Southern Nuclear

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Enclosure 2 to this letter contains Proprietary Information to be withheld from public disclosure per 10 CFR 2.390. When separated from Enclosure 2, this transmittal document is decontrolled.

January 8, 2019

Docket Nos.: 50-321
50-366

NL-19-0009

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555-0001

Edwin I. Hatch Nuclear Plant – Units 1 and 2
Supplemental Response to Alternative Request HNP-ISI-ALT-05-04

Ladies and Gentlemen:

By letter dated June 21, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML18172A281), and as supplemented by letter dated November 29, 2018 (ADAMS Accession No. ML18333A382), Southern Nuclear Operating Company (SNC) submitted proposed Alternative Request No. HNP-ISI-ALT-05-04 (Proposed Alternative) to certain requirements of the American Society of Mechanical Engineers, Boiler and Pressure Vessel Code (ASME Code), for the fifth 10-year Inservice Inspection (ISI) Program for the Edwin I. Hatch Nuclear Plant, Units 1 and 2 (Hatch). Specifically, pursuant to Title 10 of the Code of Federal Regulations (10 CFR) paragraph 50.55a(z)(1), SNC requested approval to implement alternative BWRVIP Guidelines in lieu of ASME Code Section XI Table IWB-2500-1 Examination Category B-N-1 and B-N-2 requirements.

Based on a follow-up call held on December 20, 2018 between the Nuclear Regulatory Commission (NRC) staff and SNC, it was requested that SNC transmit the latest Unit 1 core shroud flaw evaluation calculation. Enclosures 2 and 3 contain the proprietary and non-proprietary versions, respectively, of the requested calculation. Enclosure 1 contains the supporting affidavit signed by Electric Power Research Institute (EPRI), the owner of the proprietary information in Enclosure 2. This affidavit sets forth the basis on which the information in Enclosure 2 may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR 2.390 of the Commission's regulations. Accordingly, it is respectfully requested that the information, which is proprietary to EPRI, be withheld from public disclosure in accordance with 10 CFR 2.390 of the Commission's regulations.

This letter contains no NRC commitments. If you have any questions, please contact Jamie Coleman at 205.992.6611.

Respectfully submitted,

C. A. Gayheart
Regulatory Affairs Director

CAG/RMJ

Enclosures:
1. EPRI Affidavit Requesting Withholding of Proprietary Information
2. Hatch Unit 1 Core Shroud Leakage Calculation (Proprietary)
3. Hatch Unit 1 Core Shroud Leakage Calculation (Non-Proprietary)

Cc: Regional Administrator, Region II
NRR Project Manager – Hatch
Senior Resident Inspector – Hatch
RTYPE: CHA02.004

Edwin I. Hatch Nuclear Plant – Units 1 and 2
Supplemental Response to Alternative Request HNP-ISI-ALT-05-04

Enclosure 1

EPRI Affidavit Requesting Withholding of Proprietary Information

ELECTRIC POWER
RESEARCH INSTITUTE

NEIL WILMSHURST
Vice President and
Chief Nuclear Officer

Ref. EPRI Docket No. 99902016

January 7, 2019

Document Control Desk
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Request for Withholding of the following Proprietary Information Included in:

Southern Nuclear Company, E. I. Hatch Nuclear Plant
Core Shroud Leakage Evaluation of Hatch Nuclear Plant, Unit 1,
Core Shroud Leakage Rate Calculation
Revision 1, dated January 2019

To Whom It May Concern:

This is a request under 10 C.F.R. §2.390(a)(4) that the U.S. Nuclear Regulatory Commission ("NRC") withhold from public disclosure the report identified in the enclosed Affidavit consisting of the proprietary information owned by Electric Power Research Institute, Inc. ("EPRI") identified above in the attached report. Proprietary and non-proprietary versions of the Report and the Affidavit in support of this request are enclosed.

EPRI desires to disclose the Proprietary Information in confidence to assist the NRC review of the enclosed submittal to the NRC by Southern Company. The Proprietary Information is not to be divulged to anyone outside of the NRC or to any of its contractors, nor shall any copies be made of the Proprietary Information provided herein. EPRI welcomes any discussions and/or questions relating to the information enclosed.

If you have any questions about the legal aspects of this request for withholding, please do not hesitate to contact me at (704) 595-2732. Questions on the content of the Report should be directed to Andy McGehee of EPRI at (704) 502-6440.

Sincerely,

Attachment(s)

ELECTRIC POWER RESEARCH INSTITUTE

AFFIDAVIT

RE: Request for Withholding of the Following ProprietaryInformation Included In:

Southern Nuclear Company, E. I. Hatch Nuclear Plant
Core Shroud Leakage Evaluation of Hatch Nuclear Plant, Unit 1,
Core Shroud Leakage Rate Calculation
Revision 1, dated January 2019

I, Neil Wilmshurst, being duly sworn, depose and state as follows:

I am the Vice President and Chief Nuclear Officer at Electric Power Research Institute, Inc. whose principal office is located at 3420 Hillview Avenue, Palo Alto, California ("EPRI") and I have been specifically delegated responsibility for the above-listed Report contains EPRI Proprietary Information that is sought under this Affidavit to be withheld "Proprietary Information". I am authorized to apply to the U.S. Nuclear Regulatory Commission ("NRC") for the withholding of the Proprietary Information on behalf of EPRI.

EPRI Proprietary Information is identified in the above referenced report with text inside double brackets. Examples of such identification is as follows:

{{This sentence is an example}}

Tables containing EPRI Proprietary Information are identified with double brackets before and after the object. In each case the proprietary notation refers to this affidavit and all the bases included below, which provide the reasons for the proprietary determination.

EPRI requests that the Proprietary Information be withheld from the public on the following bases:

Withholding Based Upon Privileged And Confidential Trade Secrets Or Commercial Or Financial Information (see e.g. 10 C.F.R. §2.390(a)(4))::

a. The Proprietary Information is owned by EPRI and has been held in confidence by EPRI. All entities accepting copies of the Proprietary Information do so subject to written agreements imposing an obligation upon the recipient to maintain the confidentiality of the Proprietary Information. The Proprietary Information is disclosed only to parties who agree, in writing, to preserve the confidentiality thereof.

b. EPRI considers the Proprietary Information contained therein to constitute trade secrets of EPRI. As such, EPRI holds the information in confidence and disclosure thereof is strictly limited to individuals and entities who have agreed, in writing, to maintain the confidentiality of the Information.

c. The information sought to be withheld is considered to be proprietary for the following reasons. EPRI made a substantial economic investment to develop the Proprietary Information and, by prohibiting public disclosure, EPRI derives an economic benefit in the form of licensing royalties and other additional fees from the confidential nature of the Proprietary Information. If the Proprietary Information were publicly available to consultants and/or other businesses providing services in the electric and/or nuclear power industry, they would be able to use the Proprietary Information for their own commercial benefit and profit and without expending the substantial economic resources required of EPRI to develop the Proprietary Information.

d. EPRI's classification of the Proprietary Information as trade secrets is justified by the Uniform Trade Secrets Act which California adopted in 1984 and a version of which has been adopted by over forty states. The California Uniform Trade Secrets Act, California Civil Code §§3426 – 3426.11, defines a "trade secret" as follows:

> "'Trade secret' means information, including a formula, pattern, compilation, program device, method, technique, or process, that:
>
> (1) Derives independent economic value, actual or potential, from not being generally known to the public or to other persons who can obtain economic value from its disclosure or use; and
>
> (2) Is the subject of efforts that are reasonable under the circumstances to maintain its secrecy."

e. The Proprietary Information contained therein are not generally known or available to the public. EPRI developed the Information only after making a determination that the Proprietary Information was not available from public sources. EPRI made a substantial investment of both money and employee hours in the development of the Propretary Information. EPRI was required to devote these resources and effort to derive the Proprietary Information. As a result of such effort and cost, both in terms of dollars spent and dedicated employee time, the Proprietary Information is highly valuable to EPRI.

f. A public disclosure of the Proprietary Information would be highly likely to cause substantial harm to EPRI's competitive position and the ability of EPRI to license the Proprietary Information both domestically and internationally. The Proprietary Information and Report can only be acquired and/or duplicated by others using an equivalent investment of time and effort.

I have read the foregoing and the matters stated herein are true and correct to the best of my knowledge, information and belief. I make this affidavit under penalty of perjury under the laws of the United States of America and under the laws of the State of California.

Executed at 1300 W WT Harris Blvd, Charlotte, NC being the premises and place of business of Electric Power Research Institute, Inc.

Date 1-7-2019

[signature]

Neil Wilmshurst

(State of North Carolina)
(County of Mecklenburg)

Subscribed and sworn to (or affirmed) before me on this 2 day of January 2019 by Neil Wilmshurst, proved to me on the basis of satisfactory evidence to be the person(s) who appeared before me.

