ATTACHMENT 2

Evaluation of Leaking McGuire 2 Containment Spray Piping

~~Attachment #1~~

STRUCTURAL INTEGRITY Associates	CALCULATION PACKAGE	FILE No.: MNS-02Q-301 PROJECT No.: MNS-02Q

PROJECT NAME: Evaluation of Leaking McGuire 2 Containment Spray Piping

CLIENT: Duke Energy Corporation

CALCULATION TITLE: Determination of Allowable Flaw Size and Leakage

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1.0 OBJECTIVE

Develop allowable flaw size (including appropriate safety factor) as a function of applied stress for the McGuire Nuclear Station (MNS) Containment Spray Piping System (NS). Calculate leakage rates based on the allowable flaw sizes.

2.0 METHODOLOGY

Using the limit load methodology described in Appendix C of ASME Section XI [1], C-3320, failure bending stress is calculated as follows:

$P_b' = Z*SF\,(P_m + P_b + P_e/SF) - P_m$ (For flux welds)

$P_b' = SF\,(P_m + P_b) - P_m$ (For non-flux welds)

Where Z = weld type factor
P_b' = failure bending stress, psi
P_m = primary membrane stress, psi
P_b = primary bending stress, psi
P_e = expansion bending stress, psi
SF = safety factor (2.77 for normal/upset; 1.39 for emergency/faulted [1])

Allowable flaw lengths at each weld location are determined using the methodology outlined in Appendix C of Section XI of the ASME Code [1]. For given values of P_m and half-flaw angle θ, then the angle β to the neutral axis is calculated as:

$$\beta = \tfrac{1}{2}\,[\pi - (a/t)\theta - \pi P_m/(3S_m)]$$, where

a = flaw depth, inches
t = pipe wall thickness, inches
S_m = Design stress intensity, psi

Based on θ and β, a value of failure bending stress is calculated:

$$P_b' = (6S_m/\pi)\,[2 \sin\beta - (a/t)\sin\theta]$$

The value of θ is varied until P_b' based on θ and P_m equals P_b' based on the applied stresses. For longer flaws for which $\theta + \beta > \pi$, a somewhat different set of equations is used to calculate β and P_b' based on θ, but this condition does not occur when the flaws are through-wall (a/t = 1).

The leakage calculations are performed with the EPRI computer program PICEP [2].

3.0 INPUT AND ASSUMPTIONS

Duke has provided the following input [3]:

- McGuire Nuclear Station, Unit 2
- ASME Section XI, Code Edition 1998 with 2000 Addenda
- Containment Spray Piping System (NS)
- Pipe Specification MCS-1206.00-02-0002
- Design Pressure: 170 psig
- Design Temperature: 190°F
- Pipe Size: 8"
- Schedule: 10
- Pipe Material: SA-312 TP304
- Elbow Material: SA-403 WP304
- Type of Weld: GTAW
- Range of crack sizes to be evaluated: 0.2" - 4"

The following assumptions are made:

- Flaws assumed to be through-wall
- Smooth fatigue-type crack assumed to maximize leakage

For operability analysis, the factor of safety is chosen for Service Level C and D conditions as 1.39 from Section XI. To allow evaluation of a range of conditions, parametric evaluations are provided for the allowable flaw size and leakage.

4.0 ANALYSIS

4.1 Allowable Flaw Size

Excel workbook MNS02301.XLS, included in the project computer files, calculates failure bending stress and allowable flaw length based on the stress and moment values. All welds use the gas tungsten arc weld (GTAW) method, which is non-flux [3]; therefore, the non-flux equation for P_b' based on stress is used, and P_e and Z are not used. For 8" schedule 10 piping, the outside diameter is $D_o = 8.625"$ and the thickness is $t = 0.148"$. Axial stress is $P_m = PD_o/4t = 170*8.625/(4*0.148) =$ 2,477 psi. For both materials S_m is 20,000 psi at 190°F [4]. Since flaws are assumed through-wall, $a/t = 1.0$.

Table 1 shows allowable flaw size in radians and degrees for each value of bending stress chosen. Flaw half length c is calculated based on the flaw half angle and the pipe outside diameter. For evaluating a specific location using this table, P_b should include Service Level C and D primary bending stresses; that is, deadweight (DW) and safe shutdown earthquake (SSE), for example.

