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RS-06-088

July 17, 2006

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

Braidwood Station, Units 1 and 2
Facility Operating License Nos. NPF-72 and NPF-77
NRC Docket Nos. STN 50-456 and STN 50-457

Byron Station, Units 1 and 2
Facility Operating License Nos. NPF-37 and NPF-66
NRC Docket Nos. STN 50-454 and STN 50-455

Subject: Requested Information Concerning Pressurizer Heater Sleeve Flaw at Braidwood Station

In a teleconference on May 31, 2006, Exelon Generation Company, LLC (EGC) provided information to the NRC regarding the discovery, evaluation, and repair of a flaw in a pressurizer heater sleeve weld at Braidwood Station Unit 1. EGC identified and repaired this flaw at Braidwood Station Unit 1 during the Spring 2006 refueling outage.

During the May 31, 2006 teleconference, the NRC requested additional information concerning: 1) the fabrication history of pressurizer heater sleeves at both Braidwood and Byron Stations; 2) the results of a metallurgical evaluation of the flaw; and 3) the operability assessment for all of the remaining pressurizer heater sleeves.

Attachment 1 to this letter provides the number of heater sleeves from each unit at Braidwood and Byron that were fabricated from the Material Heat of the flawed heater sleeve. Attachment 2 provides a metallurgical evaluation of the flaw. Attachment 3 provides Braidwood Station Operability Evaluation 06-002, Revision 2. Attachment 4 provides an operability assessment for the remaining heater sleeves at Braidwood and Byron Stations that was developed by Westinghouse Electric Company LLC (Westinghouse). The Westinghouse operability assessment includes a fracture mechanics evaluation (i.e., a crack growth calculation and leakage assessment). The information in Attachments 2 and 4 have been incorporated into the Braidwood Station Operability Evaluation, which is provided in Attachment 3.

Attachment 4 contains information proprietary to Westinghouse Electric Company LLC. Therefore, EGC requests that this information be withheld from public disclosure in accordance with 10 CFR 2.390, "Public inspections, exemptions, requests for withholding," paragraph (b)(4), and 10 CFR 9.17, "Agency records exempt from public disclosure," paragraph (a)(4). Attachment 5 provides an affidavit that sets forth the basis on which the information may be withheld from public disclosure by the NRC and addresses with specificity the considerations listed in 10 CFR 2.390, paragraph (b) (4). Attachment 6 provides a non-proprietary version of the document.

During a subsequent teleconference on June 8, 2006, the NRC requested additional information concerning the Braidwood Station Operability Evaluation and the source documents (i.e., the metallurgical evaluation provided in Attachment 2 and the Westinghouse operability assessment provided in Attachment 4). This additional requested information included the critical depth size without safety factors for a part through-wall 360° crack, and the critical crack size without safety factors for a through-wall crack. This requested information is provided below, and has been incorporated into Braidwood Station Operability Evaluation 06-002, Revision 2.

Question 1:
What is the critical depth size without safety factors for a part through wall 360° crack?

Answer:
Critical depth ratio without any safety margins, that is, depths at which the incipient plastic collapse stress equals the axial applied stress, for the full-circumferential inside surface part-through-wall flaw for the pressurizer heater sleeve at the butt-weld for the internal pressure loading under operating loading conditions is 91% of the wall thickness for the ASME Code minimum strength properties. The critical crack depth would be greater if the calculation is based on the actual material properties from any of the four heats used in the EGC heater sleeve tubes. This is computed using the ASME Code Section XI Division 1 Appendix C membrane stress incipient collapse load equations with flaw angle around the circumference of 360°.

Question 2:
What is the critical crack size without safety factors for a through wall crack?

Answer:
Critical circumferential flaw length without any safety margins, that is, length at which the incipient plastic collapse stress equals the applied axial stress, for the circumferential through-wall flaw for the pressurizer heater sleeve at the butt-weld for the internal pressure loading under operating loading conditions is computed as 212° around the circumference of the tube for the ASME Code minimum strength properties. The critical crack length would be greater if the calculation is based on the actual material properties from any of the four heats used in the EGC heater sleeve tubes. This is computed using the ASME Code Section XI Division 1 Appendix C membrane stress incipient collapse load equations with flaw depth ratio $a/t = 1$.

Should you have any questions concerning this information, please contact Mr. John L. Schrage at (630) 657-2821.

Respectfully,

Joseph A. Bauer

Joseph A. Bauer
Manager - Licensing

Attachments:

1. Fabrication Information, Braidwood Station and Byron Station Pressurizer Heater Sleeves
2. Metallurgical Evaluation, Number 52 Pressurizer Heater Assembly, Braidwood Unit 1
3. Braidwood Station Operability Evaluation 06-002, Revision 2
4. Westinghouse Electric Company LLC Operability Assessment, Braidwood Units 1 & 2 and Byron Units 1 & 2 Pressurizer Heater Sleeves (Proprietary)
5. Westinghouse Electric Company LLC Affidavit
6. Westinghouse Electric Company LLC Operability Assessment, Braidwood Units 1 & 2 and Byron Units 1 & 2 Pressurizer Heater Sleeves (Non-Proprietary)

ATTACHMENT 1

Fabrication Information

Braidwood Station and Byron Station Pressurizer Heater Sleeves

1. Number of Pressurizer Heater Sleeves Fabricated from the Material Heat of the Flawed Braidwood Heater Sleeve

Unit	**Number of Affected Heater Sleeves**[1]
Braidwood Unit 1	70
Braidwood Unit 2	78
Byron Unit 1	14
Byron Unit 2	0

[1] The pressurizer for each unit is equipped with 78 heaters.

ATTACHMENT 2

Metallurgical Evaluation

Number 52 Pressurizer Heater Assembly
Braidwood Unit 1

Exelon PowerLabs

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To: Carl Dunn, Braidwood Station
Dan Skoza, Braidwood Station

From: Jim Chynoweth
(815) 458-7598
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Project Number: BRW-02989

Subject: **Metallurgical Evaluations of a Leak in the #52 Heater Assembly on the Braidwood Unit 1 Pressurizer**

ATI #480489, Westinghouse Pressurizer Heater

Date: 05/24/2006

DESCRIPTION AND BACKGROUND

During the Braidwood A1R12 refueling outage, boric acid deposits were detected on insulation located below the pressurizer. The precise leak location could not be confirmed by field non-destructive examinations. However, based on the deposit patterns, deposit chemical analysis and insulation impingement marks, it was concluded that a small primary coolant leak occurred in the upper socket weld for the #52 heater coupling. The component configuration and specified materials are shown in Figure 1.

The #52 heater and approximately two inches of the pressure tube above the suspect weld were removed. This report summarizes the laboratory testing and metallurgical failure analysis of the removed components. Due to radioactive sample contamination, the evaluations were performed at the BWXT Services, Inc. laboratory in Lynchburg, Virginia under the direction of Exelon PowerLabs.

CONCLUSIONS

The primary system leak was located in the pressure tube heat-affected zone, approximately 0.090" above the upper coupling weld toe. The leak occurred at the 110° orientation, which is near the insulation impingement mark that was identified during the outage inspections.

The failure was caused by circumferential, intergranular stress corrosion cracking (IGSCC) that initiated from the inner surface of the pressure tube. The cracking propagated thru the pressure tube heat-affected zone, which was heavily sensitized during fabrication of the multi-pass socket weld. There was an adequate gap in the socket-welded connection and the fillet weld leg lengths met the design requirements.

The leak coincided with a 0.005" deep grinding mark on the external surface of the tube. While the grinding may have contributed to the thru wall location by reducing the local thickness, it was not considered a primary cause for the internally initiated cracking.

EPRI materials literature indicates sensitized 300 series stainless steels can be susceptible to IGSCC in stagnant or dead end PWR coolant environments that contain oxygen. Qualitative EDS evaluations identified a high oxygen content in the crack deposits, which indicates the crevice region that initiated the cracking was exposed to an oxygenated environment.

Semi-quantitative EDS evaluations indicated the component materials were consistent with the specified chemical grades (i.e., Type 316 stainless steel for the pressure tube and coupling, Type 308L stainless steel for the upper coupling weld.)

The pressure tube material exhibited two microstructural anomalies that were likely related to the fabrication process: 1) The tube material had a duplex grain size that ranged from ASTM #2/3 to ASTM #8/9, and 2) The tube material within 0.006" of the inner diameter surface was potentially susceptible to intergranular corrosion based on local grain boundary ditching during an ASTM A262-Practice A test. Since the IGSCC initiated from the inner diameter of the tube, the presence of a susceptible, inner surface layer would have contributed to crack initiation.

The metallurgical sections revealed evidence of crack tip blunting in the secondary crack branches near the outer diameter of the thru wall leak. The blunted appearance suggests the cracks were present for a relatively long period of time and the crack growth rate was relatively low.

No evidence of intergranular corrosion or cracking was detected in a metallurgical section thru the crevice region for the lower coupling to heater sheath weld.

REQUIREMENTS AND TEST PLAN

The testing goals were to precisely determine the leak location and characterize the failure mechanism. The following test plan was reviewed and approved by a PowerLabs ANSI Level III. The test plan was also reviewed by Braidwood and Corporate Engineering personnel.

1. Perform visual and macroscopic inspections of the samples. Photograph relevant features and document the general condition of the coupling welds.
2. Ultrasonically clean the samples in iso-propanol or acetone.
3. Perform a fluorescent dye penetrant examination of the external component surfaces. Use an extended dwell time of at least 60 minutes to maximize sensitivity.
4. Examine the sample surface using a stereoscope.
5. Attach Tygon tubing to the upper end of the heater sample and perform a low pressure (90 psi minimum) helium leak test.
6. Perform an ultrasonic shear wave examination of the upper coupling weld. Use 60 degree

and/or 45 degree inspection angles and examine the weld from the coupling and pressure tube surfaces.

7. Section the sample as necessary to allow for steps 8, 9 and 10.
8. Examine areas of interest using BWXT's real-time, microfocus X-ray system. (Optional Test)
9. Metallographic examinations
10. Scanning electron microscope (SEM) and Energy Dispersive Spectroscopy (EDS).

The laboratory work was performed by BWXT Services, Incorporated under Exelon PowerLabs PO 00059971-00001-2006050069. The NDE evaluations were observed by an Areva Level III. The metallurgical evaluations were observed by an Exelon PowerLabs metallurgical engineer.

The assigned and certified technicians to perform the Project Test Plan: BWXT Services.
Applicable Specification: N/A Year/Revision: N/A Hold Points: No
Test plan approved by: J. Chynoweth 05/04/2006
(Qualified ANSI Level III Signature)

RESULTS AND OBSERVATIONS

Visual Inspection

The as-received components are shown in Figures 2 and 3. Sample 1 contained the lower heater end, heater coupling and approximately ¾" of the pressure tube. Sample 2 was a ring section that measured approximately 1¼" long, which was removed from the pressure tube area immediately above sample 1. Sample 2 contained an axial surface discoloration that provided a false 'positive' dye penetrant indication during the initial field inspections. The discoloration measured approximately 1" long x 0.3" wide.

Both samples had been scribed to identify the component side that was oriented toward the outer diameter of the pressurizer during service. In this report, the scribe marks will be the '0' degree position and circumferential orientations will be referenced in a clockwise manner as looking upward toward the bottom of the heater. Using this convention, the suspected leak location was near the 90° position of the upper coupling weld, based on the insulation impingement pattern that was observed in the field. The sample 2 surface discoloration was located near the 250° to 270° degree positions.

The external surfaces of the heater sheath, coupling, coupling welds and pressure tube were in generally good condition. The welds exhibited local regions of grinding/polishing (Figures 4-7). The final weld quality and weld profiles were relatively good, although there was a minor geometry change at a weld pass stop point near the 135° position. The fillet legs exceeded the 0.19" design minimum at all locations. No cracking was observed.

External NDE and Stereoscope Examinations

The extended dwell time, fluorescent dye penetrant examination identified one very faint indication in the sample 1 pressure tube section (Figure 8). The indication measured approximately 1/64" long and was located approximately 3/32" above the toe of the upper coupling weld, near the 110° orientation. Since the indication was associated with a shallow external grinding mark, it was initially believed that the indication was related to the grinding and was not source of the thru wall leak. However, subsequent laboratory sectioning confirmed that the indication was the thru wall portion of the leak.

Stereoscope photos of the external dye penetrant indication are provided in Figures 9 and 10. The indication followed an external grinding mark and was angled by approximately 20° to the circumferential direction. Based on stereoscope photo measurements, the angled portion of the dye penetrant indication measured 0.023" long and was located approximately 0.090" to 0.110" from the toe of the upper coupling weld. The external grinding mark measured approximately 0.005" deep.

The low pressure, 90 psi helium leak test did not detect the thru wall leak. This suggests the leak path was very tight and/or filled with deposits.

No indications were detected by the ultrasonic inspections of the upper and lower coupling welds.

The surface discoloration on sample 2 was examined in a stereoscope. The surface had a rough texture that appeared to retain traces of oxide or foreign material. No cracking was identified.

Internal Inspections and NDE

The coupling was transversely sectioned to allow for removal of the internal heater. In order to remove the heater, the heater required moderate tapping with a rod and hammer. Portions of the heater sheath surface were covered with black and grayish-white deposits (Figure 11). Away from the deposits, the sheath diameter measured 0.872" to 0.874". The deposits measured up to 0.030" thick.

The samples were axially sectioned thru the 0° and 180° locations to allow for inspections of the internal surfaces. A visual inspection identified at least 1/16" of gap at the base of the coupling's upper socket connection (Figure 12). The gap size was consistent around the sample, which suggests the pressure tube was relatively straight within the socket. There was no evidence of an axial seam weld.

The upper weld region was examined using the real-time, micro-focus X-ray system. The examination detected linear circumferential indications in the pressure tube region that surrounded the dye penetrant indication. As shown in Figure 13, there were several closely spaced branches between the 70° to 140° positions. There were no indications in the socket weld or adjacent coupling material.

Stereoscope inspections were performed on the exposed inner diameter of the pressure tube. Linear circumferential cracking was detected between the 40 to 190 degree positions (Figures 14 and 15). Near the 130° position, one of the crack branches turned and propagated in an axial manner for approximately 1/8". Traces of grayish-white deposits were present near the cracking. There was also evidence of internal, circumferential boring in regions that did not contain deposits. In several areas, there were local patches of axial scuffing and/or pitting.

Metallographic Examinations

Six axially oriented metallographic samples were prepared thru the 40°, 65°, 110°, 140°, 180° and 270° positions of the sample 1 pressure tube. The mounted sections included the upper coupling weld, adjacent coupling, pressure tube heat-affected zone and HAZ cracking.

Macro-etching revealed the coupling to pressure tube socket weld was fabricated using 5 or more passes (Figures 16-18). The tube side fillet legs measured 0.2" to 0.32" long and the coupling side legs measured 0.22" to 0.26" long. In general the shortest leg lengths were located near 110° (leak) position. All the leg lengths met the 0.19" minimum design length. All the weld sections exhibited good penetration at the root and relatively deep penetration into both base metal components. The pressure tube wall thickness measured 0.108" near the thru wall leak and up to 0.113" in the other evaluated sections.

Microscopic examinations were performed on the six axial sections thru the upper coupling weld and representative photos are provided in Figures 19 thru 26. The results are summarized below.

1. All evaluated sections contained branched, intergranular cracks that initiated from the internal surface of the pressure tube (Figures 19, 20 and 21). The cracks were located in the heat-affected zone for the upper coupling weld. At some locations, multiple cracks were present in the evaluated section (Figure 22). No transgranular features were observed. There was no cracking in the coupling or weld.
2. The thru wall leak exhibited branched, intergranular features that were consistent with the intergranular cracking observed in the other sections (Figures 23, 24 and 25). Portions of the thru wall crack and secondary branches were oxide-filled. Near the external tube surface, the crack tips on the secondary branches were blunted, which suggests the cracking had been present for a long period of time and the crack growth rate was relatively slow.
3. The following maximum crack depths were measured in the axial sections: 0.010" in the 40° section, 0.070" at 65°, 0.090" at 90°, thru wall at 110°, 0.030" at 140°, 0.002" at 180°, and 0.015" at 270°.
4. Based on the grain boundary ditching after oxalic acid etching, portions of the pressure tube heat-affected zone microstructure were heavily sensitized, particularly near the inner surface of the tube.
5. The tube microstructure throughout the samples exhibited a duplex grain size. The largest grains were similar to ASTM size 2/3 and the small grains were similar to ASTM size 8/9. In general, the percentage of small grains increased near the inner diameter surface.
6. The microstructure at the inner diameter of the tube (i.e., the bored/reamed surface) did not exhibit a large amount of grain twinning or grain deformation.
7. Patches of shallow, intergranular oxide-filled penetrations were observed at multiple heat-affected zone locations on the inner surface of the evaluated sections (Figure 26). The depth of the intergranular penetrations was typically less than 0.002".

A circumferential metallurgical section was prepared thru the axial surface discoloration in sample 2. The section was located approximately 1¾" above the coupling's upper weld toe, which is considered representative of a tube location that is outside of the weld heat-affected zone. The tube microstructure contained duplex grains that were similar to the grains observed in the weld area sections (Figure 27). No microstructural anomalies were associated with the surface discoloration.

The inner surface of the tube contained shallow, intergranular oxide-filled penetrations that were less than 0.001" deep (Figure 28).

The pressure tube material in the circumferential metallurgical mount was evaluated for susceptibility to intergranular corrosion per ASTM A262, Practice A (i.e., oxalic acid etch test). After the test exposure, the microstructure along the inner surface exhibited a 'dual structure', which means there was partial grain boundary ditching that did not completely surrounding any single grain (Figure 29). The presence of the grain boundary ditching indicates the material near the inner diameter surface could be susceptible to intergranular corrosion in some environments. The grain boundary ditching was only observed within 0.006" of the inner surface of the tube. The microstructure in the remainder of the tube (i.e., away from the weld and away from the inner diameter surface) exhibited a 'stepped structure', which means it would have a low susceptibility to intergranular corrosion. The presence of grain boundary ditching in a tube sample away from the weld region suggests the near-surface intergranular susceptibility was not related to the welding process.

The coupling was also examined after the ASTM A262, Practice A exposure. The testing indicated the coupling material was not susceptible to intergranular corrosion, except for a local region in the weld heat-affected zone (Figure 30). The coupling base metal did not exhibit a duplex grain size.

For comparison purposes, an axial metallurgical mount was also prepared thru the lower coupling weld and base metal components. As shown in Figure 31, the lower weld was also fabricated using 5 or more passes. A microscopic exam detected no evidence of intergranular corrosion or cracking in the wetted crevice between the heater sheath and the coupling (Figure 32).

Scanning Electron Microscope and EDS Evaluations

Semi-quantitative EDS chemistry evaluations were performed on the pressure tube, coupling and upper coupling weld. A representative spectrum for the pressure tube is shown in Figure 33. The tube and coupling material compositions were consistent with Type 316 stainless steel, which was the specified material chemistry for these components (i.e., SA-213, TP316 and SA-182, Gr. F316). The weld metal chemistry was typical of a diluted 300 series stainless steel filler metal that contains less molybdenum than Type 316 (e.g., Type 308/308L stainless steel). It should be noted, the EDS technique cannot accurately measure elements that may be present at low concentrations (e.g., carbon).

