EXAMINATION OF SECTIONS OF THE PRESSURIZER PORV LINE SAFE-END FAILURE FROM THE PALISADES NUCLEAR GENERATING STATION

TR-MCC-306

PALISADES, P.O. C-0008170

OCTOBER 1993

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DISK 101

ENCLOSURE 2

Consumers Power Company
Palisades Plant
Docket 50-255

METALLURGICAL EXAMINATION REPORT - NON-PROPRIETARY
EXAMINATION OF SECTIONS OF THE PRESSURIZER PORV LINE SAFE-END FAILURE FROM THE PALISADES NUCLEAR GENERATING STATION
(TAC No. 87760)

November 1, 1993

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MATERIALS
AND CHEMISTRY

ABB-CE NUCLEAR OPERATIONS
COMBUSTION ENGINEERING, INC.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

Section 1.0

INTRODUCTION

The Palisades plant is a two loop pressurized water reactor (PWR) designed by Combustion Engineering (C-E) that entered into commercial operation in December 1971. The Palisades pressurizer was included as part of C-E's scope of supply and it was delivered with an Inconel 600 (NiCrFe) safe-end at the top to receive the field welded 4 inch stainless steel pipe connection to the power operated relief valve (PORV). The Inconel 600 safe-end was supplied in the stress relieved condition and was derived from SB-166 forged bar stock.

On September 16, 1993 a leak was discovered in the 4 inch PORV line at the top of the pressurizer. Upon further investigation it was confirmed that a circumferential crack had developed near the safe-end weld. Plant cooldown was initiated. A root cause investigation was initiated by Palisades and several sample sections were sent to ABB Combustion Engineering Nuclear Services for examination under Palisades P.O. C-0008170. The objectives of this examination were to:

(1) Perform chemical analysis of the safe-end base metal and weld metal.

(2) Characterize the fracture surface, the heat affected zone (HAZ) and the Inconel 600 base metal.

(3) Characterize what appeared to be a weld repair included in sample mount #3 supplied by Palisades.

The objectives were accomplished by a variety of examinations and tests via:

- visual examination
- scanning electron microscopy
- energy dispersive spectroscopy analysis
- light optical microscopy
- microhardness testing
- bulk chemical analysis
- microstructure evaluation
- sensitization assessment

The examination of the 4 samples submitted is compete. The purpose of this report is to document the results and provide conclusions based on an evaluation of the results.

Section 2.0

BACKGROUND

The Palisades in-service inspection program identified a possible flaw in the PORV nozzle safe-end to stainless steel pipe weld during the June 1993 refueling outage. This possible flaw indication was evaluated and determined at that time to be an original construction flaw which would not impact structural integrity.

On September 16, 1993, during heatup following a refueling outage, plant operating personnel noticed an increasing trend in the containment sump level. Shortly thereafter, an auxiliary operator conducting rounds in containment reported a steam leak near the pressurizer. On closer inspection an unisolable leak was identified in the power operated relief valve (PORV) line near the pressurizer nozzle. While cooling down, at low pressure, further visual inspection confirmed the presence of a circumferential crack in or adjacent to the Inconel 600 safe-end to pipe weld.

On September 17, 1993 the crack was further defined as approximately 3 inches in length which is about 20% of the circumference.

A doughnut section encompassing part of the safe-end containing the crack and a portion of the PORV line was removed for repair purposes and metallurgical evaluation. This section was divided with one part being evaluated by Consumers Power Company and ABB Combustion Engineering while the other part was provided to the USNRC for evaluation at Brookhaven National Laboratory.

Section 3.0

CHEMICAL ANALYSIS SAMPLES

Samples of weld metal and Inconel 600 base metal were taken in a region remote from the cracked region and sent to ABB Combustion Engineering Materials/Chemical Technology for chemical analysis. Photographs of these samples were taken and are shown in Figures 3-1 and 3-2.

