ATTACHMENT 2 TO

2CAN101403

STRUCTURAL INTEGRITY ASSOCIATES CALCULATION 1401289.301

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CALCULATION PACKAGE

File No.: 1401289.301

Project No.: 1401289
Quality Program: ☒ Nuclear ☐ Commercial

PROJECT NAME:
ANO Leaking Flaw Evaluation

CONTRACT NO.:
10423246, Change Request No. 00109841

CLIENT:
Entergy Arkansas, Inc.

PLANT:
Arkansas Nuclear One, Unit 2

CALCULATION TITLE:
Evaluation of a Through-Wall Leak in a Service Water Tee (Dwg 2HCC-2003-1)

Document Revision	Affected Pages	Revision Description	Project Manager Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1 - 12	Initial Issue	Eric J. Houston 10/31/2014	**Preparer:** Adam C. Roukema 10/31/2014 **Checker:** Brad P. Dawson 10/31/2014

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1.0 INTRODUCTION

Arkansas Nuclear One has identified a pinhole leak in a 6-inch branch connection (Sweep-o-let) in the service water system. The system is safety related, and therefore requires an evaluation to demonstrate operability. The objective of this calculation is to determine the allowable through-wall flaw lengths in accordance with ASME Code Case N-513-4 [1].

2.0 TECHNICAL APPROACH

The flaw evaluation herein is based on the criteria prescribed in ASME Code Case N-513-4, allowing for the temporary acceptance of through-wall flaws in moderate energy Class 2 or Class 3 piping. N-513-4 allows non-planar, through-wall flaws to be characterized and evaluated as planar (i.e., crack-like), through-wall flaws in the axial and circumferential directions.

In addition to straight pipe, N-513-4 evaluation criteria includes rules for the evaluation of piping components such as elbows, branch tees and reducers. Flaws in these components may be evaluated as if in straight pipe provided the stresses used in the evaluation are adjusted to account for geometric differences. Details are provided in N-513-4 for determining these adjusted stresses. The leaking flaw is in the carbon steel sweep-o-let, near the dissimilar metal weld at the adjoining stainless steel elbow. Therefore, the evaluation approach for branch connections in N-513-4 is appropriate. Although the attached elbow material has significantly higher toughness than the carbon steel (which if used would result in a much larger allowable through-wall flaw) the influence of the higher toughness on the allowable through-wall flaw is ignored and the system is evaluated as only carbon steel.

N-513-4 has been approved and published by ASME. It is recognized in ASME committee that the technical approach is very conservative. Simple treatment of piping component flaw evaluation using hand calculations was an important objective in the development of the approach recognizing the trade-off being conservative results. N-513-4 allows for alternative methods to calculate the stresses used in the analysis to reduce conservatism. N-513-4 has not been generically reviewed by the NRC.

Code Case N-513-4 evaluation criteria rely on the methods given in ASME Section XI, Appendix C [2]. Linear Elastic Fracture Mechanics (LEFM) criteria are conservatively employed as described in Article C-7000. Equations for through-wall stress intensity factor parameters F_m, F_b and F are given in the Code Case, Appendix I. Allowable flaw lengths are determined through iteration comparing calculated stress intensity factors to a critical fracture toughness defined in C-7200 of Section XI, Appendix C.

3.0 DESIGN INPUTS AND ASSUMPTIONS

The piping design Code of Construction is ASME Section III - 1971 with Addenda through Summer 1971 [3] except for the items listed below:

A) Use ASME Section III – 1971 Winter 1972 Addenda, NC-3611.1(b)(4)(c) and NC-3650 with Code Case 1606-1, for the following:
   a. Moments
   b. Design Loading Combinations

c. Section Modulus

d. Stress Limits

B) Use ASME Section III – 1974 [4], NC-3673.2 for the following:
   a. Flexibility Factors
   b. Stress Intensification Factors

The sweep-o-let material is ASME A105 Gr II carbon steel and the run piping is A106 Gr. B [5] carbon steel. For the analysis, A106 Gr. B carbon properties are conservatively used. In addition, the fracture toughness of the two materials are assumed to be comparable.

