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COOPER NUCLEAR STATION
CORE SHROUD H3 WELD EVALUATION - 2018, REVISION 0

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1.0 INTRODUCTION

Nebraska Public Power District (NPPD) conducted visual testing (VT) examinations of the Cooper Nuclear Station (CNS) core shroud horizontal weld H3 during the fall 2018 maintenance outage (RE30). General Electric Hitachi (GE-H) was the inspection vendor who performed the 2018 VT examinations, which identified reportable indications on the ID [1, 2]. IHI Southwest Technologies, Inc (ISwT) performed ultrasonic testing (UT) on the H3 weld in during the fall 2014 outage. ISwT reviewed their data from 2014 and provided an addendum to the 2014 inspections in 2018 [3]. Furthermore, AREVA also performed UT of the lower side of the H3 weld in 2005. Indications from this inspection are also included in Reference [3].

NPDD has contracted Structural Integrity Associates, Inc. (SI) to evaluate the indications identified in References [1, 2 and 3]. The Boiling Water Reactor Vessel and Internals Project (BWRVIP) has provided inspection and flaw evaluation guidance for Boiling Water Reactor (BWR) core shroud circumferential welds in BWRVIP-76, Revision 1-A [4], BWRVIP-14-A [5], and BWRVIP-99-A [6]. This evaluation follows the general guidance outlined in BWRVIP-76, Revision 1-A [4], for plant specific evaluations with some added assumptions. These are described in Sections 4.0 and 5.0.

This calculation supersedes SI calculation 1501658.301, Revision 1 [7] for the H3 weld. Evaluations for all other welds in Reference [7] remain valid. For the H3 weld, the end of the evaluation interval changes from 2024 to 2020.

2.0 OBJECTIVE

The objective of this calculation is to provide a technical basis for a 2-year reinspection interval for the CNS circumferential H3 weld using a conservative treatment of current inspection data.

3.0 LIST OF ACRONYMS

The following acronyms are used in this calculation:

BWRVIP	Boiling Water Reactor Vessel and Internals Project
CNS	Cooper Nuclear Station
DEF	Depth Evaluation Factor
DLL	Distributed Ligament Length
DSE	Depth Sizing Error
EFPY	Effective Full Power Years
EOI	End of Interval
EPFM	Elastic-Plastic Fracture Mechanics
EPRI	Electric Power Research Institute
GE-H	General Electric-Hitachi
ID	Inside Diameter
IGSCC	Intergranular Stress Corrosion Cracking
ISwT	IHI Southwest Technologies, Inc.
LEF	Length Evaluation Factor
LEFM	Linear Elastic Fracture Mechanics
LSE	Length Sizing Error
NPPD	Nebraska Pubic Power District
NWC	Normal Water Chemistry

OD	Outside Diameter
RMS	Root Mean Square
SI	Structural Integrity Associates, Inc.
UT	Ultrasonic Testing
VT	Visual Testing
WRS	Weld Residual Stress

4.0 METHODOLOGY

This section documents the methodology used to perform the flaw evaluations. Since the evaluations possibly require deviation from BWRVIP-76, Revision 1-A approved methodology, two independent methodologies are used in this analysis: one using K-independent crack growth rates and one using K-dependent crack growth rates. Using two independent methodologies gives additional assurance that the acceptance criteria can met using different assumptions.

4.1 K-Independent Flaw Evaluation Approach

The following plant-specific flaw evaluation methodology is utilized for the K-independent approach:

1. Tabulate all reportable indications and un-inspected regions for the H3 weld upper and lower sides from both ID and OD inspections, using the most recent shroud VT inspection data obtained during RE30 [1, 2]. Further, indications reported by ISwT using UT in 2014 [3] are added to the indications in 2018. This approach provides a bounding treatment of the inspection data based on both UT and VT testing from multiple outages. UT results from the AREVA inspections in 2005 [3] are considered in the final flaw distribution to ensure the circumferential locations of the known indications are included; however, these indications are not included in Table 1 since there is more recent UT and VT data that is acceptable to use based on BWRVIP-76, Revision 1-A required inspection coverage.
2. Assume all 2014 UT indications and 2018 VT indications are 100% through-wall cracks. Assume all regions uninspected by VT are also 100% through-wall cracks for the entire uninspected region. This takes no credit for the statistical method outlined in BWRVIP-76, Revision 1-A [4, Appendix H] for uninspected regions.
3. Grow all indications in the circumferential direction, including the indications postulated in the uninspected regions, using the normal water chemistry (NWC) intergranular stress corrosion cracking (IGSCC) growth rate of 5.0×10^{-5} in/hr [8] for stainless steel.
    a. VT indications from 2018 are grown for 2 years (until 2020)
    b. UT indications from 2014 are grown for 6 years (until 2020)
    c. A 100% capacity factor is assumed for this evaluation with 365.25 days/year.
4. Treat all reportable indications, above and below the weld, to be in the same plane.
5. If applicable, combine the end of evaluation interval flaw distribution using proximity criterion from BWRVIP-158-A that two adjacent flaws closer than a distance of *{{*
}} must be combined [9].

6. Apply structural credit for the top guide aligner lugs which are welded over the H3 weld and provide redundant structural support. The minimum shear area based on cracking above and below the H3 weld is utilized and is converted to an equivalent area based on the shroud thickness to be used in the evaluation.
7. Obtain loading, geometry, and material type design inputs from the CNS shroud flaw evaluation design input compilation [10].
8. Obtain the bounding fluence on the shroud inside surface, at 54 effective full power years (EFPY) of operation from Reference [11],
9. Determine the appropriate failure mechanism and evaluation methodology, based on the fluence values determined above, using the guidance given in BWRVIP-100, Revision 1-A [12].
10. Calculate the available structural margin using the Distributed Ligament Length (DLL) computer program [13].

4.2 K-Dependent Flaw Evaluation Approach

The following plant-specific flaw evaluation methodology is utilized for the K-dependent approach:

1. For this approach, rather than growing each reported indication in the length and depth direction then combining adjacent flaws, a conservative approach is taken in which 100% of the H3 weld circumference is assumed to be cracked to the depth of the maximum flaw depth at the end of the interval. The initial flaw depths are taken from the inspection reports given in Reference [3]. The uncertainties associated with each inspection are conservatively added to the initial flaw depths. As there are results from multiple inspections that took place during different intervals, the projected crack growth is dependent on the year in which the flaw was recorded. Since the maximum flaw depths reported by AREVA are deeper than those reported by ISwT, the maximum flaw depth is grown 25 years, or 12 years from 2018. This approach provides a bounding treatment of the inspection data from both inspection vendors. This approach also considers a longer interval than the K-independent approach since K-dependent crack growth rates are much slower than the K-independent rates.
2. End of interval flaw depths are calculated based on the K-dependent crack growth methods given in BWRVIP-14-A [5] and BWRVIP-99-A [6]. Since these methods are valid for flaw depths up to {{ }} of the wall thickness, if the flaw depth is greater than *{{ }}* within the evaluation interval, the appropriate K-independent crack growth rate (CGR) is used for flaw growth subsequent to the time at which the flaw was grown to *{{ }}* through-wall. This final flaw size is then evaluated using DLL in order to confirm that the required structural margin exists.
3. Fluence is used to determine the appropriate crack growth evaluation methodology using the guidance given in BWRVIP-14-A [5] or BWRVIP-99-A [6]. For weld fluence lower than {{ }} crack growth rates from BWRVIP-14-A [5] are used, and for weld fluence greater than {{ }} crack growth rates from BWRVIP-99-A [6] are used. See Section 4.2.1 for more details.
4. Obtain loading, geometry, and material type design inputs from the CNS shroud flaw evaluation design input compilation [10].
5. Obtain the bounding fluence on the shroud inside surface, at 54 EFPY of operation from Reference [11].

6. Determine the appropriate failure mechanism and evaluation methodology, based on the fluence values determined above, using the guidance given in BWRVIP-100, Revision 1-A [12].
7. Calculate the available structural margin using the DLL computer program [13].

4.2.1 Crack Growth for Fluence Greater than {{ }}

The K-dependent crack growth rate for NWC in regions with fluence greater than {{ }} but less than {{ }} is obtained from Section 8.3.1 of Reference [6]. The crack growth rate is given by the following equation:

{{ }} (1)

where: da/dt = Crack growth rate, in/hr
K = Stress intensity factor, $ksi\sqrt{in}$

Note: This equation is applicable to normal operation where the plant is maintaining conditions as specified to meet Action Level 1 of the EPRI Water Chemistry Guidelines [14].

5.0 ASSUMPTIONS

The following assumptions are used in this evaluation:

1. For the K-independent approach, all VT and UT indications are assumed to be cracked through-wall.

   This assumption is acceptable because it conservatively bounds the as-reported indication depths.

2. For the K-independent approach, 100% of all uninspected regions are assumed to be cracked through-wall based on 2018 VT data.

   This assumption is acceptable because it conservatively takes no structural credit for the material condition in the uninspected regions. Furthermore, end of interval flaw distributions are compared with uninspected UT areas from 2014. If a region is identified as free of indications but was not inspected with UT in 2014, no structural credit is taken for that region.

3. For the K-dependent approach, the bounding maximum flaw depth is determined from the inspection data in Reference [3] and a 360° flaw with a depth equal to the maximum depth is assumed to exist in the weld.

   This assumption is acceptable and conservative because it is bounding. Also per Appendix D of BWRVIP-76, Rev. 1-A [4], if the inspected length is greater than 50% of the weld length, the flaw depth of the uninspected region should be set equal to the average flaw depth of the observed cracks in the inspected region.

4. The bounding fluence at end of life (54 EFPY) [11] is used to determine the applicable failure mode and analysis methodology.

   This assumption is conservative because it applies the maximum fluence projected at the end of the reactor license which results in the material condition with the lowest toughness.

5. Normal water chemistry (NWC) is assumed for all welds addressed in this evaluation.

   This is conservative because NWC requires the use of higher crack growth rates.

6. It is assumed that IGSCC in the H3 weld will not extend in the aligner lug welds and that structural credit can be taken for a portion of the aligner lug weld area.

   This is reasonable since there is little driving stress that would cause the horizontal cracks in the H3 weld heat affected zone to turn perpendicular and extend through the fillet or groove welds.

7. The Reference [3] UT data does not contain depth sizing for the top side (ring side) of the H3 weld. It is assumed that the UT results for the bottom side (plate side) of the H3 weld from Reference [3] bound any crack depth that may exist on the top side of the weld.

   This assumption is supported by weld residual stress analysis outlined in Appendix B as well as industry operating experience which has shown that the initial depth used in this calculation is conservative and bounds fleet data available in BWRVIP-278 [15]. Also, GE-H performed VT of the OD of the CNS H3 weld in 2018 at 4 different azimuths for a total of 80° coverage and found no indications [2]. This supports the assumption that there is no cracking on the OD of weld H3.

6.0 DESIGN INPUTS

The following design inputs are used for this evaluation:

1. Inspection Data: Weld H3 inspection data from VT examinations performed by GE-H in 2018 [1, 2], ISwT in 2014 and AREVA in 2005 [3] are included in this evaluation. Table 1 presents inspection results from all inspections as well as end of interval (EOI) lengths based on an EOI of Fall 2020. VT data from 2018 is grown for 2 years while UT data from 2014 is grown for 6 years.
2. NDE Uncertainty: For the 2018 VT data, measurements in References [1, 2] were made by landmark. Therefore, the length evaluation factor (LEF) is:

   LEF: *{{ }}* [16, Table 3.1-1]

   For the 2014 ISwT UT data, measurements for the ring side (upper) in Reference [3] use UT Demonstration 63 from Reference [16]. Measurements for the plate side (lower) in Reference [3] use UT Demonstration 61 from Reference [16]. Both examinations were near side. The length sizing error (LSE), depth sizing error (DSE) and depth evaluation factor (DEF) values are:

   Upper LSE (RMS): *{{ }}* [16, UT Demo 63]

   Lower LSE (RMS): *{{ }}* [16, UT Demo 61]

   Lower DSE (RMS): *{{ }}* [16, UT Demo 61]

   Lower DEF: *{{ }}* [16, UT Demo 61]

   For the 2005 AREVA UT data, depth measurements in Reference [3] were obtained from near side UT based on Reference [17].

Lower DSE (RMS): {{ }} inch [18]

Lower DEF: {{ }} inch [18]

Based on Reference [19], no adjustment to the measured flaw size is required in the length direction since the LSE RMS values are less than {{ }}. Since the DSE RMS value in the depth direction is greater than {{ }}, a DEF is required for depth measurements.

A DEF of {{ }} inch is used for all UT depth measurements.

3. Loads: All relevant stresses were taken from the Design Input Compilation calculation [10, Table 9].

Service Level A/B	Pm=0.355 ksi	Pb=0.287 ksi
Service Level C/D	Pm=0.910 ksi	Pb=0.583 ksi

Note that these stresses conservatively omit deadweight.

