Tennessee Valley Authority, Post Office Box 2000, Decatur, Alabama 35609-2000

April 12, 2001

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555

Gentlemen:

In the Matter of) Docket No. 50-260
Tennessee Valley Authority)

BROWNS FERRY NUCLEAR PLANT (BFN) - UNIT 2 - SUBMITTAL OF EVALUATION OF INTERGRANULAR STRESS CORROSION CRACKING (IGSCC) INDICATION ON RESIDUAL HEAT REMOVAL SYSTEM PIPING WELDMENT

In accordance with guidance specified in NRC Generic Letter (GL) 88-01, TVA is submitting an evaluation of an IGSCC indication in a heat affected zone of a weld located on Residual Heat Removal (RHR) system piping. During performance of scheduled inservice inspection of the Residual Heat Removal (RHR) system piping, TVA identified an indication in weld DRHR-2-09 not previously identified as a flaw. In accordance with the GL, if any cracks are identified that do not meet the criteria for continued operation without evaluation given in Section XI of the Code, NRC approval of flaw evaluations and/or repairs in accordance with IWB-3640 and IWA-4130 is required before resumption of operation.

TVA completed a stress corrosion crack growth analysis in accordance with NUREG-0313, Revision 2, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping." Based on the conservative assumptions used, TVA's analysis demonstrates that weld DRHR-2-09 is acceptable for at least 2 additional 24-month operating cycles.

D030

BFN Unit 2 is currently in the Cycle 11 refueling outage. Therefore, if NRC determines approval of this evaluation is required prior to Unit 2 restart, TVA requests approval on an expedited basis. This short review period is necessary to support the unit's return to service.

Enclosure 1 to this letter provides the evaluation of weld DRHR-2-09. To further aid NRC in their review of this issue, Enclosure 2 provides the staff with a copy of Calculation CD-Q2074-990016. Enclosure 3 provides isometric drawing 2-ISI-0221-C, Sheet 1, which depicts the Unit 2 RHR System weld in question.

If you have any questions about this evaluation, please telephone me at (256) 729-2636.

Sincerely,

T. E. Abney
Manager of Licensing
and Industry Affairs

Enclosures
cc: See page 3

cc (Enclosures):

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ENCLOSURE 1

TENNESSEE VALLEY AUTHORITY
BROWNS FERRY NUCLEAR PLANT (BFN)
UNIT 2
EVALUATION OF INTERGRANULAR STRESS CORROSION CRACKING
(IGSCC) INDICATION FOR WELD DRHR-2-09

Background

BFN Unit 2 is in the second Ten-Year Inservice Inspection Interval. The code of record for BFN Unit 2 is ASME Section XI, 1986 Edition (no addenda). Standards for ASME Section XI Class 1 nondestructive examination evaluation are in accordance with IWB-3000 of the ASME Section XI Code, 1989 Edition (no addenda).

During the present Unit 2, Cycle 11 refueling outage, ultrasonic test (UT) inspections of Residual Heat Removal (RHR) system pipe welds conducted in conjunction with the guidance of Generic Letter (GL) 88-01 revealed an IGSCC indication, not previously identified as a flaw, in the Heat Affected Zone (HAZ) of weld number DRHR-2-09. Weld DRHR-2-09 is in RHR System Loop 1 and is a 24-inch diameter, (A-358 Type 304 stainless steel, Schedule 80), pipe-to-tee (A-403 Type 304 stainless steel) weld. The weld filler metal is ER308 (Gas Tungsten Arc Weld) for the root and hot-pass and E308-16 (Shielded Metal Arc Weld) for the remaining portion of the weld. Manual UT examination of the weld was conducted with nondestructive examination (NDE) procedures and techniques that have been qualified in accordance with Appendix VIII of ASME Section XI Performance Demonstration Initiative (PDI) program at the Electric Power Research Institute (EPRI).

The UT results indicate a flaw located at approximately 161 to 170 degree azimuth or 34 to 36 inches clockwise from top dead center of the pipe. The pipe has a wall thickness of 1.20 inches (t). The indication is 2 inches in length (l) with a maximum depth of 0.25 inches (a). The UT data positions the indication in the HAZ of the type 304 stainless steel material of the pipe. The flaw is unacceptable per Table IWB-3514-2. The flaw aspect ratio (flaw depth versus length (a/l)), is a/l = 0.125 with an a/t of 20.83 percent. For an aspect ratio of 0.125 the maximum allowable surface flaw depth is 10.93 percent of the 1.20 inch pipe wall thickness which is 0.131 inches.

The indication was detected using manual UT examination with 45 degree and 70 degree shear wave search units. Scans were also performed with a 70 degree shear wave search unit in order to confirm both a previously identified indication being tracked near 23.5 to 27.0 inches and the indication (not previously identified) at 34 to 36 inches. No scan was performed from the tee side due to component configuration.

The flaw located near 23.5 to 27.0 inches has not shown any growth since its initial inspection and sizing performed in 1989 and successive inspections. Further, TVA's experience with other IGSCC Category E welds (identified flaws and IHSI treatment) at BFN has not shown any indication growth. Therefore, TVA does not consider the flaw near 23.5 to 27.0 inches and the adjacent flaw at 34 to 36 inches to be active in nature.

Inspection History Of Weld DRHR-2-09

In 1984, Induction Heat Stress Improvement (IHSI) was applied to the accessible, Unit 2, Residual Heat Removal System pipe welds to mitigate IGSCC. In conjunction with the IHSI process, weld DRHR-2-09 was examined pre-IHSI using manual UT techniques. In 1989, post-IHSI examinations were conducted with a combination of manual and automated examination techniques. These examinations did not reveal the presence of an IGSCC indication at the 34 to 36 inch area from the top dead center location. Automated examination techniques were not performed in this region due to the close proximity of structural elements near the location; therefore, manual techniques were employed to provide additional coverage. Unit 2 was subsequently shutdown by TVA in 1985 as part of an extensive recovery program and restarted in May of 1991.

TVA conducted scheduled examinations in 1989 and 1994 using automated UT techniques, and in 1997 using manual techniques, and in April 2001 using manual techniques. The manual and automated techniques utilized during the 1983-1994 period were qualified under the "old" NDE Coordination Plan developed by EPRI.

A review of the 1994 automated data shows that the indication (34 to 36 inches) was present utilizing a 60 degree refracted longitudinal search unit but was masked by weld geometry when examining with the 45 degree primary qualified detection angle and therefore was not characterized as IGSCC due to limitations of the qualified UT techniques employed by the industry in the 1994 timeframe.

A detailed review of the 1989, 1994, and 1997 data was performed to assess the characterization activities and identify any differences between these data and the 2001 manual data as provided for in IWA-1400(h). The primary reason that the indication is now characterized as IGSCC is directly attributable to enhanced, qualified manual UT techniques which include additional detection angles. The procedure, personnel, and equipment utilized during the current Cycle 11 outage were qualified in accordance with Appendix VIII. The flaw's detection and characterization as IGSCC are directly attributable to the enhanced techniques required to successfully qualify to the more stringent Appendix VIII, Supplement 2 requirements. The primary attributes contained in the qualified procedure that enhance discrimination of UT indications when interrogating geometry and flaw features are:

> The examinations for single-sided welds are performed using 45-degree, 60-degree, and 70-degree shear waves and 60-degree refracted longitudinal waves. Previous examinations did not incorporate the 60-degree and 70-degree shear wave that is now utilized during evaluation to ascertain indication characteristics.

The qualified Appendix VIII approach coupled with the shallow flaw characteristics explains the changes between the previous inspections and the 2001 inspection results. Based on the ultrasonic data review, the subject weld flaw did not initiate after the post-IHSI UT examinations performed in 1989. The data indicates that the flaw previously existed and appears to have experienced no growth during the same period.

In addition, TVA has performed a review of seven BFN Unit 2 Category E welds with IGSCC flaws (16 Category E welds total, seven with IHSI mitigation) and concluded that no flaw growth has occurred since IHSI mitigation, (i.e., six operating cycles). Attachment B (sheets 1-7) provides the weld flaw size comparisons for the seven Category E welds with IGSCC flaws from the time of original detection and demonstrate that no flaw growth has occurred since IHSI mitigation.

TVA also performed a review of the IHSI process control parameters and the actual IHSI data recorded for weld DRHR-2-09. This review has determined that the IHSI process control specification (General Electric Procedure P50YP214, Revision 4, Table 1) parameters were met.

<u>Expansion Of Inspection Sample</u>

Weld DRHR-2-09 is presently classified as a Category E weld. Examination of seven category E welds has been conducted during the current Unit 2 Cycle 11 outage. Since no "significant" growth or additional indications were found, no sample expansion is required per the guidance provided in GL 88-01. Significant indication growth for IHSI mitigated Category E welds is defined in NUREG 0313 as growth to length or depth exceeding criteria for

IHSI mitigation (10 percent of circumference or 30 percent in depth). Since the indication is not new and does not meet the definition of significant growth, no expanded sample is required.

Structural Evaluation Of The DRHR-2-09 Indication

Volumetric and surface examinations of ASME Code Class 1 components are required to be evaluated by comparing the examination results with the acceptance standard specified in Table IWB-3410-1, to determine if the component is acceptable for continued service. Table IWB-3410-1 requires that weld DRHR-2-09 meet the acceptance standard of IWB-3514 for exam category B-J. IWB-3514.3 ("Allowable Flaw Standards for Austenitic Piping") states in part, "The acceptance of these flaws shall be governed by the allowable flaw standards for the volumetric examination method in Table IWB-3514-2."

Attachment A to this enclosure contains the IWB-3500 flaw evaluation. As concluded in Attachment A, the flaw does not meet the acceptance criteria of Table IWB-3514-2. A flaw that exceeds the size of allowable flaws defined in IWB-3500 may be evaluated by analytical procedures, such as those described in ASME Section XI, IWB-3640, Appendix A, to calculate its growth until the next inspection or the end of service life of the component.

Enclosure 2 provides a structural evaluation of the indication that was performed to determine the ability of the pipe to support continued unit operation. Crack growth analysis was conducted using the computer program pc-CRACK. The crack growth rate parameters specified in GL 88-01 were utilized in the evaluation. For evaluation purposes the indication was assumed to have an initial depth of 0.27 inches and was conservatively assumed to extend 360 degrees around the circumference of the pipe. Since the weld had been stress improved using IHSI, the residual stress was assumed to be zero. A fatigue growth analysis was also performed which conservatively assumed the initial flaw size was equal to the end of period flaw size calculated in IGSCC growth analysis. The crack growth evaluation indicates that a depth of 0.301 inches is predicted following four calendar years of continued operation. Using the ASME Section XI acceptable flaw size, the predicted size is well within the maximum allowable for continued operation. Thus, TVA considers that continued operation in the current "as-is" condition is acceptable for a minimum of 2 additional 24-month operating cycles. Additionally, inspection of weld DRHR-2-09 will be conducted per GL 88-01 guidance which will insure that any possible flaw growth will remain within acceptable values.

Conclusion

Weld DRHR-2-09 is classified as an IGSCC Category E weld. IGSCC Category E welds are those with known cracks but have been reinforced by an acceptable weld overlay or have been mitigated by a stress improvement treatment, with subsequent examination by qualified examiners and procedures to verify the extent of cracking. IGSCC Category E welds are required to be inspected at least once every two refueling cycles after repair or acceptance by analytical evaluation. TVA does not consider the flaw in weld DRHR-2-09 an active flaw with significance to warrant reclassification to an IGSCC Category F weld. The adjacent flaw and similar welds with flaws and stress improvement (Category E per GL 88-01) have been reviewed for past BFN Unit 2 operating cycles and no growth was found. Therefore, since the flaw was pre-existing and there has been a history of no growth for welds with IHSI, this weld should maintain its current classification of Category E.

TVA completed a stress corrosion crack growth analysis in accordance with NUREG-0313, Revision 2, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping." Based on the conservative assumptions used, TVA's analysis demonstrates that weld DRHR-2-09 is acceptable for at least 2 additional 24-month operating cycles.

Future Inspections

Consistent with GL 88-01 guidance, weld DRHR-2-09 will remain classified as a Category E weld (crack reinforced by weld overlay or mitigated by IHSI). Future inspections will be conducted per the schedule listed in Table 1 of GL 88-01. As previously stated in TVA's reply to GL 88-01 (Reference), TVA will provide future inspection information only in the event of changes in the current indication or the discovery of new indications.

REFERENCE

TVA letter to NRC dated August 1, 1988, Browns Ferry Nuclear Plant (BFN) Response to Bulletin 88-01, IGSCC in BWR Austenitic Stainless Steel Piping

ATTACHMENT A

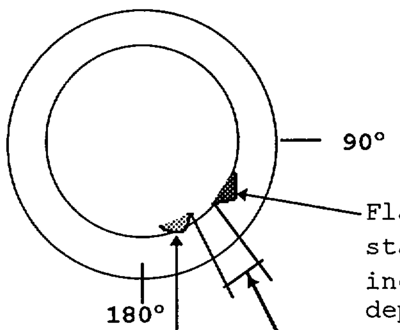
ASME SECTION XI IWB-3500 EVALUATION OF WELD DRHR-2-09

1) **Determine Region and Orientation of Flaw.** The weld region should be identified by the nearest weld. The orientation is either [A]xial or [C]ircumferential.

