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April 15, 2020

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555-0001

Limerick Generating Station, Unit 1
Renewed Facility Operating License No. NPF-39
NRC Docket No. 50-352

Subject: Submittal of Analytical Evaluation of Core Spray Injection Nozzle-to-Safe End Weld (N5A)

In accordance with the American Society of Mechanical Engineers (ASME) Code, Section XI, 2007 Edition with 2008 Addenda, IWB-3134(b) ("Review by Authorities"), Limerick Generating Station, Unit 1, is submitting an analytical evaluation associated with the Core Spray Injection nozzle-to-safe end weld (N5A).

As discussed in the attached report, an analytical evaluation was performed to disposition an indication associated with the Core Spray Injection nozzle-to-safe end weld (N5A). The indication is circumferentially oriented, measured by ultrasonic testing to be approximately 2.0 inches long, 0.3 inches through wall, and has a surface separation distance of 0.35 inches from the inside surface. The indication is located in the weld material. This is an embedded flaw and does not display any characteristics of an IGSCC flaw. Instead, this is likely a construction flaw that is now more clearly visible due to the change in ultrasonic examination technology. The nozzle-to-safe end weld is a dissimilar metal weld joining the SA508 CL 2 low alloy steel nozzle to the SB166 safe end with an Alloy 82 weld with an Alloy 182 butter.

As concluded in this evaluation, the required safety factors will be maintained during operation with this indication over the next five operating cycles, by which time the weld/ indication will be examined in accordance with BWRVIP-75A requirements.

There are no regulatory commitments in this letter.

If you have any questions concerning this letter, please contact Tom Loomis at (610) 765-5510.

Respectfully,

D. P. Helker

David P. Helker
Sr. Manager, Licensing
Exelon Generation Company, LLC

Attachment: Evaluation of Unit 1 DCA-319-1 N5A Flaw Identified in IR 04332524

cc: Regional Administrator, Region I, USNRC
USNRC Senior Resident Inspector, Limerick Generating Station
Project Manager USNRC, Limerick Generation Station
R. R. Janati, Commonwealth of Pennsylvania

Attachment

Evaluation of Unit 1 DCA-319-1 N5A Flaw Identified in IR 04332524

Engineering Change	
EC Number :	0000631225 000
Status/Date :	CLOSED 04/07/2020
Facility :	LIM
Type/Sub-type:	EVAL MECH

Print Date: 04/08/2020

Exelon.

EC Title: EVALUATION OF UNIT 1 DCA-319-1 N5A FLAW IDENTIFIED IN IR 04332524

Mod Nbr : KW1: SR KW2: KW3: KW4: KW5:

Master EC :	N	Work Group :		Temporary :	N
Outage :	N	Alert Group:	A5252NESDM	Aprd Reqd Date:	04/17/2020
WO Required :	N	Image Addr :		Exp Insvc Date:	
Adv Wk Appvd:	N	Alt Ref. :		Expires On :	01/01/2023
Auto-Advance:	Y	Priority :		Auto-Asbuild :	N
Caveat Outst:	N	Department :		Discipline :	
Resp Engr :	TODD	SWOYER			
Location :					

Milestone	**Date**	**PassPort**	**Name**		**Req By**
110-PREPARE EC	04/05/2020	E060449	SWOYER	TODD	APPROVED
120-REVIEW EC	04/07/2020	E060449	SWOYER	TODD	APPROVED

Todd Swoyer signing for Emmanuel Rosa per telecon. The following are the independent reviewer comments:
This Independent Review used procedure CC-AA-103-100, Attachment "D", to verify that the above response conforms to all applicable design, configuration control, codes and licensing basis requirements. The inputs were found to be correct and appropriate.
The design method used is appropriate and the output is reasonable for the given inputs. The results support the stated purpose.
All reviewer comments have been satisfactorily resolved and incorporated.

210-DEPT RVW-01	04/05/2020	E060449	SWOYER	TODD	APPROVED

The following is an email from Ron Janowiak from corporate, dated 04/04/20 at 15:09, performing an indepdent review of the fracture mechanics portion of this technical evaluation.
.
Based upon e-mail correspondence provided to me between Limerick Engineering and Structural Integrity Associates (SIA)(Richard Mattson and DJ Shim) dated April 3, 2020, I was asked to perform an independent review (i.e. sanity check) of the conclusion reached by SIA that a surface flaw bounded an embedded flaw of the same dimensions (as noted by SIA in that correspondence). The surface flaw was the subject of Limerick evaluation LGS-12Q-301 (December 2007) entitled "Flaw Evaluation of Limerick Unit 1 Core Spray Nozzle N5 Weld." SIA performed that evaluation. The size of that
flaw was documented as approximately 2.1 inches long and 0.695 inches deep.
The recently discovered embedded flaw has the dimensions of 1.97 inches long and 0.323 inches deep, which is both shorter and shallower than that previously evaluated. It is my understanding that Limerick Engineering intends to use the 2007 analysis as technical justification for the recently discovered embedded flaw.

.
During my independent review, I discussed with DJ Shim his unverified analysis (back-of the envelope) for the embedded flaw. We agreed that a surface flaw bounds an embedded flaw from a fracture mechanics perspective. My review of the ASME BPV Section XI, Appendix C, code provisions reached this same conclusion in my independent review. It was also noted that the embedded flaw is smaller in both length and depth than the surface flaw. The internal surface flaw also experiences system pressure on the crack face that an embedded flaw does not, thus increasing the stress intensity factor for the surface flaw; the embedded flaw obviously does not experience system pressure.
.
I also understand that the loads used in the previous analysis did not chan
change; however, it was not within the scope of my independent review to confirm this.

300-APPROVE EC	04/07/2020	E074144	MCCORMICK	RORY	APPROVED
800-ATTR CLOSED	04/05/2020	E060449	SWOYER	TODD	CLOSED

Units

Fac	Unit	Description
LIM	01	UNIT ONE

Systems

Fac	System	Description
LIM	918	RX VESSEL AND INTERNALS

This Engineering Technical Evaluation is being prepared in accordance with Procedure CC-AA-309-101, Revision 15.

Document Number: EC 631225, Rev. 0

Title: EVALUATION OF UNIT 1 DCA-319-1 N5A FLAW IDENTIFIED IN IR 04332524

Reason for evaluation/scope:
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Per IR 04332524, during 1R18 NDE technicians performed an automated phased-array ultrasonic testing (PAUT) examination of component DCA-319-1 N5A per work order 4941659-04 for the Augmented Inservice Inspection (ISI) program. DCA-319-1 N5A is the 10 inch diameter weld that connects the carbon steel reactor vessel nozzle to the Inconel safe end on the N5A nozzle (Az. 60 Deg), which is the 'B' core spray injection line.

The automated PAUT examination revealed a subsurface indication recorded approximately 11.6" clockwise from top dead center. The indication is located in the weld material adjacent to the upstream weld fusion line. This is an embedded indication, typical of a fabrication indication, it is not ID connected, and does not display any characteristics indicative of intergranular stress corrosion cracking (IGSCC). The 1R18 examination determined that the indication exceeds the allowable a/t value of Table IWB-3514-2, which is unacceptable for continued service, and must be accepted by analytical evaluation in accordance with
ASME Section XI, IWB-3132.3. The examination results are included in this evaluation as Attachment 01.

This Engineering Technical Evaluation is written to evaluate the N5A weld for continued service.

Detailed evaluation:
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DCA-319-1 N5A has previously been identified at LGS with a subsurface flaw connected to the inside surface of the pipe (see IR 00709152), which required evaluation in accordance with ASME Code, section IWB-3600, using a detailed stress analysis for acceptance. This analysis was completed by Structural Integrity Associates (SIA) under document LGS-12Q-301 (See Attachment 2) and qualified a surface flaw measuring 2.1 inches long and 0.695 inches deep on the DCA-319-1 N5A weld.

The analysis proved the acceptability of the indication found in 1998 for continued operation until March 2008. Weld DCA-319-1 N5A was mechanically stress improved in 1R05 (1994). Reference BWRVIP 2007-367. The analysis did not take credit for performing mechanical stress improvement process (MSIP) on the weld. MSIP is utilized to produce compressive residual stresses in the component, which has been effective in mitigating crack growth. The analysis also conservatively assumed the plant has been at full power since 1998. Thus, for crack growth analysis the number of hours as well as the number of cycles of operation is computed accordingly.

A linear elastic fracture mechanics analysis was performed for the observed indication to compute the crack propagation due to stress corrosion and fatigue crack growth rate. The fatigue crack growth rate was evaluated for the 10 years of operation followed by 10 years of stress corrosion crack growth to project the total indication size. The projected indication size was compared to the allowable flaw size calculated from IWB-3610. The analysis concluded the indication identified in 1998 would be below the allowable flaw size in March 2008. The analysis is included as Attachment 2 to this EC.

During a 2008 ultrasonic testing performed of DCA-319-1 N5A, the flaw was found to be subsurface and not connected to the ID. The previously identified and evaluated flaw is the same flaw at the same location as identified in IR 04332524. Therefore, there is only one flaw in DCA-319-1 N5A.

This technical evaluation will compare the ID-connected flaw identified in IR 00709152 to the subsurface flaw identified during 1R18 (Ref IR 04332524) to show how the flaw evaluation in Attachment 2 is applicable to the newly identified flaw.

- The flaw identified in IR 04332524 is a subsurface flaw with a length of 1.97 inches, depth of 0.323, and separation of 0.361 inches to the surface (See Attachment 1). The flaw evaluated in Attachment 2 is 2.1 inches long, 0.695 inches deep, and connected to the ID Surface. The subsurface flaw is both shorter and shallower than the previously evaluated flaw in Attachment 2.
- A surface flaw bounds an embedded/subsurface flaw from a fracture mechanics perspective. The subsurface flaw does not experience system pressure on the crack face like an internal flaw does. This would decrease the stress intensity for the subsurface flaw.
- The crack growth due to IGSCC is not needed for a subsurface flaw since it is not exposed to a water environment like an ID-connected flaw is. However, this technical evaluation does not take credit for removing the amount of crack growth due to SCC.
- Based on review of calculation SR-1600-2 and LEAM-MUR-0049, the moment loading used in Attachment 2 along with the design temperature and pressure remain unchanged for the current plant configuration. The loads used within the analysis were taken from SR-1600-2 because the Unit 1 configuration matches Unit 2. Therefore, there are no changes required to the inputs used in the previous flaw evaluation.