4. Material Type: Shroud base metal: 304 stainless steel [10, Section 3.1.2]
5. Fluence: 9.46×10^{20} n/cm^2 at 54 EFPY [11]
6. Geometry: Wall thickness: 1.5 inches [10]

   Inside Radius: 87.25 inches [10]

   Aligner Lug Dimensions: See Figure 1 and Figure 2

7.0 STRUCTURAL EVALUATIONS

7.1 K-Independent Evaluation

7.1.1 K-Independent Crack Growth Rate

Each tip of each flaw identified by UT during the 2014 ISwT examination will grow in the circumferential direction by 2.63 inches from 2014 to 2020, as shown below:

$$(5\text{x}10^{-5} \text{ in/hr}) (6 \text{ years}) (365.25 \text{ days/year}) (24 \text{ hours/day}) = 2.63 \text{ inches / flaw tip}$$

Each tip of each flaw identified by VT during the 2018 GE-H examination will grow in the circumferential direction by 0.88 inches from 2018 to 2020, as shown below:

$$(5\text{x}10^{-5} \text{ in/hr}) (2 \text{ years}) (365.25 \text{ days/year}) (24 \text{ hours/day}) = 0.88 \text{ inches / flaw tip}$$

7.1.2 Inspection Uncertainty

Each tip of each flaw identified by VT during the 2018 GE-H examination will include a {{ }} inches inspection uncertainty [16, Table 3.1-1]. This applies for as-found flaws as well as flaws assumed in uninspected regions.

Since the LSE RMS for the UT data is less than *{{* *}}*, no inspection uncertainty is applied to the UT data [19].

7.1.3 Added Ligament Due to Aligner Lug Weld Area

There are two aligner lugs that are welded to the shroud at the H3 weld location at 0°, 90°, 180° and 270° that serve to align the top guide in place [20]. These lugs are welded on all sides and cover the H3 weld and extend some distance on either side of the H3 weld. Figure 1 shows the general configuration of the aligner lug assembly and the relation to the H3 weld. Figure 2 shows a detailed drawing of one of the lugs based on dimensions from Reference [20].

In order to take credit for any load carrying capacity that the aligner lug welds may take, the following methodology is used:

1. Upper and lower examination boundaries are identified based on UT data from Reference [3] which identify the distance from the weld centerline for each indication. The upper boundary is 1.20" from weld centerline and the lower boundary is 0.94" from the weld centerline.
2. It is assumed that the weld area in between the upper and lower boundaries is not available for structural reinforcement since there is the potential for a crack to exist at both boundaries, thereby causing a discontinuation of available ligament.
3. Available areas are calculated above the upper boundary and below the lower boundary. The available weld area is determined by:

   Weld Area = Σ Weld Length x Weld Thickness

   For a Fillet Weld: Weld Thickness = 0.707 x Fillet Leg = 0.707(0.5) = 0.354"

   For a Groove Weld: Weld Thickness = Groove Width = 0.500"

   Available weld lengths are shown in Figure 2 with ligaments shown as Dim A to Dim G

   For areas below the lower boundary

   $$\text{Weld Area} = L_{DimA} \cdot T_{DimA} + L_{DimB} \cdot T_{DimB} + L_{DimC} \cdot T_{DimC}$$
   $$= 1.06 \cdot 0.354 + 2.00 \cdot 0.354 + 1.06 \cdot 0.500$$
   $$= 1.612 \text{ in}^2 \text{ per lug}$$
   $$= 3.223 \text{ in}^2 \text{ for both lugs}$$

   For areas above the upper boundary

   $$\text{Weld Area} = L_{DimD} \cdot T_{DimD} + L_{DimE} \cdot T_{DimE} + L_{DimF} \cdot T_{DimF} + L_{DimG} \cdot T_{DimG}$$
   $$= 0.80 \cdot 0.500 + 1.15 \cdot 0.500 + 1.42 \cdot 0.500 + 1.80 \cdot 0.354$$
   $$= 2.290 \text{ in}^2 \text{ per lug}$$
   $$= 4.579 \text{ in}^2 \text{ for both lugs}$$

4. The weld area available is the minimum of the upper and lower bounded areas.

5. For simplicity, this area is converted to an equivalent H3 weld length using a H3 weld thickness of 1.5"

   Equivalent H3 Weld Length = 3.223 / 1.5 = 2.149"

   = 1.40 degrees

6. For regions that have fully cracked H3 weld metal at 0°, 90°, 180° and 270°, the equivalent length of 1.40 degrees is added as "good metal" in the evaluation, centered at 0°, 90°, 180° or 270°, as appropriate.

7.1.4 Fluence and Failure Mechanisms

The fluence for the H3 weld is 9.46×10^{20} n/cm^2 at 54 EFPY [11]. Based on guidance given in BWRVIP-100, Revision 1-A [12], the applicable failure mode is *{{ }}*. Both limit load and elastic-plastic fracture mechanics (EPFM) are considered in the analysis.

7.1.5 Fracture Mechanics Evaluations

Table 1 summarizes the as-reported indications in weld H3 for CNS. Table 1 also has end of interval (based on 2020) flaw lengths calculated using K-independent crack growth from Section 7.1.1 and inspection uncertainty from Section 7.1.2 included, as appropriate, for each inspection type. Table 2 summarizes the end of evaluation interval flaw distribution when combining overlapping regions. Figure 3 shows a visual representation of the end of interval flaw distribution from Table 2. Table 3 summarizes the flaw distribution when structural credit is given to the aligner lug weld metal from Section 7.1.3. Detailed calculations are included in spreadsheet "Cooper 1801303 H3 Evaluation.xlsx."

The applied stresses for the H3 weld are provided in Section 6.0, Item 3. In performing the structural integrity analysis of the weld, both normal/upset and emergency/faulted conditions must be considered.

Appendix A contains the DLL output used in this analysis. The output file contains an echo of the inputs used for the evaluation.

7.2 K-Dependent Evaluation

7.2.1 K-Dependent Crack Growth Rate

This section discusses the calculations performed to develop the stress intensity factor distributions and the crack growth rate curves. Per Section 6.0, Item 5, the fluence at 54 EFPY is greater than *{{ }}* and less than *{{ }}*; therefore, the BWRVIP-99-A [6] crack growth law will be used in this calculation.

BWRVIP-99-A [6] provides guidance for the determination of the stress intensity factor used in crack growth calculations for welds with fluence greater than *{{ }}* but less than {{ }}. Section 8.5 of [6] recommends the use of a *{{ }}*. The weld residual stress distribution is applicable to both inside surface and outside surface connected flaws. The membrane stresses given in Section 6.0, Item 3 are lower than {{ }}; therefore, it is conservative. The curve-fit expression for the normalized K_I distribution taken from BWRVIP-99-A [6], Figure 9-2 is:

{{ (2)

where

}}

The normalized stress intensity factor, K, curve and curve fit equation are included in Excel spreadsheet "K_VS_A_For_High_Fluence.xlsx" and are shown in Figure 4. To calculate the stress intensity factor for a given flaw depth, Equation 2 is multiplied by the square root of the shroud thickness ($\sqrt{t}$).

Figure 5 shows the crack depth versus time associated with the K distribution from Figure 4. Note that the stress intensity factor remains positive throughout the shroud thickness. This behavior could result in through-wall growth of a flaw given a sufficiently long evaluation interval.

The K-dependent crack growth calculation is performed in spreadsheet "Cooper K Dependent Flaw Calculation.xlsx" using an initial depth of 0.82 and a DEF of *{{* *}}* inch from Section 6.0, Item 2. For the K-dependent analysis, a total of 25 years of crack growth is calculated using an initial flaw depth of 0.963 inch. This growth is assumed to start in 2005, the date of the AREVA UT inspection data in Reference [3], which gives an end of interval of 2030. The end of interval flaw depth is 1.098 inches.

7.2.2 Fracture Mechanics Evaluation

A 360-degree part through-wall flaw of 1.098 inches is assumed for the K-dependent evaluation. Figure 6 shows the geometry of this flaw case.

The applied stresses for the H3 weld are provided in Section 6.0, Item 3. In performing the structural integrity analysis of the weld, both normal/upset and emergency/faulted conditions must be considered.

The indication profiles are input into DLL to calculate the structural factors at the end of the evaluation interval. Appendix A contains the DLL output files. The output files contain an echo of the inputs used for the evaluation.

7.3 Weld Residual Stress Considerations

Appendix B provides a technical basis for why an ID connected crack would likely arrest at or before 0.92 inches based on combined operational and residual stress K values.

8.0 RESULTS OF ANALYSIS

Table 4 presents the results of the K-independent analysis which assumes through-wall cracking for a large majority of the H3 weld. The results show that the required structural margin exists for an interval to 2020 considering both limit load and EPFM analysis.

Table 5 presents the results of the K-dependent analysis which assumes part through-wall cracking for the entire H3 weld circumference. The results show that the required structural margin exists for an interval to 2030 considering both limit load and EPFM analysis.

9.0 OPERATING EXPERIENCE

Appended C provides an overview of relevant industry operating experience for cracking in the core shroud H3 weld. Based on the industry operating experience in BWRVIP-278 [15], the CNS data is in-line with industry experience, and the assumption of equivalent cracking on the plate and ring side is reasonable.

10.0 CONCLUSIONS AND DISCUSSION

Two independent analysis methodologies were performed to evaluate cracking in the CNS core shroud H3 weld.

The first methodology uses K-independent crack growth rates and conservatively combines all VT and UT data for the upper and lower sides of the weld, including uninspected regions, NDE uncertainty and crack growth. This analysis also takes structural credit for the aligner lug welds. This evaluation shows that the required structural margin is met, as shown in Table 4.

The second methodology uses K-dependent crack growth rates assuming the deepest measured flaw, grown to 2030, adjusted for NDE uncertainty. This evaluation shows that the required structural margin is met, as shown in Table 5.

Appendix B provides a technical basis for why an ID connected flaw will arrest much more shallow than the depth considered in the evaluation herein. Appendix C provides industry operating experience that further corroborates this.

11.0 REFERENCES

1. General Electric Hitachi INR CNS RE 30 IVVI-18-07 Shroud R1, "Shroud H3 ID," SI File No. 1801303.201.
2. General Electric Hitachi IVVI Data Sheets Cooper Nuclear Station, RE Fall 2018 IVVI-BWRVIP, "Shroud OD," October 17, 2018, SI File No. 1801303.201.
3. Addendum #2 to Final Report, IHI Project #13-0305 (2018), "Automated Ultrasonic Examination of the Core Shroud at Cooper Nuclear Station RE-28," October 2018, SI File No. 1801303.201.
4. *BWRVIP-76, Revision 1-A: BWR Vessel and Internals Project: BWR Core Shroud Inspection and Flaw Evaluation Guidelines*. EPRI, Palo Alto, CA: 2015. 3002005566. **EPRI Proprietary Information.**
5. *BWRVIP-14-A: BWR Vessel and Internals Project, Evaluation of Crack Growth in BWR Stainless Steel RPV Internals*. EPRI, Palo Alto, CA: 2008. 1016569. **EPRI Proprietary Information.**
6. *BWRVIP-99-A: BWR Vessel and Internals Project, Crack Growth Rates in Irradiated Stainless Steels in BWR Internal Components*. EPRI, Palo Alto, CA: 2008. 1016566. **EPRI Proprietary Information.**
7. SI Calculation 1501658.301, Revision 1, "Updated Flaw Evaluation for Cooper Nuclear Station, Core Shroud Circumferential Weld H1 through H7 and Vertical Weld V16."
8. BWRVIP Letter 2012-074 from Chuck Wirtz and Randy Stark to All BWRVIP Committee Members, "Superseded "Needed" Guidance Regarding Crack Growth Assumptions," dated March 22, 2012.

9. *BWRVIP-158-A: Flaw Proximity Rules for Assessment of BWR Internals.* EPRI, Palo Alto, CA: 2010. 1020998. **EPRI Proprietary Information.**

10. Structural Integrity Associates Calculation 1300350.308, Revision 1, "Cooper Nuclear Station Shroud Flaw Evaluation Design Input Compilation."