The pressure tube crack between the 90 and 110 degree positions was exposed by laboratory bending. As shown in Figure 34, the crack surface was covered with a heavy accumulation of gray and dark deposits. Based on the deposit pattern, the crack depth measured approximately 0.090" deep toward the 90° end of the sample and was greater than 90% thru wall throughout most of the exposed length. Scanning electron microscopy revealed the crack surface had intergranular features in regions that were not shielded by surface deposits (Figure 35). Near the 110° (leak) side of the exposed crack, the intergranular features extended to the external surface of the tube.

The crack surface deposits were qualitatively evaluated using EDS techniques and a representative spectrum is shown in Figure 36. The deposits contained a high oxygen peak and lesser amounts of iron, chromium, nickel and molybdenum, which is consistent with Type 316 stainless steel oxidation/corrosion products. The deposits were also evaluated at a low accelerating voltage to enhance the detection of elements with low voltage peaks (e.g., chlorine). The resulting spectrum contained oxygen and boron (Figure 37), which is consistent with boric acid deposits. Similar results were obtained for deposits collected from the outer diameter of the heater sheath.

EDS evaluations were also performed on the material within a relatively shallow crack on a metallurgical mount (Figures 38 and 39). The resulting spectrum was consistent with base metal corrosion/oxidation products (i.e., oxygen, iron, chromium, nickel and molybdenum).

DISCUSSION AND COMMENTS

The pressure tube material was specified as ASME SA-213, TP316, which allows for up to 0.08 wt.% carbon. Based on the CMTR data retrieved by the site, the Unit 1 pressure tubes were fabricated from two material heats that contained 0.055% carbon. Since Type 316 stainless steel is not a low carbon grade, it is susceptible to grain boundary sensitization when it was exposed to elevated temperatures (e.g., during welding). As a result, the presence of a sensitized microstructure in the pressure tube heat-affected zone is not considered abnormal. Due to the thin nature of the pressure tube component, it is not abnormal that the heat-affected zone extended to the inner diameter of the tube, particularly for a multi-pass socket weld that exhibited deep penetration. Westinghouse technical personnel reported the presence of multi-pass welds is not abnormal for the weld sizes present in the samples.

The branched, intergranular cracking that resulted in the leak is typical of intergranular stress corrosion cracking (IGSCC). EPRI materials literature indicates IGSCC is relatively uncommon for Type 304 or Type 316 stainless steel in a PWR environment. However, IGSCC was reported in several situations where heavily sensitized stainless steel was exposed to a stagnant, oxygenated coolant environment (Reference: EPRI TR-10002792, 'Materials Handbook for Nuclear Plant Pressure Boundary Applications', Chapter I, Pg. 3-35). The EPRI document also indicated ions such as chlorides, fluorides, sulfates and thiosulfates could promote stress corrosion cracking.

The pressurizer heater design results in a dead end crevice between the outer diameter of the heater sheath and the inner diameter of the pressure tube. If the crevice was exposed to an oxygenated PWR environment, the sensitized regions in the Type 316 pressure tube could be susceptible to IGSCC. Based on the detected oxygen in the EDS evaluations of the crack deposits, the crevice was exposed to an oxygen containing environment.

Based on the partially ditched microstructure observed after the ASTM A262, Practice A testing, the pressure tube material within 0.006" of the inner diameter surface is potentially susceptible to intergranular corrosion. Since the grain boundary attack was observed in areas away from the weld heat-affected zone, the susceptibility was not related to heating from the welding process. The presence of a locally susceptible microstructure would have contributed to intergranular crack initiation on the inner diameter of the tube. It would also explain why there were shallow intergranular penetrations on the inner surface of a tube section that was approximately 1¾" away from the weld toe.

The presence of duplex grains in the pressure tube microstructure is not considered typical of standard tube manufacturing processes. However, the duplex grains would not be prohibited by the pressure tube material specification (i.e., ASME SA-213, TP316). The presence of the duplex grains and an inner diameter microstructure that is potentially susceptible to intergranular corrosion suggests there may have been process anomalies during tube fabrication.

The internal surface of the pressure tube contained internal machining marks, which indicated the surface had been bored or reamed. If the residual stresses from the boring/reaming process were high, it is possible that the boring contributed to the IGSCC initiation.

STATEMENT OF QUALITY

Testing was performed with standards and/or equipment that have accuracies traceable to nationally recognized standards or to physical constants, by qualified personnel, and in accordance with the **Exelon** PowerLabs Quality Assurance Program revision 17 dated 08/30/2005.

Technicians: BWXT Services, Inc.

Prepared/Approved by: *Jim Chynoweth*
Senior Metallurgical Engineer 05/24/2006

Reviewed by: *Bernard W. Piechalak*
Manager, Tech Services West 05/24/2006

Project review and approval is electronically authenticated in Exelon PowerLabs project record.

cc: R. Gesior, Asset Mgmt. & Engr. Prog., Cantera
R. Hall, Engr. Prog., Cantera
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PowerLabs F/A Fleet Distribution

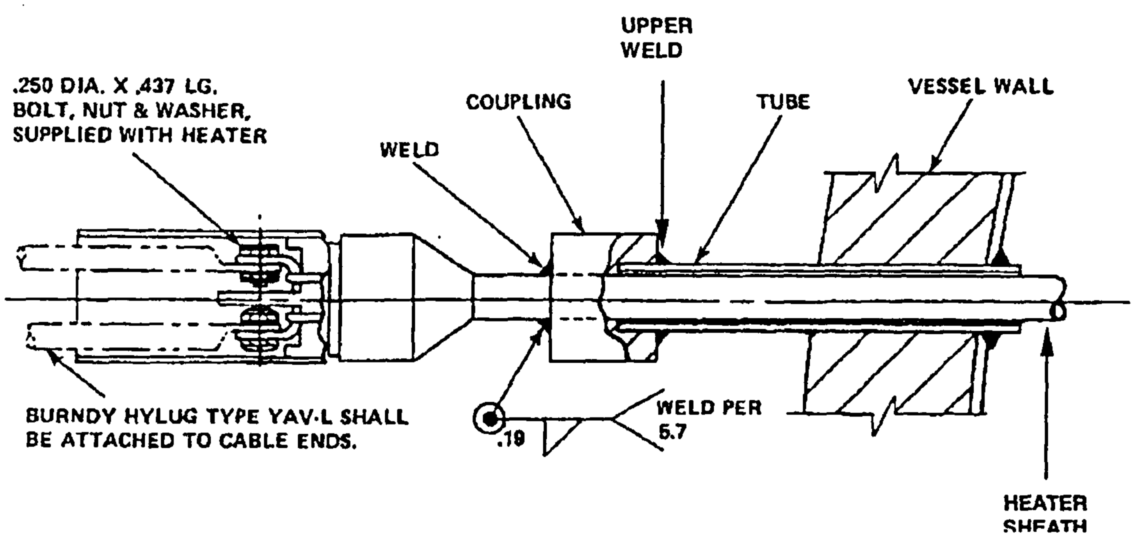


Figure 1 – A drawing that illustrates the general configuration of the pressurizer heater components. Based on Westinghouse drawing EDSK-379353B, the pressure tube was fabricated from SA-213, TP316 stainless steel and had nominal dimensions of 1.125" OD x 0.110" thick. The pressure tube was socket welded to the upper side of the coupling, which was fabricated from SA-182, Gr. F316 stainless steel. Fabrication records indicated the weld filler metal was Type 308L stainless steel. The heater sheath was fillet welded to the lower side of the coupling and extends thru the inner diameter of the pressure tube into the pressurizer vessel. During service, the crevice between the heater sheath and the pressure tube is exposed to wetted, stagnant conditions.

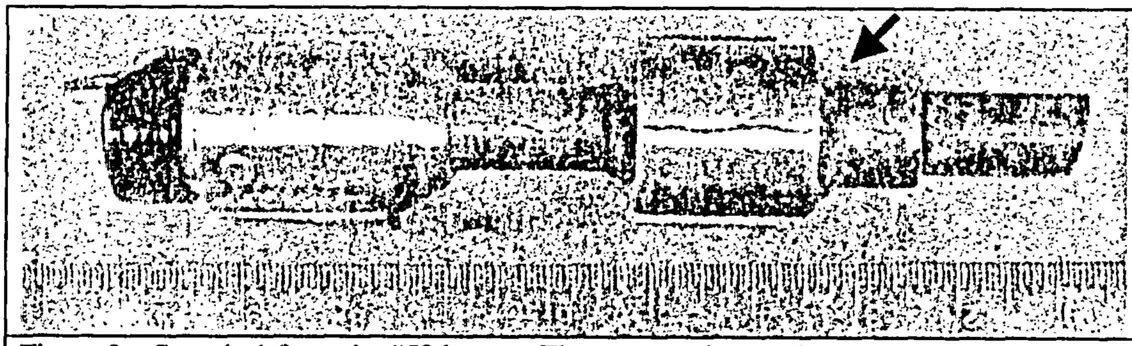


Figure 2 – Sample 1 from the #52 heater. The arrow points to the socket weld that connected the pressure tube to the coupling.

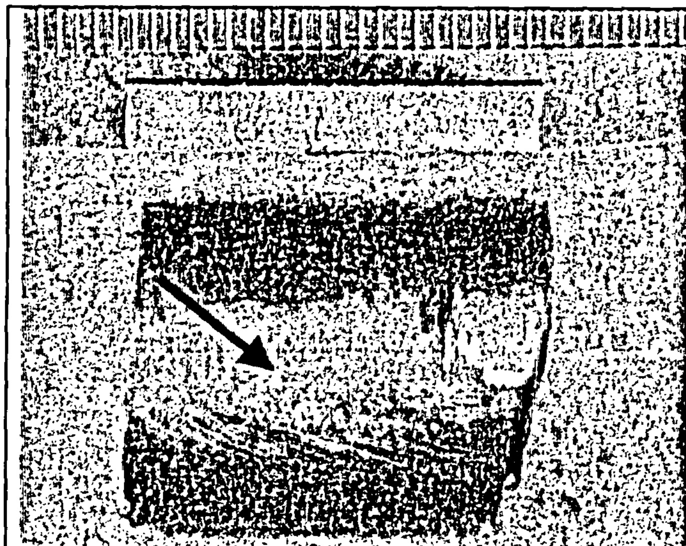


Figure 3 – The as-received sample 2 ring section from the #52 heater pressure tube. The arrow points to a surface discoloration that generated a false positive indication during the initial field NDE.

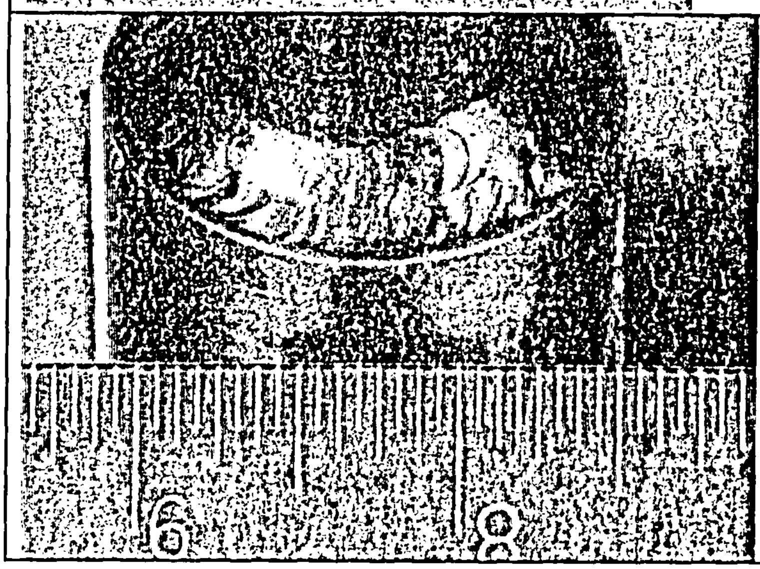


Figure 4 – A macro-photo of the upper coupling weld as looking toward the 0 degree side. The weld was fabricated using multiple passes. There was evidence of local grinding on the surface of the weld.

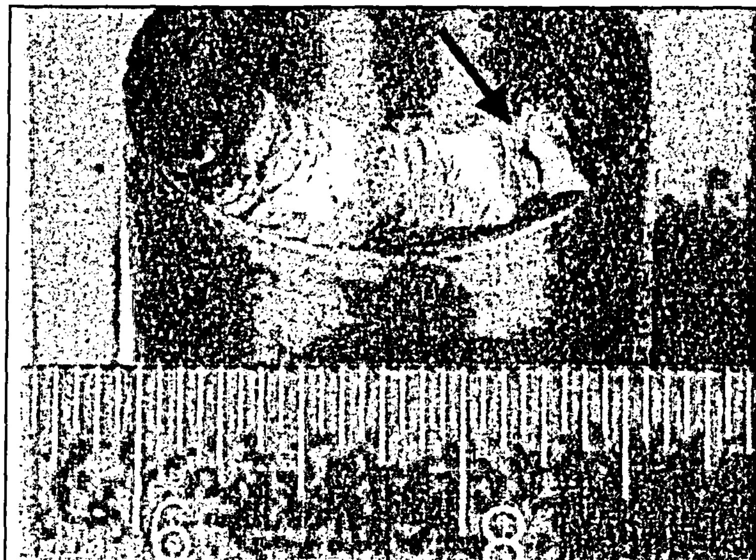


Figure 5 – The 90 side of the upper coupling weld. The arrow points to a minor geometry change at the end of a weld bead at the 135 degree position.

Figure 6 – The 180 degree side of the upper coupling weld.

Figure 7 – The 270 degree side of the upper coupling weld.

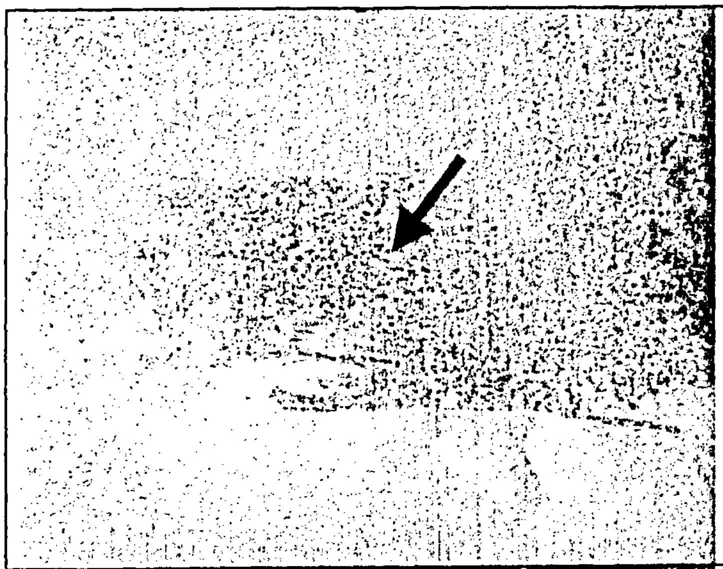


Figure 8 – A photo showing the faint indication that was detected by the fluorescent dye penetrant exam. The indication was located in the pressure tube heat-affected zone and measured approximately 1/64" long.

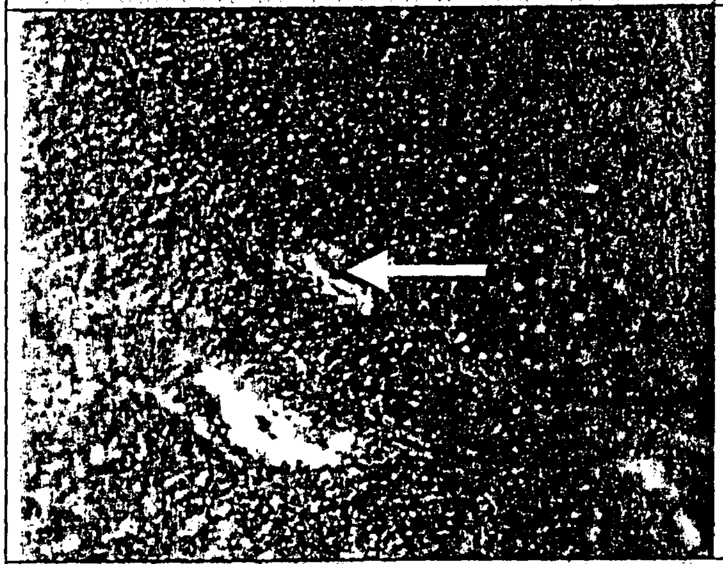


Figure 9 - A stereoscope photo of the indication detected by the dye penetrant exam. The indication measured 0.023" long and was located in a 0.005" deep grinding mark.

Figure 10 – A second stereoscope photo of the dye penetant indication. The photo was taken using low angle lighting to accentuate the grinding marks. The arrow points to the location of the thru wall crack. The coupling weld is located toward the left side of the photo.

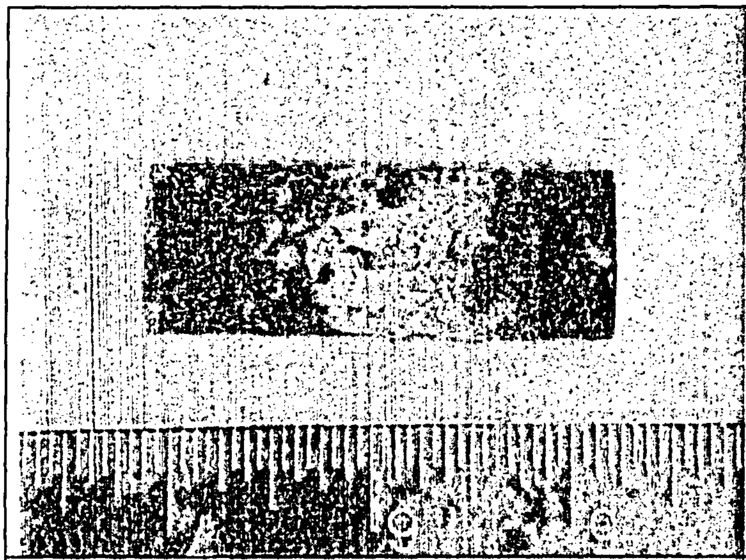


Figure 11 - The surface of the heater sheath after it was removed from the coupling. The sample contained local accumulations of black and grayish-white deposits.

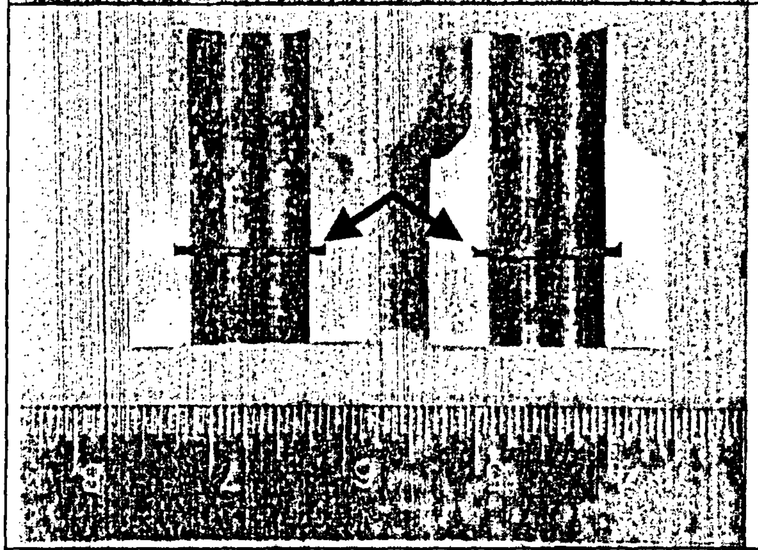


Figure 12 – A photo showing the inner surface of the sample 1 coupling and pressure tube after axial sectioning. The arrows point to the gap near the bottom of the socket connection.

