Westinghouse Non-Proprietary Class 3

WCAP-16132-NP

August 2003

H.B. Robinson Unit 2 RPVH Inspection Fall 2002 Inspection Coverage Evaluation

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TABLE OF CONTENTS

1 INTRODUCTION

During Refueling Outage 21, in October 2002, Westinghouse performed nondestructive examinations (NDE) of reactor vessel head penetration tubes and J-groove welds at H.B. Robinson Unit 2. The purpose of the NDE inspection program was to identify the presence of primary water stress corrosion cracking (PWSCC) on the accessible OD and ID surfaces of the head penetration tubes and the partial penetration J-Groove welds attaching the penetrations to the reactor vessel head.

The reactor vessel head at H.B. Robinson Unit 2 contains 69 alloy 600 penetration tubes that are shrunk fit in the reactor vessel head and attached with alloy 182 partial penetration J-groove welds. The reactor vessel head was manufactured by Combustion Engineering.

There are a variety of configurations for the 69 penetration tubes, each configuration requiring special consideration for examination. The penetration tube configurations are as follows:

- 45 penetration tubes with thermal sleeves installed
- 7 penetration tubes with part length drive shafts
- 17 penetration tubes without thermal sleeves

The reactor vessel head penetration nondestructive examination scope at H.B. Robinson Unit 2 included:

1. Eddy current and ultrasonic examinations of the seventeen open penetration tubes from the penetration tube ID surfaces using the Westinghouse 7010 Open Housing Scanner, and

2. Eddy current examinations of the fifty-two sleeved penetration tubes from the penetration tube ID surfaces using the Westinghouse Eddy Current Gapscanner.

3. Eddy current examinations of all sixty-nine J-groove welds and penetration tube OD surfaces using the Westinghouse Grooveman manipulator,

This report documents a review of the fall 2002 RVHP examination results to identify the inspection coverage achieved, taking into account the effect of as-built geometry and the J-weld fillet contour.

For all inspections performed at H.B. Robinson the inspection coverage lengths are illustrated on Figure 1.

2 INSPECTION COVERAGE

2.1 TUBE ID INSPECTIONS

Examination data from the Westinghouse Gapscanner and the Westinghouse Open Housing Scanner were reviewed to establish the extent of coverage achieved. Both scanners deliver probes to the penetration tube ID surface and scan the tubes in a vertical motion and index in the tubes circumferentially.

Inspection coverage on the lower extreme of the tube was verified through the identification of the bottom edge of the tube, or exit signal, in the C-scan display of the eddy current data. In all cases, the exit signal was visible, as shown in the column identified "Tube ID Bottom" in Table 1. Inspection coverage above the weld was verified by a direct read of the inspection height. This review of the inspection data from the Gapscanner and Open Housing Scanner confirmed that the eddy current exit signal is present in the C-scans for all 69 penetrations and that the inspection coverage above the weld was at least 2.0" above the upper elevation of the welds. Examples of the eddy current C-scan displays for penetrations #1, 5, 15, 37 and 63 are shown in Figures 2 through 6.

2.2 J-GROOVE WELD INSPECTIONS

All 69 J-Groove welds were examined using eddy current techniques with the Grooveman end effector, which delivers the eddy current probes along the weld surface and along the penetration tube OD surface that extends below the RPVH.

Two separate inspections are performed with this scanner. The first one delivers two eddy current probes in tandem along J-weld surface on reactor pressure vessel head, or ROOF scan, and the second delivers one eddy current probe along the tube OD surface, the TUBE scan. The mechanism is designed to produce the appropriate probe motion trajectory for each scan to achieve full inspection coverage from the J-weld roof scan to the tube scan. This coverage is illustrated in Figure 7.

As a verification, we have also reviewed available videotapes that were recorded for training purposes during the last inspection at H.B. Robinson. Review of these videotapes confirms the probe trajectory and that the anticipated overlap between the ROOF and TUBE scans was achieved. Still photos from reviewed video are shown in Figures 8 through 10.

Examination data from the "ROOF," or weld scans, from the Grooveman end effector were reviewed to establish the extent of J-Groove weld coverage achieved. For J-Groove weld eddy current inspections, the recognizable location in the C-scans is the boundary line between the stainless steel cladding on the head and the inconel buttering. The boundary between the end of the weld fillet and the tube is not readily recognizable because of the similarities of the materials. We have reviewed the inspection data and measured the inspection extent from the tube along the full J-weld width and over the stainless steel cladding (JG-E distance on Fig.1). Examples of the eddy current C-scan displays for penetrations #7, 21, 42, 47 and 57 are shown in Figures 11 through 15 and the individual measurements for all 69 penetrations are included in the column identifies as "J-Weld Ext (inch)" in Table 1. From these measurements we confirmed the full J-weld surface inspection coverage in all cases, and the additionally inspected surface that extends at least [ ][a,c,e] beyond the cladding and buttering interface (JG-E minus JG-L on Fig.1), incorporating lessons learned from the North Anna inspection of Fall 2002.

2.3 PENETRATION TUBE OD INSPECTIONS

The OD surfaces of all 69 penetration tubes were examined using eddy current techniques with the Grooveman end effector.

Examination data from the "TUBE", or penetration OD surface scans, from the Grooveman end effector were reviewed to establish the extent of penetration coverage achieved. For this purpose eddy current data from each individual tube scan were reviewed to identify the probe position coverage on the "low side" of the J-groove weld (THmin On Fig.1). This position represents the zone with the least coverage below the J-groove weld fillet. All other locations around the tube circumference have increasing coverage of the tube to a maximum achieved at the "high side" weld location. The inspection coverage below the J-weld fillet is illustrated in Figures 16 and 17.

Recent experience with vessel head examinations has shown that the calculated tube lengths inside the vessel head are not always representative of the dimensions found in the vessel head as-built condition. In most instances, the tube lengths are calculated based on the elevation where the tube intersects the vessel head and does not take into account the weld fillet on the tube. During vessel manufacture the length of the fillet was not a controlled dimension and can vary from tube to tube. During the examinations in the fall of 2002, accurate dimensioning of these tubes was not included in the inspection program.

Since as-built information is not available related to the H.B. Robinson fillet weld geometry, measurements were made on the Jamesport reactor vessel head located at Westinghouse facility in Waltz Mill, PA.

Measurements made on the Jamesport head show that the actual (as-built) J-weld fillet covers the penetration tube to a distance of approximately [ ]^{a,c,e} from the elevation where the penetration tube intersects the reactor vessel head. This is illustrated in Figure 18. Actual contours from the Jamesport head are shown in Figures 19 and 20.

The H.B. Robinson penetration tubes have shorter lengths under the head as compared to the Jamesport head. The Jamesport head tubes extend approximately [ ]^{a,c,e} below the head ID on the low side (0° circumferential orientation). The tube lengths below the head ID at Robinson measure [ ]^{a,c,e}, on average.

Two penetration locations for the Robinson vessel head were assessed with respect to design versus as-built geometries of the J-weld fillet contours. The two locations selected were those with intersect angles of [ ]^{a,c,e}. These two penetration geometries are shown in Figures 21 and 22. From these sketches it is evident that the length of the straight tube section below the head is actually [ ]^{a,c,e}, as compared to a design dimension of approximately [ ]^{a,c,e}, due to the presence of the fillet on the J-groove weld. For central penetrations, measurements on the Jamesport head show the weld fillet extends approximately [ ]^{a,c,e} down the tube. The as-built geometry, taking into account the presence of the weld fillet, has been found to have an impact on the inspection of the tube OD surface, by reducing the length of inspectable surface, especially on the downhill side of the weld (0° azimuth).

Additional independent measurements on the actual weld heights were extracted from UT data collected for open penetrations. The actual weld heights measured with 0° UT transducer are included in the columns identified as "H.B. Robinson THmax UT" and "H.B. Robinson THmin UT" in Table 1 for penetrations 46 through 57. These results confirm the estimated as-built heights with average differences of [ ]a,c,e.

The inspection coverage achieved on the OD surfaces of the penetration tubes is shown in Table 1. The column identified as "H.B. Robinson THmin (inch)" is the length of coverage achieved on the tube below the weld fillet on the downhill side of the weld (0° azimuth). The column identified as "H.B. Robinson THmax (inch)" is the length of coverage achieved on the tube below the weld fillet on the uphill side of the weld (180° azimuth). Reported inspection heights take into account the actual probe elevation as well as the size of the field of the eddy current coil. The length of tube inspected on the downhill side of the penetrations, below the weld fillet, ranges from a minimum of [ ]a,c,e to a maximum of [ ]a,c,e. The length of tube inspected on the uphill side of the penetrations, below the weld fillet, ranges from a minimum of [ ]a,c,e to a maximum of [ ]a,c,e.

2.4 EXAMINATION COVERAGE SUMMARY

Review of the reactor vessel head penetration data from the October 2002 nondestructive examination of the H.B. Robinson Unit 2 reactor vessel head penetrations indicates the following:

1. Coverage on the penetration tube ID surfaces extended from the bottom of all 69 tubes to elevations at least 2.0 inches above the uphill side of the welds.

2. Coverage of the J-groove weld surfaces extended from the penetration tube to at least [ ]a,c,e beyond the cladding and buttering interface.

3. Coverage of the penetration tube OD surfaces ranged from a minimum of [ ]a,c,e to a maximum of [ ]a,c,e below the weld fillets on the uphill sides of the penetrations and from a minimum of [ ]a,c,e to a maximum of [ ]a,c,e on the downhill sides of the penetrations.

The limitation of coverage on the penetration tube OD surfaces has been investigated and is attributable to interference resulting from the original design of the end effector clamping mechanism. At that time, the mechanism design did not allow the probe to reach within approximately [ ]a,c,e from the bottom of the tube. This mechanical limitation, combined with the configuration of the weld fillet effectively reduce the "inspectable length" of the penetration tube OD surfaces. Given the design of the end effector at the time these examinations were performed the coverage achieved is believed to be the most achievable at that time.

3 STRESS AND FRACTURE EVALUATION OF AS-BUILT CONFIGURATION

To investigate the impact of the weld size being larger than the drawing implies, finite element analyses were constructed for two of the rows of penetrations where the inspection coverage was the most limited, the rows designated 27 degrees, and the outermost row, designated 46 degrees.