In summary, the subsurface flaw identified in IR 04332524 is bounded by the SIA flaw evaluated in Attachment 2 (LGS-12Q-301). The flaw is acceptable for ten years of service based on the crack growth evaluation in Attachment 2. This is conservative for a subsurface flaw since crack growth due to SCC is not required.

The subsurface flaw is indicative of a fabrication defect and is not service induced. The NDE data was sent to EPRI to perform an independent review of the PAUT data from DCA-319-1 N5A. EPRI concluded that the PAUT data from DCA-319-1 N5A shows an embedded fabrication flaw. Also, the EPRI conclusions discuss the relationship of the flaw size between the 2008 and 2020 examination techniques. The 2008 examination results were not used for this technical evaluation. The SIA flaw evaluation included as Attachment 2 to this EC use the 1998 examination results to size the flaw.

Assignment 04332524-02 was generated to Programs to include the requirement for a ten-year inspection interval for the DCA-319-1 N5A nozzle to safe-end weld. Refinement of the crack growth evaluation for the subsurface flaw can be performed to increase the inspection internal, if desired.

Administrative considerations:

This Engineering Technical Evaluation by Engineering (T. Swoyer and R. McCormick) on 4/05/20 was screened per HU-AA-1212, Revision 9. This evaluation is of Low risk consequence (potential adverse reduction in safety margin). It has been determined to have a risk rank of 1, and it does not require supplemental review. Per procedure, since this evaluation is safety related components, an independent review is required.

Conclusions/findings:
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The results of the analysis presented in the SIA flaw evaluation included in Attachment 2 applies to the subsurface flaw identified in IR 04332524. The indication found is acceptable for continued service based on the requirements of ASME Code, Section XI. A ten-year inspection interval is required based on this analysis.

References:
===========
1. Issue Report 04332524, Dated 04/03/2020
2. CC-AA-309-101, Revision 15
3. HU-AA-1212, Revision 9
4. ASME Section XI, 2001 Edition with 2003 Addenda
5. SR-1600-2, Revision 0A
6. LEAM-MUR-0049, Revision 0

Attachments:
============

Attachment 1 – CNF-002 Flaw Examination Results
Attachment 2 – LGS-12Q-301, SIA Flaw Evaluation
Attachment 3 – EPRI Letter

See milestones for preparer, reviewer, and approver.

HITACHI

Customer Notification Form (CNF)

Project:	Li1R18	**CNF No.:**	CNF-002	**Project No.:**	200714
Component Identification:	DCA-319-1 N5A			**Date:**	April 3, 2020

Subject:

Subsurface Unacceptable Indication

Data Sheet:	**Examination Type:**	**Work Order Number:**
N/A	Phased Array UT	494165904

Conditions Found:

The Automated inspection of the above listed weld revealed a subsurface indication that was recorded @ approximately 11.6" CW from Top Dead Center. The indication is located in the weld material adjacent to the upstream weld fusion line. This indication was recorded in previous examinations and was found to be acceptable. The examination during this outage found the indication parameters now exceed the allowable a/t% to table IWB-3514-2. See page 2 for the Flaw Evaluation Sheet.

Prepared By:	**Title:**	**Signature**
Andre' Rachal	**UT Level III**	[signature]
Received By:	**Title:**	**Signature:**
PATRICK IRWIN	UT LEVEL III	Patrick Irwin

HITACHI

ASME Section XI Flaw Evaluation Sheet

Project: Li1R18
Weld ID: DCA-319-1 N5A
Indication: 1

	Measured	Rounded		Measured	Rounded
Flaw Through Wall =	0.323	0.3	"T" nominal =	1.31	1.3
Flaw Length "l" =	1.97	2.0	"T" measured =	1.30	1.3
Surface Separation "S" =	0.361	0.35			

ASME Section XI, 2007 Edition, 2008 Addenda
Table IWB-3514-2, Austenitic Steels Inservice Examinations 2.0" T

a/l	Surface %	Subsurface %	Surface %	Subsurface %
0.00	10.0	10.0	~	~
0.05	10.2	10.2	10.30	10.30 Y
0.10	10.4	10.4	~	~
0.15	10.5	10.5	~	~
0.20	10.7	10.7	~	~
0.25	10.9	10.9	~	~
0.30	11.1	11.1	~	~
0.35	11.2	11.2	~	~
0.40	11.4	11.4	~	~
0.45	11.6	11.6	~	~
0.50	11.7	11.7	~	~
			Allowed 10.30	Allowed 10.30

a = 0.150
a/l value = 0.075
Y = 1.000

Flaw is Subsurface

Allowed a/t = 10.3%
a/t = 11.5%

Flaw is unacceptable by the referenced Table.

Revised: 9/27/13

Comments: ASME Section XI rounding performed in accordance with IWA-3200 and ASTM E29.
All measurements converted from metric to US standard for evaluation.

2.0" table was used for a more conservative allowable a/t.
Flaw is rejectable to the 1.0" and 2.0" tables
Upper Tip-(.616") Lower Tip-(.939") S-Dimension closest to the inside surface

Evaluated By: [signature] Level: III Date: 4/3/2020

Reviewed By: [signature] Level: III Date: 4-3-2020

Structural Integrity Associates, Inc.	CALCULATION PACKAGE	File No.: LGS-12Q-301 Project No.: LGS-12Q

PROJECT NAME: Flaw Evaluation of Limerick Unit 1 Core Spray Nozzle N5 Weld

Contract No: GSA No. 01002562

CLIENT: Exelon Nuclear | **PLANT:** Limerick Unit 1

CALCULATION TITLE: Flaw Evaluation of Core Spray Nozzle N5 Nozzle-to-Safe-End Weld

OPE-07-005 Supporting Analysis For DCA-319-1 N5A Weld Indication

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1 - 15 A1 - A11 Computer Files	Original Issue	G. A. Miessi 12/18/07	G. A. Miessi 12/18/07 S. S. Tang 12/18/07
1	1 - 19 A1 - A11 Computer Files	Use Revised Design Input Change Fatigue Crack Growth Law	G. A. Miessi 12/21/07	G. A. Miessi 12/21/07 S. S. Tang 12/21/07

SI Form F2001R2a

Table of Contents

List of Tables

List of Figures

1 INTRODUCTION

A flaw evaluation is performed to disposition a flaw in the core spray nozzle-to-safe-end weld of the N5 core spray nozzle at Limerick Unit 1. The circumferential flaw, which is approximately 2.1 inches long and 0.695 inches deep, was first reported during the 1998 refueling outage. At the time, the indication was reported as a subsurface and found to be acceptable per the ASME Code, Section XI acceptance standards of Table IWB-3510-1. The weld is a dissimilar metal weld joining the low alloy steel nozzle to the Alloy 600 safe-end with an Alloy 82 weld and Alloy 182 weld butter.

2 TECHNICAL APPROACH

The flaw evaluation consists of the following tasks:

- Perform a flaw evaluation based on the guidelines of ASME B&PV Code, Section XI, IWB-3610 to calculate the allowable flaw size for the core spray nozzle weld. Applied stresses due to the moment loading from the piping design analysis are used. Given that the material of the dissimilar weld is Alloy 182, a nickel based austenitic steel, the flaw acceptance criteria for austenitic steel, based on limit load, was utilized based on Paragraph IWB-3641 of Reference 1.

- Determine the stress intensity factors at the flaw and perform stress corrosion and fatigue crack growth analyses to compare end-of-evaluation period flaw size to the allowable flaw size computed above. The evaluation period is 10 years.

3 DESIGN INPUT

3.1 Design and Operating Conditions

The design and operating conditions of the core spray system are provided by Reference 2.

- Design Temperature = 582°F
- Design Pressure = 1250 psig
- Normal Operating Temperature = 546°F
- Normal Operating Pressure = 1000 psig

Due to power uprate, the pressure and temperature data has changed. The following new values are provided by Reference 3:

- Normal Operating Temperature = 553°F
- Normal Operating Pressure = 1053 psig

3.2 Component Dimensions

The geometry and some dimensions of the core spray nozzle N5 assembly are shown in Figure 1, which is obtained from Reference 4. Reference 5 provides more dimensions of the assembly. The nozzle safe-end where the indication was discovered is a 14-inch OD pipe [4, 5]. The nominal dimensions of the safe-end (nozzle side) are:

- Nominal Outer Diameter = 14.25 in.
- Nominal Wall Thickness = 1.31 in.

The measured thickness at the core spray nozzle-to-safe-end weld is 1.48 inches [7].

3.3 Material Properties

The core spray nozzle to safe-end weld butter containing the indication is fabricated from Alloy 182 per Reference 4. As shown in Figure 1, the different materials of the core spray nozzle assembly are as follows [4]:

Component	Material
N5 Nozzle Forging	SA-508 Class 2
N5 Safe-End Forging	Alloy 600 (SB 166)
Weld	Alloy 82
Weld Butter	Alloy 182
Nozzle ID Cladding	Type 309/308L Stainless Steel

The design allowable stress, S_m, of the weld metal is taken to be the same as that of Alloy 600, the base metal of the safe-end. At the normal operating temperature of 553°F [2, 3], S_y is equal to 30,100 psi and the ultimate strength S_u is 80,000 psi [6]. Therefore, the flow stress, σ_f, defined as $(S_y + S_u)/2$ is equal to 55,050 psi.

3.4 Flaw Characterization

The flaw examination report summarized in Reference 7 indicates that the flaw is a 2.1 inches long circumferential flaw which is 0.695 inches deep. The thickness at the flaw location is reported as 1.48 inches; therefore, the flaw depth to thickness ratio is 0.47.