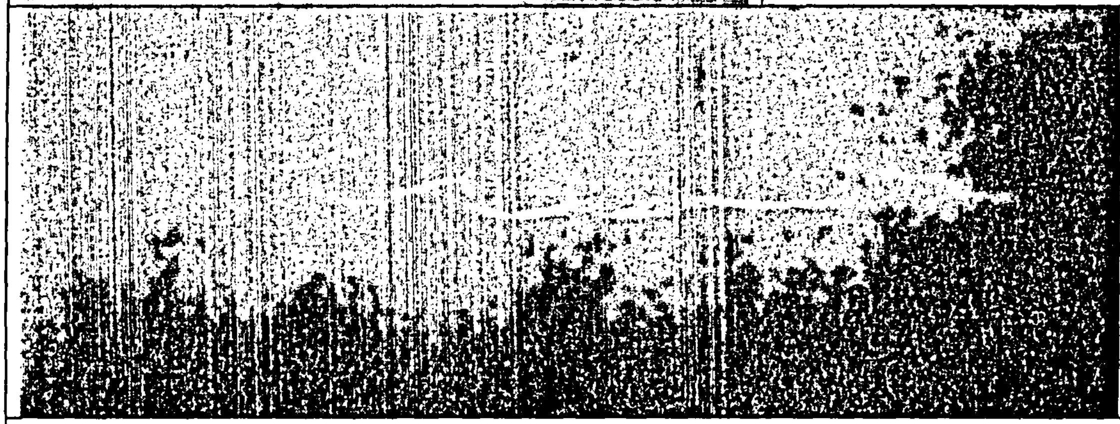
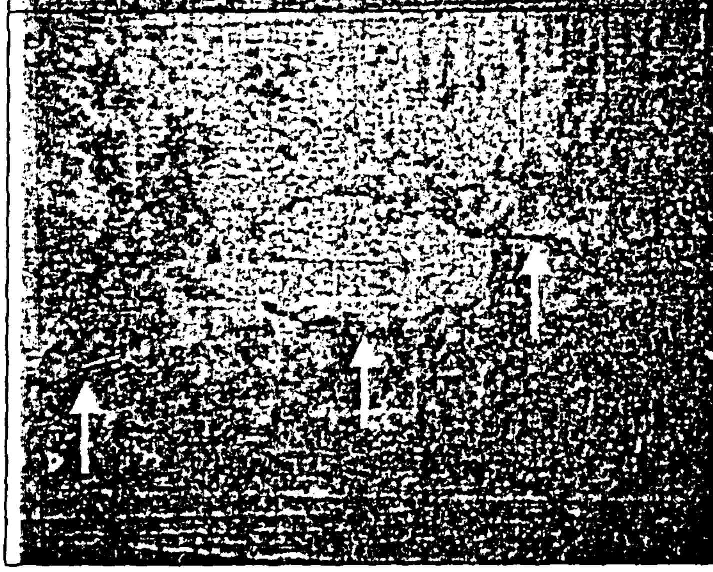


Figure 13 – A micro-focus, X-ray photograph between the 70° to 140° positions. The branched, circumferential indications were located in the pressure tube heat-affected zone.

	Figure 14 – A stereoscope photo of an internal circumferential crack near the 120 degree position (arrows). Also note the circumferential boring marks in the regions without deposits.
	Figure 15 - A stereoscope photo showing several irregular, circumferential cracks on the internal surface of the pressure tube near 110 degree location.

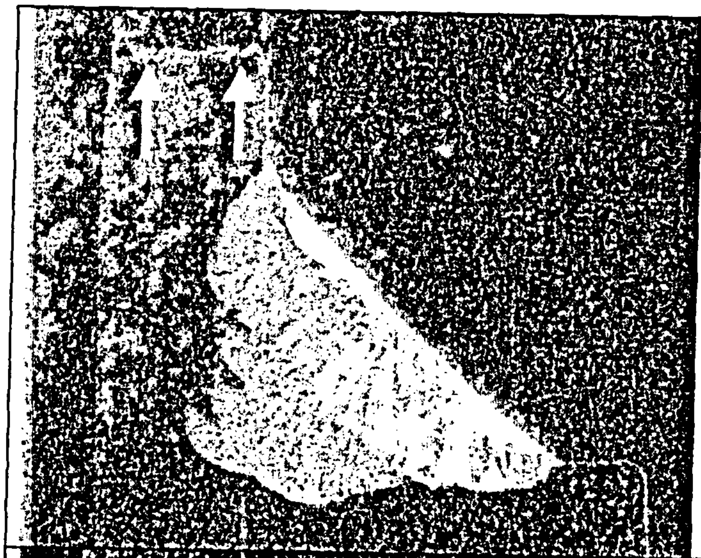


Figure 16 - A macro-etched photo of an axial section thru the upper weld at the 110 degree orientation. Note the thru wall crack in the tube wall near the upper left side of the photo (arrows). Based on the etching pattern, the weld was fabricated with 5 passes. The tube side fillet leg measured 0.2" long and the coupling side leg measured approximately 0.22" long.

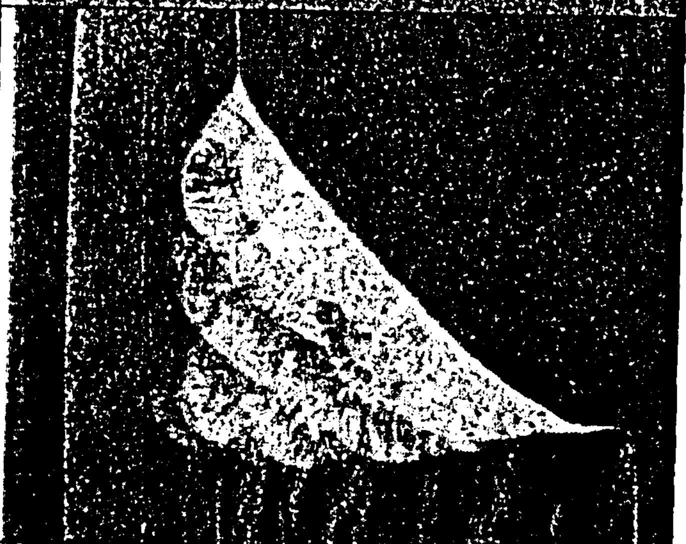


Figure 17 - A macro-etched view of an axial section thru the upper coupling weld at the 270 degree position. Note the multiple weld passes. At this location, the fillet leg lengths measured approximately 0.25" long.

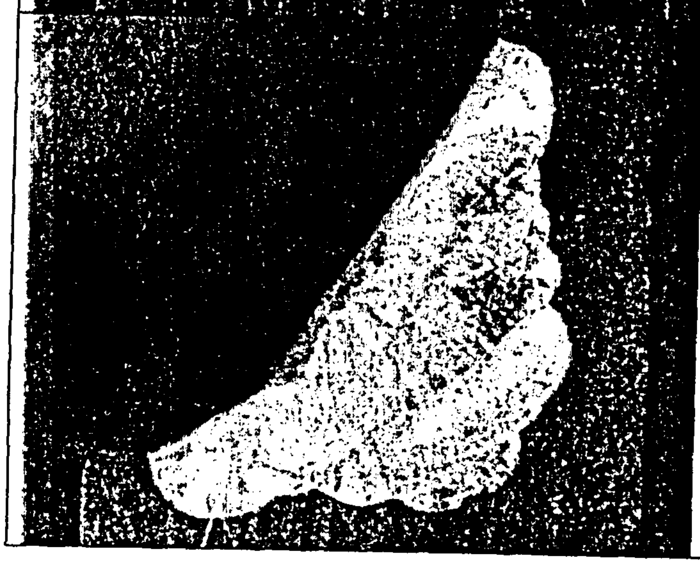


Figure 18 – A macro-etched section thru the 40 degree position. The tube side leg in this section measured 0.32" long.

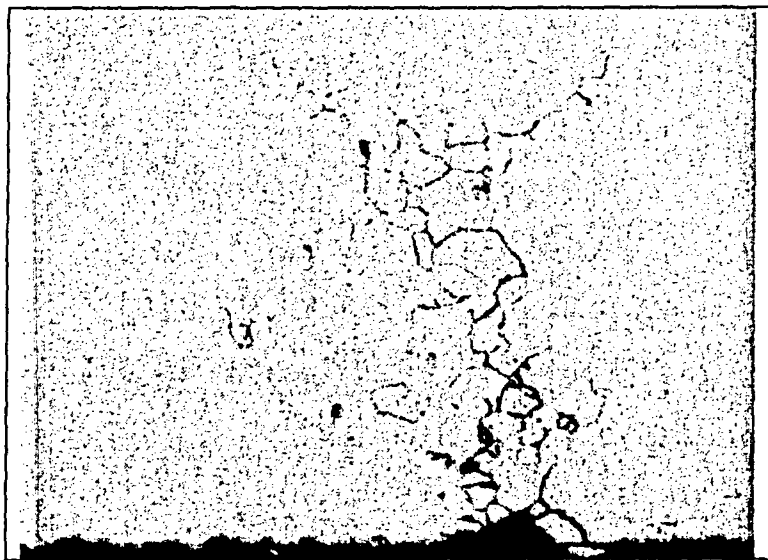


Figure 19 – An un-etched view of cracking in an axial metallurgical section thru the 40 degree location.

250x Magnification

Figure 20 - An etched view of the Figure 19 crack region. All the cracking was intergranular. The heavy grain boundary etching and grain fallout is typical of a sensitized microstructure.

250x Magnification
10% Oxalic-Elect. Etch

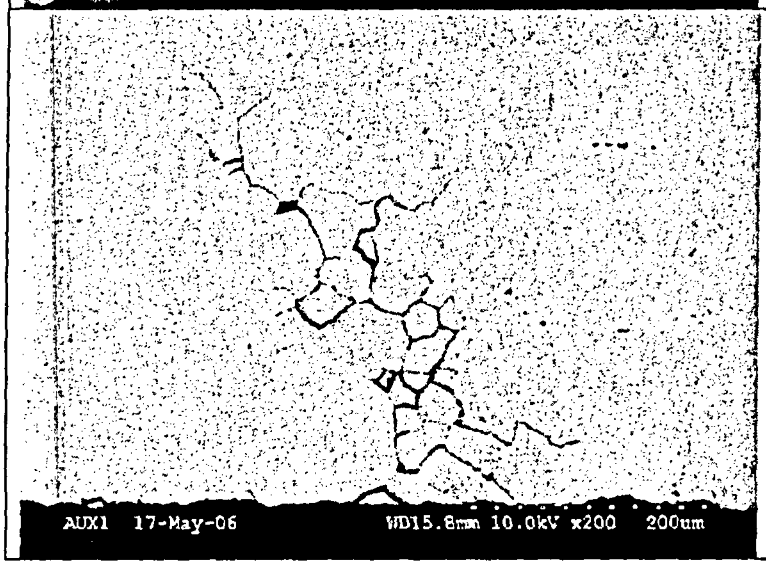


Figure 21 – A backscatter SEM photo of the 270 degree metallographic section. The branched, intergranular cracking measured 0.015" deep. The cracking initiated from the inner surface of the tube.

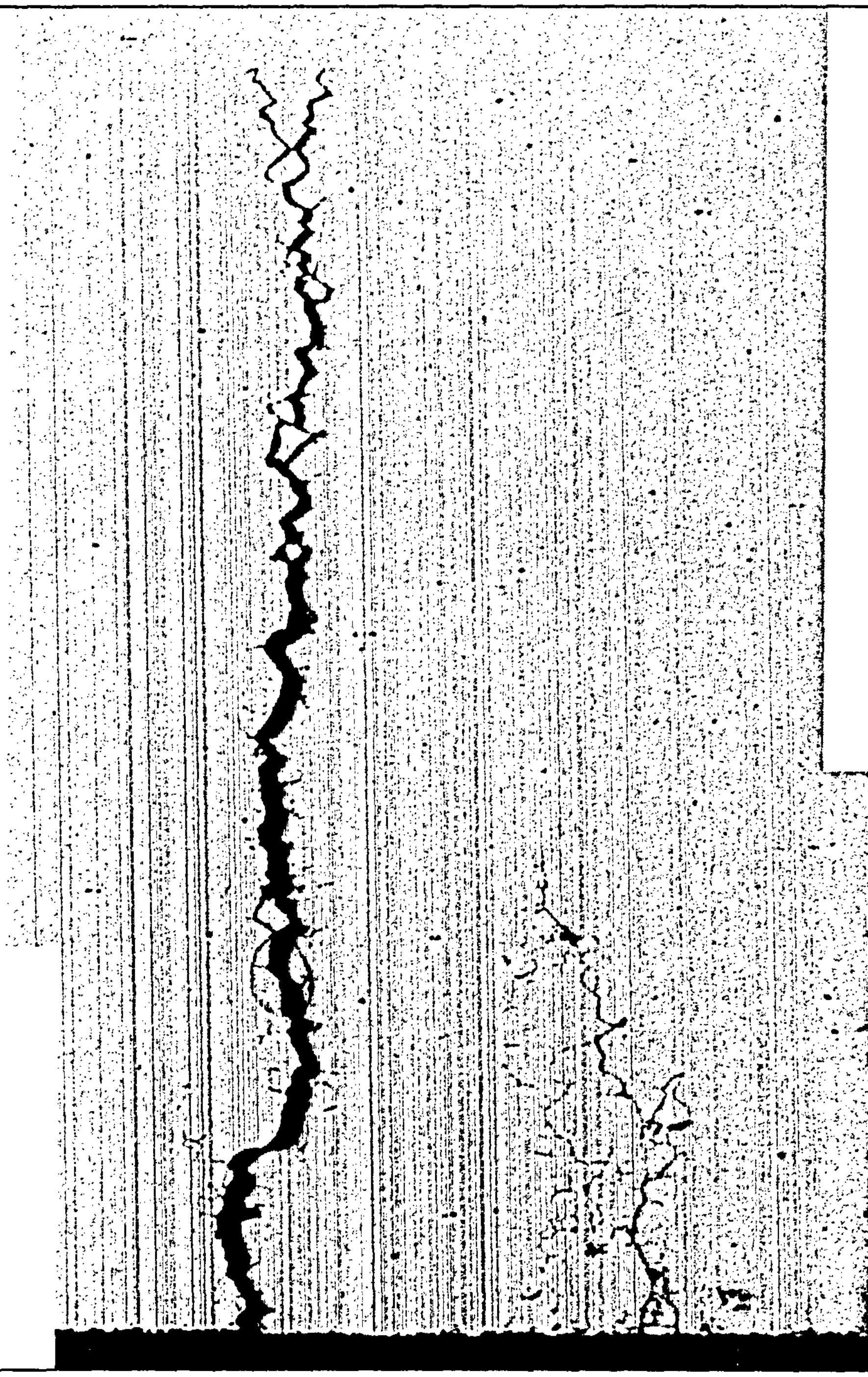


Figure 22 – A montage of the axial metallographic section thru the 65 degree position. Some of the metallurgical sections contained more than one crack that initiated from the inner surface of the tube. The large crack in this photo was 0.070" inches deep. (100x Magnification)

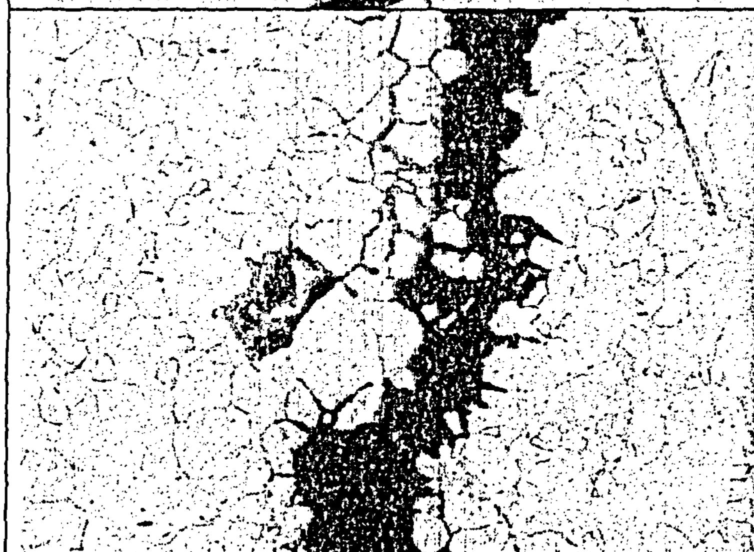
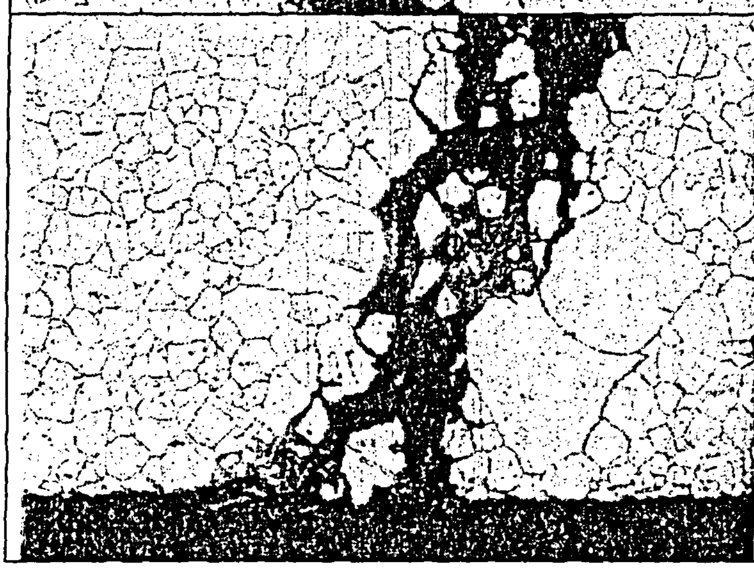
	Figure 23 - An un-etched metallographic view near the external surface of the thru wall crack. Note the blunted appearance of the secondary branches. Subsequent etching revealed the branches were intergranular in nature. 170 Magnification
	Figure 24 - Intergranular cracking near the midpoint of the thru wall crack. Note the intergranular, oxide-filled branches. 170x Magnification HCl-2% Bromic Etch
	Figure 25 - Intergranular cracking near the ID of the thru wall leak. Note the oxide-filled cracking and the large variation in the adjacent grain size. 170x Magnification HCl-2% Bromic Etch

Figure 26 – A photo showing a patch of intergranular, oxide-filled penetrations on the inner surface of the pressure tube at 180 degree location. Similar cracking was present at multiple heat-affected zone locations.