Region: **Weld DRHR-2-09**
Orientation: **C** .

2) **Sketch Flaw Geometry.**

c calculated = Πd = $(\Pi)(24'')$ =75.4 inches
c measured = 76 inches
Flaw start = $(34/76) \times (360^{\circ}) = 161^{\circ}$
Flaw end = $(36/76) \times (360^{\circ}) = 170.5^{\circ}$



Flaw identified from Unit 2 Cycle 5B - [Flaw start 23.25 inches (113.3°) to flaw end 27 inches (128°)], length of flaw = 3.75 inches, depth of flaw = 0.27 inches]

"S" Dimension between indications = 7", which is greater than $2d_1$or $2d_2$ in Figure IWA 3330-1. The two flaws are not considered to be a single planar flaw.

Previous indication, identified as a flaw during Unit 2 Cycle 11 refueling outage- [Flaw start 34 inches (161°) to flaw end 36 inches (170.5°), length of flaw = 2.0 inches, depth of flaw = 0.25 inches]

3) **Classify Flaw.** Combine flaws in close proximity to other flaws and to the surface per the proximity rule of IWA-3300, ASME Section XI, 1989 edition with no addenda. Classify flaw as either:

Inside Surface: ■
Outside Surface: ☐
Subsurface: ☐

4) **Size Flaw.** Calculate flaw depth.

Surface Flaws:
Flaw Depth, a = **0.25** (in)
Flaw Length, L = **2.0** (in)

Subsurface Flaws:
Flaw Depth, a = **N/A** (in)
Half Depth, a = **N/A** (in)
Flaw Length, L = **N/A** (in)

5) **Calculate Aspect Ratio of Flaw.**

Flaw Aspect Ratio, a/L = (0.25)/(2.0) = **0.125**

ATTACHMENT A

ASME SECTION XI IWB-3500 EVALUATION OF WELD DRHR-2-09

6) **IWB-3500 Flaw Evaluation.** For the given a/L aspect ratio, determine the allowable flaw depth, a (surface) and 2a (subsurface), in accordance with IWB-3510 of the Code and record the value below. If the flaw depth recorded in step 4 is below the allowable value, check the box "Acceptable per IWB-3500" below. Otherwise, Check box "Unacceptable per IWB-3500" and continue to step 7.

Inside Surface Flaws:
Actual flaw information: t = 1.2"; a/t = (0.25)/(1.2) x 100= 20.83%
ASME Section XI, 1989 edition with no addenda, a/t allowable interpolated from Table IWB-3514-2 "Inservice Examination" = 10.93%

	Nominal Wall =	1.0 inch	1.2 inch	2.0 inch
Table value	a/l = 0.1	a/t = 11.0%	10.88%	a/t = 10.4%
Interpolation	a/l = 0.125	a/t = na	a/t = **10.93%**	a/t = na
Table value	a/l = 0.15	a/t = 11.1%	10.98%	a/t = 10.5%

IWB-3500 Allowable Depth = a = 10.93 % of 1.2 inches = **0.131** (in)

Outside Surface Flaws
IWB-3500 Allowable Depth = a = **N/A** (in)

Subsurface Flaws:
IWB-3500 Allowable Depth = 2a = **N/A** (in)

IWB-3500 ACCEPTABILITY:

0.25 inch flaw depth exceeds 0.131 inch IWB-3500 Allowable Depth.

☐ Acceptable per IWB-3500
■ Unacceptable per IWB-3500

A flaw that exceeds the size of allowable flaws defined in IWB-3500 may be evaluated by analytical procedures to calculate its growth until the next inspection or the end of service lifetime of the component. The component containing the flaw is acceptable for continued service during the evaluated time period if conditions noted in IWB-3600 are satisfied.

IWB-3600 ACCEPTABILITY:

■ Acceptable per IWB-3600 - Refer to TVA document calculation CD- Q2074-990016 (EDMS accession number R14 010410 106)

☐ Unacceptable per IWB-3600

ATTACHMENT A

ASME SECTION XI IWB-3500 EVALUATION OF WELD DRHR-2-09

Material Reference Information

Pipe: A 358 type 304 stainless steel
Tee: A 403 type 304 stainless steel
Weld filler material: ER-308 for GTAW process on root and hot pass, E308-16 for SMAW process remainder of weld.

Prepared by: K. L. Groom, reviewed by: R. L. Phillips

Attachment B, Sheet 1

WELD KR-2-14

Indication #	Cycle	Length	Depth	YEAR
1	5	2.10″	0.13″	1982
1	6	1.50″	0.11″	1993
1	8	1.40″	< 0.15″	1996
1	10	1.90″	< 0.10″	1999

Attachment B, Sheet 2

WELD KR-2-41

Indication #	Cycle	Length	Depth	YEAR
1, 2, 3, 4, 5	5	4.00″	0.20″	1982
6, 7	5	0.375″	0.20″	
8, 9	5	0.50″	0.20″	
1, 2, 3, 4, 5	6	2.30″	0.20″	1993
6, 7	6	0.20″	< 0.20″	
8, 9	6	0.20″	< 0.20″	
1, 2, 3, 4, 5	8	2.30″	0.25″	1996
6, 7	8	0.20″	0.15″	
8, 9	8	0.20″	< 0.10″	
1, 2, 3, 4, 5	10	2.20″	0.20″	1999
6, 7	10	0.20″	0.15″	
8, 9	10	0.20″	0.10″	

Attachment B, Sheet 3

WELD KR-2-36

Indication #	Cycle	Length	Depth	YEAR
1	5	2.20″	0.29″	1982
2	5	1.10″	0.17″	
3	5	1.20″	0.17″	
4	5	1.20″	0.17″	
5	5	2.30″	0.12″	
6	5	1.00″	0.20″	
7	5	1.00″	0.16″	
1	6	2.00″	0.21″	1993
2	6	1.25″	0.20″	
3	6	1.10″	0.15″	
4	6	1.00″	0.15″	
5	6	1.75′	0.21″	
6	6	1.30″	0.15″	
7	6	1.00″	0.19″	
1	8	1.50″	0.18″	1996
2	8	1.80″	0.20″	
3	8	1.60″	0.11″	
4	8	1.20″	0.08″	
5	8	1.75″	0.22″	
6	8	1.20″	0.14″	
7	8	1.00″	< 0.19″	
1	10	1.60″	0.20″	1999
2	10	1.70″	0.20″	
3	10	1.60″	0.11″	
4	10	1.20″	0.10″	
5	10	1.80″	0.20″	
6	10	1.20″	0.15″	
7	10	1.00″	0.15″	

Attachment B, Sheet 4

WELD GR-2-53

Indication #	Cycle	Length	Depth	YEAR
1	5B	1.80″	0.20″	1989
1	7	1.80″	0.22″	1994
1	9	1.80″	0.22″	1997
1	11	1.80″	0.20″	2001

Attachment B, Sheet 5

WELD DRHR-2-09

Indication #	Cycle	Length	Depth	YEAR
1	5B	3.60″	0.20″	1989
1	7	3.70″	0.27″	1994
1	9	3.75″	0.25″	1997
1	11	3.50″	0.20″	2001

Attachment B, Sheet 6

WELD DRHR-2-22

Indication #	Cycle	Length	Depth	YEAR
1	5B	1.00″	0.20″	1989
1	7	1.00″	0.20″	1994
1	9	1.00″	0.20″	1997
1	11	1.00″	0.20″	2001

Attachment B, Sheet 7

WELD KR-2-37

Indication #	Cycle	Length	Depth	YEAR
1	5	4.00″	0.13″	1982
2	5	1.00″	0.10″	
3	5	1.00″	0.04″	
4	5	2.00″	0.08″	
1	6	3.00″	0.09″	1993
2	6	1.00″	< 0.10″	
3	6	1.00″	< 0.10″	
4	6	3.40″	< 0.10″	
1	8	3.00″	< 0.10″	1996
2	8	1.00″	< 0.10″	
3	8	1.00″	< 0.10″	
4	8	3.40″	< 0.10″	
1	10	3.00″	< 0.10″	1999
2	10	1.00″	< 0.10″	
3	10	1.00″	< 0.10″	
4	10	3.40″	< 0.10″	

ENCLOSURE 2

TENNESSEE VALLEY AUTHORITY
BROWNS FERRY NUCLEAR PLANT (BFN)
UNIT 2

TVA CALCULATION CD-Q2074-990016,
EVALUATION OF IGSCC INDICATION AT WELD DRHR-2-09

(SEE ATTACHED)

TVAN CALCULATION COVERSHEET / CCRIS UPDATE

ORIGINAL

REV 0 EDMS / RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
B46890310599	Calculations (nuclear)	R14 010410 106

Title:
Evaluation of IGSCC Flaws in Weld DRHR-2-09

CALC ID	TYPE	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	BFN	CEB	CD-Q2074-990016	2	3	Entire calc ☒
NEW							Selected pages ☐

ACTION	NEW ☐ REVISION ☒	DELETE ☐ RENAME ☐	SUPERSEDE ☐ DUPLICATE ☐	CCRIS UPDATE ONLY ☐ (D. V. & Approval Signatures Not Required)	No CCRIS Changes ☐ (For calc revision, CCRIS has been reviewed and no CCRIS changes required)

UNIT(S)	SYSTEMS	UNIDS
2	Recirc (068), RHR (074)	N/A

DCN, EDC, N/A	APPLICABLE DESIGN DOCUMENT(S)	CLASSIFICATION
N/A	(see references)	E

QUALITY RELATED?	SAFETY RELATED? (If yes, QR = yes)	UNVERIFIED ASSUMPTION?	SPECIAL REQUIREMENTS AND/OR LIMITING CONDITIONS?	DESIGN OUTPUT ATTACHMENT?	SAR / TS AFFECTED
Yes ☒ No ☐	Yes ☒ No ☐	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☒

PREPARER PHONE NO	PREPARING ORG (BRANCH)	DESIGN VERIFICATION METHOD
729-7826	CEB	Design Review

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
Eric J. Frevold	4/10/01	Larry C. Rinaca	4/10/01
DESIGN VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Larry C. Rinaca	4/10/01	L.R. Madison Jr.	4/10/01

STATEMENT OF PROBLEM / ABSTRACT

This calculation documents a fracture mechanics evaluation of two IGSCC flaws in weld DRHR-2-09. The weld is located on the 24" branch side of the tee that connects the 24" RHR loop I return piping to the 28" Recirc pump B discharge piping. This calculation utilizes the pc-CRACK computer program to calculate the crack growth due to IGSCC and fatigue, and also to perform an end-of-period flaw stability evaluation. The evaluation is performed in accordance with the requirements of ASME Section XI, NUREG 0313 R2, and Generic Letter 88-01. (3 [initials] 4/11/01)

The results of this calculation demonstrate that the two flaws in weld DRHR-2-09 are acceptable for at least two additional fuel cycles. Acceptability for longer term service is contingent on the results of subsequent examinations.

MICROFICHE / EFICHE	Yes ☐ No ☒	FICHE NUMBER(S)

☐ LOAD INTO EDMS AND DESTROY
☒ LOAD INTO EDMS AND RETURN CALCULATION TO CALCULATION LIBRARY. ADDRESS: BFN
☐ LOAD INTO EDMS AND RETURN CALCULATION TO:

TVAN CALCULATION COVERSHEET / CCRIS UPDATE

CALC ID

TYPE	PLANT	BRANCH	NUMBER	REV
CN	BFN	CEB	CD-Q2074-990016	3

BLDG	ROOM	ELEV	COORD/AZIM	FIRM	Print Report Yes ☐

CATEGORIES

KEY NOUNS (A-add, D-delete)

ACTION (A/D)	KEY NOUN	A/D	KEY NOUN

CROSS-REFERENCES (A-add, C-change, D-delete)

ACTION (A/C/D)	XREF CODE	XREF TYPE	XREF PLANT	XREF BRANCH	XREF NUMBER	XREF REV
A	P	IO	BFN		SPP-9.1	

CCRIS ONLY UPDATES:
Following are required only when making keyword/cross reference CCRIS updates and page 1 of form NEDP-2-1 is not included:

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
PREPARER PHONE NO.	EDMS ACCESSION NO. R21 010410 004		

QA Record

TVAN CALCULATION COVERSHEET

Title	BFN 2 IGSCC Flaw Evaluation of Weld DRHR-2-09	Plant BFN Unit 2	Page 1 of 33

Preparing Organization CEB	Key Nouns (For EDM) IGSCC, Fracture Mechanics, Induction Heating Stress Improvement

Calculation Identifier CD-Q2074-990016	Each time these calculations are issued, preparer must ensure that the original (R0) RIMS/EDM accession number is filled in.		
	Rev	(for EDM use)	EDM Accession Number
Applicable Design Document(s) ASME Section XI NUREG 0313 R2	R0	890317E0029	B46 890310 599
	R1		R14 990223 106
UNID System(s) 74	R2		R14 990817 102
	R3		

	R0	R1	R2	R3
DCN, EDC, NA	NA	NA	NA	
Prepared	W. A. Pavinich	L. C. Rinaca	R. W. Huffman	
Checked	P. A. Walker	K. R. Spates	E J Frevold 8-5-99	
Design Verified	P. A. Walker C. R. Cantrell	K. R. Spates	E J Frevold 8-5-99	
Approved	J. A. Roach	L. R. Madison	L. R. Madison	
Approval Date	3-10-89	2-23-99	8-16-99	
SAR Affected?	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☐
Revision applicability	Entire calc ☒ Selected pgs ☐	Entire calc ☒ Selected pgs ☐	Entire calc ☒ Selected pgs ☐	Entire calc ☐ Selected pgs ☐

	Yes	No
Quality Related?	☒	☐
Safety related? If yes, mark Quality Related yes	☒	☐
These calculations contain unverified assumption(s) that must	☐	☒
These calculations contain special requirements and/or	☐	☒
These calculations contain a design output attachment?	☐	☒
Calculation Classification	ESSENTIAL	
Microfiche generated	☐	☒
Number	ORIGINAL	

Statement of Problem:
A flaw attributed to Intergranular Stress Corrosion Cracking (IGSCC) was found in weld DRHR-2-09 of the Residual Heat Removal (RHR) System. Evaluation is required to determine acceptability until the next scheduled examination.