3.5 Applied Stresses

The applicable loads at the location of the indication are provided by Reference 8 which contains stress results from a piping analysis of the core spray piping system. It should be noted that a note on Page 8 of Reference 2 states that the Reference 8 piping analysis, which is for Limerick Unit 2, is applicable to Unit 1. Bending moments due to deadweight, seismic loadings and thermal expansion are extracted from the piping analysis at the node representing the pipe to safe-end weld (Node 75) as shown in the isometric drawing of the core spray system [9]. The bending moments and calculated stresses at the flaw location are shown in Table 1. The stresses were calculated using the nominal thickness instead of the larger measured thickness for conservatism.

The stresses due to through-wall thermal gradients (ΔT_1 and ΔT_2) are added to the calculated stresses. The core spray nozzle is protected by a thermal sleeve and is expected to experience less severe through-wall thermal gradients than specified with the design transients. The through-wall thermal gradients at the nozzle-to-safe-end weld are also expected to be less than those at the pipe to safe-end location. The corresponding thermal transient stress, shown in Table 1, are calculated simply as

$$\sigma_T = E\alpha\Delta T/(1-\nu^2)$$

where,

E is Young's modulus
α is the coefficient of thermal expansion.
ΔT is conservatively taken as the temperature difference between the reactor pressure and the HPCI at the injection time. For all the other transients, the maximum at the pipe-to-safe-end weld is conservatively used.

The core spray nozzle to safe-end weld is near the tapered transition of the safe-end and is likely subjected to the effects of the thermal gradients T_A and T_B which have not been included in this analysis. The maximum sum of ΔT_1, ΔT_2 and T_A-T_B from the piping analysis is 357°F versus the ΔT of 451°F used for the maximum transient in this evaluation. It is believed that the stresses computed from EαΔT are conservative.

The plant transient data showing the number of HPCI injections since September 1985 is obtained from Reference 14 and the material properties are taken at an average temperature of 300°F from Reference 6.

Table 1: Core Spray Nozzle N5 Loads and Stresses

Ro	Ri	t_{nom}	Z
(in)	(in)	(in)	(in^3)
7.125	5.813	1.31	158.3

Load	P (psi)	MX (ft-kips)	MY (ft-kips)	MZ (ft-kips)	σ (ksi)
Pressure	1053	--	--	--	2.095
DW	--	1.242	0.971	-5.084	0.404
Thermal	--	10.944	13.764	12.491	1.656
OBE	--	2.749	2.603	5.118	0.483
SAM	--	2.645	23.955	6.100	1.885
Max Thermal		11.400	17.000	15.692	1.956
P+DW+T					4.155

Transient	E ksi	α in/in/°F	ΔT °F	σ_T (ksi)	σ (ksi)
Max	29800	7.30E-06	451	107.814	112.268
All others	29800	7.30E-06	14	3.347	7.801

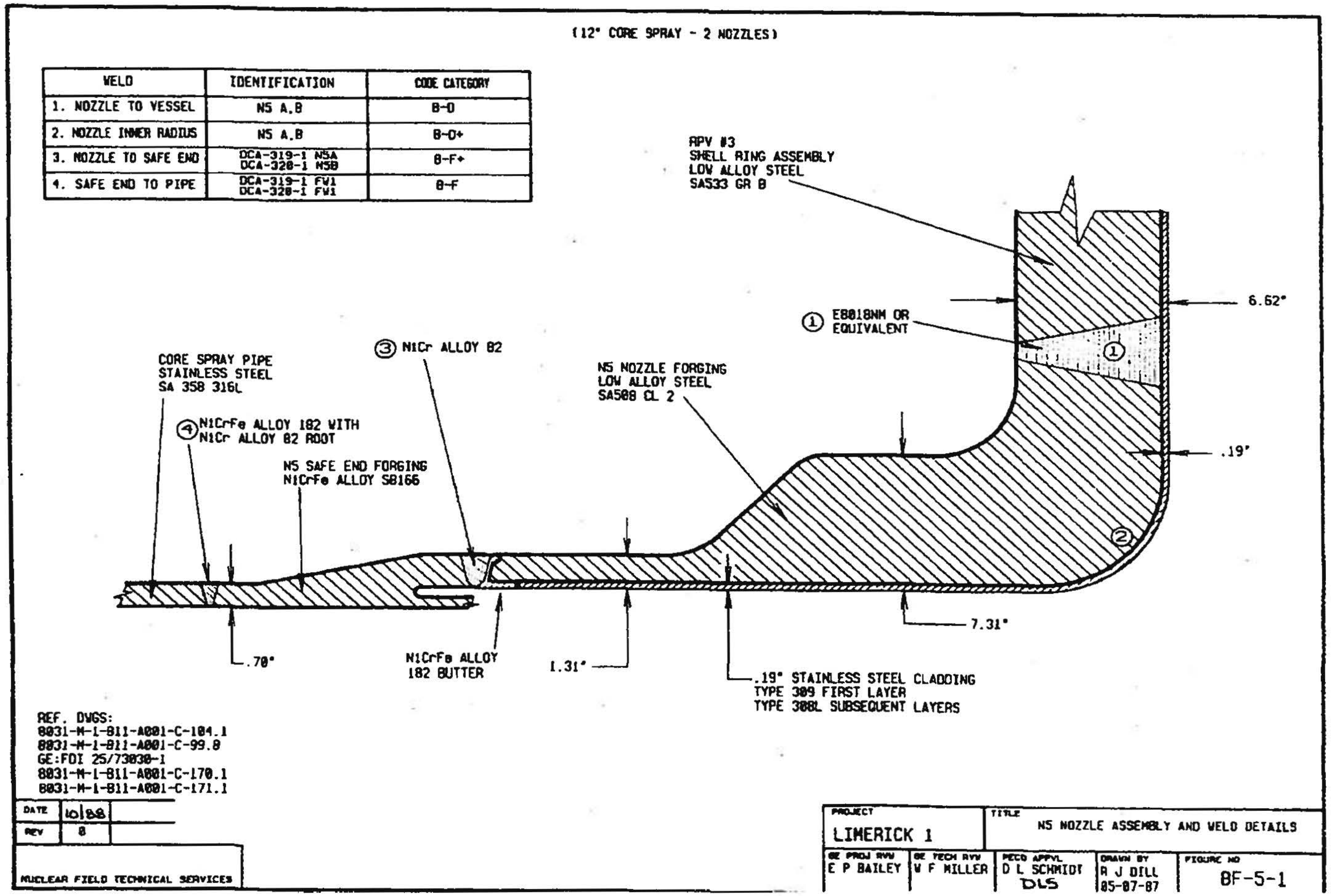

Figure 1: Core Spray N5 Nozzle Assembly

Attachment 2 to EC 631225, Rev. 0
Page 6 of 24

4 ASSUMPTIONS

1. The flaw is assumed to be in the weld butter since Alloy 182 is known to be susceptible to SCC in BWR environment.

2. The core spray nozzle (N5) under consideration was subjected to the mechanical stress improvement process (MSIP) in 1994 during refueling outage 1R05. MSIP is utilized to produce compressive residual stresses in the component to which it is applied. However, no residual stress was included in this evaluation. This is believed to be a conservative approach based on data from a core spray nozzle analysis for another plant that showed beneficial compressive stresses in the weld region after weld repair and MSIP. The geometry differ somewhat but not drastically from the Limerick case: the nozzle thickness is 1.25" but its OD is 11.5" and the safe-end taper is on the ID side. Also, the MSIP at the other plant was applied over the weld whereas at Limerick it is applied on the safe-end taper [17]. Nonetheless, at each plant, verification analyses of the MSIP process are performed to ensure that it produces compressive axial residual stresses in the weld. Hence, ignoring any MSIP effect is believed to be conservative.

3. It is assumed that the flaw has been surface connected since 1998, the year the indication was first reported. Therefore, all crack growth analyses start from 1998.

4. It is conservatively assumed that the plant has been on 100% full operation since 1998. Thus, for all crack growth analysis, the number of hours as well as the number of cycles of operation is computed accordingly and, in the case of fatigue crack growth, based on specified plant design cycles.

5 CALCULATIONS

5.1 Allowable Flaw Size Calculation

The material of the flawed weld butter is Alloy 182 which is a nickel based austenitic steel and the weld is a flux weld. Therefore, per the screen criteria in ASME Code, Section XI, Appendix C [1], the elastic-plastic fracture mechanics (EPFM) based methodology described in Appendix C is used in this evaluation. The technical approach consists of determining the critical flaw size (circumferential extent and through-wall depth) in the pipe that will cause the flawed pipe to fracture by ductile crack extension.

The stress ratios are calculated as follows:

For combined loading,

$$Stress\ Ratio = \frac{Z}{\sigma_f}\left(\sigma_m + \sigma_b - \frac{\sigma_e}{SF_b}\right)$$

and, for membrane stress,

$$Stress\ Ratio = \frac{ZSF_m\sigma_m}{\sigma_f}$$

where,

$$Z = 1.30[1 + 0.010(NPS - 4)]$$

σ_m and σ_b are the primary membrane and primary bending stresses, respectively.
σ_e is the secondary bending stress.
σ_f is the flow stress
SF_b is the safety factor for bending stress
NSP is the nominal pipe size

The material properties of Alloy 182 are assumed to be the same as those of its Alloy 600. Given that the flaw in the weld butter is in close proximity to the nozzle, the allowable flaw size could be affected by the material properties of the low alloy (SA 508 Class 2) steel nozzle. However, the flow stress of the low alloy steel is much higher than that of Alloy 600 (72.7 ksi vs. 55.1ksi at 553°F). Therefore, using the flow stress of Alloy 600 is conservative as it yields a smaller allowable flaw size.

The tables of Appendix C are used to determine the allowable flaw depth-to-thickness ratio for each service level. The results of the analysis are presented in Table 3. It can be seen that the allowable flaw depth is 75% of wall thickness, which is greater than the depth of the reported flaw depth of 47% of wall thickness. Since the stress ratios are small, the flaw length can be as long as 60% of the circumference of the nozzle.