11. CNS Review of TransWare Calculations NPP-FLU-003-R-003, Revision 0, NPP-FLU-003-R-006 and NPP-FLU-003-R-007, Reactor Pressure Vessel Fluence Evaluation, Nebraska Public Power District Calculation NEDC 07-033 Rev. 1C1, August 9, 2011, SI File No. 1300350.207P. **TransWare Proprietary Information.**

12. *BWRVIP-100, Revision 1-A: BWR Vessel and Internals Project, Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds.* EPRI, Palo Alto, CA: 2016. 3002008388. **EPRI Proprietary Information.**

13. *BWRVIP-235: BWR Vessel and Internals Project, BWR Core Shroud Distributed Ligament Length (DLL) Computer Program (Version 3.1).* EPRI, Palo Alto, CA: 2009 1018251. **EPRI Proprietary Information.**

14. *BWRVIP-190 Revision 1: BWR Vessel and Internals Project, Volume 1: BWR Water Chemistry Guidelines - Mandatory, Needed, and Good Practice Guidance.* EPRI, Palo Alto, CA: 2014. 3002002623. **EPRI Proprietary Information.**

15. *BWRVIP-278: BWR Vessel and Internals Project, Technical Basis for Revision of the BWRVIP-76 Core Shroud Inspection Program.* EPRI, Palo Alto, CA: 2013. 3002000650. **EPRI Proprietary Information.**

16. *TR-105696-R19 (BWRVIP-03) Revision 19: BWR Vessel and Internals Project, Reactor Pressure Vessel and Internals Examination Guidelines.* EPRI, Palo Alto, CA: 2015. 3002008095. **EPRI Proprietary Information.**

17. AREVA Report, 51-5058461-00, "Cooper Nuclear Station RFO22 2005 Core Shroud Ultrasonic Examination." SI File No. 1501658.202.

18. Email from K. Thomas (NPPD) to G. Stevens (SI), "FW: Shroud Tool Instrument Uncertainties," January 24, 2005, 6:31 p.m., with attached document, SI File No. 1501658.205.

19. BWRVIP Letter 2004-426 From Robin Dyle/Tom Mulford to All BWRVIP Committee Members, Subject: "Consideration of NDE Uncertainty in Flaw Evaluations," Dated September 30, 2004.

20. Willamette Iron and Steel Company Drawing No E 854, Sheet 2, Revision D, "Shroud," SI File No 1801303.202.

21. Final Report, IsWT Project #13-0305, "Automated Ultrasonic Examination of the Core Shroud at Cooper Nuclear Station RE-28," November 2014, SI File No. 1801303.201.

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Table 1. Core Shroud Weld H3 Inspection Summary

Region Number	Start, Deg	End, Deg	Length, Deg	Length, in	Initiating Surface[1]	Side of Weld	NDE Method[2]	Depth, in	EOI Start[3], Deg	EOI End[3], Deg
1	1	7	6.00	9.22	ID	Upper	VT	N/A	-0.10	8.10
2	7	20	13.00	19.97	U-I	Upper/Lower	VT	N/A	5.90	21.10
3	17.57	26.30	8.73	13.41	ID	Upper	UT	N/A	15.86	28.01
4	20	40	20.00	30.72	ID	Upper	VT	N/A	18.90	41.10
5	24.10	27.78	3.68	5.65	ID	Upper	UT	N/A	22.39	29.49
6	28.85	41.14	12.29	18.88	ID	Upper	UT	N/A	27.14	42.85
7	40	48	8.00	12.29	U-I	Upper/Lower	VT	N/A	38.90	49.10
8	41.02	49.63	8.61	13.22	ID	Upper	UT	N/A	39.31	51.34
9	48	70	22.00	33.79	ID	Upper	VT	N/A	46.90	71.10
10	51.29	65.18	13.89	21.33	ID	Upper	UT	N/A	49.58	66.89
11	64	67	3.00	4.61	ID	Lower	VT	N/A	62.90	68.10
12	70	76	6.00	9.22	U-I	Upper/Lower	VT	N/A	68.90	77.10
13	72.05	80.85	8.80	13.52	ID	Lower	UT	0.24	70.34	82.56
14	74.09	77.12	3.03	4.65	ID	Upper	UT	N/A	72.38	78.83
15	76	82	6.00	9.22	ID	Upper	VT	N/A	74.90	83.10
16	79	83	4.00	6.14	ID	Lower	VT	N/A	77.90	84.10
17	86	89	3.00	4.61	ID	Lower	VT	N/A	84.90	90.10
18	91	96	5.00	7.68	ID	Upper	VT	N/A	89.90	97.10
19	93.44	105.61	12.17	18.69	ID	Upper	UT	N/A	91.73	107.32
20	96	111	15.00	23.04	U-I	Upper/Lower	VT	N/A	94.90	112.10
21	111	130	19.00	29.18	ID	Upper	VT	N/A	109.90	131.10
22	117	119	2.00	3.07	ID	Lower	VT	N/A	115.90	120.10
23	125.01	135.95	10.94	16.80	ID	Upper	UT	N/A	123.30	137.66
24	128	130	2.00	3.07	ID	Lower	VT	N/A	126.90	131.10
25	128.28	133.70	5.42	8.32	ID	Lower	UT	0.60	126.57	135.41
26	130	143	13.00	19.97	U-I	Upper/Lower	VT	N/A	128.90	144.10
27	138.74	146.34	7.60	11.67	ID	Upper	UT	N/A	137.03	148.05
28	143	148	5.00	7.68	ID	Upper	VT	N/A	141.90	149.10
29	156.68	163.08	6.40	9.83	ID	Lower	UT	0.70	154.97	164.79
30	157	165	8.00	12.29	U-I	Upper/Lower	VT	N/A	155.90	166.10
31	165	177	12.00	18.43	ID	Lower	VT	N/A	163.90	178.10

See Next Page for Notes

Table 1 (Concluded). Core Shroud Weld H3 Inspection Summary

Region Number	Start, Deg	End, Deg	Length, Deg	Length, in	Initiating Surface[1]	Side of Weld	NDE Method[2]	Depth, in	EOI Start[3], Deg	EOI End[3], Deg
32	185	206	21.00	32.25	U-I	Upper/Lower	VT	N/A	183.90	207.10
33	206	222	16.00	24.57	ID	Upper	VT	N/A	204.90	223.10
34	212.77	231.65	18.88	29.00	ID	Upper	UT	N/A	211.06	233.36
35	222	229	7.00	10.75	U-I	Upper/Lower	VT	N/A	220.90	230.10
36	227.73	231.65	3.92	6.02	ID	Lower	UT	0.24	226.02	233.36
37	229	230	1.00	1.54	ID	Lower	VT	N/A	227.90	231.10
38	229	244	15.00	23.04	ID	Upper	VT	N/A	227.90	245.10
39	233.13	243.94	10.81	16.60	ID	Upper	UT	N/A	231.42	245.65
40	244	255	11.00	16.89	U-I	Upper/Lower	VT	N/A	242.90	256.10
41	255	260	5.00	7.68	ID	Upper	VT	N/A	253.90	261.10
42	257.41	261.15	3.74	5.74	ID	Upper	UT	N/A	255.70	262.86
43	271.00	288.40	17.40	26.72	ID	Upper	UT	N/A	269.29	290.11
44	274	275	1.00	1.54	ID	Upper	VT	N/A	272.90	276.10
45	275	294	19.00	29.18	U-I	Upper/Lower	VT	N/A	273.90	295.10
46	281.28	284.43	3.15	4.84	ID	Upper	UT	N/A	279.57	286.14
47	294	310	16.00	24.57	ID	Upper	VT	N/A	292.90	311.10
48	304.97	322.18	17.21	26.43	ID	Upper	UT	N/A	303.26	323.89
49	309	310	1.00	1.54	ID	Lower	VT	N/A	307.90	311.10
50	309.37	316.91	7.54	11.58	ID	Lower	UT	0.24	307.66	318.62
51	310	317	7.00	10.75	U-I	Upper/Lower	VT	N/A	308.90	318.10
52	317	320	3.00	4.61	ID	Upper	VT	N/A	315.90	321.10
53	327	334	7.00	10.75	ID	Upper	VT	N/A	325.90	335.10
54	328.89	336.61	7.72	11.86	ID	Upper	UT	N/A	327.18	338.32
55	329.99	340.96	10.97	16.85	ID	Lower	UT	0.28	328.28	342.67
56	333	337	4.00	6.14	ID	Lower	VT	N/A	331.90	338.10
57	336	340	4.00	6.14	ID	Upper	VT	N/A	334.90	341.10
58	338.33	345.75	7.42	11.40	ID	Upper	UT	N/A	336.62	347.46
59	340	345	5.00	7.68	U-I	Upper/Lower	VT	N/A	338.90	346.10
60	341.39	344.04	2.65	4.07	ID	Lower	UT	0.36	339.68	345.75
61	345	359	14.00	21.50	ID	Upper	VT	N/A	343.90	360.10
62	349	357	8.00	12.29	ID	Lower	VT	N/A	347.90	358.10

Notes: 1. U-I denotes uninspected regions based on 2018 VT data [1, 2].
2. All VT data is from 2018 [1, 2]. All UT data was taken 2014 and reanalyzed in 2018 [3].
3. 2018 VT data is grown for 2 years to 2020. 2014 UT data is grown for 6 years to 2020. See Section 7.1.

Table 2. 2020 Flaw Distribution

Region Number	Start, Deg	End, Deg	Depth, in
1	0.00	84.10	1.50
2	84.10	84.90	0.00
3	84.90	149.10	1.50
4	149.10	154.97	0.00
5	154.97	178.10	1.50
6[1]	178.10	183.90	1.50
7	183.90	262.86	1.50
8	262.86	269.29	0.00
9	269.29	323.89	1.50
10	323.89	325.90	0.00
11	325.90	360.00	1.50

Note:

1. This region was uninspected by UT [21] and will therefore be treated as a through-wall flaw.

Table 3. 2020 Flaw Distribution with Structural Credit for Aligner Lug Welds

Region Number	Start, Deg	End, Deg	Depth, in
1	0.00	0.70	0.00
2	0.70	84.10	1.50
3	84.10	84.90	0.00
4	84.90	89.30	1.50
5	89.30	90.70	0.00
6	90.70	149.10	1.50
7	149.10	154.97	0.00
8	154.97	179.30	1.50
9[1]	179.30	180.70	0.00
10	180.70	262.86	1.50
11[2]	262.86	270.69[3]	0.00
12	270.69	323.89	1.50
13	323.89	325.90	0.00
14	325.90	359.30	1.50
15	359.30	360.00	0.00

Notes:

1. This is a combined region of unflawed shroud and aligner lug welds.
2. Additional structural credit is not given for the aligner lug welds since the H3 weld is not cracked here and already provides full support.
3. This distance has been modified slightly based on the end of Region 8 in Table 2.

Table 4. Summary of K-Independent DLL Results

<table>
<tr><th colspan="2">Minimum Structural Margin</th><th>Required Structural Margin</th><th>End of Interval</th></tr>
<tr><td>Limit Load</td><td>4.79 (Service Level A/B)
1.74 (Service Level C/D)</td><td>SF > 2.77
SF > 1.39</td><td rowspan="2">2020</td></tr>
<tr><td>EPFM</td><td>$T_{app} = 0.194$
(Service Level A/B)
$T_{app} = 0.256$
(Service Level C/D)</td><td>$T_{app} < 40$
$T_{app} < 21$</td></tr>
</table>

Table 5. 2030 K-Dependent Flaw Profile and DLL Results

Initial Flaw Depth (1) (in)	End of Interval Flaw Depth (2) (in)	Evaluation Method	Service Level A/B		Service Level C/D		End of Interval
			Results	Acceptance Criterion	Results	Acceptance Criterion	
0.963	1.098	Limit Load	SF = 38.99	SF > 2.77	SF = 16.56	SF > 1.39	2030
		EPFM	T_{app} = 1.384	T_{app} < 1268	T_{app} = 2.022	T_{app} < 915	

Notes:

1. Maximum recorded depth in Reference [3] plus DEF of *{{* *}}* from Section 6.0, Item 2. See Assumption 7.
2. End of interval flaw growth is calculated using Equation 1.