Signature Candra B Sheriff (Seal)

CANDRA B SHERIFF
Notary Public
Cabarrus
County
NORTH CAROLINA

My Commission Expires 12 day of August, 2023

Edwin I. Hatch Nuclear Plant – Units 1 and 2
Supplemental Response to Alternative Request HNP-ISI-ALT-05-04

Enclosure 3

Hatch Unit 1 Core Shroud Leakage Calculation (Non-Proprietary)

Structural Integrity Associates, Inc.®

CALCULATION PACKAGE

File No.: 1500880.303

Project No.: 1801566

Quality Program: ☒ Nuclear ☐ Commercial

PROJECT NAME:

Update of Hatch Shroud Flaw Evaluation Calculation

CONTRACT NO.:

Purchase Order SNC54443-0009, Rev. 0

CLIENT:

E. I. Hatch Nuclear Plant - Southern Company

PLANT:

E. I. Hatch Nuclear Plant

CALCULATION TITLE:

Core Shroud Leakage Evaluation of Hatch Nuclear Plant, Unit 1 – Core Shroud Leakage Rate Calculation

Document Revision	Affected Pages	Revision Description	Project Manager Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1 - 20 A-1 – A-12	Initial Issue	Daniel V. Sommerville 1/11/16	**Responsible Engineer** Stephen M. Parker 1/11/16 **Responsible Verifier** Gole Mukhim 1/11/16
1	2, 8, 10, 11, 13- 16, A-3, A-7, A-8, A-9	Added formatting for proprietary information.	Matthew Walter 1/7/2019	**Responsible Engineer** Matthew Walter 1/7/2019 **Responsible Verifier** Chris Lohse 1/7/2019

PROPRIETARY INFORMATION NOTICE

THIS DOCUMENT CONTAINS **EPRI PROPRIETARY INFORMATION**. SUCH INFORMATION IS IDENTIFIED IN THE LIST OF REFERENCES AND IS IDENTIFIED IN THE TEXT BY DOUBLE BRACKETS, A REVISION BAR IN THE RIGHT HAND MARGIN, AND RED, ITALIC FONT AS SHOWN IN THE FOLLOWING EXAMPLE, {{ *THIS INFORMATION IS EPRI PROPRIETARY* }}.

NOTE: FOR THIS NON-PROPRIETARY VERSION, INFORMATION IN RED BRACKET HAS BEEN REDACTED AS SHOWN IN THE FOLLOWING EXAMPLE, {{ }}.

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1.0 INTRODUCTION

Multiple reportable indications were detected in the E. I. Hatch Nuclear Plant, Unit 1 (HNP1) core shroud during the Spring 2014 refueling outage. Numerous axially oriented indications were reported on the outside and inside surfaces of the core shroud in the vicinity of the core shroud circumferential weld H4 as well as multiple co-linear flaws in the core shroud axial welds V5 and V6. These flaws were evaluated and leakage calculations were performed to determine their acceptability for continued operation [1].

The purpose of this evaluation is to update the leakage calculations performed in Reference [1] to consider updated methodologies and the behavior of long co-linear cracks. In Reference [2], a plant-specific analysis was performed to investigate whether very long flaws would result in crack opening areas (COA) that are not adequately predicted using the existing handbook fracture mechanics solutions. The resulting finite element analysis (FEA) calculated larger COAs for large cracks than those calculated using the existing handbook solutions. The Reference [2] study was extended to investigate the behavior of co-linear flaws identified in the HNP1 core shroud [3]. The results of these plant-specific studies are incorporated in this updated core leakage calculation. The leakage calculations also incorporate the latest methodology developed in References [4, 13] which accounts for the effects of crack morphology and treatment of through-wall cracking in uninspected regions of the core shroud, respectively.

2.0 OBJECTIVE

The objective of the work documented in this calculation package is to revise the HNP1 core shroud combined leakage evaluation for the H4-V4 weld intersection and V6 weld through-wall indications documented in Reference [1], considering the following:

1. The results of the analyses performed in References [2, 3] to account for the effects of long single and multiple co-linear cracks.
2. A three cycle operating interval.
3. The results of the updated core leakage methodology documented in References [4, 13].

3.0 METHODOLOGY

The leakage calculation is performed using methods consistent with those given in BWRVIP-76, Rev. 1 [5]. The leakage calculation is performed using the following process:

1. Calculate end of interval crack length.
2. Calculate end of interval COA.
3. Determine leakage rate multiplier
4. Calculate through wall leakage rate.

Each item is addressed separately as follows.

3.1 End of Interval Crack Lengths

To predict the crack length at the end of three cycles of operation (6 years), the following is considered:

1. Location and dimensions of the flaws.
2. Applicable material properties.
3. Flaw sizing uncertainty associated with the core shroud weld inspections.
4. Crack growth rate due to degradation mechanisms.
5. Plastic zone size due to small-scale yielding at the crack-tip

Each of these aspects is described separately below.

3.1.1 Characterization of Flaws

The number, orientation, and dimensions of the reported indications are obtained from the inspection notification reports (INRs) provided by General Electric Hitachi Nuclear Energy Americas, LLC (GEH) [6]. The INRs are also used to infer the likely initiation and growth mechanism for the reportable indications which is necessary in order to identify which crack growth mechanisms to consider in the evaluation.

The as-measured lengths of the through-wall indications identified in the HNP1 core shroud H4-V4 weld intersection and V6 weld [6.j, 6.k] are the initial crack lengths used for this calculation.

3.1.2 Material Properties

Tensile properties are selected at a temperature and fluence level such that the plastic zone sizes are bounding. BWRVIP-100-A [7] and the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section II, Part D [8.a] are also used to select the appropriate tensile properties for the fluence level and temperature. The bounding fluence along the entire core shroud height at 49.3 effective full power years (EFPY) [9] is conservatively used for this evaluation. The current refueling outage is 1R27 and the end of design life EFPY is reported to be 49.3 EFPY in Reference [9] which corresponds to refueling outage 1R36.

3.1.3 Inspection Uncertainty

Inspection uncertainties provided in the inspection method demonstration documentation, appropriate to the inspection method and delivery system, are conservatively applied to the length of all reportable indications [10].

3.1.4 Crack Growth

Consistent with the methods provided in BWRVIP-76, Rev. 1 [5] and the clarifying guidance given in References [4, 11] intergranular stress corrosion crack growth (IGSCC) is calculated for the evaluation interval and added to each end of each reportable indication. Fatigue crack growth is not a relevant mechanism for the core shroud [5, Section K.3]; therefore, IGSCC is the only relevant crack growth mechanism.

The IGSCC length crack growth rate provided in BWRVIP-76, Rev. 1 [5] and BWRVIP-14-A [11] is used for all flaws:

$$\frac{da}{dt} = 5.0 \cdot 10^{-5} \cdot \frac{in}{hr}$$

For a three cycle operating interval (six years), the resulting total crack growth is 2.63 inches.

3.1.5 Plastic Zone Size

The radius of the plastic zone size is added as an additional crack length at each end of each flaw. The plastic zone size correction is estimated, for conditions of small scale yielding, using the following equation [12, pg. 16]:

$$r_Y = \frac{1}{2 \cdot \pi} \cdot \left(\frac{K_I}{\sigma_{Yield}}\right)^2 \qquad \text{Equation (1)}$$

Where K_I is the Mode I stress intensity factor, ksi-in$^{0.5}$

α is used to adjust for plane strain or plane stress conditions at the crack tip, where:

Plane Strain: $\alpha=1/6\pi$

Plane Stress: $\alpha=1/2\pi$

σ_{Yield} is yield stress, ksi

For the off-axis parallel flaws identified in the V4/H4 weld intersection, the stress intensity factor, K_I, is determined using a linear-elastic fracture mechanics (LEFM) solution as presented in Reference [12, pg. 582] for a single longitudinal through-wall crack in a cylinder (see Figure 1). Use of the single flaw equations to calculate K_I for parallel flaws is conservative since the K_I solutions for parallel flaws result in smaller values [12, pg. 256]. The equations used are:

$$K_I = SF \cdot \sigma\sqrt{\pi a} \cdot F(\lambda) \qquad \text{Equation (2)}$$

Where: SF is the structural factor for operating conditions. 2.77 for Normal (Level A) and Upset (Level B) conditions. 1.39 for Emergency (Level C) and Faulted (Level D) conditions, unitless

$\sigma = p\frac{R}{t}$, is the hoop stress, ksi

a half crack length (see Figure 2), in.

$$F(\lambda) = (1 + 1.25\lambda^2)^{1/2} \qquad 0 \le \lambda \le 1$$
$$= 0.6 + 0.9\lambda \qquad 1 \le \lambda \le 5$$

$$\lambda = a/\sqrt{Rt}$$

For the co-linear flaw identified in the V6 weld, the stress intensity factor, K_I, used is equal to the fracture toughness, K_{Ic}, for the irradiated core shroud material. As K_I cannot be greater than K_{Ic} for this calculation, this approach is conservative.

