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INSPECTION OF CIRCUMFERENTIAL IGA/SCC IN BRUCE UNIT 4 SGS

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Abstract

Circumferential IGA/SCC has been detected in the roll-transition zone of tubes in Bruce A SGs for over a decade, but recently became more pronounced in Unit 4 BO4 in 2006 and the spring of 2007. A number of ET probes have been developed to detect and characterize this degradation, including C-3/8, +Point and X-Probe. Comparisons of the inspection results from these probes and metallurgical results from removed tubes have provided insight into the strengths and limitations of each probe and how the probes can complement each other. This paper will discuss the evolution of the ET inspection approach for circumferential IGA/SCC and how the results have been used in recent FFS assessments in the Bruce Unit 4 SGs.

Introduction

The Bruce A Steam Generators are recirculating, U-tube SGs having 11 mm OD x 1.11 mm wall (0.51" OD x 0.044" wall) sensitized Alloy 600 tubing. The Bruce A Station was commissioned in the late 1970's. Unit 2 was shut down in 1996, Unit 1 in 1997, and Units 3 and 4 were shut down in 1998. Units 3 and 4 were then returned to service in 2004 and 2003 respectively. Circumferential cracking in the roll transition zone (RTZ) of the Bruce A SGs was first observed in Unit 1 in 1997, and subsequent inspections of Units 3 and 4 resulted in the identification of additional cracking in Unit 4. During the extended layup between 1997 and 2003/2004, the Unit 3 and 4 SGs both experienced significant degradation of the RTZ of tubes in the sludge pile region. This degradation was attributed to poor layup conditions during the early part of the extended shutdown. ET inspection results and examination of removed tubes demonstrated that the degradation was predominately pitting and IGA at the RTZ, with minimal cracking. Since restart, Unit 3 continues to show a modest progression of pitting degradation at the RTZ. Unit 4, on the other hand, has shown much more aggressive RTZ degradation, predominately in BO4 during the 2006 and Spring 2007 inspection outages. This degradation consists of extensive pitting and IGA at the RTZ, including deep, circumferential bands of IGA/SCC up to 100%tw.

Detailed discussion of the mechanism causing the pitting is beyond the scope of this paper, however it is believed that the significant degradation observed in 2006 and Spring 2007 occurred during the prior inspection outages as a result of exposing the secondary side of the SGs to oxidizing conditions. During the Spring and Fall 2007 outages, the secondary side chemistry was carefully controlled to minimize exposure to oxidizing conditions, and as a result only modest progression of pitting and volumetric IGA was observed in the subsequent inspections.

The purpose of this paper is to discuss the ET inspection probes that are used to detect and size the RTZ degradation in the Bruce SGs, and to compare the ET inspection results with metallurgical examination results from tubes removed from the Bruce Unit 4 SGs. Improvements in the understanding of the ET probe capability have resulted in corresponding improvements in the engineering analyses used to demonstrate fitness for service (FFS) of the SGs.

Description of the Degradation

The degradation that is the focus of this paper is Intergranular Attack and Stress Corrosion Cracking (IGA/SCC) at the Hot Leg Roll Transition Zone (HL RTZ). This region is located on the hot leg of the SG, at the secondary face of the tubesheet, as shown in Figure 1. The residual strains in this region from the expansion of the upper rolled joint probably contribute to the circumferential stress corrosion cracking component of the degradation. This region is also exposed to a harsh environment during operation and lay-up as a result of sludge piles on the secondary face of the tubesheets in the Bruce A SGs.

The degradation at the RTZ has manifested itself in several ways since it was first discovered. In 1997, prior to the shutdown of Bruce A, the degradation was primarily circumferential SCC. During the extended layup from 1997 to 2003, the degradation mechanism was primarily pitting and volumetric IGA, with minimal cracking, as evidenced by metallurgical examination of removed tubes. Often the pitting was clustered in circumferentially oriented bands at the RTZ, leading to them being characterized as circumferential indications (crack-like) by ET inspections. The pitting and volumetric IGA type of degradation continues to be observed following restart, but is progressing at a modest rate. In the 2006 and Spring 2007 inspections, Unit 4 BO4 experienced significant regions of deep, circumferential bands of IGA.

Probes Used for RTZ Degradation In Bruce A SGs

A number of ET probes have been used to detect and size degradation in the TTS region of the Bruce SGs. They include the bobbin, C-3/4, C-3/8, +Point and X-Probe eddy current probes. Each of these inspection methods offers their own benefits and shortcomings with regards to their ability to detect and size the TTS degradation.

Bobbin Probe

The bobbin probe has long been the workhorse probe for performing SG tube inspections. It has a high scan speed, is relatively easy to analyze, and is sensitive to volumetric and axially-oriented indications. Unfortunately, it is not sensitive to circumferentially-oriented indications. As a result, the bobbin probe is insensitive to detecting tight circumferential bands of IGA or circumferential SCC. The bobbin probe has sensitivity to volumetric IGA patches having some axial extent, but it is not sensitive enough to be used as the primary inspection tool for the RTZ degradation. The bobbin probe is not used for detection and sizing of IGA/SCC in the RTZ in the Bruce A SGs.

C-3/4 Probe

The C-3/4 probe was developed by AECL to detect circumferentially oriented IGA/SCC in the Bruce tubing. This probe offers similar scan rates to the bobbin probe, but is sensitive to indications that are circumferentially oriented. The C-3/4 has four sets of coils located around the circumference of the probe, each having a window of approximately 90° angular extent. It is possible to gain some insight into the angular extent of circumferential flaws based on the number of coils that detect the flaw.

C-3/8 Probe

The C-3/8 probe is similar to the C-3/4 probe, except that it has eight sets of coils around the circumference of the probe instead of four. The field of view for each coil set overlaps with its neighbours, providing improved sensitivity to flaws having short circumferential extent and improved resolution of the angular extent of these flaws. The C-3/8 probe has a proven track record of detecting IGA/SCC in the RTZ, and it continues to be the primary detection and sizing probe in Bruce A and B SGs. There are two sizing curves available to the ET analysts when using the C-3/8 to size flaws in the RTZ, one for volumetric indications and one for axial indications. Therefore, the practice for sizing RTZ indications with C-3/8 is as follows: the C-3/8 is used to detect indications, these indications are then characterized with

the +Point (or X-Probe) as being circumferential or volumetric, and finally the C-3/8 indications are sized based on the response using the appropriate sizing curve.

+Point

The +Point probe is widely used in the nuclear industry to examine and characterize flaws in SG tubing. It has been used in the Bruce SGs to provide characterization of indications detected by the C-3/4 or C-3/8 probe for some time. One of the most significant disadvantages of the +Point probe is that since it is a rotating probe, it has a much lower axial scan rate than any of the other ET probes, and therefore using it is very time consuming. As a result, it is not practical for use as a detection tool for a large population of tubes. Since the restart of Units 3 and 4, the +Point probe has been used to characterize nearly all indications detected by the C-3/8 probe as being circumferential (crack-like), volumetric, or non-defect like. Due to the small diameter of the Bruce SG tubes, it has not been possible to incorporate a pancake coil into the +Point. As a result, the +Point probe used in the Bruce SGs cannot be used to reliably size the depth of flaws.

X-Probe

The X-Probe is an array probe that offers good sensitivity to axial, circumferential and volumetric flaws. It is capable of detecting, characterizing and sizing flaws in any orientation. It has a scan rate similar to the bobbin or C-3/8 probe, but due to the large volume of data produced, more analysis time is required than for the bobbin or C-3/8 probe. The X-Probe has been used as a characterization tool for Bruce A SG indications in the RTZ since the Units 3 and 4 were restarted in 2003/2004. The role of the X-Probe has evolved since restart as more confidence in its detection and sizing capability in the field has been obtained from comparisons with metallurgical results of removed tubes and comparisons to C-3/8 and +Point ET results. The X-Probe that has been used in the Bruce SG tubes has 8 physical sets of coils that are sensitive to circumferential flaws (plus 8 additional interpolated channels), and 16 sets of coils that are sensitive to axial flaws. A new, "high-resolution" X-Probe has been developed that has 12 sets of coils that are sensitive to flaws in each of the axial and circumferential directions. This probe has been deployed to the field on a trial basis and is in the process of being qualified.