333x Magnification

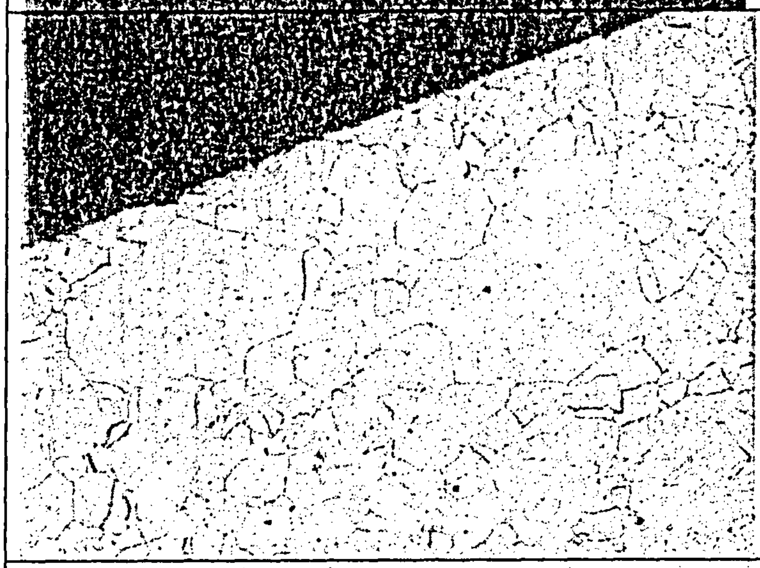


Figure 27 – An etched, circumferential metallurgical section thru the axial surface discoloration in sample 2. The duplex grain size is similar to the structure observed in the weld area mounts. There were no microstructural differences in the region that contained the discoloration.

170x Magnification
HCl-2% Bromic Etch)

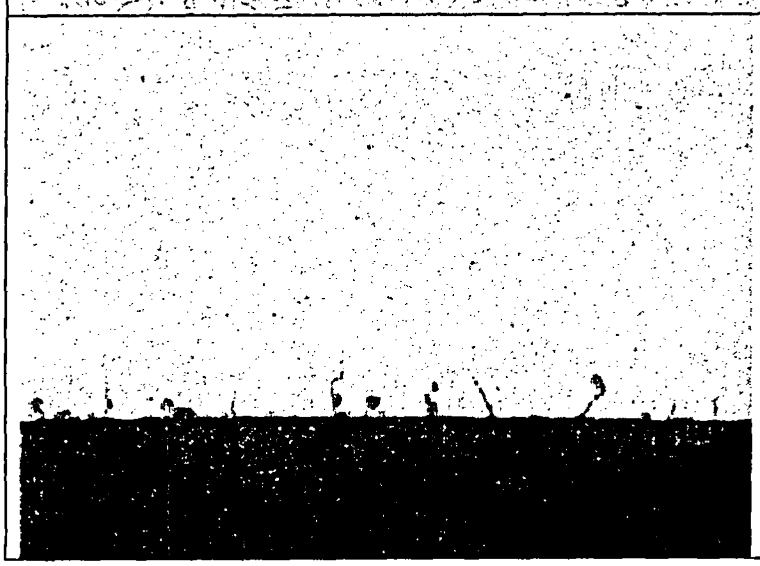


Figure 28 – Shallow intergranular penetrations on the internal surface of the pressure tube. The metallurgical section was located approximately 1¾" above the toe of the upper coupling weld. Note the rounded, oxide-filled appearance of several penetrations.

333x Magnification

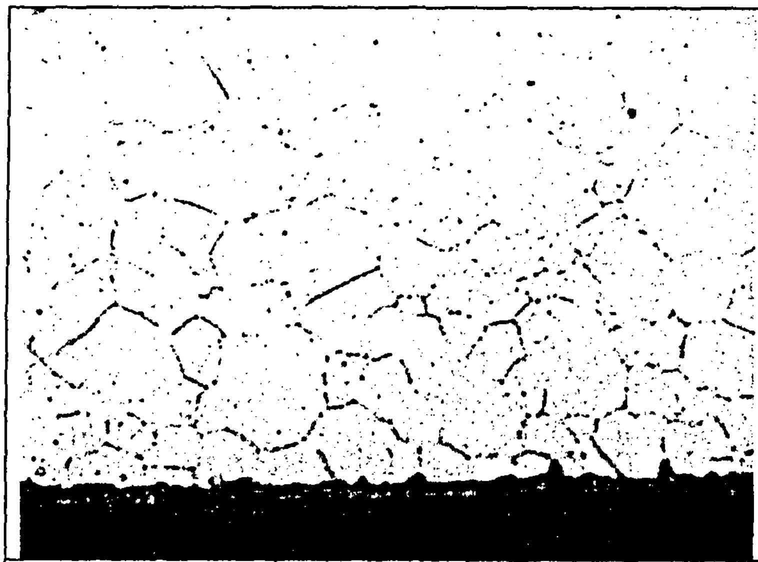


Figure 29 – The partially ditched microstructure that was observed near the inner tube surface after exposure to A262-Practice A etching. The grain boundary attack suggests the material near the tube ID was potentially susceptible to intergranular corrosion. Since the evaluated section was located away from the weld, the susceptibility was not related to the welding process. (333x Mag.)

Figure 30 – The coupling heat-affected zone microstructure after it was exposed to A262, Practice A testing. There was a thin region of grain boundary ditching in the heat-affected zone. The remainder of the coupling sample exhibited no ditching. The microstructure did not exhibit duplex grain sizes.

170x Magnification

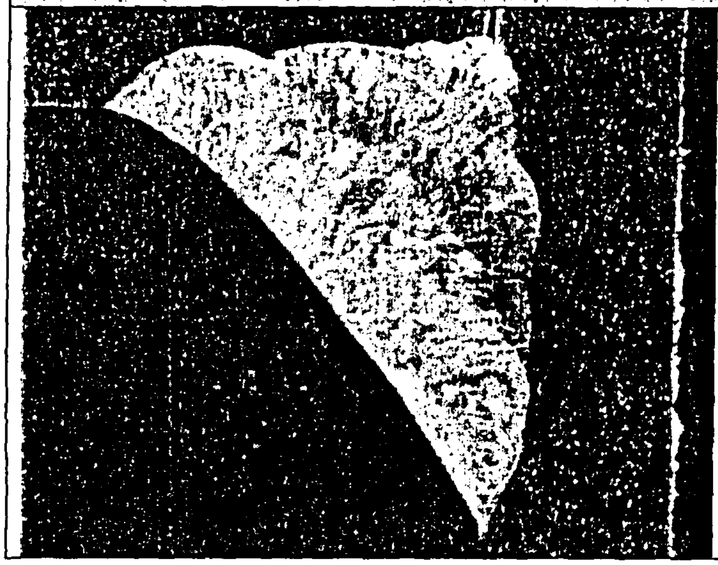


Figure 31 – A macro-etched section thru the lower coupling weld. The weld was fabricated using 5 or more passes.

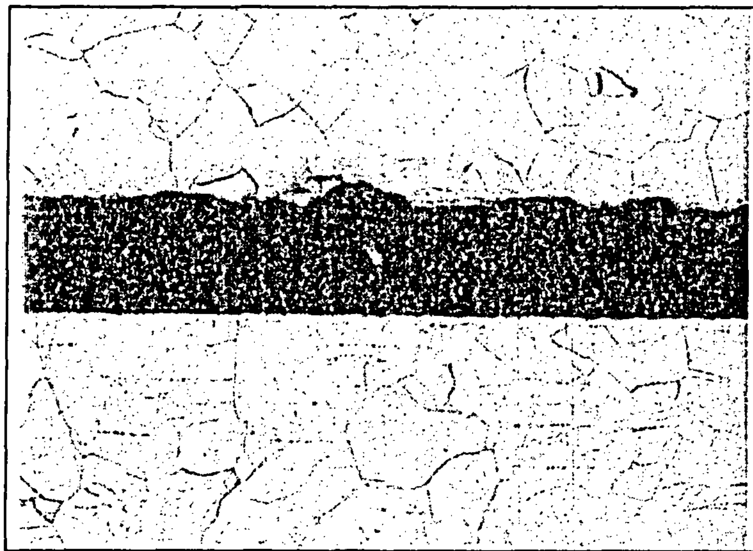


Figure 32 – The etched microstructure of the coupling (upper sample) and heater sheath, in the wetted crevice near the lower coupling weld. There was no evidence of intergranular corrosion or cracking in the sample.

170x Magnification
HCl-2% Bromic Etch

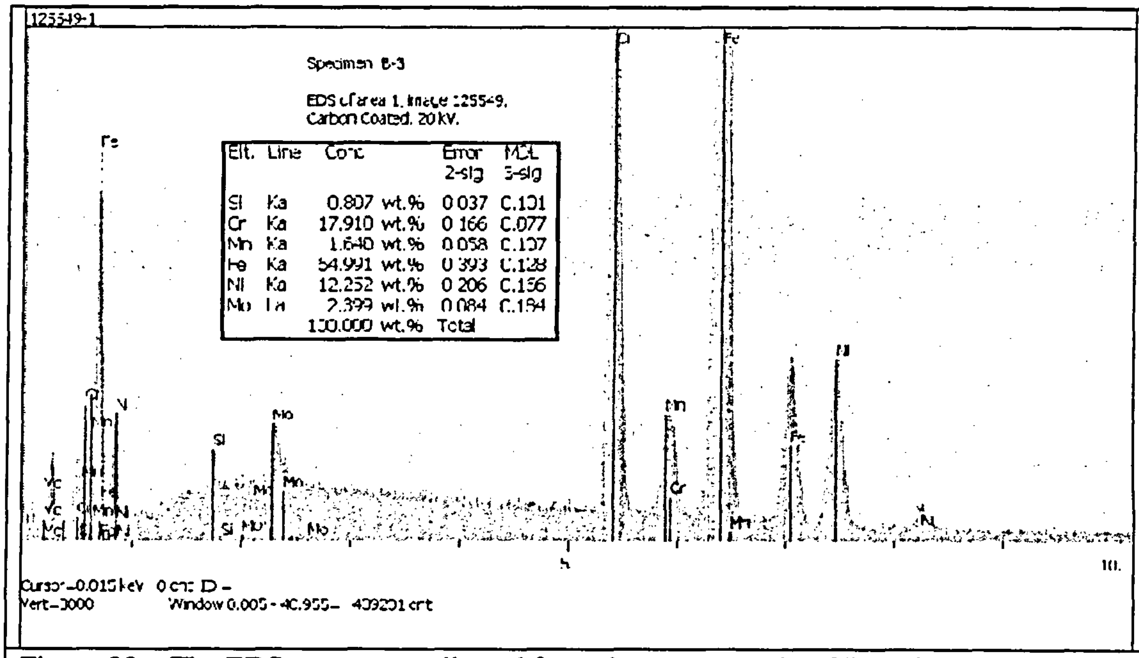


Figure 33 – The EDS spectrum collected from the pressure tube. The calculated composition is consistent with Type 316 stainless. The coupling was also consistent with Type 316 stainless steel.

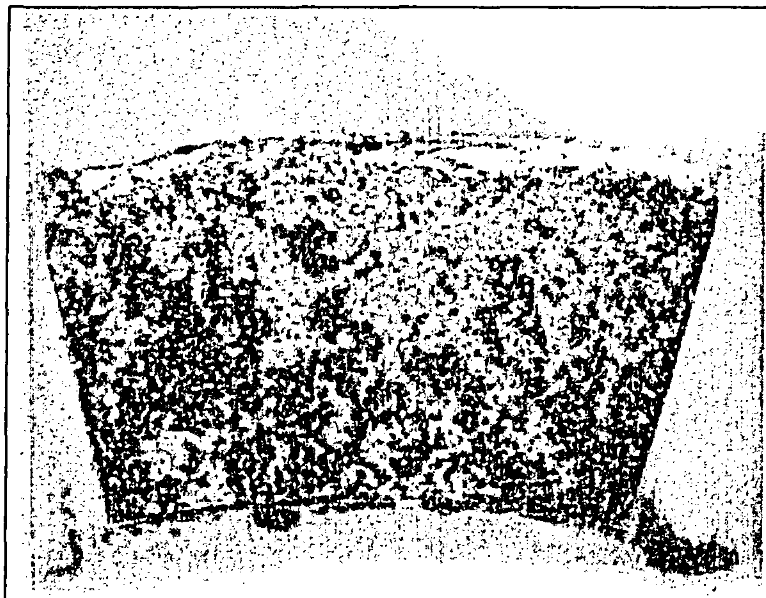


Figure 34 – The exposed portion of the tube fracture between the 90 degree and 110 degree locations. The reflective region near the upper side of the sample was broken open in the lab.

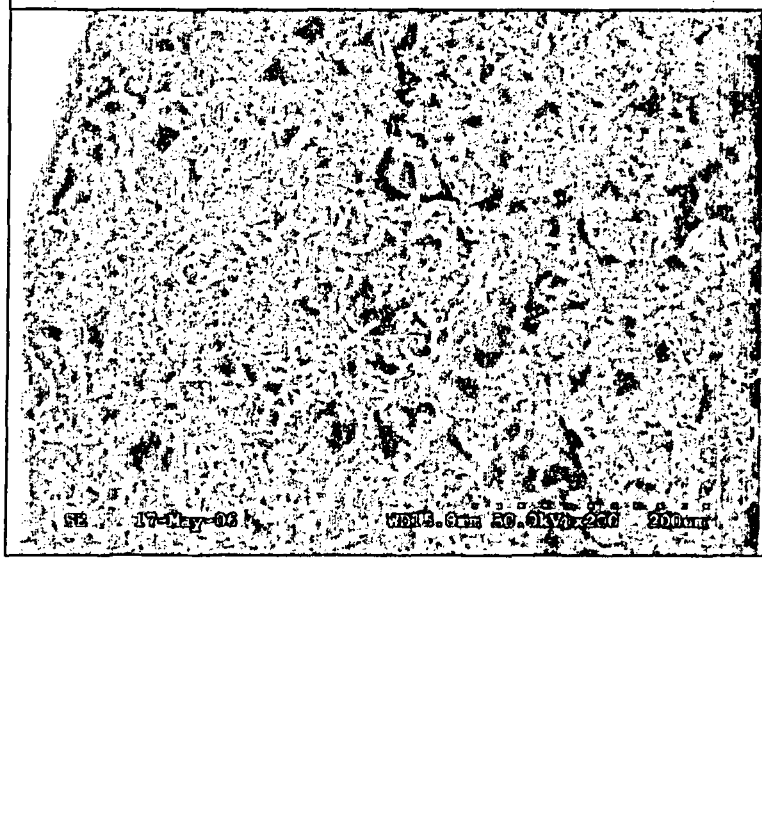


Figure 35 – A scanning electron microscope photo of the exposed crack surface near the 110 degree location. The crack surface had intergranular features. The outer diameter of the tube is located toward the upper left side of the photo.

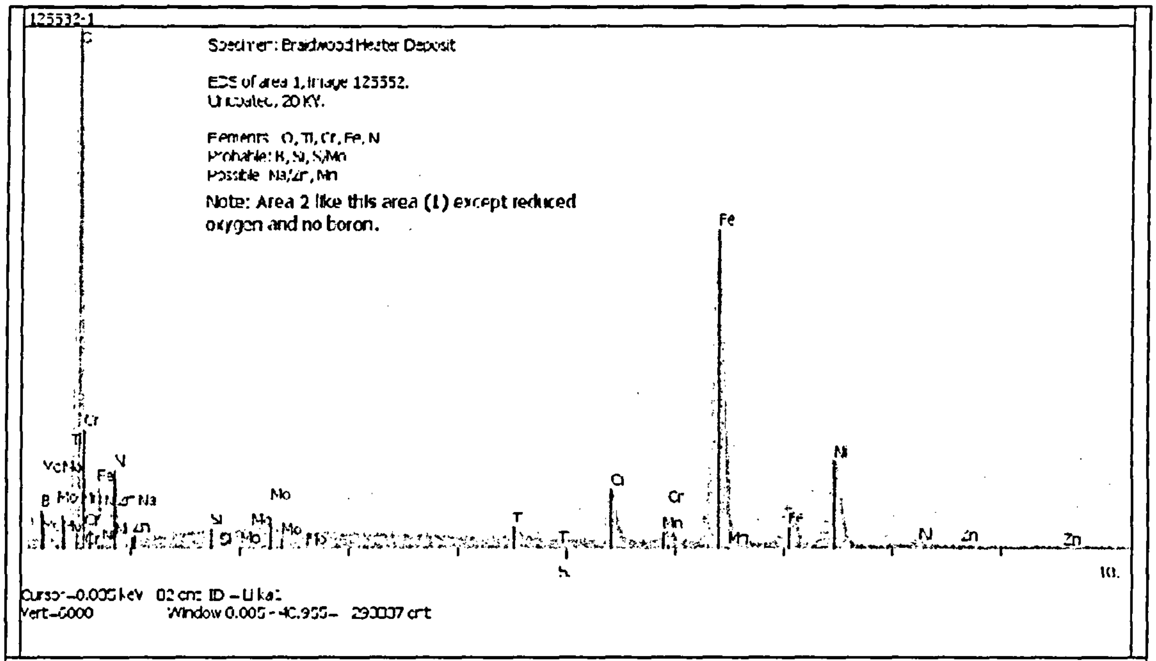


Figure 36 – The EDS spectrum collected from dark deposits on the exposed crack surface. The spectrum contains relatively large oxygen (O), iron (Fe), nickel (Ni) and chromium (Cr) peaks, which is typical of stainless steel corrosion/oxidation products. Similar results were obtained for the deposits on the surface of the heater sheath.

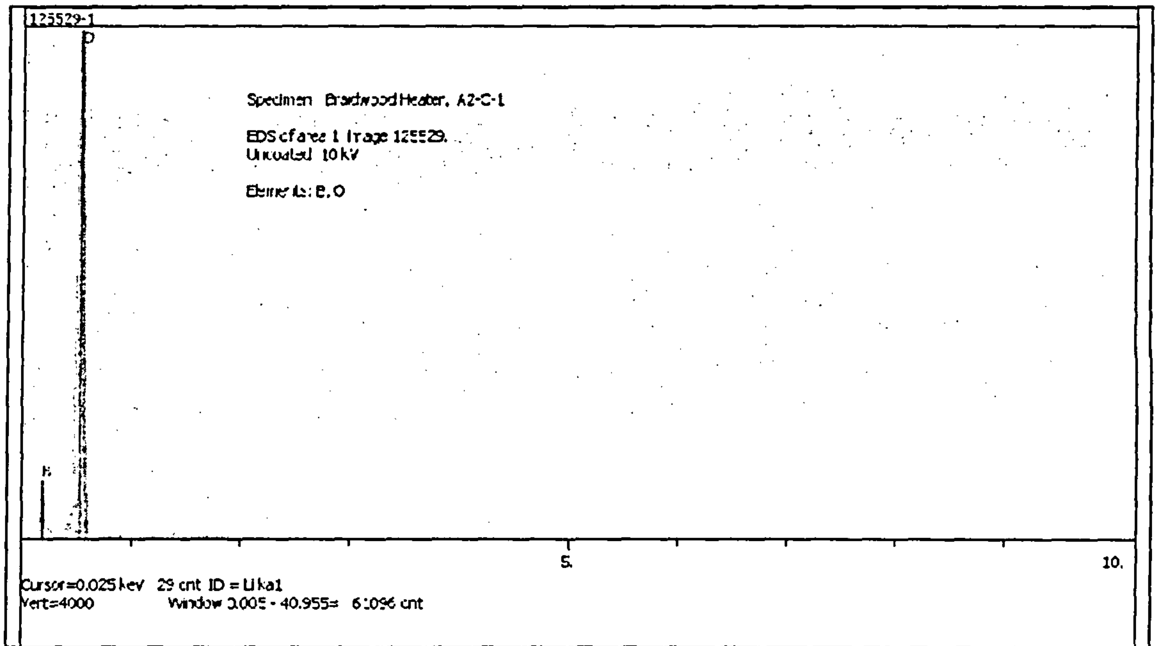


Figure 37 – A low voltage EDS spectrum collected from a grayish region on the exposed crack surface. The boron (B) peak is typical of a boric acid deposit.