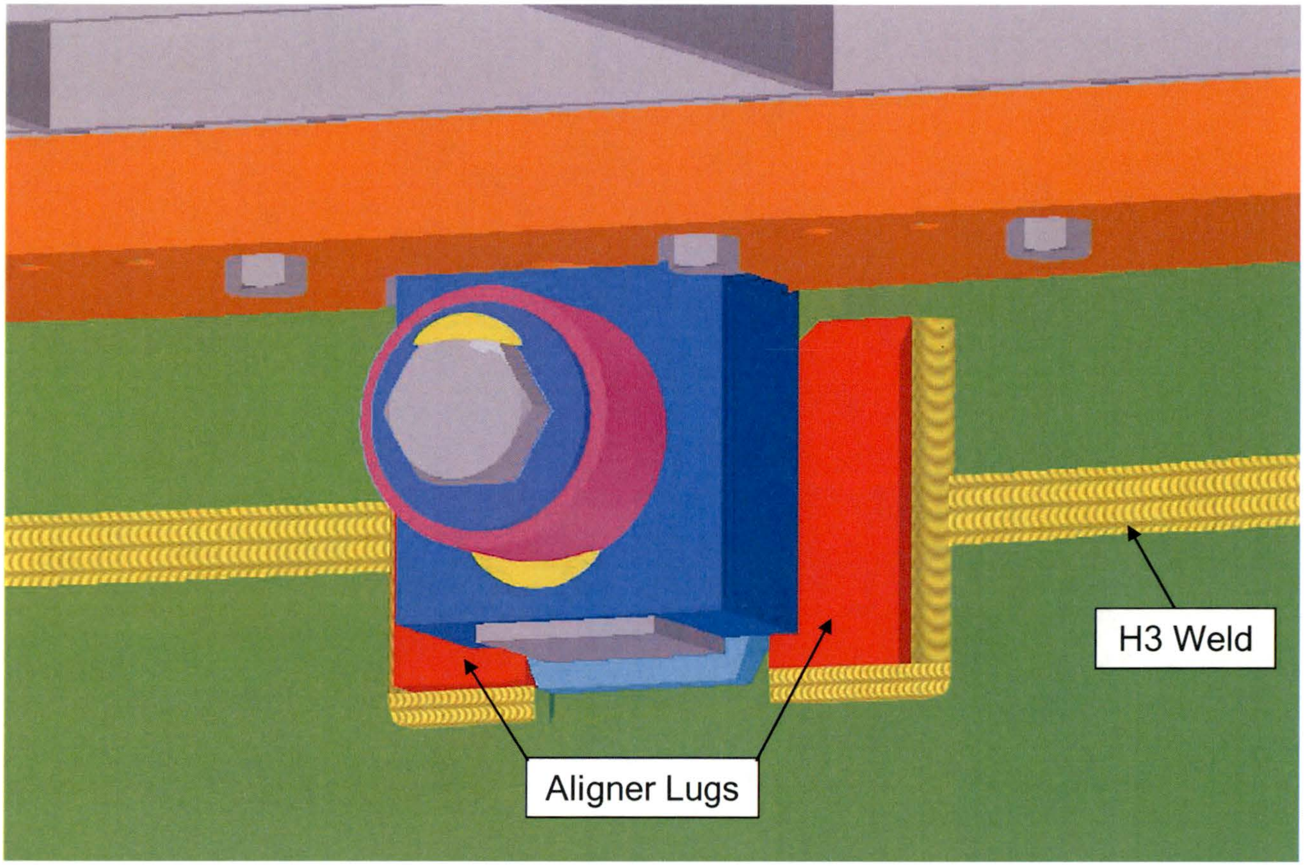
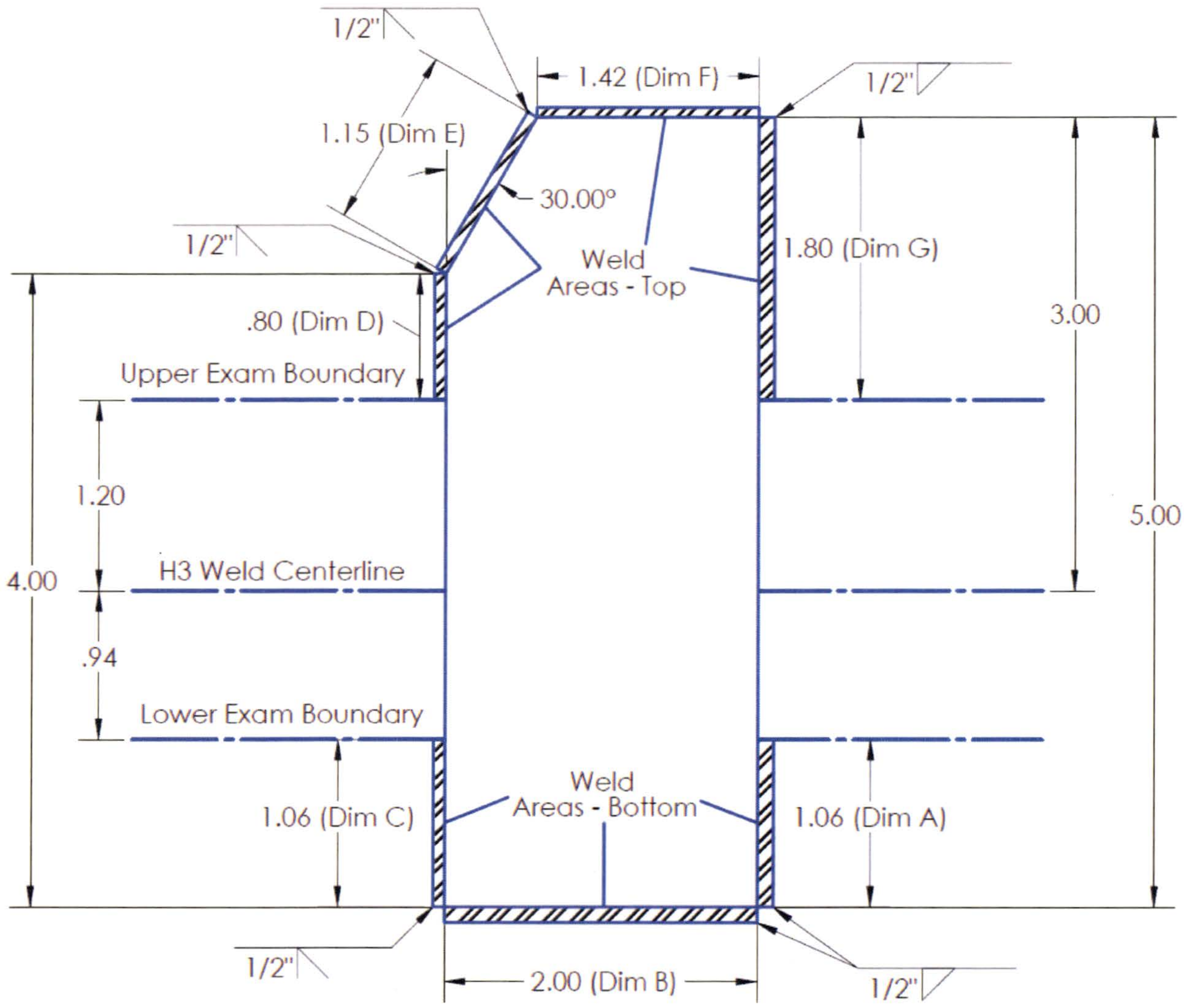


Figure 1. General Configuration of the Aligner Lugs



Notes: 1. Lug dimensions are taken from Reference [20].
2. Upper and lower examination boundaries are based on Reference [3].
3. Bottom and right welds are 1/2" fillet welds with a weld throat of 0.707·0.5 = 0.354".
4. Left, taper and top welds are 1/2" groove welds with a weld throat of 1/2".

Figure 2. Aligner Lug and Weld Dimensions

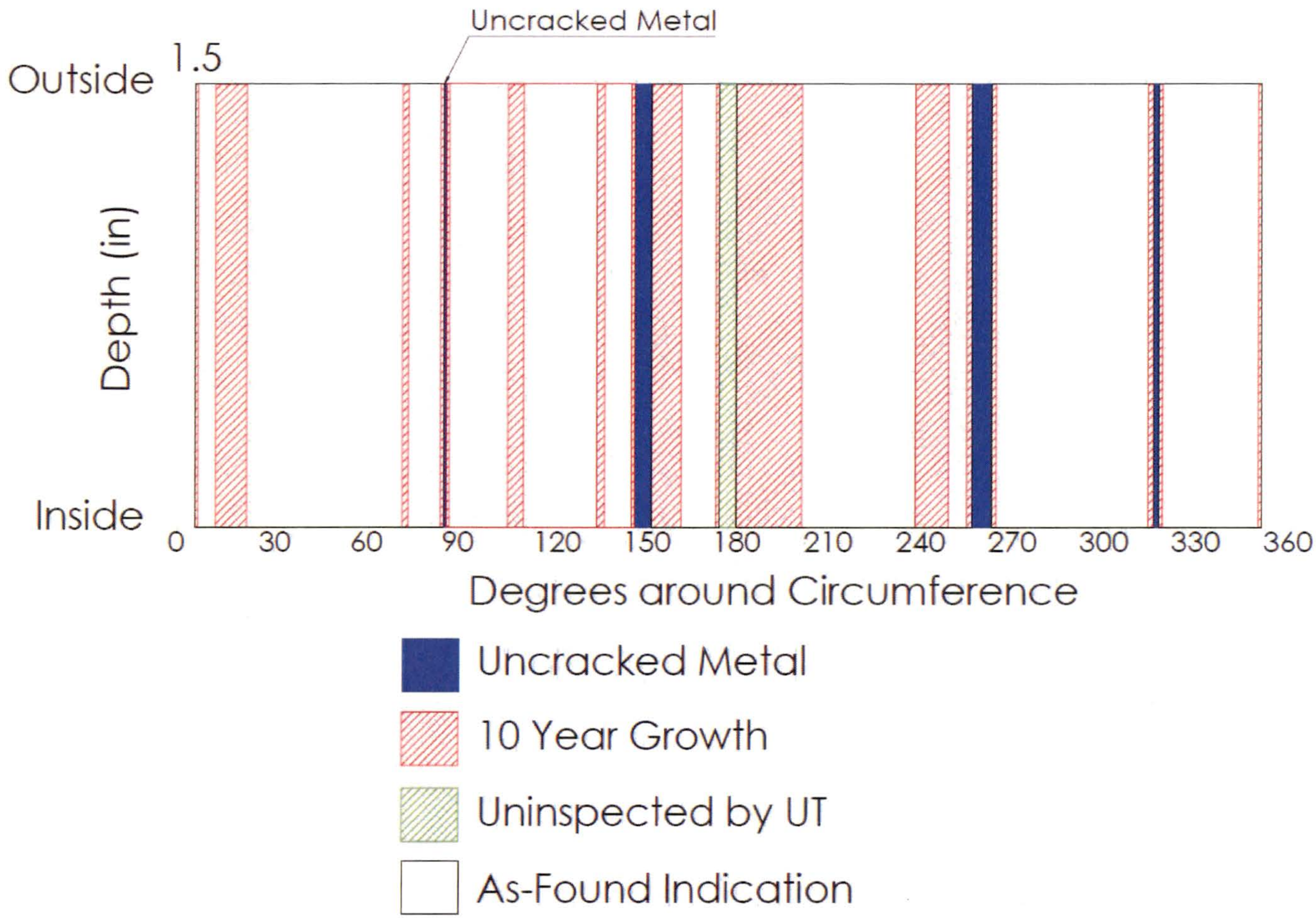


Figure 3. 2020 Through-Wall Flaw Distribution

Figure 4. Normalized Stress Intensity Factor Distribution for High Fluence Welds [6, Figure 9-2]

Figure 5. K-Dependent Crack Growth for 1.5 Inch Thick Core Shroud [6, Figure 9-2]

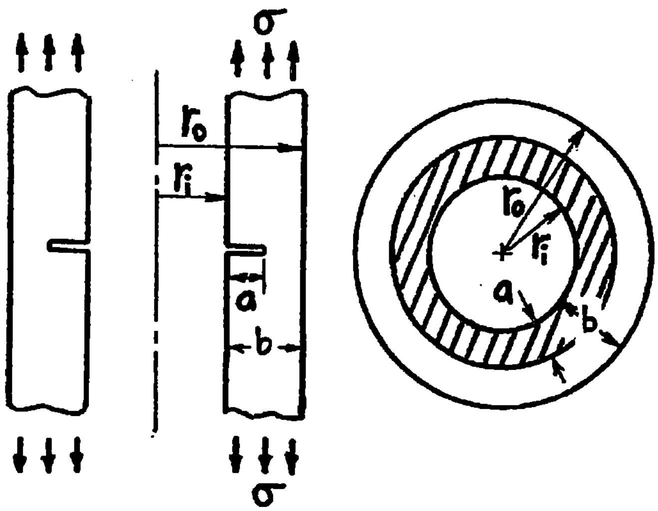


Figure 6. Assumed Flaw Distribution for K-Dependent Evaluation

{{This information}} is EPRI Proprietary Information

APPENDIX A

DLL OUTPUT FILES

DLL File for K-Independent Approach

DLL: DISTRIBUTED LIGAMENT LENGTH EVALUATION, REV. 3.1.2009.11
START OF THIS ANALYSIS: 10/19/2018 18:02:36

Summary Of Inputs:
=================

Title : H3 Cooper 2 year inspection interval
Note : K-Independent Through-Wall Crack With Lug Weld Area
Flaw Type/Orientation : SHROUD, Distributed circumferential flaws
Engineering Units : English
Output Options : Detailed
Upset Safety Factor, SF : 2.77
Upset Membrane Stress, Pm : 355 psi
Upset Bending Stress, Pb : 287 psi
Faulted Safety Factor, SF : 1.39
Faulted Membrane Stress, Pm : 910 psi
Faulted Bending Stress, Pb : 583 psi
Mean Radius, Rm : 88.00 inches
Wall Thickness, t : 1.500 inches
NDE Flaw Length Uncertainty : 0.000 inches
NDE Flaw Depth Uncertainty : 0.000 inches
Allowable Stress Intensity, Sm : 16950 psi
Fluence : 9.5e+020 n/cm^2

Region	Starting Angle (deg.)	Ending Angle (deg.)	Crack Depth (inches)	Material Thickness (inches)
1	0.0000	0.7000	0.0000	1.5000
2	0.7000	84.1000	1.5000	0.0000
3	84.1000	84.9000	0.0000	1.5000
4	84.9000	89.3000	1.5000	0.0000
5	89.3000	90.7000	0.0000	1.5000
6	90.7000	149.1000	1.5000	0.0000
7	149.1000	154.9700	0.0000	1.5000
8	154.9700	179.3000	1.5000	0.0000
9	179.3000	180.7000	0.0000	1.5000
10	180.7000	262.8600	1.5000	0.0000
11	262.8600	270.6900	0.0000	1.5000
12	270.6900	323.8900	1.5000	0.0000
13	323.8900	325.9000	0.0000	1.5000
14	325.9000	359.3000	1.5000	0.0000
15	359.3000	360.0000	0.0000	1.5000

Adjusted Flaws Summary - for initial Limit Load Analysis only
==

Region flaws adjusted for:

Examination Uncertainty of 0.00 inches in Length
Examination Uncertainty of 0.00 inches in Depth

Start End Length Length Depth

Flaw	(deg.)	(deg.)	(deg.)	(inch)	(inch)
1	0.7000	84.1000	83.4000	128.0932	1.5000
2	84.9000	89.3000	4.4000	6.7579	1.5000
3	90.7000	149.1000	58.4000	89.6960	1.5000
4	154.9700	179.3000	24.3300	37.3682	1.5000
5	180.7000	262.8600	82.1600	126.1887	1.5000
6	270.6900	323.8900	53.2000	81.7093	1.5000
7	325.9000	360.7000	34.8000	53.4490	1.5000

Limit Load Results - Upset Service Level:
==

Note: The following limit load results assume that
the flaws take compression.