3.2 Crack Opening Area

The COA is determined for the crack configuration presented in Figure 1 and Eq. (3) below [12, Part VII]. The handbook solution for COA has been shown to result in lower values than those from a finite element analysis [2] for large cracks. Therefore, the handbook solution results are adjusted by applying the factors F_{FEA} and F_{CL} to account for the effects of large single and multiple co-linear cracks, where applicable [2, 3]:

$$A = \frac{\sigma}{E'}(2\pi Rt) \cdot G(\lambda) \cdot F_{FEA} \cdot F_{CL} \qquad \text{Equation (3)}$$

Where:

A	is the crack opening area, in^2
$\sigma = p\frac{R}{t}$	is the hoop stress, ksi
p	is the internal pressure difference across the core shroud, ksi
R	is the core shroud mean radius, in.
t	is the core shroud thickness, in.

$$E' = \begin{cases} E \ \text{(plane stress)} \\ \frac{E}{(1-v^2)} \ \text{(plane strain)} \end{cases}$$

Note: For this application, plane stress is conservative. Therefore, E' is equal to the modulus of elasticity [12, Part VII].

$$G(\lambda) = \lambda^2 + 0.625\lambda^4 \qquad 0 < \lambda \leq 1$$
$$= 0.14 + 0.36\lambda^2 + 0.72\lambda^3 + 0.405\lambda^4 \qquad 1 \leq \lambda \leq 5$$

$$\lambda = a/\sqrt{Rt}$$

a	is the half crack length (see Figure 2), in.
F_{FEA}	is the adjustment factor to account for the difference in COA calculated using FEA [2] for long cracks. This factor is equal to one plus the percent difference between the FEA and LEFM COA calculations, unitless
F_{CL}	is the adjustment factor to account for the effect of co-linear cracking on the COA, unitless

3.3 Leakage Rate Multiplier

Guidance is available in Reference [13] that can be used to determine the extent of off-axis, through-wall cracking assumed to exist in uninspected core shroud weld regions. Table 1 excerpted from Reference [13, Table 1], provides leak rate multipliers that can be used to determine the total calculated leakage rate at the end of interval for the entire weld. The examination coverage is defined as the inspected weld length divided by the total weld length. Leakage rate multipliers are available for EVT-1 and UT examinations at various percentiles of examination coverage. The multiplier used in this evaluation is provided in Section 6.0.

3.4 Leakage Rate and Loss Coefficient Calculation

The volumetric leakage rate through a through-wall crack can be determined using the methodology given in Reference [4]:

$$Q = C_f \cdot COA \cdot \sqrt{\frac{2 \cdot g \cdot \Delta P}{\gamma}} \qquad \text{Equation (4)}$$

{{ }} Equation (5)

Where:	γ	is the coolant density, lbf/ft^3
	g	is the gravitational acceleration, in/s^2
	ΔP	is the pressure differential across the length of the crack, psi
	T	is the thickness of the reactor internal component, in
	δ	is the average COD, equal to COA / L. This is an approximation based on a rectangular COA shape which results in an average COD larger than that for an elliptically shaped COA, in
	COA	is the crack opening area (See Section 3.2), in^2
	L	is the total crack length, in
	n_t	is the number of turns per unit length, {{ }}, unitless

This equation is consistent with the equation given in BWRVIP-76 [5] and includes the ability to consider head loss from additional factors not considered in BWRVIP-76 [5], such as IGSCC morphology. Based on discussions in Reference [4], NRC studies [14, 15, 16] have shown that crack morphology parameters along the crack flow path have a significant impact on predicted leak rates. The crack morphology parameters are the surface roughness, the number of turns the crack makes, and the ratio of the actual flow path length to the thickness of the pipe. The two software programs most commonly used to compute leakage rates in the nuclear industry are PICEP [17] and SQUIRT [18].

These software programs calculate fracture mechanics parameters such as the crack opening displacement (COD) and the leakage rates. These computer codes have been benchmarked against experimental data. Both PICEP and SQUIRT are based on the same thermal hydraulics model [19, 20]. Both of these codes have been mainly used for the analysis of Leak-Before-Break (LBB) where more leakage is desirable from a detection point of view. Considerable conservatism is added to the LBB leakage calculations by imposing a factor of 10 on the leakage rate calculation and a factor 2 on the crack length considered for leakage. The problem of leakage through the BWR reactor internals is much simpler in that there is no likelihood of water flashing in the path and hence the flow is single phase. This is true even if the reactor coolant is subcooled since the pressure drop between the inside and outside of the core shroud, for example, is on the order of 30 psi. Therefore, simple fluid mechanical relationships are employed to calculate the head loss due to friction and crack morphology. The approach used herein is consistent with that discussed in Reference [4].

A note of caution about units in Eq. (4). In FPS (Foot, Pound and Second) units, density is given in terms of a force unit i.e. $\gamma = \rho$ g. In MKS (Meter, Kilogram and Second) units, the density ρ is in mass units and hence the g terms cancel out and the denominator will just be ρ on the right hand side of Eq. (4).

4.0 DESIGN INPUTS

The design inputs used for this calculation are identified below:

Geometry:

The shroud geometry is taken from Reference [21]:

- Shroud ID: 174.5 in. [21.a]
- Shroud Thickness, t: 1.5 in. [21.b]

Loads:

The upper shroud RIPD values used for this analysis are taken from Reference [22], and are summarized as follows:

- Level C RIPD: 29.5 psi
- Level D RIPD: 29.5 psi

For the purposes of this evaluation, the Level C and D RIPD values are used as they yield the largest crack opening displacement.

IGSCC Crack Growth Rate:

- The length CGR: 5×10^{-5} in/hr (Section 3.1.4)

Reactor Coolant Water Chemistry:

HNP1 implemented HWC in September 1987, and started Noble Metal Chemical Addition (NMCA) in March of 1999 [22, 23]. {{

}}.

Shroud Fluence:

The peak core shroud fluence at 49.3 EFPY is: 3.77×10^{21} n/cm^2 [9]

Material Type:

The shroud material is SA-240 TP304 stainless steel [21.a].

Material Properties:

For fluence values greater than {{

}}, and the following static initiation, plane strain, mode I fracture toughness is applicable:

- {{ }}

The material flow stress and yield stress both increase with fluence [7]. It is conservative to use un-irradiated materials properties since this will result in a larger plastic zone size and a smaller allowable flaw size. Consequently, un-irradiated tensile properties are used [8.a]:

- σ_Y (un-irradiated, 550 °F): 18.9 ksi
- Elastic Modulus of Type 304 Stainless Steel at 550°: 25.55×10^6 psi
- Poisson's Ration of Type 304 Stainless Steel at 550°: 0.3

For the leakage rate calculations the fluid density is:

- Coolant density, γ: 53.9 lbf/ft^3, water at 400 °F [25] (see Assumption 5.4)

Initial Flaw Distribution:

The flaw lengths, depths, locations, and distributions are taken from the 2014 INRs [6]. It is only necessary to consider through-wall indications for the leakage calculation, which were identified at the H4-V4 weld intersection [6.j] and the V6 weld [6.k]. Figure 3 and Figure 4 illustrate the HNP1 core shroud configuration, weld locations, and identify historically reported indications.

Three unique indications were identified in the V6 weld. Indications 2 and 3 are the same flaw identified on the inside and outside of the shroud wall, confirming that the indication is through-wall [6.k, pg 2 of 2]. Co-linear part through-wall indications exists above and below the through-wall flaw. Indication 1 is 3.5 inches long and has an initial ligament length of 18.5 inches to indication 2. The start of indication 4 is at 90 inches and the end of indication 2 is at 86.3, resulting in an initial ligament length of 3.7 inches between the flaws. Due to the small ligament length and projected crack growth over three

cycles, the cracking identified in indications 2, 3, and 4 are considered to be a single indication starting at 65.9 inches and ending at 96.1 inches, with a total initial length of 30.2 inches. See Figure 5 for details regarding the V6 weld flaw configuration.

The combined length of indications 2, 3, and 4 is evaluated with indication 1 to consider the effects of co-linear flaws on the crack opening.

