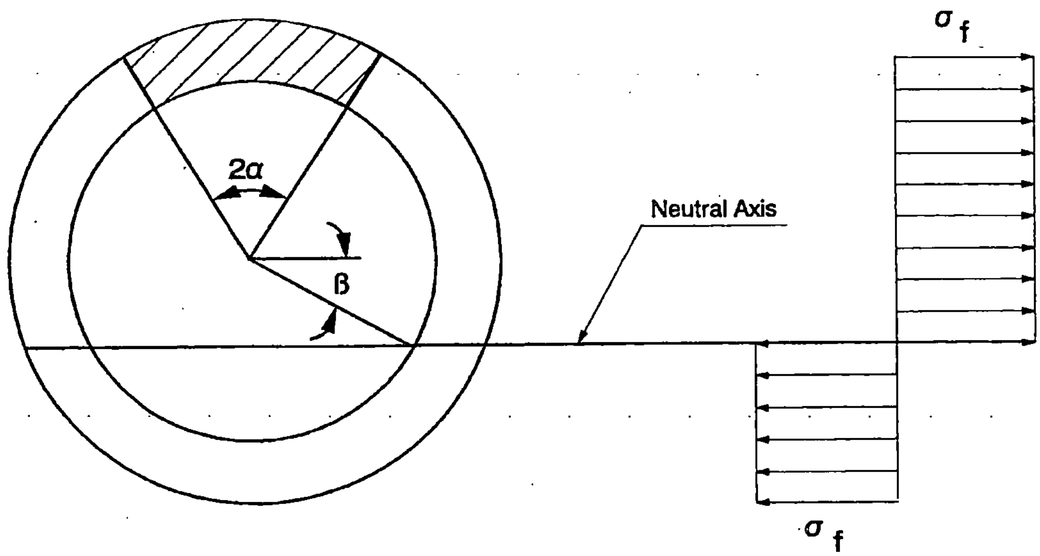

Figure 7-1 [ ]^{a,c,e} Stress Distribution

8.0 ASSESSMENT OF FATIGUE CRACK GROWTH

The fatigue crack growth (FCG) analysis is not a requirement for the LBB analysis (see References 8-1 and 8-2) since the LBB analysis is based on the postulation of a through-wall flaw, whereas the FCG analysis is performed based on the surface flaw. In addition Reference 8-3 has indicated that, "the Commission deleted the fatigue crack growth analysis in the proposed rule. This requirement was found to be unnecessary because it was bounded by the crack stability analysis."

Also, since the growth of a flaw which leaks 8 gpm would be expected to be minimal between the time that leakage reaches 8 gpm and the time that the plant would be shutdown; therefore, only a limited number of cycles would be expected to occur.

8.1 REFERENCES

8-1 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.

8-2 NUREG-0800 Revision 1, March 2007, Standard Review Plan: 3.6.3 Leak-Before-Break Evaluation Procedures.

8-3 Nuclear Regulatory Commission, 10 CFR 50, Modification of General Design Criteria 4 Requirements for Protection Against Dynamic Effects of Postulated Pipe Ruptures, Final Rule, Federal Register/Vol. 52, No. 207/Tuesday, October 27, 1987/Rules and Regulations, pp. 41288-41295.

9.0 ASSESSMENT OF MARGINS

The results of the leak rates of Section 6.4 and the corresponding stability evaluations of Section 7.3 are used in performing the assessment of margins. Margins are shown in Table 9-1 for the governing locations on D.C. Cook Units 1 and 2. All the LBB recommended margins are satisfied.

In summary, margins at the critical locations are relative to:

1. Flaw Size - Using faulted loads obtained by the absolute sum method, a margin of 2 or more exists between the critical flaw and the flaw having a leak rate of 8 gpm (the leakage flaw).

2. Leak Rate - A margin of 10 exists between the calculated leak rate from the leakage flaw and the plant leak detection capability of 0.8 gpm.

3. Loads - At the critical locations the leakage flaw was shown to be stable using the faulted loads obtained by the absolute sum method (i.e., a flaw twice the leakage flaw size is shown to be stable; hence the leakage flaw size is stable). A margin of 1 on loads using the absolute summation of faulted load combinations is satisfied.

Table 9-1 Leakage Flaw Sizes, Critical Flaw Sizes, and Margin for the D.C. Cook Units 1 and 2 SI Lines

Segment	Pipe Size	Welding Process	Weld Location Node	Critical Flaw Size (in)	Leakage Flaw Size (in)	Margin
SI-CL-I	10-inch	SAW	158F_U2L3	14.47	5.25	2.8
	6-inch	SMAW	156_U2L3	8.28[(1)]	4.14	>2.0[(1)]
		SAW	408N_U2L2	8.46	3.66	2.3
SI-HL-I	6-inch	SMAW	181_U2L1	6.31	2.93	2.2
		SAW	536F_U2L3	8.22	3.96	2.1
SI-HL-II	6-inch	SMAW	526N_U2L3	8.03	3.06	2.6
		SAW	526F_U2L3	7.67	3.10	2.5
SI-HL-III	8-inch	SMAW	142N_U1L14	12.20	5.00	2.4
		SAW	142F_U1L14	11.36	5.01	2.3

Note:

[1]Margin of 2.0 is demonstrated based on the methodology in Section 7.2

10.0 CONCLUSIONS

This report justifies the elimination of SI line breaks from the structural design basis for D.C. Cook Units 1 and 2 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.

   Note: Alloy 82/182 welds do not exist at the D.C. Cook Units 1 and 2 SI lines.

b. Water hammer should not occur in the SI line piping because of system design, testing, and operational considerations.

c. The effects of low and high cycle fatigue on the integrity of the SI line piping are negligible.

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

e. Ample margin exists between the small stable flaw sizes of item (d) and larger stable flaws.

f. Ample margin exists in the material properties used to demonstrate end-of-service life (fully aged) stability of the critical flaws.

For the critical locations, postulated flaws will be stable because of the ample margins described in d, e, and f above.

Based on loading, pipe geometry, welding process, and material properties considerations, enveloping critical (governing) locations were determined at which Leak-Before-Break crack stability evaluations were made. Through-wall flaw sizes were postulated which would cause a leak at a rate of ten (10) times the leakage detection system capability of the plant. Large margins for such flaw sizes were demonstrated against flaw instability. Finally, fatigue crack growth assessment was shown not to be an issue for the SI line piping. Therefore, the Leak-Before-Break conditions and margins are satisfied for D.C. Cook Units 1 and 2 SI line piping. It is demonstrated that the dynamic effects of the pipe rupture resulting from postulated breaks in the SI line piping need not be considered in the structural design basis of D.C. Cook Units 1 and 2.

APPENDIX A: LIMIT MOMENT

[

] a,c,e

a,c,e

Figure A-1 Pipe with a Through-Wall Crack in Bending

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