Analyses of the design configurations had already been completed, and the stress results from these new analyses of the as-welded configuration have been compared with the earlier analyses. The stresses were used in a crack growth evaluation that provides new insight into the effects of the longer welds.

Stress Analysis. The finite element model originally used for the analysis of the H.B. Robinson head penetrations was modified to approximate the as-built weld size, for two rows of penetrations. The weld size was determined using two key pieces of information. The lower extent of the weld was determined from the actual NDE data taken on the penetrations of interest. The second set of data were obtained from measurements on the Jamesport head, from a canceled plant, which is kept in the Westinghouse Waltz Mill facility. A series of measurements performed on the J-groove welds which exist in that head led to the conclusion that [

]a,c,e

These two pieces of data are sufficient to construct an approximate as-built weld configuration for H.B. Robinson, and the results of the stress analysis are shown in Figures 23 through 26. Figure 23 shows the results for the lower hillside for the 27 degree penetrations, with the results plotted as a function of distance from the bottom of the weld. It may be easily seen that the stresses at the bottom of the actual weld are much lower than would be predicted using the design weld configuration. [

]a,c,e

The as-built weld configuration is very similar to the design configuration for the uphill side of the weld, so the stresses are very similar, as shown in Figure 24, as well as Figure 26.

[

]a,c,e

Crack Growth. The stresses discussed above were used to calculate crack growth for a through-wall flaw in each of the two penetration angles for which as-built stresses were calculated. The purpose of these calculations was to estimate the potential future growth of a flaw, which might have gone undetected due to the lack of inspection coverage. The crack growth model used was from reprt MRP-55 Rev. 1, and was consistent with the NRC guidance letter of April 11, 2003.

Figure 27 shows the results for the downhill side of the 27-degree penetrations, for both the as-built and the design configurations. In each case, the flaw upper end is located 0.5 inches below the weld bottom, and the crack growth is calculated as a function of time. [

]^{a,c,e}

For the 46-degree location, the results are shown in Figures 29 and 30. [

]^{a,c,e}

Therefore it can be seen that the predicted crack growth on the downhill side of the two penetration types analyzed is negligible, and inspection coverage during the H.B. Robinson Refueling Outage 21 examinations was sufficient to justify the proposed examination deferral.

a,c

a,c

a,c

a,c

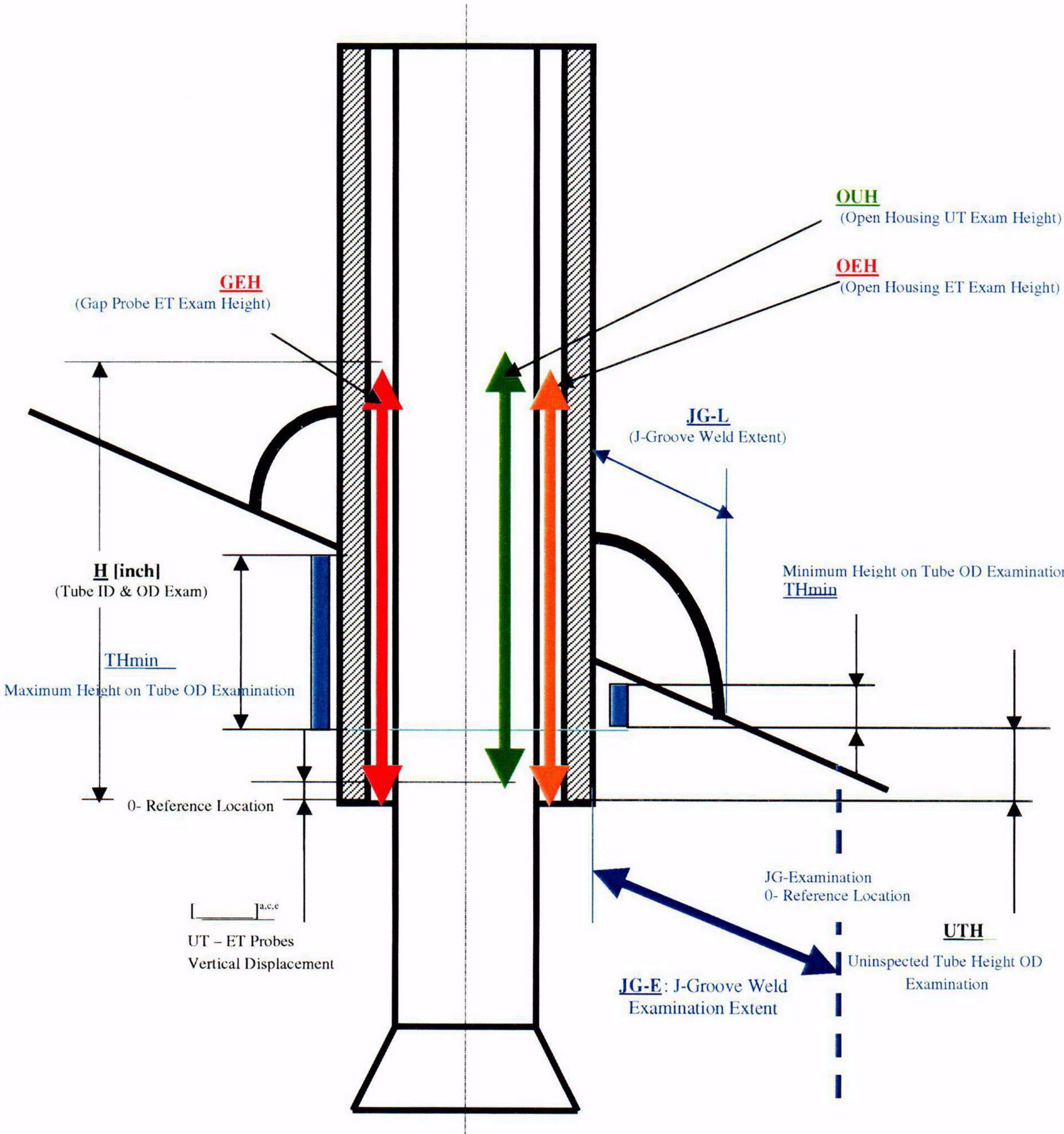


Figure 1 RPVH CRDM Penetration Examination Lengths of Examined Areas along the Tube ID, OD and the J-Groove Weld

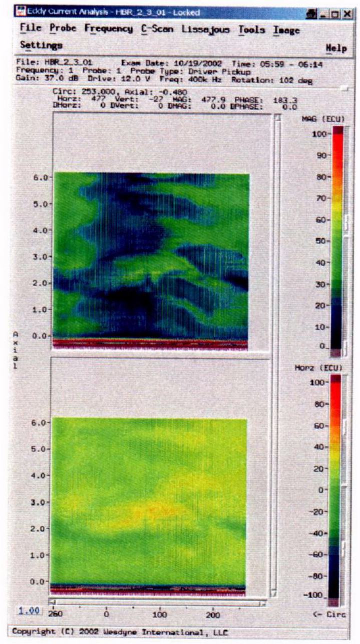


Figure 2 **H.B. Robinson Penetration No. 1 Open Housing-Scanner Examination Tube End Visible on the Bottom [ ]^{a,c,e}**

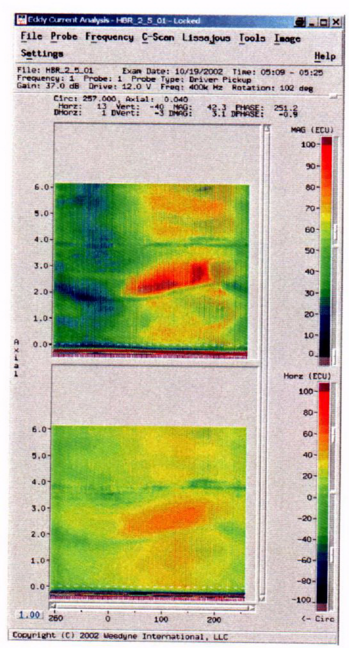


Figure 3 **H.B. Robinson Penetration No. 5 Open Housing-Scanner Examination Tube End Visible on the Bottom [ ]^{a,c,e}**

C02

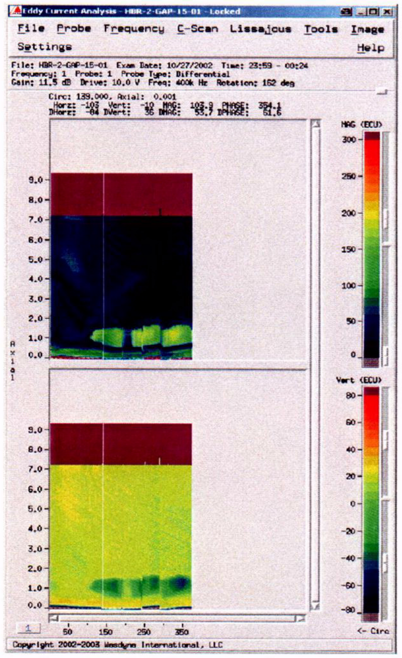


Figure 4 H.B. Robinson Penetration No. 15 Gap-Scanner Examination Tube End Visible on the Bottom [$]^{a,c,e}$

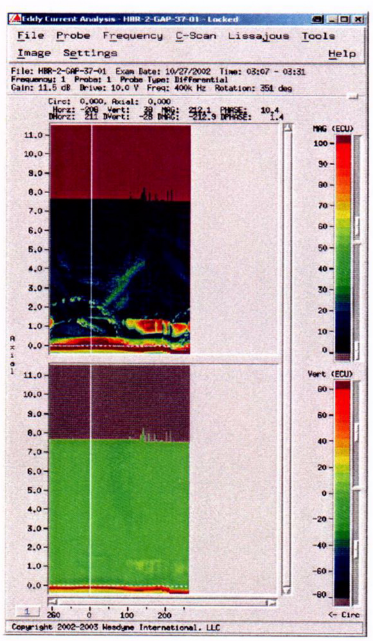


Figure 5 H.B. Robinson Penetration No. 37 Gap-Scanner Examination Tube End Visible on the Bottom [$]^{a,c,e}$