Abstract
This calculation documents a fracture mechanics analysis of the subject weld relative to the criteria of ASME Section XI and NUREG 0313 R2. Revision 1 of the calculation addresses consideration of operating pressure increases, increase in fuel cycle duration from 18 to 24 months and applies appropriate consideration of pipe loads from the analysis of record. A two fuel cycle duration (i.e., time between period examinations) was considered for subcritical flaw growth. The weld was found to be acceptable for continued service. Acceptability for longer term service is contingent on periodic examination / evaluation results.

Rev. 2 revised references. 6-14-99

☒ Microfilm and return calculation to Calculation Library. Address:

☐ Microfilm and return calculation to:

☐ Microfilm and destroy.

ORIGINAL

TVA 10697 (DNE 6-86)

DNE CALCULATIONS

QA Record

TITLE: BFN2 IGSCC Flaw Evaluation of Weld DRHR-2-9	PLANT/UNIT: BFN Unit 2
PREPARING ORGANIZATION: NE-MT	KEY NOUNS (Consult RIMS DESCRIPTORS LIST): Fracture Mechanics, IGSCC, Fatigue Crack Growth
BRANCH/PROJECT IDENTIFIERS: BFN-MTB-020	Each time these calculations are issued, preparers must ensure that the original (RO) RIMS accession number is filled in. (23)

Rev	(for RIMS' use)	RIMS accession number
R0	890317E0029	B46 '89 0310 599
R _		
R _		
R _		

APPLICABLE DESIGN DOCUMENT(S): ASME Section XI; ASME Section III; NUREG 0313 Rev 2

SAR SECTION(S):

UNID SYSTEM(S): 74

	Revision 0	R1	R2	R3
ECN No. (or indicate Not Applicable)	N/A			
Prepared	Wayne A. Pavinich			
Checked	Patrick A. Walker			
Reviewed	Patrick A. Walker			
Approved	James A. [signature]			
Date	MAR 10 1989			
List all pages added by this revision.				
List all pages deleted by this revision.				
List all pages changed by this revision.				

Use form TVA 10534 if more space required.

KDG 2-22-99

Safety-related? Yes ☒ No ☐

Statement of Problem

An IGSCC indication was found in weld DRHR-2-9 of the Residual Heat Removal System.

Abstract

These calculations contain an unverified assumption(s) that must be verified later. Yes ☐ No ☒

This calculation provides an assessment of leaving the IGSCC indication unrepaired. This calculation utilizes the pc-CRACK Computer program to calculate stable flaw sizes, IGSCC growth rates, and fatigue crack growth rates.

Appendix A, Fracture Mechanics Analysis - 2 pages
Appendix B, IGSCC Crack Growth Evaluation - 5 pages
Appendix C, Fatigue Crack Growth Evaluation - 5 pages

This calculation contains 23 total pages.

☐ Microfilm and store calculations in RIMS Service Center.

Microfilm and destroy. ☐

☒ Microfilm and return calculations to: Marc Dunaway

Address: WT 10D226 HK

cc: ~~RIMS, SL 26 C-K~~

H Voon, Trailer #7, BFN

TVAN CALCULATION RECORD OF REVISION	
CALCULATION IDENTIFIER CD-Q2074-990016	Page 2
Title BFN 2 IGSCC FLAW EVALUATION OF WELD DRHR-2-9	

Revision No.	DESCRIPTION OF REVISION
0	Original - 23 Pages Total
1	Revised to consider increased operating pressure noted by BFN PER 98-00~~6783~~ 7484-000 ** (KH 2-23-99) and the BFN Power Uprate Program. Also considers change from 18 to 24 month fuel cycle and applies appropriate pipe loads from analysis of record (R0 assumes maximum allowable stress). SAR sections * See below have been reviewed by Krys Gromek and this revision of the calculation does not affect the SAR. Changed Calculation Identifier from BFN-MTB-020 to CD-Q2074-990016 Pages Added: i, 3a, 24-31 Pages Replaced: 2, 5-23 Pages Changed: none Pages Deleted: none Total Pages in Revision 1: 33 ** Reference BFPER 99-000663-000. * Chapter 4, Appendix C, SAR Change Requests 17-244 and 17-247.
2	Revised References for BFN PER 98-007484-000. This revision does not affect the pc-Crack results or SAR. Page Deleted: 3A, 4 Page Replaced: 3, 7 Total Pages in Revision 2: 31

TVA 40709 [01-1999] NEDP-2-2 [01-08-1999]

TVAN CALCULATION RECORD OF REVISION

CALCULATION IDENTIFIER: **CD-Q2074-990016**

Title **Evaluation of IGSCC Flaws in Weld DRHR-2-09**

Revision No.	DESCRIPTION OF REVISION
3	**During the unit 2 cycle 11 refueling outage an additional flaw was identified in weld DRHR-2-09, although there was no additional growth in the previously identified flaw. Revision 3 of this calculation incorporates the effects of the new flaw into the structural evaluation of this weld. The original IGSCC and fatigue crack growth evaluations conservatively assumed a 0.27" deep crack around the entire inner circumference of the weld. As such, it was not necessary to revise these evaluations due to an additional 0.25" deep circumferential crack. It was necessary however to revise the flaw stability evaluation.** **Pages added: i.1, i.2, 2.1, 32** **Pages deleted: none** **Pages changed: i, 6, 7, 8, 9, 10, 11, 12, 13** **Pages replaced: 3, 23, 24** **Total pages: 35** **The SAR (specifically FSAR sections 4.2, 4.3, 4.8, 4.12, Appendix C) has been reviewed by Eric Frevold and this revision of the calculation does not affect the SAR. The Technical Specifications have also been reviewed and determined to be unaffected by this calculation revision.**

TVAN CALCULATION DESIGN VERIFICATION FORM	
Calculation Identifier: **CD-Q2074-990016**	Revision **3**
Method of design verification used: 1. Design Review ☒ 2. Alternate Calculation ☐ 3. Qualification Test ☐	Design Verifier: [signature] Date: 4/10/01

Comments:

The above noted calculation revision has been reviewed and determined to be technically adequate based on the use of accepted sound engineering practices and techniques.

Prepared By: *[signature]* Date: 2/10/99
Checked By: *[signature]* Date: 2/16/99

TABLE OF CONTENTS

Prepared By: JCR Date: 2/10/99
Checked By: [signature] Date: 2/16/99

1.0 PURPOSE

The purpose of this calculation is to determine whether or not DRHR-2-09, a girth butt weld in the Reactor Water Recirculation (RECIRC) System, is acceptable for continued operation for a period of two BFN Unit 2 fuel cycles considering the initial flaws ~~size~~ identified in Section 6.1 below. Although this weld is numbered as a Residual Heat Removal (RHR) System weld, per the inservice inspection weld map (ref 4.15), it is located in an unisolable portion of the pipe connecting the RHR supply to the RECIRC pump discharge line and is therefore exposed to RECIRC operating conditions. Revision 1 of this calculation was made to address the following considerations: R3

- The duration of a fuel cycle is increased from 18 to 24 months (see reference 4.17).
- Design / Operating temperatures and pressures are changed to reflect the reference 4.13 modes of operation which includes power uprate of the Unit 2 nuclear steam supply system (see reference 4.16).
- Application of sustained pipe loads (deadweight, thermal expansion, etc.) for prediction of subcritical crack growth due to IGSCC.

2.0 BACKGROUND

During the Post-IHSI Examination of IGSCC susceptible welds, a circumferential intergranular stress corrosion crack (IGSCC) indication was detected by UT inspection in weld DRHR-2-09. This indication was in excess of the allowable flaw standard of Table IWB-3514-3 of the ASME Code Section XI 1977 Edition with Addenda through Summer 1978. This calculation was then initiated to help provide final disposition of CAQR BFP890172. Subsequently, during the U2C11 refueling outage, an additional flaw was detected in this weld. R3

3.0 ASSUMPTIONS

This analysis utilizes the procedures described in NRC Generic Letter 88-01 (ref 4.1) and NUREG 0313 rev. 2 (ref 4.2) to evaluate the effect of the flaws on the structural integrity of weld DRHR-2-09. Since the procedures are closely followed, there are no assumptions as to the method of analysis. The residual stress field used for computation of subcritical crack growth due to IGSCC is noted in Section 6.1 and justified by data given in Attachment B. Any other assumptions for the purpose of conservative analytical simplification are noted and justified in the body of the calculation. R3

4.0 SOURCES OF DESIGN INPUT INFORMATION (REFERENCES)

4.1 NRC Position on IGSCC in BWR Austenitic Stainless Steel Piping (Generic Letter 88-01).

REV	DESIGN	DATE
3	DESIGN EJG	DATE 4/10/01
	CHKD JCR	DATE 4/10/01

4.2 Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping, NUREG-0313 Rev. 2

4.3 NOI No. U2/C5B-107

4.4 ASME Section III, Appendix I, 1980 9 Edition R3

4.5 pc-CRACK User's Manual for Version 2.1, ~~Copy 27~~, Structural Integrity Associates, San Jose, CA

4.6 TVA drawings: R53 47BM452-5, Sheet 1, R2; 0-47W452-10, R11; 2-47E811-1, ~~R51~~; ~~47W335-6, R3;~~
DRAVO drawing: E2458 IC 32, R1. R3

4.7 ~~Deleted by Revision 1~~ SPP-9.1, "ASME Section XI", revision 2.

4.8 ASME Section XI, IWB 3640, 1980 9 Edition

4.9 EPRI NP-3375, "Induction Heating Stress Improvement", Research Project T 1113-1, Final Report, November 1983, General Electric, San Jose, CA

4.10 Deleted by Revision 1

4.11 EPRI NP-4690-SR, "Evaluation of Flaws in Austenitic Steel Piping", July 1986

4.12 BFNP Unit 2, FSAR, ~~page 4.2-9~~ Section 4.2.5 R3

4.13 TVA Calculation MD-Q0068-870088, R8 "Reactor Water Recirculation (RWR) System - Modes of Operation" (R14 980804 105)

4.14 TVA Calculation CD-Q2068-871118, ~~R18~~ R19 "Piping Analysis Summary - Reactor Water Recirculation System" (R14 ~~990420 121~~ 991115 102) R3

4.15 BFNP Unit 2 Drawing 2-ISI-0221-C, Sheet 1, R0 "Residual Heat Removal System Weld Locations"

4.16 Problem Evaluation Report BFN PER 98-007484-000

4.17 Problem Evaluation Report BFN PER 98-000663-000

4.18 NOI No. U2C11-006 R3

5.0 DESIGN INPUT DATA

5.1 Pipe Dimensions (Ref 4.6)

Outside Diameter	= 24 inches
Wall Thickness	= 1.219 inches

5.2 Design Pressure and Temperature (Ref 4.13)

Design Pressure	= 1326 psig
Design Temp	= 562^{o}F

REV	DESIGN	DATE
3	ECF	4/10/01
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5.3 Operating Pressure and Temperature (Ref 4.13)

Normal Pressure	= 1273 psig
Normal Temp	= 552°F
Upset Pressure	= 1558 psig
Upset Temp	= 532°F

5.4 Pipe Material (Ref 4.14 & Ref 4.15)

A-358 TP304 CL 1

5.5 Pipe Allowable Stresses (Ref 4.4)

Sm = 16.8 ksi @ 562°F (Design)
Sm = 16.9 ksi @ 552°F (Max Operating)

5.6 Pipe Loads (Ref 4.14)

Based on comparison of ref 4.14 (piping stress summary calculation) with ref 4.15 (ISI weld map)and ref 4.6 (mechanical layout drawing 47W452-10), the weld in question connects the 24 inch RHR supply to the 28 inch RECIRC pump discharge line. The closest node that is representative of this point is 281 which per the analysis isometric of ref 4.14, lies between node 269 representing the center of the Tee and node 280A representing a spring hanger that is 2'-7" from node 269. Actual piping moments and stresses are taken from the computer outputs generated by Revision 5 of ref 4.14. Although the calculation package has been revised a number of times since rev 5, these changes / conditions have not resulted in significant changes in piping loads at the location in question. A copy of the postprocessor stress summary for node 281 is included as Attachment A to this calculation.