5.2 Stress Intensity Factors Calculation

A linear elastic fracture mechanics analysis is performed for the observed indication to compute the crack propagation due to stress corrosion and fatigue crack growth. The fracture mechanics model of an elliptical surface flaw in a cylinder obtained from Reference 10, is used in this evaluation. The initial flaw aspect ratio of 0.33 (0.695/2.1) is used in the calculation of the stress intensity factors.

Using the applied stresses computed in Section 3.5, the stress intensity factors due to the different load combinations are determined. In the calculation of stress intensity factors, the pressure stress is taken as the membrane stress, which is constant across the wall thickness. The stresses from the deadweight, seismic and thermal expansion moment loads are taken as linearly varying through-wall bending stresses.

The calculated stress intensity factors are presented in Figure 2.

5.3 Fatigue Crack Growth Analysis

Since the indication is surface connected, the crack propagation due to fatigue crack growth (FCG) after 10 years of operation is calculated using the fatigue crack growth rate for Alloy 182 welds exposed to BWR environment per NUREG/CR-6721 [15]. Reference 15 indicates that the fatigue crack growth rate for Alloy 600 in air may be used with a factor of 2 for the Alloy 182 weld metal. An additional term to account for a BWR water environment is also prescribed by Reference 15. The fatigue crack growth law is shown below:

$$\left(\frac{da}{dN}\right)_{env} = \left(\frac{da}{dN}\right)_{air} + A \cdot T_r^{1-m}\left(\frac{da}{dN}\right)_{air}^{m}$$

where,

$(da/dN)_{air} = C_{A600}\,(1\text{-}0.82R)^{-2.2}\,(\Delta K)^{4.1}$, m/cycle
$A = 4.4\text{x}10^{-7}$
T_r = rise time, seconds
$m = 0.33$
$C_{A600} = 4.835\text{x}10^{-14} + 1.622\text{x}10^{-16}T - 1.49\,\text{x}10^{-18}T^2 + 4.355\,\text{x}10^{-21}T^3$
T = temperature inside pipe, °C (taken as the maximum during the transient)
R = R ratio = (K_{min}/K_{max})
$\Delta K = K_{max} - K_{min}$ = range of stress intensity factor, Mpa-m$^{0.5}$

The largest rise time of 17388 seconds corresponding to the startup transient and the maximum operating temperature of 566°F (297°C) are used in this analysis.

The core spray nozzle system was analyzed in Reference 2 for a number of design transients which are illustrated in the load histogram provided in Reference 16. The applicable design cyclic events are summarized in Table 2.

The fatigue crack growth analysis is implemented in spreadsheet "LGS-12Q-301.xls," worksheet "A-182 BWR (LGS-12Q-301)" for 10 years of operation. The initial flaw depth of 0.695" and flaw length of 2.1" are used in the evaluation. The largest stress ranges are from the HPCI injections associated with the Loss of Feedwater transients and the step changes that occur during startup. Per Reference 14, there have been only 2 such transients since 1998. The calculated maximum stress range will be used for those 2 HPCI injection transients. For simplicity, the maximum stress range from the remaining transients is conservatively used for all the rest of the cyclic transient events. Thus, the 8683 total number of design cycles for a 40-year plant life is divided by 4 to obtain the number of cycles corresponding to 10 years (2171). The analysis is conservatively performed for 2198 cycles of the maximum stress and 2 cycles of the HPCI injection transient.

The results of the fatigue crack growth analysis are summarized in Table 4 and illustrated in Figure 3.

5.4 Stress Corrosion Crack Growth Analysis

A stress corrosion crack (SCC) growth analysis is performed to determine how much the final flaw calculated after fatigue crack growth will grow in 10 years. The stress corrosion crack growth is performed after the fatigue crack growth analysis using the end-of-evaluation period flaw size from the FCG as initial flaw size for the SCC growth analysis. The initial flaw aspect ratio of 0.33 (0.695/2.1) is assumed for this analysis.

BWRVIP-59 [13] provides stress corrosion crack growth laws for high nickel bases austenitic alloys for different reactor pressure vessel water chemistry conditions. Since flow in the core spray system is occasional, the SCC growth law for normal water chemistry is used in this evaluation, even though Limerick Unit 1 is on hydrogen water chemistry. The SCC growth law for normal water chemistry is:

$$\frac{da}{dt} = C_o K_I^n \text{ in/hr for } K_I \leq 25 \text{ ksi}\sqrt{\text{in}}$$

$$\frac{da}{dt} = C_1 \text{ in/hr for } K_I > 25 \text{ ksi}\sqrt{\text{in}}$$

where,

K_I = stress intensity factor at flaw tip (ksi√in)
C_o = 1.6×10^{-8}
C_1 = 5.0×10^{-5}
n = 2.5

Sustained steady-state normal operating stresses are the only stresses that need to be considered for the SCC growth analysis. The sustained stress intensity factors calculated in Section 5.2 are used in the SCC growth analysis. The SCC growth analysis is performed with **pc-CRACK™** [12]. The results of the analysis are presented in Table 5 and illustrated in Figure 4. The flaw reaches 58% of the wall thickness in 10 years. The **pc-CRACK™** output file is shown in Appendix A.

Table 2: Design Transients

No.	Description	$T_{initial}$ (°F)	T_{final} (°F)	ΔT (°F)	Max. Rate (°F/hr)	Max. Pressure (psi)	Cycles
1	Leak test	70	100	30	60	1250	130
2	SLC Operation, Test	100	50	50	Step	0	130
3	Startup, Step	406	50	356	Step	250	10
4	Startup/Shutdown Normal	100	546	446	100	1000	120
5	Increase to Power	546	522	24	Step	1000	300
6	Turbine Trip 100% Bypass	522	490	32	1280	1000	10
7	Partial FW Heater Bypass	522	512	10	300	1000	70
8	T-G Trip, OBE + SRV	400	546	146	100	1125	50
9	T-G Trip, SRV	522	522	0	0	1000	7650
10	T-G Trip, All Other Scrams	546	400	146	100	1125	180
11	SLC Operation	522	60	462	462	1000	10
12	Loss of FW Pumps, Step	561	40	521	Step	1125	10
13	Loss of FW Pumps, Ramp	40	561	521	802	1125	10
14	Reactor Overpressure	522	562	40	13091	1350	1
15	Improper Start of Recirc. Pumps	522	268	254	Step	1000	1
16	Improper Startup	100	546	446	100	1000	1

Table 3: Allowable Flaw Size Calculations

Z factor	$l/\pi D$
1.430	0.047

Service Level	σ_m (ksi)	σ_b (ksi)	σ_e (ksi)	SF_m	SF_b	S_y (ksi)	S_u (ksi)	σ_f (ksi)	Stress Ratio		Allowable a/t
									Combined	Membrane	
A	2.095	2.771	1.656	2.7	2.3	31.2	80.0	55.6	0.149	0.146	0.75
B	2.095	2.771	1.656	2.4	2.0	31.2	80.0	55.6	0.152	0.130	0.75
C	2.095	2.771	1.656	1.8	1.6	31.2	80.0	55.6	0.159	0.097	0.75
D	2.095	2.771	1.656	1.3	1.4	31.2	80.0	55.6	0.164	0.070	0.75

Table 4: Fatigue Crack Growth Results

Cycles	Kmax (ksi-in$^{1/2}$)	Kmin (ksi-in$^{1/2}$)	DeltaK (ksi-in$^{1/2}$)	R	Da/Dn	Da (in)	a (in)	a/t
1	9.90	0.00	9.90	0.00	1.83E-05	1.83E-05	0.695	0.47
100	9.90	0.00	9.90	0.00	1.83E-05	1.83E-05	0.697	0.47
200	10.00	0.00	10.00	0.00	1.84E-05	1.84E-05	0.699	0.47
300	10.00	0.00	10.00	0.00	1.84E-05	1.84E-05	0.701	0.47
400	10.00	0.00	10.00	0.00	1.84E-05	1.84E-05	0.702	0.47
500	10.00	0.00	10.00	0.00	1.85E-05	1.85E-05	0.704	0.48
600	10.00	0.00	10.00	0.00	1.85E-05	1.85E-05	0.706	0.48
700	10.00	0.00	10.00	0.00	1.86E-05	1.86E-05	0.708	0.48
800	10.10	0.00	10.10	0.00	1.86E-05	1.86E-05	0.710	0.48
900	10.10	0.00	10.10	0.00	1.87E-05	1.87E-05	0.712	0.48
1000	10.10	0.00	10.10	0.00	1.87E-05	1.87E-05	0.714	0.48
1100	10.10	0.00	10.10	0.00	1.87E-05	1.87E-05	0.715	0.48
1200	10.10	0.00	10.10	0.00	1.88E-05	1.88E-05	0.717	0.48
1300	10.10	0.00	10.10	0.00	1.88E-05	1.88E-05	0.719	0.49
1400	10.20	0.00	10.20	0.00	1.89E-05	1.89E-05	0.721	0.49
1500	10.20	0.00	10.20	0.00	1.89E-05	1.89E-05	0.723	0.49
1600	10.20	0.00	10.20	0.00	1.89E-05	1.89E-05	0.725	0.49
1700	10.20	0.00	10.20	0.00	1.90E-05	1.90E-05	0.727	0.49
1800	10.20	0.00	10.20	0.00	1.90E-05	1.90E-05	0.729	0.49
1900	10.20	0.00	10.20	0.00	1.91E-05	1.91E-05	0.731	0.49
2000	10.30	0.00	10.30	0.00	1.91E-05	1.91E-05	0.732	0.49
2100	10.30	0.00	10.30	0.00	1.92E-05	1.92E-05	0.734	0.50
2200	147.60	0.00	147.60	0.00	7.87E-03	7.87E-03	0.752	0.51