C03

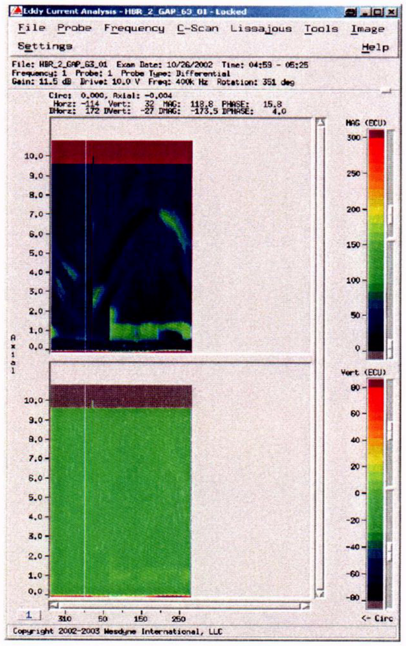


Figure 6 H.B. Robinson Penetration No. 63 Gap-Scanner Examination Tube End Visible on the Bottom [ ]^{a,c,e}

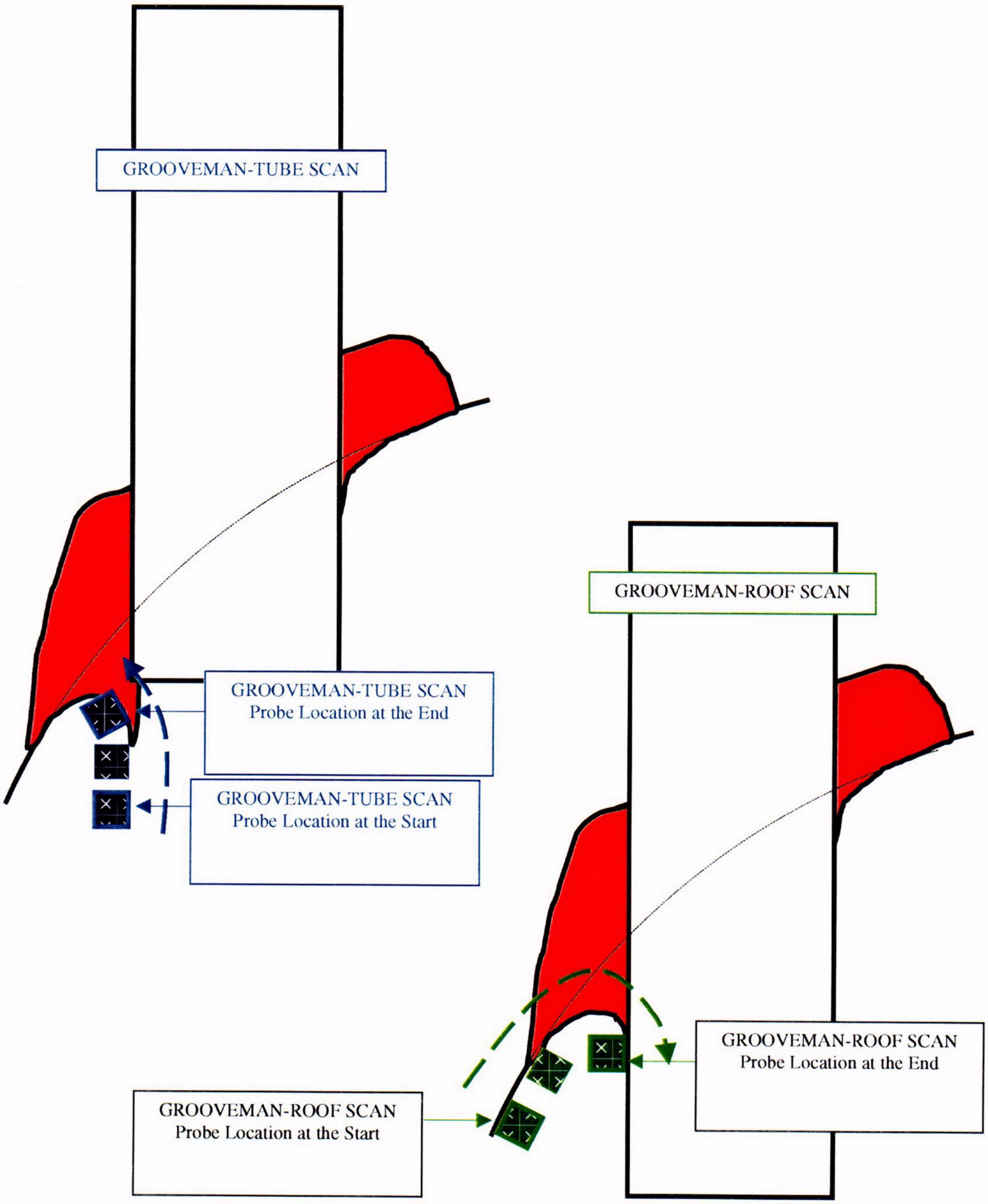


Figure 7 Illustration that Shows Full Coverage of Surface (Eddy Current) Examination Along RPVH J-Weld and Penetration Tube with Two Separate Examination Scans with the "Grooveman" Scanning Mechanisms along J-Weld (ROOF SCAN) and along the Tube (TUBE SCAN) for Weld's Low Point (circumferential position at 0° orientation)

C05

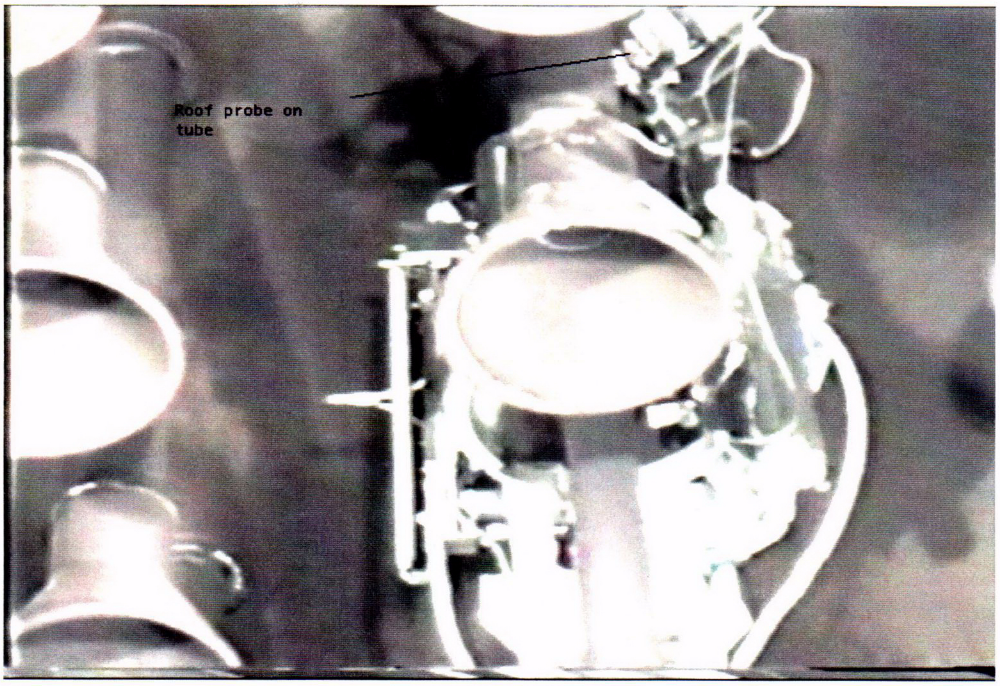


Figure 8 Video Verification for Groveman Roof-Scanner Probe Trajectory

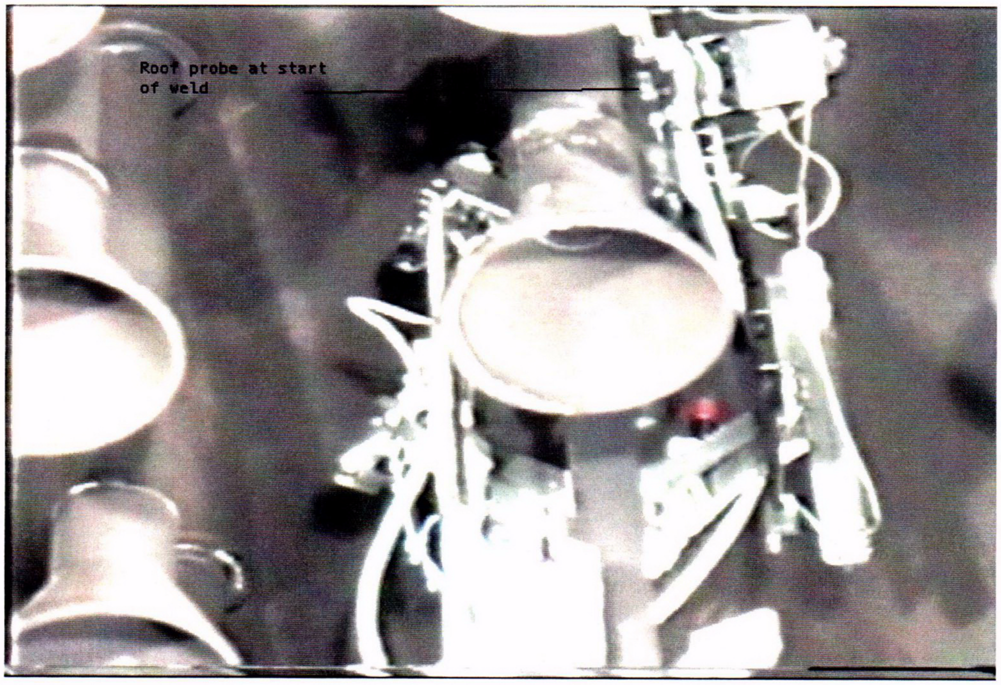
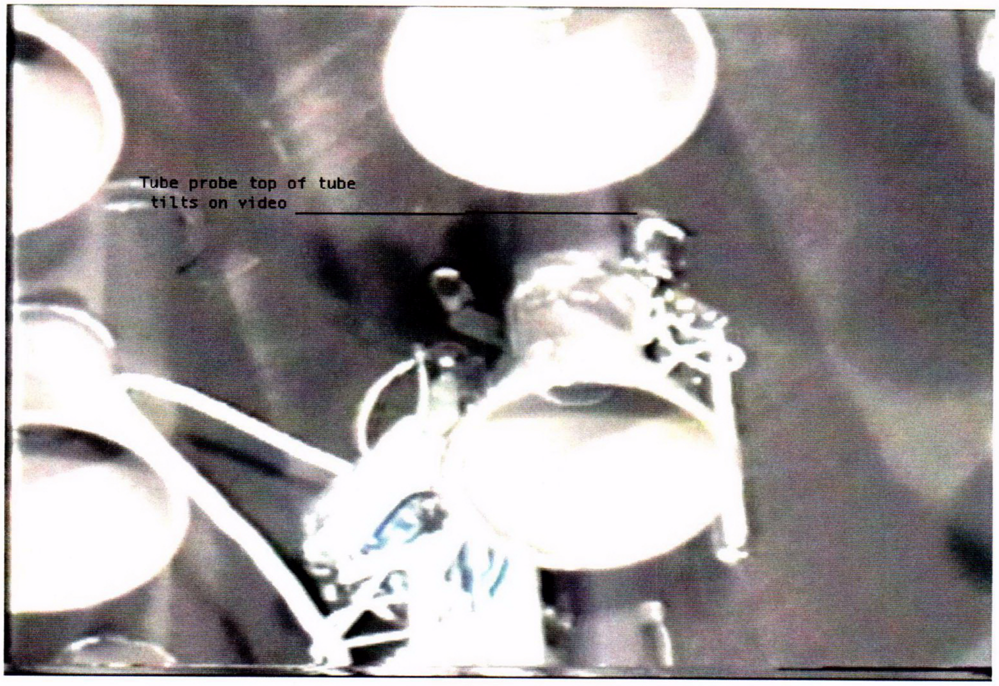