6.0 COMPUTATIONS/ANALYSIS

Following the procedures of ASME Section XI, IWB-3640, Code Case N-436 and EPRI NP-4690-SR, the flaw in the subject weld will be evaluated by:

1. Computing subcritical flaw growth considering growth mechanisms due to both continued IGSCC and fatigue over a period of 2 fuel cycles. Following the Cycle ~~10~~ 11 refueling outage, BFN Unit 2 will operate for a period of 24 months between subsequent refuelings. Therefore the period of service is 2 x 2 = 4 years. Although any subcritical crack growth due to fatigue and IGSCC will be concurrent over the 4 year evaluation period, to address this with reasonable analytic simplicity, the IGSCC growth analysis will be executed first with the resulting final crack size utilized by a fatigue crack growth analysis. To ensure conservatism, a R3

REV	DESIGN	DATE
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case where fatigue crack growth is considered first followed by an IGSCC growth will be addressed.

2. Comparing the predicted end of period flaw size with allowable flaw depth as permitted by ASME Section XI for the loading conditions at DRHR-2-09.

6.1 IGSCC Crack Growth Analysis

IGSCC occurs as a result of the application of sustained stress at the flaw location over a period of time. The time dependent model of IGSCC is reflected by the following differential equation which is recommended by the NRC in ref 4.2:

$$\frac{da}{dt} = 3.590 \times 10^{-8} \cdot (K_I)^{2.161}$$

where: da/dt = growth rate (in / hour)

K_I = crack stress intensity factor due to sustained stress $(ksi \cdot \sqrt{in})$

Sustained stresses include not only those due to pressure, deadweight and thermal expansion but also those due to residual stresses. Residual welding stresses are considered a major factor in initiating and propagating IGSCC since the typical residual stress field is highly tensile on the inside pipe surface where exposure to the undesirable environment (i.e., oxygenated BWR primary water) occurs. To mitigate the potential for IGSCC at BFN Unit 2, most reactor coolant system girth butt welds, including DRHR-2-09 have been subjected to Induction Heating Stress Improvement (IHSI). As indicated by ref 4.9, IHSI has been demonstrated to alter the residual stress field to produce substantial compressive residual stresses at the pipe inside surface.

To project subcritical crack growth at DRHR-2-09 due to IGSCC, the Linear Elastic Fracture Mechanics Module of the reference 4.5 software (pc-CRACK™) is used to solve the growth rate equation with:

- a conservative assumption that the existing ~~crack is~~ cracks are constant depth extending completely around (i.e., 360°) the pipe circumference, R3

- the applied stresses at node 281 due to sustained conditions (i.e., pressure, deadweight and thermal expansion) assumed to be constant through the wall thickness:

$$\sigma_{PRESSURE} = 5.555\ \text{ksi} \cdot \frac{1273}{1326} = 5.333\ \text{ksi}$$

$$\sigma_{DEADWEIGHT} = 0.860\ \text{ksi}$$

$$\sigma_{THERMAL} = 7.736\ \text{ksi}$$

$$\sigma_{APPLIED} = 5.333\ \text{ksi} + 0.860\ \text{ksi} + 7.736\ \text{ksi} = 13.929\ \text{ksi},$$

- residual stress field based on reference 4.9 as derived in Attachment B of this calculation:

$$\sigma_{RESIDUAL} = -14\text{ksi} + 22.97\frac{\text{ksi}}{\text{in}} \cdot X$$

- an initial crack depth ~~size~~ based on the larger of the two flaws ~~most recent nondestructive evaluation~~ (examination summary sheets given in Attachment C):

  a_i = 0.27 in = flaw depth ~~and~~
  ~~l = 3.75 in = flaw length (not used in crack growth projection)~~ R3

- the evaluation period is taken as 4 calendar years (2 - 2 year fuel cycles or:

$$4\ \text{years} \cdot 365\frac{\text{days}}{\text{year}} \cdot 24\frac{\text{hours}}{\text{day}} = 35040\ \text{hours} \Rightarrow \textit{use}\ 35000\ \text{hours}$$

pc-CRACK™ output for this case is reflected by Table 8.1 which indicates about .031 inches growth due to IGSCC over 2 fuel cycles to reach a final size of 0.301 inches.

6.2 Fatigue Crack Growth Analysis

There is also potential that the subject crack will undergo additional subcritical crack growth as a result of fatigue (i.e., repetitive load cycles). The cycle dependent model of fatigue crack growth is expressed by the following differential equation taken from reference 4.11:

$$\frac{da}{dN} = C \cdot E \cdot S \cdot (\Delta K_I)^n$$

where: da/dN = cyclic growth rate (in/cycle)
$\Delta K_I = K_{MAX} - K_{MIN}$ = crack stress intensity factor due to one load cycle $(\text{ksi} \cdot \sqrt{\text{in}})$

REV	DESIGN	DATE
3	DESIGN EQF / CHKD [signature]	4/10/01 / 4/10/01

$C = 1.589 \times 10^{-9}$ for K_I in $\text{ksi}\sqrt{\text{in}}$

$n = 3.3$

$E = 10$ = factor for BWR environments

$S = (1 - 0.5 \cdot R^2)^{-4} = 1.0 \Rightarrow$ for $R = 0$

$$R = \frac{K_{MIN}}{K_{MAX}} = 0 \text{ if } K_{MIN} = 0$$

$$\frac{da}{dN} = 1.589 \times 10^{-8} \cdot (\Delta K_I)^{3.3}$$

Cyclic stresses considered in this analysis are those resulting from typical plant startup to full power and return to cold shutdown.

To project subcritical crack growth at DRHR-2-09 due to fatigue, the Linear Elastic Fracture Mechanics Module of the reference 4.5 software (pc-CRACK™) is again used to solve the growth rate equation with:

- a conservative assumption that the existing cracks are ~~crack is~~ constant depth extending completely around (i.e., 360°) the pipe circumference, R3

- the cyclic stresses at node 281 is due to design pressure and thermal expansion (i.e., piping analysis equation 10) assumed to be constant through the wall thickness:

$$\sigma_{PRESSURE} = 5.555 \text{ ksi}$$

$$\sigma_{THERMAL} = 7.736 \text{ ksi}$$

$$\sigma_{CYCLIC} = 5.555 \text{ ksi} + 7.736 \text{ ksi} = +13.291 \text{ ksi},$$

- an initial crack depth ~~size~~ based on most recent nondestructive evaluation (examination summary sheets given in Attachment C): R3

  a_i = 0.301 in = initial flaw depth from Section 6.1 above,
  ~~l = 3.75 in + Δl_{IGSCC} = initial flaw length (not used in fatigue crack growth projection)~~ R3

- the number of startup-shutdown cycles is conservatively taken as twice the number of hydrotests plus startup cycles defined for 4 years (i.e., 2 fuel cycles) out of the 40 year life of the plant per reference 4.12:

REV	DESIGN	DATE
3	[initials]	4/10/01
	CHKD [signature]	DATE 4/10/01

Prepared By: [signature] Date: 2/10/99
Checked By: [signature] Date: 2/16/99

$$2 \cdot \left(\frac{130 \text{ cycles}}{40 \text{ years}} + \frac{120 \text{ cycles}}{40 \text{ years}}\right) \cdot 4 \text{ years} = 50 \text{ cycles}$$

pc-CRACK™ output for this case is reflected by Table 8.2 which indicates about .009 inches growth due to fatigue over ~~the~~2 fuel cycles to reach a final size of 0.310 inches.

Reversing the order of the IGSCC and fatigue analysis, a second IGSCC crack growth analysis is executed using an initial crack size of:

$$a_i = 0.270 \text{ in} + 0.009 \text{ in} = 0.279 \text{ in}$$

pc-CRACK™ output is shown by Table 8.3 which indicates a final crack size (a_f) of 0.315 in which is slightly greater than the 0.309 in depth indicated from Table 8.2. As such, a depth of 0.315 in will be utilized as the end-of-period flaw depth.

Consistent with reference 4.2, at each flaw location the end-of-period flaw length will be calculated by assuming the flaw length increases by 2 times the percentage increase in flaw depth.

$$l_{f.1} := \left[1 + \left(2 \cdot \frac{0.315 \cdot \text{in} - 0.270 \cdot \text{in}}{0.270 \cdot \text{in}}\right)\right] \cdot 3.75 \cdot \text{in} \qquad l_{f.1} = 5 \cdot \text{in}$$

$$l_{f.2} := \left[1 + \left(2 \cdot \frac{0.315 \cdot \text{in} - 0.250 \cdot \text{in}}{0.250 \cdot \text{in}}\right)\right] \cdot 2.0 \cdot \text{in} \qquad l_{f.2} = 3.04 \cdot \text{in}$$

R3

Since the two cracks will remain less than 20% of the circumference in total length after crack growth, they may be treated as one crack with length equal to the sum of the lengths.

$$l_f := l_{f.1} + l_{f.2} \qquad l_f = 8.04 \cdot \text{in}$$

6.3 Allowable Flaw Size

Allowable size for a circumferential flaw in austenitic stainless steel pipe can be computed using the procedure of ASME Section XI, Code Case N-436 which considers either plastic collapse or ductile tearing failure modes as appropriate. The reference 4.5 pc-CRACK™ software provides capability to execute this procedure through its Codes and Standards Module. Input for this procedure includes membrane bending and expansion stresses, material design stress intensity and weld fabrication technique (i.e., either gas tungsten arc weld (GTAW), shielded metal arc weld (SMAW) or submerged arc weld (SAW)). The worst case is SAW (i.e., ductile tearing failure mode) which will be conservatively assumed in this analysis. The procedure requires consideration of the worst of either normal/upset or emergency/faulted plant conditions. Input stresses are as follows:

REV	DESIGN [signature]	DATE 4/10/01
3	CHKD [signature]	DATE 4/10/01

Prepared By: [signature] Date: 2/10/99

Checked By: [signature] Date: 2/16/99

Primary Membrane (Pressure) - All Conditions

$$Pm = 5.555 \text{ ksi} \cdot \frac{1558 \text{ psi}}{\sout{1373}\ 1326 \text{ psi}} = \sout{6.303}\ 6.527 \text{ ksi}$$

R3

Primary Bending (Deadweight + OBE) - Upset Condition

$$Pb_{upset} = 0.860 \text{ ksi} + 4.611 \text{ ksi} = 5.471 \text{ ksi}$$ = primary bending

Primary Bending (Deadweight + SSE) - Emergency Condition

$$Pb_{emerg} = 0.860 \text{ ksi} + 9.223 \text{ ksi} = 10.083 \text{ ksi}$$

Secondary Bending (Thermal Expansion) - All Conditions

$$Pe = 7.736 \text{ ksi}$$

pc-CRACK™ output for upset and emergency conditions is shown by Table 8.4. AS can be seen, for projected end-of-period flaw determined in Section 6.2 above and the applied loads for either upset or emergency conditions, the allowable flaw depth-to-wall thickness ratio (i.e., a/t) is controlled by the upset condition at a value of ~~0.5372~~ 0.4519 which is significantly greater than the actual a_f/t of ~~0.2584~~ 0.2625. R3

7.0 SUMMARY AND CONCLUSIONS

Based on the numerical results determined in Section 6 above, the existing flaws in weld DRHR-2-09 satisfy ~~ies~~ the structural acceptance criteria of reference 4.8. As such, DRHR-2-09 is acceptable for continued service for a period of up to 2 fuel cycles (4 years plant operation) from the refueling cycle ~~9~~ 11 inservice inspection and additional 2 fuel cycle periods (24 months per cycle) as long as crack growth relative to the cycle ~~9~~ 11 inspection is not detected in subsequent periodic inspections. R3

8.0 TABULAR AND GRAPHICAL RESULTS

Tabular results from this analysis are shown starting on the following page.