Table 5: Stress Corrosion Crack Growth Results

Time (hr)	K (ksi-in$^{1/2}$)	da/dt (in/hr)	da (in)	a (in)	a/t
4383	5.56E+00	1.17E-06	1.17E-06	0.757	0.51
8766	5.58E+00	1.18E-06	1.18E-06	0.7623	0.52
13149	5.61E+00	1.19E-06	1.19E-06	0.7675	0.52
17532	5.63E+00	1.20E-06	1.20E-06	0.7727	0.52
21915	5.66E+00	1.22E-06	1.22E-06	0.7779	0.53
26298	5.68E+00	1.23E-06	1.23E-06	0.7833	0.53
30681	5.71E+00	1.25E-06	1.25E-06	0.7888	0.53
35064	5.73E+00	1.26E-06	1.26E-06	0.7943	0.54
39447	5.76E+00	1.27E-06	1.27E-06	0.7998	0.54
43830	5.78E+00	1.29E-06	1.29E-06	0.8054	0.54
48213	5.81E+00	1.30E-06	1.30E-06	0.8111	0.55
52596	5.84E+00	1.32E-06	1.32E-06	0.8169	0.55
56979	5.86E+00	1.33E-06	1.33E-06	0.8226	0.56
61362	5.89E+00	1.35E-06	1.35E-06	0.8285	0.56
65745	5.92E+00	1.36E-06	1.36E-06	0.8345	0.56
70128	5.94E+00	1.38E-06	1.38E-06	0.8405	0.57
74511	5.97E+00	1.39E-06	1.39E-06	0.8465	0.57
78894	6.00E+00	1.41E-06	1.41E-06	0.8527	0.58
83277	6.03E+00	1.43E-06	1.43E-06	0.859	0.58
87660	6.06E+00	1.45E-06	1.45E-06	0.8652	0.58