The following design inputs are used in this calculation:

1. Outside diameter = 6.625 inches [5, Line Item 14]
2. Nominal wall thickness = 0.280 inch (based on standard pipe size) [5, Line Item 14]
3. Design temperature = 130°F [6, Page 114]
4. Design pressure = 150 psig [6, Page 114]
5. Material stress allowable = 15 ksi [7, PDF Page 19]
6. Young's modulus = 27,900 ksi [7, PDF Page 19]
7. NDE inspection results [8]

The moment loadings applied to the piping are obtained from the piping stress report [7] for the element located between nodes 25 and 225. The bounding moments are shown in Table 1.

Determination of the fracture toughness, J_{IC}, used in the evaluation is based on Section XI, Appendix C, C-8320 [2], which specifies that 'reasonable lower bound fracture toughness data' may be used to determine the allowable stress intensity factor, K_{Ic}. The NRC's Pipe Fracture Encyclopedia [9] contains numerous CVN test results for A106 Gr. B carbon steel at low temperature, which are reproduced in Table 2. The minimum reported value of 293 in-lb/in^2 is used in the analysis.

The following assumptions are used in this calculation:

1. Poisson's ratio is assumed to be 0.3.
2. The impact of weld residual stress on the structural stability of the observed flaw is assumed negligible. Weld residual stresses are secondary (i.e., self-limiting) and do not contribute significantly to gross structural failure in ductile materials in the presence of a through-wall flaw. In addition, the contribution, if any, to flaw growth due to secondary weld residual stresses is not required as the Code Case specifies a frequent re-inspection interval.
3. A corrosion allowance is not considered (the ongoing inspection requirements in Code Case N-513-4 address the possibility of flaw growth during the temporary acceptance period).

4.0 CALCULATIONS

The applied stresses and resulting stress intensity factors are conservatively calculated using an evaluated wall thickness, t_{eval}, 0.175 inches.

4.1 Minimum Required Wall Thickness

An evaluation of ASME Section III, NC-3650 equations 3, 8, 9B, 9D, and 10 has been conducted using inputs discussed in Section 3.0. Based on these equations the minimum required wall thickness is 0.115 inch.

4.2 Applied Loads

Axial and circumferential (i.e., hoop) stresses are calculated from the moment loads in Table 1 and the design pressure. The evaluated wall thickness, t_{eval}, is used to determine the section properties. The nominal wall thickness, t_{nom}, is used to calculate the flexibility characteristic 'h' in accordance with the guidance of N-513-4.

4.2.1 Hoop Stress

For the allowable axial flaw length on a branch tee, the hoop stress, σ_h, may be determined from Equation 13 of N-513-4:

$$\sigma_h = \frac{pD_o}{2t} \quad (1)$$

where:

p = internal design pressure, psig
D_o = outside diameter, in
t = evaluated wall thickness = t_{eval}, in

4.2.2 Axial Stresses

For the allowable circumferential flaw length, the axial stress due to pressure, deadweight and seismic loading is presented below. For axial membrane stress due to pressure, σ_m, Equation 14 of N-513-4 is used. Note that there is a typo in the published version of this equation; the correct form is:

$$\sigma_m = B_1 \frac{pD_o}{2t} \quad (2)$$

B_1 is the primary stress index for pressure loading. As allowed by the Code Case, the primary stress indices B_1 and B_2 are taken from a more recent edition of the ASME Code [10, Table NB-3681(a)-1]. For branch connections, B_1 is 0.5.