REV	DESIGN	DATE	CHKD	DATE
3	[initials]	4/10/01	[initials]	4/10/01

Prepared By: JCR Date: 2/10/99
Checked By: [signature] Date: 2/16/99

TABLE 8.1- IGSCC CRACK GROWTH AT DRHR-2-09

pc-CRACK™

VERSION 2.1

Date: 9-Feb-1999
Time: 17:10:10.18

STRESS CORROSION CRACK GROWTH ANALYSIS

IGSCC CRACK GROWTH @ DRHR-2-09

INITIAL CRACK SIZE= 0.2700
WALL THICKNESS= 1.2190
MAX CRACK SIZE FOR SCCG= 0.9752

STRESS CORROSION CRACK GROWTH LAW

LAW ID	C	N	Kthres	K1C
NRCCG	3.590E-08	2.1610	1.0000	100.0000

STRESS COEFFICIENTS

CASE ID	C0	C1	C2	C3
SUSTAIN	13.9290	0.0000	0.0000	0.0000
RESIDUAL	-14.0000	22.9700	0.0000	0.0000
CYCLIC	13.2900	0.0000	0.0000	0.0000

CASE ID	Kmax SCALE FACTOR
SUSTAIN	1.0000
RESIDUAL	1.0000

TIME	TIME INCREMENT	PRINT INCREMENT
35000.0	100.0	500.0

crack model:CIRCUMFERENTIAL CRACK IN CYLINDER (T/R=0.1)

CRACK SIZE	STRESS INTENSITY FACTOR CASE SUSTAIN	CASE RESIDUAL	CASE CYCLIC
0.0195	3.824	-3.772	3.649
0.0390	5.433	-5.256	5.184
0.0585	6.684	-6.341	6.377
0.0780	7.752	-7.209	7.396
0.0975	8.706	-7.932	8.306
0.1170	9.579	-8.548	9.139
0.1365	10.449	-9.129	9.969
0.1560	11.300	-9.663	10.782
0.1755	12.123	-10.143	11.567
0.1950	12.925	-10.574	12.332
0.2145	13.708	-10.962	13.079
0.2340	14.476	-11.310	13.812

Table 8.1 (continued)

0.2536	15.275	-11.655	14.574
0.2731	16.109	-12.001	15.370
0.2926	16.942	-12.316	16.165
0.3121	17.773	-12.601	16.958
0.3316	18.605	-12.857	17.751
0.3511	19.437	-13.085	18.545
0.3706	20.314	-13.323	19.382
0.3901	21.330	-13.651	20.351
0.4096	22.357	-13.956	21.332
0.4291	23.396	-14.239	22.322
0.4486	24.445	-14.498	23.324
0.4681	25.506	-14.735	24.336
0.4876	26.578	-14.947	25.359
0.5071	27.720	-15.179	26.448
0.5266	28.875	-15.387	27.550
0.5461	30.043	-15.570	28.665
0.5656	31.225	-15.728	29.792
0.5851	32.419	-15.861	30.932
0.6046	33.627	-15.967	32.084
0.6241	34.921	-16.073	33.319
0.6436	36.254	-16.158	34.591
0.6631	37.604	-16.212	35.879
0.6826	38.969	-16.235	37.181
0.7021	40.349	-16.226	38.498
0.7216	41.744	-16.184	39.829
0.7412	43.208	-16.176	41.226
0.7607	44.742	-16.205	42.690
0.7802	46.294	-16.204	44.170
0.7997	47.862	-16.173	45.667
0.8192	49.448	-16.111	47.180
0.8387	51.051	-16.017	48.709
0.8582	52.709	-15.853	50.291
0.8777	54.499	-15.527	51.999
0.8972	56.310	-15.150	53.726
0.9167	58.140	-14.721	55.472
0.9362	59.989	-14.238	57.237
0.9557	61.858	-13.700	59.020
0.9752	63.745	-13.108	60.821

TIME	KMAX	DA/DT	DA	A	A/THK
500.0	4.04	7.333E-07	0.0001	0.2704	0.222
1000.0	4.05	7.369E-07	0.0001	0.2707	0.222
1500.0	4.06	7.406E-07	0.0001	0.2711	0.222
2000.0	4.07	7.443E-07	0.0001	0.2715	0.223
2500.0	4.08	7.480E-07	0.0001	0.2718	0.223
3000.0	4.09	7.517E-07	0.0001	0.2722	0.223
3500.0	4.10	7.555E-07	0.0001	0.2726	0.224
4000.0	4.10	7.592E-07	0.0001	0.2730	0.224
4500.0	4.11	7.632E-07	0.0001	0.2734	0.224
5000.0	4.12	7.673E-07	0.0001	0.2737	0.225
5500.0	4.13	7.714E-07	0.0001	0.2741	0.225
6000.0	4.15	7.755E-07	0.0001	0.2745	0.225
6500.0	4.16	7.797E-07	0.0001	0.2749	0.226
7000.0	4.17	7.839E-07	0.0001	0.2753	0.226
7500.0	4.18	7.881E-07	0.0001	0.2757	0.226

Prepared By: [signature] Date: 2/10/99
Checked By: [signature] Date: 2/16/99

Table 8.1 (continued)

8000.0	4.19	7.924E-07	0.0001	0.2761	0.226
8500.0	4.20	7.967E-07	0.0001	0.2765	0.227
9000.0	4.21	8.011E-07	0.0001	0.2769	0.227
9500.0	4.22	8.055E-07	0.0001	0.2773	0.227
10000.0	4.23	8.099E-07	0.0001	0.2777	0.228
10500.0	4.24	8.144E-07	0.0001	0.2781	0.228
11000.0	4.25	8.189E-07	0.0001	0.2785	0.228
11500.0	4.26	8.234E-07	0.0001	0.2789	0.229
12000.0	4.27	8.280E-07	0.0001	0.2793	0.229
12500.0	4.28	8.326E-07	0.0001	0.2797	0.229
13000.0	4.29	8.373E-07	0.0001	0.2802	0.230
13500.0	4.31	8.420E-07	0.0001	0.2806	0.230
14000.0	4.32	8.467E-07	0.0001	0.2810	0.231
14500.0	4.33	8.515E-07	0.0001	0.2814	0.231
15000.0	4.34	8.563E-07	0.0001	0.2819	0.231
15500.0	4.35	8.612E-07	0.0001	0.2823	0.232
16000.0	4.36	8.661E-07	0.0001	0.2827	0.232
16500.0	4.37	8.710E-07	0.0001	0.2831	0.232
17000.0	4.39	8.760E-07	0.0001	0.2836	0.233
17500.0	4.40	8.811E-07	0.0001	0.2840	0.233
18000.0	4.41	8.861E-07	0.0001	0.2845	0.233
18500.0	4.42	8.913E-07	0.0001	0.2849	0.234
19000.0	4.43	8.964E-07	0.0001	0.2854	0.234
19500.0	4.44	9.017E-07	0.0001	0.2858	0.234
20000.0	4.46	9.069E-07	0.0001	0.2863	0.235
20500.0	4.47	9.122E-07	0.0001	0.2867	0.235
21000.0	4.48	9.176E-07	0.0001	0.2872	0.236
21500.0	4.49	9.230E-07	0.0001	0.2876	0.236
22000.0	4.51	9.285E-07	0.0001	0.2881	0.236
22500.0	4.52	9.340E-07	0.0001	0.2886	0.237
23000.0	4.53	9.395E-07	0.0001	0.2890	0.237
23500.0	4.54	9.451E-07	0.0001	0.2895	0.237
24000.0	4.56	9.508E-07	0.0001	0.2900	0.238
24500.0	4.57	9.565E-07	0.0001	0.2905	0.238
25000.0	4.58	9.623E-07	0.0001	0.2909	0.239
25500.0	4.59	9.681E-07	0.0001	0.2914	0.239
26000.0	4.61	9.740E-07	0.0001	0.2919	0.239
26500.0	4.62	9.799E-07	0.0001	0.2924	0.240
27000.0	4.63	9.860E-07	0.0001	0.2929	0.240
27500.0	4.65	9.924E-07	0.0001	0.2934	0.241
28000.0	4.66	9.989E-07	0.0001	0.2939	0.241
28500.0	4.67	1.005E-06	0.0001	0.2944	0.241
29000.0	4.69	1.012E-06	0.0001	0.2949	0.242
29500.0	4.70	1.019E-06	0.0001	0.2954	0.242
30000.0	4.72	1.025E-06	0.0001	0.2959	0.243
30500.0	4.73	1.032E-06	0.0001	0.2964	0.243
31000.0	4.75	1.039E-06	0.0001	0.2969	0.244
31500.0	4.76	1.046E-06	0.0001	0.2975	0.244
32000.0	4.77	1.053E-06	0.0001	0.2980	0.244
32500.0	4.79	1.060E-06	0.0001	0.2985	0.245
33000.0	4.80	1.067E-06	0.0001	0.2990	0.245
33500.0	4.82	1.074E-06	0.0001	0.2996	0.246
34000.0	4.83	1.081E-06	0.0001	0.3001	0.246
34500.0	4.85	1.089E-06	0.0001	0.3007	0.247
35000.0	4.87	1.096E-06	0.0001	0.3012	0.247

TABLE 8.2 - FATIGUE CRACK GROWTH AT DRHR-2-09

pc-CRACK™

STRUCTURAL INTEGRITY ASSOCIATES, INC.
SAN JOSE, CA (408)978-8200
VERSION 2.1

Date: 9-Feb-1999
Time: 17:21: 8.46

FATIGUE CRACK GROWTH ANALYSIS

FATIGUE CRACK GROWTH @ DRHR-2-09

INITIAL CRACK SIZE= 0.3010
WALL THICKNESS= 1.2190
MAX CRACK SIZE FOR FCG= 0.9752

PARIS CRACK GROWTH LAW:
da/dN = C * (dK)^n
where
dK = Kmax - Kmin
dK > dKthres
Kmax < K1c

CURRENT LAWS:

LAW ID	C	n	dKthres	K1c
FCGSS	1.589E-08	3.300	0.000	100.000

STRESS COEFFICIENTS

CASE ID	C0	C1	C2	C3
SUSTAIN	13.9290	0.0000	0.0000	0.0000
RESIDUAL	-14.0000	22.9700	0.0000	0.0000
CYCLIC	13.2900	0.0000	0.0000	0.0000

NUMBER OF CYCLE BLOCKS= 1
PRINT INCREMENT OF CYCLE BLOCK= 1

SUBBLOCK	NUMBER OF CYCLES	CALCULATION INCREMENT	PRINT INCREMENT	FCG LAW ID
1	50	1	2	FCGSS

	Kmax		Kmin	
SUBBLOCK	CASE ID	SCALE FACTOR	CASE ID	SCALE FACTOR
1	CYCLIC	1.0000	CYCLIC	0.0000

crack model:CIRCUMFERENTIAL CRACK IN CYLINDER (T/R=0.1)

CRACK	STRESS INTENSITY FACTOR		
SIZE	CASE SUSTAIN	CASE RESIDUAL	CASE CYCLIC
0.0195	3.824	-3.772	3.649
0.0390	5.433	-5.256	5.184

Prepared By: *JCR* Date: *2/10/99*

Checked By: *EU* Date: *2/16/99*

Table 8.2 (continued)

0.0585	6.684	-6.341	6.377
0.0780	7.752	-7.209	7.396
0.0975	8.706	-7.932	8.306
0.1170	9.579	-8.548	9.139
0.1365	10.449	-9.129	9.969
0.1560	11.300	-9.663	10.782
0.1755	12.123	-10.143	11.567
0.1950	12.925	-10.574	12.332
0.2145	13.708	-10.962	13.079
0.2340	14.476	-11.310	13.812
0.2536	15.275	-11.655	14.574
0.2731	16.109	-12.001	15.370
0.2926	16.942	-12.316	16.165
0.3121	17.773	-12.601	16.958
0.3316	18.605	-12.857	17.751
0.3511	19.437	-13.085	18.545
0.3706	20.314	-13.323	19.382
0.3901	21.330	-13.651	20.351
0.4096	22.357	-13.956	21.332
0.4291	23.396	-14.239	22.322
0.4486	24.445	-14.498	23.324
0.4681	25.506	-14.735	24.336
0.4876	26.578	-14.947	25.359
0.5071	27.720	-15.179	26.448
0.5266	28.875	-15.387	27.550
0.5461	30.043	-15.570	28.665
0.5656	31.225	-15.728	29.792
0.5851	32.419	-15.861	30.932
0.6046	33.627	-15.967	32.084
0.6241	34.921	-16.073	33.319
0.6436	36.254	-16.158	34.591
0.6631	37.604	-16.212	35.879
0.6826	38.969	-16.235	37.181
0.7021	40.349	-16.226	38.498
0.7216	41.744	-16.184	39.829
0.7412	43.208	-16.176	41.226
0.7607	44.742	-16.205	42.690
0.7802	46.294	-16.204	44.170
0.7997	47.862	-16.173	45.667
0.8192	49.448	-16.111	47.180
0.8387	51.051	-16.017	48.709
0.8582	52.709	-15.853	50.291
0.8777	54.499	-15.527	51.999
0.8972	56.310	-15.150	53.726
0.9167	58.140	-14.721	55.472
0.9362	59.989	-14.238	57.237
0.9557	61.858	-13.700	59.020
0.9752	63.745	-13.108	60.821

Prepared By: [signature] Date: 2/10/99
Checked By: [signature] Date: 2/16/99

Table 8.2 (continued)