Comparison of ET Response to Metallurgical Examination Results

A significant number of tubes have been removed from the Bruce A Unit 3 and Unit 4 SGs since they were restarted in 2003 and 2004. A total of 54 tubes have been removed from the Unit 4 SGs, as summarized in Table 1. Typically, the removed tubes have indications that were detected by one or more ET probes; however, in 2005 a number of tubes in regions of the SG considered to be at greatest risk of RTZ IGA/SCC were removed for metallurgical examination, even though no ET indications were detected.

The removed tubes from the 2005 removal campaign can be further categorized with respect to the types of ET probes that could detect indications in the RTZ prior to the tubes being removed. Twenty-one tubes did not have any indications detectable to any of the ET probes, ten tubes had indications detectable to only the +Point and/or X-Probe, but not the C-3/8 probe, and seven of the removed tubes had indications detectable to the C-3/8 probe in addition to the +Point and/or X-Probe. These details are also provided in Table 1.

Table 1 - Summary of Tubes Removed from Bruce A SGs Since 2004

Reason for Tube Removal	2004	2005				2006	2007 Spring	2007 Fall	2008	Total
		No ET Ind.	No C-3/8 Ind.	C-3/8 Ind.	Total					
Randomly Selected Tubes in the Sludge Pile Region ¹	0	19	7	0	26	0	0	0	0	26
Pre-Selected Tubes Adjacent to Tubes with Previous RTZ Circumferential Indications ¹	0	2	3	0	5	0	0	0	0	5
Targeted Tubes Having Significant ET Indications in the RTZ	2	0	0	7	7	10	4	0	0	23
Total	2	21	10	7	38	10	4	0	0	54

A more detailed comparison of the ET results with the metallurgical results is provided in Appendix A. Details of this comparison are discussed in the following sections.

Removed Tubes with no ET Indications

The tube-pull campaign in 2005 included 19 randomly selected and 2 targeted (pre-selected) tubes (based on proximity to tubes with historical RTZ circumferential indications) that were removed even though they had no indications detectable to any of the ET probes. Subsequent metallurgical examination of these 21 tubes yielded the following observations of the RTZ region:

- 12 tubes had no degradation in the RTZ region
- 4 tubes had degradation (pitting, wastage and/or shallow IGA) less than 10%tw
- 4 tubes had general corrosion and pitting between 10%tw and 28%tw
- 1 tube had a 10%tw crack-like feature and a 19%tw pit

These results are consistent with the expected performance of the ET probes based in their reported capability. The deepest undetected crack-like feature was 10%tw, and the deepest undetected pit was 28%tw.

Removed Tubes with no C-3/8 Indications

The 2005 tube pull campaign also included the removal of 7 randomly selected and 3 targeted tubes that had no detectable indications to the C-3/8 probe, but did have indications detectable to the +Point and/or X-Probe. These tubes were scheduled for inspection with C-3/8, +Point and X-Probe because they were pre-selected for removal and there was a desire to obtain ET data from all probes to compare with the metallurgical results. Under normal inspection circumstances, these tubes would only have been inspected with C-3/8, would not have had any detectable indications, and therefore would have been left in service. Subsequent metallurgical examination of these 10 tubes yielded the following observations of the RTZ region:

¹ These tubes were selected prior to the outage, without knowledge of the 2005 ET results.

- 1 tube (BO1 R37C59) had a circumferential indication reported by both +Point and X-Probe. Examination of the removed tube confirmed a 43%tw by 20° circumferential extent crack (Figure 2), and a cluster of small crack-like features (Figure 3) having a maximum depth of 47%tw and an overall circumferential extent of approximately 60°. Similar crack-like features separated by ligaments had been observed on previous tube removals from Unit 4, and are known to be difficult to detect by any of the ET probes.
- 7 tubes had volumetric indications reported by both +Point and X-Probe. Metallurgical examination confirmed general corrosion and pitting in six tubes ranging from 0%tw to ~40%tw to 50%tw, without any evidence of IGA or cracking. The remaining tube had evidence of 35%tw general wastage, shallow IGA, including a 10%tw crack-like feature (Figure 4) and pitting with shallow IGA at the base (Figure 5).
- 2 tubes had volumetric indications that were only detected by the +Point or X-Probe. Both tubes had pitting and general attack with no evidence of crack-like features or IGA. The maximum pit depths were 22%tw and 35%tw.

These results are consistent with the expected performance of the C-3/8 probe. The largest individual crack-like features not detected by C-3/8 were 43%tw by 20° circumferential extent, and the largest multiple crack-like feature not detected was up to 47%tw over a region 60° circumferential extent. The deepest localized pit not detected by C-3/8 was approximately 40%tw to 50%tw.

Removed Tubes with C-3/8 Indications

Twenty-three of the tubes removed from Unit 4 since restart had indications detectable to C-3/8. 22 of the tubes had indications that were also detected by +Point and X-Probe. The remaining tube had no detectable indications by +Point, and a copper indication by X-Probe. Analysis of the removed tube identified 15%tw general wastage in this tube, suggesting that the C-3/8 indication was likely caused by the copper as opposed to the degradation.

Comparison of +Point and X-Probe Characterization and Sizing

- 7 tubes had only circumferential indications reported by both +Point and X-Probe. Five of these tubes had through-wall, circumferential IGA/SCC based on metallurgical examination. A photograph of the typical degradation associated with these calls is provided in Figure 6. All five tubes had 100%tw depths reported by C-3/8 and/or X-Probe. The depths for the remaining tubes is summarized as follows:
 - Metallurgical: 51%tw, C-3/8 59%tw, X-Probe 45%tw
 - Metallurgical: 64%tw, C-3/8 47%tw, X-Probe 68%tw
- 4 tubes had only volumetric indications reported by +Point and X-Probe. These tubes had distinct pits and general corrosion, such as that shown in Figure 7. One tube had a very small circumferential feature and minimal IGA, as shown in Figure 8. The C-3/8 and X-Probe both had a tendency to undersize the pit depths, especially for small isolated pits.
- 6 tubes had circumferential indications as characterized by +Point, but circumferential and volumetric indications as characterized by X-Probe. In general, it appears that the X-Probe is picking up the same circumferential indication as the +Point, but the X-Probe analyst is also identifying additional volumetric degradation around the circumference of the tube. Five of the six tubes had circumferential IGA/SCC degradation 90%tw to 100%tw based on metallurgical results. The depths reported by C-3/8 and X-Probe ranged from 73%tw to 100%tw. Typical metallographic results for these tubes are shown in Figure 9. The reason for the multiple calls is evident from the metallurgical examination results, as shown in Figure 10, which shows the combination of circumferential and axial degradation caused by the IGA. The maximum depths reported by C-3/8 and X-Probe for this tube were 67%tw and 68%tw respectively, while laboratory UT identified depths of up to 60%tw. The maximum depth identified by metallurgical examination was 37%tw.

- 3 tubes had circumferential indications called by +Point, but only volumetric indications called by X-Probe. These flaws are very complex, and include circumferential bands of volumetric pitting (often below the surface of the tube) and patches of IGA, as shown in Figure 11 and Figure 12. While the C-3/8, +Point and X-Probe can all readily detect these indications, characterization and depth sizing can be a challenge. The C-3/8 sizing, which is based on the crack sizing curve as a result of the +Point characterization, is more reliable for these flaws. The X-Probe sizing is based on a volumetric sizing curve, and underestimates the depth by as much as 30%tw.
- 1 tube had a circumferential indication called by +Point, and a CAI (circumferential/axial indication) called by X-Probe. The CAI call was introduced in 2007 to refine the X-Probe characterization of flaws that have both volumetric and circumferential characteristics, such as the circumferential bands of pitting shown in Figure 11. The only removed tube with a CAI call broke during removal, so we do not know what the flaw looked like before removal, however from cross-sections obtained after removal, it is apparent that the flaw was intergranular in nature.

Effect of ET Interpretation on FFS Approach

Additional knowledge related to the capabilities and interpretation of the ET signals was gained with each inspection of the Bruce Unit 4 SGs. This knowledge was partly a result of the comparison of C-3/8, +Point and X-Probe ET results with metallurgical results obtained from the removed tubes, and partly a result of learning more from the large circumferential indications that were observed in the 2006 and the Spring of 2007 about how the degradation progressed.