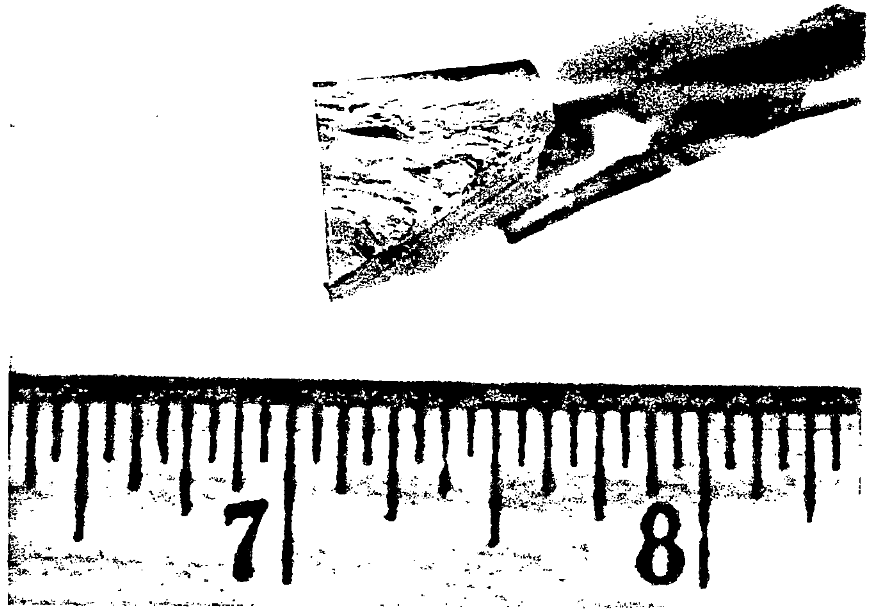
It was reported by CPCo that there were 4 distinct weld passes visible in the weld and the objective of this task was to obtain chemical analysis in each of the 4 weld zones. On examination of the as-received etched weld metal it was not obvious that 4 distinct passes were present. The prepared surfaced was reground, polished and etched using 10% oxalic acid. Upon re-examination it was clear that there were perhaps 15 to 20 passes, seen in Figure 3-3.

To produce 4 samples for analysis, drilling with a small diameter bit was attempted to produce chips but this approach proved difficult. It was decided to cut the weld into 4 sections using Al_2O_3 cutoff wheels and obtain chemical analysis on each. The sketch in Figure 3-4 approximates the weld sectioning. A 1/4 inch thick section was used and the likely high dilution areas were set aside as shown in the sketch. A new file was obtained and was successful in generating filings appropriate for analysis from each of the four cut samples.

Except for carbon analysis the bulk elemental analysis was obtained using an inductively coupled plasma (ICP) spectrometer. Carbon was determined on a LECO IR-412 instrument using the combustion technique.

Table 3-1 lists the analysis results obtained on the weld sample along with 1968 code requirements for I-82 and I-182 weld filler metals for comparison. Energy Dispersive Spectroscopy (EDS) analysis was also performed on each of the weld samples (1 through 4) and the results are included as Figures 3-5 through 3-8 respectively.

Samples from the base metal were similarly prepared and analyzed using the ICP and combustion techniques. The results of this analysis are tabulated in Table 3-2 along with the 1965 code requirements for SB-166 bar for comparison. The EDS results for the base metal are shown in Figure 3-9.



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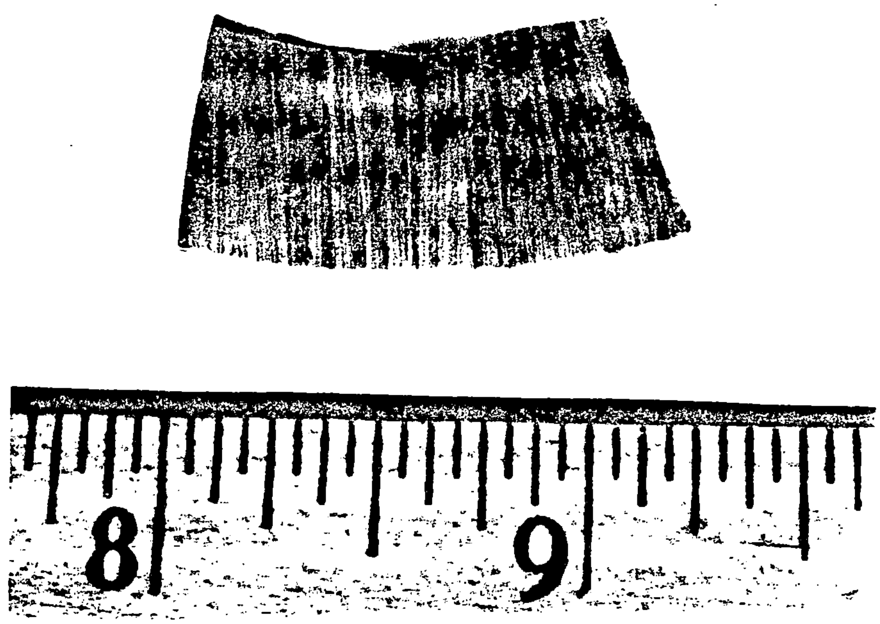