Note: The limit load results have been rotated by -0.7000 degrees.

Alpha (deg.)	Moment (in-lbs)	Pb' (psi)	Safety Factor	Result
0.0	2.105e+008	5768	9.5379	---->Acceptable
5.0	2.055e+008	5631	9.3242	---->Acceptable
10.0	2.002e+008	5487	9.0998	---->Acceptable
15.0	1.948e+008	5338	8.8684	---->Acceptable
20.0	1.892e+008	5185	8.6287	---->Acceptable
25.0	1.834e+008	5027	8.3826	---->Acceptable
30.0	1.776e+008	4866	8.1320	---->Acceptable
35.0	1.716e+008	4703	7.8787	---->Acceptable
40.0	1.657e+008	4540	7.6248	---->Acceptable
45.0	1.598e+008	4378	7.3721	---->Acceptable
50.0	1.519e+008	4162	7.0355	---->Acceptable
55.0	1.483e+008	4065	6.8844	---->Acceptable
60.0	1.430e+008	3919	6.6571	---->Acceptable
65.0	1.345e+008	3685	6.2930	---->Acceptable
70.0	1.302e+008	3567	6.1084	---->Acceptable
75.0	1.253e+008	3433	5.9003	---->Acceptable
80.0	1.208e+008	3309	5.7079	---->Acceptable
85.0	1.188e+008	3254	5.6217	---->Acceptable
90.0	1.150e+008	3152	5.4627	---->Acceptable
95.0	1.116e+008	3058	5.3168	---->Acceptable
100.0	1.066e+008	2921	5.1026	---->Acceptable
105.0	1.041e+008	2854	4.9982	---->Acceptable
110.0	1.022e+008	2800	4.9144	---->Acceptable
115.0	1.007e+008	2760	4.8518	---->Acceptable
120.0	9.975e+007	2734	4.8108	---->Acceptable
125.0	9.931e+007	2721	4.7919	---->Acceptable
130.0	9.939e+007	2723	4.7951	---->Acceptable
135.0	9.998e+007	2740	4.8204	---->Acceptable
140.0	1.011e+008	2770	4.8676	---->Acceptable
145.0	1.027e+008	2814	4.9364	---->Acceptable
150.0	1.048e+008	2872	5.0263	---->Acceptable
155.0	1.074e+008	2943	5.1365	---->Acceptable
160.0	1.104e+008	3026	5.2662	---->Acceptable
165.0	1.149e+008	3149	5.4584	---->Acceptable
170.0	1.180e+008	3233	5.5889	---->Acceptable
175.0	1.214e+008	3327	5.7357	---->Acceptable

180.0	1.270e+008	3479	5.9720	---->Acceptable
185.0	1.327e+008	3635	6.2150	---->Acceptable
190.0	1.388e+008	3803	6.4770	---->Acceptable
195.0	1.442e+008	3952	6.7085	---->Acceptable
200.0	1.498e+008	4106	6.9482	---->Acceptable
205.0	1.556e+008	4264	7.1942	---->Acceptable
210.0	1.615e+008	4425	7.4449	---->Acceptable
215.0	1.674e+008	4587	7.6981	---->Acceptable
220.0	1.733e+008	4750	7.9520	---->Acceptable
225.0	1.772e+008	4856	8.1176	---->Acceptable
230.0	1.832e+008	5020	8.3725	---->Acceptable
235.0	1.890e+008	5179	8.6192	---->Acceptable
240.0	1.944e+008	5328	8.8523	---->Acceptable
245.0	1.997e+008	5473	9.0778	---->Acceptable
250.0	2.048e+008	5613	9.2961	---->Acceptable
255.0	2.097e+008	5745	9.5023	---->Acceptable
260.0	2.142e+008	5869	9.6947	---->Acceptable
265.0	2.183e+008	5983	9.8720	---->Acceptable
270.0	2.221e+008	6086	10.0328	---->Acceptable
275.0	2.254e+008	6178	10.1758	---->Acceptable
280.0	2.284e+008	6258	10.3000	---->Acceptable
285.0	2.308e+008	6325	10.4044	---->Acceptable
290.0	2.328e+008	6378	10.4882	---->Acceptable
295.0	2.342e+008	6419	10.5509	---->Acceptable
300.0	2.352e+008	6445	10.5918	---->Acceptable
305.0	2.356e+008	6457	10.6107	---->Acceptable
310.0	2.356e+008	6455	10.6075	---->Acceptable
315.0	2.350e+008	6439	10.5822	---->Acceptable
320.0	2.339e+008	6408	10.5350	---->Acceptable
325.0	2.322e+008	6364	10.4662	---->Acceptable
330.0	2.301e+008	6307	10.3763	---->Acceptable
335.0	2.276e+008	6236	10.2661	---->Acceptable
340.0	2.245e+008	6153	10.1364	---->Acceptable
345.0	2.210e+008	6057	9.9881	---->Acceptable
350.0	2.193e+008	6009	9.9122	---->Acceptable
355.0	2.151e+008	5895	9.7346	---->Acceptable

Acceptable. Minimum Safety Factor = 4.7919 at 125.0 Degrees

Limit Load Results - Faulted Service Level:
==

Note: The following limit load results assume that
the flaws take compression.

Note: The limit load results have been rotated by -0.7000 degrees.

Alpha (deg.)	Moment (in-lbs)	Pb' (psi)	Safety Factor	Result
0.0	1.695e+008	4645	3.7208	---->Acceptable
5.0	1.656e+008	4537	3.6482	---->Acceptable
10.0	1.593e+008	4366	3.5340	---->Acceptable
15.0	1.539e+008	4218	3.4344	---->Acceptable
20.0	1.483e+008	4064	3.3313	---->Acceptable
25.0	1.425e+008	3906	3.2255	---->Acceptable
30.0	1.367e+008	3745	3.1178	---->Acceptable

35.0	1.307e+008	3582	3.0089	---->Acceptable
40.0	1.248e+008	3419	2.8997	---->Acceptable
45.0	1.199e+008	3285	2.8098	---->Acceptable
50.0	1.140e+008	3125	2.7025	---->Acceptable
55.0	1.084e+008	2969	2.5982	---->Acceptable
60.0	1.019e+008	2792	2.4797	---->Acceptable
65.0	9.751e+007	2672	2.3992	---->Acceptable
70.0	9.022e+007	2472	2.2655	---->Acceptable
75.0	8.744e+007	2396	2.2144	---->Acceptable
80.0	8.293e+007	2273	2.1317	---->Acceptable
85.0	7.779e+007	2132	2.0372	---->Acceptable
90.0	7.406e+007	2030	1.9689	---->Acceptable
95.0	7.167e+007	1964	1.9250	---->Acceptable
100.0	6.875e+007	1884	1.8714	---->Acceptable
105.0	6.631e+007	1817	1.8265	---->Acceptable
110.0	6.434e+007	1763	1.7904	---->Acceptable
115.0	6.287e+007	1723	1.7635	---->Acceptable
120.0	6.191e+007	1697	1.7459	---->Acceptable
125.0	6.147e+007	1684	1.7378	---->Acceptable
130.0	6.155e+007	1687	1.7391	---->Acceptable
135.0	6.214e+007	1703	1.7500	---->Acceptable
140.0	6.325e+007	1733	1.7703	---->Acceptable
145.0	6.486e+007	1777	1.7999	---->Acceptable
150.0	6.696e+007	1835	1.8386	---->Acceptable
155.0	6.955e+007	1906	1.8860	---->Acceptable
160.0	7.258e+007	1989	1.9417	---->Acceptable
165.0	7.606e+007	2084	2.0055	---->Acceptable
170.0	7.796e+007	2136	2.0405	---->Acceptable
175.0	8.439e+007	2313	2.1585	---->Acceptable
180.0	8.689e+007	2381	2.2044	---->Acceptable
185.0	9.270e+007	2540	2.3110	---->Acceptable
190.0	9.788e+007	2682	2.4061	---->Acceptable
195.0	1.033e+008	2831	2.5056	---->Acceptable
200.0	1.089e+008	2985	2.6087	---->Acceptable
205.0	1.147e+008	3143	2.7145	---->Acceptable
210.0	1.206e+008	3304	2.8223	---->Acceptable
215.0	1.265e+008	3466	2.9312	---->Acceptable
220.0	1.324e+008	3629	3.0404	---->Acceptable
225.0	1.394e+008	3820	3.1678	---->Acceptable
230.0	1.453e+008	3981	3.2760	---->Acceptable
235.0	1.511e+008	4140	3.3821	---->Acceptable
240.0	1.565e+008	4290	3.4826	---->Acceptable
245.0	1.619e+008	4436	3.5807	---->Acceptable
250.0	1.670e+008	4576	3.6746	---->Acceptable
255.0	1.718e+008	4709	3.7633	---->Acceptable
260.0	1.763e+008	4832	3.8460	---->Acceptable
265.0	1.774e+008	4862	3.8658	---->Acceptable
270.0	1.812e+008	4965	3.9350	---->Acceptable
275.0	1.845e+008	5057	3.9965	---->Acceptable
280.0	1.874e+008	5136	4.0499	---->Acceptable
285.0	1.899e+008	5203	4.0947	---->Acceptable
290.0	1.919e+008	5257	4.1308	---->Acceptable
295.0	1.933e+008	5297	4.1577	---->Acceptable
300.0	1.943e+008	5324	4.1753	---->Acceptable
305.0	1.947e+008	5336	4.1835	---->Acceptable
310.0	1.946e+008	5334	4.1821	---->Acceptable
315.0	1.941e+008	5318	4.1712	---->Acceptable
320.0	1.929e+008	5287	4.1509	---->Acceptable
325.0	1.913e+008	5243	4.1213	---->Acceptable

330.0	1.892e+008	5185	4.0827	---->Acceptable
335.0	1.866e+008	5115	4.0353	---->Acceptable
340.0	1.836e+008	5031	3.9795	---->Acceptable
345.0	1.832e+008	5020	3.9722	---->Acceptable
350.0	1.783e+008	4887	3.8826	---->Acceptable
355.0	1.741e+008	4771	3.8052	---->Acceptable

Acceptable. Minimum Safety Factor = 1.7378 at 125.0 Degrees

Adjusted Flaws Summary - for LEFM, EPFM and Crack Growth Analysis
==

Region flaws adjusted for:

Examination Uncertainty of 0.00 inches in Length
Examination Uncertainty of 0.00 inches in Depth

Flaw	Start (deg.)	End (deg.)	Length (deg.)	Length (inch)	Depth (inch)
1	0.7000	84.1000	83.4000	128.0932	1.5000
2	84.9000	89.3000	4.4000	6.7579	1.5000
3	90.7000	149.1000	58.4000	89.6960	1.5000
4	154.9700	179.3000	24.3300	37.3682	1.5000
5	180.7000	262.8600	82.1600	126.1887	1.5000
6	270.6900	323.8900	53.2000	81.7093	1.5000
7	325.9000	359.3000	33.4000	51.2987	1.5000