Implications of Probe Capability on Fitness for Service Assessments

The approach used to demonstrate Fitness for Service of the Bruce A SGs for RTZ degradation has evolved since Unit 4 was restarted in 2003. Initially, the primary inspection probes for RTZ degradation were the C-3/8 probe, which was used for detection, and the +Point probe, which was used to characterize all indications detectable to C-3/8. All tubes with indications detectable to +Point were plugged, and tubes that had no indications detectable to +Point remained in service. The depth of flaws was determined from the C-3/8 probe, using sizing curves based on the character of the flaw (circumferential or volumetric) as determined by +Point. The depth of the indications and the +Point characterization did not affect the plugging decision, but this information was used as input to the condition monitoring evaluation and the operational assessment to determine flaw growth rates and trends in the population of flaws. At this time, the X-Probe results were used as supplementary information, and did not affect plugging decisions or FFS assessments.

As confidence in the field performance of the X-Probe was gained by analysis of removed tubes and comparisons of the X-Probe and +Point inspection results, the X-Probe was given a more prominent role in the assessment framework. Most recently, the plugging decision is based on both +Point and X-Probe inspection results – in order for any tube with a C-3/8 indication in the RTZ to remain in service, it must have no indications detectable to both X-Probe and +Point. FFS assessments are based primarily on the X-Probe characterization and sizing, although the C-3/8 and +Point results are also considered. Use of the X-Probe results has also allowed the flaw model to progress from a single circumferential flaw to a combination of a single circumferential flaw with pitting and general degradation around the remainder of the tube circumference, to the current model which looks at the overall percent degraded area (PDA) of the tube degradation.

Estimating PDA Using the X-Probe

The X-Probe estimates of PDA are obtained based on the circumferential and axial (volumetric) depths reported on each of the X-Probe channels around the circumference of the tube. A comparison of the flaw profile obtained from the X-Probe with the profile obtained from metallurgical examination of three tubes removed from Unit 4 BO4 in the Spring of 2007 is provided in Figure 13. The X-Probe degradation

profiles show excellent agreement with the actual profiles obtained from metallurgical examination, and the X-Probe estimates of PDA are within ± 10 PDA of the true degraded area. As a result, it is possible to base the Fitness for Service assessments on the PDA of the observed and predicted flaw population, rather than being restricted to specific flaw models based on independently growing one or more circumferential and/or volumetric flaws.

Conclusion

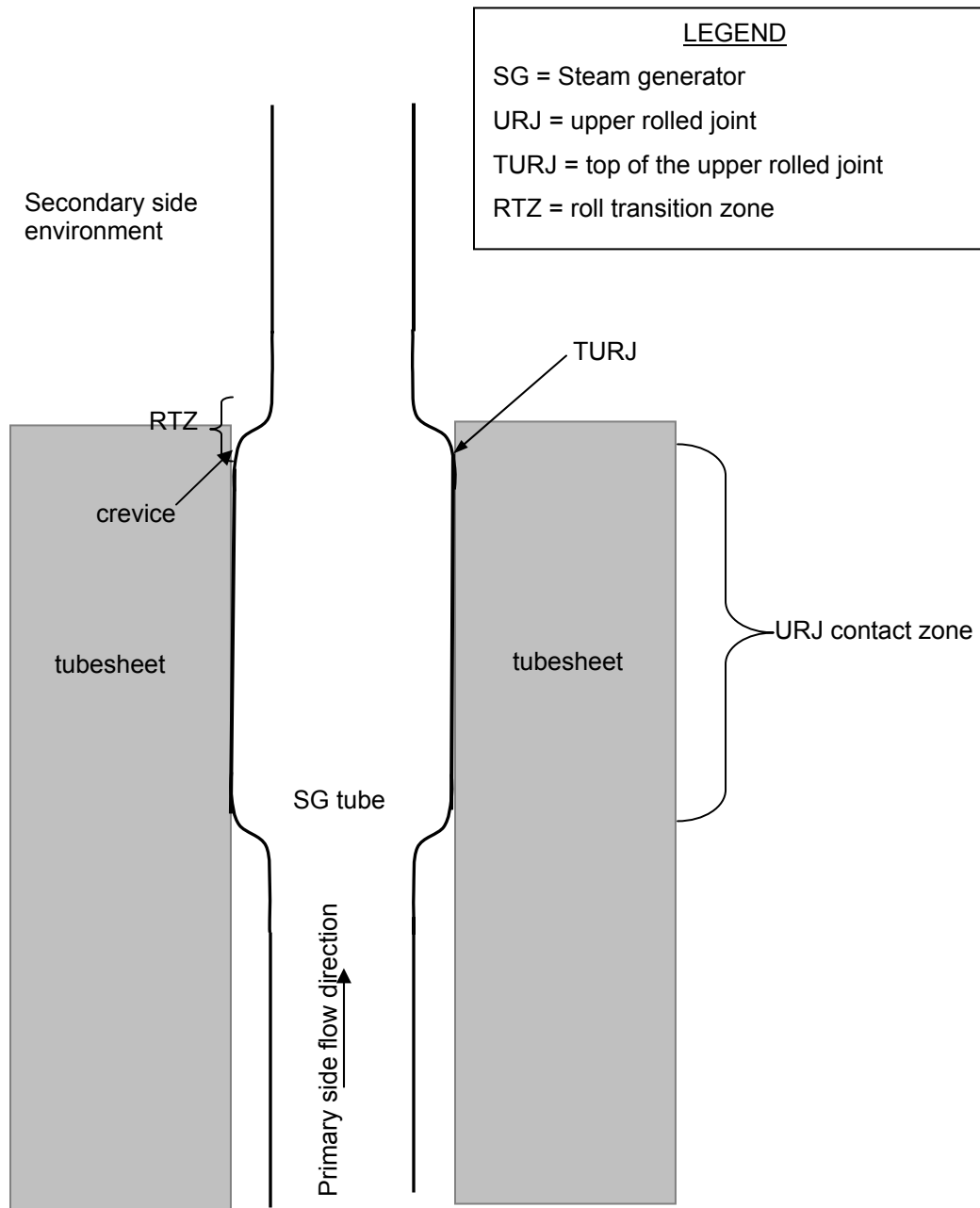
The metallurgical results of the tubes removed from Bruce Unit 4 since 2004 demonstrate good agreement between the ET inspection results and the actual flaws in the tubes. There is no evidence to suggest that a significant number of large flaws (greater than 40%tw and 70° in circumferential extent) is not being detected by the ET methods being used in the Bruce A SGs. Furthermore, the results suggest that the C-3/8 probe has adequate capability to detect significant IGA/SCC flaws at the RTZ, and remains an appropriate tool for the primary detection of these flaws. In most cases, the +Point and X-Probe have a demonstrated ability to accurately distinguish between circumferential (crack-like) flaws and volumetric flaws (pitting and general wastage). There are cases where characterization of RTZ indications with either of these probes is difficult, but these flaws typically consist of IGA patches having a combination of volumetric and circumferentially-oriented features. As a result, it is not surprising that the ET probes have difficulty fully characterizing these flaws. Overall, the X-Probe appears to be slightly more sensitive to detecting and characterizing IGA patches than the +Point probe.

Both the C-3/8 probe and X-Probe provide good sizing capability of deep, circumferential flaws. Sizing for isolated volumetric pits with limited axial and circumferential extent in the RTZ is less reliable for both the C-3/8 and X-Probe, with metallurgical examinations providing evidence that these pits can be undersized by the ET probes. The X-Probe also has a demonstrated ability to estimate the percent degraded area (PDA) for large flaws having multiple circumferential and volumetric IGA flaws.

The approach used to demonstrate fitness for service of the Bruce A SGs has evolved by incorporating the knowledge gained from comparison of the ET inspection results with metallurgical examination results of removed tubes. This knowledge has led to an expanded role for X-Probe inspection results in the assessments.

Acknowledgements

The authors would like to acknowledge Kinetrics for performing the metallurgical work on the removed tubes.