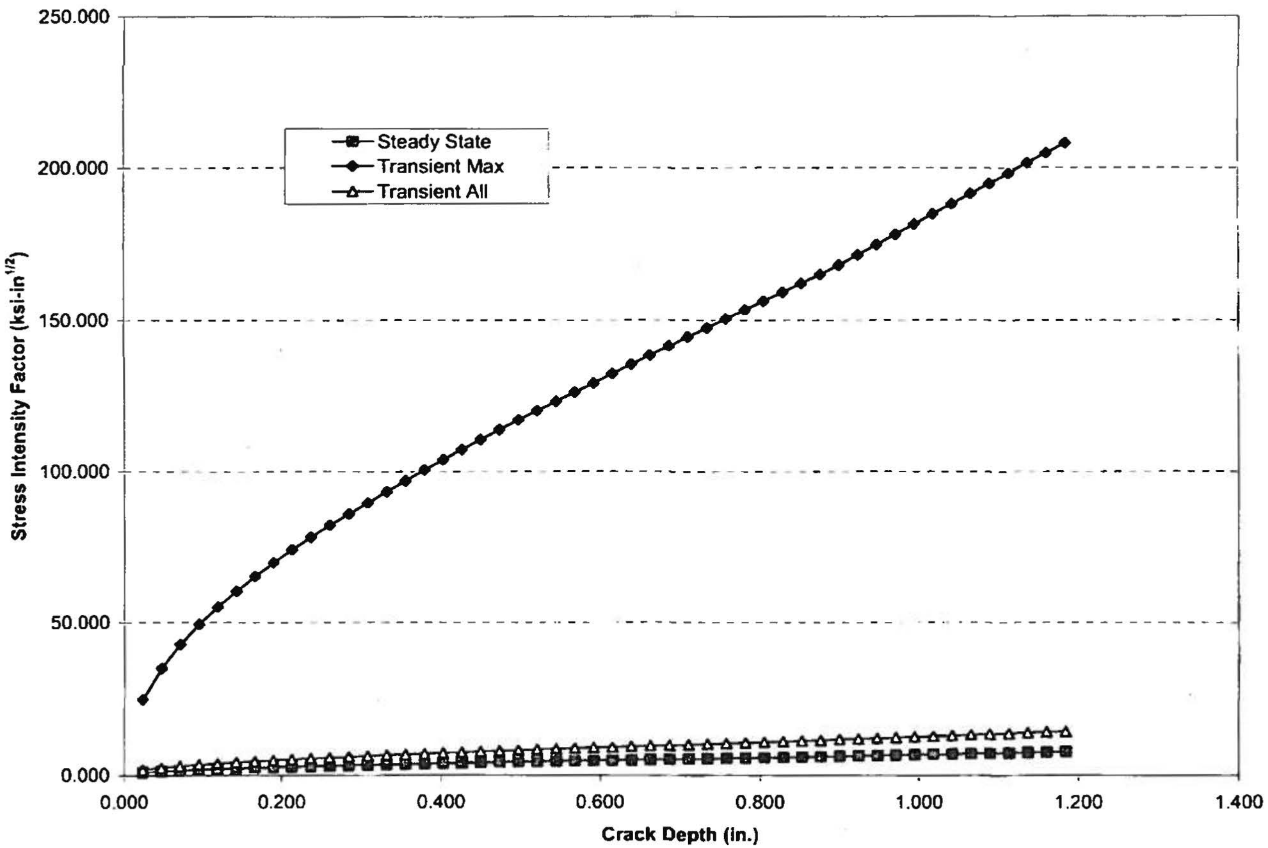

Figure 2: Applied Stress Intensity Factor

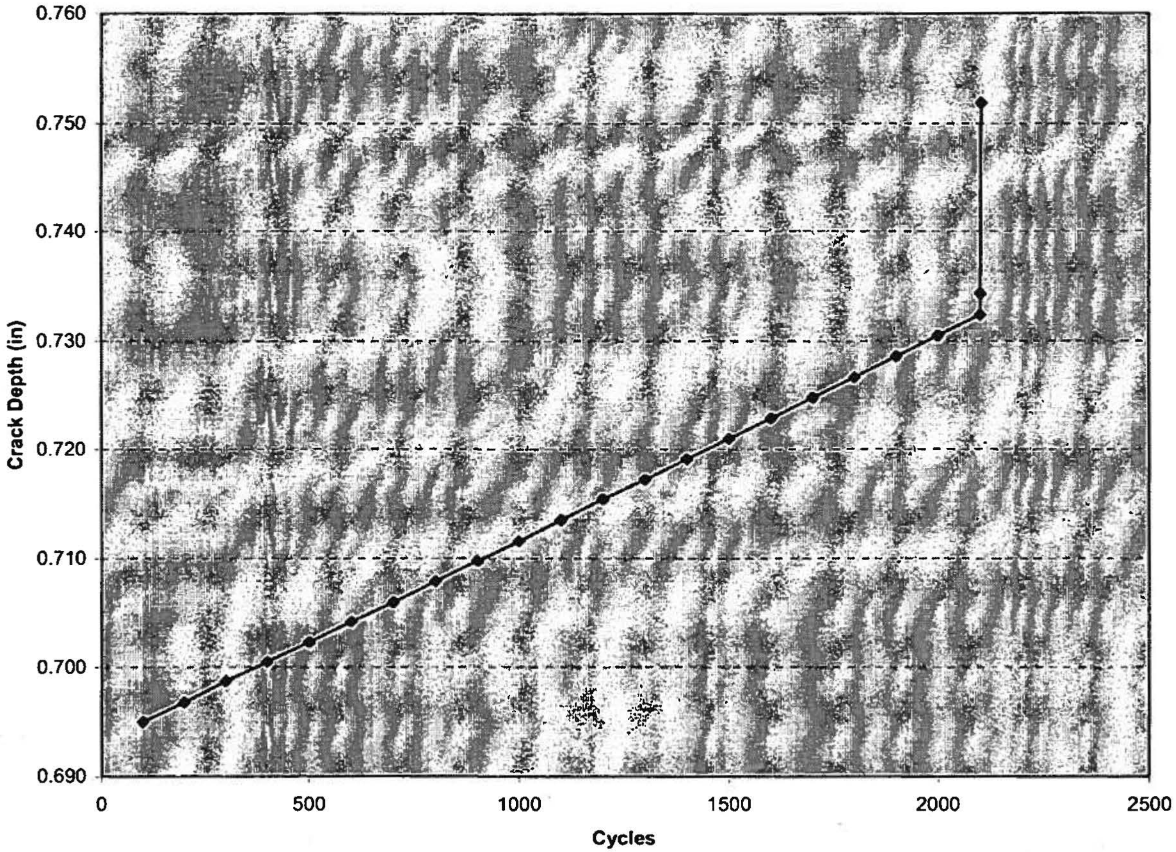

Figure 3: Fatigue Crack Growth Results

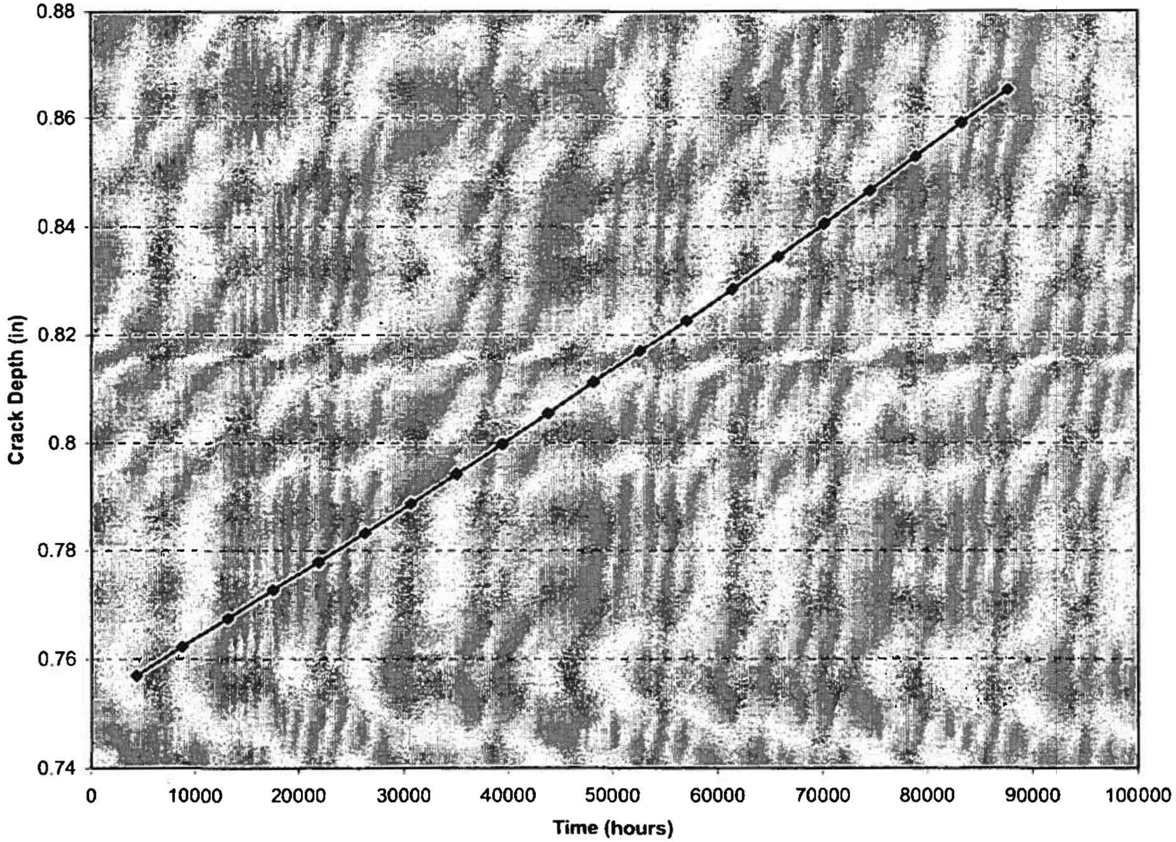

Figure 4: Stress Corrosion Crack Growth Results

6 CONCLUSIONS AND DISCUSSIONS

The results of the evaluation presented in this calculation package show that the indication found during the inservice inspection of the core spray nozzle in 1998 is acceptable for continued operation based on the requirements of ASME Code, Section XI. The allowable flaw depth for the observed flaw length is 75% of pipe wall thickness.

A fatigue crack growth analysis was performed for 10 years of operation starting with the initial flaw size reported in 1998. The flaw was projected to grow to 0.752" (a/t= 0.5) in 10 years. The fatigue crack growth evaluation was then followed by 10 years of stress corrosion crack growth starting with the final flaw size computed by fatigue crack growth. The flaw was projected to extend an additional 0.113 inches to 0.865 inches, which corresponds to an a/t of 0.58, well below the calculated allowable of 0.75.

7 REFERENCES

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4. Nuclear Field Technical Services Drawing No BF-5-1, "N5 Nozzle Assembly and Weld Details,", SI File No. LGS-12Q-203.
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16. E-mail from George Budock (Exelon) to Angah Miessi (SIA), "FW: ME-913 Run from Appendix E.PDF;U1 Core Spray Stress Report.PDF; Load Histogram P" dated Monday 12/9/2007 with attachment "Load Histogram Page 23.PDF", SI File No. LGS-12Q-202.
17. O'Donnell & Associates, Inc., "Analytical Verification of the Mechanical Stress Improvement Process for 10" Nozzle," Calc No. 2001-410-001-00, February 1989.

APPENDIX A

pc-CRACK OUTPUT FILE

Filename	Description	Pages
SCC.OUT	Stress Corrosion Crack Growth Analysis	A2- A5

tm
pc-CRACK for Windows
Version 3.1-98348
(C) Copyright '84 - '98
Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557
Voice: 408-978-8200
Fax: 408-978-8964
E-mail: pccrack@structint.com

Linear Elastic Fracture Mechanics

Date: Fri Dec 21 04:31:36 2007
Input Data and Results File: SCC_R1.LFM

Title: Limerick Core Spray Nozzle N5, SCC

Load Cases:

Case ID: Steady State --- K vs a

Depth	K
0.0240	0.9150
0.0470	1.2930
0.0710	1.5830
0.0950	1.8270
0.1180	2.0420
0.1420	2.2360
0.1660	2.4170
0.1890	2.5870
0.2130	2.7470
0.2370	2.8980
0.2600	3.0430
0.2840	3.1820
0.3080	3.3190
0.3320	3.4550
0.3550	3.5870
0.3790	3.7160
0.4030	3.8420
0.4260	3.9660
0.4500	4.0870
0.4740	4.2060
0.4970	4.3220
0.5210	4.4370
0.5450	4.5510
0.5680	4.6620
0.5920	4.7730
0.6160	4.8880
0.6390	5.0030
0.6630	5.1160
0.6870	5.2290
0.7100	5.3410
0.7340	5.4520

0.7580	5.5630
0.7810	5.6730
0.8050	5.7820
0.8290	5.8910
0.8520	5.9990
0.8760	6.1070
0.9000	6.2220
0.9240	6.3450
0.9470	6.4690
0.9710	6.5920
0.9950	6.7150
1.0180	6.8380
1.0420	6.9620
1.0660	7.0850
1.0890	7.2090
1.1130	7.3330
1.1370	7.4570
1.1600	7.5810
1.1840	7.7050

Case ID	Stress Coefficients C0	C1	C2	C3	Type
Steady State	0	0	0	0	K vs a

Crack Model: User Input K Versus Crack Size

Crack Parameters:
Max. crack size: 1.1000

--------------------Stress Intensity Factor--------------------

Crack Size	Case Steady Sta
0.0220	0.88213
0.0440	1.2437
0.0660	1.52258
0.0880	1.75583
0.1100	1.96722
0.1320	2.15517
0.1540	2.3265
0.1760	2.49091
0.1980	2.647
0.2200	2.79104
0.2420	2.92952
0.2640	3.06617
0.2860	3.19342
0.3080	3.319
0.3300	3.44367
0.3520	3.56978
0.3740	3.68913
0.3960	3.80525
0.4180	3.92287

0.4400	4.03658
0.4620	4.1465
0.4840	4.25643
0.5060	4.36512
0.5280	4.47025
0.5500	4.57513
0.5720	4.6805
0.5940	4.78258
0.6160	4.888
0.6380	4.998
0.6600	5.10188
0.6820	5.20546
0.7040	5.31178
0.7260	5.415
0.7480	5.51675
0.7700	5.62039
0.7920	5.72296
0.8140	5.82288
0.8360	5.92387
0.8580	6.026
0.8800	6.12617
0.9020	6.23225
0.9240	6.345
0.9460	6.46361
0.9680	6.57662
0.9900	6.68937
1.0120	6.80591
1.0340	6.92067
1.0560	7.03375
1.0780	7.1497
1.1000	7.26583

```
Crack Growth Laws:

Law ID:   SCC Alloy182
  Type:   Corrosion
 Model:   Paris

   da/dN = c * (dK)^n
 where
   dK = Kmax - Kmin
   dK > Kthres
   Kmax < K1c

Material parameters:
       c =  1.6000e-008
       n =      2.5000
  Kthres =      0.0000


Material Fracture Toughness KIc:

Material ID: Alloy 182

     Depth          KIc
```

```
    0.0000      25.0000
    1.1000      25.0000


Initial crack size=     0.7520
Max. crack size=         1.1000

Number of blocks=            1
Print increment of block=    1
```

Subblock	Cycles /Time	Calc. incre.	Print incre.	Crk. Grw. Law	Mat. K1c
SteadySCC	87660	1	4383	SCC Alloy182	Alloy 182

Subblock	Kmax Case ID	Kmax Scale Factor	Kmin Case ID	Kmin Scale Factor
SteadySCC	Steady State	1.0000		

Crack growth results:

Total Cycles /Time	Subblock Cycles /Time	Kmax	Kmin	DeltaK	R	DaDn /DaDt	Da	a
Block:	1							
4383	4383	5.56e+000	0.00e+000	5.56e+000	0.00	1.17e-006	1.17e-006	0.757
8766	8766	5.58e+000	0.00e+000	5.58e+000	0.00	1.18e-006	1.18e-006	0.7623
13149	13149	5.61e+000	0.00e+000	5.61e+000	0.00	1.19e-006	1.19e-006	0.7675
17532	17532	5.63e+000	0.00e+000	5.63e+000	0.00	1.20e-006	1.20e-006	0.7727
21915	21915	5.66e+000	0.00e+000	5.66e+000	0.00	1.22e-006	1.22e-006	0.7779
26298	26298	5.68e+000	0.00e+000	5.68e+000	0.00	1.23e-006	1.23e-006	0.7833
30681	30681	5.71e+000	0.00e+000	5.71e+000	0.00	1.25e-006	1.25e-006	0.7888
35064	35064	5.73e+000	0.00e+000	5.73e+000	0.00	1.26e-006	1.26e-006	0.7943
39447	39447	5.76e+000	0.00e+000	5.76e+000	0.00	1.27e-006	1.27e-006	0.7998
43830	43830	5.78e+000	0.00e+000	5.78e+000	0.00	1.29e-006	1.29e-006	0.8054
48213	48213	5.81e+000	0.00e+000	5.81e+000	0.00	1.30e-006	1.30e-006	0.8111
52596	52596	5.84e+000	0.00e+000	5.84e+000	0.00	1.32e-006	1.32e-006	0.8169
56979	56979	5.86e+000	0.00e+000	5.86e+000	0.00	1.33e-006	1.33e-006	0.8226
61362	61362	5.89e+000	0.00e+000	5.89e+000	0.00	1.35e-006	1.35e-006	0.8285
65745	65745	5.92e+000	0.00e+000	5.92e+000	0.00	1.36e-006	1.36e-006	0.8345
70128	70128	5.94e+000	0.00e+000	5.94e+000	0.00	1.38e-006	1.38e-006	0.8405
74511	74511	5.97e+000	0.00e+000	5.97e+000	0.00	1.39e-006	1.39e-006	0.8465
78894	78894	6.00e+000	0.00e+000	6.00e+000	0.00	1.41e-006	1.41e-006	0.8527
83277	83277	6.03e+000	0.00e+000	6.03e+000	0.00	1.43e-006	1.43e-006	0.859
87660	87660	6.06e+000	0.00e+000	6.06e+000	0.00	1.45e-006	1.45e-006	0.8652

End of pc-CRACK Output

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Nondestructive Evaluation (NDE) 20200406-002

April 6th, 2020

Michelle Karasek
3146 Sanatoga Rd
Pottstown, PA 19464-3418

Subject: Independent review of encoded ultrasonic examination data from dissimilar metal weld DCA-319-1 (N5A) at Unit 1 of the Limerick Generating Station

Dear Michelle Karasek:

EPRI NDE Center staff performed an independent review of the supplied automated phased array examination data from dissimilar metal weld DCA-319-1 (N5A) at unit 1 of the Limerick Generating Station. The review was performed after Exelon's inspection vendor, GE Hitachi Nuclear Energy Americas (GEH), reported an embedded weld fabrication flaw. Examination data from the previous 2008 and current 2020 examinations were provided to EPRI. The location of the reported indication can be seen in the 2008 (left) and 2020 (right) UT polar views at the approximate 90° positions shown in Figure 1.