EPFM Results - Specified Margin On Load Method - Upset Service Level:
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Poisson's Ratio : 0.30
Elastic Modulus : 2.8e+007 psi
Flow Stress : 77931.9 psi
Yield Stress : 68517.6 psi
C : 153.221
n : 0.514491

Original Flaws

Flaw Region	Half Crack Length (inch)	Crack Depth (inch)	Flaw Boundary (deg)	Nominal Stress (psi)	Stress Intensity Margin (psi-(in)^.5)	Applied J-Integral Factor (KJ/m^2)	Ductile Crack Extension (inch)
0-1	64.047	1.5000	0.7000	1778.	183973.	193.	0.0614
0-2	64.047	1.5000	84.1000	1778.	183973.	193.	0.0614
1-1	3.379	1.5000	84.9000	1778.	9241.	0.	0.0000
1-2	3.379	1.5000	89.3000	1778.	9241.	0.	0.0000
2-1	44.848	1.5000	90.7000	1778.	107344.	66.	0.0076
2-2	44.848	1.5000	149.1000	1778.	107344.	66.	0.0076
3-1	18.684	1.5000	154.9700	1778.	33627.	6.	0.0001
3-2	18.684	1.5000	179.3000	1778.	33627.	6.	0.0001
4-1	63.094	1.5000	180.7000	1778.	158083.	142.	0.0341
4-2	63.094	1.5000	262.8600	1778.	158083.	142.	0.0341

5-1	40.855	1.5000	270.6900	1778.	82798.	39.	0.0028
5-2	40.855	1.5000	323.8900	1778.	82798.	39.	0.0028
6-1	25.649	1.5000	325.9000	1778.	70125.	28.	0.0014
6-2	25.649	1.5000	359.3000	1778.	70125.	28.	0.0014

Original Flaws - Crack Extension

Flaw Region	Half Crack Length (inch)	Crack Depth (inch)	Flaw Boundary (deg)
0-1	64.108	1.5000	0.6600
0-2	64.108	1.5000	84.1400
1-1	3.379	1.5000	84.9000
1-2	3.379	1.5000	89.3000
2-1	44.856	1.5000	90.6951
2-2	44.856	1.5000	149.1049
3-1	18.684	1.5000	154.9699
3-2	18.684	1.5000	179.3001
4-1	63.128	1.5000	180.6778
4-2	63.128	1.5000	262.8822
5-1	40.857	1.5000	270.6882
5-2	40.857	1.5000	323.8918
6-1	25.651	1.5000	325.8991
6-2	25.651	1.5000	359.3009

Original Flaws Plastic Adjusted Flaws

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Half Crack Angle (deg)	Crack Depth (inch)	Flaw Boundary (deg)
0-1	184157.	42.489	1.5000	-0.0886
0-2	184157.	42.489	1.5000	84.8886
1-1	9241.	2.202	1.5000	84.8981
1-2	9241.	2.202	1.5000	89.3019
2-1	107499.	29.460	1.5000	90.4400
2-2	107499.	29.460	1.5000	149.3600
3-1	33628.	12.190	1.5000	154.9450
3-2	33628.	12.190	1.5000	179.3250
4-1	158898.	41.659	1.5000	180.1205
4-2	158898.	41.659	1.5000	263.4395
5-1	82831.	26.753	1.5000	270.5368
5-2	82831.	26.753	1.5000	324.0432
6-1	70165.	16.810	1.5000	325.7904
6-2	70165.	16.810	1.5000	359.4096

Original Flaws - Plastic Adjusted Results

Flaw Stress Applied
Intensity J-Integral

Region	Factor (psi-(in)^.5)	(KJ/m^2)
0-1	187621.	200.362
0-2	187621.	200.362
1-1	9258.	0.488
1-2	9258.	0.488
2-1	116474.	77.217
2-2	116474.	77.217
3-1	33892.	6.538
3-2	33892.	6.538
4-1	183786.	192.254
4-2	183786.	192.254
5-1	85749.	41.851
5-2	85749.	41.851
6-1	75343.	32.310
6-2	75343.	32.310

Incremented Flaws

Flaw Region	Half Crack Length (inch)	Crack Depth (inch)	Flaw Boundary (deg)	Nominal Stress Margin (psi)
0-1	67.249	1.5000	-1.3850	1778.
0-2	67.249	1.5000	86.1850	1778.
1-1	3.548	1.5000	84.7900	1778.
1-2	3.548	1.5000	89.4100	1778.
2-1	47.090	1.5000	89.2400	1778.
2-2	47.090	1.5000	150.5600	1778.
3-1	19.618	1.5000	154.3618	1778.
3-2	19.618	1.5000	179.9083	1778.
4-1	66.249	1.5000	178.6460	1778.
4-2	66.249	1.5000	264.9140	1778.
5-1	42.897	1.5000	269.3600	1778.
5-2	42.897	1.5000	325.2200	1778.
6-1	26.932	1.5000	325.0650	1778.
6-2	26.932	1.5000	360.1350	1778.

Incremented Flaws Crack Extension

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)	Ductile Crack Extension (inch)	Half Crack Length (inch)	Crack Depth (inch)	Flaw Boundary (deg)
0-1	193662.	213.	0.0750	67.324	1.5000	-1.4338
0-2	193662.	213.	0.0750	67.324	1.5000	86.2338
1-1	10414.	1.	0.0000	3.548	1.5000	84.7900
1-2	10414.	1.	0.0000	3.548	1.5000	89.4100
2-1	134950.	104.	0.0184	47.109	1.5000	89.2280
2-2	134950.	104.	0.0184	47.109	1.5000	150.5720
3-1	42113.	10.	0.0002	19.619	1.5000	154.3616
3-2	42113.	10.	0.0002	19.619	1.5000	179.9084

4-1	190622.	207.	0.0705	66.320	1.5000	178.6001
4-2	190622.	207.	0.0705	66.320	1.5000	264.9599
5-1	123420.	87.	0.0130	42.910	1.5000	269.3515
5-2	123420.	87.	0.0130	42.910	1.5000	325.2285
6-1	80475.	37.	0.0025	26.934	1.5000	325.0634
6-2	80475.	37.	0.0025	26.934	1.5000	360.1366

Incremented Flaws Plastic Adjusted Flaws

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Half Crack Angle (deg)	Crack Depth (inch)	Flaw Boundary (deg)
0-1	193890.	44.664	1.5000	-2.2636
0-2	193890.	44.664	1.5000	87.0636
1-1	10414.	2.312	1.5000	84.7876
1-2	10414.	2.312	1.5000	89.4124
2-1	135001.	31.074	1.5000	88.8257
2-2	135001.	31.074	1.5000	150.9743
3-1	42115.	12.813	1.5000	154.3225
3-2	42115.	12.813	1.5000	179.9475
4-1	190836.	43.984	1.5000	177.7962
4-2	190836.	43.984	1.5000	265.7638
5-1	123456.	28.275	1.5000	269.0151
5-2	123456.	28.275	1.5000	325.5649
6-1	80482.	17.680	1.5000	324.9204
6-2	80482.	17.680	1.5000	360.2796

Incremented Flaws - Plastic Adjusted Results

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)
0-1	197785.	222.659
0-2	197785.	222.659
1-1	10444.	0.621
1-2	10444.	0.621
2-1	136720.	106.394
2-2	136720.	106.394
3-1	42870.	10.461
3-2	42870.	10.461
4-1	194593.	215.529
4-2	194593.	215.529
5-1	124864.	88.742
5-2	124864.	88.742
6-1	81084.	37.422
6-2	81084.	37.422

Final Results

Flaw Region	J Applied (KJ/m^2)	dJ (KJ/m^2)	da (m)	dJ/da (N/m^2)	T Applied @ J-Applied	Delta A (mm)	T Material	Specified Margin Achieved (Tmat > Tapp)
0-1	211.511	22.297	0.081	274120.	0.183	1.87128	38.	Yes
0-2	211.511	22.297	0.081	274120.	0.183	1.87128	38.	Yes
1-1	0.554	0.133	0.004	30983.	0.021	0.00002	10614.	Yes
1-2	0.554	0.133	0.004	30983.	0.021	0.00002	10614.	Yes
2-1	91.805	29.177	0.057	512259.	0.343	0.36951	85.	Yes
2-2	91.805	29.177	0.057	512259.	0.343	0.36951	85.	Yes
3-1	8.499	3.923	0.024	165322.	0.111	0.00362	807.	Yes
3-2	8.499	3.923	0.024	165322.	0.111	0.00362	807.	Yes
4-1	203.891	23.274	0.080	290457.	0.194	1.74249	40.	Yes
4-2	203.891	23.274	0.080	290457.	0.194	1.74249	40.	Yes
5-1	65.297	46.891	0.052	903731.	0.604	0.19055	118.	Yes
5-2	65.297	46.891	0.052	903731.	0.604	0.19055	118.	Yes
6-1	34.866	5.112	0.033	156934.	0.105	0.05628	213.	Yes
6-2	34.866	5.112	0.033	156934.	0.105	0.05628	213.	Yes

EPFM Results - Specified Margin On Load Method - Faulted Service Level:
==

Poisson's Ratio : 0.30
Elastic Modulus : 2.8e+007 psi
Flow Stress : 77931.9 psi
Yield Stress : 68517.6 psi
C : 153.221
n : 0.514491

Original Flaws

Flaw Region	Half Crack Length (inch)	Crack Depth (inch)	Flaw Boundary (deg)	Nominal Stress (psi)	Stress Intensity Margin (psi-(in)^.5)	Applied J-Integral Factor (KJ/m^2)	Ductile Crack Extension (inch)
0-1	64.047	1.5000	0.7000	2075.	214691.	262.	0.1120
0-2	64.047	1.5000	84.1000	2075.	214691.	262.	0.1120
1-1	3.379	1.5000	84.9000	2075.	10784.	1.	0.0000
1-2	3.379	1.5000	89.3000	2075.	10784.	1.	0.0000
2-1	44.848	1.5000	90.7000	2075.	125268.	89.	0.0138
2-2	44.848	1.5000	149.1000	2075.	125268.	89.	0.0138
3-1	18.684	1.5000	154.9700	2075.	39242.	9.	0.0002
3-2	18.684	1.5000	179.3000	2075.	39242.	9.	0.0002
4-1	63.094	1.5000	180.7000	2075.	184478.	194.	0.0621
4-2	63.094	1.5000	262.8600	2075.	184478.	194.	0.0621
5-1	40.855	1.5000	270.6900	2075.	96623.	53.	0.0050
5-2	40.855	1.5000	323.8900	2075.	96623.	53.	0.0050
6-1	25.649	1.5000	325.9000	2075.	81834.	38.	0.0026
6-2	25.649	1.5000	359.3000	2075.	81834.	38.	0.0026

Original Flaws - Crack Extension

Flaw Region	Half Crack Length (inch)	Crack Depth (inch)	Flaw Boundary (deg)
0-1	64.159	1.5000	0.6271
0-2	64.159	1.5000	84.1729
1-1	3.379	1.5000	84.9000
1-2	3.379	1.5000	89.3000
2-1	44.862	1.5000	90.6910
2-2	44.862	1.5000	149.1090
3-1	18.684	1.5000	154.9699
3-2	18.684	1.5000	179.3001
4-1	63.156	1.5000	180.6596
4-2	63.156	1.5000	262.9004
5-1	40.860	1.5000	270.6867
5-2	40.860	1.5000	323.8933
6-1	25.652	1.5000	325.8983
6-2	25.652	1.5000	359.3017

Original Flaws Plastic Adjusted Flaws

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Half Crack Angle (deg)	Crack Depth (inch)	Flaw Boundary (deg)
0-1	215083.	42.794	1.5000	-0.3940
0-2	215083.	42.794	1.5000	85.1940
1-1	10784.	2.203	1.5000	84.8974
1-2	10784.	2.203	1.5000	89.3026
2-1	125598.	29.557	1.5000	90.3428
2-2	125598.	29.557	1.5000	149.4572
3-1	39243.	12.199	1.5000	154.9359
3-2	39243.	12.199	1.5000	179.3341
4-1	186223.	41.886	1.5000	179.8941
4-2	186223.	41.886	1.5000	263.6659
5-1	96693.	26.810	1.5000	270.4804
5-2	96693.	26.810	1.5000	324.0996
6-1	81920.	16.850	1.5000	325.7502
6-2	81920.	16.850	1.5000	359.4498

Original Flaws - Plastic Adjusted Results

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)
0-1	220604.	276.999
0-2	220604.	276.999
1-1	10812.	0.665
1-2	10812.	0.665
2-1	140602.	112.521
2-2	140602.	112.521

3-1	39664.	8.955
3-2	39664.	8.955
4-1	215692.	264.802
4-2	215692.	264.802
5-1	101418.	58.545
5-2	101418.	58.545
6-1	90502.	46.620
6-2	90502.	46.620

Incremented Flaws

Flaw Region	Half Crack Length (inch)	Crack Depth (inch)	Flaw Boundary (deg)	Nominal Stress Margin (psi)
0-1	67.249	1.5000	-1.3850	2075.
0-2	67.249	1.5000	86.1850	2075.
1-1	3.548	1.5000	84.7900	2075.
1-2	3.548	1.5000	89.4100	2075.
2-1	47.090	1.5000	89.2400	2075.
2-2	47.090	1.5000	150.5600	2075.
3-1	19.618	1.5000	154.3618	2075.
3-2	19.618	1.5000	179.9083	2075.
4-1	66.249	1.5000	178.6460	2075.
4-2	66.249	1.5000	264.9140	2075.
5-1	42.897	1.5000	269.3600	2075.
5-2	42.897	1.5000	325.2200	2075.
6-1	26.932	1.5000	325.0650	2075.
6-2	26.932	1.5000	360.1350	2075.

