Revision 0
October 12, 1995

Dresden Unit 2
Recirculation Line Flaw Evaluation Report

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1.0 Introduction:

This report provides a summary of the scope and results of ultrasonic examinations (UT) performed on intergranular stress corrosion cracking, IGSCC, susceptible stainless steel weldments during the D2R14 refuel outage. It also includes the evaluation and disposition of those flaws which exceeded the ASME Section XI, 1989 Edition acceptance standard. (Reference 1)

1.1 Examination Scope

As shown below, a total of 148 IGSCC susceptible weldments were ultrasonically examined during the current D2R14 outage. This examination scope meets or exceeds the requirements of Generic Letter 88-01. The examination scope includes:

1. Eight (8) Category "A" weldments.
2. Thirty-five (35) Category "C" weldments.
3. All sixty-seven (67) Category "D" weldments.
4. All thirty-seven (37) Category "E" weldments.
5. One (1) Category "F" weldments.

Raytheon Inc. performed the UT using Level II and III examiners qualified by EPRI. Both manual and automated UT techniques were utilized.

Flaws exceeding the acceptance criteria delineated in IWB-3514 of ASME Section XI, 1989 Edition were detected in two (2) recirculation weldments. These flaws exhibited characteristics such as flaw branching, observed when skewing the transducer, and being located in the heat affected zone, HAZ, which are consistent with IGSCC. Furthermore, the recirculation piping is susceptible to IGSCC and has a prior history of IGSCC. Consequently, these flaws are categorized as IGSCC induced. The requirement of Generic Letter 88-01 to expand the inspection sample was satisfied since all weldments that are in the same IGSCC categories as the flawed weldments have been included in the original inspection sample for the current outage.

2.0 Flaw Description:

2.1 Weld PD1A-D14

PD1A-D14 is an elbow-to-pipe weld on the 28" NPS recirculation pump discharge, A loop. Prior to D2R14, it was classified as an IGSCC category "F" weldment, which was examined during the D2R13 refuel outage.

One (1) IGSCC flaw indication had been observed on this weld since 1986. During the current outage (D2R14), the depth of the existing flaw, located in the HAZ on the elbow side of the weld, was determined to be deeper than the previously measured depth.

For comparison purposes, the flaw characteristics obtained from inspections conducted during the current outage (D2R14) and the previous outage (D2R13) are provided below. Figure 2.1 graphically presents the flaw characteristics from the present inspection.

Flaw Characterization:

D2R14 (1995)	1.0" long x 0.25" deep, started at 32.25" clockwise from reference (Reference point is the extrados of elbow).
D2R13 (1993)	1.0" long x 0.15" deep, started at 32.25" clockwise from reference (Reference point is the extrados of elbow).

2.2 Weld PS2-TEE/202-4B

PS2-TEE/202-4B is the valve-to-tee weld on the 28" NPS loop B recirculation pump suction line. Prior to D2R14, it was classified as an IGSCC category "D" weldment, which was examined during the D2R12 refuel outage. The only recordable indications observed were determined to be caused by the ID geometry.

During the current outage, D2R14, two (2) circumferential flaws were detected in the weld heat affected zone (HAZ) on the tee side of the weld.

The flaw characteristics are as follow:

Flaw indication # 1: 1.75" long x 0.35" deep, started at 13.75" clockwise from reference (Reference point is 180° from reactor vessel)

Flaw indication # 2: 2.85" long x 0.33" deep, started at 65.3" clockwise from reference (Reference point is 180° from reactor vessel)

Figure 2.2 graphically presents these flaw characteristics from the present inspection.

Figure 2.1 **Weld PD1A-D14 Flaw Characterization**

OD = 28.0"
t = 1.357"