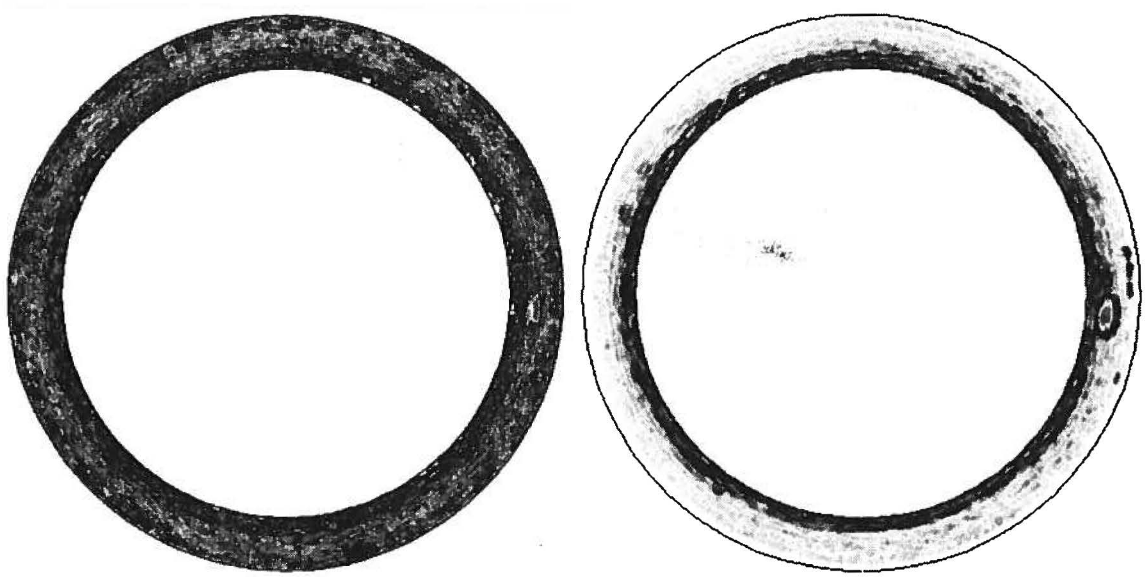

Figure 1
Polar views showing location of reported embedded flaw in the N5A DMW (2008 examination data on left, 2020 on right)

The indication reported by GEH as an embedded weld fabrication flaw was confirmed during EPRI's independent review of the 2008 and 2020 ultrasonic examination data files. It was observed that the none of the data contains a "corner trap" response or other responses that would indicate that the reported flaw is connected to the inside surface. Therefore, EPRI concurs with the GEH examiners' characterization of the flaw as being embedded. The observed characteristics of the ultrasonic responses, along with the flaw not being connected to the inside surface, rule out stress corrosion cracking as being a likely origin of the indication.

The reported flaw was located near the safe-end side weld fusion line and is positioned along the upper boundary of the ASME Code[1] inner one-third examination volume. Figure 2 shows the side-view image of the ultrasonic response using the 45°RL examination data during both the 2008 (top) and 2020 (bottom) examinations. The focal law used to generate the 45°RL examination angle during the 2020 examination is intended to interrogate the inside surface of the component by electronically focusing the ultrasonic energy at 1.3" [34mm] of material depth. This electronic focal depth corresponds to the inside surface of the DMW. If the reported flaw were attributed to an inside surface connected flaw, it is expected that the examination data would exhibit a "corner trap" response linking the reported ultrasonic indication to the inside surface; however, no such response is present.

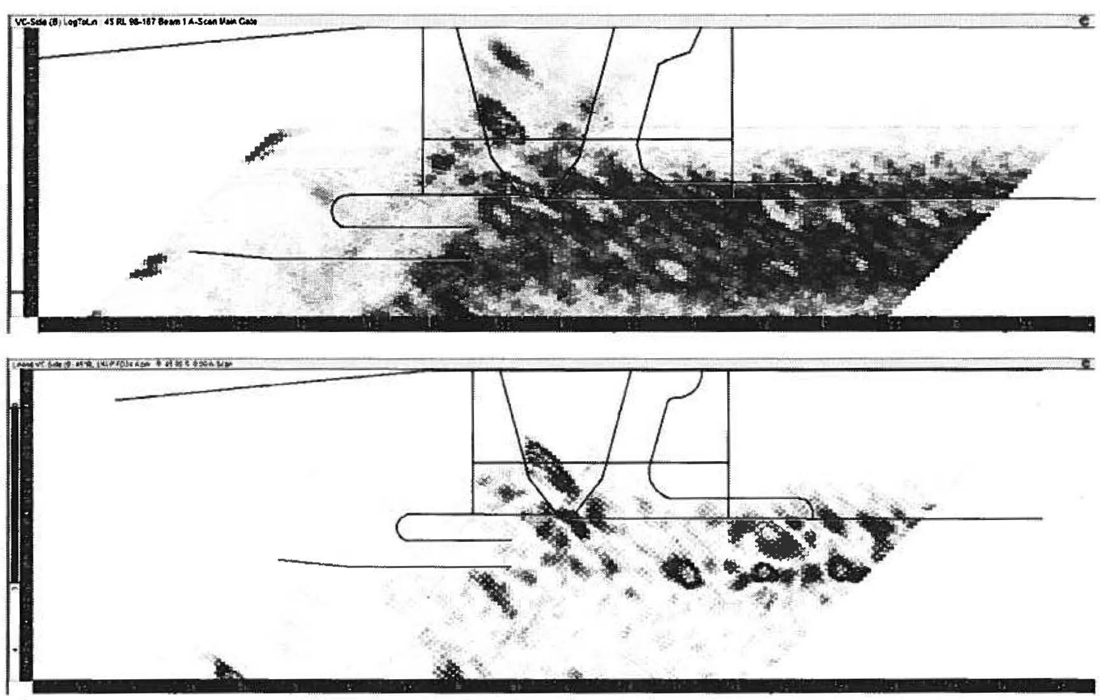

Figure 2
45°RL B-scan presentation (side view) showing location of the reported embedded flaw (2008 examination data on top, 2020 on bottom)

Figure 3 shows the side view image of the ultrasonic response obtained from the 60°RL examination angle during the 2008 examination (top) and 2020 examination (bottom). The focal law used to generate the 60°RL examination angle during the 2020 examination is intended to interrogate a thickness region that is approximately 0.79" [20mm] below the outside surface of the component. This focal depth corresponds to the depth location of the reported flaw. The 60°RL examination data also displays an embedded ultrasonic indication located along the upper boundary of the ASME Code examination volume.

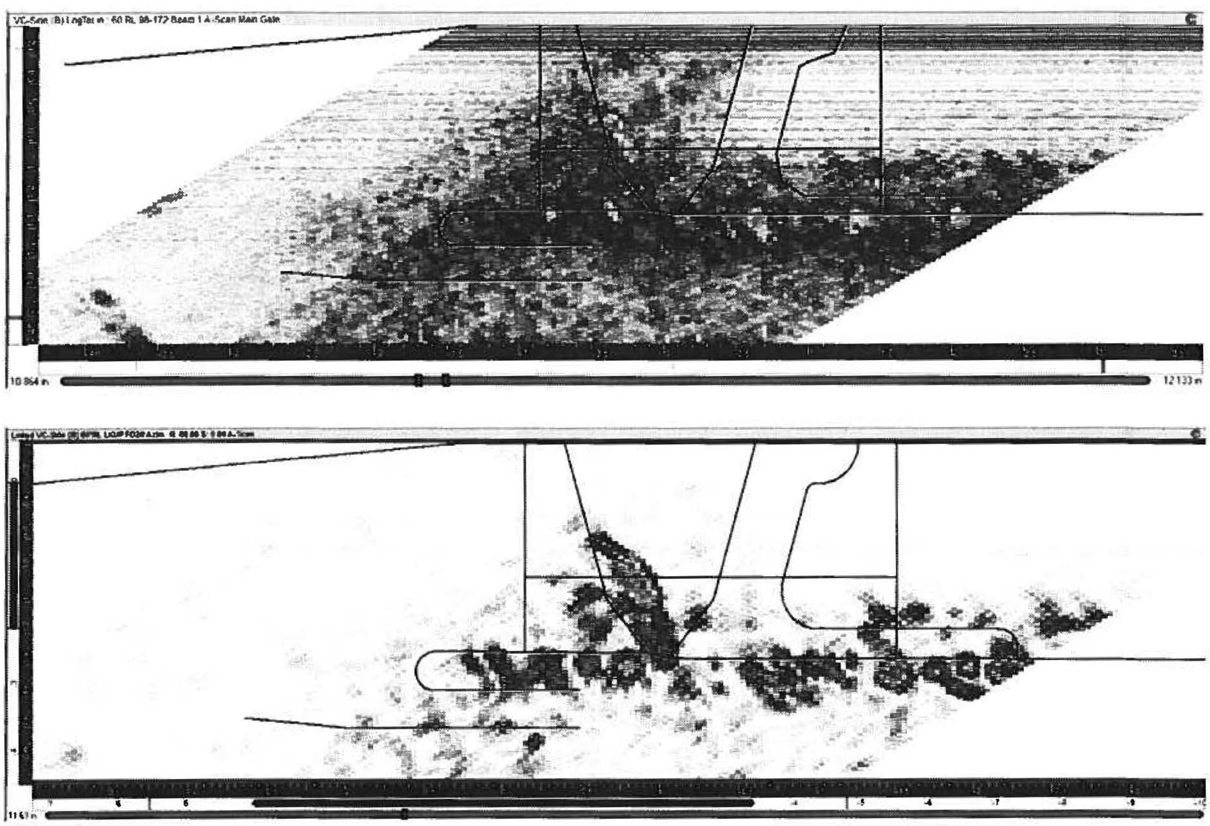

Figure 3
60°RL B-scan presentation (side view) of showing location of the reported embedded flaw (2008 examination data on top, 2020 on bottom)

The reported flaw indication was also detected at the same location using the 0° examination data (see Figure 4). 0° examination angles are well suited for detection of weld fabrication flaws. Since these examination angles are not well suited for detection of inside surface connected SCC flaws, the ability to readily identify the reported flaw with the 0° examination angle provides additional evidence that it is attributed to a weld fabrication related reflector.