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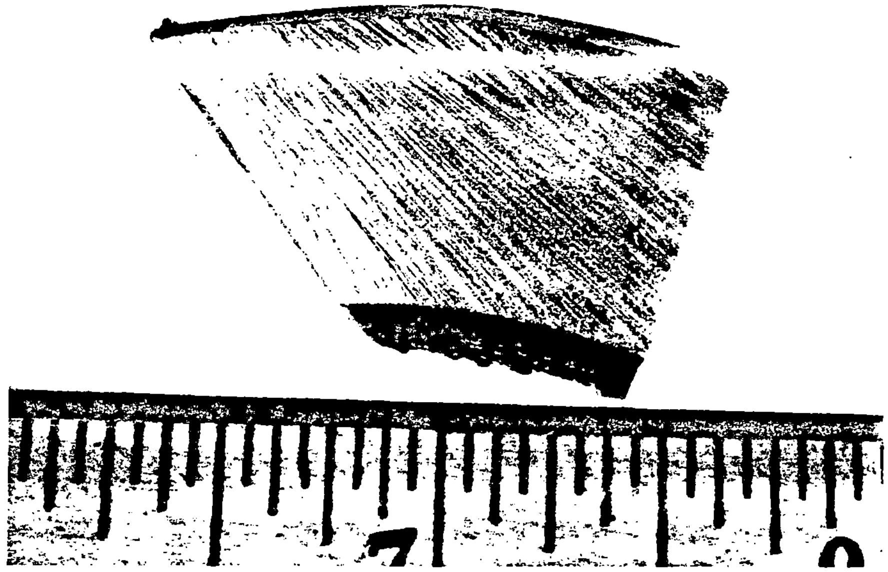
Figure 3-1. As-Received Weld Metal Sample.



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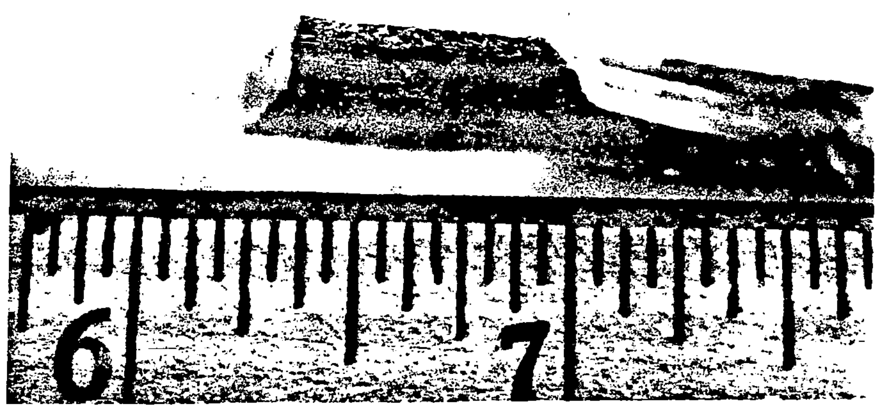

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Figure 3-2. As-Received Inconel 600 Base Metal Sample.