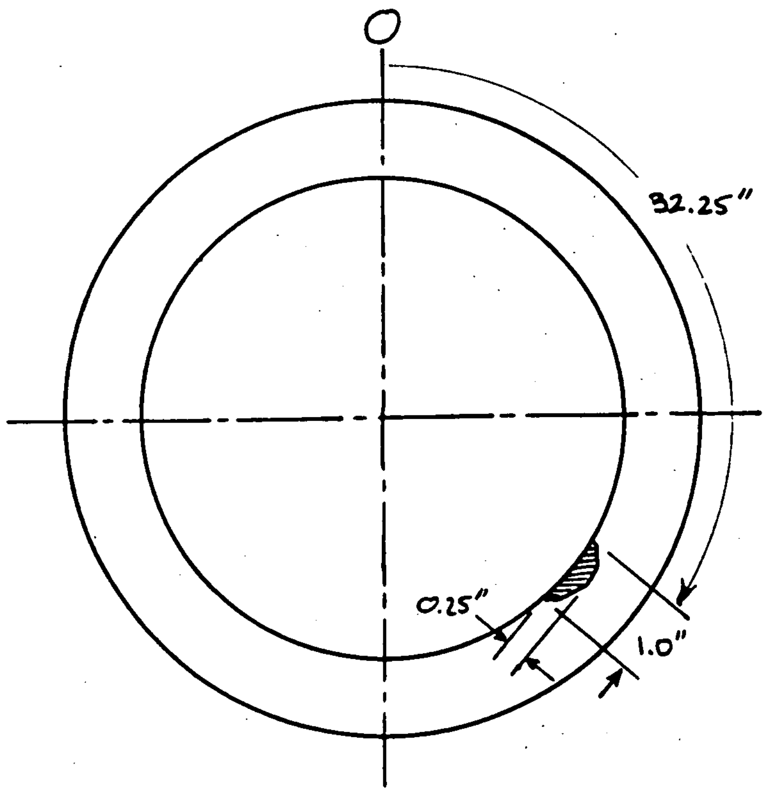
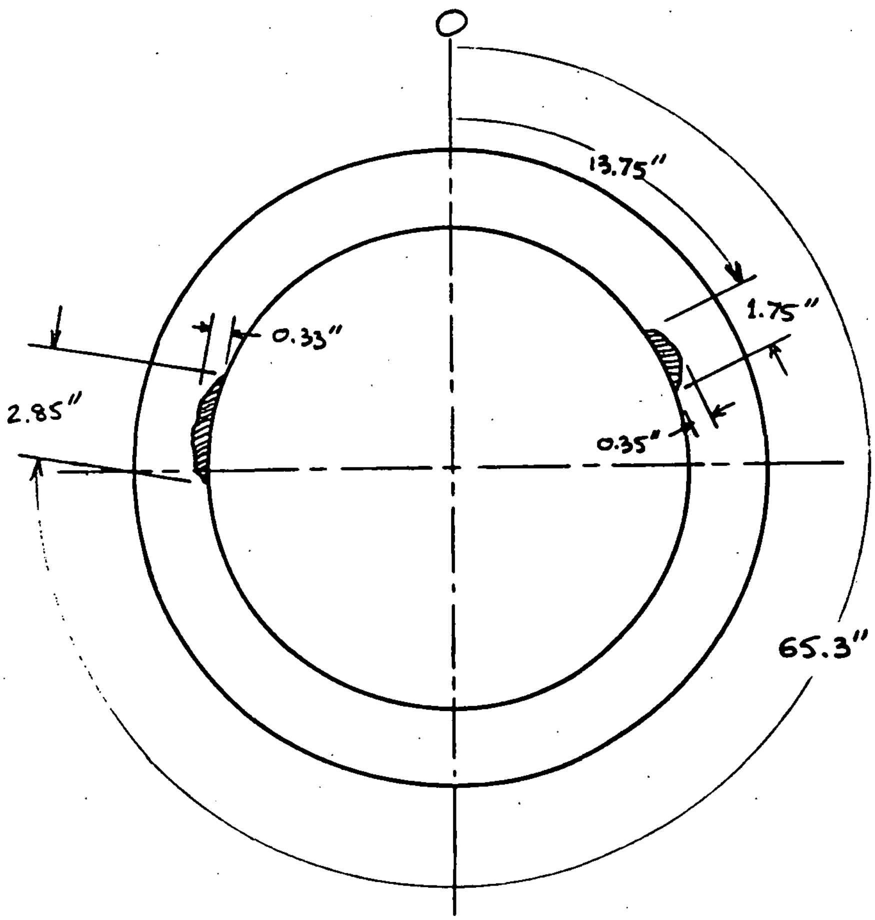


Figure 2.2 Weld PS2-TEE/202-4B Flaw Characterization

OD = 28.0"
t = 1.200"



3.0 Flaw Evaluation Methodology:

The inspection reports, References 3 and 4, identify the elbow and tee fittings, containing the flaws, as SA403 WP304 austenitic stainless steel. Therefore, the evaluation and acceptance requirements of IWB-3640 are used for the evaluation of these flaws. The rules of IWB-3641 of ASME Section XI, 1989 Edition are applicable because the following conditions are met:

(a) Piping/fitting NPS ≥ 4 with the flaw within $\sqrt{rt}$ of the weld.