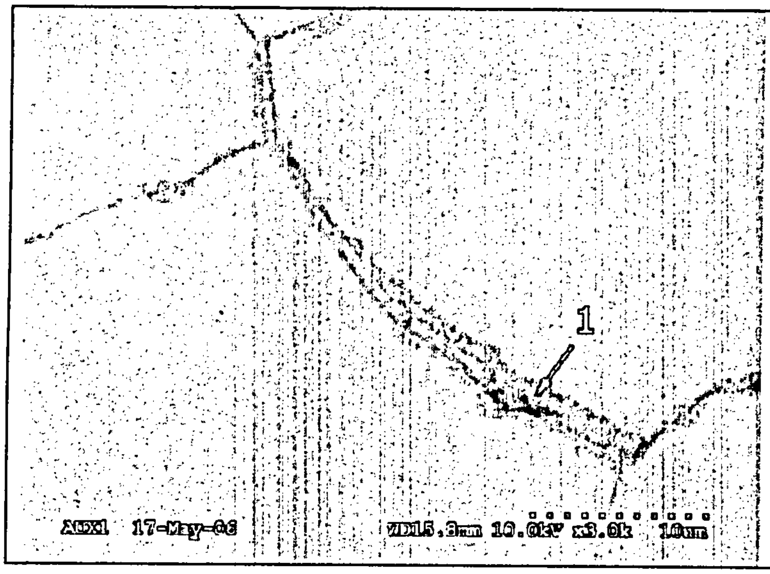


Figure 38 – A scanning electron microscope photo of an oxide-filled crack in the 270 degree section. The arrow points to the location of the Figure 39 EDS analysis. Also note the local corrosion/oxidation on the sides of the cracks.

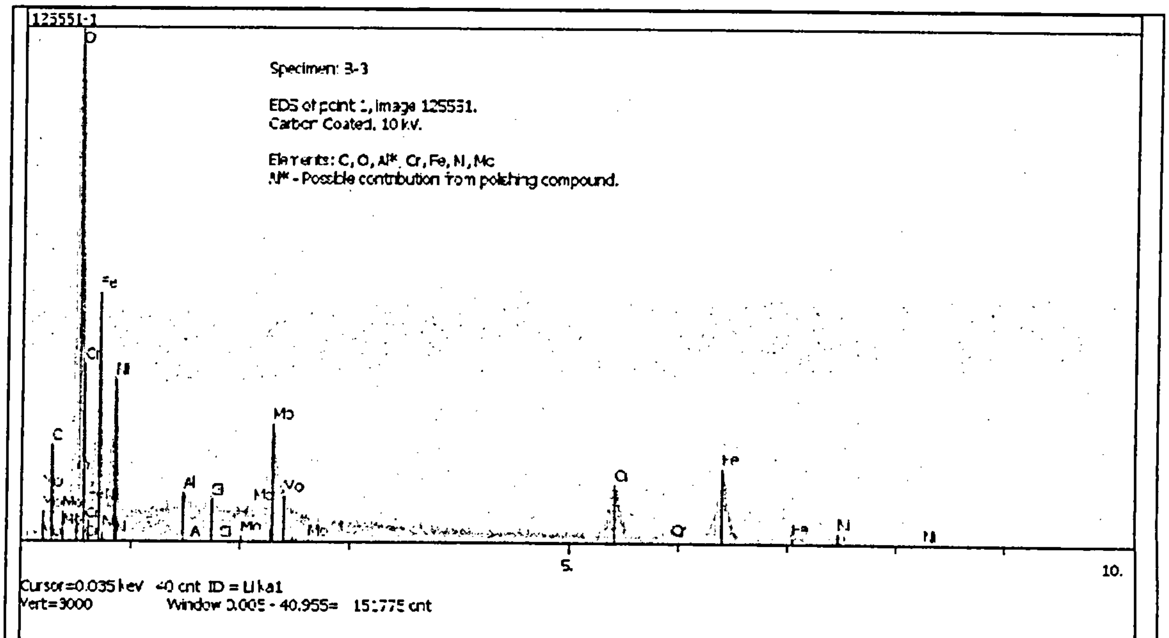


Figure 39 – A low voltage EDS spectrum collected from oxide within the Figure 38 crack. Note the oxygen and base metal element peaks.

ATTACHMENT 3

Braidwood Station Operability Evaluation 06-002, Revision 2

1.0 ISSUE IDENTIFICATION:

1.1 CR #: 493933

1.2 OpEval #: 06-002 Revision: 2

General Information:

1.3 Affected Station(s): Braidwood

1.4 Unit(s): 01 and 02

1.5 System: RY, RC

1.6 Component(s) Affected: 1RY01S, 2RY01S

1.7 **Detailed description of what SSC is degraded or the nonconforming condition and by what means and when first discovered:**

During A1R12, evidence of a leak was identified from the area of the Unit 1 pressurizer lower head, based on the existence of boric acid deposits. Based on the noted spray pattern and discoloration of the pressurizer insulation, it was concluded that the number 52 heater sleeve had developed a through-wall flaw. The suspected portion of the pressurizer number 52 heater sleeve segment was removed from the Unit 1 pressurizer during A1R12 to perform confirmatory testing.

Testing was performed on the number 52 heater sleeve as directed by Exelon PowerLabs. The findings of the Exelon PowerLabs failure analysis published on May 24, 2006 identified the cause of the leak as circumferentially oriented intergranular stress corrosion cracking (IGSCC) in the area of the sleeve-to-coupling weld heat affected zone (HAZ). IGSCC is a material failure mode driven by material characteristics (alloy used, annealing process, etc.), applied tensile stress and environmental factors (local chemistry). The pressurizer heater sleeves in service at Braidwood Station all have the same material characteristics, operate under nearly the same tensile stresses, and potentially have the same local environmental conditions. The identification of IGSCC in the number 52 heater sleeve in Unit 1 indicates there may be a potential for IGSCC to exist in the remaining Unit 1 and Unit 2 pressurizer heater sleeves.

2.0 EVALUATION:

2.1 Describe the safety function(s) or safety support function(s) of the SSC. As a minimum the following should be addressed, as applicable, in describing the SSC safety or safety support function(s):

- **Does the SSC receive/initiate an RPS or ESF actuation signal?** No
- **Is the SSC in the main flow path of an ECCS or support system?** No
- **Is the SSC used to:**
  - **Maintain reactor coolant pressure boundary integrity?** Yes
  - **Shutdown the reactor?** No
  - **Maintain the reactor in a safe shutdown condition?** No
  - **Prevent or mitigate the consequences of an accident that could result in offsite exposures comparable to 10 CFR 50.34(a)(1) or 10 CFR 100.11 guidelines, as applicable.** No.
- **Does the SSC provide required support (i.e., cooling, lubrication, etc.) to a TS required SSC?** No
- **Is the SSC used to provide isolation between safety trains, or between safety and non-safety ties?** No
- **Is the SSC required to be operated manually to mitigate a design basis event?** No
- **Have all safety functions described in TS been included?** Yes
- **Have all safety functions described in UFSAR or pending revisions been included?** Yes
- **Have all safety functions of the SSC required during normal operation and potential accident conditions been included?** Yes
- **Is the SSC used to assess conditions for Emergency Action Levels (EALs)?** No

The pressurizer provides a point in the reactor coolant system (RCS) where liquid and vapor are maintained in equilibrium under saturated conditions for pressure control purposes to prevent bulk boiling in the remainder of the RCS. The pressurizer surge line connects the pressurizer to one RCS hot leg. The line enables continuous coolant volume adjustments between the RCS and pressurizer.

Key functions of the pressurizer include maintaining required primary system pressure during steady state operation, and limiting the pressure changes caused by reactor coolant thermal expansion and contraction during normal load transients. At initiation of the plant startup, the RCS is completely filled, and the pressurizer heaters are energized. The Residual Heat Removal System (RHRS) is operating and is connected to the Chemical and Volume Control System (CVCS) via the low-pressure letdown line to control reactor coolant pressure. After the reactor coolant pumps are started, the residual heat removal pumps are stopped but pressure control via the RHRS and low-pressure letdown line is continued until the pressurizer steam bubble is formed. Indication of steam bubble formation is provided in the control room by the damping out of the RCS pressure fluctuations, and by pressurizer level indication. The RHRS is then isolated from the RCS and the system pressure is controlled by normal letdown and the pressurizer spray and pressurizer heaters.

Electrical immersion heaters, located in the lower section of the pressurizer vessel, keep the water in the pressurizer at saturation temperature and maintain a constant operating pressure. A minimum required available capacity of pressurizer heaters ensures that the RCS pressure can be maintained. The pressurizer heater design is such that following loss of offsite power and assuming a single failure, sufficient heater capacity is available to stabilize pressurizer pressure and preclude boiling in the RCS. If pressurizer heaters are not available to maintain pressurizer pressure, the RCS could be cooled by secondary side steam release at a rate that exceeds pressurizer heat losses.

Pressurizer heaters are potential missiles within Containment. Because the heaters would be ejected in a downward direction, no damage to safety related structures, systems or components would occur.

The surge line nozzle and removable electric heaters are installed in the bottom head of the pressurizer.

2.2 Describe the following, as applicable: (a) the effect of the degraded or nonconforming condition on the SSC safety function(s); (b) any requirements or commitments established for the SSC and any challenges to these; (c) the circumstances of the degraded/nonconforming condition, including the possible failure mechanism(s); (d) whether the potential failure is time dependent and whether the condition will continue to degrade and/or will the potential consequences increase; and (e) the safest plant configuration, including the effect of transitional action:

a) No specific degraded or non-conforming condition has been identified with the currently installed pressurizer heater sleeves. However, based on the failure mechanism being circumferentially oriented IGSCC for the failed heater sleeve, other pressurizer heater sleeves on Unit 1 and Unit 2 could also potentially be adversely affected. The safety significance associated with the potential existence of cracks in the heater sleeves is addressed in Section 2.3 of this evaluation.

b) The heater sleeves are part of the reactor coolant system pressure boundary. Per the requirements of TS 3.4.13, through-wall leakage of an RCS pressure boundary component is not allowed.

c) As described above, the potential failure mechanism of a pressurizer heater sleeve would include a through-wall flaw resulting from IGSCC.

d) IGSCC is a time-dependant failure mode. Testing results of the failed sleeve concluded that the cracks seen on the failed pressurizer heater sleeve were present for a relatively long period of time and that the crack growth rate was relatively low. This conclusion was based in part on the crack tip blunting observed in the secondary crack branches of the failed heater sleeve.

e) The current plant condition is safe and acceptable. Safety significance of the identified cracking is discussed further in Section 2.3 of this evaluation.

	YES	NO
2.3 Is SSC operability supported? Explain basis (e.g., analysis, test, operating experience, engineering judgment, etc.):	[x]	[ ]

If 2.3 = NO, notify Operations Shift Management *immediately*.
If 2.3 = YES, clearly document the basis for the determination.

Operability Assessment
The remaining pressurizer heater sleeves on Unit 1 were inspected during A1R12 and no boric acid deposits were found. A VT-2 examination of the heater sleeve 52 repair was performed as the final maintenance test of that repair. Additionally, a normal Mode 3 VT-2 inspection of all pressurizer heater penetrations (at normal operating temperature and pressure) was performed post-A1R12 to confirm primary system integrity. No evidence of pressure boundary leakage was identified.

For the Unit 2 pressurizer, a post-A2R11 Mode 3 VT-2 inspection was performed at normal operating temperature and pressure. Note that the Unit is maintained at normal operating temperature and pressure for a minimum of four hours prior to performing the VT-2 inspection of insulated components. As documented on the VT2 visual examination record for the pressurizer, no indications of boron were observed. This inspection specifically included an inspection of the bottom of the pressurizer.

There have been no other instances in the industry of circumferential cracking of the pressurizer heater sleeves due to IGSCC, such as that observed on the Braidwood Unit 1 sleeve. There are at least 12 Westinghouse PWR's with the same configuration of welded stainless steel heater sleeves. The plants range from 20 to 25 years in age. This equates to over 20,000 sleeve-years of experience with no other identified through-wall heater sleeve flaw. This suggests a low probability for a through-wall flaw to develop.

Should a through-wall flaw occur in a pressurizer heater sleeve, unidentified leakage inside containment would increase, which would be detectable utilizing the available leak detections methods (containment sump flow, level, particulate radioactivity monitor). The estimated leakage rate for flaws at the critical length (145 degree circumferential flaw) is approximately 0.1gpm. This leakage rate would be observable under the existing Exelon RCS Leakage Rate monitoring procedure, ER-AP-331-1003. Considering the flaw could grow to as large as 212 degrees prior to failure (see Safety Signficance section below for additional details), the leakage could be considerably more than 0.1 gpm, making a leak easier to detect.

A complete loss of a single pressurizer heater sleeve is equivalent to a 0.9-inch diameter hole in the RCS pressure boundary. The subsequent mass loss would be in excess of the makeup capability of a single centrifugal charging pump. Although there might be some reference leg heating effects that could possible obscure the pressurizer level transient (indicate higher than actual), the mass and energy loss would result in a significant pressurizer pressure and level decrease.

Operators are trained to discern between the pressurizer level and pressure transients resulting from a pressurizer water space leak and that caused by a steam space leak. Pressurizer level may actually rise during a steam space leak. Based on alternate indications from the CVCS system, pressurizer pressure, and containment parameters, operators can quickly determine that the RCS inventory is being lost and enter the appropriate procedure to address the LOCA. The impact on indicated pressurizer level during a water space leak would be almost imperceptible and again, the operator will quickly diagnose the inventory loss and take the appropriate actions.

Operators have been trained to be very sensitive to small changes in the results of RCS Leakrate Calculations. 1/2BwOSR 3.4.13.1, Unit One/Two Reactor Coolant System Water Inventory Balance Surveillance requires that operators have specific knowledge of the requirements contained in ER-AP-331-1003, RCS Leakage Monitoring and Action Plan. The expected leakage for a 145-degree circumferential flaw is 0.1 gpm. This is at the threshold that requires additional monitoring and identification per ER-AP-331-1003. In addition, surveillances 1/2BwOSR 3.4.13.1 require action to address any unexpected increase in unidentified leakage.

ER-AP-331-1003 recognizes that the sources of very small leak rates are difficult to identify. This procedure requires the involvement of multiple disciplines and station management to identify adverse trends in unidentified leakage. Monitoring and identification efforts increase as the amount of unidentified leakage increases above baseline levels. No specific sources of unidentified leakage have additional relative importance. The identification and resolution of ALL leakage sources are aggressively pursued.

Thus, the operational procedure and engineering administrative procedure discussed above establish a methodology that tends to filter out parameters and conditions that could obscure the identification of an increase in RCS leakage.

Safety Significance Assessment

This is the first known case of IGSCC in type 316 stainless steel pressurizer heater sleeves in the industry. There have been numerous cases of Primary Water Stress Corrosion Cracking (PWSCC) related failures in Combustion Engineering plants using Alloy 600 (Inconel 600) for pressurizer heater sleeve material. In 2003, while the industry was dealing with the PWSCC issues with Inconel, the Westinghouse Owners Group issued an operability assessment for units affected by PWSCC in pressurizer heater sleeves under WCAP-16180, Operability Assessment for Combustion Engineering Plants with Hypothetical Circumferential Flaw Indications in Pressurizer Heater Sleeves. When the Exelon PowerLabs preliminary results indicated the possibility of similar circumferentially oriented IGSCC flaws in the Braidwood and Byron pressurizers, Westinghouse was engaged to support a similar operability assessment. The Westinghouse effort is documented in Westinghouse letter LTR-RCPL-06-75. Since the

Braidwood Unit 2 pressurizer was manufactured using the same material specifications and assembly procedures, and since Unit 2 operates with similar chemistry controls, there is a potential that IGSCC of the Unit 2 heater sleeves may also exist.

The Westinghouse operability assessment (including supplemental assessment) concluded the following:

The time for a through-wall flaw with a length equal to that found in heater sleeve number 52 (approximately 90 degrees) to grow to the critical flaw length (point of potential heater ejection from the pressurizer) was found to exceed 10 years, thereby allowing for several visual inspections to find boron before a critical flaw length was reached.

Circumferential flaws as long as 145 degrees around the pressurizer heater sleeve inner circumference were determined to be acceptable and are within the ASME Code allowable limits assuring the integrity of the sleeve. With the removal of safety factors, the circumferential flaw could grow to 212 degrees under operating load conditions before a failure would occur, based on ASME Code minimum strength properties. Using actual material properties would result in an even greater flaw length prior to failure.

With safety factors removed, the calculated critical crack depth (maximum depth of crack prior to failure) for a 360 degree flaw is a 91% through-wall crack. The critical crack depth is based on ASME Code minimum strength properties. Using actual material properties would result in an even greater critical crack depth prior to failure.

Crack growth rates are not available due to this being a new phenomenon. As a result, the fracture analysis conclusions of the cracking that occurred at heater number 52 were conservatively based on Boiling Water Reactor crack growth rates (with respect to PWR environmental conditions) using crack growth values that are a function of stress intensity factor. This approach provides a bounding growth rate consistent with the qualitative assessment of the cracks' age and slow growth.

For a postulated severance or ejection of a heater sleeve due to circumferential flaws, a break at the location of the bottom of the pressurizer is bounded by the current LOCA analysis.

From a mass standpoint, the number of heater sleeve ejections is not limited since multiple sleeve ejections would equate to a pressurizer surge line failure. That is, the failure of the surge line is considered more limiting than the concurrent failure of all heater sleeves. The RCS cold leg LOCA analysis bounds the pressurizer surge line failure.

Assuming heater sleeve material properties are the minimum values from the ASME Code, the estimated leakage rate for flaws at the critical length is approximately 0.1gpm. This leak rate would be observable under the existing Exelon RCS Leakage Rate monitoring procedure.

Reference 2.5.2.1 and 2.5.2.8 (attached) provide additional details regarding the above conclusions.

	YES	NO
2.4 Are compensatory and/or corrective actions required?	[x]	[ ]

If 2.4 = YES, complete section 3.0 (if NO, N/A section 3.0).