**Figure 1 - Location of IGA/SCC at HL RTZ**

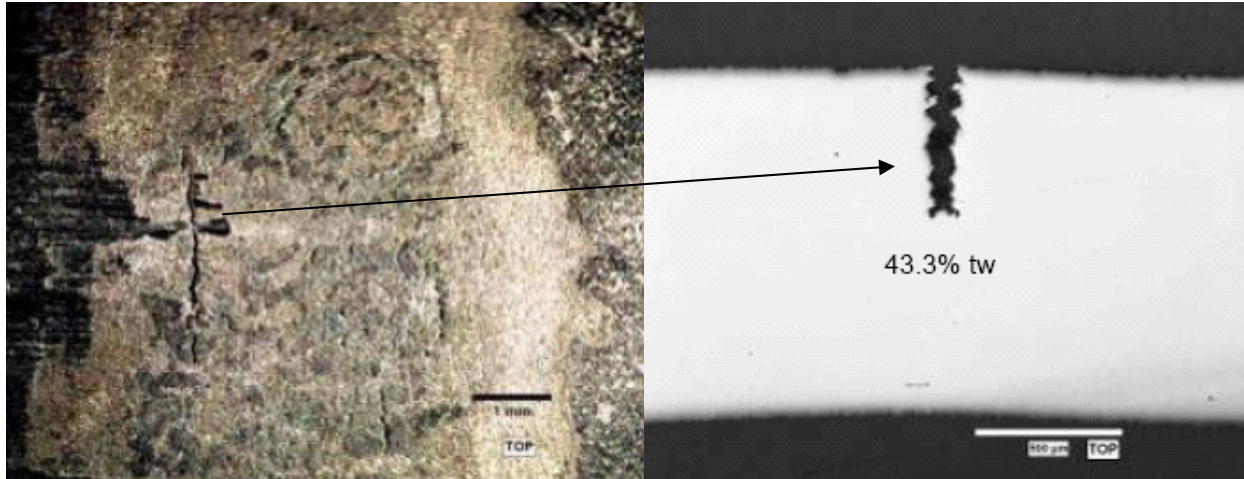


Figure 2 – Crack-like Feature in BO1 R37C59 Detected by +Point and X-Probe, 43.3%tw x 20° Circumferential Extent