For axial bending stress, σ_b, due to deadweight and seismic moments, Equation 15 of N-513-4 may be used:

$$\sigma_b = B_2 \frac{D_o M_b}{2I} \quad (3)$$

where:

M_b = resultant primary bending moment, in-lbs.
I = moment of inertia based on evaluated wall thickness, in^4

The coefficient B_2 for branch connections is $0.5*C_2$ (but not < 1.0) and [10, NB-3683.8]:

$$C_2 = 1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \quad (4)$$

where:

R_m = mean nominal radius of run pipe, in
T_r = nominal wall thickness of run pipe, in
r'_m = mean nominal radius of branch pipe, in
T'_b = nominal wall of branch pipe, in
r_p = outside nominal radius of branch pipe, in

For axial bending stress, σ_e, due to thermal expansion, Equation 16 of N-513-4 may be used:

$$\sigma_e = i\frac{D_o M_e}{2I} \quad (5)$$

where:

i = stress intensification factor
M_e = resultant thermal expansion moment, in-lbs.

The stress intensification factor is calculated based on a welding tee as [4, Figure NC-3673.2(b)-1]:

$$i = \frac{0.9}{h^{2/3}} \quad \text{and} \quad h = \frac{4.4t_n}{r} \quad (6, 7)$$

where:

h = flexibility characteristic
t_n = nominal wall thickness of run piping, in
r = mean radius of run piping, in

4.3 Stress Intensity Factor Calculations

For LEFM analysis, the stress intensity factor, K_I, for an axial flaw is taken from Article C-7000 [2] as prescribed by N-513-4 and is given below:

$$K_I = K_{Im} + K_{Ir}$$

where:

$K_{Im} = (SF_m)F\sigma_h(\pi a/Q)^{0.5}$
SF_m = structural factor for membrane stress (see Table 3)
F = through-wall stress intensity factor parameter for an axial flaw under hoop stress (given in Appendix I of N-513-4)

σ_h = hoop stress, ksi
a = flaw depth (taken as half flaw length for through-wall flaw per Appendix I of N-513-4), in
Q = flaw shape parameter (unity per Appendix I of N-513-4)
K_{Ir} = K_I from residual stresses at flaw location (assumed negligible)

Only the hoop stress influences the allowable axial flaw length, which is a function of pressure.

For LEFM analysis, the stress intensity factor, K_I, for a circumferential flaw is taken from Article C-7000 [2] as prescribed by N-513-4 and is given below:

$$K_I = K_{Im} + K_{Ib} + K_{Ir}$$

where:

$K_{Im} = (SF_m)F_m\sigma_m(\pi a)^{0.5}$
F_m = through-wall stress intensity factor parameter for a circumferential flaw under membrane stress (given in Appendix I of N-513-4)
σ_m = membrane stress, ksi
$K_{Ib} = [(SF_b)\sigma_b + \sigma_e]F_b(\pi a)^{0.5}$
SF_b = structural factor for bending stress (see Table 3)
σ_b = bending stress, ksi
σ_e = thermal stress, ksi
F_b = through-wall stress intensity factor parameter for a circumferential flaw under bending stress (given in Appendix I of N-513-4)
K_{Ir} = K_I from residual stresses at flaw location (assumed negligible)

Note that the through-wall flaw stress intensity factor parameters are a function of flaw length.

Table 4 shows the specific load combinations considered herein for the allowable circumferential flaw calculations.

4.4 Critical Fracture Toughness Determination

For LEFM analysis, the static fracture toughness for crack initiation under plane strain conditions, K_{Ic}, is taken from Article C-7000 [2] as prescribed by N-513-4 and is given below:

$$K_{Ic} = \sqrt{\frac{J_{Ic}E'}{1000}}$$

where:

J_{Ic} = material toughness, in-lb/in^2
$E' = E/(1-\nu^2)$
E = Young's modulus, ksi
ν = Poisson's ratio

Based on the design input listed above, K_{Ic} = 94.7 ksi-in$^{0.5}$. The allowable flaw lengths are determined iteratively by increasing flaw length until the stress intensity factor is equal to the static fracture toughness.

5.0 RESULTS

Based on inputs in Section 3.0, moments in Table 1 and using equations from Section 4.0, the allowable through-wall flaw in the circumferential direction is 2.7 inches and the allowable through-wall flaw in the axial direction is 5.8 inches. The allowable through-wall flaw lengths are based on an evaluated wall thickness of 0.175 inch. Based on the inspection data given in Reference [8], the analyzed thickness and flaw lengths easily bound the observed thinning. Thus, the acceptance criteria of Code Case N-513-4 are met.