Figure 9 Video Verification for Groveman Roof-Scanner Probe Trajectory



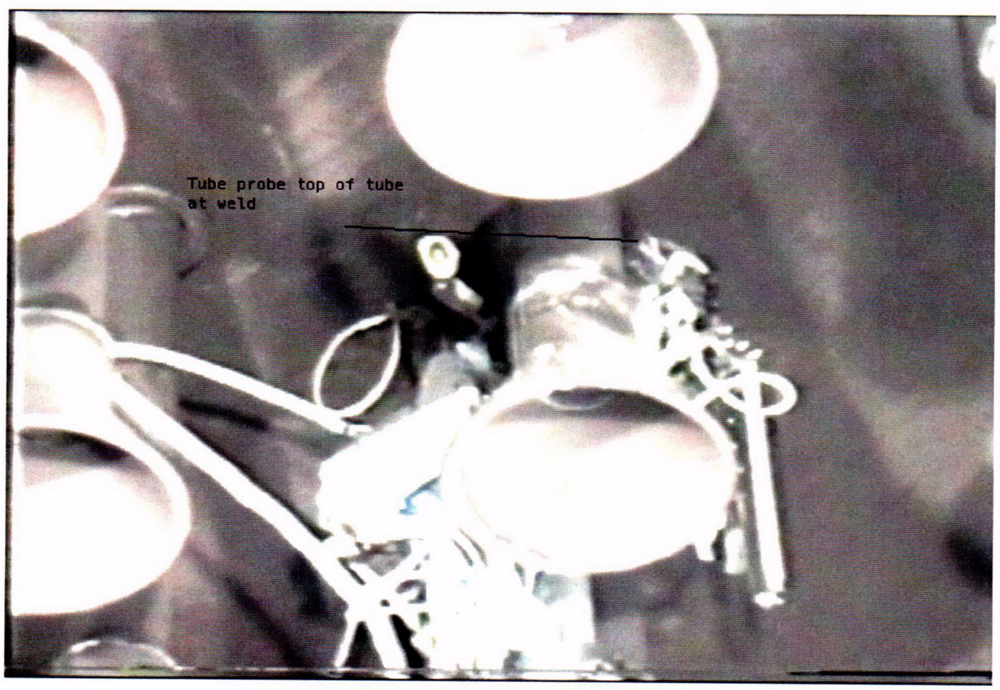


Figure 10 Video Verification for Groveman Tube-Scanner Probe Trajectory

C07

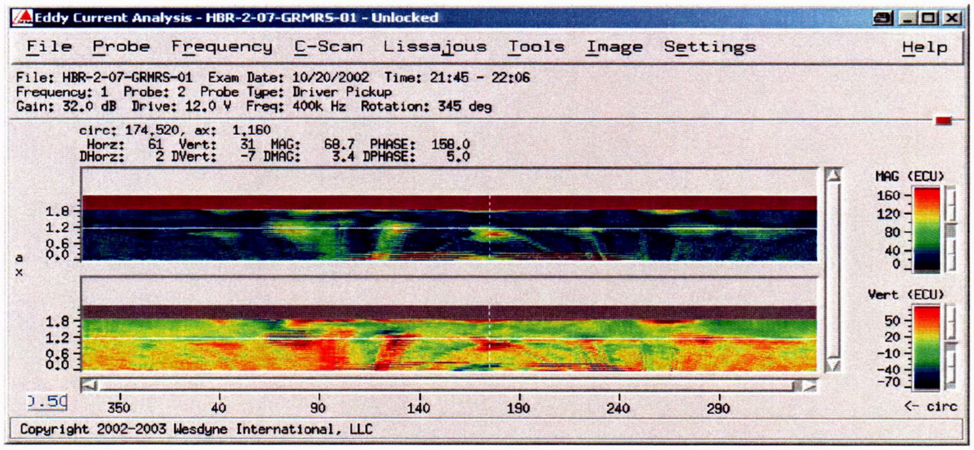


Figure 11 **H.B. Robinson Penetration No.7 J-weld Examination Coverage on Cladded Surface**
[ ]a,c,e

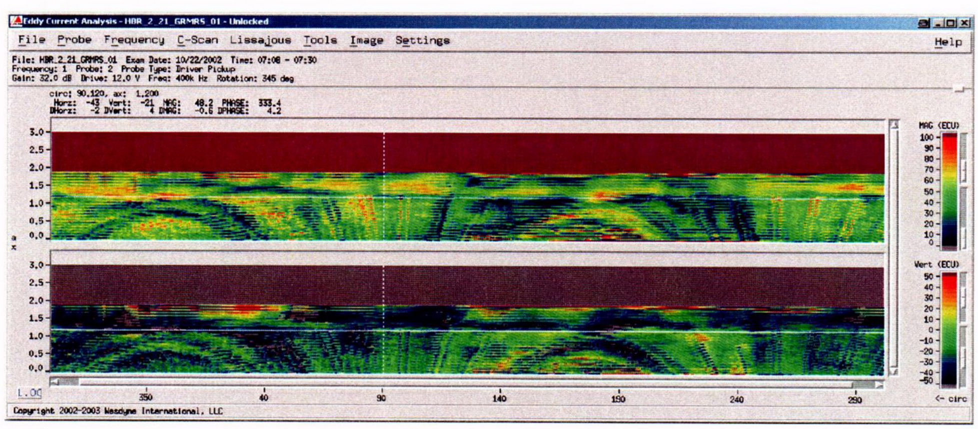


Figure 12 **H.B. Robinson Penetration No.21 J-weld Examination Coverage on Cladded Surface**
[ ]a,c,e

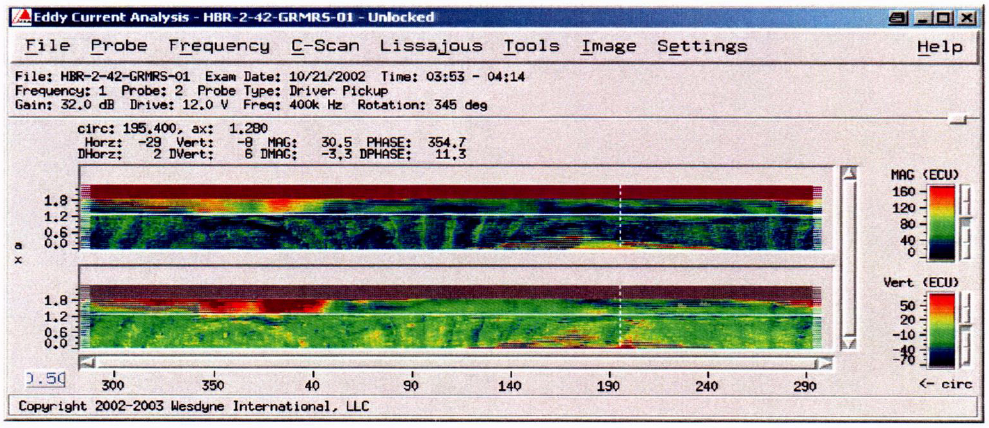


Figure 13 H.B. Robinson Penetration No.42 J-weld Examination Coverage on Cladded Surface
[ ]a,c,e

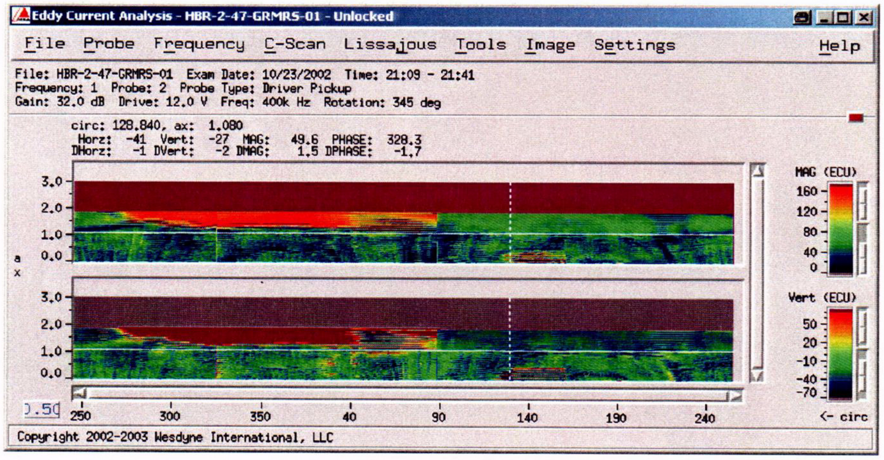


Figure 14 H.B. Robinson Penetration No.47 J-weld Examination Coverage on Cladded Surface
[ ]a,c,e