Incremented Flaws Crack Extension

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)	Ductile Crack Extension (inch)	Half Crack Length (inch)	Crack Depth (inch)	Flaw Boundary (deg)
0-1	225998.	291.	0.1367	67.386	1.5000	-1.4740
0-2	225998.	291.	0.1367	67.386	1.5000	86.2740
1-1	12153.	1.	0.0000	3.548	1.5000	84.7900
1-2	12153.	1.	0.0000	3.548	1.5000	89.4100
2-1	157483.	141.	0.0336	47.124	1.5000	89.2181
2-2	157483.	141.	0.0336	47.124	1.5000	150.5819
3-1	49144.	14.	0.0004	19.619	1.5000	154.3615
3-2	49144.	14.	0.0004	19.619	1.5000	179.9085
4-1	222450.	282.	0.1285	66.378	1.5000	178.5623
4-2	222450.	282.	0.1285	66.378	1.5000	264.9977
5-1	144028.	118.	0.0237	42.921	1.5000	269.3446
5-2	144028.	118.	0.0237	42.921	1.5000	325.2354
6-1	93912.	50.	0.0045	26.936	1.5000	325.0621
6-2	93912.	50.	0.0045	26.936	1.5000	360.1379

Incremented Flaws Plastic Adjusted Flaws

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Half Crack Angle (deg)	Crack Depth (inch)	Flaw Boundary (deg)
0-1	226484.	45.006	1.5000	-2.6062
0-2	226484.	45.006	1.5000	87.4062
1-1	12153.	2.313	1.5000	84.7867
1-2	12153.	2.313	1.5000	89.4133
2-1	157591.	31.230	1.5000	88.6700
2-2	157591.	31.230	1.5000	151.1300
3-1	49150.	12.827	1.5000	154.3082
3-2	49150.	12.827	1.5000	179.9618
4-1	222905.	44.314	1.5000	177.4656
4-2	222905.	44.314	1.5000	266.0944
5-1	144103.	28.404	1.5000	268.8862
5-2	144103.	28.404	1.5000	325.6938
6-1	93926.	17.733	1.5000	324.8673
6-2	93926.	17.733	1.5000	360.3327

Incremented Flaws - Plastic Adjusted Results

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)
0-1	232694.	308.192
0-2	232694.	308.192
1-1	12201.	0.847
1-2	12201.	0.847
2-1	160326.	146.306
2-2	160326.	146.306
3-1	50360.	14.435
3-2	50360.	14.435
4-1	228894.	298.209
4-2	228894.	298.209
5-1	146344.	121.899
5-2	146344.	121.899
6-1	94884.	51.244
6-2	94884.	51.244

Final Results

Flaw Region	J Applied (KJ/m^2)	dJ (KJ/m^2)	da (m)	dJ/da (N/m^2)	T Applied	Delta A @ J-Applied (mm)	T Material	Specified Margin Achieved (Tmat > Tapp)
0-1	292.595	31.193	0.081	383494.	0.256	3.51617	21.	Yes
0-2	292.595	31.193	0.081	383494.	0.256	3.51617	21.	Yes
1-1	0.756	0.182	0.004	42397.	0.028	0.00003	7918.	Yes
1-2	0.756	0.182	0.004	42397.	0.028	0.00003	7918.	Yes

2-1	129.414	33.785	0.057	593166.	0.397	0.72020	62.	Yes
2-2	129.414	33.785	0.057	593166.	0.397	0.72020	62.	Yes
3-1	11.695	5.481	0.024	230975.	0.154	0.00673	597.	Yes
3-2	11.695	5.481	0.024	230975.	0.154	0.00673	597.	Yes
4-1	281.505	33.407	0.080	416904.	0.279	3.26177	23.	Yes
4-2	281.505	33.407	0.080	416904.	0.279	3.26177	23.	Yes
5-1	90.222	63.354	0.052	1221043.	0.816	0.35722	87.	Yes
5-2	90.222	63.354	0.052	1221043.	0.816	0.35722	87.	Yes
6-1	48.932	4.624	0.033	141944.	0.095	0.10876	155.	Yes
6-2	48.932	4.624	0.033	141944.	0.095	0.10876	155.	Yes

END OF THIS ANALYSIS: 10/19/2018 18:02:47

DLL File for K-Dependent Approach

DLL: DISTRIBUTED LIGAMENT LENGTH EVALUATION, REV. 3.1.2009.11
START OF THIS ANALYSIS: 10/19/2018 18:03:12

Summary Of Inputs:
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Title	: H3 Cooper 25 year inspection interval
Note	: K-Dependent 360 Deg Part Through-Wall Flaw
Flaw Type/Orientation	: SHROUD, Circumferential 360 deg. Part through-wall flaw
Engineering Units	: English
Output Options	: Detailed
Upset Safety Factor, SF	: 2.77
Upset Membrane Stress, Pm	: 355 psi
Upset Bending Stress, Pb	: 287 psi
Faulted Safety Factor, SF	: 1.39
Faulted Membrane Stress, Pm	: 910 psi
Faulted Bending Stress, Pb	: 583 psi
Mean Radius, Rm	: 88.00 inches
Wall Thickness, t	: 1.500 inches
NDE Flaw Length Uncertainty	: 0.000 inches
NDE Flaw Depth Uncertainty	: 0.000 inches
Allowable Stress Intensity, Sm	: 16950 psi
Fluence	: 9.5e+020 n/cm^2

Region	Starting Angle (deg.)	Ending Angle (deg.)	Crack Depth (inches)	Material Thickness (inches)
1	0.0000	360.0000	1.0980	0.4020

Adjusted Flaws Summary - for initial Limit Load Analysis only
==

Region flaw adjusted for:

Examination Uncertainty of 0.00 inches in Length
Examination Uncertainty of 0.00 inches in Depth

Flaw	Start (deg.)	End (deg.)	Length (deg.)	Length (inch)	Depth (inch)
1	0.0000	360.0000	360.0000	552.9203	1.0980

Limit Load Results - Upset Service Level:
===

Note: The following limit load results assume that
the flaws take compression.

Alpha (deg.)	Moment (in-lbs)	Pb' (psi)	Safety Factor	Result
0.0	9.025e+008	24732	39.0760	--->Acceptable

5.0	9.025e+008	24732	39.0760	---->Acceptable
10.0	9.025e+008	24732	39.0760	---->Acceptable
15.0	9.025e+008	24732	39.0760	---->Acceptable
20.0	9.025e+008	24732	39.0760	---->Acceptable
25.0	9.025e+008	24732	39.0760	---->Acceptable
30.0	9.025e+008	24732	39.0760	---->Acceptable
35.0	9.025e+008	24732	39.0760	---->Acceptable
40.0	9.025e+008	24732	39.0760	---->Acceptable
45.0	9.025e+008	24732	39.0760	---->Acceptable
50.0	9.025e+008	24732	39.0760	---->Acceptable
55.0	9.025e+008	24732	39.0760	---->Acceptable
60.0	9.025e+008	24732	39.0760	---->Acceptable
65.0	9.025e+008	24732	39.0760	---->Acceptable
70.0	9.025e+008	24732	39.0760	---->Acceptable
75.0	9.025e+008	24732	39.0760	---->Acceptable
80.0	9.025e+008	24732	39.0760	---->Acceptable
85.0	9.025e+008	24732	39.0760	---->Acceptable
90.0	9.025e+008	24732	39.0760	---->Acceptable
95.0	9.025e+008	24732	39.0760	---->Acceptable
100.0	9.025e+008	24732	39.0760	---->Acceptable
105.0	9.025e+008	24732	39.0760	---->Acceptable
110.0	9.025e+008	24732	39.0760	---->Acceptable
115.0	9.025e+008	24732	39.0760	---->Acceptable
120.0	9.025e+008	24732	39.0760	---->Acceptable
125.0	9.025e+008	24732	39.0760	---->Acceptable
130.0	9.025e+008	24732	39.0760	---->Acceptable
135.0	9.025e+008	24732	39.0760	---->Acceptable
140.0	9.025e+008	24732	39.0760	---->Acceptable
145.0	9.025e+008	24732	39.0760	---->Acceptable
150.0	9.025e+008	24732	39.0760	---->Acceptable
155.0	9.025e+008	24732	39.0760	---->Acceptable
160.0	9.025e+008	24732	39.0760	---->Acceptable
165.0	9.025e+008	24732	39.0760	---->Acceptable
170.0	9.025e+008	24732	39.0760	---->Acceptable
175.0	9.025e+008	24732	39.0760	---->Acceptable
180.0	9.025e+008	24732	39.0760	---->Acceptable
185.0	9.025e+008	24732	39.0760	---->Acceptable
190.0	9.025e+008	24732	39.0760	---->Acceptable
195.0	9.025e+008	24732	39.0760	---->Acceptable
200.0	9.025e+008	24732	39.0760	---->Acceptable
205.0	9.004e+008	24675	38.9869	---->Acceptable
210.0	9.004e+008	24675	38.9869	---->Acceptable
215.0	9.004e+008	24675	38.9869	---->Acceptable
220.0	9.004e+008	24675	38.9869	---->Acceptable
225.0	9.004e+008	24675	38.9869	---->Acceptable
230.0	9.004e+008	24675	38.9869	---->Acceptable
235.0	9.004e+008	24675	38.9869	---->Acceptable
240.0	9.004e+008	24675	38.9869	---->Acceptable
245.0	9.004e+008	24675	38.9869	---->Acceptable
250.0	9.004e+008	24675	38.9869	---->Acceptable
255.0	9.004e+008	24675	38.9869	---->Acceptable
260.0	9.004e+008	24675	38.9869	---->Acceptable
265.0	9.004e+008	24675	38.9869	---->Acceptable
270.0	9.004e+008	24675	38.9869	---->Acceptable
275.0	9.004e+008	24675	38.9869	---->Acceptable
280.0	9.004e+008	24675	38.9869	---->Acceptable
285.0	9.004e+008	24675	38.9869	---->Acceptable
290.0	9.004e+008	24675	38.9869	---->Acceptable
295.0	9.004e+008	24675	38.9869	---->Acceptable

300.0	9.004e+008	24675	38.9869	---->Acceptable
305.0	9.004e+008	24675	38.9869	---->Acceptable
310.0	9.004e+008	24675	38.9869	---->Acceptable
315.0	9.004e+008	24675	38.9869	---->Acceptable
320.0	9.004e+008	24675	38.9869	---->Acceptable
325.0	9.004e+008	24675	38.9869	---->Acceptable
330.0	9.004e+008	24675	38.9869	---->Acceptable
335.0	9.004e+008	24675	38.9869	---->Acceptable
340.0	9.004e+008	24675	38.9869	---->Acceptable
345.0	9.004e+008	24675	38.9869	---->Acceptable
350.0	9.004e+008	24675	38.9869	---->Acceptable
355.0	9.004e+008	24675	38.9869	---->Acceptable

Acceptable. Minimum Safety Factor = 38.9869 at 255.0 Degrees

Limit Load Results - Faulted Service Level:
===

Note: The following limit load results assume that
the flaws take compression.