Figure 3 - Multiple Crack-like Features in BO1 R37C59

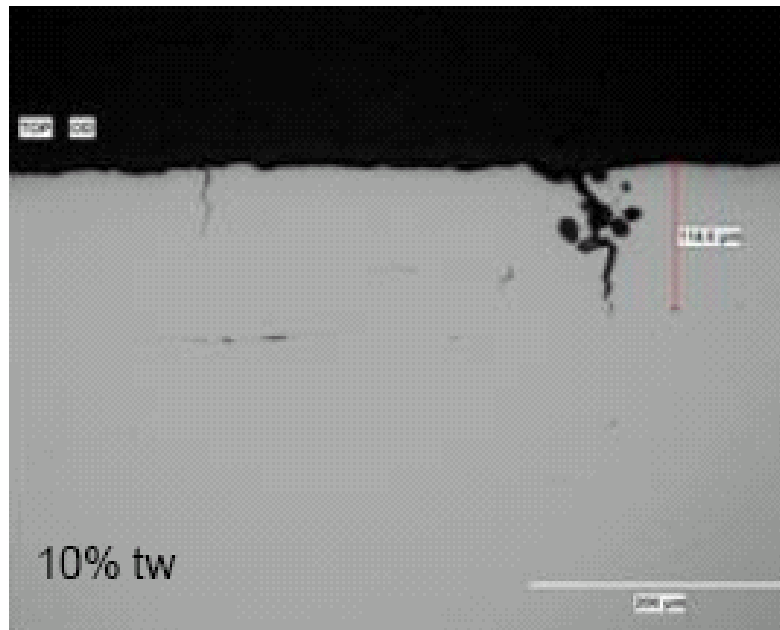


Figure 4 - IGA and 10%tw Crack-like Feature in BO4 R43C45

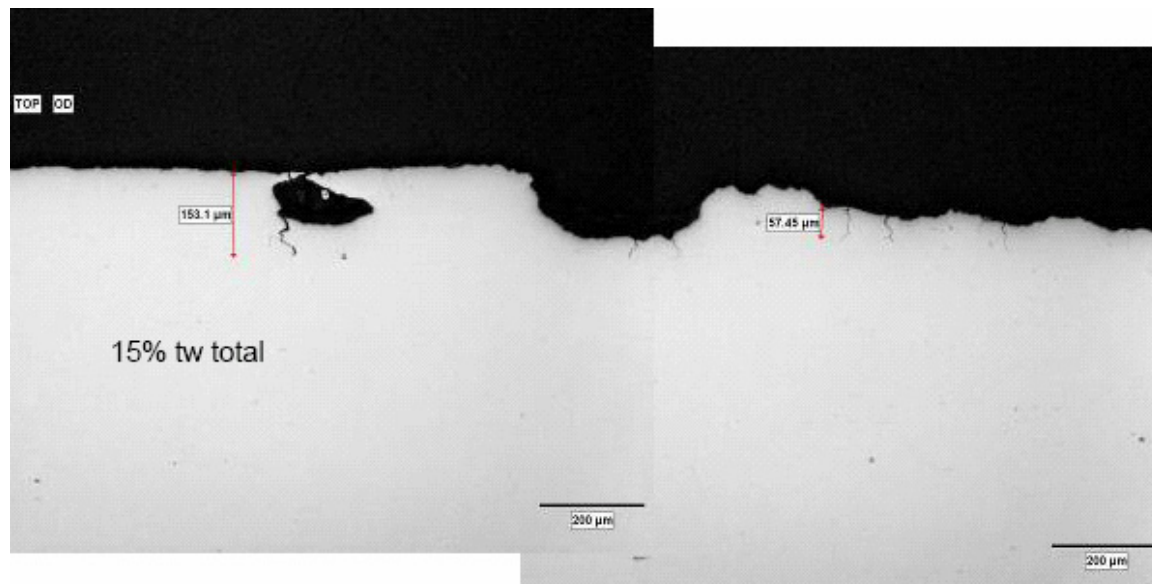


Figure 5 - Pit with Shallow IGA at Base in BO4 R43C45

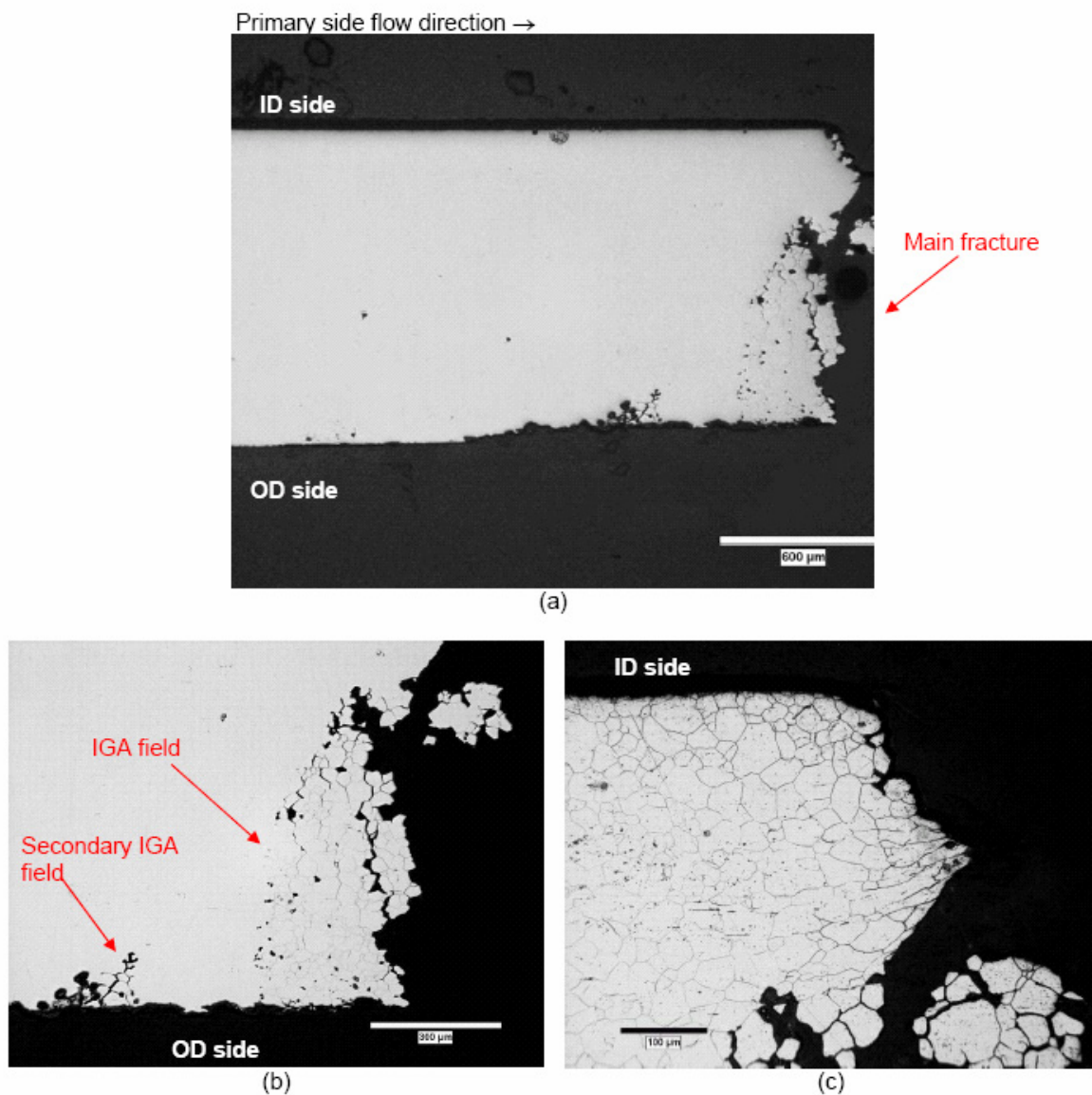


Figure 6 - Tube Having 100%tw IGA Attack with Minimal Pitting or General Wastage (BO4 R27C59)

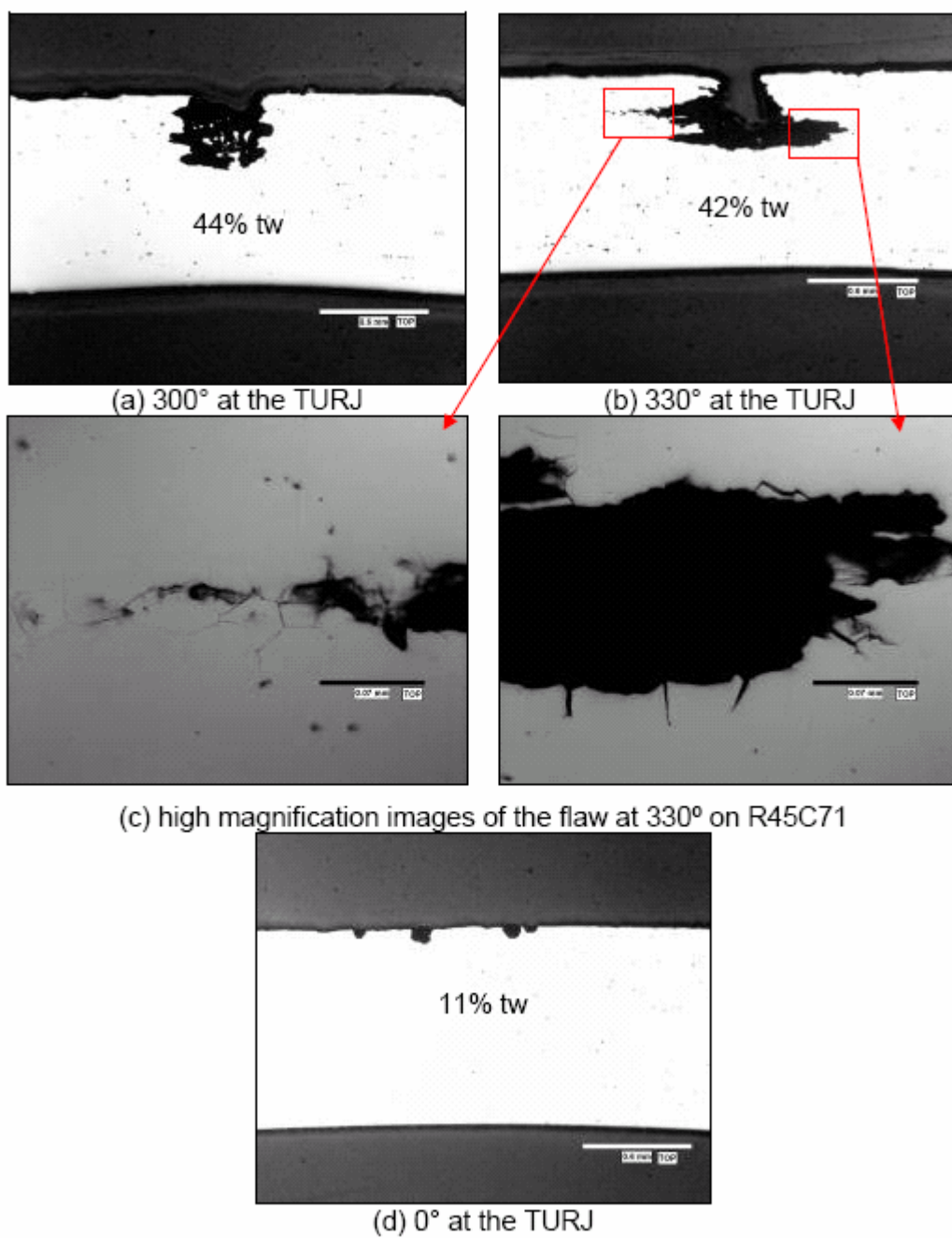


Figure 7 – Tube Having Volumetric Pitting (BO6 R45C71)

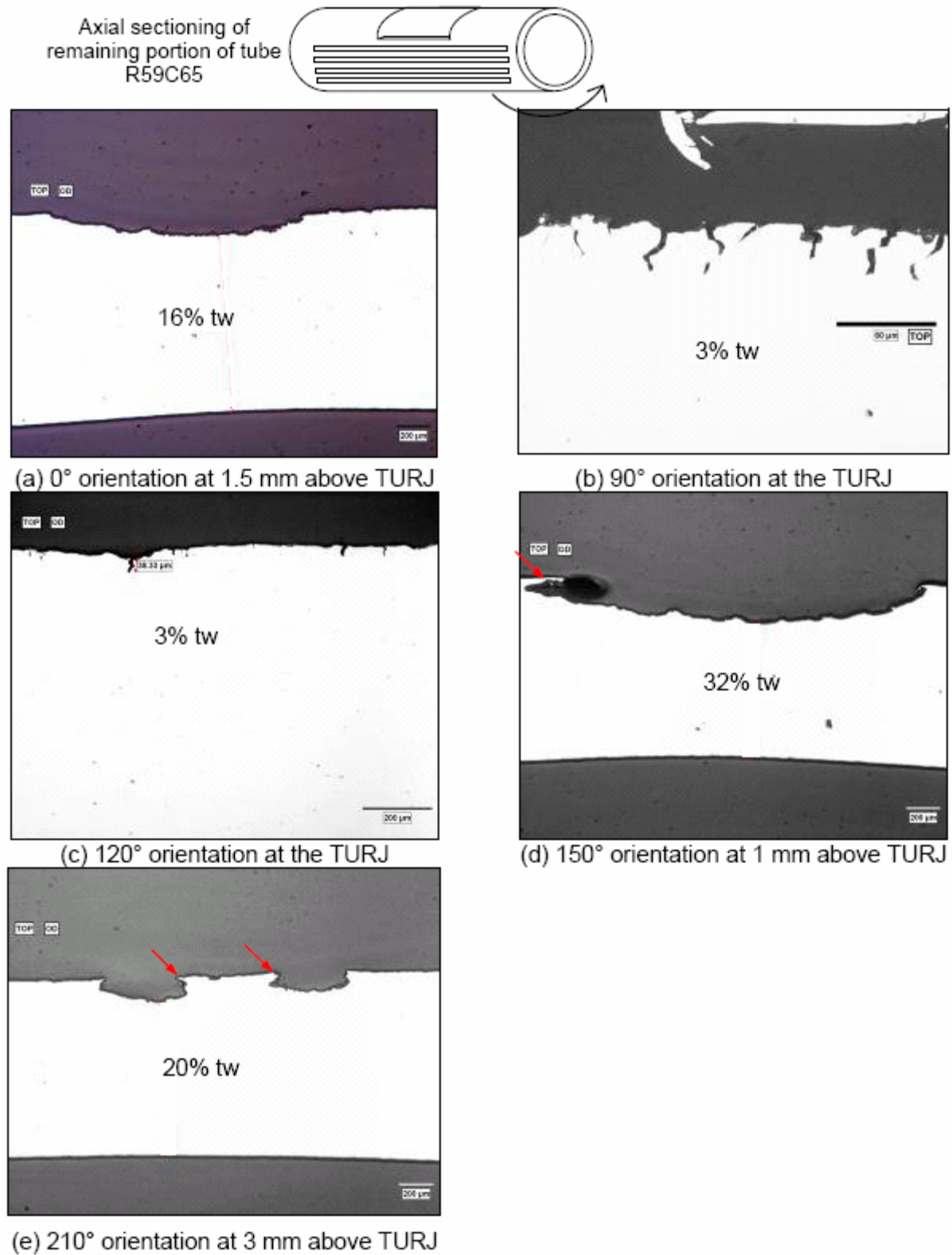


Figure 8 - Tube Having Volumetric Degradation and Wastage with some IGA (BO7 R59C65)