Inspection Uncertainty:

Evaluation factors to account for inspection uncertainties for the ultrasonic testing (UT) inspection data are taken from the applicable demonstrations for the inspection tooling identified in the INRs. The evaluation factors are taken from BWRVIP-03 [10.a] and BWRVIP Letter 2014-015 [10.b]. Bounding length evaluation factors are taken from the applicable demonstrations. No depth evaluation factors are used since only through-wall flaws are considered for the leakage rate evaluation. The following length evaluation factors are used:

- TEIDE Tool UT Length Evaluation Factor: {{ }}
- Shroud OD UT tool Length Evaluation Factor: {{ }}

Operating Cycle Duration:

HNP1 is on a 2 year operating cycle [22]. In this calculation, the evaluation is performed for 6 years.

5.0 ASSUMPTIONS

The following assumptions are used in this evaluation.

1. The 49.3 EFPY peak fluence is used to determine the fracture toughness for all flaws.

   This assumption is conservative because it applies the maximum fluence projected at the end of the operating license to all locations. The current refueling outage is 1R27 and the end of design life EFPY is reported to be 49.3 EFPY in Reference [9], which corresponds to refueling outage 1R36.

2. A 100% capacity factor is assumed for crack growth.

   This assumption is conservative because it uses the largest number of hours possible, each year, for crack growth.

3. Flaws are allowed to grow through the horizontal welds.

   Inspection data from the HNP1 core shroud shows evidence of flaws growing through the weld [6]; therefore, this assumption is considered appropriate.

4. Leakage rates are calculated using a conservative fluid temperature of 400 °F.

   In the event of emergency core cooling, initially the fluid from the feedwater system enters the core. The normal operating feedwater temperature for HNP1 is 400 °F [28]. Supplemental cooling is provided by fluid from the suppression pool and condenser fluid, which operate at temperatures lower than the feedwater system. For this reason, use of the normal operating feedwater temperature is a conservative upper bound temperature for the purposes of determining the fluid density.

6.0 CALCULATIONS AND RESULTS

Calculations are performed using the MathCAD software [26], ANSYS Mechanical APDL [27], and MS Excel. The calculations performed for this core leakage evaluation and associated supporting files are identified in Appendix A.

The COA for the core shroud through-wall flaws are calculated using LEFM methods and adjusted using the results from Reference [2] by applying multiplication factors to account for the increased COA values calculated using FEA methods. The COAs for the flaws identified in the H4-V4 weld intersection are increased by 3.43% (F_{FEA}= 1.0343) and the flaw in the V6 weld is increased by 12% (F_{FEA}= 1.12) based on the values summarized in the supporting files in Reference [2]. These percent increases are based on the predicted crack length at the end of three cycles.

After calculating the crack lengths at the end of three operating cycles, the flaw configuration for the co-linear flaws identified in the V6 weld was determined. The end of interval crack length of the through-wall flaw is approximately 38.0 inches with a ligament length of 10.7 inches to a 11.3 inch co-linear part through-wall flaw. The inspection results of these co-linear flaws, aligned end-to-end in series and parallel to the V6 axial weld, are shown in Figure 5. The COA of this co-linear flaw configuration is calculated in ANSYS by modifying the finite element model created in [3]. SI performed a plant specific FEA of the V6 co-linear flaws rather than using the scaling factor approach developed in Reference [3] because the end of interval flaws in the V6 weld are slightly longer than the range of flaws considered in Reference [3]. Rather than extrapolate the results in Reference [3] or revise the previous work documented in Reference [3], all of which remains valid, SI decided to use the model and methodology documented in Reference [3] to perform a plant specific, flaw specific analysis of the V6 co-linear flaw configuration. The boundary conditions and loads applied to the model are shown in Figure 6 and Figure 7, respectively. The resulting COA for the through-wall flaw is 0.460 in^2 and is similar to that calculated for a single flaw configuration, including an adjustment factor F_{FEA}= 1.12, which is 0.466 in^2. As the single flaw configuration results in a larger COA and leakage rate, it is conservative to disregard the effect that the co-linear part through-wall flaw has on the through-wall flaw. Therefore, no adjustment (i.e., F_{CL}= 1.0) is needed for the V6 weld through-wall flaw to account for the effects of the co-linear flaw configuration.

Leakage rates are calculated for the four through-wall flaws reported in the H4-V4 intersection examined in 2014, which consists of a 28.8 inch window (~5.2%) [6.j, Sht. 5] out of ~552 inch shroud circumference at this elevation using a leakage rate multiplier of 26 as described in Section 3.3 and summarized in Table 1. The through-wall indication in the V6 weld is also included in the total leakage rate calculation. Leakage rates are calculated for three cycles of operation.

The cumulative leakage rate for the core shroud reported and assumed through-wall flaws after three cycles of operation is 49.1 GPM.

7.0 CONCLUSIONS

The cumulative leakage rate calculated for all reported and assumed through-wall cracks in the HNP1 core shroud, after three operating cycles of 2 years each, is 49.1 GPM. The through-wall cracks contributing to the leakage rate are those located in the core shroud H4-V4 weld intersection and V6 weld. This leakage rate should be combined with other applicable leakage rates and compared to the current LOCA leakage margin.

8.0 REFERENCES

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Table 1. Uninspected Region Leak Rate Multiplier

[[ ]]