Code Case N-513-4, Paragraph 3.2(c) requires that the remaining ligament average thickness over the degraded area be sufficient to resist pressure blowout [1, Equation 8]. Table 5 shows the required average thickness, $t_{c,avg}$, as a function of the equivalent diameter of the circular region, d_{adj}, for which the wall thickness is less than t_{adj}. Based on the inspection data given in Reference [8], the values in Table 5 easily bound the observed thinning. Thus, the Code Case requirement is met.

6.0 CONCLUSIONS

Arkansas Nuclear One has identified a pinhole leak in a 6-inch branch connection (Sweep-o-let) in the service water system. Allowable through-wall flaw lengths have been calculated in accordance with ASME Code Case N-513-4. Because N-513-4 has not been generically reviewed by the NRC, justification for continued operation without repair or replacement until the next scheduled outage requires NRC review and approval.

The allowable through-wall flaw in the circumferential and axial directions is 2.7 inches and 5.8 inches, respectively. The allowable through-wall flaw lengths are based on an evaluated wall thickness of 0.175 inch. Table 5 shows the requirements to meet the Code Case pressure blowout limits.

The observed pinhole leak is easily bounded by the results of the analysis; thus, the acceptance criteria of Code Case N-513-4 are met. The system should be considered operable but degraded.

7.0 REFERENCES

1. ASME Code Case N-513-4, "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or 3 Piping Section XI, Division 1," Cases of ASME Boiler and Pressure Vessel Code, May 7, 2014.
2. ASME Boiler and Pressure Vessel Code, Section XI, Appendix C, 2001 Edition with 2003 Addenda.
3. ASME Boiler and Pressure Vessel Code, Section III, 1971 Edition with Addenda through Summer 1971.
4. ASME Boiler and Pressure Vessel Code, Section III, 1974 Edition.
5. Entergy Drawing No. 2HBC-33-2, Sheet 1, Revision 16, "Large Pipe Isometric Service Water Supply Header #1," SI File No. 1401289.201.
6. Entergy Calculation No. 88-E-0200-15, Revision 3, "P-T Calculation for Unit 2 Service Water System," SI File No. 1401289.201.
7. Entergy Calculation No. 90-D-2003-08, Revision 3, "Supply Piping Analysis for Piping in DCP 90-2003," SI File No 1401289.201.
8. Entergy UT Thickness Examination Report No. 2-BOP-UT-14-040, SI File No. 1401289.201.
9. Pipe Fracture Encyclopedia, US Nuclear Regulatory Commission, Volume 1, 1997.
10. ASME Boiler and Pressure Vessel Code, Section III, 2004 Edition.

Table 1: Applied Moment Loading for Bounding Moments

Deadweight (in-lbs)	OBE (in-lbs)	DBE (in-lbs)	Thermal (in-lbs)
6902	21471	30657	5408

Notes:

1. Square Root Sum of the Squares (SRSS) is used to calculate moments from Reference [7].
2. Moments are from the bounding location, which is at node 225.

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Table 2: J_{IC} Values for A106 Gr. B Carbon Steel from NRC's Pipe Fracture Database [9]