2.5 Reference Documents:

2.5.1 Technical Specifications Section(s):

- TRM 3.4.f	RCS Structural Integrity
- TS 3.4	Reactor Coolant System (RCS)
- TS 3.4.9 and associated bases	Pressurizer
- TS 3.4.13 and associated bases	RCS Operational Leakage
- TS 3.4.15 and associated bases	RCS Leakage Detection Instrumentation

2.5.2 UFSAR Section(s):

- UFSAR Section 3.5	Missile Protection
- UFSAR Section 5.4.2.5.2	Natural Circulation Flow
- UFSAR Section 5.4.3	Reactor Coolant Piping
- UFSAR Section 5.4.10	Pressurizer
- UFSAR Section 15.0	Accident Analyses
- UFSAR Section 15.6	Decrease in Reactor Coolant Inventory

2.5.3 Other:

1. Westinghouse Letter LTR-RCPL-06-75 Revision 2 dated June 7, 2006, "Operability Assessment for Braidwood Units 1 & 2 and Byron Units 1 & 2 Pressurizer Heater Sleeves With Potential Circumferential Cracking" - Attached
2. Exelon PowerLabs Report BRW-02989 dated 05/24/2006, "Metallurgical Evaluations of Leak in the #52 Heater Assembly on the Braidwood Unit 1 Pressurizer
3. WCAP-16180, "Operability Assessment for Combustion Engineering Plants with Hypothetical Circumferential Flaw Indications in Pressurizer Heater Sleeves"
4. ASME Boiler and Pressure Vessel Code, 1971 through Summer 1973 Edition.
5. IR 480489, 04/19/2006, "Boric Acid Accumulation Bottom of PZR. (Investigate Source)"
6. ER-AP-331-1003, "RCS Leakage Monitoring and Action Plan"
7. Westinghouse Letter CAE-06-62 / CCE-06-60 (LTR-MRCDA-06-106), "Responses to Exelon's Request for Additional Information on Exelon Pressurizer Operability Evaluation" dated June 16, 2006 - Attached
8. WO 645401-01 – Post A2R11 VT-2 Examination of Class 1 Systems for leakage

3.0 ACTION ITEM LIST:

If, through evaluating SSC operability, it is determined that the degraded or nonconforming SSC does *not* prevent accomplishment of the specified safety function(s) in the TS or UFSAR and the intention is to continue operating the plant in that condition, then record below, as appropriate, any required compensatory actions to support operability and/or corrective actions required to restore full qualification. For corrective actions, document when the actions should be completed (e.g., immediate, within next 13 week period, next outage, etc.) and the basis for timeliness of the action. Corrective action timeframes longer than the next refueling outage are to be explicitly justified as part of the OpEval or deficiency tracking documentation being used to perform the corrective action.

Compensatory Action #1: None

Responsible Dept./Supv.:

Action Due:

Action Tracking #:

Corrective Action #1: Establish controls to perform a bare metal visual inspection for detection of boron deposits at the pressurizer heater sleeve locations, to be performed every refueling outage for Units 1 and 2 pending more definitive industry (PWR Owners Group) guidance.

Responsible Dept./Supv.: A8951NESPR

Action Due: 10/31/2006

Basis for timeliness of action: Based on crack growth rates developed by Westinghouse, a through-wall flaw similar to that identified on Unit 1 pressurizer heater sleeve number 52 would take approximately 10 years to progress to the critical flaw length. Thus, a failed sleeve would be identifiable during the post-outage VT-2 inspection performed in Mode 3 at normal operating temperature and pressure.

Action Tracking #: 493933-03

Corrective Action #2:

Responsible Dept./Supv.:

Action Due:

Basis for timeliness of action:

Action Tracking #:

4.0 SIGNATURES:

4.1 Preparer(s) Raymond J Bel Date 07/14/2006

Date

4.2 Reviewer Date 7/14/06
(10 CFR 50.59 screener qualified or active SRO license holder)

4.3 Sr. Manager Design Engg/Designee Concurrence Date 7/14/06

4.4 Operations Shift Management Approval Date 7-14-06

4.5 Ensure the completed form is forwarded to the OEPM for processing and Action Tracking entry as appropriate.

Third Party Reviewer Not required, based on HU-AA-1212 screening Date

5.0 OPERABILITY EVALUATION CLOSURE:

5.1 Corrective actions are complete, as necessary, and the OpEval is ready for closure

(OEPM) Date

5.2 Operations Shift Management Approval Date

5.3 Ensure the completed form is forwarded to the OEPM for processing, Action Tracking entry, and cancellation of any open compensatory actions, as appropriate.

ATTACHMENT 4

Westinghouse Electric Company LLC Operability Assessment
Braidwood Units 1 & 2 and Byron Units 1 & 2
Pressurizer Heater Sleeves
(Proprietary)

ATTACHMENT 5

Westinghouse Electric Company LLC Affidavit

Westinghouse

Westinghouse Electric Company
Nuclear Services
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

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

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Our ref: CAW-06-2162

June 7, 2006

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-RCPL-06-75, Revision 2 P-Attachment, "Operability Assessment for Braidwood Units 1 & 2 and Byron Units 1 & 2 Pressurizer Heater Sleeves with Potential Circumferential Cracking" (Proprietary)

The proprietary information for which withholding is being requested in the above-referenced report is further identified in Affidavit CAW-06-2162 signed by the owner of the proprietary information, Westinghouse Electric Company LLC. The affidavit, which accompanies this letter, sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.390 of the Commission's regulations.

Accordingly, this letter authorizes the utilization of the accompanying affidavit by Exelon Nuclear.

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference this letter, CAW-06-2162, and should be addressed to B. F. Maurer, Acting Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

BFMaurer

B. F. Maurer, Acting Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: G. Shukla

bcc: B. F. Maurer (ECE 4-7A) 1L
R. Bastien, 1L (Nivelles, Belgium)
C. Brinkman, 1L (Westinghouse Electric Co., 12300 Twinbrook Parkway, Suite 330, Rockville, MD 20852)
RCPL Administrative Aide (ECE 4-7A) 1L, 1A (letter and affidavit only)

CAW-06-2162

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared B. F. Maurer, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse), and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

B F Maurer

B. F. Maurer, Acting Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed
before me this 7th day
of June, 2006

Sharon L. Fiori

Notary Public

Notarial Seal
Sharon L. Fiori, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires January 29, 2007
Member, Pennsylvania Association Of Notaries

(1) I am Acting Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC (Westinghouse), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rule making proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information that is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in LTR-RCPL-06-75, Revision 2 P-Attachment, "Operability Assessment for Braidwood Units 1 & 2 and Byron Units 1 & 2 Pressurizer Heater Sleeves with Potential Circumferential Cracking" (Proprietary), dated June 7, 2006, being transmitted by Exelon Nuclear letter and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse for the Braidwood Units 1 & 2 and Byron Units 1 & 2 is expected to be applicable for other licensee submittals in response to certain NRC requirements for justification of plant operability with pressurizer heater sleeves with potential circumferential cracking.

This information is part of that which will enable Westinghouse to:

(a) Determine the acceptability of plant operation if cracks are found.

(b) Assist the customer to obtain NRC approval.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for licensing documentation.

(b) Westinghouse can sell support and defense of continued safe operation with potential cracks in pressurizer heater sleeves.

(c) The information requested to be withheld reveals the distinguishing aspects of a methodology which was developed by Westinghouse.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar operability assessments and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

ATTACHMENT 6

Westinghouse Electric Company LLC Operability Assessment
Braidwood Units 1 & 2 and Byron Units 1 & 2
Pressurizer Heater Sleeves
(Non-Proprietary)

LTR-RCPL-06-75 Revision 2 NP-Attachment

Operability Assessment for Braidwood Units 1 & 2 and Byron Units 1 & 2 Pressurizer Heater Sleeves with Potential Circumferential Cracking

June 7, 2006

Westinghouse Electric Company LLC
P.O. Box 355
Pittsburgh, PA 15230-0355

Operability Assessment for Braidwood Units 1 & 2 and Byron Units 1 & 2 Pressurizer Heater Sleeves With Potential Circumferential Cracking

Introduction

During the Spring 2006 (A1R12) outage at Braidwood Unit 1, boric acid deposits were found during insulation removal in the pressurizer surge line area. Following an extensive investigation, the leakage was identified to originate from the number 52 pressurizer heater, at the upper weld between the pressure tube and heater coupling. Visual inspection of all 78 pressurizer heaters was performed to determine the initial extent of condition. Heater number 52 was identified as the only source of boric acid leakage from the pressurizer.

The heater coupling at location number 52 was cut out of the system and the tube was plugged. The coupling was shipped to a testing facility to determine the cause of the weld failure. Preliminary failure analysis results provided by Exelon are indicative of cracking in the heat affected zone of the heater sleeve tubing. The nature of the degradation appears to be intergranular stress corrosion cracking (IGSCC). Figure 1 includes a schematic representation of the crack profile.

This letter provides an evaluation of the cracking that occurred at heater number 52 with respect to the potential for circumferential cracking in other heater sleeves at Braidwood Units 1 & 2 and Byron Units 1 & 2. Westinghouse has performed a qualitative operability assessment to address concerns related to the potential for similar cracking in other heater sleeves and continued operation of the Braidwood and Byron units.

Background

Pressurizer heater sleeve leakage was first identified in the late 1980's at Combustion Engineering (CE) designed plants. These occurrences of heater sleeve cracking were attributed to degradation of Alloy 600 heater sleeve material via primary water stress corrosion cracking (PWSCC). (The pressurizer heater sleeves at all four of the Braidwood and Byron units are comprised of stainless steel material, which is not susceptible to PWSCC). Since that time, comprehensive evaluations of the issue of Alloy 600 degradation have led to effective programs for managing the degradation of Alloy 600 small bore nozzles, including pressurizer heater sleeves. Until recently, non-destructive examinations (NDE) of leaking Alloy 600 heater sleeves had revealed that the flaws were axially oriented. However, in the course of repairing all of the heater sleeves at Palo Verde Unit 2 in the Fall of 2003, non-destructive testing of sleeves prior to replacement revealed circumferentially oriented indications at several penetration locations. Additional NDE at that unit confirmed the existence of circumferentially oriented flaws in five heater sleeves.

The significance of circumferentially oriented flaws is that if the flaw is allowed to grow, it could potentially reach the critical flaw length and result in a sleeve separation. If such a flaw was located below the partial penetration sleeve to pressurizer shell attachment weld, such as the cracking which occurred at Braidwood Unit 1, an ejection of the heater sleeve could occur, with a resulting loss of reactor coolant. The circumferential flaws found thus far in Alloy 600 heater sleeves have been above the attachment weld, and thus did not represent a breach of the pressure boundary.

Because of the potential safety significance of circumferential cracks in the CE-designed Alloy 600 heater sleeves, the Westinghouse Owners Group (WOG) initiated an effort to develop an operability assessment for the CE plants, shortly after the inspection results from Palo Verde indicated the possible existence of circumferentially-oriented flaws in their pressurizer heater sleeves. The operability assessment included an analytical program designed to evaluate the potential for a heater sleeve ejection incident and evaluation of the effects of such an occurrence on plant design basis analyses. This program was applied in conjunction with the utilities' inspection programs to demonstrate continued safe operation of the CE fleet, and is documented in Reference 1. It is understood that this assessment was accepted by the NRC, in 2005.

The Reference 1 operability assessment represented an analytical program designed to evaluate the potential for a heater sleeve ejection incident and evaluate the effects of such an occurrence on plant design basis analyses. The operability assessment focused on three primary areas: 1) pressurizer heater sleeve fabrication review, 2) effects of a heater sleeve ejection event on plant operation, and 3) pressurizer heater sleeve integrity evaluation. The assessment concluded that it would take 7.5 years for a 120° circumferential through-wall crack that will easily produce observable leakage, to grow to the critical size that could result in an ejected heater sleeve. Given plant awareness of the potential for leaking heater sleeves, such a time period would provide several opportunities for utilities to inspect the pressurizer bottom head for evidence of leakage during refueling outages, during which leakage from cracks could be visually detected prior to any cracks reaching critical crack size. Even assuming a maximum fuel cycle of 24 months (most plant fuel cycles are 18-20 months), there would be multiple opportunities for the detection of a leaking crack. This provided assurance for the CE plants that a circumferential crack would not grow to failure before it could be detected and repaired.

In addition, an assessment of potential effects on plant operation concluded that existing design analyses would remain bounding in the event of a pressurizer heater sleeve ejection. Ejection of a heater sleeve was found to be equivalent to a small break LOCA (SBLOCA). The consequences of such an event are bounded by the results of existing SBLOCA emergency core cooling system (ECCS) performance analysis. If a postulated sleeve ejection were to occur, the event would be handled by existing Operator Response and Emergency Procedure Guidance. The guidance provided in existing plant operating procedures would provide adequate operator direction to mitigate such an occurrence.

In response to leakage of primary coolant as the result of through-wall cracking of pressurizer heater sleeves at CE-designed plants, the Combustion Engineering Owners Group plants initiated periodic visual inspections of the bottom head of pressurizers to determine if leakage from heater sleeves was occurring. It was concluded that visual inspection of the pressurizer bottom head was an effective method for detecting a leaking sleeve and for detecting damage to the pressurizer shell as a result of boric acid corrosion. Since 1989, visual inspections have been effective at detecting leaking heater sleeves at CE-designed plants. These inspections have not only been effective at detecting leakage occurring at very low rates, but also in detecting leakage before any corrosion damage occurred to the pressurizer shell.

For Braidwood Unit 1, the immediate corrective action was to remove the failed heater coupling and to fillet weld a plug in the pressure tube to allow restart of Unit 1 from the A1R12 refueling outage. Further corrective actions to prevent recurrence will be determined from the results of the laboratory analysis of the failed heater sleeve.

A review of previous industry experience did not identify any similar events at other operating plants of Westinghouse design. All previous events involving pressurizer heater sleeve leakage were for CE-designed plants using Alloy 600 materials, whereas the Westinghouse design at Braidwood Units 1 & 2 and Byron Units 1 & 2 uses stainless steel components. Westinghouse plants do not have any history of pressurizer heater failures of this nature.

Root Cause of Braidwood Unit 1 Pressurizer Heater Leakage

Preliminary results of a root cause investigation into the accumulation of boric acid on the bottom of the Braidwood Unit 1 pressurizer have been summarized in Reference 2. Ten possible leakage causes were identified for root cause evaluation. These possible causes included sources external to the pressurizer, pressure tube welds, coupling welds, pressurizer base metal failures, and pressure tube base metal failures. Nine possible causes were eliminated by information known and discovered during the investigation. The last potential cause of the boric acid leakage identified rouging in the convection cover insulation sleeve for heater number 52. Rouging could be caused by steam impingement on the stainless steel material. Review of the boric acid flow patterns on the insulation and the bottom of the pressurizer vessel were consistent with the physical evidence of failure of the pressure tube to heater coupling weld above heater number 52.

Metallurgical Evaluation

The heater coupling and part of the heater sleeve cut from heater number 52 were shipped to a testing facility to determine the cause of the weld failure. The heater sleeve was fabricated from SA 213 Type 316 stainless steel pipe material and the coupling was fabricated from SA-182 Type 316 stainless steel bar material. The sleeve to coupling joint fillet weld is fabricated with Type 308L weld metal.

The metallurgical investigation included low pressure helium leak tests to verify the presence and location of a through-wall flaw, fluorescent dye penetrant and UT examinations, micro-focus X-ray examination, surface examination of the affected areas, metallographic examination on axial sections taken at several locations around the circumference, fractographic examinations by light optical and scanning electron microscopy, and semi-quantitative chemistry assessments by energy dispersive spectroscopy (EDS) analysis. Additional examinations supporting the root cause assessment are in progress.

The results of the initial laboratory examinations showed that the cracking was located in the sleeve, approximately 0.09 inch above the toe of the upper coupling (fillet) weld. The results of the examinations confirmed that cracking was initiated at the ID surface of the sleeve and extended primarily between the 40 degree and 190 degree clock locations (approximately 150 degrees in circumferential extent). The crack extended 95% through wall between the 90 and 110 degree locations and went through wall at approximately the 110 degree position, which corresponds to the leak location. A schematic representation of the crack penetration around the circumference is illustrated in Figure 1. The metallographic and fractographic examinations confirmed that the crack progression showed an intergranular (IG) morphology. Evidence of crack tip blunting and oxide deposits was observed, associated with secondary cracks near the OD surface of the sleeve in the through wall crack. This suggested either a relatively slow crack progression rate near the OD surface or long duration of time since the onset of leakage. ASTM A262 Practice A (oxalic acid etch) testing confirmed that the microstructure was heavily sensitized in the heat affected zone (HAZ) of the fillet weld. The metallography results also confirmed that the grain size of the sleeve material varied significantly, ranging from relatively coarse grains (ASTM size 2/3) to fine grains (size 8/9).

The metallography results of the fillet weld showed that approximately six weld beads were involved in the weld and the weld leg measured approximately 0.3 inch on the sleeve. The weld bead morphology did not suggest evidence of any weld repair at the joint. Surface examinations on the ID showed circumferential scars suggesting the evidence of potential 'reaming' operation on the ID surface of the tube. EDS chemistry analysis of the deposits from the OD surface and fracture surface did not confirm the presence of any contaminants. Other than the major alloying elements (iron, chromium, nickel and molybdenum), the only elements identified were boron (from boric acid) and oxygen. The semi-quantitative chemistry assessments also showed that the sleeve and weld materials corresponded to Type 316 and Type 308 stainless steel materials respectively.

A detailed review of the fabrication records for the sleeve and the fillet weld suggested that the pressurizer heater penetration sleeves from Braidwood Unit 1 came from two heats of material, Heat No.M8062 (B&W) and Heat No. 00200 (Teledyne). Eight of the penetration sleeves were from the first heat (No. M8062). The remaining seventy heater sleeves were fabricated from the second heat (No. 00200). The affected heater number 52 belongs to the second heat of material (Heat No. 00200 from Teledyne).

A search of certification records showed that both heats met the SA 213 code requirements. The records showed that the sleeves (tubes) tubes are fabricated from Type 316 stainless steel, procured in the cold drawn, solution annealed, and water quenched condition. The mechanical properties, including the hardness values of the two heats, are consistent with this condition. The certifications records do not indicate the temperature of anneal, but indicate they meet the SA-213 code which specifies solution anneal at a minimum of 1900°F followed by water quenching.

The weld fabrication records showed that the fillet weld was fabricated by GTAW process with Type 308L weld metal. The fillet weld leg height was specified as 0.19 inches minimum. The records indicate that reaming was performed on the sleeve ID for the two heats, but the reaming was performed after welding.

The number of weld passes (six) on the sleeve for heater number 52 could result in slightly higher residual stresses than a sleeve with fewer weld passes, but previous data from Westinghouse simulation mock-up tests suggests that much of the weld residual stress is developed during the first couple of weld passes. Reaming on the ID is specified in the records for the two heats but the reaming is done after the weld, which is a much better situation compared to welding after reaming. The actual residual stresses from reaming, as well as weld residual stresses, are being assessed under longer term task work for Braidwood Unit 1.

The overall results of the laboratory examinations to date suggested that the observed cracking in the sleeve occurred in the HAZ at the toe of the sleeve to coupling upper fillet weld by intergranular stress corrosion cracking (IGSCC). The cracking was initiated at the ID surface and progressed radially outward, resulting in a through wall leak at the 110 degree clock location. The blunted crack tip morphology and the crack deposits near the OD surface suggested a slow crack growth rate and/or a long duration of leakage.