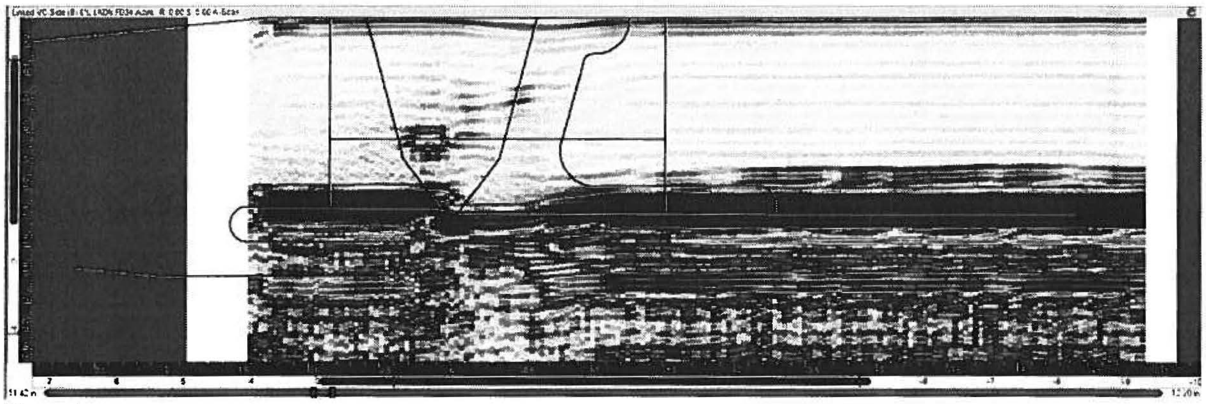

Figure 4
0° B-scan presentation (side view) showing location of reported flaw within the weld material (2020 examination)

Figure 5 shows the C-scan (roll-out view) presentation, which is the same presentation that would be represented by a radiograph. The 2008 examination data is shown in the top image while the 2020 examination data is shown in the bottom image. The horizontal axis represented by the green index rulers located along the bottoms of these images correspond to the circumferential axis of the component. The vertical axis represented by the blue scan rulers along the left edges represent the longitudinal axis of the nozzle The inside-surface layer of parallel clad beads on the nozzle side are visible along the upper portion of the images while the safe-end side of the weld joint is shown on the lower portion of the images. The location of the weld is displayed as the area of slightly increased amplitude (e.g. pattern of darker blue responses) that extends for the complete 360° circumference of the roll-out views. The reported embedded flaw is clearly evident in each image as the high-amplitude (i.e. red) response located within the safe-end side of the visible weld pattern.

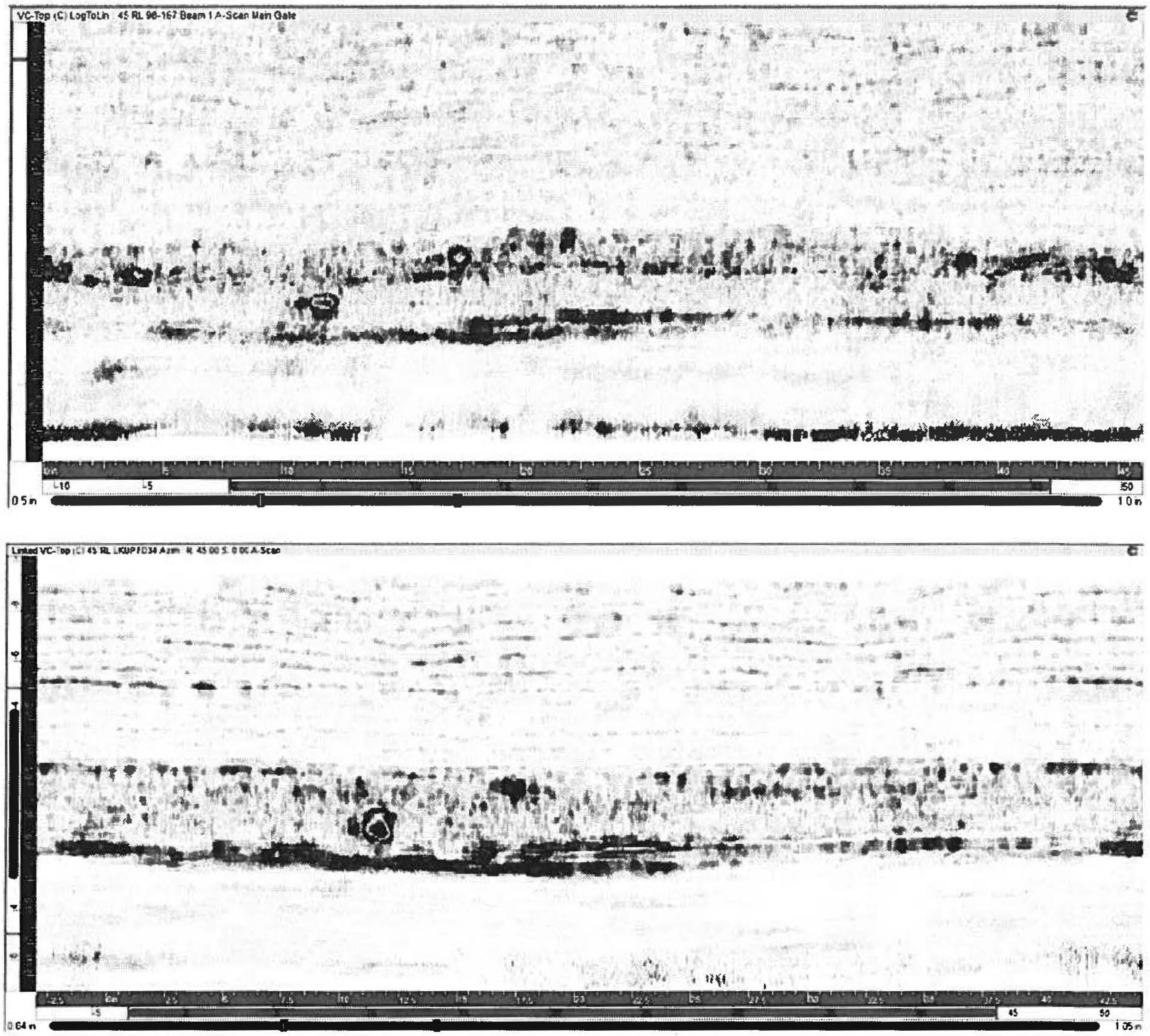

Figure 5
C-Scan (plan view) presentation showing location of reported embedded flaw (2008 examination data on top, 2020 on bottom)

A comparison was also performed between the 2008 and 2020 examination data files. The 2008 examination was conducted using an encoded conventional (i.e. non-phased array) ultrasonic examination technique while the 2020 examination was performed using an encoded phased array ultrasonic examination technique. The responses between the two sets of examination data are very similar, as can be observed by comparing the ultrasonic indications present in figures 1, 2, 3 and 5. As the ultrasonic indications present in the 2020 examination data do not contain any "new" responses propagating out from the response present in 2008, the change in flaw size is most likely a result of differences between the examination techniques. It is evident that the phased array technique used in 2020 is capable of obtaining an improved signal-to-noise ratio when compared to the 2008 conventional ultrasonic examination technique.

Measuring the through-wall extent of fabrication related flaws is not included in the ASME Section XI, Appendix VIII, Supplement 10 qualification requirements for the examination of dissimilar metal welds. However, these qualified examination procedures often detect and are then used to measure the size of fabrication related flaws. Measuring the through-wall extent of embedded weld fabrication flaws is often times more subjective than measuring the through-wall extent of an inside surface SCC flaw as there are several different types and shapes of weld fabrication flaws. The through-wall extent of the ultrasonic indication was measured using the -6dB drop (i.e. 50% drop) sizing method to provide Exelon with an estimated size that can be used to independently validate the reported flaw size. Any reported through-wall extent ranging from approximately 0.30" to approximately 0.35" [7.6mm to 8.9mm] should be considered valid.

Conclusions

The ultrasonic indication reported as an embedded fabrication flaw by the inspection vendor was confirmed during EPRI's review of the examination data. Upon EPRI's review, it was concluded that the reported indication is not connected to the inside surface, so EPRI NDE staff concur with the inspection vendor that the reported flaw is associated with an embedded weld fabrication flaw. The examination data reviewed from 2008 and 2020 ultrasonic examinations appeared to be of high quality. The small increase in reported size of the flaw appears to be attributed to changes between the two examination techniques as no "new" responses were observed propagating outwards from the indication that was present in the 2008 examination data. By comparing the examination data sets shown in Figure 1, it is possible to see that the phased array examination technique utilized in 2020 (right) was capable of obtaining an improved signal-to-noise ratio from the flaw when compared to the conventional ultrasonic examination technique used in 2008 (left).

Sincerely,

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20200406-002/jyb

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