A106 Grade B					
Database Reference	Temperature (°C)	Temperature (°F)	JIC (kJ/m^2)	JIC (lb_f-in/in^2)	KIC (ksi-$in^{0.5}$)
2	24	75	97	552	133
2	24	75	336	1919	249
16	25	77	81	464	122
16	25	77	418	2386	277
16	25	77	270	1542	223
16	25	77	193	1104	189
22	24	75	224	1278	203
22	20	68	112	641	144
22	20	68	117	668	147
22	23	73	214	1223	199
22	20	68	167	954	175
22	20	68	223	1271	202
22	20	68	108	617	141
23	52	126	116	663	146
23	23	73	103	590	138
23	23	73	105	600	139
23	23	73	93	528	131
24	23	73	76	431	118
24	23	73	82	469	123
24	57	135	51	293	97
25	23	73	77	439	119
25	23	73	70	400	114
25	57	135	62	356	107
90	20	68	235	1342	208
90	20	68	219	1251	201
90	20	68	255	1456	217
90	20	68	281	1605	228
90	20	68	281	1605	228
90	20	68	335	1913	248
90	20	68	421	2404	279
90	20	68	385	2198	266
90	20	68	175	999	180
90	20	68	172	982	178
90	20	68	178	1016	181
90	20	68	214	1222	199
90	20	68	275	1570	225
90	20	68	133	759	157
90	20	68	140	799	161
90	20	68	174	994	179
90	20	68	111	634	143
90	20	68	190	1085	187
90	20	68	71	405	114
90	20	68	110	628	142
90	20	68	104	594	138
90	20	68	104	594	138
90	20	68	97	554	134
90	20	68	89	508	128
90	20	68	88	502	127
90	20	68	267	1525	222

Table 3: Axial and Circumferential Structural Factors [2]

Service Level	Membrane Stress, SF_m	Bending Stress, SF_b
A	2.7	2.3
B	2.4	2.0
C	1.8	1.6
D	1.3	1.4

Table 4: Load Combinations for Circumferential Flaw Analyses

Load Combination	Service Level
P+DW+TH	A
P+DW+TH+OBE	B
P+DW+TH+DBE	D

Table 5: Pressure Blowout Check

d_{adj}	$t_{c,avg}$
0.25	0.01
0.75	0.03
1.25	0.04
1.75	0.06
2.25	0.08
2.75	0.10
3.25	0.11
3.75	0.13
4.25	0.15
4.75	0.17
5.25	0.19

ATTACHMENT 3 TO

2CAN101403

UT THICKNESS EXAMINATION

REPORT 2-BOP-UT-14-040

Entergy

UT Thickness Examination

Site/Unit:	ANO-2 / 2	Procedure:	CEP-NDE-0505	Outage No.:	N/A
Summary No.:	FW-1 2HCC-2003-1	Procedure Rev.:	004	Report No.:	2-BOP-UT-14-040
Workscope:	BOP\Non-Outage	Work Order No.:	396448	Page:	1 of 4

Code: Info Only Cat./Item: N/A/N/A Location: U2 TB 335'

Drawing No.: 2HCC-2003-1 Description: SW Leak at SS to CS FW-1

System ID: SW

Component ID: 2HCC-2003-1 SW Leak Size/Length: 6" Thickness/Diameter: 0.280"

Limitations: None

Temp. Tool Mfg.: PTC Serial No.: 109537 Surface Temp.: 70 °F

Couplant: ULTRAGEL II Batch No.: 12M020 Cal. Report No.: N/A

Examination Surface: Inside ☐ Outside ☑ Surface Condition: Ground Flush

Lo Location: TDC (leak at 24") looking @ TEE MWT 10/24/14 Wo Location: Centerline of Weld

*														
Tmin	scan	.069"	Lo 24"	Wo .3"										
Tmin	grid	.226"												
Tmax	grid	.577"												
Tavg	grid	.353"												

Comments:

***See Supplemental Report for 360° readings around pipe and Star pattern readings at leak location. Lowest scanned reading was 0.069" near leak. Equipment used: Panametrics 37DL Plus #51324510, Panametrics transducer D795 5 Mhz .2" #10101, CS Step #93-6900, SS Step10-3009 CAL IN/OUT acceptable. This flaw is considered Non-Planar**

Results: Accept ☐ Reject ☐ Info ☑ Ref. CR-ANO-2-2014-2970

Percent Of Coverage Obtained > 90%: N/A Reviewed Previous Data: N/A

Examiner	Level	Signature	Date	Reviewer	Signature	Date
Taylor, Michael W.	II	[signature]	10/21/2014	N/A		
Examiner N/A	N/A			Site Review Panther, Ken	Ken Panther	10/22/2014
Other Jackson, Rickey		[signature]	10/21/2014	ANII Review N/A		