(b) Piping/fitting materials are made of wrought stainless steel, Ni-CR-Fe alloy.

(c) Materials have a specified minimum yield strength less than 45 ksi.

(d) Material S_m values are given in Table I-1.2 of Section III, 1989 Edition.

As required in IWB-3641 of Reference 1, flaw growth analyses are performed on the flaws to determine their maximum growth from fatigue and stress corrosion cracking mechanisms for a defined evaluation period. Although Generic Letter 88-01 requires these welds to be examined during the next refueling outage, the longest evaluation period is determined for each weld to establish the margin on the inspection interval. The calculated maximum flaw dimensions at the end of the evaluation period are compared with the calculated maximum allowable flaw dimensions for both normal /upset conditions and emergency/faulted conditions to determine the acceptability for continued service.

The flaw growth analyses are performed for fatigue crack growth following the methodology of Reference 1 Appendix C and for IGSCC following the methodology of NUREG-0313, Reference 5. The evaluation period for the flaw growth analyses was determined as the time necessary for the flaw depth to grow to approximately the IWB-3641.3 limit of 0.6 a/t. The fatigue crack growth is based on the normal/ upset operating events expected to occur during the evaluation period. The transient definition and transient stresses developed for Dresden Unit 3 Recirculation system are used in this evaluation. The IGSCC crack growth rate is developed using the residual stress distribution and da/dt relationship defined in Appendix A of Reference 5.

The end of evaluation flaw size(i.e. maximum depth, a_f, and maximum length, l_f) are evaluated using the applied stress values for the bounding normal/upset and emergency/faulted design basis loading combinations. These bounding design basis loading conditions are used to establish critical crack size which must be greater than the end of evaluation flaw size. Because these flaws are located within the weld material, as defined in Figure IWB-3641-1 of Reference 1, the critical flaw size is defined using the criteria for SAW, submerged arc weld, in Appendix C of Reference 1. The evaluation formulae of Appendix C, C-3320, of Reference 1 are used to calculate the critical flaw sizes. The critical flaw sizes are calculated using the required safety factors of 2.77 for normal/upset conditions and 1.39 for the emergency/faulted conditions.

4.0 Load Definition:

4.1 Design Basis Loads:

The design basis loads are provided in Table 4.1 for weld PD1A-D14 and Table 4.2 for weld PS2-TEE/202-4B, Reference 6. The loads provided are deadweight, thermal and OBE seismic (OBE). In accordance with Dresden FSAR, SSE is twice OBE. The loads provided are the axial force and three (3) moments at each weld, and include the effects of the permanent lead shielding added during the current refuel outage. The axial force and three (3) moments will be used in the calculations. Typical fracture mechanics analyses ignore the effects of the torsional moment on circumferential flaws; however, it will be considered in this evaluation for conservatism. Input data for pressure, temperature and thermal gradients are taken from the Class 1 piping fatigue calculations for Unit 3 which has similar operating conditions, pipe size and material properties to Unit 2.

Table 4.1 Weld PD1A-D14 Loop A Recirculation Pump Discharge:
Maximum Temperature = 550°F   Maximum Pressure = 1185 psi

	Fa (lbf)	Ma (ft-lbf)	Mb (ft-lbf)	Mc (ft-lbf)
Weight	1799	-3187	-15559	25523
Thermal	-419	12175	-11055	-2473
OBE	9476	27125	36687	50613

The design pressure (1325 psi) is conservatively used in the PD1A-D14 evaluation.

Table 4.2 Weld PS2-TEE/202-4B Loop B Recirculation Suction:
Maximum Temperature = 550°F Maximum Pressure = 1100 psi

	Fa (lbf)	Ma (ft-lbf)	Mb (ft-lbf)	Mc (ft-lbf)
Weight	24508	-153	1457	-20273
Thermal	-1546	7093	3061	-7656
OBE	4062	18998	39778	40423

4.2 Fatigue Load Definition:

Weld PD1A-D14 Loop A Recirculation Pump Discharge:

The normal/upset design basis transient events are defined in Reference 6 for this line. The Shutdown Cooling thermal gradients defined for this line are very small (i.e. $\Delta T_1 \approx$ 15°F and $\Delta T_2 \approx$ 3°F) and considered insignificant. The restart of an idle recirculation loop event is more significant and included in this evaluation. During this event, the discharge line is reheated from 490°F to 540°F causing the inside of the line to be in compression and the outside to be in tension. Using an as welded butt weld, the Reference 6 thermal transient temperatures for this event are:

ΔT_1 = 45.4°F ΔT_2 = 30.83°F

Weld PS2-TEE/202-4B Loop B Recirculation Suction:

The normal/upset design basis transient events are defined in Reference 6 for this line. The thermal gradients defined for this line are zero except for the restart of an idle recirculation loop and the Shutdown Cooling events. Using an as welded tapered transition weld, the Reference 6 thermal transients temperatures for these events are:

Table 4.3 Thermal Transient Temperature Differentials for Weld PS2-TEE/202-4B Loop B Recirculation Suction:

	ΔT_1(°F)	ΔT_2(°F)	T_a(°F)	T_b(°F)
Shutdown Cooling	15.72	2.78	357.4	333.2
Restart of Idle Loop	-44.75	-27.01	513.72	533.93

In addition to the through wall bending stress values produced by these transient event temperature differentials, the pressure, weight, thermal and residual stress values were combined for the fatigue crack growth calculation.

4.3 IGSCC Load Definition:

The flaw growth caused by IGSCC is calculated based on the residual stress combined with the pressure, weight and thermal stress values. For these evaluations the axial residual stress through wall distribution was defined as recommended in NRC NUREG-0313, Reference 5, with inside surface tensile stress peaking at 30,000.0 psi.

5.0 Flaw Growth Results:

5.1 IGSCC Crack Growth Results:

The calculated IGSCC crack growth was based on the previously defined residual stress combined with the normal operating pressure, weight and thermal stress values. The NUREG-0313 crack growth rate of

$$da/dt = 3.590 \times 10^{-8} K_I^{2.161} \text{ in/hour}$$

was used to project the crack growth for a 360° circumferential surface flaw model.

PD1A-D14 Weld:
The flaw in weld PD1A-D14 grows from 0.25" to a depth of 0.7344" in 35000 hours. The a/t ratio for this projected depth is 0.54 which is less than the

maximum of 0.6 permitted by IWB-3641.3 of Reference 1. As recommended in NUREG-0313, the flaw aspect ratio would change from 4 to 1 to 12 to 1 making the end of evaluation flaw length 9.0". These results are summarized in Table 5.1.

PS2-TEE/202-4B Weld:
Using the larger flaw depth of the first flaw in weld PS2-TEE/202-4B, the flaw depth grows from 0.35" to 0.7162" in 45000 hours. The a/t ratio for this projected depth is 0.597 which is less than the maximum of 0.6 permitted by IWB-3641.3 of Reference 1. Following the recommendation in NUREG-0313, the aspect ratio of the end of evaluation period flaw would be increased by 2.06 over the initial aspect ratio. Assuming both flaws grow to the same depth, the length of the first flaw would grow from 1.75" to 7.4" and the second flaw would grow from 2.85" to 12.8" during the evaluation period. These results are summarized in Table 5.1.

Table 5.1 IGSCC Crack Growth Results

	Initial Flaw Dimensions (in)		End of Evaluation Period Flaw Dimensions (in)	
Weld No.	a	l	a_f	l_f
PD1A-D14	0.25	1.0	0.734	9.0
PS2-TEE/202-4B #1	0.35	1.75	0.716	7.4
PS2-TEE/202-4B #2	0.33	2.85	0.716	12.8

5.2 Fatigue Crack Growth Results:

The fatigue crack growth was calculated using the residual and weight stresses combined with the stress ranges generated by the combined pressure, thermal and thermal transient stresses. For this calculation, 5 startup and shutdown events with 1 restart of an idle loop occurring during each startup and shutdown event were postulated to occur during the evaluation period. The fatigue crack growth was determined using a 360° circumferential surface flaw model and the fatigue crack growth rates provided in Figure C-3210-1 of Appendix C in Reference 1. The fatigue crack growth for the PD1A-D14 weld flaw was calculated for both an initial flaw depth of 0.25", the current flaw depth, and an initial flaw depth of 0.740", the end of evaluation IGSCC flaw depth. In both cases, the crack growth calculated was less then 0.00003" (total) for the postulated events. Based on this result, the fatigue crack growth was considered to be insignificant for both the DP1A-D14 and PS2-TEE/202-4B weld flaws.