C09

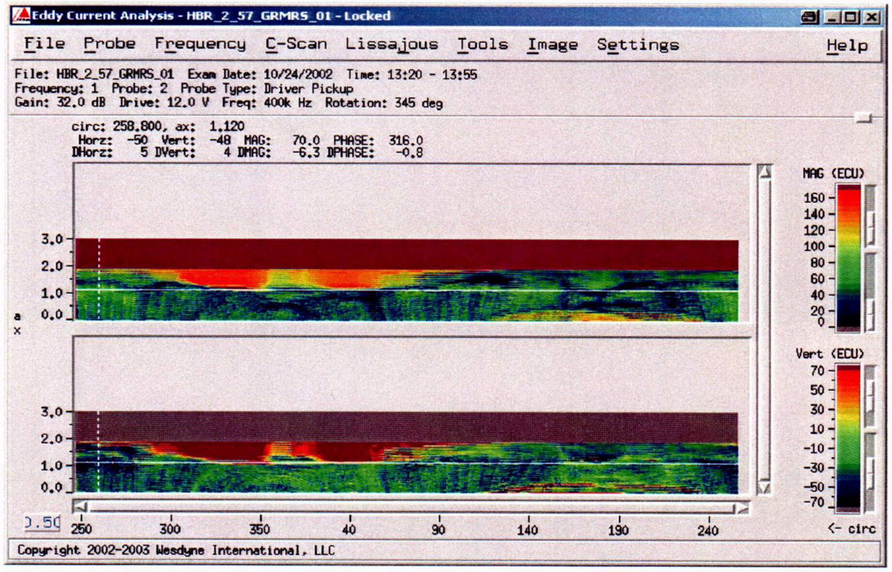


Figure 15 H.B. Robinson Penetration No.57 J-weld Examination Coverage on Cladded Surface [ ]a,c,e

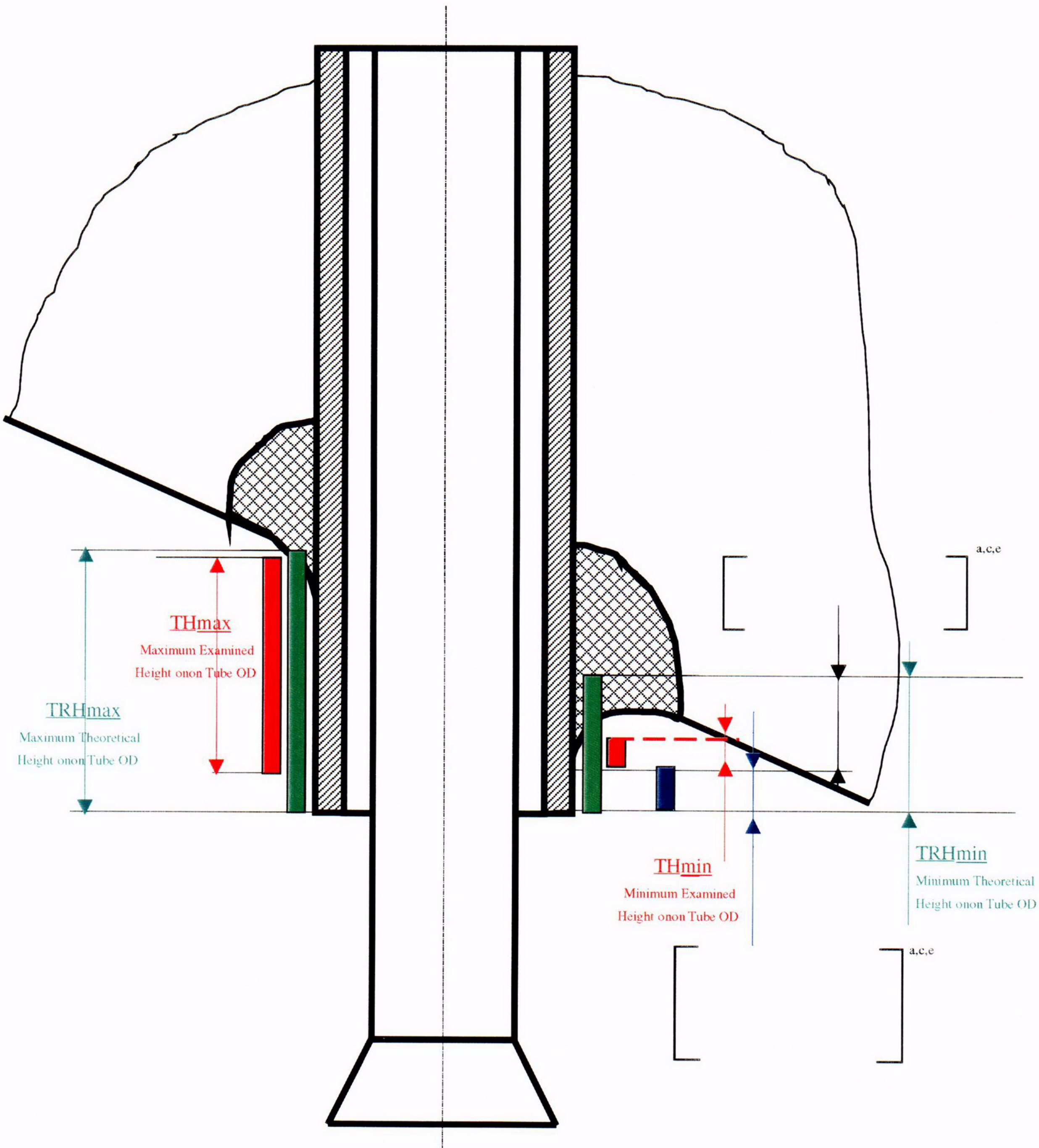


Figure 16 Layout for Surface Inspection Coverage for CRDM Tube OD Surface

C11

a,c,e

Figure 17 Graph Showing the Coverage for Tube OD Inspection on Penetration No. 40

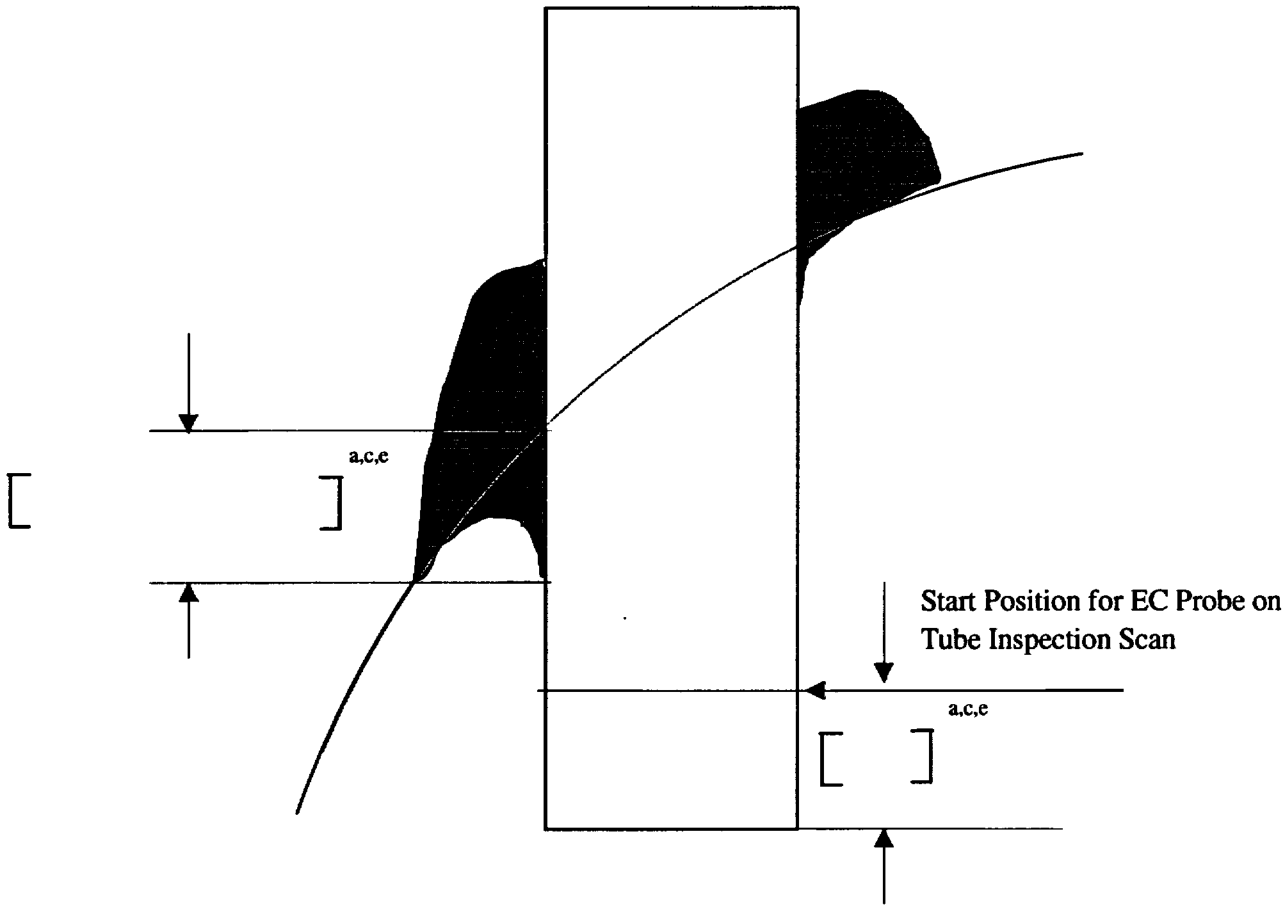
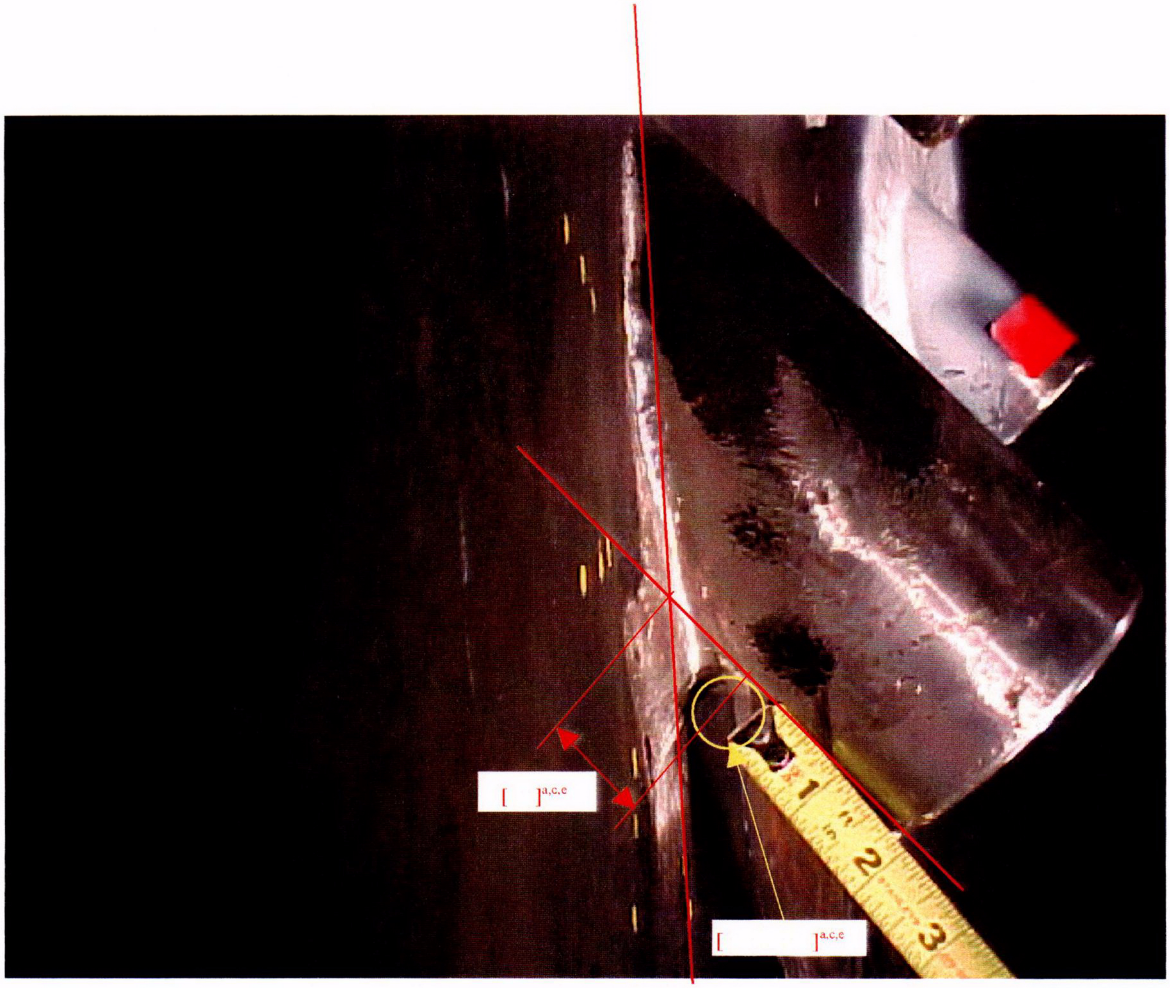