TOTAL CYCLE	SUBBLOCK CYCLE	KMAX	KMIN	DELTAK	R	DADN	DA	A	A/T
BLOCK 1									
2	2	16.51	0.00	16.51	0.00	1.7E-04	0.0002	0.3013	0.25
4	4	16.53	0.00	16.53	0.00	1.7E-04	0.0002	0.3017	0.25
6	6	16.54	0.00	16.54	0.00	1.7E-04	0.0002	0.3020	0.25
8	8	16.56	0.00	16.56	0.00	1.7E-04	0.0002	0.3023	0.25
10	10	16.57	0.00	16.57	0.00	1.7E-04	0.0002	0.3027	0.25
12	12	16.58	0.00	16.58	0.00	1.7E-04	0.0002	0.3030	0.25
14	14	16.60	0.00	16.60	0.00	1.7E-04	0.0002	0.3033	0.25
16	16	16.61	0.00	16.61	0.00	1.7E-04	0.0002	0.3037	0.25
18	18	16.62	0.00	16.62	0.00	1.7E-04	0.0002	0.3040	0.25
20	20	16.64	0.00	16.64	0.00	1.7E-04	0.0002	0.3044	0.25
22	22	16.65	0.00	16.65	0.00	1.7E-04	0.0002	0.3047	0.25
24	24	16.67	0.00	16.67	0.00	1.7E-04	0.0002	0.3050	0.25
26	26	16.68	0.00	16.68	0.00	1.7E-04	0.0002	0.3054	0.25
28	28	16.69	0.00	16.69	0.00	1.7E-04	0.0002	0.3057	0.25
30	30	16.71	0.00	16.71	0.00	1.7E-04	0.0002	0.3061	0.25
32	32	16.72	0.00	16.72	0.00	1.7E-04	0.0002	0.3064	0.25
34	34	16.74	0.00	16.74	0.00	1.7E-04	0.0002	0.3068	0.25
36	36	16.75	0.00	16.75	0.00	1.7E-04	0.0002	0.3071	0.25
38	38	16.76	0.00	16.76	0.00	1.7E-04	0.0002	0.3075	0.25
40	40	16.78	0.00	16.78	0.00	1.7E-04	0.0002	0.3078	0.25
42	42	16.79	0.00	16.79	0.00	1.8E-04	0.0002	0.3082	0.25
44	44	16.81	0.00	16.81	0.00	1.8E-04	0.0002	0.3085	0.25
46	46	16.82	0.00	16.82	0.00	1.8E-04	0.0002	0.3089	0.25
48	48	16.84	0.00	16.84	0.00	1.8E-04	0.0002	0.3092	0.25
50	50	16.85	0.00	16.85	0.00	1.8E-04	0.0002	0.3096	0.25

Prepared By: [signature] Date: 2/10/99

Checked By: [signature] Date: 2/16/99

Table 8.3 - IGSCC CRACK GROWTH @ DRHR-2-09, CASE 2

Date: 9-Feb-1999
Time: 17:28:30.72

STRESS CORROSION CRACK GROWTH ANALYSIS

IGSCC CRACK GROWTH @ DRHR-2-09, CASE 2

INITIAL CRACK SIZE= 0.2790
WALL THICKNESS= 1.2190
MAX CRACK SIZE FOR SCCG= 0.9752

STRESS CORROSION CRACK GROWTH LAW

LAW ID	C	N	Kthres	K1C
NRCCG	3.590E-08	2.1610	1.0000	100.0000

STRESS COEFFICIENTS

CASE ID	C0	C1	C2	C3
SUSTAIN	13.9290	0.0000	0.0000	0.0000
RESIDUAL	-14.0000	22.9700	0.0000	0.0000
CYCLIC	13.2900	0.0000	0.0000	0.0000

Kmax CASE ID	SCALE FACTOR
SUSTAIN	1.0000
RESIDUAL	1.0000

TIME	TIME INCREMENT	PRINT INCREMENT
35000.0	100.0	500.0

crack model:CIRCUMFERENTIAL CRACK IN CYLINDER (T/R=0.1)

CRACK SIZE	---STRESS INTENSITY FACTOR--- CASE SUSTAIN	CASE RESIDUAL	CASE CYCLIC
0.0195	3.824	-3.772	3.649
0.0390	5.433	-5.256	5.184
0.0585	6.684	-6.341	6.377
0.0780	7.752	-7.209	7.396
0.0975	8.706	-7.932	8.306
0.1170	9.579	-8.548	9.139
0.1365	10.449	-9.129	9.969
0.1560	11.300	-9.663	10.782
0.1755	12.123	-10.143	11.567
0.1950	12.925	-10.574	12.332
0.2145	13.708	-10.962	13.079
0.2340	14.476	-11.310	13.812

Table 8.3 (continued)

0.2536	15.275	-11.655	14.574
0.2731	16.109	-12.001	15.370
0.2926	16.942	-12.316	16.165
0.3121	17.773	-12.601	16.958
0.3316	18.605	-12.857	17.751
0.3511	19.437	-13.085	18.545
0.3706	20.314	-13.323	19.382
0.3901	21.330	-13.651	20.351
0.4096	22.357	-13.956	21.332
0.4291	23.396	-14.239	22.322
0.4486	24.445	-14.498	23.324
0.4681	25.506	-14.735	24.336
0.4876	26.578	-14.947	25.359
0.5071	27.720	-15.179	26.448
0.5266	28.875	-15.387	27.550
0.5461	30.043	-15.570	28.665
0.5656	31.225	-15.728	29.792
0.5851	32.419	-15.861	30.932
0.6046	33.627	-15.967	32.084
0.6241	34.921	-16.073	33.319
0.6436	36.254	-16.158	34.591
0.6631	37.604	-16.212	35.879
0.6826	38.969	-16.235	37.181
0.7021	40.349	-16.226	38.498
0.7216	41.744	-16.184	39.829
0.7412	43.208	-16.176	41.226
0.7607	44.742	-16.205	42.690
0.7802	46.294	-16.204	44.170
0.7997	47.862	-16.173	45.667
0.8192	49.448	-16.111	47.180
0.8387	51.051	-16.017	48.709
0.8582	52.709	-15.853	50.291
0.8777	54.499	-15.527	51.999
0.8972	56.310	-15.150	53.726
0.9167	58.140	-14.721	55.472
0.9362	59.989	-14.238	57.237
0.9557	61.858	-13.700	59.020
0.9752	63.745	-13.108	60.821

TIME	KMAX	DA/DT	DA	A	A/THK
500.0	4.27	8.290E-07	0.0001	0.2794	0.229
1000.0	4.29	8.336E-07	0.0001	0.2798	0.230
1500.0	4.30	8.383E-07	0.0001	0.2802	0.230
2000.0	4.31	8.430E-07	0.0001	0.2807	0.230
2500.0	4.32	8.477E-07	0.0001	0.2811	0.231
3000.0	4.33	8.525E-07	0.0001	0.2815	0.231
3500.0	4.34	8.573E-07	0.0001	0.2819	0.231
4000.0	4.35	8.622E-07	0.0001	0.2824	0.232
4500.0	4.36	8.671E-07	0.0001	0.2828	0.232
5000.0	4.38	8.721E-07	0.0001	0.2832	0.232
5500.0	4.39	8.771E-07	0.0001	0.2837	0.233
6000.0	4.40	8.821E-07	0.0001	0.2841	0.233
6500.0	4.41	8.872E-07	0.0001	0.2846	0.233
7000.0	4.42	8.924E-07	0.0001	0.2850	0.234
7500.0	4.44	8.976E-07	0.0001	0.2855	0.234

Prepared By: [signature] Date: 2/10/99
Checked By: [signature] Date: 2/16/99

Table 8.3 (continued)

8000.0	4.45	9.028E-07	0.0001	0.2859	0.235
8500.0	4.46	9.081E-07	0.0001	0.2864	0.235
9000.0	4.47	9.134E-07	0.0001	0.2868	0.235
9500.0	4.48	9.187E-07	0.0001	0.2873	0.236
10000.0	4.50	9.242E-07	0.0001	0.2877	0.236
10500.0	4.51	9.296E-07	0.0001	0.2882	0.236
11000.0	4.52	9.352E-07	0.0001	0.2887	0.237
11500.0	4.53	9.407E-07	0.0001	0.2891	0.237
12000.0	4.55	9.463E-07	0.0001	0.2896	0.238
12500.0	4.56	9.520E-07	0.0001	0.2901	0.238
13000.0	4.57	9.577E-07	0.0001	0.2906	0.238
13500.0	4.58	9.635E-07	0.0001	0.2910	0.239
14000.0	4.60	9.694E-07	0.0001	0.2915	0.239
14500.0	4.61	9.752E-07	0.0001	0.2920	0.240
15000.0	4.62	9.812E-07	0.0001	0.2925	0.240
15500.0	4.64	9.874E-07	0.0001	0.2930	0.240
16000.0	4.65	9.938E-07	0.0001	0.2935	0.241
16500.0	4.66	1.000E-06	0.0001	0.2940	0.241
17000.0	4.68	1.007E-06	0.0001	0.2945	0.242
17500.0	4.69	1.013E-06	0.0001	0.2950	0.242
18000.0	4.71	1.020E-06	0.0001	0.2955	0.242
18500.0	4.72	1.027E-06	0.0001	0.2960	0.243
19000.0	4.73	1.034E-06	0.0001	0.2965	0.243
19500.0	4.75	1.040E-06	0.0001	0.2970	0.244
20000.0	4.76	1.047E-06	0.0001	0.2976	0.244
20500.0	4.78	1.054E-06	0.0001	0.2981	0.245
21000.0	4.79	1.061E-06	0.0001	0.2986	0.245
21500.0	4.81	1.069E-06	0.0001	0.2992	0.245
22000.0	4.82	1.076E-06	0.0001	0.2997	0.246
22500.0	4.84	1.083E-06	0.0001	0.3002	0.246
23000.0	4.85	1.090E-06	0.0001	0.3008	0.247
23500.0	4.87	1.098E-06	0.0001	0.3013	0.247
24000.0	4.88	1.105E-06	0.0001	0.3019	0.248
24500.0	4.90	1.113E-06	0.0001	0.3024	0.248
25000.0	4.92	1.121E-06	0.0001	0.3030	0.249
25500.0	4.93	1.128E-06	0.0001	0.3036	0.249
26000.0	4.95	1.136E-06	0.0001	0.3041	0.249
26500.0	4.96	1.144E-06	0.0001	0.3047	0.250
27000.0	4.98	1.152E-06	0.0001	0.3053	0.250
27500.0	4.99	1.160E-06	0.0001	0.3058	0.251
28000.0	5.01	1.169E-06	0.0001	0.3064	0.251
28500.0	5.03	1.177E-06	0.0001	0.3070	0.252
29000.0	5.04	1.185E-06	0.0001	0.3076	0.252
29500.0	5.06	1.194E-06	0.0001	0.3082	0.253
30000.0	5.08	1.202E-06	0.0001	0.3088	0.253
30500.0	5.09	1.211E-06	0.0001	0.3094	0.254
31000.0	5.11	1.220E-06	0.0001	0.3100	0.254
31500.0	5.13	1.229E-06	0.0001	0.3106	0.255
32000.0	5.15	1.237E-06	0.0001	0.3112	0.255
32500.0	5.16	1.247E-06	0.0001	0.3119	0.256
33000.0	5.18	1.256E-06	0.0001	0.3125	0.256
33500.0	5.20	1.266E-06	0.0001	0.3131	0.257
34000.0	5.22	1.276E-06	0.0001	0.3138	0.257
34500.0	5.24	1.285E-06	0.0001	0.3144	0.258
35000.0	5.26	1.296E-06	0.0001	0.3150	0.258

Table 8.4

CD-Q2074-990016 R3
Page 23
This page replaced by revision 3

Prepared by: [signature] Date: 4/10/01
Checked by: [signature] Date: 4/10/01

pc-CRACK

STRUCTURAL INTEGRITY ASSOCIATES, INC.
SAN JOSE, CA (408)978-8200
VERSION 2.1

Date: 10-Apr-2001
Time: 17:55: 2.63

ALLOWABLE FLAW SIZE EVALUATIONS
USING ASME SECTION XI, IWB-3640/50 PROCEDURES AND CRITERIA
FOR CIRCUMFERENTIAL CRACKS IN STAINLESS STEEL PIPING

MATERIAL IS SPECIFIED AS SUBMERGED ARC WELD
DEFAULT PROPERTIES:
DESIGN STRESS = 16.95
FLOW STRESS = 50.85

ALLOWABLE FLAW SIZE AT WELD DRHR-2-09; NORMAL/UPSET CONDITION

USER SUPPLIED MATERIAL PROPERTIES:
DESIGN STRESS = 16.80
FLOW STRESS = 50.40

PIPE GEOMETRY:
OUTER DIAMETER = 24.0000
WALL THICKNESS = 1.2000
CRACK GEOMETRY:
CRACK DEPTH = 0.3150
CRACK LENGTH = 8.0400

THE FLAWED PIPE IS ASSUMED TO FAIL DUE TO UNSTABLE DUCTILE TEARING (EPFM)

THE ALLOWABLE FLAW SIZE IS DETERMINED USING CODE TABLES AND DEFAULT SAFETY FACTORS FOR NORMAL OPERATING (INCL. UPSET & TEST) CONDITIONS

MEMBRANE STRESS (Pm) = 6.5270 (SAFETY FACTOR = 2.770)
BENDING STRESS (Pb) = 5.4710 (SAFETY FACTOR = 2.770)
EXPANSION STRESS (Pe) = 7.7360 (SAFETY FACTOR = 1.000)
DESIGN STRESS = 16.8000
(Pm + Pb)/Sm = 0.7142
STRESS RATIO = 0.9508 (DOES NOT INCLUDE S.F.)
M FACTOR = 1.0800
a/t = 0.2625
l/circumference = 0.1066
ALLOWABLE a/t = 0.4519

	l/circumference					
	0.00	0.10	0.20	0.30	0.40	0.50
ALLOWABLE a/t	0.6000	0.4663	0.2485	0.1792	0.1295	0.1197