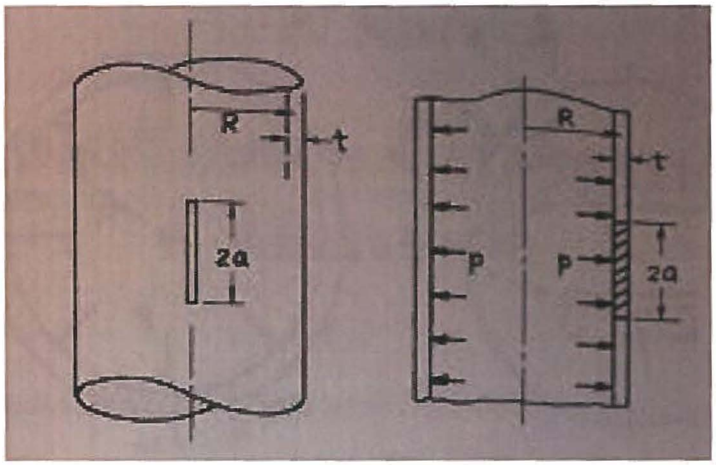

Figure 1. Single Through-wall Axial Crack in an Internally Pressurized Cylinder

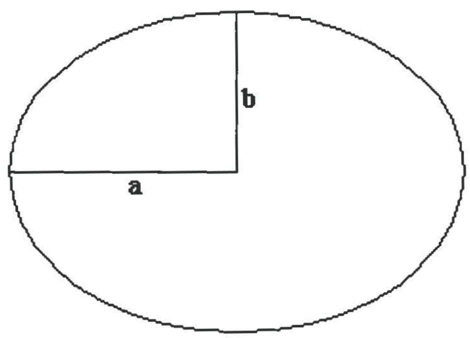

Figure 2. Example of an Elliptical-Shaped Crack

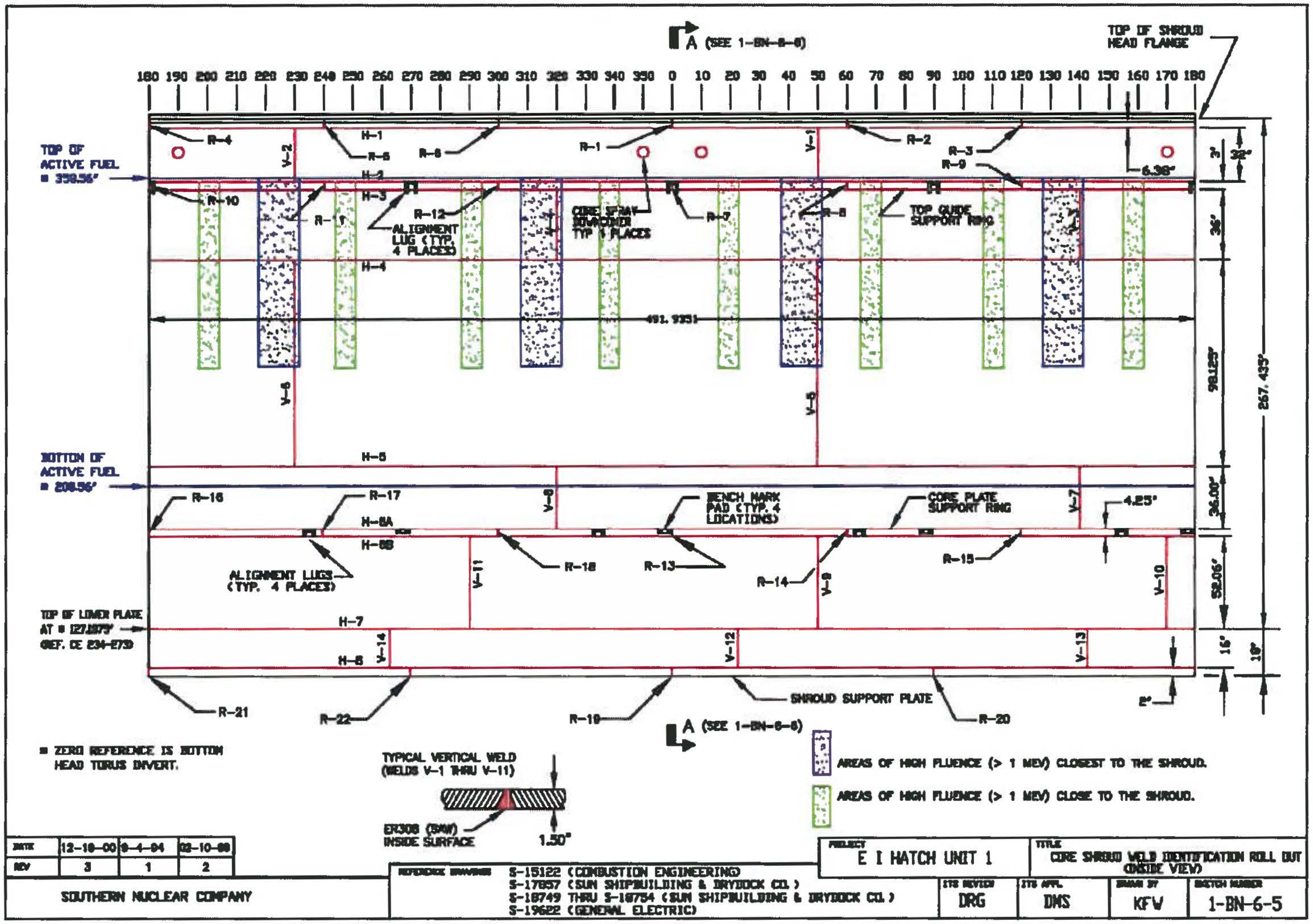

Figure 3. HNP1 Core Shroud Configuration [22]

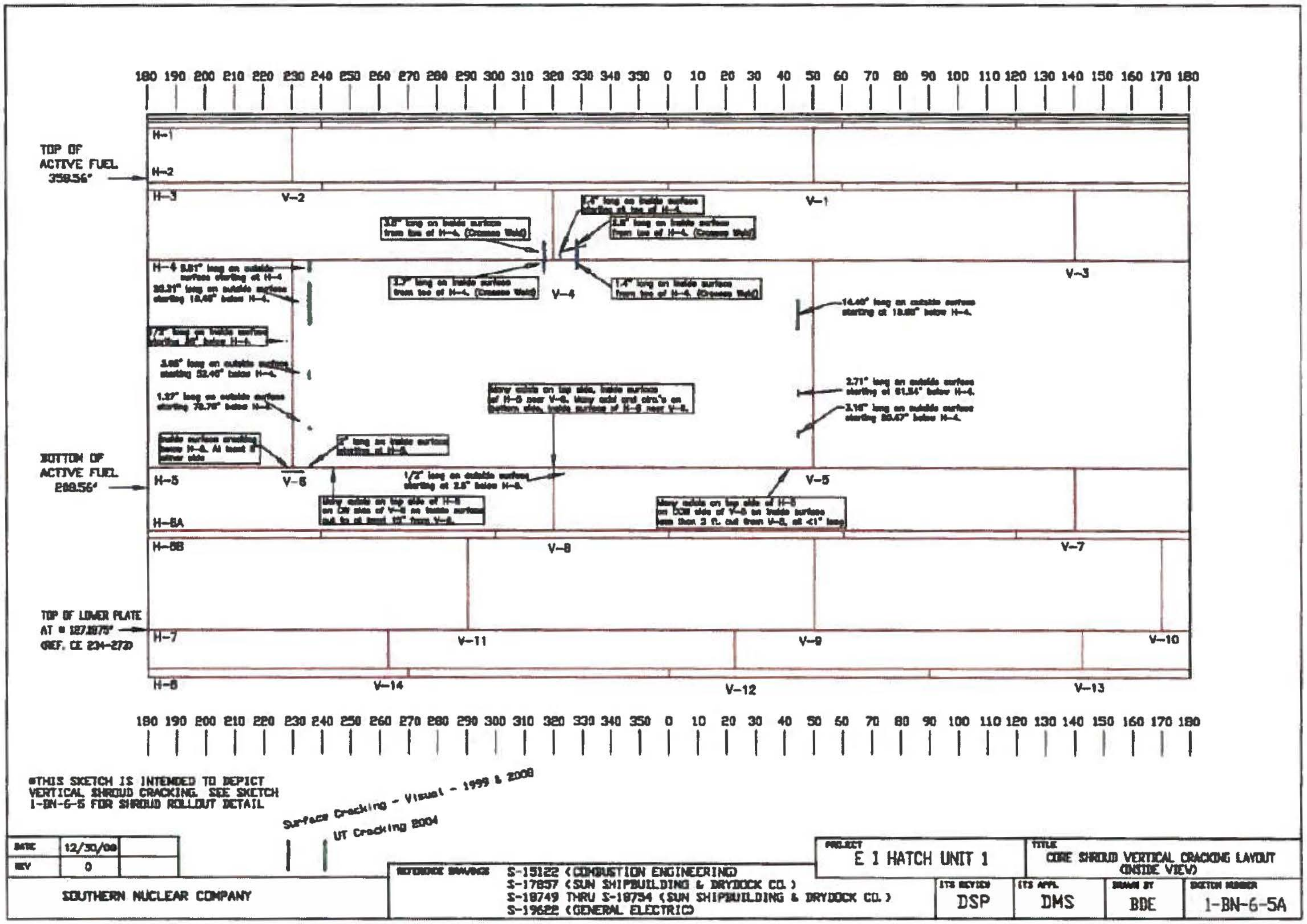

Figure 4. Previous HNP1 Core Shroud Inspection Results [22]