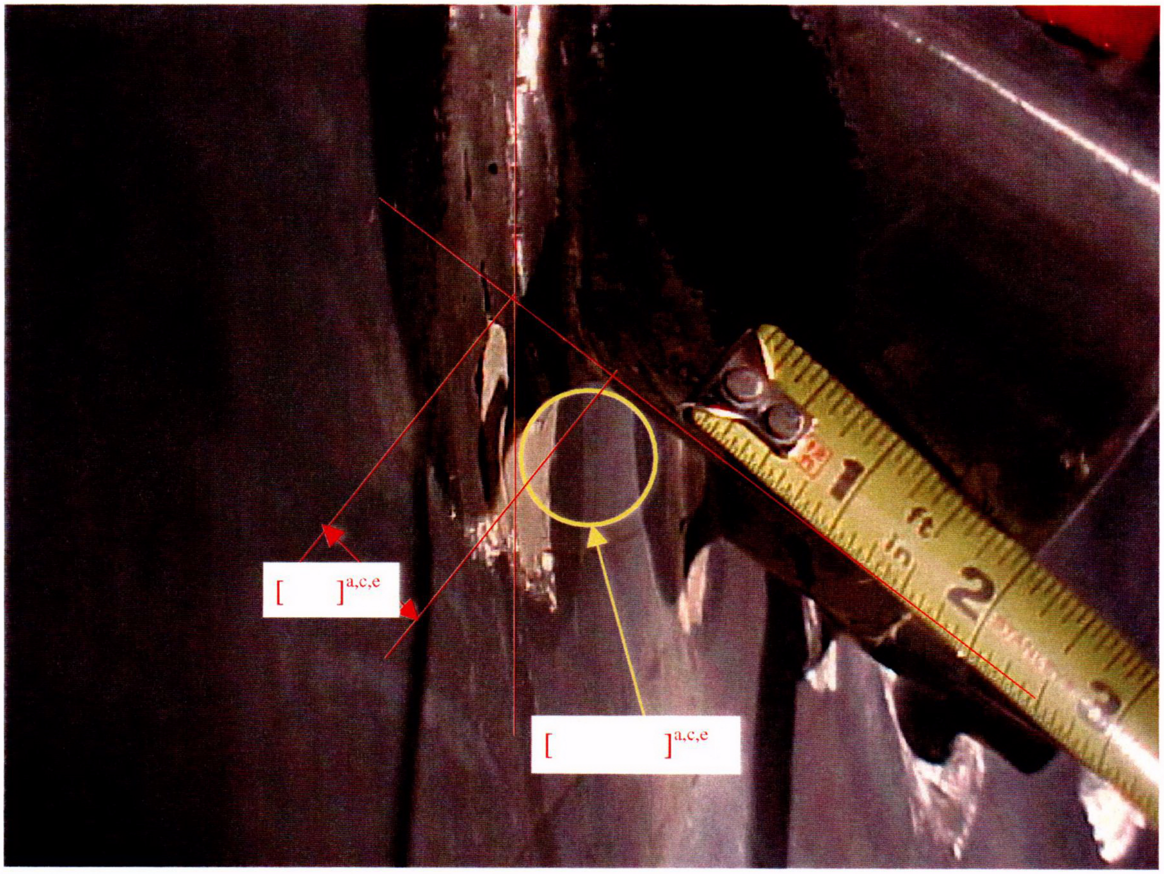
Figure 18 Illustration that Shows As-Built Deviation from Designed Geometry at the Weld's Low Point (circumferential position at 0° orientation), and Approximate Start Location for the "Grooveman" Tube Scans



Peripheral Penetration [ ]a,c,e on James-Port RPVH at
Westinghouse Waltz Mill Facility
Weld Fillet Radius]a,c,e
Weld Fillet Overlap, down the tube from theoretical Intersection [ ]a,c,e

Figure 19 Illustration that shows As-Built Deviation from Designed Geometry at the Weld's Low Point (circumferential position at 0° orientation).

C12



Peripheral Penetration [ ]a,c,e on James-Port RPVH at
Westinghouse Waltz Mill Facility
Weld Fillet Radius [ ]a,c,e
Weld Fillet Overlap, down the tube from theoretical Intersection [ ]a,c,e

Figure 20 Illustration that shows As-Built Deviation from Designed Geometry at the Weld's Low Point (circumferential position at 0° orientation).