6.0 Flaw Evaluation Results:

The critical flaw sizes are determined using the Reference 1 Appendix C formulation for flaws in SAW material and the bounding combination of pressure, weight, thermal and seismic loads for the normal/upset and emergency/faulted design basis load combinations. The stress values used for these evaluations are presented in Table 6.1

Table 6.1 Stress Values Used to Calculate the Critical Flaw Sizes

	Stress Values Used To Calculate The Critical Flaw Size (psi)				
Weld No.	P_{mn}	P_{bn}	P_e	P_{mf}	P_{bf}
PD1A-D14	6920	1631	276	7004	2762
PS2-TEE/202-4B	6715	1481	201	6755	2587

Based on these stress values and the code required safety factors of 2.77 for normal/upset and 1.39 for emergency/faulted conditions, the limiting condition for determining the critical flaw size is the normal/upset condition. The SAW Z factor used for these evaluations was 1.612.

The evaluation for the two flaws in weld PS2-TEE.202-4B may be performed as separate flaws. The first flaw starts at 13.75" and extends to 15.5 " on the circumference which is 84.2" long. Conservatively, assuming that all IGSCC growth is toward the second flaw, the end of evaluation period flaw will extend back toward the second flaw to 8.1" on the pipe circumference. The second flaw starts at 65.3" and extends to 68.15 " on the pipe circumference. Again assuming that all IGSCC growth is toward the first flaw, the end of evaluation period will extend to 78.1" on the pipe circumference. Using the mean radius, the distance separating the two flaws is 14.2" which is significantly larger than the flaw separation criteria of 2.4" for throughwall flaws. Consequently, these flaws maybe evaluated as separate flaws. However, this evaluation conservatively evaluated these flaws as a single flaw. Considering the IGSCC growth to increase the length of each flaw equally on each side of the flaw places the starting point of the first flaw at 18.3" on the pipe circumference and the end of the second flaw at 60.3" on the pipe circumference for a total combined flaw length of 42.2". For the end of evaluation period flaw depth, the critical flaw length required by the ASME B&PV Code IWB-3641.2 is presented in Table 6.2.

Table 6.2 Critical Flaw Sizes

	End of Evaluation Period Flaw Size (in)		Critical Flaw Size (in)	
Weld No.	a_f	l_f	a_c	l_c
PD1A-D14	0.735	9.0	0.735	48.0
PS2-TEE/202-4B #1	0.716	7.4 (1)	0.716	44.0
PS2-TEE/202-4B #1	0.716	12.8 (1)	0.716	44.0

Note 1. Treating these separate flaws as one continuous flaws would produce a total end of evaluation flaw length of 42.2".

7.0 Conclusions:

The evaluation for the 0.25" deep by 1.0" long flaw found in the PD1A-D14 weld of the Loop A recirculation pump discharge line determined this weld to be acceptable for 35000 hours of system operating time. The evaluation for the 0.35" deep by 1.75" long and 0.33" deep by 2.85" long flaws found in the PS2-TEE/202-4B weld of the Loop B recirculation pump suction line determined these welds to be acceptable 45000 hours of system operating time. Both evaluations produced a margin for inspection of at least twice the inspection time interval required by NUREG-0313, i.e. one refuel cycle for these welds. These conclusions were reached using the methodology and acceptance criteria of IWB-3640 of the ASME B&PV Code, Section XI, Reference 1. The end of evaluation period flaw sizes considered crack growth from IGSCC and Fatigue mechanism, and calculated the IGSCC growth as specified in NUREG-0313, Reference 5. The end of evaluation period flaw sizes were shown to be less than the critical flaw sizes which were calculated as directed in Appendix C of the code, Reference 1.

Welds PS2-TEE/202-4B and PD1A-D14 are now classified as IGSCC category "F". In accordance with the rules of Generic Letter 88-01 for IGSCC category "F", these two (2) weldments will be subject to examination every refuel outage, starting with the D2R15 refuel outage.

8.0 References:

1) ASME Boiler and Pressure Vessel Code, Section XI, 1989 Edition.

2) ASME Boiler and Pressure Vessel Code, Section III, 1989 Edition.

3) Ultrasonic Testing Data Sheet D240, dated 8/25/95, for weld PD1A-D14 at Dresden Unit 2.

4) Ultrasonic Testing Data Sheet D344, dated 9/20/95, for weld PS2-TEE/202-4B at Dresden Unit 2.

5) "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping", NUREG-0313, Revision 2, January 1988

6) "Flaw Evaluation for PD1A-D14 and PS2-TEE/202-4B Welds in Dresden Unit 2 Recirculation System", ComEd Calculation No. NED-P-MSD-085, Revision 0.