Entergy

Supplemental Report

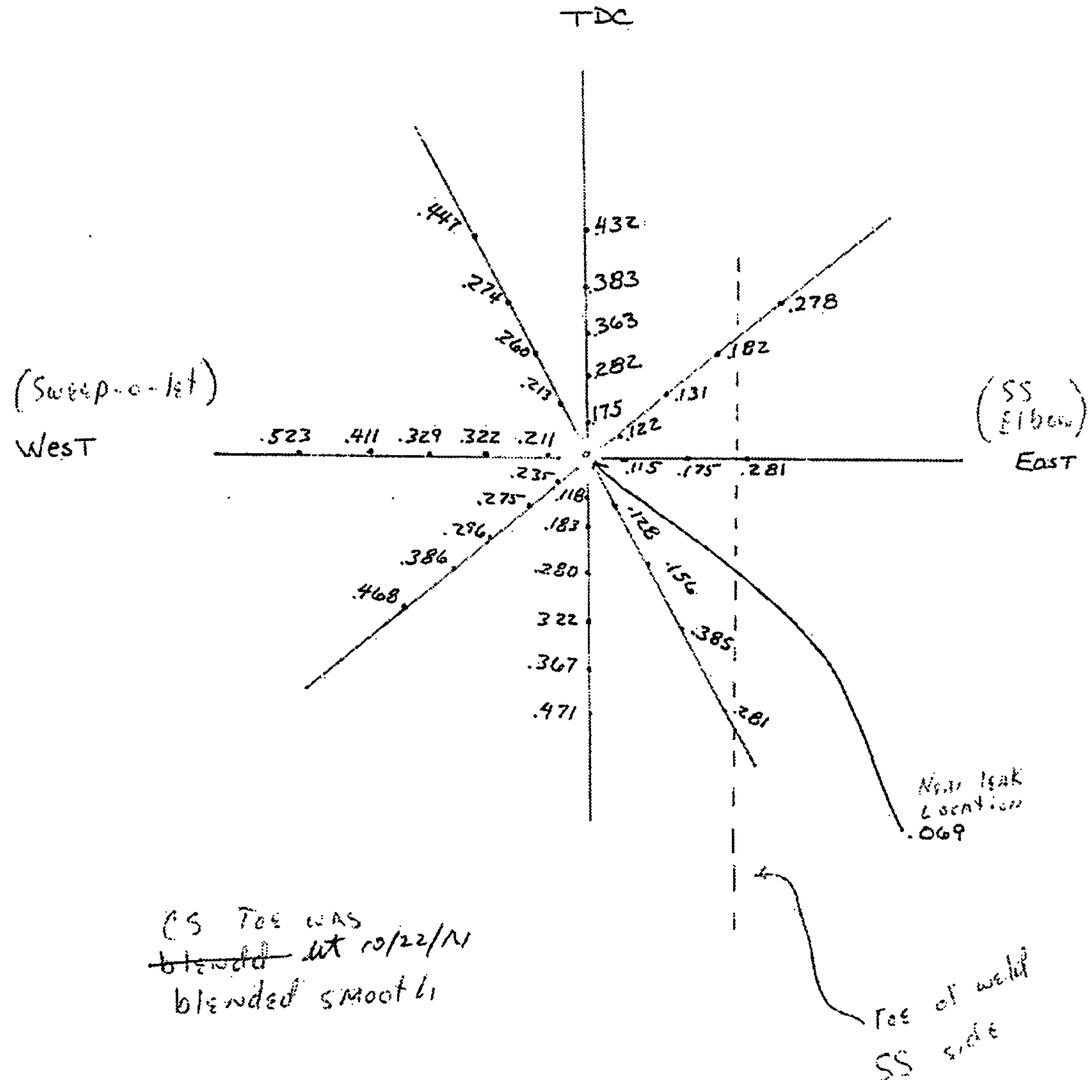
Report No.: 2-BOP-UT-14-040

Summary No.: FW-1 2HCC-2003-1

Examiner:	Taylor, Michael W.	Level:	II	Reviewer:	N/A	Date:	
Examiner:	N/A	Level:	N/A	Site Review:	Panther, Ken	Date:	10/22/2014
Other:	Jackson, Rickey	Level:	N/A	ANII Review:	N/A	Date:	