Table 1. Allowable Flaw Size

P_m, psi	P_b, psi	Z	SF	P_b', psi	θ, rad	θ, °	c, in
2477	1000	1.00	1.39	2356	1.996	114	8.6
2477	2000	1.00	1.39	3746	1.921	110	8.3
2477	3000	1.00	1.39	5136	1.853	106	8.0
2477	4000	1.00	1.39	6526	1.791	103	7.7
2477	5000	1.00	1.39	7916	1.732	99	7.5
2477	6000	1.00	1.39	9306	1.677	96	7.2
2477	7000	1.00	1.39	10696	1.625	93	7.0
2477	8000	1.00	1.39	12086	1.575	90	6.8
2477	9000	1.00	1.39	13476	1.527	87	6.6
2477	10000	1.00	1.39	14866	1.482	85	6.4
2477	11000	1.00	1.39	16256	1.438	82	6.2
2477	12000	1.00	1.39	17646	1.395	80	6.0
2477	13000	1.00	1.39	19036	1.353	78	5.8
2477	14000	1.00	1.39	20426	1.313	75	5.7
2477	15000	1.00	1.39	21816	1.274	73	5.5
2477	16000	1.00	1.39	23206	1.236	71	5.3
2477	17000	1.00	1.39	24596	1.198	69	5.2
2477	18000	1.00	1.39	25986	1.161	67	5.0
2477	19000	1.00	1.39	27376	1.125	64	4.9
2477	20000	1.00	1.39	28766	1.090	62	4.7

4.2 Leakage

Although PICEP has not been qualified under SI's Quality Assurance (QA) program, it is widely accepted for use in LBB evaluations and has been evaluated by the US NRC [5]. As a check, the SI-developed program pc-LEAK, which has been qualified under SI's QA program, is used.

The previously-stated pipe section properties of D_o = 8.625" and t = 0.148" are input. Maximum crack size of 4" is used [3]. Material properties are taken as follows, at a temperature of 200°F [4]:

- Modulus of Elasticity = 27,600 ksi
- Ultimate tensile strength = 71.0 ksi
- Yield strength = 25.0 ksi
- Flow stress = (71.0 + 25.0)/2 = 48.0 ksi
- α = 4.7, n = 3.8, taken at 75°F [7]

Other leakage input is described as follows. The roughness is 0.000197 inch [6]. Several values of sustained bending stress are used ranging from 0 to 20 ksi. Pressure and temperature are 184.7 psia and 190°F [3]. The entrance loss coefficient is chosen as 0.61, which is also the default value. The following other parameters are also input to PICEP:

- MODE = 0 (compute critical crack length, crack opening displacement, and leakage)
- IPLAS = 2 (perform plastic zone correction)
- ISOL = 2 (combined tension and bending solution)
- IFDIR = 0 (circumferential crack)
- IFAREA = 1 (elliptical crack)
- NDIV = 8 (number of crack length increments)
- COD = 0 (ignored since MODE is not 1)
- TRACT = 0 (pipe axial nonpressure load)
- BMOM = 0 (pipe bending moment, stress is input instead)
- PMSTR = 0 (pipe membrane stress, pressure is input instead)
- IN = 3 (initially subcooled liquid water)
- PB = external pressure = 14.7 psia
- AR = ratio of the crack exit to inlet area = 1.0
- N45 = number of 45 deg turns = 0
- N90 = number of 90 deg turns = 0
- ZF = 1.0 (assume plastic collapse)
- SFV = 1.0 (safety factor for critical crack length)

The following input is specific to pc-LEAK. From equation 27 of the PICEP manual, the 0.61 entrance loss coefficient corresponds to a factor on pressure drop of $1/0.61^2$ = roughly 2.7, which is the input used for pc-LEAK. The pc-LEAK case for analysis is case 5: liquid water, circumferential crack, and axial plus bending stress. The following other input is used:

- YES for abbreviated output file
- 0 = Initial average crack opening, inches
- 2 = Beta for plastic zone corrections (plane stress)
- 1 = Iterations for plastic zone correction
- 0.2 = Increment for crack length (2c)

Table 2 shows the leakage rates calculated by PICEP, based on a range of flaw angles and bending moments, and Figure 1 plots these results. Results calculated by pc-LEAK are somewhat smaller, but similar in magnitude. For evaluating a specific location using this table, P_b should include only sustained loads, but should include secondary as well as primary loads; that is, DW, thermal expansion (TE), and thermal anchor movement (TAM), for example.