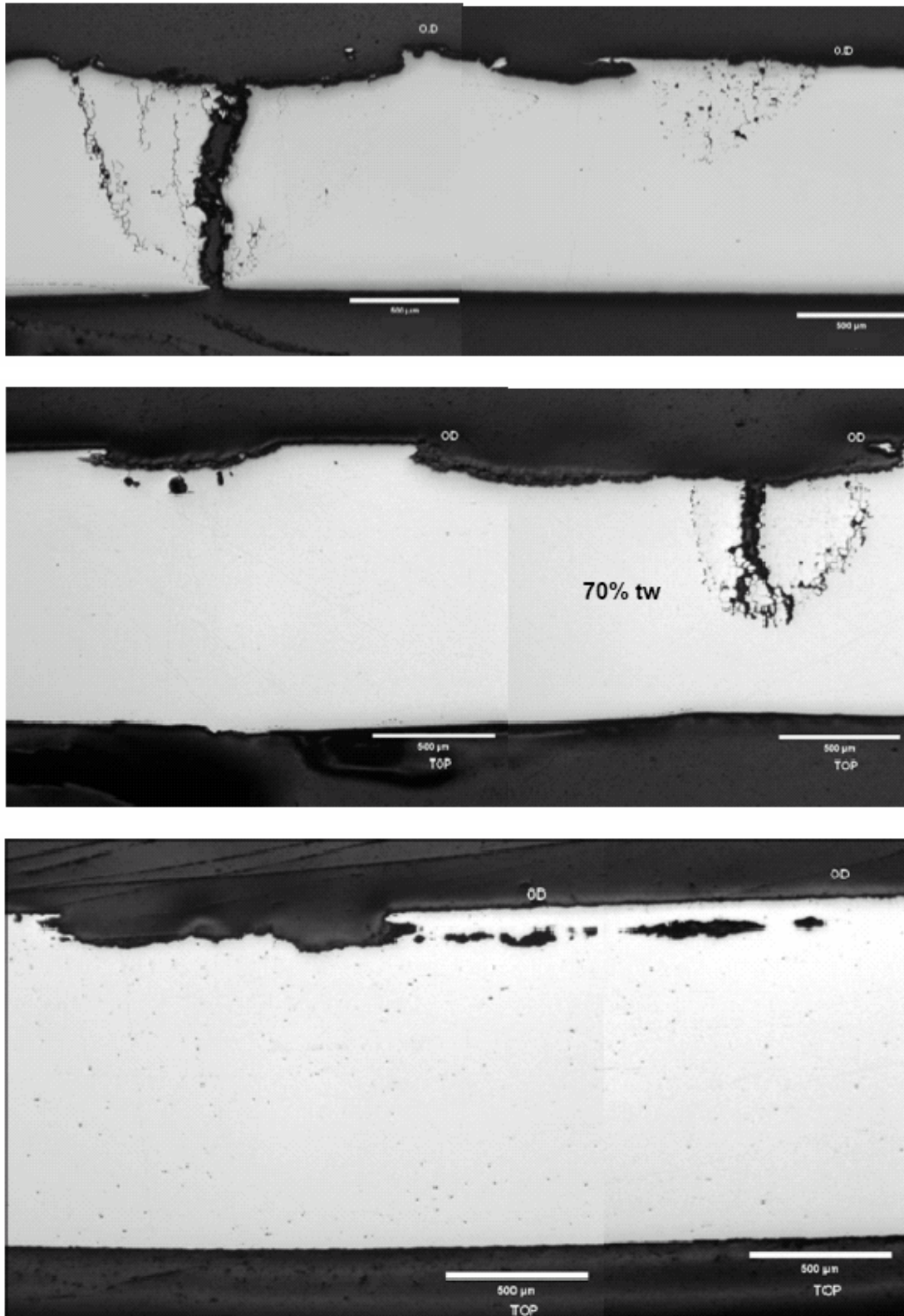


Figure 9 - Degradation at Three Circumferential Locations Showing a 100%tw Crack in IGA, 70%tw IGA patch with Crack-Like Feature, and General Wastage (BO4 R27C55)



Figure 10 - Combined Volumetric and Circumferential IGA (BO4 R46C44)

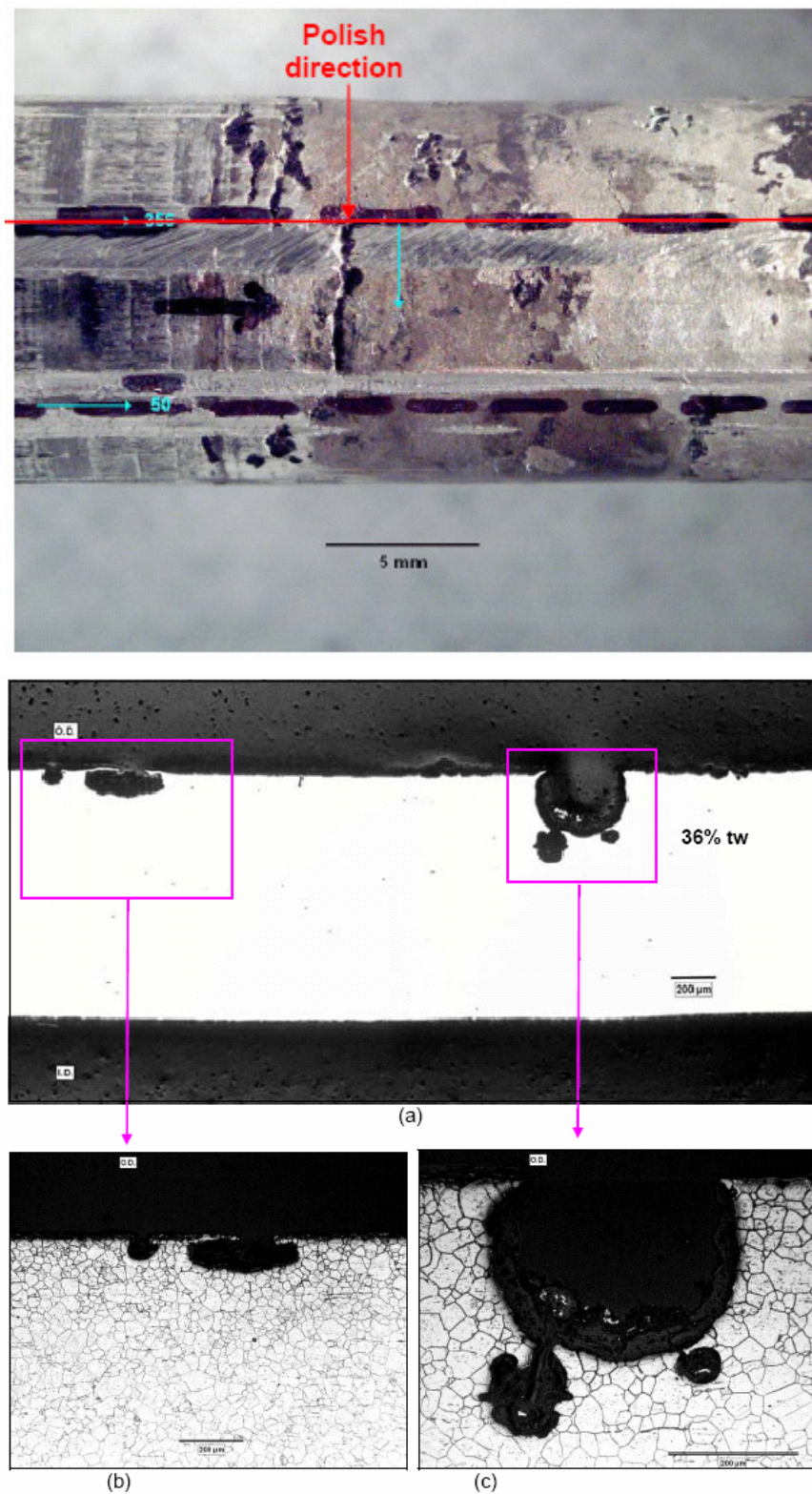


Figure 11 - Tube with Circumferentially Oriented Pitting (BO4 R36C80)