Comments: **The leak was located at the toe of weld on the Sweep-o-let side of weld. UT readings taken in a Star pattern around leak location to establish a wear area. Each row is incremented every 45° with each reading taken every .25" away from leak. This flaw is considered Non-Planar.**

Sketch or Photo: \\jdcnsetsp001\IDDEAL\Iddeal Ver 8\Iddeal_Server\Iddeal_ANO\Documents\ANO BOP 2014\MIC\2HCC Star.jpg



Entergy

Supplemental Report

Report No.: **2-BOP-UT-14-040**

Summary No.: **FW-1 2HCC-2003-1**

Examiner:	**Taylor, Michael W.**	Level:	**II**	Reviewer:	**N/A**	Date:	
Examiner:	**N/A**	Level:	**N/A**	Site Review:	**Panther, Ken**	Date:	**10/22/2014**
Other:	**Jackson, Rickey**	Level:	N/A	ANII Review:	**N/A**	Date:	

Comments: **UT readings taken 360° around pipe at the plane of the leak for circuferential thicknesses. 01 reading was taken at TDC. Also scanned 100% circumferentially around pipe looking for other low readings and none were found.** O2 reading is north of O1 reading. MT 10/22/14
"A"- taken on CS Sweep-O-Let, "B"- taken on weld, "C"- taken on SS Elbow

Sketch or Photo: \\jdcnsetsp001\IDDEAL\Iddeal Ver 8\Iddeal_Server\Iddeal_ANO\Documents\ANO BOP 2014\MIC\2HCC Grid.jpg

	A	B	C
01	0.450	0.313	0.277
02	0.577	0.319	0.282
03	0.544	0.309	0.285
04	0.477	0.302	0.285
05	0.533	0.390	0.299
06	0.562	0.416	0.285
07	0.436	0.411	0.286
08	0.505	0.415	0.281
09	0.512	0.448	0.290
10	0.490	0.357	0.282
11	0.434	0.431	0.278
12	0.445	0.443	0.296
13	0.388	0.303	0.309
14	0.437	0.309	0.293
15	0.447	0.295	0.289
16	0.367	0.409	0.285
17	0.321	0.350	0.286
18	0.318	0.309	0.286
19	0.283	0.245	0.300
20	0.235	0.250	0.275
21	0.258	0.226	0.284
22	0.283	0.262	0.282
23	0.351	0.363	0.281
24	0.388	0.301	0.272
25	0.456	0.240	0.276
26	0.486	0.254	0.258
27	0.465	0.287	0.265
28	0.442	0.398	0.265
29	0.480	0.403	0.281
30	0.490	0.392	0.269
31	0.480	0.416	0.274
32	0.494	0.459	0.279

Entergy

Supplemental Report

Report No.: 2-BOP-UT-14-040

Summary No.: FW-1 2HCC-2003-1

Examiner:	Taylor, Michael W.	Level:	II	Reviewer:	N/A	Date:	
Examiner:	N/A	Level:	N/A	Site Review:	Panther, Ken	Date:	10/22/2014
Other:	Jackson, Rickey	Level:	N/A	ANII Review:	N/A	Date:	

Comments: **Pictures before and after grinding weld flat. Picture on left shows weld still painted with stain appearing on SS elbow. Picture on the right is after grinding weld flat showing the leak to be at the toe of the weld on the Sweep-o-let side.** LEAK is in lowes South quadrant of FW-1. MT 10/22/14

Sketch or Photo: \\jdcnsetsp001\IDDEAL\Iddeal Ver 8\Iddeal_Server\Iddeal_ANO\Documents\ANO BOP 2014\Photos\WO396448 U2 SW leak\DSCF2747.JPG

\\jdcnsetsp001\IDDEAL\Iddeal Ver 8\Iddeal_Server\Iddeal_ANO\Documents\ANO BOP 2014\Photos\WO396448 U2 SW leak\DSCF2597.JPG