Table 2. Leakage Rate versus Crack Length (2c) and Sustained Bending Stress (P_b)

	Leakage, gpm								
2c, in	P_b= 0 ksi	P_b= 2.5 ksi	P_b= 5 ksi	P_b= 7.5 ksi	P_b= 10 ksi	P_b= 12.5 ksi	P_b= 15 ksi	P_b= 17.5 ksi	P_b= 20 ksi
0.2	0.0001	0.0002	0.0005	0.0010	0.0018	0.0041	0.0084	0.0163	0.0292
0.4	0.0004	0.0014	0.0029	0.0066	0.0146	0.0300	0.0573	0.1013	0.1668
0.6	0.0013	0.0041	0.0100	0.0228	0.0477	0.0927	0.1671	0.2800	0.4407
0.8	0.0028	0.0096	0.0247	0.0541	0.1087	0.2026	0.3504	0.5671	0.8696
1	0.0053	0.0201	0.0497	0.1052	0.2043	0.3679	0.6176	0.9773	1.4752
1.2	0.0090	0.0365	0.0878	0.1805	0.3404	0.5966	0.9801	1.5272	2.2570
1.4	0.0148	0.0605	0.1418	0.2842	0.5227	0.8967	1.4503	2.2305	3.2565
1.6	0.0238	0.0938	0.2147	0.4204	0.7573	1.2773	2.0426	3.0883	4.5089
1.8	0.0362	0.1382	0.3093	0.5931	1.0495	1.7482	2.7707	4.1434	6.0497
2	0.0528	0.1956	0.4284	0.8067	1.4073	2.3216	3.6248	5.4254	7.9232
2.2	0.0745	0.2678	0.5751	1.0658	1.8376	3.0093	4.6488	6.9644	10.1746
2.4	0.1021	0.3568	0.7523	1.3751	2.3491	3.8160	5.8657	8.7971	12.8618
2.6	0.1366	0.4647	0.9633	1.7399	2.9509	4.7416	7.3019	10.9646	16.0414
2.8	0.1791	0.5935	1.2114	2.1664	3.6538	5.8235	8.9870	13.5127	19.7817
3	0.2308	0.7454	1.5002	2.6607	4.4695	7.0833	10.9549	16.4953	24.1660
3.2	0.2928	0.9227	1.8338	3.2298	5.3804	8.5422	13.2418	19.9711	29.2858
3.4	0.3665	1.1277	2.2163	3.8834	6.4205	10.2266	15.8939	24.0128	35.2494
3.6	0.4534	1.3632	2.6524	4.6282	7.6115	12.1666	18.9584	28.6900	42.1508
3.8	0.5549	1.6316	3.1473	5.4750	8.9720	14.3925	22.4866	34.0933	50.1464
4	0.6726	1.9360	3.7066	6.4148	10.5221	16.9441	26.5473	40.3212	59.3774