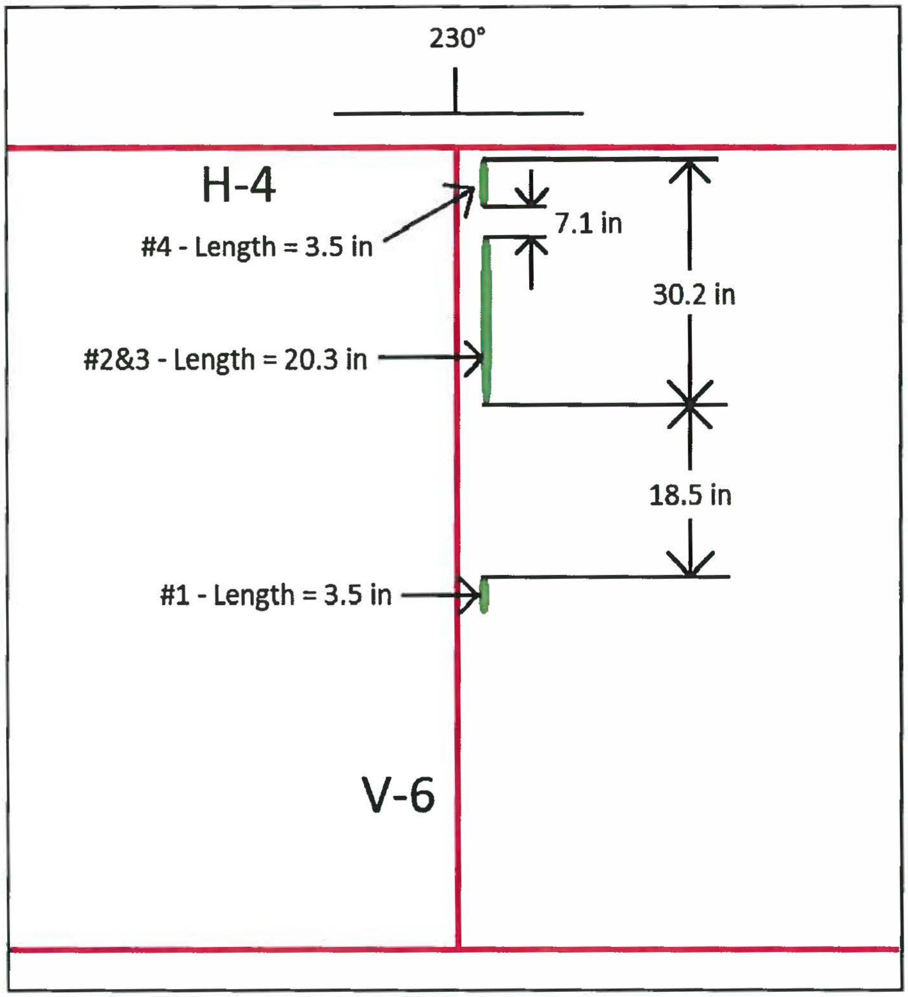

Figure 5. HNP1 V6 Weld Co-linear Indication Results

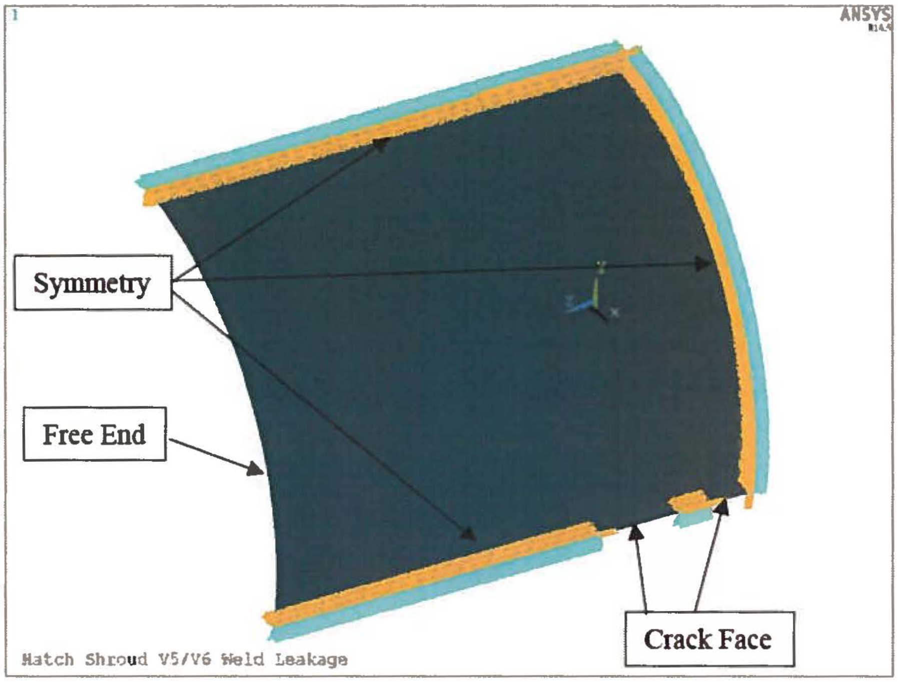

Figure 6. FEA Model Boundary Conditions
(The cyan and orange symbols along the perimeter of the model indicates symmetry constraints)

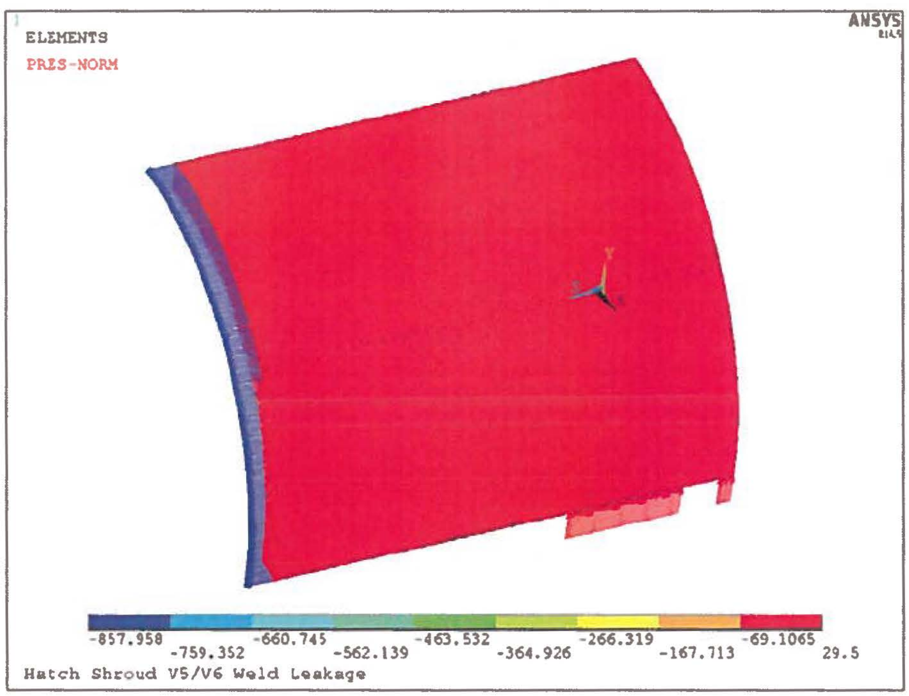

Figure 7. FEA Model Pressure Loads

Appendix A

CALCULATIONS AND SUPPORTING FILES

File Name	Description
Loop.inp	ANSYS Mechanical APDL input file that calculates the Hatch-Colinear.inp input file for a ligament length of 12.3 inches. Input script is provided in Appendix A.
Hatch-Colinear.inp	ANSYS Mechanical APDL input file that defines builds the FEA model, defines loads and boundary conditions, and solves the resulting displacements of the crack openings. Input script is provided in Appendix A. This file was adjusted by changing the value of the crack length definition parameters "crack", "cocrack1", and "cocrack2" to define the co-linear crack configuration in the HNP1 V6 core shroud weld.
Displacement.txt	ANSYS Mechanical APDL output file that reports the maximum displacement of the crack opening the HNP1 co-linear crack configuration. Output results are provided in Appendix A.
Ligament Length Calc.xlsx	MS Excel spreadsheet to calculate the ligament length between the co-linear cracks studied in the HNP1 V6 core shroud weld.

Structural Integrity Associates, Inc.®

Responsible Engineer: Stephen Parker
Date: 30OCT2015
Plant: HNP1

Calculation Title: HNP1 core shroud leakage evaluation

Objective: Perform:
1. Leakage calculation for the through-wall indications.

Inputs:

$Ri := \frac{174.5}{2} \cdot in$	Inside radius of shroud at H4 location
$t := 1.5 \cdot in$	Wall thickness of shroud at H4 location
$RIPDab := 11.6 \cdot psi$	Level A/B RIPD
$RIPDcd := 29.5 \cdot psi$	Level C/D RIPD
$SFab := 2.77$	Level A/B SF
$SFcd := 1.39$	Level C/D SF <--- ONLY THIS VALUE IS USED
$CGR := 5 \cdot 10^{-5} \cdot \frac{in}{hr}$	SCC length crack growth rate
$\sigma y := 18900 \cdot psi$	Yield strength of shroud material, unirradiated, 550 F.
$E := 25.55 \times 10^{6} \cdot psi$	Elastic modulus, 550 F
LEF := { }	Length evaluation factor
$g := 386.6 \cdot \frac{in}{s^2}$	Newton's proportionality constant
$\gamma := 53.9 \frac{lbf}{ft^3}$	Density of water at 400 F
$f := .02$	Friction factor for loss coefficient

{ }

{ }

Calculations:

1. Calculate leakage at end of three operating cycles for the V4/H4 weld intersection through-wall flaws.

Flaws - 8.0" at V4/H4 @ ~-15 inches
5.5" at V4/H4 @ ~-6 inches
6.2" at V4/H4 @ ~-1 inches
5.3" at V4/H4 @ ~3 inches

$$Rm := Ri + \frac{t}{2} \qquad Rm = 88 \cdot in$$

$$\sigma := RIPDcd \cdot \frac{(Rm)}{t}$$

$$l\_i := \begin{pmatrix} 8.0 \\ 5.5 \\ 6.2 \\ 5.3 \end{pmatrix} in$$

$$l\_f := l\_i + 2 \cdot LEF + 2 \cdot 6 \cdot yr \cdot CGR \cdot 365 \frac{day}{yr} \cdot 24 \cdot \frac{hr}{day} \qquad l\_f = \begin{pmatrix} 13.554 \\ 11.054 \\ 11.754 \\ 10.854 \end{pmatrix} \cdot in$$

Iterate to find plastic zone size correction factor on a flaw specific basis for the flaws in the V4/H4 weld intersection:

$$i := 0, 1..3$$

Iteration 1:

$$\lambda := \frac{\frac{l\_f}{2}}{(Rm \cdot t)^{0.5}} \qquad \lambda = \begin{pmatrix} 0.59 \\ 0.481 \\ 0.512 \\ 0.472 \end{pmatrix}$$

$$F(\lambda) := \begin{cases} \left(1 + 1.25 \cdot \lambda^2\right)^{0.5} & \text{if } 0 \le \lambda \le 1 \\ ((0.6 + 0.9 \cdot \lambda)) & \text{if } 1 \le \lambda \le 5 \end{cases} \qquad F(\lambda_i) = \begin{pmatrix} 1.198 \\ 1.135 \\ 1.152 \\ 1.131 \end{pmatrix}$$

$$KI1(\lambda,l\_f) := SFcd\cdot\sigma\cdot\left[\pi\cdot\left(\frac{l\_f}{2}\right)\right]^{0.5}\cdot F(\lambda)$$

$$KI1\left(\lambda_i,l\_f_i\right) = \begin{pmatrix} 13296 \\ 11382 \\ 11908 \\ 11233 \end{pmatrix}\cdot psi\cdot in^{0.5}$$

$$ry1(\lambda,l\_f) := \frac{1}{2\cdot\pi}\cdot\left(\frac{KI1(\lambda,l\_f)}{\sigma y}\right)^2$$

$$ry1\left(\lambda_i,l\_f_i\right) = \begin{pmatrix} 0.079 \\ 0.058 \\ 0.063 \\ 0.056 \end{pmatrix}\cdot in$$