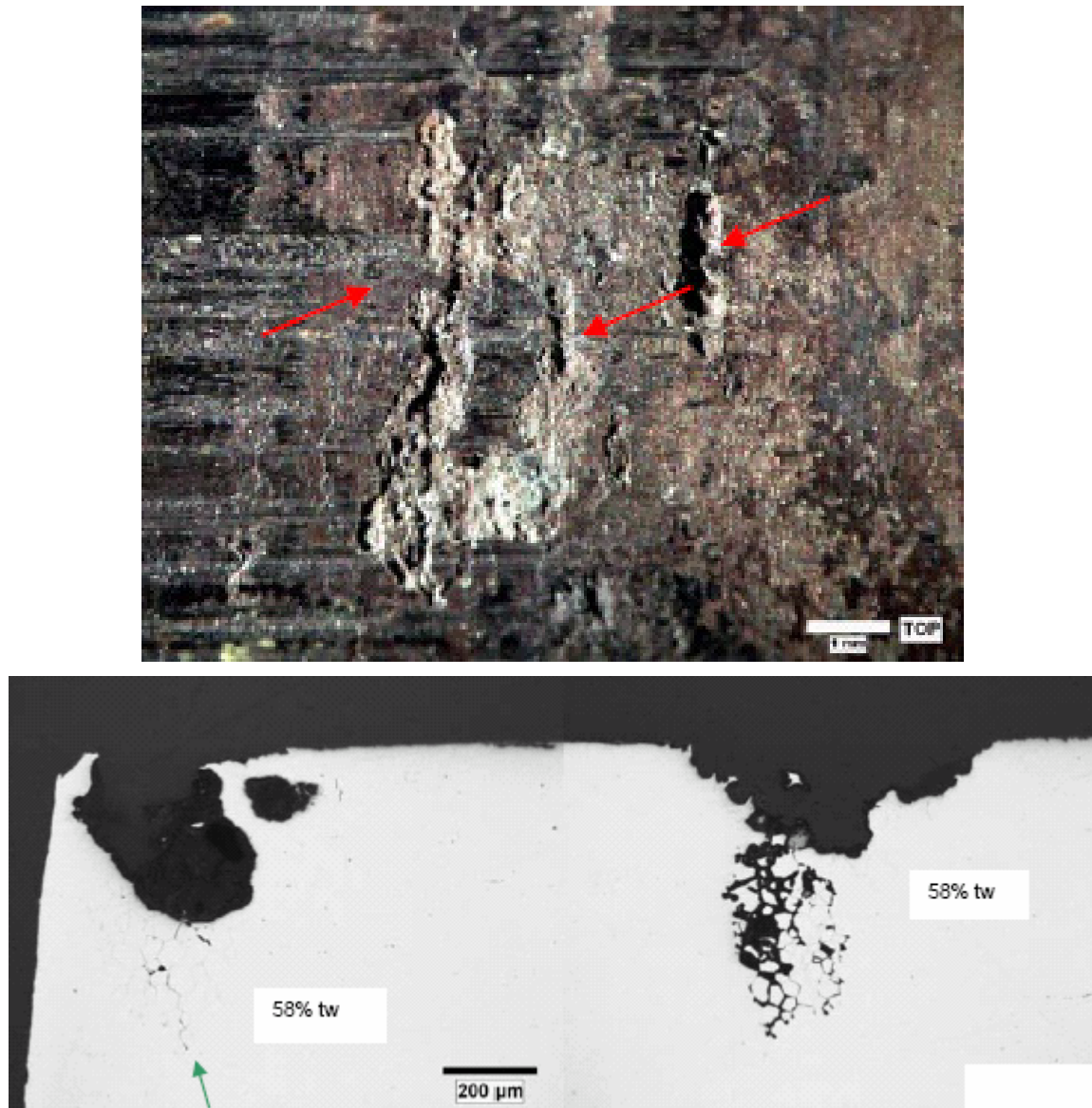


Figure 12 - Tube with Combination of Pitting and IGA (BO4 R26C34)

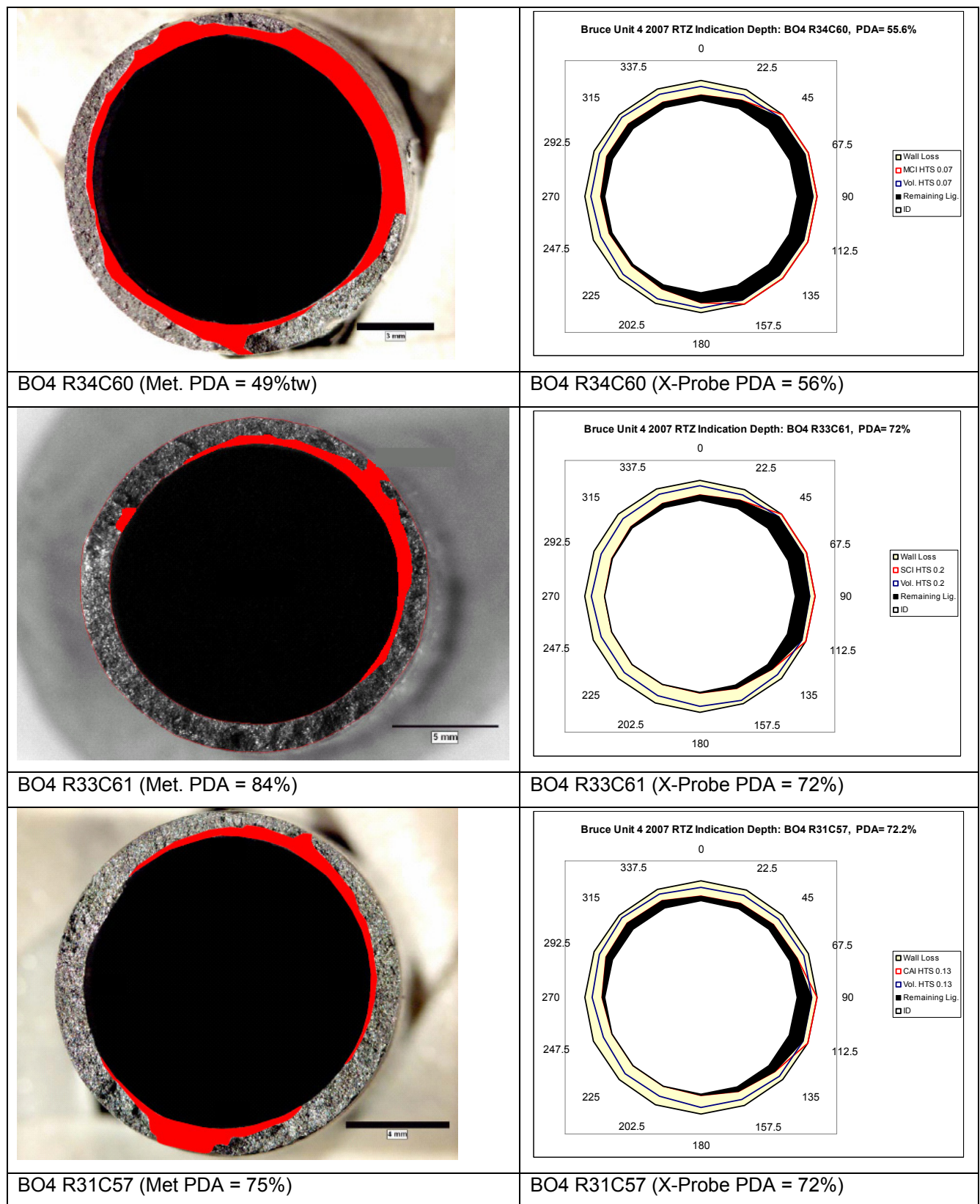


Figure 13 - Comparison of PDA Based on Metallurgical and X-Probe Results

Appendix A - Comparison of ET Results and Metallurgical Examination Results for Bruce Unit 4 Removed Tubes