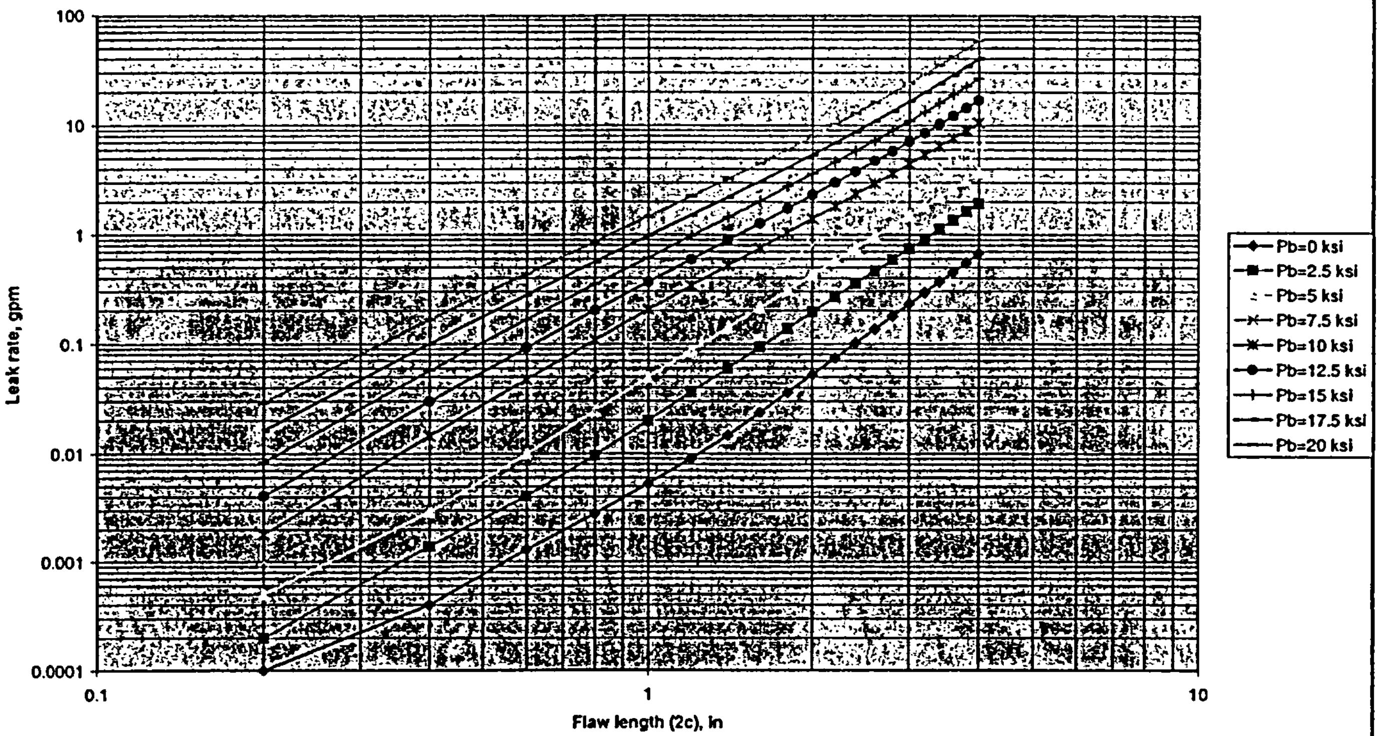

Figure 1. Leakage Rate versus Crack Length (2c) and Sustained Bending Stress (P_b)

5.0 DISCUSSION

The allowable flaw sizes show that the piping is very flaw tolerant as the pressure stress is very low. Austenitic stainless steel welded by GTAW (TIG welding) fails in a very ductile manner, such that the Appendix C approach is applicable to evaluate the flaws in the piping. It is conservative to add the length of any actual flaw indications to compare against the calculated single flaws, in terms of assessing the margin.

The assumption of a smooth crack is conservative in that it minimizes the flow loss; therefore, the calculated leakage rates are conservatively high. PICEP generally calculates higher leakage than pc-LEAK because the inclusion of plasticity (which is handled only through a plastic zone correction factor in pc-LEAK) produces larger crack opening areas. For this calculation, that is conservative.

Note that the value of P_b for calculating allowable flaw size should include Service Level C and D primary bending stresses (typically DW + SSE), while P_b for calculating leakage should include primary plus secondary stresses due to sustained loads (typically DW + TE + TAM).

Revision	0			
Preparer/Date	WFW 03/18/04			
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6.0 REFERENCES

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2. Norris, D. M., and Chexal, B., *PICEP: Pipe Crack Evaluation Computer Program*, EPRI Report No. NP-3596-SR, Revision 1.

3. E-mail from Hoang Dinh (Duke) to Art Deardorff and Bill Weitze (SI) dated 3/16/2004 12:07 PM (PST), Subject: Re: Design Input for Crack and Leakage Calculations, SI File No. MNS-02Q-201.

4. ASME Boiler and Pressure Vessel Code, Section III Appendices, 1989 Edition.

5. NUREG/CR-5128, *Evaluation and Refinement of Leak-Rate Estimation Models*, Battelle for USNRC, April 1991.

6. *Calculation of Leak Rates Through Cracks in Pipes and Tubes*, EPRI Report No. NP-3395, December 1983.

7. Zahoor, Akram, *Ductile Fracture Handbook*, EPRI Report No. NP-6301-D, Volume 3, January 1991 (Research Project 1757-69, prepared for Novetech Corporation and the Electric Power Research Institute).

8. pc-LEAK, Version 2.0-8/20/98, Structural Integrity Associates.