ALLOWABLE FLAW SIZE AT WELD DRHR-2-09; EMERG/FAULTED CONDITION

USER SUPPLIED MATERIAL PROPERTIES:
DESIGN STRESS = 16.80
FLOW STRESS = 50.40

PIPE GEOMETRY:
OUTER DIAMETER = 24.0000
WALL THICKNESS = 1.2000
CRACK GEOMETRY:
CRACK DEPTH = 0.3150
CRACK LENGTH = 8.0400

THE FLAWED PIPE IS ASSUMED TO FAIL DUE TO UNSTABLE DUCTILE TEARING (EPFM)

THE ALLOWABLE FLAW SIZE IS DETERMINED USING CODE TABLES AND DEFAULT SAFETY FACTORS FOR EMERGENCY AND FAULTED CONDITIONS

MEMBRANE STRESS (Pm) = 6.5270 (SAFETY FACTOR = 1.390)
BENDING STRESS (Pb) = 10.0830 (SAFETY FACTOR = 1.390)
EXPANSION STRESS (Pe) = 7.7360 (SAFETY FACTOR = 1.000)
DESIGN STRESS = 16.8000
(Pm + Pb)/Sm = 0.9887
STRESS RATIO = 1.4256 (DOES NOT INCLUDE S.F.)
M FACTOR = 1.0800
a/t = 0.2625
l/circumference = 0.1066
ALLOWABLE a/t = 0.6000

	l/circumference					
	0.00	0.10	0.20	0.30	0.40	0.50
ALLOWABLE a/t	0.6000	0.6000	0.6000	0.5293	0.4272	0.3298

ATTACHMENT A

INFORMATION ONLY

CLASS 2 POST PROCESSOR PID = 19028 1999-02-01 10:06:22 PAGE 207
N1-268-1R BROWNS FERRY 2 REACTOR WATER RECIR SYS

```
*****************************
*                           *
*     ASME CODE CLASS 2     *
*     STRESS EVALUATION     *
*                           *
*****************************
```

MEMBER NAME	NODE NAME	SIF ID.	EQN NO.	LOGIC PATH	PRESSURE STRESS (PSI)	SUSTAINED STRESS (PSI)	OCCASIONAL STRESS (PSI)	EXPANSION STRESS (PSI)	I OR U	CODE STRESS (PSI)	STRESS RATIO	STRESS DIFFERENCE (PSI)	ALLOWABLE STRESS (PSI)
1360	269	WTEE	8		5555.	954.	0.	0.	I	6509.	0.451	7917.	14426.
			10	SAM	0.	0.	0.	12311.	I	12311.	0.455	14733.	27044.
			11	SAM	5555.	954.	0.	12311.	I	18820.	0.454	22650.	41470.
			9U		5555.	954.	5686.	0.	I	12195.	0.704	5116.	17311.
			9U+10		5555.	954.	5686.	12311.	I	24506.	0.552	19849.	44355.
			9E		5555.	954.	11372.	0.	I	17881.	0.689	8086.	25967.
			9E1		6670.	954.	5686.	0.	I	13310.	0.615	8329.	21639.
			9E2		6670.	954.	11372.	0.	I	18996.	0.658	9856.	28852.
			9F		6670.	954.	11372.	0.	I	18996.	0.549	15627.	34622.
			AV		6670.	802.	9566.	4605.	U	21643.	1.160	-2987.	18656.
			PR9U+10		5555.	954.	5686.	12311.	I	24506.	0.739	8670.	33176.
			PR10	SAM	0.	0.	0.	12311.	I	12311.	0.569	9324.	21635.
1360	281		8		5555.	860.	0.	0.	I	6415.	0.445	8011.	14426.
			10	SAM	0.	0.	0.	7736.	I	7736.	0.286	19308.	27044.
			11	SAM	5555.	860.	0.	7736.	I	14151.	0.341	27319.	41470.
			9U		5555.	860.	4611.	0.	I	11027.	0.637	6285.	17311.
			9U+10		5555.	860.	4611.	7736.	I	18763.	0.423	25593.	44355.
			9E		5555.	860.	9223.	0.	I	15638.	0.602	10329.	25967.
			9E1		6670.	860.	4611.	0.	I	12141.	0.561	9498.	21639.
			9E2		6670.	860.	9223.	0.	I	16752.	0.581	12100.	28852.
			9F		6670.	860.	9223.	0.	I	16752.	0.484	17870.	34622.
			AV		6670.	860.	9223.	4910.	U	21662.	1.161	-3006.	18656.
			PR9U+10		5555.	860.	4611.	7736.	I	18763.	0.566	14413.	33176.
			PR10	SAM	0.	0.	0.	7736.	I	7736.	0.358	13899.	21635.
1365	281		8		5555.	860.	0.	0.	I	6415.	0.445	8011.	14426.
			10	SAM	0.	0.	0.	7736.	I	7736.	0.286	19308.	27044.
			11	SAM	5555.	860.	0.	7736.	I	14151.	0.341	27319.	41470.
			9U		5555.	860.	4611.	0.	I	11027.	0.637	6285.	17311.
			9U+10		5555.	860.	4611.	7736.	I	18763.	0.423	25593.	44355.
			9E		5555.	860.	9223.	0.	I	15638.	0.602	10329.	25967.
			9E1		6670.	860.	4611.	0.	I	12141.	0.561	9498.	21639.
			9E2		6670.	860.	9223.	0.	I	16752.	0.581	12100.	28852.
			9F		6670.	860.	9223.	0.	I	16752.	0.484	17870.	34622.
			AV		6670.	860.	9223.	4910.	U	21662.	1.161	-3006.	18656.
			PR9U+10		5555.	860.	4611.	7736.	I	18763.	0.566	14413.	33176.
			PR10	SAM	0.	0.	0.	7736.	I	7736.	0.358	13899.	21635.

Prepared By: JCR Date: 2/10/99
Checked By: EW Date: 2/16/99

ATTACHMENT B
RESIDUAL STRESS PREDICTION AT DRHR-2-09

EPRI NP-3375 provides the results of a laboratory test program sponsored by the BWR Owner's Group to demonstrate the benefit of performing IHSI on welds susceptible to IGSCC. Areas investigated included:

- Process Effectiveness - found to be very good with compressive residual stress on the inside surface at the weld fusion line on the order of material yield strength. Effective retention of the compressive residual stress was found to be reduced when the pipe was exposed to high (i.e., approaching material yield) applied stress subsequent to the treatment; however, this applied stress level is well above typical service stresses.

- Application in Operating Plants - found that even when IHSI is applied to pipes containing IGSCC indications, the resulting compressive residual stress field remains substantial.

In Section 5.0 of the NP-3375, residual stress data for IHSI applications to pipes with pre-existing defects is provided. Figures 5-2 through 5-6 in that document reflect axial residual stress measurements in and near a pipe joint that contains a defect but has been subjected to IHSI. These figures reflect several azimuth positions and distances from the weld fusion line with the crack located 0.060 inches from the weld fusion line. The stress distribution follows a more or less linear profile through the thickness. As can be seen, compressive residual stress is the greatest at the fusion line with a magnitude of -44 ksi, reducing to -36 ksi at the crack, then to -28 ksi at 0.120 inches and finally to -16 ksi at 0.600 inches. To provide a conservative approximation for weld DRHR-2-09, a residual stress distribution similar to the one observed at 0.600 inches from the weld fusion line (Figure 5.5) can be applied. For analysis, the inside surface stresses will be taken as -14 ksi with a linear variation to +14 ksi on the outside surface. The residual stress distribution over the 1.219 inch wall thickness at DRHR-2-09 can be expressed by the formula:

$$\sigma_{RESIDUAL} = C_0 + C_1 \cdot X$$

where: X = through-thickness dimension (in)
C_0 = inside surface stress (-14 ksi)

$$C_1 = \frac{14-(-14)}{1.219} = 22.97 \cdot \frac{ksi}{in}$$

A graphical representation of this simplified but conservative residual stress distribution is shown overlaid on the residual stress field reflected by Figure 5-5 from NP-3375 on the following page.

Prepared By: JLR Date: 2/10/99

Checked By: KH Date: 2/16/99

Figure 5-5 from NP-3375 with Conservative Linear Residual Stress Distribution Used For Analysis of DRHR-2-09

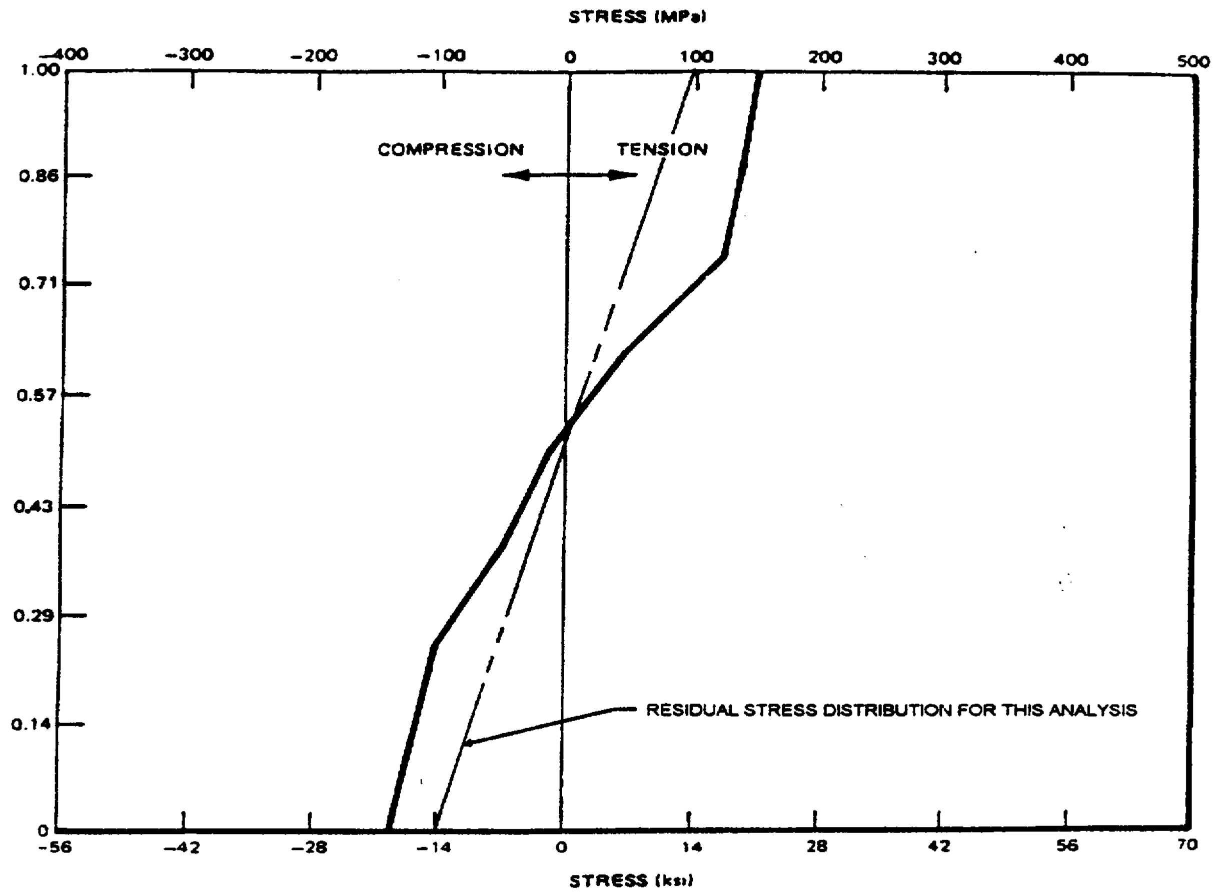


Figure 5-5. Through Wall Axial Residual Stress Distribution for Specimen RS-06 Joint E. Pre-Cracked Plus IHSI-312.5° Azimuth, 15.2 mm (0.600 Inches) From Weld Fusion Line

ATTACHMENT C

DRHR-2-09 INSERVICE INSPECTION DATA SHEETS

3 Information Only Pages Follow:

1. U2C7 Examination Summary and Resolution Sheet
2. U2C7 Data Analysis Report
3. U2C9 Examination Summary and Resolution Sheet

Attachment C (cont'd)

CD-Q2074-990016
Page 29 of
THIS PAGE ADDED BY R1

INFORMATION ONLY

TVA TENNESSEE VALLEY AUTHORITY	EXAMINATION SUMMARY and RESOLUTION SHEET	REPORT NO. R- ~~074~~ 0318 DH 10/21/94

PROJECT : BFNP	PROCEDURE : N-UT-42 REV: 5 TC: 94-27
UNIT : 2 CYCLE : 7	NDE METHOD : MT ☐ PT ☐ UT ☒ VT ☐
SYSTEM : 074 RHR	CONFIG : PIPE TO : TEE
WELD NO : DRHR-2-09	CALIBRATION SHEET NO. (S) : C223, C224, C235, C236, C229 C228
EXAMINER : D. B. SELLS Lv II	
EXAMINER : C. E. SHAW Lv II	
EXAMINER : N. R. BENTLEY Lv III	
EXAMINER : Lv	

THIS REPORT CONTAINS THE DATA ASSOCIATED WITH THE AUTOMATED AND MANUAL ULTRASONIC EXAMINATION OF WELD DRHR-2-09 PER NUREG 0313 GUIDELINES.