IGSCC in austenitic stainless steels is known to occur in sensitized microstructure, in the presence of oxygen or other contaminants (such as sulfur compounds) and high stress (combination of operating stress and residual stress). More recently, enhanced crack growth was reported in heavily cold worked stainless steel samples. Additional work is in progress to identify the root cause of the observed cracking in the Braidwood Unit 1 pressurizer heater sleeve.

Fracture Mechanics Evaluation

Figure 2 shows the arrangement of a total of 78 heater tubes extending from the pressurizer lower head. Exelon inspections during the A1R12 outage indicated leakage in one of the heater sleeve tubes at the fillet weld attaching the heater tube to the sleeve adapter (see Figure 3) at the heater number 52 location outside the pressurizer bottom head.

A fracture mechanics evaluation has been performed in support of continued operability to the next outage or inspection period for each of the Braidwood and Byron units. The evaluation includes both flaw growth analysis as well as leakage estimation on the remaining heater sleeves using the hypothetical flaws similar to the one measured on heater sleeve number 52.

Experience based on the operability assessment of the Combustion Engineering (CE) design pressurizer as reported in Reference 1 has been used. However, the assessment in Reference 1 is applicable to the heater sleeve flaws inside the pressurizer bottom head heater sleeve nozzle borehole and in the J-groove weld regions, as opposed to the fillet weld heat affected zone (HAZ) outside the bottom head at the Braidwood and Byron units. As a result, an assessment of the postulated tube circumferential flaws for Braidwood and Byron tubes was performed using the actual material data available and the design loads on the tube. It is noted that no leakage from the J-groove welds was observed in the annulus region during the visual inspections at Braidwood Unit 1 in the A1R12 outage, nor has any been observed in visual inspections of the annulus regions below the pressurizer during past inspections at the other Braidwood and Byron units. There has been no industry occurrence of leakage at the J-groove weld for plants with stainless steel pressurizer heater sleeves; thus, there is no reason to believe that cracking of the J-groove region at the Braidwood and Byron units is a concern.

Besides the flaw evaluation at the fillet weld location, several other conclusions on issues such as SBLOCA may be adapted from the CE pressurizer report as the tube geometries for the Westinghouse-designed Exelon units and the CE-designed Millstone 2 units are very close to each other. For the Exelon units, heater sleeve tubes have a wall thickness of [ ]^{a,c,e} inch and an inside diameter of [ ]^{a,c,e} inch compared to those for Millstone of [ ]^{a,c,e} inch and [ ]^{a,c,e} inch, respectively. The materials of construction are, of course, different.

In support of continued operation of Braidwood Units 1 & 2 and Byron Units 1 & 2, Westinghouse has performed a qualitative assessment of crack growth rates for postulated circumferential crack sizes and potential leak rates for limiting crack sizes, to address continued operation in the postulated event that other heater sleeves may be in service with circumferential cracks that have not yet gone through-wall. The evaluations utilize the heater tube geometry shown in Figure 3 and Table 3. It is noted that the Braidwood 1, Braidwood 2, Byron 1, and Byron 2 pressurizer heater wells are constructed with the same geometries and of the same materials. The loads placed on the pressurizer heater wells for stress analysis are the same for all four units.

Tube loads were taken from applicable design reports, as described in Table 4. These design reports show only pressure load was considered in the analysis; self-weight and seismic loads were not included. Although the design reports did not include bending moments, a bending moment of 100 inch-lbs was applied in addition to the pressure load for conservatism in the flaw assessment. Normal Operating temperature of 653°F was considered in the analysis. Stress corrosion crack growth rate properties were used for [ ]^{b,c,e} (see Figures 4, 5, and 6). The tube temperature at the end of the heater tube is expected to be closer to 550°F than to the 653°F normal operating temperature; therefore, it was considered appropriate to base the crack growth rate properties based on a temperature of 288°C (550°F). The crack growth evaluation considers the flaw to be located in the tube, consistent with the observed location of the through-wall crack (0.09 inch above the weld toe). Residual stress in the tube wall was not considered, since the crack location was above the weld and the residual stress distribution at the weld is not currently known. Use of the conservative BWR crack growth rates (with respect to PWR environment) is considered to compensate for not including residual stresses in this assessment. Circumferential flaw stress intensity factors are developed from ASME Section XI, Appendix C, Article C-4311, 2004 Edition guidelines. Circumferential flaw stability calculations utilize ASME Section XI, Appendix C, Article C-5322, 2004 Edition guidelines. Material mechanical properties are taken from the ASME Code, Section III, 1971 Edition through Summer 1973 Addenda (Reference 4) for allowable strength, yield strength, and modulus of elasticity as a function of temperature. Material ultimate strength properties did not appear in the ASME Code until the 1974 edition, and are therefore taken from that Code edition. Actual material yield and ultimate strength properties were derived from material certification records, and are shown in Tables 1 and 2.

For leak rate calculations, applicable material properties were taken from the actual material properties from Westinghouse records (Certified Material Test Reports (CMTRs)). Actual properties are available only at room temperature. Material properties at 653°F are scaled by the ratio of the actual/ASME Code Section III properties. Leakage rates are calculated at 653°F.

Inside Surface Flaw Assessment:

First, an inside surface flaw with various initial crack depths but similar aspect ratio to the one found in tube number 52 and shown in Figure 1 was addressed through crack growth analysis and remaining life estimation. These initial flaw depths range from about 20% through wall to 90% of the wall thickness. ASME Section XI Appendix C solutions (Reference 5) were used for computing the crack tip stress intensity factors. For the crack profile of heater sleeve 52 as shown in Figure 1, an aspect ratio of 6.4 was calculated. The ASME Code suggest an aspect ratio of 6, and this value was used in the analysis. The crack geometry is defined in Figures 7 and 8. Stress intensity factor as a function of flaw depth is shown in Figure 9. These results were curve fitted with a 3rd order polynomial with the flaw depth ratio as a parameter and used in subsequent flaw growth calculations. A time increment of one hour was used for crack growth calculations.

Figure 10 shows ID circumferential flaw growth as a function of time for three different initial flaws, 25%, 50% and 75% depths. It can be seen that flaws as deep as 50 to 60% of the wall thickness have more than 3 years prior to reaching the through-wall. Flaws as deep as 75% of the wall thickness has at least 2 years of time prior to reaching the outside surface.

The remaining life for various ranges of flaws using the BWR environment properties are shown in Figure 11. This figure shows that the small flaws have long expected life, beyond 10 to 15 years. Only very deep flaws, even as high as the ASME Code maximum allowable depths have at least 2 years using the most conservative IGSCC data for stainless steels in the BWR environment.

All these calculations have used crack growth properties from BWR environment which are expected to be highly conservative. With PWR environment, expected remaining life for the flaws to reach the outside surface should be significantly higher than those calculated here. Unfortunately there are no available data on this phenomenon, as yet.

The heater sleeve allowable stress for ID surface flaws per ASME Section XI Appendix C as a function of the flaw depth to thickness ratio is shown in Figure 12. This figure shows that the applied axial stress (which includes the effects of the assumed bending loads) is well below the allowable stress indicating the tube integrity is maintained.

Through-wall Flaw Assessment:

Crack tip stress intensity factors for through-wall flaws were determined using the solutions available in Reference 6, and were computed to assess the stability of the through-wall leaking flaws. Figure 13 shows that all the flaws within a total of 90 degrees angle around the circumference have very low stress intensity factors, within [ ]b,c,e. These are of the same order as the ID surface finite depth deep flaws with about 75% through-wall thickness. The time for a through-wall flaw with a length equal to that found in sleeve 52 to grow to the critical length was found to exceed [ ]b,c,e, thereby allowing for several visual inspections to find boron before a critical flaw length was reached.

Figure 14 shows applied axial stress due to pressure load (and the assumed bending load) and the allowable stress per the ASME Code Case N-513-1 for the through-wall flaws. This figure shows that circumferential cracks as long as about [ ]b,c,e degrees around the circumference are acceptable and are within the Code allowable limits assuring the integrity of the tube.

Fracture Mechanics Evaluation Summary and Conclusions:

The assessment of inside surface flaws in the pressurizer heater sleeve tubes showed that the expected life for a flaw starting as deep as 75% of the wall thickness is at least two years prior to reaching the outside surface and forming a through-wall flaw.

Through-wall flaws as large as [ ]b,c,e degrees around the circumference still have very low crack tip stress intensity factors, and a long period of time is required for a flaw such as that found in sleeve # 52 to grow to a critical length. ASME Code allowable stress indicates that any through-wall flaws up to [ ]b,c,e degrees around the circumference were determined to be acceptable.

All the evaluations were performed using conservative crack growth properties that correspond to the BWR environment. Under the PWR environment, the remaining life is expected to be higher than those predicted by this evaluation.

Parametric Leak Rate Calculations

Parametric leakage rate calculations were performed for the hypothetical through-wall circumferential flaws in the pressurizer heater sleeve for Braidwood Unit 1, and would be applicable to all four Braidwood and Byron Units.

Leakage rates were computed for various through-wall circumferential flaws using the steady state normal operating pressure and small moment loads (the effect of bending loads was evaluated and found to be insignificant). Calculations were performed in two steps: first, estimation of the crack opening areas for various assumed circumferential through-wall crack lengths from the sleeve geometry, loading and the material properties followed by leak rate predictions. Two-phase flow and the IGSCC crack morphology were considered in the calculations. Material properties for SA213 TP316 were taken from Certified Material Test Reports (CMTRs) and the ASME Code interpolation method was used to obtain properties at operating temperature.

The procedures used in these calculations have been reviewed and approved by the NRC in prior Leak Before-Break (LBB) applications. Using the results of the leak rate calculations, the leak rate as a function of crack length has been plotted in Figure 15.

The leakage rate assessments showed that the leak rate for a circumferential through-wall flaw in the heater sleeve is in the range of [ ]^{b,c,e} gallons per minute for the flaws that extend approximately 1/3 of the circumference of the heater sleeve. Material property variation effects on the leak rate calculations were considered and found to be insignificant. It is important to realize that much smaller through-wall flaws will result in boric acid deposits on the heater sleeve. This is the primary means for detection of these small leaks, through visual inspections.

The RCS pressure boundary required leak detection capability for the plants is 1 gpm. However, the actual capability is closer to 0.1 gpm. All plants monitor their leakage rates constantly, and are very sensitive to departures from average leak rates. Typically, even small departures from the average unidentified leak rates are investigated.

A specific leak rate criterion is not required for the pressurizer heater sleeves for two reasons. First, the leakage rates necessary to show the visual evidence of boron deposits on the pressurizer heater sleeve are much lower than the technical specification limit. Second, all plants have significantly increased their sensitivity to leakage monitoring in the past two years in response to the Davis Besse incident. Very small changes in the unidentified leakages at the pressurizer heater sleeves are carefully investigated.

The risk consequences associated with the leakage which occurred prior to the A1R12 outage were minimal. Based on the amount of boric acid present, the leak size was determined to be extremely small and the associated leak rate would be too small to be captured by normal surveillance methods. All 78 pressurizer heater tubes and couplings were visually inspected in the A1R12 outage. The visual inspections identified only heater 52 as the leakage source. The amount of leakage was well within the capacity of the normal charging system; therefore, the effect on normal plant operation was insignificant. The leak was identified through refueling outage inspection activities, not during plant operation.

Design Analysis Safety Considerations

Westinghouse considers any break size smaller than 0.375 inch equivalent diameter for a liquid space break and any break size smaller than 0.875 inch for a vapor space break to be capable of being made up with normal charging flow. Anything larger than these approximations would be considered a Loss of

Coolant Accident (LOCA). The ID of the pressurizer heater sleeves is 0.905 inch for Braidwood Unit 1 and Byron Units 1 & 2, and the ID is 0.8905 inch for Braidwood Unit 2. Therefore, a postulated complete break or ejection of a pressurizer heater sleeve would be considered a LOCA event. A LOCA in the pressurizer due to heater pressure boundary failure would be considered a hot leg break in analysis space. The Braidwood Units 1 & 2 and Byron Units 1 & 2 LOCA analyses are performed assuming the break is on the cold leg, since for a number of reasons, this assumption gives the worst results with regard to break location in the loop piping. Thus, a break at the location of the bottom of the pressurizer is bounded by the current LOCA analysis. The number of heater failures is also bounded by the current LOCA analysis. From a mass loss standpoint, the number of heater sleeve breaks in the pressurizer is not limited because multiple ejections will only equate to a surge line break and nothing more. This is considered implicit with the LOCA analysis. As such, no further concerns exist regarding the impact of circumferential cracking in one or more heater sleeves, with respect to the plant LOCA analyses.

These results are consistent with the findings of the CE heater sleeve operability study in Reference 1, which concluded that existing design analyses would remain bounding in the event of a pressurizer heater sleeve ejection. Ejection of a heater sleeve was found to be equivalent to a small break LOCA (SBLOCA). The consequences of such an event were found to be bounded by the results of existing SBLOCA emergency core cooling system (ECCS) performance analysis.

With respect to Braidwood Units 1 & 2 and Byron Units 1 & 2, the conclusions with respect to plant design analyses and plant response to a heater sleeve ejection are similar to those found in the Reference 1 (CE) operability assessment. Existing design analyses bound the postulated ejection of one or more heater sleeves affected by circumferential cracking. If a postulated sleeve ejection were to occur, the event would be handled by existing Operator Response and Emergency Procedure Guidance. The guidance provided in existing plant operating procedures would provide adequate operator direction to mitigate such an occurrence.

Operating History of Stainless Steel Heater Sleeves in Westinghouse-Designed Plants

Aside from the circumferential cracking attributed to PWSCC in Alloy 600 heater sleeves in CE-designed pressurizers that has been observed at various plants since the late 1980's, there have been no other instances of circumferential cracking of pressurizer heater sleeves such as that observed in one sleeve at Braidwood Unit 1 in the A1R12 outage. There are at least 12 plants of Westinghouse design in operation with the same configuration of welded stainless steel heater sleeves, with a total of 936 such heater sleeves in service. These plants are in the range of 20-25 years old. This represents over 20,000 sleeve-years of operating experience for the stainless steel heater sleeve design in use at Braidwood Units 1 & 2 and Byron Units 1 & 2, with the heater at location 52 of Braidwood Unit 1 being the only occurrence of IGSCC-induced circumferential cracking. With no other occurrences if leakage occurring in this large populations of stainless steel heater sleeves with an average of 20 years of operating experience, this data suggests an extremely low probability of occurrence of cracking in another heater sleeve at Braidwood Units 1 & 2 and Byron Units 1 & 2.

Operability Assessment Conclusions

For postulated circumferential cracks in the Braidwood Units 1 & 2 and Byron Units 1 & 2 pressurizer heater sleeves, an assessment of inside surface through-wall flaws in the pressurizer heater sleeve tubes shows that flaws as deep as 75% of the wall thickness have at least a remaining life expectancy of two years prior to reaching the outside surface and forming a through-wall flaw. Through-wall flaws as large as 120 degrees around the circumference still have very low crack tip stress intensity factors showing the integrity of the tube is maintained.

Leakage rate assessments for Braidwood Unit 1 (applicable to all four Braidwood and Byron units) show that the circumferential through-wall flaw in the heater sleeve is in the range of [ ][b,c,e] gallons per minute for the flaws that extend approximately 1/3 of the circumference of the heater sleeve. It is important to realize that much smaller through-wall flaws will result in boric acid deposits of the heater sleeve. The RCS pressure boundary required leak detection capability for the plants is 1 gpm. However, the actual capability is closer to 0.1 gpm. All plants monitor their leakage rates constantly, and are very sensitive to departures from average leak rates. Typically, even small departures from the average unidentified leak rates are investigated.

Operating experience for this design of stainless steel heater sleeve, totaling over 20,000 sleeve-years of operating experience for the stainless steel heater sleeve design in use at Braidwood Units 1 & 2 and Byron Units 1 & 2, indicates that the heater at location 52 of Braidwood Unit 1 represents the only occurrence of IGSCC-induced circumferential cracking in the industry. With no other occurrences of leakage occurring in this large populations of stainless steel heater sleeves with an average of 20 years of operating experience, this data suggests an extremely low probability of occurrence of cracking in another heater sleeve at Braidwood Units 1 & 2 and Byron Units 1 & 2 during continued operation. As a precautionary measure, bare metal visual inspection for detection of boron deposits in the annulus region and at heater sleeve welds will be performed at every outage for each of the Braidwood and Byron units, pending more definitive industry (PWR Owners Group) guidance.

For a postulated severance or ejection of a heater sleeve due to circumferential cracking, a break at the location of the bottom of the pressurizer is bounded by the current LOCA analysis. The number of heater failures is also bounded by the current LOCA analysis. From a mass loss standpoint, the number of heater sleeve breaks in the pressurizer is not limited because multiple ejections will only equate to a surge line break and nothing more. This is considered implicit with the LOCA analysis. As such, no further concerns exist regarding the impact of circumferential cracking in one or more heater sleeves, with respect to the plant LOCA analyses. These results are consistent with the findings of a much more detailed operability assessment for CE heater sleeves in Reference 1, which concluded that existing design analyses would remain bounding in the event of a pressurizer heater sleeve ejection. Ejection of a heater sleeve was found to be equivalent to a small break LOCA (SBLOCA). The consequences of such an event were found to be bounded by the results of existing SBLOCA emergency core cooling system (ECCS) performance analysis.

As previously discussed, bare metal visual inspection of the heater sleeve welds, the bottom of the pressurizer and annulus region will be performed for detection of boron deposits at every outage for each of the Braidwood and Byron units, pending more definitive industry (PWR Owners Group) guidance. Verification of no leaking heater sleeves at each outage through bare metal visual inspection, and the low probability of occurrence of such leakage given the extensive operating experience for stainless steel heater sleeves coupled with the results of this operability assessment, will provide a basis for the continued safe operation of Braidwood Units 1 & 2 and Byron Units 1 & 2.

References

1) WCAP-16180-NP, Revision 0, "Operability Assessment for Combustion Engineering Plants with Hypothetical Circumferential Flaw Indications in Pressurizer Heater Sleeves", December 2003.

2) Root Cause Investigation Report (Preliminary), "Boric Acid Accumulation on Bottom of PZR Due To Weld Failure on PZR Heater #52", transmitted by e-mail from Gary.Alkire@exeloncorp.com to G. Rao (Westinghouse), dated 5/22/06.

3) H. Fujimori, "JSME SCC Curve for Alloy 182 in BWR Normal Water Condition", Hitachi Ltd., Attachment 4, Meeting Minutes, Task Group on SCC Reference Curves, ASME Section XI, February 15, 2006, Portland, Oregon. {taken from the JSME Code Fitness for Service Rules, 2005}

4) a. ASME Boiler and Pressure Vessel Code, Section III, 1971 Edition through Summer 1973 Addenda.
b. ASME Boiler and Pressure Vessel Code, Section III, 1974 Edition (used for material ultimate strength properties only)

5) ASME Code, Section XI, Appendix C, 2004 Edition.

6) Yukio Takahashi, "Evaluation of leak-before-break assessment methodology for pipes with a circumferential through-wall crack. Part I: stress intensity factor and limit load solutions", International Journal of Pressure Vessels and Piping, Vol.79, 2002, pg: 385-392.