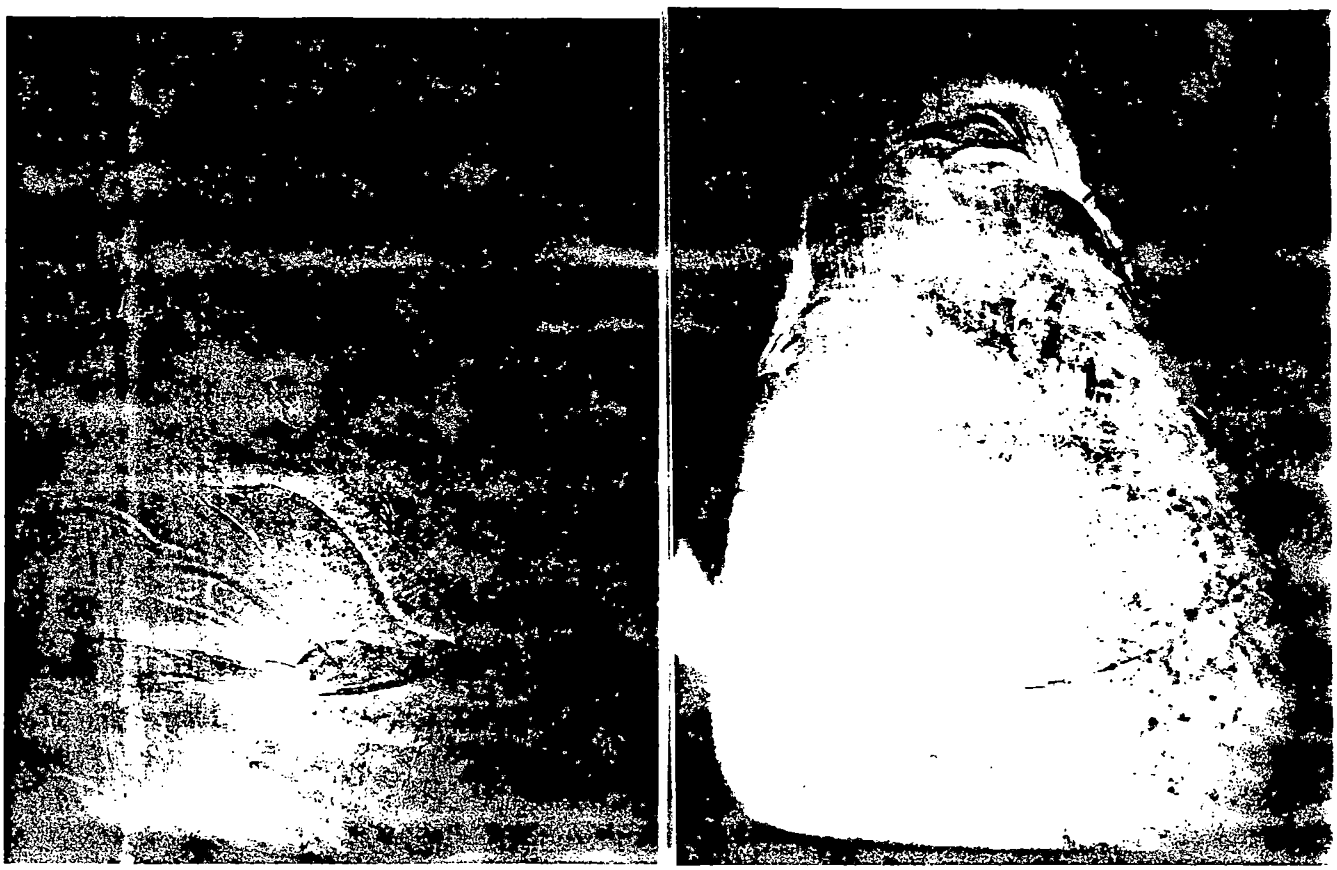

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Figure 3-3. Oxalic Acid Etch of Weld Sample Showing Multiple Passes (15-20). Two Exposures Shown to Highlight Different Areas.

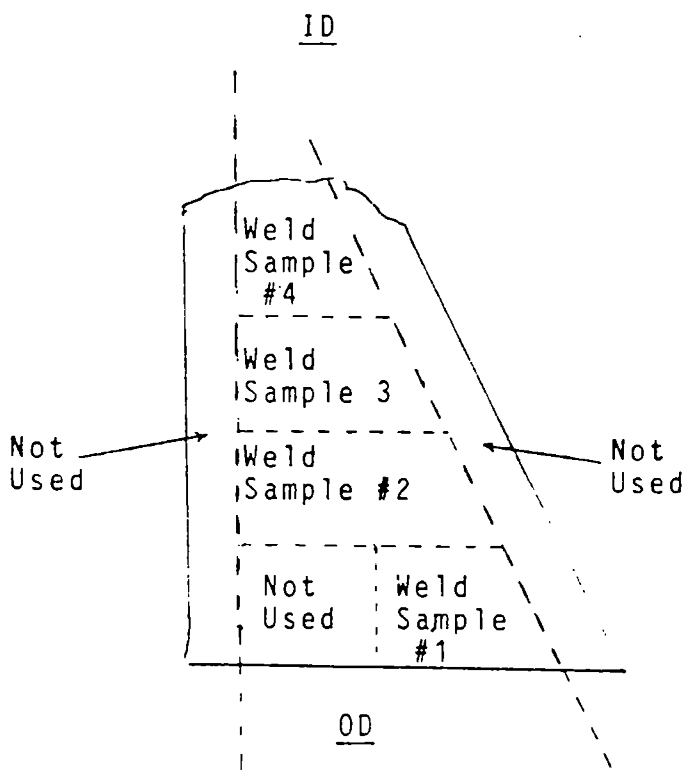
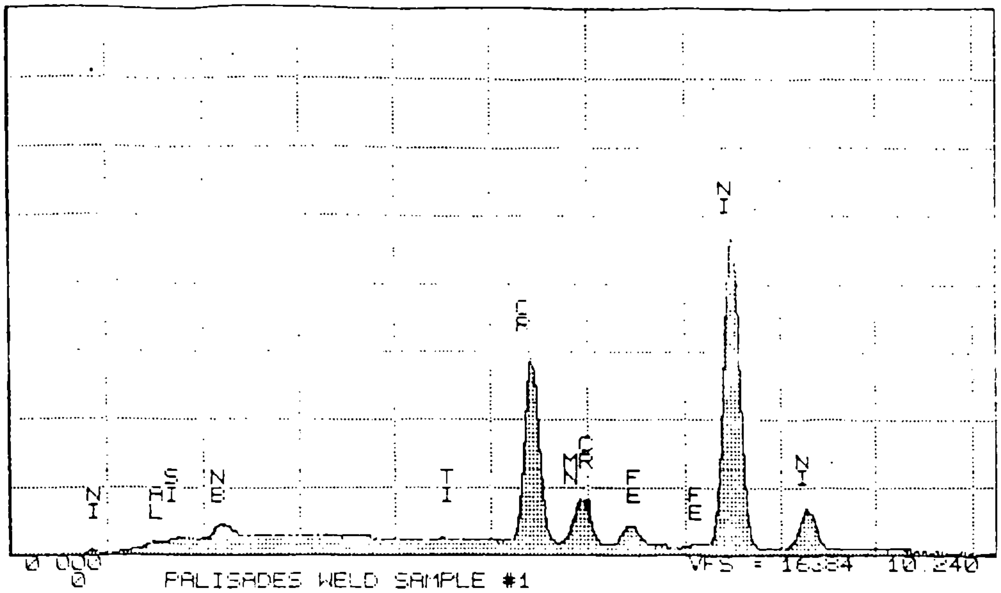