Iteration 2:

$$\lambda 2(\lambda,l\_f) := \frac{\frac{l\_f}{2} + ry1(\lambda,l\_f)}{(Rm\cdot t)^{0.5}}$$

$$\lambda 2\left(\lambda_i,l\_f_i\right) = \begin{pmatrix} 0.597 \\ 0.486 \\ 0.517 \\ 0.477 \end{pmatrix}$$

$$F2(\lambda,l\_f) := \begin{cases} \left(1 + 1.25\cdot\lambda 2(\lambda,l\_f)^2\right)^{0.5} & \text{if } 0 \le \lambda 2(\lambda,l\_f) \le 1 \\ ((0.6 + 0.9\cdot\lambda 2(\lambda,l\_f))) & \text{if } 1 \le \lambda 2(\lambda,l\_f) \le 5 \end{cases}$$

$$F2\left(\lambda_i,l\_f_i\right) = \begin{pmatrix} 1.202 \\ 1.138 \\ 1.155 \\ 1.133 \end{pmatrix}$$

$$KI2(\lambda,l\_f) := SFcd\cdot\sigma\cdot\left[\pi\cdot\left(\frac{l\_f}{2} + ry1(\lambda,l\_f)\right)\right]^{0.5}\cdot F2(\lambda,l\_f)$$

$$KI2\left(\lambda_i,l\_f_i\right) = \begin{pmatrix} 13421 \\ 11468 \\ 12003 \\ 11317 \end{pmatrix}\cdot psi\cdot in^{0.5}$$

$$ry2(\lambda,l\_f) := \frac{1}{2\cdot\pi}\cdot\left(\frac{KI2(\lambda,l\_f)}{\sigma y}\right)^2$$

$$ry2\left(\lambda_i,l\_f_i\right) = \begin{pmatrix} 0.08 \\ 0.059 \\ 0.064 \\ 0.057 \end{pmatrix}\cdot in$$

$$PC(\lambda,l\_f) := \frac{ry2(\lambda,l\_f) - ry1(\lambda,l\_f)}{ry1(\lambda,l\_f)}\cdot 100$$

$$PC\left(\lambda_i,l\_f_i\right) = \begin{pmatrix} 1.879 \\ 1.52 \\ 1.613 \\ 1.495 \end{pmatrix}$$

$KI1(\lambda, l\_f) := KI2(\lambda, l\_f)$

$ry1(\lambda, l\_f) := ry2(\lambda, l\_f)$

Iteration 3:

$$\lambda 2(\lambda, l\_f) := \frac{\frac{l\_f}{2} + ry1(\lambda, l\_f)}{(Rm \cdot t)^{0.5}} \qquad \lambda 2(\lambda_i, l\_f_i) = \begin{pmatrix} 0.597 \\ 0.486 \\ 0.517 \\ 0.477 \end{pmatrix}$$

$$F2(\lambda, l\_f) := \begin{cases} \left(1 + 1.25 \cdot \lambda 2(\lambda, l\_f)^2\right)^{0.5} & \text{if } 0 \le \lambda 2(\lambda, l\_f) \le 1 \\ ((0.6 + 0.9 \cdot \lambda 2(\lambda, l\_f))) & \text{if } 1 \le \lambda 2(\lambda, l\_f) \le 5 \end{cases}$$

$$F2(\lambda_i, l\_f_i) = \begin{pmatrix} 1.202 \\ 1.138 \\ 1.155 \\ 1.133 \end{pmatrix}$$

$$KI2(\lambda, l\_f) := SFcd \cdot \sigma \cdot \left[\pi \cdot \left(\frac{l\_f}{2} + ry1(\lambda, l\_f)\right)\right]^{0.5} \cdot F2(\lambda, l\_f)$$

$$KI2(\lambda_i, l\_f_i) = \begin{pmatrix} 13423 \\ 11470 \\ 12005 \\ 11318 \end{pmatrix} \cdot psi \cdot in^{0.5}$$

$$ry2(\lambda, l\_f) := \frac{1}{2 \cdot \pi} \cdot \left(\frac{KI2(\lambda, l\_f)}{\sigma y}\right)^2 \qquad ry2(\lambda_i, l\_f_i) = \begin{pmatrix} 0.08 \\ 0.059 \\ 0.064 \\ 0.057 \end{pmatrix} \cdot in$$

$$PC(\lambda, l\_f) := \frac{ry2(\lambda, l\_f) - ry1(\lambda, l\_f)}{ry1(\lambda, l\_f)} \cdot 100 \qquad PC(\lambda_i, l\_f_i) = \begin{pmatrix} 0.035 \\ 0.023 \\ 0.026 \\ 0.022 \end{pmatrix}$$

$ry(\lambda, l\_f) := ry2(\lambda, l\_f)$

$$l\_f\_ry(\lambda, l\_f) := l\_f + 2ry(\lambda, l\_f) \qquad l\_f\_ry(\lambda_i, l\_f_i) = \begin{pmatrix} 13.715 \\ 11.171 \\ 11.882 \\ 10.968 \end{pmatrix} in$$

$$\lambda f(\lambda, l\_f) := \frac{\frac{l\_f}{2} + ry(\lambda, l\_f)}{(Rm \cdot t)^{0.5}} \qquad \lambda f(\lambda_i, l\_f_i) = \begin{pmatrix} 0.597 \\ 0.486 \\ 0.517 \\ 0.477 \end{pmatrix}$$

$$G(\lambda, l\_f) := \begin{cases} \lambda f(\lambda, l\_f)^2 + 0.625 \cdot \lambda f(\lambda, l\_f)^4 & \text{if } 0 \le \lambda f(\lambda, l\_f) \le 1 \\ 0.14 + 0.36 \cdot \lambda f(\lambda, l\_f)^2 + 0.72 \cdot \lambda f(\lambda, l\_f)^3 + 0.405 \cdot \lambda f(\lambda, l\_f)^4 & \text{if } 1 < \lambda f(\lambda, l\_f) \le 5 \end{cases}$$

$$G(\lambda_i, l\_f_i) = \begin{pmatrix} 0.436 \\ 0.271 \\ 0.312 \\ 0.26 \end{pmatrix}$$

To account for the difference in COA calculated using an FEA model versus LEFM handbook solutions, the COAs are increased by a percentage based on the crack size. A comparison of these calculation methods was performed in 1500880.301 [2] and the percent difference of COA calculated using the FEM for 14 inch cracks is 3.43% (see attached spreadsheet of 1500880.301). This correction factor is applied to the four off-axis flaws in weld H4.

$$COA(\lambda, l\_f) := \frac{1.0343\sigma}{E} \cdot 2 \cdot \pi \cdot Rm \cdot t \cdot G(\lambda, l\_f) \qquad COA(\lambda_i, l\_f_i) = \begin{pmatrix} 0.025 \\ 0.016 \\ 0.018 \\ 0.015 \end{pmatrix} \cdot in^2$$

$$\delta(\lambda, l\_f) := \frac{COA(\lambda, l\_f)}{l\_f\_ry(\lambda, l\_f)} \qquad \delta(\lambda_i, l\_f_i) = \begin{pmatrix} 1.845 \times 10^{-3} \\ 1.411 \times 10^{-3} \\ 1.526 \times 10^{-3} \\ 1.379 \times 10^{-3} \end{pmatrix} in$$

{ }

$$Cf(\lambda_i, l\_f_i) = \begin{pmatrix} 0.092 \\ 0.091 \\ 0.092 \\ 0.091 \end{pmatrix}$$

$$Q\_V4H4(\lambda, l\_f) := Cf(\lambda, l\_f)\, COA(\lambda, l\_f) \cdot \sqrt{\frac{2 \cdot g \cdot RIPDcd}{\gamma}}$$

$$Q\_V4H4(\lambda_i, l\_f_i) = \begin{pmatrix} 0.518 \\ 0.319 \\ 0.369 \\ 0.306 \end{pmatrix} \cdot \frac{gal}{min}$$