7) Westinghouse Stress Reports:

a. WNET-130(CAE)-V1, Rev. 3, August 1989, and WNET-130(CAE)-V1-S1, Rev. 0, August 1978, "Model D Series 84 Pressurizer Stress Report for Commonwealth Edison Company Byron Generating Station Unit 1".

b. WNET-130(CBE)-V1, Rev. 3, August 1989, and WNET-130(CBE)-V1-S1, Rev. 0, October 1978, "Model D Series 84 Pressurizer Stress Report for Commonwealth Edison Company Byron Generating Station Unit 2".

c. WNET-130(CCE)-V1, Rev. 3, August 1989, and WNET-130(CCE)-V1-S1, Rev. 0, September 1979, "Model D Series 84 Pressurizer Stress Report for Commonwealth Edison Company Braidwood Generating Station Unit 1".

d. WNET-130(CDE)-V1, Rev. 2, August 1989, and WNET-130(CDE)-V1-S1, Rev. 0, September 1984, "Model D Series 84 Pressurizer Stress Report for Commonwealth Edison Company Braidwood Generating Station Unit 2".

8) Westinghouse Electric Design Specification 679128, Revision 6, dated 9/12/88.

9) ASME Code Case N-513-1, "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or 3 Piping Section XI, Division 1", Approval date: March 28, 2001.

10) Westinghouse Letter STD-MCE-06-31, "Metallurgical Assessment Summary of Braidwood Pressurizer Heater Sleeve Cracking", G. Rao, May 2006.

11) Westinghouse Letter LTR-PAFM-06-40, "Parametric Leak Rate and Flaw Assessment Calculations of Braidwood Unit 1 Pressurizer Heater Sleeve Tubes", May 25, 2006.

Table 1: Actual Material Properties at Room Temperature from CMTRs

a,c,e

[ ]

Table 2: Material Properties at Operating Temperature (653°F) used in the Analysis

b,c,e

[ ]

Table 3: Tube Geometry

a,c,e

[ ]

Table 4: Operating Loads

b,c,e

[ ]

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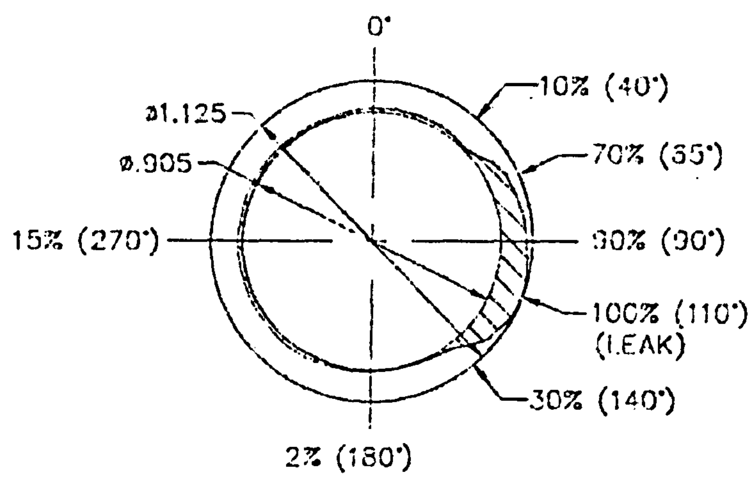
(1) Evaluations considered this heat; applicability to Byron still to be verified.
(2) Ultimate strengths from 1974 ASME Code, since they do not appear in Code until that edition.

Figure 1: Schematic Representation of Braidwood Pressurizer Heater Sleeve Crack Depth Profile



CLOCK LOCATION	40°	65°	90°	110°	140°	180°	270°
DEPTH FROM I.D. (INCHES)	0.01	0.07	0.09	0.1	0.03	0.002	0.015

Figure 2: Heater Sleeve Tube Arrangement

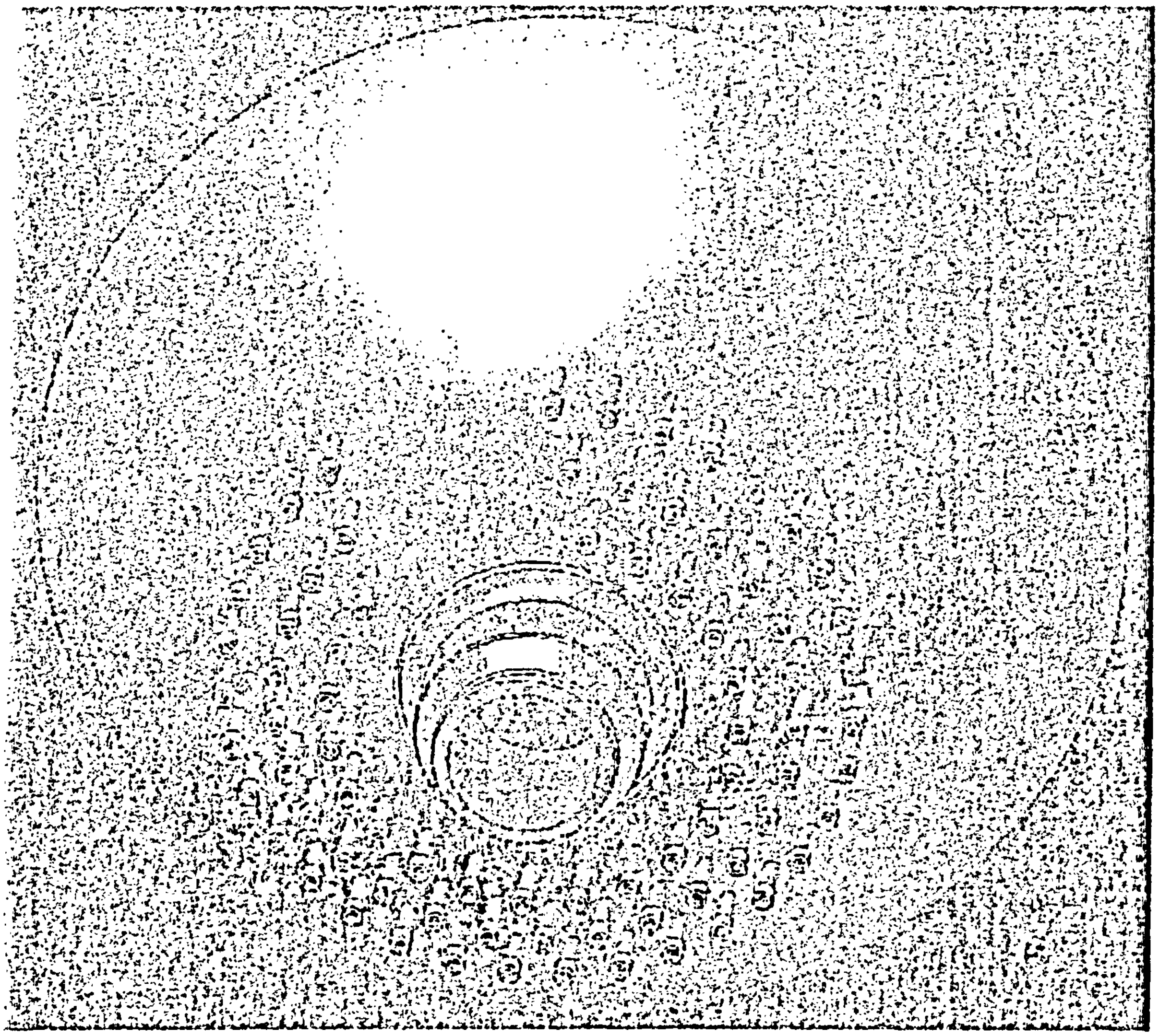


Figure 3: Heater Sleeve Tube Geometry
(excerpted from Westinghouse heater weld detail assembly drawing)

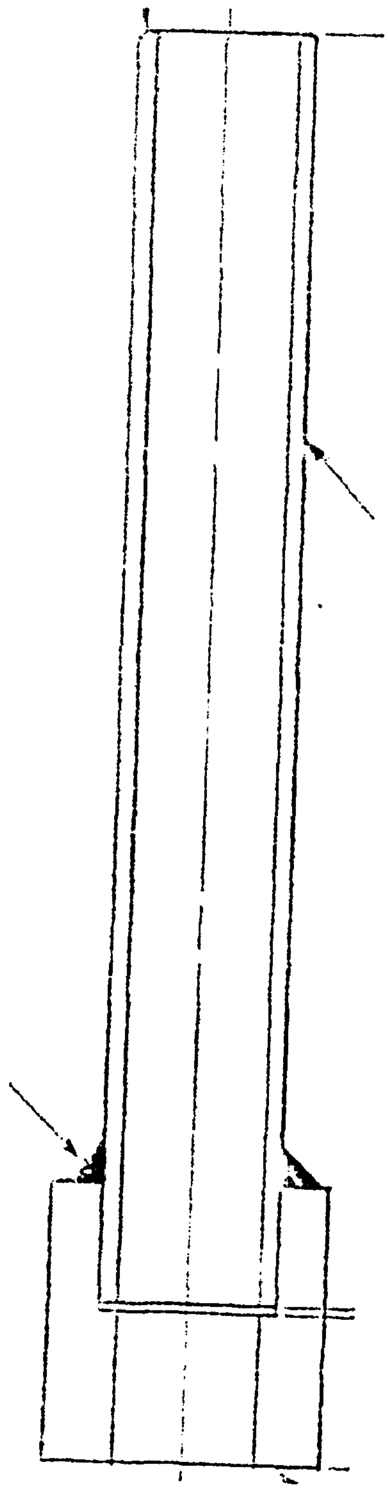


Figure 4: JSME Properties for Stainless Steel 304 in BWR environment at 288°C

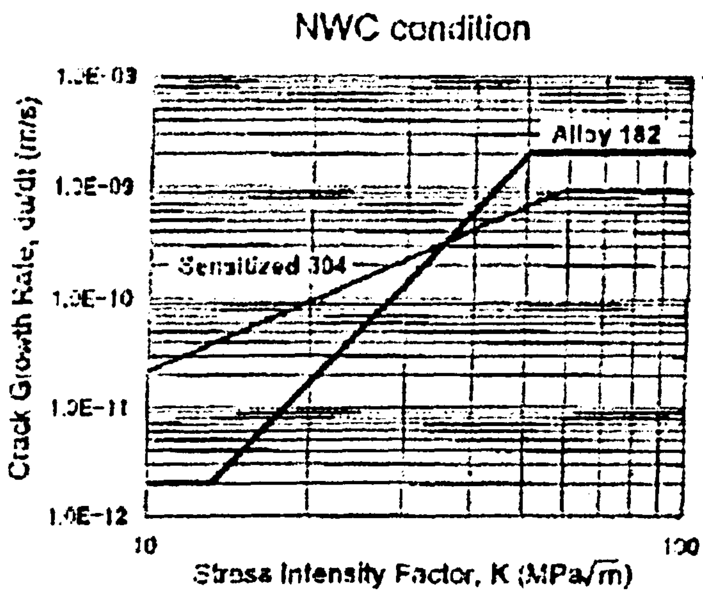


Figure 5: ASME Code Case N-513 Properties for Austenitic Piping up to 200°F

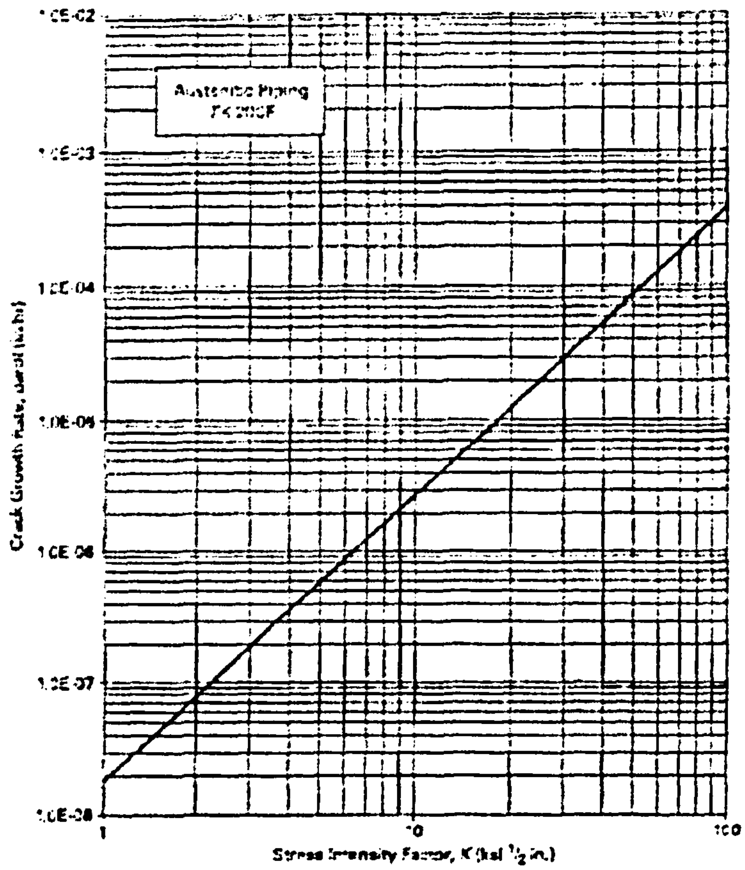


Figure 6: Comparison of JSME and ASME Code Case N-513-1 Crack Growth Properties for Stainless Steel

b,c,e

Figure 7: Inside Surface Circumferential Part-through Wall Flaw Configuration

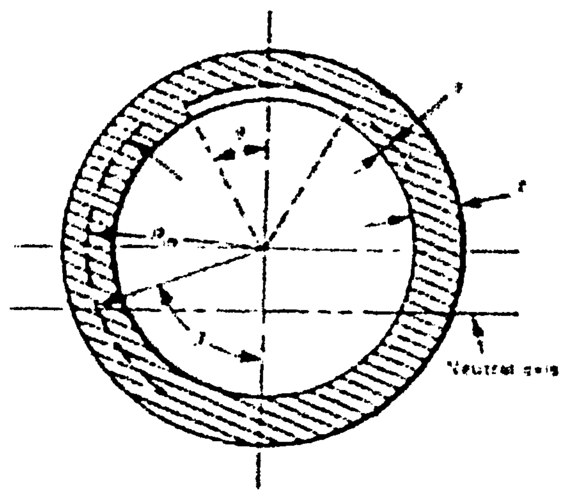


FIG. C-4310-1 CIRCUMFERENTIAL FLAW GEOMETRY

Figure 8: Circumferential Through-wall Flaw Configuration

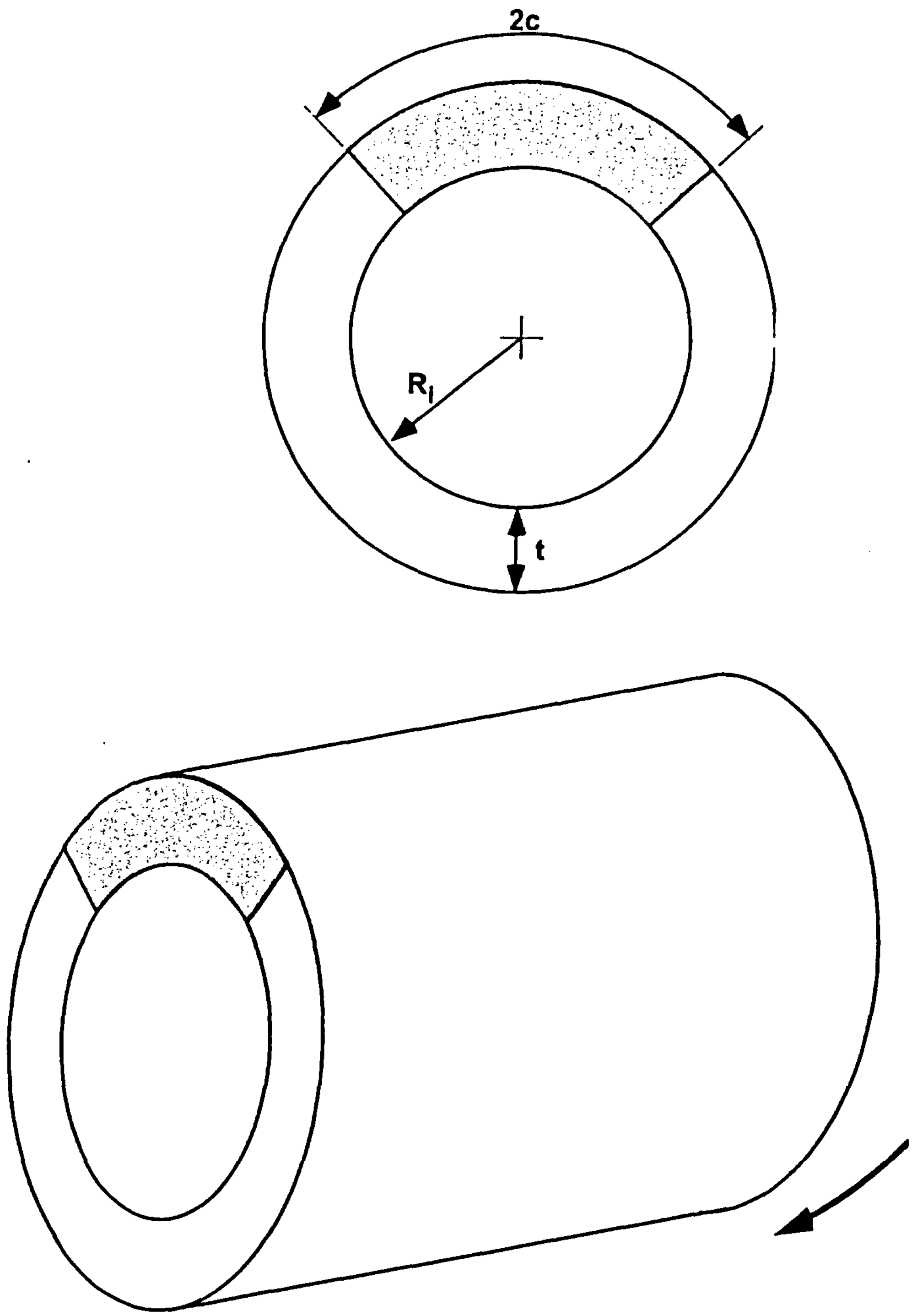


Figure 9:

Inside Surface Part-through wall Circumferential Flaw Stress Intensity Factor from ASME XI Appendix C

b,c,e

[ ]

Figure 10: Crack Growth with Time for Initial Flaw Depth/Thickness Ratios of 0.25, 0.5 and 0.75

b,c,e

Figure 11:

Expected Life vs Part-through wall Inside Flaws for Stainless Tube at Temperature

Under Normal Operating Loads

b,c,e

Figure 12: Applied and Allowable Stresses per ASME Section XI Appendix C Criteria for Circumferential ID Surface Part Through-wall Flaws

b,c,e

Figure 13:

Circumferential Through-wall Crack Tip Stress Intensity Factors for Normal Operating Pressure Load

b,c,e

Figure 14: Allowable and Applied Membrane Stress for Circumferential Through-wall Flaws

b,c,e

Figure 15

Braidwood/Byron Pressurizer Heater Sleeve Circumferential Crack Leakage Rates

b,c,e