C13

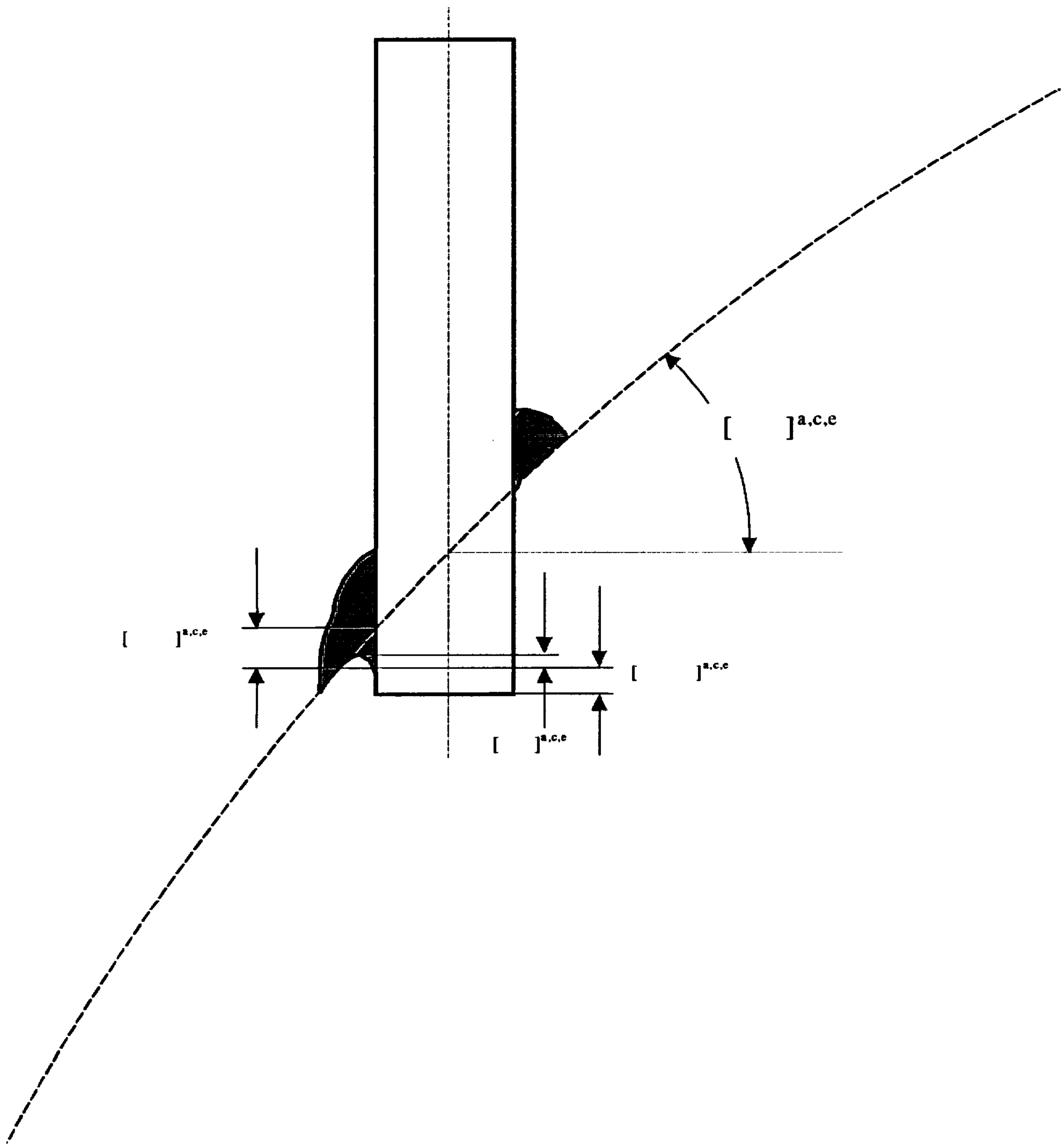


Figure 21 H.B. Robinson CRDM J-Weld Fillet Geometry for Penetration at [ ]a,c,e

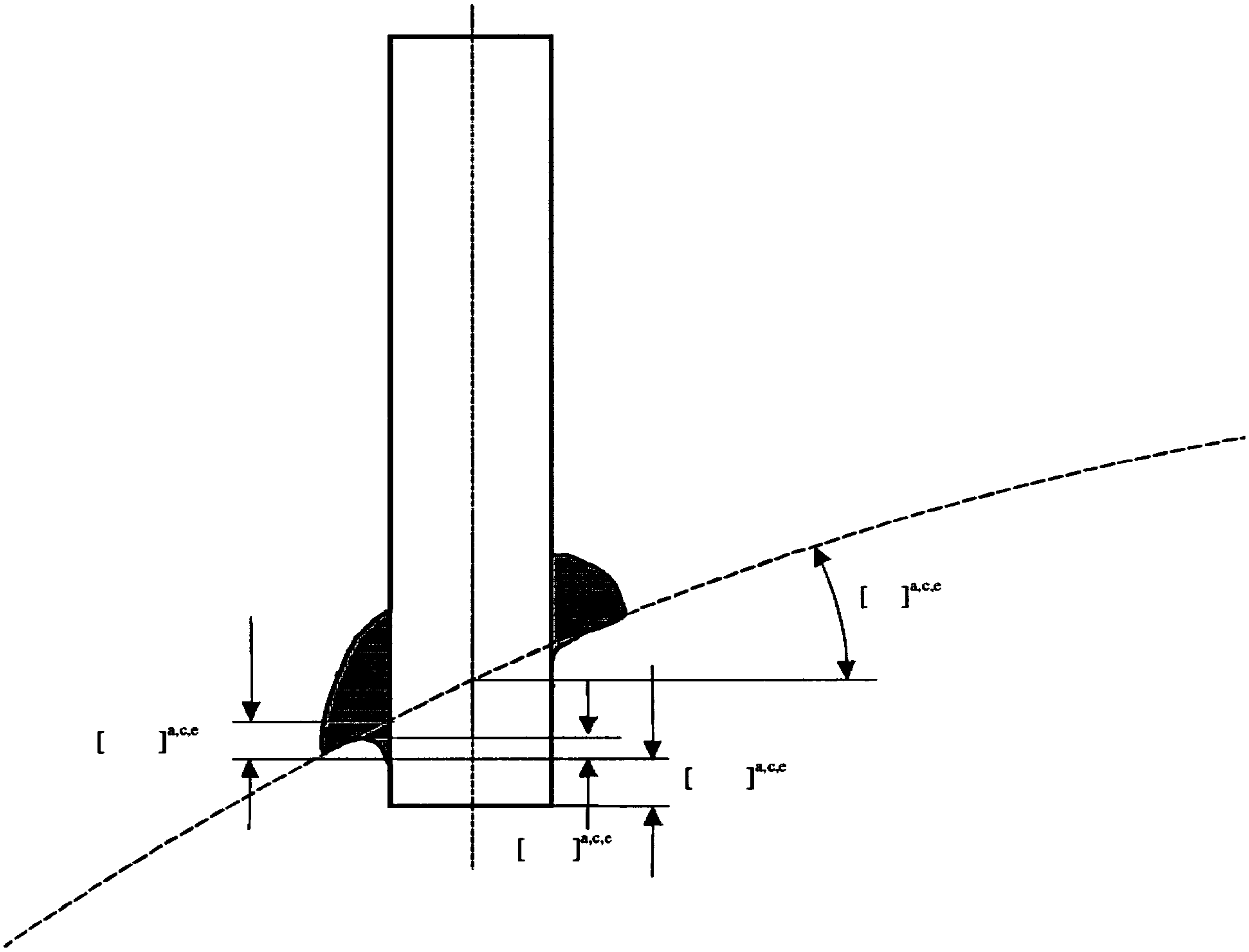


Figure 22 H.B. Robinson CRDM J-Weld Fillet Geometry for Penetration at [ ]a,c,e

a,c,e

Figure 23 Hoop Stress Distributions for As-built vs Design Weld Configurations, Lower Hillside, 27 Degree Penetrations

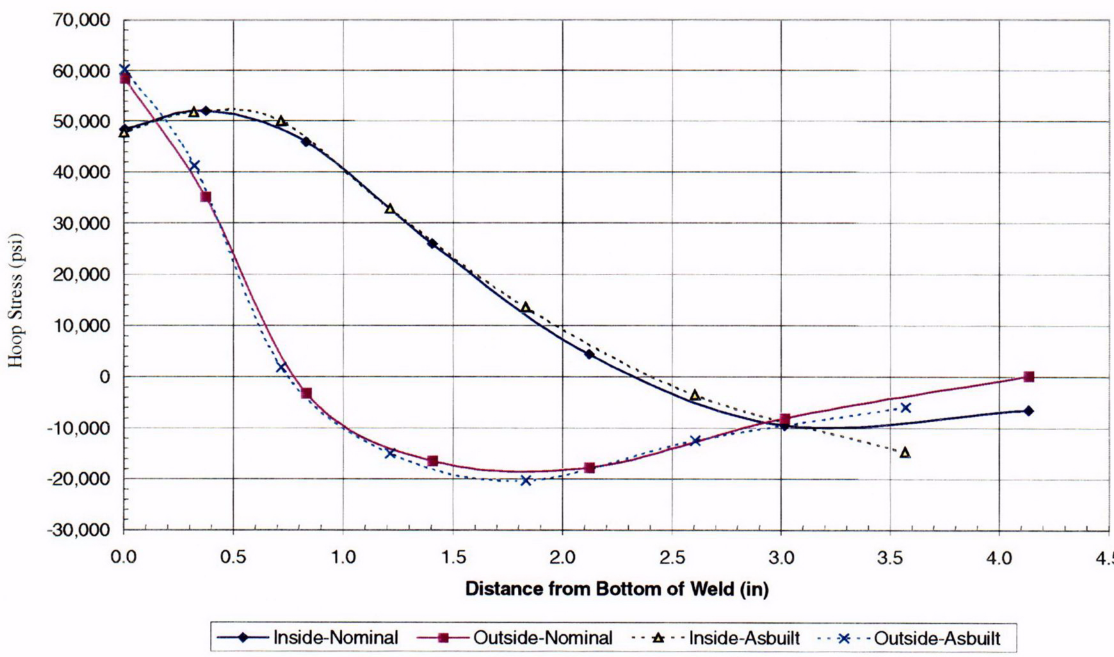


Figure 24 Hoop Stress Distributions for As-built vs Design Weld Configurations, Upper Hillside, 27 Degree Penetrations

C14

a,c,e

Figure 25 Hoop Stress Distributions for As-built vs Design Weld Configurations, Lower Hillside, 46 Degree Penetrations

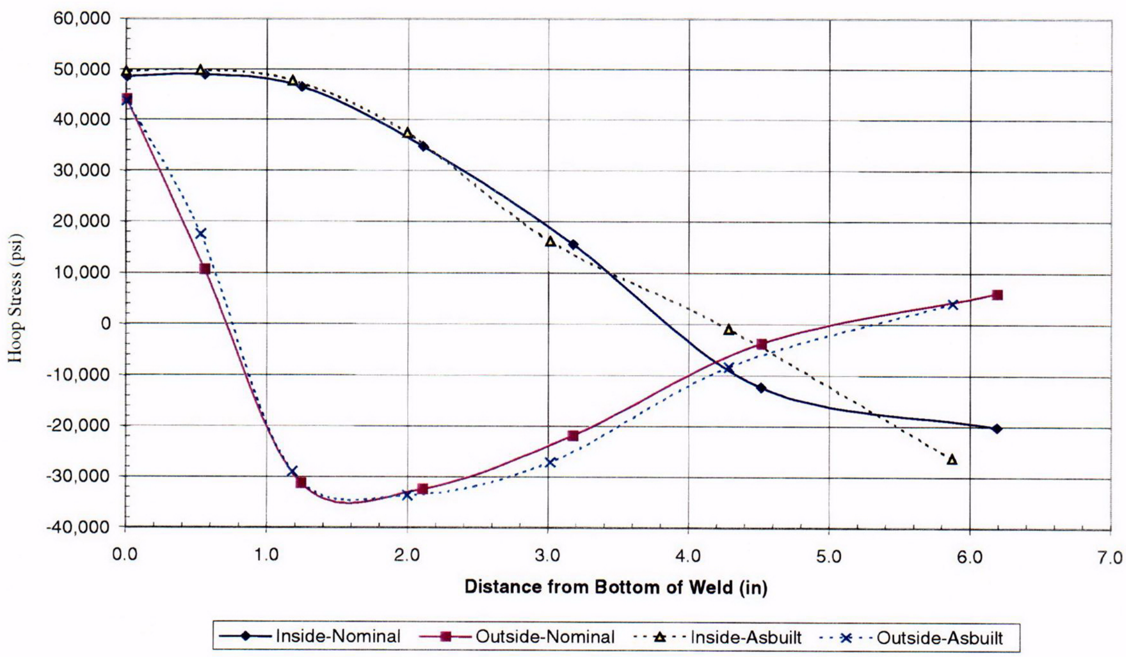


Figure 26 Hoop Stress Distributions for As-built vs Design Weld Configurations, Upper Hillside, 46 Degree Penetrations