Alpha (deg.)	Moment (in-lbs)	Pb' (psi)	Safety Factor	Result
0.0	8.688e+008	23807	16.5555	---->Acceptable
5.0	8.688e+008	23807	16.5555	---->Acceptable
10.0	8.688e+008	23807	16.5555	---->Acceptable
15.0	8.688e+008	23807	16.5555	---->Acceptable
20.0	8.688e+008	23807	16.5555	---->Acceptable
25.0	8.688e+008	23807	16.5555	---->Acceptable
30.0	8.688e+008	23807	16.5555	---->Acceptable
35.0	8.688e+008	23807	16.5555	---->Acceptable
40.0	8.688e+008	23807	16.5555	---->Acceptable
45.0	8.688e+008	23807	16.5555	---->Acceptable
50.0	8.688e+008	23807	16.5555	---->Acceptable
55.0	8.688e+008	23807	16.5555	---->Acceptable
60.0	8.688e+008	23807	16.5555	---->Acceptable
65.0	8.688e+008	23807	16.5555	---->Acceptable
70.0	8.688e+008	23807	16.5555	---->Acceptable
75.0	8.688e+008	23807	16.5555	---->Acceptable
80.0	8.688e+008	23807	16.5555	---->Acceptable
85.0	8.688e+008	23807	16.5555	---->Acceptable
90.0	8.688e+008	23807	16.5555	---->Acceptable
95.0	8.688e+008	23807	16.5555	---->Acceptable
100.0	8.688e+008	23807	16.5555	---->Acceptable
105.0	8.688e+008	23807	16.5555	---->Acceptable
110.0	8.688e+008	23807	16.5555	---->Acceptable
115.0	8.688e+008	23807	16.5555	---->Acceptable
120.0	8.688e+008	23807	16.5555	---->Acceptable
125.0	8.688e+008	23807	16.5555	---->Acceptable
130.0	8.688e+008	23807	16.5555	---->Acceptable
135.0	8.688e+008	23807	16.5555	---->Acceptable
140.0	8.688e+008	23807	16.5555	---->Acceptable
145.0	8.688e+008	23807	16.5555	---->Acceptable
150.0	8.688e+008	23807	16.5555	---->Acceptable
155.0	8.688e+008	23807	16.5555	---->Acceptable
160.0	8.688e+008	23807	16.5555	---->Acceptable
165.0	8.688e+008	23807	16.5555	---->Acceptable

170.0	8.688e+008	23807	16.5555	---->Acceptable
175.0	8.688e+008	23807	16.5555	---->Acceptable
180.0	8.688e+008	23807	16.5555	---->Acceptable
185.0	8.688e+008	23807	16.5555	---->Acceptable
190.0	8.688e+008	23807	16.5555	---->Acceptable
195.0	8.688e+008	23807	16.5555	---->Acceptable
200.0	8.688e+008	23807	16.5555	---->Acceptable
205.0	8.688e+008	23807	16.5555	---->Acceptable
210.0	8.688e+008	23807	16.5555	---->Acceptable
215.0	8.688e+008	23807	16.5555	---->Acceptable
220.0	8.688e+008	23807	16.5555	---->Acceptable
225.0	8.688e+008	23807	16.5555	---->Acceptable
230.0	8.688e+008	23807	16.5555	---->Acceptable
235.0	8.688e+008	23807	16.5555	---->Acceptable
240.0	8.688e+008	23807	16.5555	---->Acceptable
245.0	8.688e+008	23807	16.5555	---->Acceptable
250.0	8.688e+008	23807	16.5555	---->Acceptable
255.0	8.688e+008	23807	16.5555	---->Acceptable
260.0	8.688e+008	23807	16.5555	---->Acceptable
265.0	8.688e+008	23807	16.5555	---->Acceptable
270.0	8.688e+008	23807	16.5555	---->Acceptable
275.0	8.688e+008	23807	16.5555	---->Acceptable
280.0	8.688e+008	23807	16.5555	---->Acceptable
285.0	8.688e+008	23807	16.5555	---->Acceptable
290.0	8.688e+008	23807	16.5555	---->Acceptable
295.0	8.688e+008	23807	16.5555	---->Acceptable
300.0	8.688e+008	23807	16.5555	---->Acceptable
305.0	8.688e+008	23807	16.5555	---->Acceptable
310.0	8.688e+008	23807	16.5555	---->Acceptable
315.0	8.688e+008	23807	16.5555	---->Acceptable
320.0	8.688e+008	23807	16.5555	---->Acceptable
325.0	8.688e+008	23807	16.5555	---->Acceptable
330.0	8.688e+008	23807	16.5555	---->Acceptable
335.0	8.688e+008	23807	16.5555	---->Acceptable
340.0	8.688e+008	23807	16.5555	---->Acceptable
345.0	8.688e+008	23807	16.5555	---->Acceptable
350.0	8.688e+008	23807	16.5555	---->Acceptable
355.0	8.688e+008	23807	16.5555	---->Acceptable

Acceptable. Minimum Safety Factor = 16.5555 at 200.0 Degrees

Adjusted Flaws Summary - for LEFM, EPFM and Crack Growth Analysis
===

Region flaw adjusted for:

Examination Uncertainty of 0.00 inches in Length
Examination Uncertainty of 0.00 inches in Depth

Flaw	Start (deg.)	End (deg.)	Length (deg.)	Length (inch)	Depth (inch)
1	0.0000	360.0000	360.0000	552.9203	1.0980

EPFM Results - Specified Margin On Load Method - Upset Service Level:
==

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Poisson's Ratio : 0.30
Elastic Modulus : 2.8e+007 psi
Flow Stress : 77931.9 psi
Yield Stress : 68517.6 psi
C : 153.221
n : 0.514491

Original Flaws

Flaw Region	Crack Depth (inch)	Flaw Boundary (inch)	Nominal Stress Margin (psi)	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)	Ductile Crack Extension (inch)
0-1	1.09800	0.00000	1778.	25130.	3.594	0.000027
0-2	1.09800	1.09800	1778.	25130.	3.594	0.000027

Original Flaws - Crack Extension

Flaw Region	Crack Depth (inch)	Flaw Boundary (inch)
0-1	1.09803	0.00000
0-2	1.09803	1.09803

Original Flaws Plastic Adjusted Flaws

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Crack Depth (inch)	Flaw Boundary (inch)
0-1	25133.	1.10516	0.00000
0-2	25133.	1.10516	1.10516

Original Flaws - Plastic Adjusted Results

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)
0-1	25930.	3.827
0-2	25930.	3.827

Incremented Flaws

Flaw Region	Crack Depth (inch)	Flaw Boundary (inch)	Nominal Stress (psi)	Margin
0-1	1.15290	0.00000	1778.	
0-2	1.15290	1.15290	1778.	

Incremented Flaws Crack Extension

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)	Ductile Crack Extension (inch)	Crack Depth (inch)	Flaw Boundary (inch)
0-1	32374.	5.965	0.000000	1.15290	0.00000
0-2	32374.	5.965	0.000000	1.15290	1.15290

Incremented Flaws Plastic Adjusted Flaws

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Crack Depth (inch)	Flaw Boundary (inch)
0-1	32374.	1.16474	0.00000
0-2	32374.	1.16474	1.16474

Incremented Flaws - Plastic Adjusted Results

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)
0-1	34343.	6.713
0-2	34343.	6.713

Final Results

Flaw Region	J Applied (KJ/m^2)	dJ (KJ/m^2)	da (m)	dJ/da (N/m^2)	T Applied @ J-Applied	Delta A (mm)	T Material	Specified Margin Achieved (Tmat > Tapp)
0-1	5.270	2.886	0.001	2069715.	1.384	0.00143	1268.	Yes
0-2	5.270	2.886	0.001	2069715.	1.384	0.00143	1268.	Yes

EPFM Results - Specified Margin On Load Method - Faulted Service Level:
===

Poisson's Ratio : 0.30
Elastic Modulus : 2.8e+007 psi
Flow Stress : 77931.9 psi
Yield Stress : 68517.6 psi
C : 153.221
n : 0.514491

Original Flaws

Flaw Region	Crack Depth (inch)	Flaw Boundary (inch)	Nominal Stress Margin (psi)	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)	Ductile Crack Extension (inch)
0-1	1.09800	0.00000	2075.	29326.	4.895	0.000049
0-2	1.09800	1.09800	2075.	29326.	4.895	0.000049

Original Flaws - Crack Extension

Flaw Region	Crack Depth (inch)	Flaw Boundary (inch)
0-1	1.09805	0.00000
0-2	1.09805	1.09805

Original Flaws Plastic Adjusted Flaws

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Crack Depth (inch)	Flaw Boundary (inch)
0-1	29332.	1.10777	0.00000
0-2	29332.	1.10777	1.10777

Original Flaws - Plastic Adjusted Results

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)
0-1	30611.	5.333
0-2	30611.	5.333

Incremented Flaws

Flaw Region	Crack Depth (inch)	Flaw Boundary (inch)	Nominal Stress (psi)	Margin
0-1	1.15290	0.00000	2075.	
0-2	1.15290	1.15290	2075.	

Incremented Flaws Crack Extension

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)	Ductile Crack Extension (inch)	Crack Depth (inch)	Flaw Boundary (inch)
0-1	37780.	8.124	0.000000	1.15290	0.00000
0-2	37780.	8.124	0.000000	1.15290	1.15290

Incremented Flaws Plastic Adjusted Flaws

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Crack Depth (inch)	Flaw Boundary (inch)
0-1	37780.	1.16903	0.00000
0-2	37780.	1.16903	1.16903

Incremented Flaws - Plastic Adjusted Results

Flaw Region	Stress Intensity Factor (psi-(in)^.5)	Applied J-Integral (KJ/m^2)
0-1	40961.	9.550
0-2	40961.	9.550

Final Results

Flaw Region	J Applied (KJ/m^2)	dJ (KJ/m^2)	da (m)	dJ/da (N/m^2)	T Applied @ J-Applied	Delta A (mm)	T Material	Specified Margin Achieved (Tmat > Tapp)
0-1	7.442	4.216	0.001	3023666.	2.022	0.00280	915.	Yes
0-2	7.442	4.216	0.001	3023666.	2.022	0.00280	915.	Yes

END OF THIS ANALYSIS: 10/19/2018 18:03:20

APPENDIX B

TECHNICAL BASIS FOR THROUGH-WALL CRACK GROWTH BASED ON WELD RESIDUAL STRESS

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Stresses in BWR core shroud welds consist of operational stresses and fabricated-related stresses. Operational stresses occur during normal plant operation. These are the Pm and Pb stresses in Section 6.0, Item 3 for Service Level A/B. Fabrication stresses consist mainly of weld residual stresses (WRS) resulting from the welding process of the shroud plates and rings. BWRVIP-14-A [5] contains extensive investigation into the WRS distribution on the core shroud, including through-wall distributions and H3 weld specific finite element models.

The axial WRS for a circumferential weld has tensile and compressive portions at different locations through the shroud wall thickness. A normalized through-wall fracture toughness K distribution is taken from Table 5-1 [5] and adjusted for the CNS should thickness of 1.5 inches. This data was calculated using a 360° part through-wall flaw, which is directly comparable to the K-dependent approach in this calculation package (see Figure 6). The CNS adjust K distribution is shown in Figure 7.

Figure 7. Weld Residual Stress Distribution for CNS H3 Weld

Based on Figure 7,{ }}In order to determine if a crack will go into compression and arrest, operational stresses and K values must also be determined. The DLL file for the K-dependent analysis in Appendix A is modified to consider linear-elastic fracture mechanics (LEFM) by increasing the fluence to 1E23 n/cm^2. Multiple runs can be made with various part through-wall depths in order to get an operational load K distribution similar to Figure 7. Finally, a combined K distribution can be obtained by adding the WRS and operational load K values. Note that since only normal operating loads drive IGSCC growth, K factors for Service Level A/B loading are used from DLL.

Figure 8 shows the WRS K value in Figure 7 with operational K factors calculated by DLL, and combined K factors of WRS + operational K values.

Figure 8. Weld Residual Stress Distribution for CNS H3 Weld

Based on Figure 8, combined operational and WRS K values become negative with a flaw about 0.92" deep. This means that a 360° part through-wall flaw is likely to arrest at or before 0.92" deep since the crack will be in compression.

There are a couple of conservatisms in this analysis to specifically mention:

1. Deadweight loads are conservatively omitted in the Pm load calculation in Reference [10]. This is conservative since deadweight increases the compressive load the H3 weld experiences.
2. *{{*

}}

Figure 9. Standard WRS Axial Stress Distribution vs. TEPCO H3 Weld Axial Stress Distribution [5, Figure 4-2 and H-19]

It can be concluded that, based on the weld residual stress in the CNS H3 weld, there is technical justification for why an ID crack would arrest through-wall and why the OD surface has significantly less tensile stress to drive crack initiation and growth.

APPENDIX C

SUMMARY OF BWR OPERATING EXPERIENCE FOR CORE SHROUD H3 WELD CRACKING

BWRVIP-278 [15] provides the most complete, updated fleet-wide data for core shroud cracking. Average flaw depth sizes for the H1 to H7 welds on the plate side are shown in Figure 10. Figure 11 shows the depth distribution for the ring side of horizontal welds, including weld H3. Two observations can be made from these figures:

1. For the plate side, the maximum extent of cracking at the H3 weld is *{{*

   }}.

   So, 30% to 50% through-wall cracking on the plate side of the H3 weld, as seen in the CNS data [3], is not unprecedented.

2. *{{*

   }}

Figure 10. BWRVIP-278 Plate Side Horizontal Weld Average Flaw Depth [15, Figure 3-17]

Figure 11. BWRVIP-278 Ring Side Horizontal Weld Average Flaw Depth [15, Figure 3-18]

Based on the industry operating experience provided in BWRVIP-278, the CNS data is in-line with industry experience and the assumption of equivalent cracking on the plate and ring side is reasonable.