DRHR-2-09 IS A PIPE TO TEE WELD ON THE RHR SYSTEM. A 45 DEGREE SHEAR WAVE EXAMINATION TECHNIQUE WAS UTILIZED ON THE AXIAL AND CIRCUMFERENTAL SCANS 3, ~~4~~, 5, 6 A 60 DEGREE LONGITUDINAL WAVE AXIAL EXAMINATION WAS PERFORMED UPSTREAM (SCAN 3). NO AXIAL SCAN 4 WAS PERFORMED DOWNSTREAM DUE TO THE TEE CONFIGURATION.

DRHR-2-09 HAS A REPORTABLE INDICATION WHICH WAS IDENTIFIED DURING THE U2C5B OUTAGE. SUPPLEMENTAL MANUAL DETECTION AND SIZING TECHNIQUES WERE UTILIZED TO EVALUATE THIS INDICATION (SEE ATTACHED). THE RESULTS OF THIS EVALUATION DETERMINE THAT THIS INDICATION REMAINS ESSENTIALLY UNCHANGED FROM THE U2C5B SIZING DATA.

ROOT GEOMETRY WAS NOTED UPSTREAM.

APPROXIMATELY 90% COVERAGE WAS ATTAINED ON THIS WELD.

RESOLUTION BY:	REVIEWED BY:	ANII:
[signature]	[signature]	N/A
LEVEL: IIA DATE: 10/21/94	LEVEL: III DATE: 10/21/94	DATE:
		PAGE 1 OF 19

UT Data Analysis Report No. TV4-13

Examination Report Number:
Calibration Report Number:
Plant: BROWNS FERRY NUCLEAR PLT
Unit Number: 2
Weld Number: DRHR-2-9
Line: RHR
Subassembly: PIPE TO TEE
Notes:
IGSCC SIZING

Evaluation performed to 1986 ASME Code,
Code Class: B-F, B-J, or B-K-1 pipe support

All flaw data entered by system operator.
Total indications evaluated in this report: 1
****

Indication Number: 1
Wall thickness: 1.220
Indication thruwall: 0.270
Indication depth: 0.950
L-1 = 23.250 L-2 = 27.000
Evaluated as a planar indication.
Evaluated as a surface indication
Flaw 'a' dimension = 0.270
Flaw 'l' dimension = 3.750
Flaw aspect ratio = 0.072
'Y' value is inapplicable
Actual a/t(%) = 22.131
Acceptance Table used: IWB-3514-2
Allowed a/t(%) = 10.712
This indication is unacceptable.
****

Evaluated by [signature] UT Level III 10/19/94

Reviewed by [signature] Date: 10/19/94

ANII Review NA Date: NA

CD-Q2074-990016
PAGE 31 OF
THIS PAGE ADDED BY R1

Attachment C (cont'd)

INFORMATION ONLY

00012

TENNESSEE VALLEY AUTHORITY	EXAMINATION SUMMARY AND RESOLUTION SHEET	REPORT NO. R-123

PROJECT: BFNP	UNIT: U2C9	EXAMINER: Samuel T. Sharp	LV: II
SYSTEM: 074 Residual Heat Removal		EXAMINER: Dave Armstrong	LV: II
WELD I.D.: DRHR-2-09		EXAMINER: N/A	LV: N/A
CONFIG: PIPE TO: TEE		EXAMINER: N/A	LV: N/A
FLOW →		CAL SHT NO'S: C-111 & C-112	
PROCEDURE: N-UT64 REV.: 1 TC: N/A			
NDE METHOD: ■ UT ☐ PT ☐ MT ☐ VT			

THIS REPORT CONTAINS THE DATA ASSOCIATED WITH THE MANUAL ULTRASONIC EXAMINATION OF WELD DRHR-2-09 TO SATISFY THE REQUIREMENTS OF NUREG 0313.

A 45 DEGREE SHEAR WAVE AND 60 DEGREE LONGITUDINAL WAVE EXAMINATION WAS PERFORMED.

A WSY 70 AND 70° SHEAR SUPPLEMENTAL EXAMINATION WAS ALSO PERFORMED.

NO SCAN 4 WAS PERFORMED DUE TO PIPE TO TEE CONFIGURATION.

A PREVIOUSLY RECORDED INDICATION WAS VERIFIED

APPROXIMATELY 90% COVERAGE WAS ACHIEVED.

EVALUATOR: Samuel T. Sharp	LEVEL: II	DATE: 10/9/97	ANII: N/A
			DATE:
CONCURRENCE: [signature]	LEVEL: III	DATE: 10-10-97	PAGE 1 OF 6

TVA 19670C (NP 7/92)

TVA **Office of Nuclear Power**	**PROJECT:** BFN **SYSTEM:** RHRS **Unit:** 2 **WELD NO.:** DRHR 2-09	**REPORT NO.:**

DRHR-2-09 FLAW INDICATIVE OF IGSCC LOCATED AT 34-36 INCHES ON THE PIPE SIDE OF THE WELD (UPSTREAM SIDE).

LENGTH = 2.0"
THROUGHWALL = 0.25"
THICKNESS = 1.20"

a = 0.25"
l = 2.00"
t = 1.20"

a/l = 0.125

a/t = 20.83%

BASED ON ASME SECTION XI TABLE IWB-3514-2 THE MAXIMUM ALLOWABLE FLAW WITH ASPECT RATIO OF 0.13 WOULD BE 11.06% THROUGH WALL OR 0.133". THIS FLAW IS UNACCEPTABLE PER TABLE IWB-3514-2.

BY: Roger Bentley **LEVEL:** III **DATE:** 4-9-01 **PAGE** ____ **OF** ____

TVA 19669 (ONP-6-88)

Review by: [signature] 4/9/01

FROM TVA BFNP 1 256 729 4653 ... P.2

ENCLOSURE 3

TENNESSEE VALLEY AUTHORITY
BROWNS FERRY NUCLEAR PLANT (BFN)
UNIT 2
INSERVICE INSPECTION WELD ISOMETRIC DRAWING FOR WELD DRHR-2-09
2-ISI-0221-C, SHEET 1

(SEE ATTACHED)

NOTE:

1. PIPE SEGMENTS CONTAINING TWO LONGITUDINAL SEAMS WILL BE IDENTIFIED AS:

   (BASE WELD NO.)-LS-1D (DOWNSTREAM)
   (BASE WELD NO.)-LS-2D (DOWNSTREAM)
   (BASE WELD NO.)-LS-1U (UPSTREAM)
   (BASE WELD NO.)-LS-2U (UPSTREAM)

   THE -LS-1 SEAM WILL BE NUMERICALLY CLOSEST TO 0° ON THE PIPE, AND THE -LS-2 SEAM WILL BE NUMERICALLY FARTHERMOST FROM 0° ON THE PIPE. (e.g. -LS-1 AT 130°, AND -LS-2 AT 310°)

2. PIPE SEGMENTS CONTAINING ONLY ONE LONGITUDINAL SEAM WILL BE IDENTIFIED AS:

   (BASE WELD NO.)-LS-D (DOWNSTREAM)
   (BASE WELD NO.)-LS-U (UPSTREAM)

REFERENCE DRAWINGS:

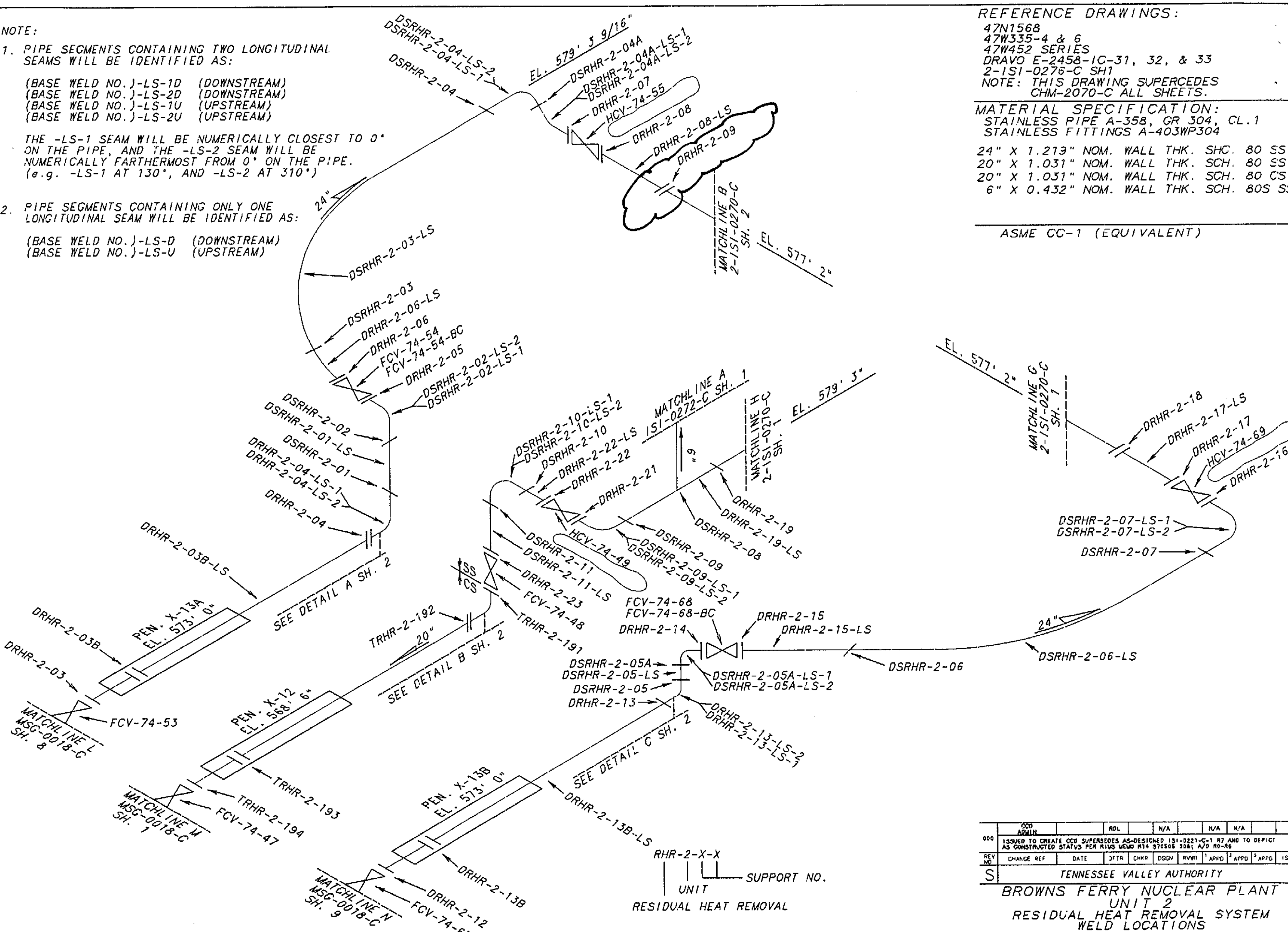
47N1568
47W335-4 & 6
47W452 SERIES
DRAVO E-2458-IC-31, 32, & 33
2-ISI-0276-C SH1
NOTE: THIS DRAWING SUPERCEDES CHM-2070-C ALL SHEETS.

MATERIAL SPECIFICATION:

STAINLESS PIPE A-358, GR 304, CL.1
STAINLESS FITTINGS A-403WP304

24" X 1.219" NOM. WALL THK. SHC. 80 SS
20" X 1.031" NOM. WALL THK. SCH. 80 SS
20" X 1.031" NOM. WALL THK. SCH. 80 CS
6" X 0.432" NOM. WALL THK. SCH. 80S SS

ASME CC-1 (EQUIVALENT)



RHR-2-X-X

RESIDUAL HEAT REMOVAL — UNIT — SUPPORT NO.

CCD ADMIN		RDL		N/A		N/A	N/A	
000	ISSUED TO CREATE CCD SUPERSEDES AS-DESIGNED ISI-0221-C-1 R7 AND TO DEPICT AS CONSTRUCTED STATUS PER RIMS MEMO R14 970508 308; A/D R0-R6							
REV NO	CHANGE REF	DATE	DFTR	CHKR	DSGN	RVWR	APPD	ISSD

S TENNESSEE VALLEY AUTHORITY

BROWNS FERRY NUCLEAR PLANT
UNIT 2
RESIDUAL HEAT REMOVAL SYSTEM
WELD LOCATIONS

DRAWN: RPG	DATE: 6-20-88	SCALE: NTS	CADAM/ISICMP
CHECKED: JES	APPROVED: GLB	SHEET 01 OF 02	REV
SUBMITTED: EDC		2-ISI-0221-C	000
		CCD	

PCADAM

ALL A/D HISTORY RESEARCHED AT R000