To account for the uninspected region of the H4 core shroud weld, multiply the leak rate for the H4 flaws by the UT multiplier determined in Table 1 of 1500205.303. This total plus the leak rate of the through-wall flaw in V6 gives:

$$Percent\_Coverage := \frac{28.8 \cdot in}{2\pi \cdot Rm} = 5.209 \cdot \%$$

$$Q\_V4H4\_Total := \sum_{i=0}^{3} Q\_V4H4(\lambda_i, l\_f_i) \cdot 26 = 39.328\,gpm$$

2. Calculate leakage at end of three operating cycles for the V4/H4 weld intersection through-wall flaws.

Flaws - 20.3" at V6 <--- Crack length increased to account for growth into co-linear crack. Updated initial crack length is 30.2 inches

$$Rm := Ri + \frac{t}{2} \qquad Rm = 88 \cdot in$$

$$\sigma := RIPDcd \cdot \frac{(Rm)}{t}$$

$$i := 0..1$$

$$l\_i := \begin{pmatrix} 30.2 \\ 3.5 \end{pmatrix} in$$

$$l\_f := l\_i + 2 \cdot LEF + 2 \cdot 6 \cdot yr \cdot CGR \cdot 365 \frac{day}{yr} \cdot 24 \cdot \frac{hr}{day} \qquad l\_f = \begin{pmatrix} 35.754 \\ 9.054 \end{pmatrix} \cdot in$$

The plastic zone size for the co-linear through-wall flaw in the V6 weld is conservatively calculated by using a stress intensity factor equal to the allowable fracture toughness (K_{IC}).

For stainless steel with an accrued fluence of{ } the fracture toughness is equal to{ }

$$ry(\lambda, l\_f) := \frac{1}{2 \cdot \pi} \cdot \left(\frac{KIC}{\sigma y}\right)^2 \qquad ry(\lambda, l\_f) = 1.114\,in$$

$$l\_f\_ry(\lambda, l\_f) := l\_f + 2ry(\lambda, l\_f)$$

$$l\_f\_ry(\lambda, l\_f) = \begin{pmatrix} 37.982 \\ 11.282 \end{pmatrix} in$$

<--- Through-wall crack length at 6 years
<--- Part through-wall co-linear crack length at 6 years (does not contribute to leakage calculation.)

$$\lambda f(\lambda, l\_f) := \frac{\frac{l\_f}{2} + ry(\lambda, l\_f)}{(Rm \cdot t)^{0.5}}$$

$$\lambda f(\lambda_0, l\_f_0) = 1.653$$

$$G(\lambda, l\_f) := \begin{cases} \lambda f(\lambda, l\_f)^2 + 0.625 \cdot \lambda f(\lambda, l\_f)^4 & \text{if } 0 \le \lambda f(\lambda, l\_f) \le 1 \\ 0.14 + 0.36 \cdot \lambda f(\lambda, l\_f)^2 + 0.72 \cdot \lambda f(\lambda, l\_f)^3 + 0.405 \cdot \lambda f(\lambda, l\_f)^4 & \text{if } 1 < \lambda f(\lambda, l\_f) \le 5 \end{cases}$$

$$G(\lambda_0, l\_f_0) = 7.399$$

To account for the difference in COA calculated using an FEA model versus LEFM handbook solutions, the COAs are increased by a percentage based on the crack size. A comparison of these calculation methods was performed in 1500880.301 [2] and the percent difference for 38 inch cracks is 12% and this correction is applied to the through-wall flaw in weld V6.

$$COA(\lambda, l\_f) := \frac{1.12\sigma}{E} \cdot 2 \cdot \pi \cdot Rm \cdot t \cdot G(\lambda, l\_f)$$

$$COA(\lambda_0, l\_f_0) = 0.466 \cdot in^2$$

$$\delta(\lambda, l\_f) := \frac{COA(\lambda, l\_f)}{l\_f\_ry(\lambda, l\_f)}$$

$$\delta(\lambda_0, l\_f_0) = 0.012 \, in$$

{ }

$$Cf(\lambda_0, l\_f_0) = 0.095$$

$$Q\_V6(\lambda, l\_f) := Cf(\lambda, l\_f) \, COA(\lambda, l\_f) \cdot \sqrt{\frac{2 \cdot g \cdot RIPDcd}{\gamma}}$$

$$Q\_V6(\lambda_0, l\_f_0) = 9.826 \cdot \frac{gal}{min}$$

3. Calculate total leakage for the through-wall flaws of the V4/H4 and V6 welds.

$$Q\_V4H4\_Total = 39.328 \, gpm$$

$$Q\_V4H4\_Total + Q\_V6(\lambda_0, l\_f_0) = 49.155 \, gpm$$

ANSYS Mechanical APDL Input

Filename: Loop.inp

```
lig = 10.718
      /INPUT,Hatch-Colinear,inp
      *get,disp,NODE,1,U,Y

      nsel,s,loc,z,cocrack1, cocrack2
      nsel,r,loc,y,0
      *get,ndcount,node,0,count
      *get,numlow,node,0,num,min
      numtemp=numlow
      maxd=0
      *get,maxdtemp,node,numtemp,u,y
      maxd=maxdtemp
      *do,tempcount,1,ndcount-1
            numtemp=ndnext(numtemp)
            *get,maxdtemp,node,numtemp,u,y
            *if,maxd,le,maxdtemp,then
                  maxd=maxdtemp
                  ndmax=numtemp
            *endif
      *enddo

      /OUTPUT,Displacement,txt,,APPEND
      /COM, %lig%   %disp%   %maxd%   %numtemp%
      /OUTPUT
      finish
      /clear,start
```

Filename: Hatch-Colinear.inp

```
!finish
!/clear,start
/FILNAME,Hatch-Leak,1
/prep7
/title, Hatch Shroud V5/V6 Weld Leakage

/com, Element Types
et,1,shell63

!Material Properties from 1200283.303
MPTEMP,1,0
MPDATA,EX,1,,25550000       !Young's Modulus = 25.55 Msi
MPDATA,PRXY,1,,.3           !Poisson's Ratio = 0.3

rad = 87.25  !Inside shroud radius
thk = 1.5    !Thickness of shroud
crack = 5.64  !HALF crack length
!lig = 12.3 !Ligament Length (can be uncommented for ligament-specific run)
pressure = 29.5
cocrack1 = crack + lig
```

```
cocrack2 = cocrack1 + 38

capload = pressure*rad/(2*thk)

R,1,thk, , , , , ,

!Shell Quadrant Modeling
k,1,0,0,0
k,2,0,0,150
FLST,2,2,8
FITEM,2,0,0,0
FITEM,2,rad,0,0
CIRCLE,P51X, , , ,90,1,       !90 Degree model

LSTR,1,2
ADRAG,1,,,,,,2

!Crack Modeling for inner crack
FLST,2,1,4,ORDE,1
FITEM,2,4
FLST,3,1,3,ORDE,1
FITEM,3,3
KGEN,2,P51X, , , , ,crack, ,0
KWPAVE,       7
ASBW,       1

!Crack modeling for outer crack
FLST,2,1,4,ORDE,1
FITEM,2,4
FLST,3,1,3,ORDE,1
FITEM,3,3
KGEN,2,P51X, , , , ,cocrack1, ,0
KWPAVE,       10
ASBW,       3

FLST,2,1,4,ORDE,1
FITEM,2,4
FLST,3,1,3,ORDE,1
FITEM,3,3
KGEN,2,P51X, , , , ,cocrack2, ,0
KWPAVE,       13
ASBW,       1

!Mesh
!Mesh Density = 0.5 inch/element
ESIZE,0.5,0,
MSHAPE,0,2D
MSHKEY,1
AMESH,2
AMESH,3
AMESH,4
AMESH,5

!All Symm
```

```
FLST,2,7,4,ORDE,7
FITEM,2,1
FITEM,2,7
FITEM,2,9
FITEM,2,-10
FITEM,2,12
FITEM,2,-13
FITEM,2,16
DL,P51X, ,SYMM

!Cap Load
FLST,2,1,4,ORDE,1
FITEM,2,3
SFL,P51X,PRES,-capload

!Internal Pressure
FLST,2,4,5,ORDE,2
FITEM,2,2
FITEM,2,-5
SFA,P51X, ,PRES,29.5

!Pressure on Crack Faces
FLST,2,2,4,ORDE,2
FITEM,2,6
FITEM,2,15
SFL,P51X,PRES,pressure


FINI

/SOL
SOLVE
FINI

/POST1
```

<u>ANSYS Mechanical APDL Output</u>

Filename: Displacement.txt

```
             Inner               Outer
             Crack               Crack
Major        Minor               Minor
Radius       Radius              Radius
  10.718    5.391163809E-04    7.70870701E-03    63078
```