C15

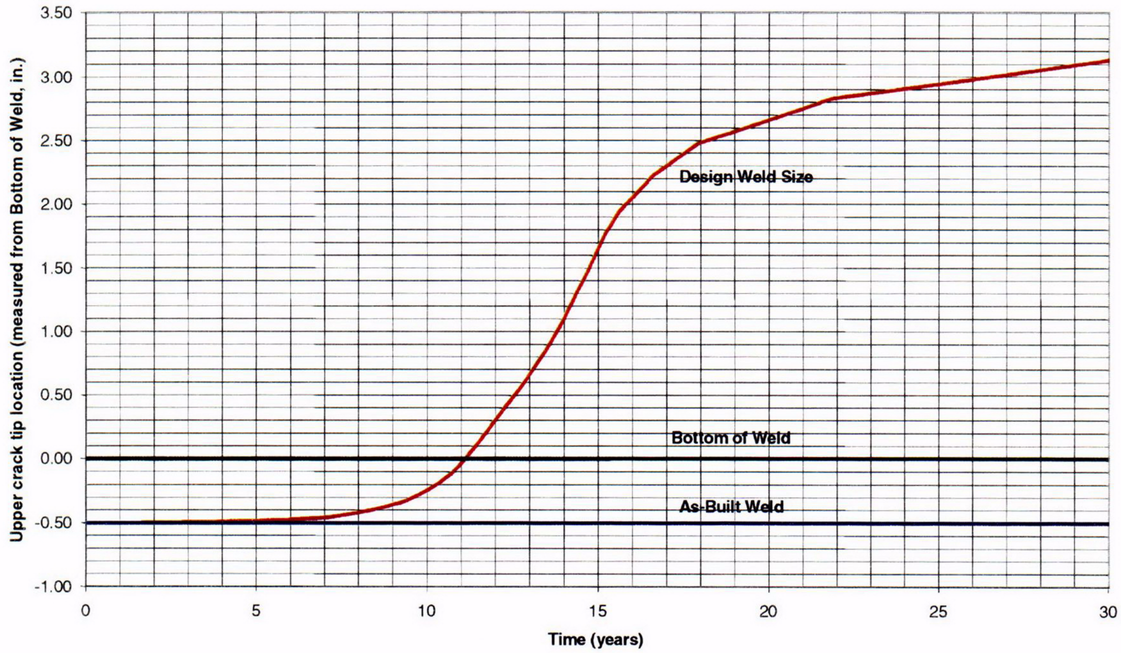


Figure 27 Comparison of Predicted PWSCC Growth for the Design Weld Configuration and the As-built Configuration, Through-Wall Flaw on the Downhill Side, 27 Degree Penetration

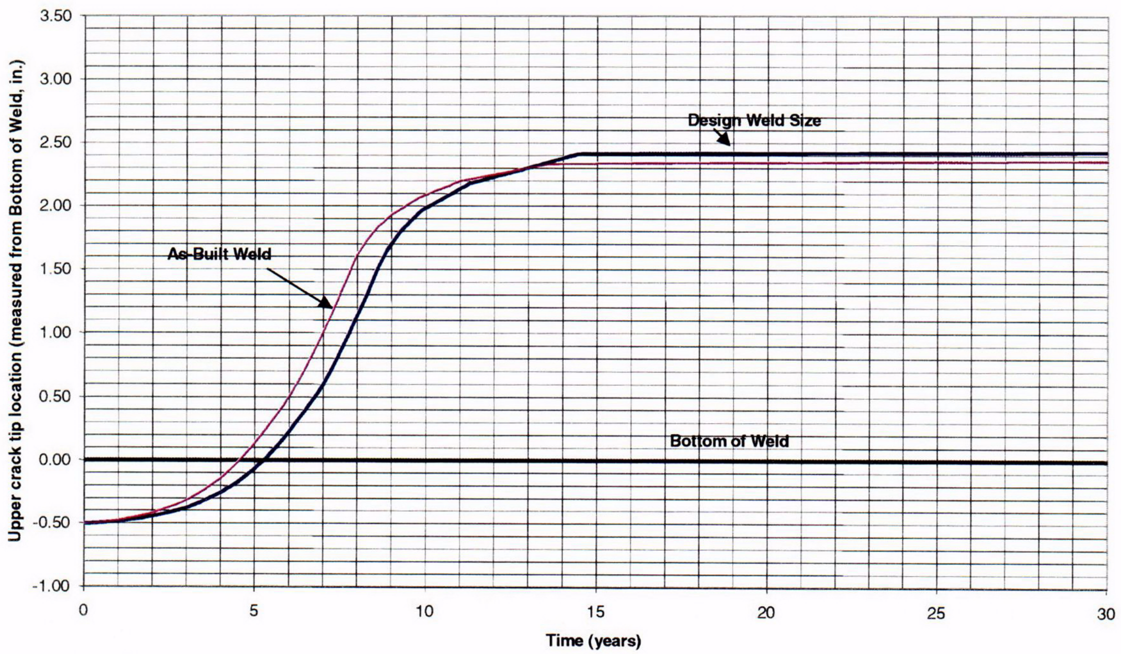


Figure 28 Comparison of Predicted PWSCC Growth for the Design Weld Configuration and the As-built Configuration, Through-Wall Flaw on the Uphill Side, 27 Degree Penetration

C16

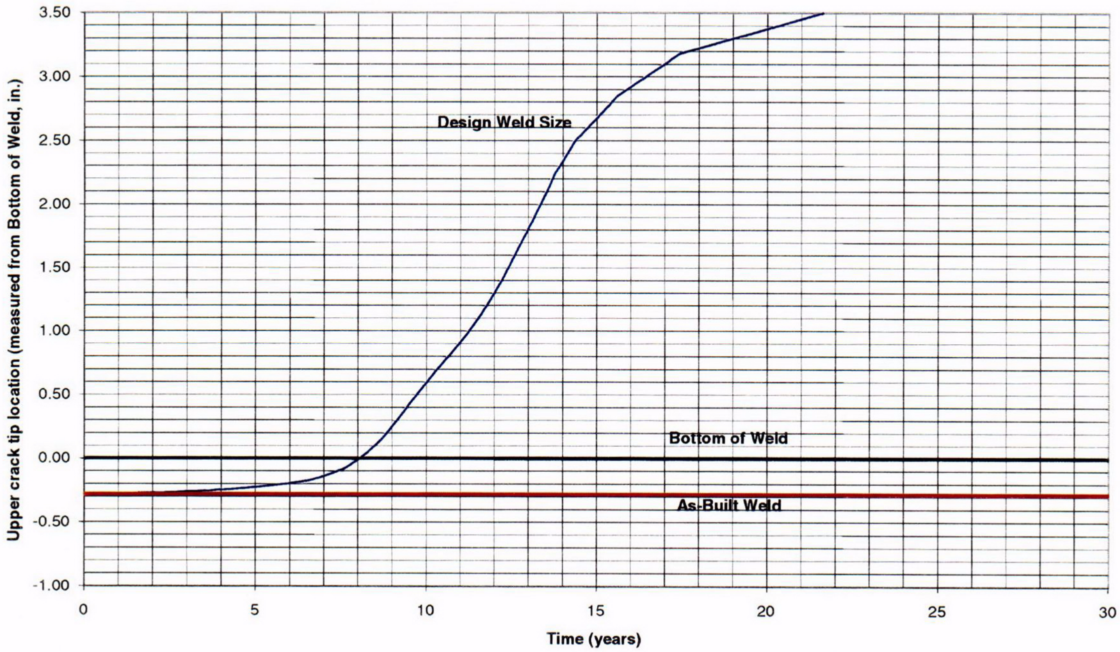


Figure 29 Comparison of Predicted PWSCC Growth for the Design Weld Configuration and the As-built Configuration, Through-Wall Flaw on the Downhill Side, 46 Degree Penetration

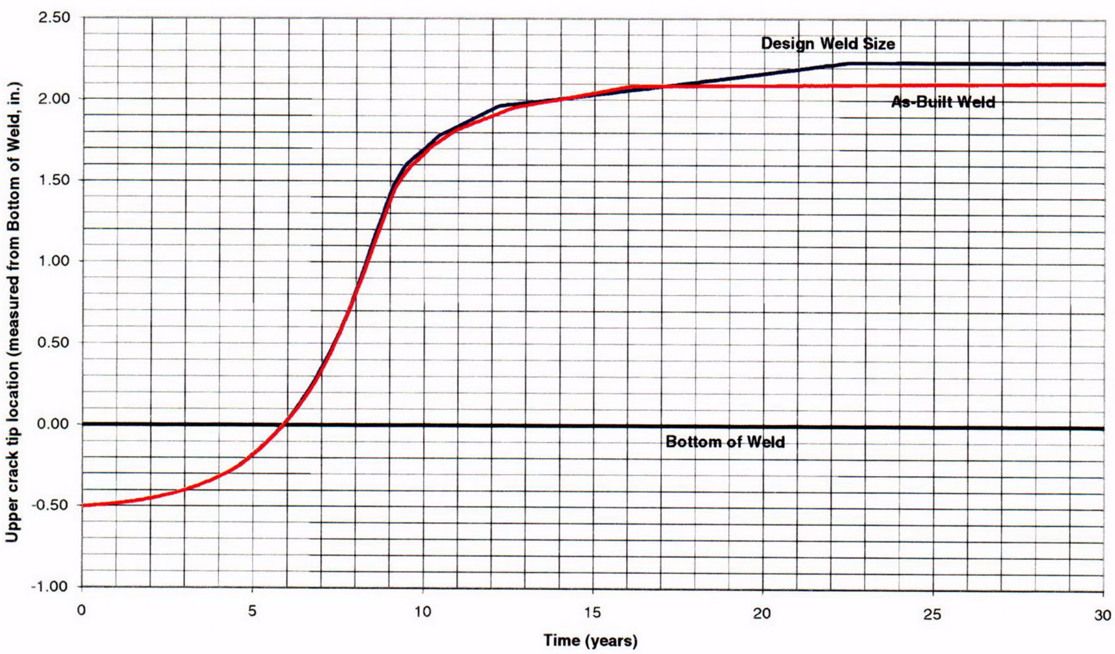


Figure 30 Comparison of Predicted PWSCC Growth for the Design Weld Configuration and the As-built Configuration, Through-Wall Flaw on the Uphill Side, 46 Degree Penetration

C17