Year	SG	Row	Column	Reason	C-3/8	+Point		X-Probe			Metallurgical			
						Character	Circ Ext.	Character	Depth	Circ Ext.	PDA	Depth	Circ. Ext.	Character
2004	BO1	40	60	ET Ind.	100% tw, 3 channel	SCI		SCI				100%tw	72	OD SCC, Minor pitting evident
	BO6	17	57	ET Ind.	100% tw, 4 channel	SCI		n/a				100%tw	109	OD SCC, Minor pitting evident, may include ID cracks
2005	BO1	16	38	Random	NDD	NDD		NDD				17%tw (SEM)		General attack, no cracking.
	BO1	21	27	Random	NDD	NDD		NDD						No significant degradation observed.
	BO1	36	58	ET Ind.	59%tw	SCI	46	SCI	45%tw			51%tw	120	OD SCC
	BO1	37	59	Adjacent	NDD	SCI's		SCI's	46%tw			44%tw	26 to 50	IG cracking and general attack. Clusters of small cracks.
	BO1	38	60	Adjacent	NDD	n/a		n/a				< 10%tw		General attack, some IGA and small cracks.
	BO1	48	32	Random	NDD	NDD		NDD						No significant degradation observed.
	BO1	58	38	Random	NDD	NDD		NDD						No significant degradation observed.
	BO1	68	48	Random	NDD	NDD		NDD						No significant degradation observed.
	BO1	85	45	ET Ind.	NQI	NDD		Copper				15%tw		General corrosion.
	BO1	9	29	Random	NDD	NDD		NDD						No significant degradation observed.
	BO4	11	29	Random	NDD	VOL		33%tw				~0%tw		Local pitting and general attack, ID IGA to 10%tw.
	BO4	31	41	Adjacent	NDD	NDD		NDD				28%tw		General corrosion and pitting, minor crack-like features.
	BO4	33	41	Adjacent	NDD	VOL		NDD				22%tw		Pitting and general corrosion, no crack-like features.
	BO4	34	42	Adjacent	NDD	VOL		VOL	22%tw			~20%tw to 40%tw		Pitting and general attack, no IGA or cracking.
	BO4	36	40	Random	NDD	VOL		VOL	25%tw			12%tw		Localized pitting and general attack.
	BO4	39	35	Random	NDD	NDD		VOL	26%tw			~12%tw to 35%tw		Pitting and general attack.
	BO4	41	45	Random	NDD	NDD		NDD				19%tw pit, 10%tw crack		Pitting, IGA and crack-like features.
	BO4	43	43	Random	NDD	VOL		VOL	30%tw			21%tw		Pitting, some evidence of IGA and crack-like features.
	BO4	43	45	Random	NDD	VOL		VOL	32%tw			10%tw crack, 3%tw IGA, 35%tw general		Pitting, general corrosion and small circ. flaws.
	BO4	47	39	Random	NDD	NDD		NDD						No significant degradation observed.
	BO4	50	60	ET Ind.	29%tw	2 VOLs	72	VOL	29%tw			~60%tw max.		Large, isolated pits.
	BO4	62	42	Random	NDD	NDD		NDD						No significant degradation observed.
	BO6	16	26	Random	NDD	NDD		NDD						No significant degradation observed.
	BO6	17	33	Random	NDD	NDD		NDD						No significant degradation observed.
	BO6	30	34	Random	NDD	NDD		NDD				9%tw		Intergranular cracks, pitting and general corrosion.
	BO6	32	38	Random	NDD	NDD		NDD				7%tw		Minor general corrosion
	BO6	45	53	ET Ind.	34%tw	VOL	75	VOL	36%tw	Large		52%tw max		Pitting and general attack around the circumference.
	BO6	45	71	ET Ind.	39%tw	VOL	72	VOL	30%tw	120		44%tw		Pitting, no crack-like features.
	BO6	53	49	Random	NDD	NDD		NDD				6%tw		Minor pitting, no IGA or crack-like features.
	BO6	55	53	Random	NDD	NDD		NDD				12%tw		General corrosion and minor pitting.
	BO7	22	28	Random	NDD	2 VOLs		VOL	24%tw			27%tw		Minor pitting, no IGA or crack-like features.
	BO7	36	32	Random	NDD	2 VOLs		VOL	to 35%tw			53%tw (df), ~42%tw (sec)		General corrosion.
	BO7	51	57	Random	NDD	NDD		NDD						No significant degradation observed.
	BO7	55	43	Random	NDD	NDD		NDD						No significant degradation observed.
	BO7	59	65	ET Ind.	40%tw	VOL	145	VOL?	43%tw	~45		32%pit, crack not sized	< 20	General attack, very small crack.
	BO7	70	46	Random	NDD	NDD		NDD				22%tw		Minor pitting, no IGA or crack-like features.
	BO7	9	31	Random	NDD	NDD		NDD						No significant degradation observed.
	BO8	19	93	Targeted	47%tw	SCI	62	SCI	68%tw	45		64%tw		Several cracks, IGA and general attack with 2 pits.
2006	BO4	21	51	ET Ind.	73%tw	SCI, MCI	167, 131	SCI, VOL	79%tw, 36%tw	45		~90%tw	155	Opened during removal, IGA and general corrosion
	BO4	22	80	ET Ind.	100%tw	SCI	90	SCI	100%tw	45		~100%tw, 37%tw pit	~20	IGA and pitting.
	BO4	25	57	ET Ind.	60%tw	SCI	104	VOLs	37%tw, 27%tw			31%tw		Pitting and general wastage, oriented circ.
	BO4	27	55	ET Ind.	100%tw	SCI	95	SCI, VOL	97%tw, 38%tw	45		100%tw		Through-wall IGA, general wastage.
	BO4	27	59	ET Ind.	100%tw	SCI	100	SCI	100%tw	45		100%tw	60 tw	Broke, through-wall IGA
	BO4	28	54	ET Ind.	93%tw	MCI	224	SCI, VOLs	83%tw, 44%tw	45		100%tw	50 tw	Broke, through-wall IGA
	BO4	36	80	ET Ind.	67%tw	SCI	207	VOLs	32%tw, 35%tw			61%tw, 36%tw		Pitting and general wastage, oriented circ.
	BO4	46	44	ET Ind.	68%tw	MCI	203	SCI, VOLs	67%tw, 34%tw	45		37%tw	~25	Trench-like pitting, wastage, IGA with circ features.
	BO4	51	81	ET Ind.	100%tw	SCI	93	SCI	100%tw	45		100%tw	35, 100 in	Through-wall IGA, no general corrosion.
	BO4	56	60	ET Ind.	52%tw	SCI & VOL	52	SCI, VOL	42%tw, 24%tw	45		61%tw pit,		Pitting, general corrosion and circ. flaws.
2007 S	BO4	31	57	ET Ind.	8 NQI's	SCI's	112, 125	CAI, CAI	77%tw, 100%tw	112, 135	75	100%tw	~360	Broke, through-wall IGA with circumferential features.
	BO4	34	60	ET Ind.	4 NQI's	MCI	189	MCI, VOL	91%tw, 27%tw, 18%	220	49	>90%tw	~360	Broke, multiple pit-like and circ. defects, extensive IGA.
	BO4	26	34	ET Ind.	4 NQI's	MCI	77	VOLs	29%tw (72% after removal)			20%tw pit, 62%tw IGA		Multiple circumferential pits.
	BO4	33	61	ET Ind.	5 NQI's	MCI	171	SCI, VOL	100%tw, 26%tw	270	84	100%tw	~360	Broke, multiple extensive, through-wall IGA sites