Figure 3-4. Sketch of Weld Sample Sectioning.



SQ: QUANTIFY

PALISADES WELD SAMPLE #1
Standardless Analysis
20.0 kV   40.0 Degrees

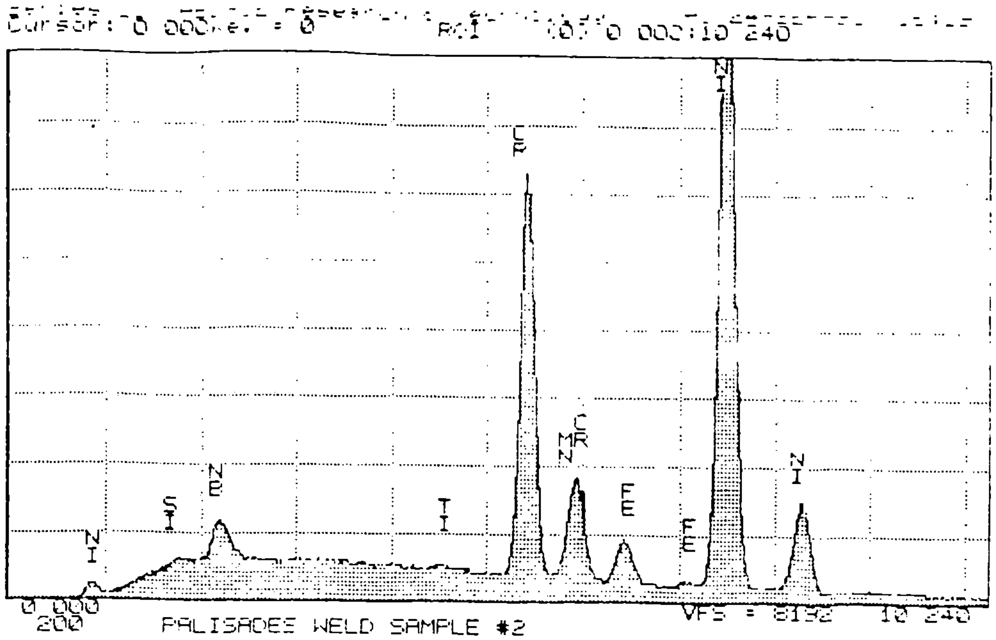
Chi-sqd = 4.17

Element	Rel. K-ratio	Net Counts
Ni-L	0.31511 +/- 0.01315	2805 +/- 117
Si-K	0.00142 +/- 0.00032	1730 +/- 383
Nb-L	0.01331 +/- 0.00075	11321 +/- 636
Ti-K	0.00179 +/- 0.00039	1637 +/- 353
Cr-K	0.15074 +/- 0.00102	109135 +/- 740
Fe-K	0.01961 +/- 0.00073	11637 +/- 430
Ni-K	0.47288 +/- 0.00216	204730 +/- 937
Al-K	0.00137 +/- 0.00035	1202 +/- 307
Mn-K	0.02356 +/- 0.00086	15270 +/- 559

ZAF Correction 20.00 kV 40.00 deg
No.of Iterations = 2

Element	K-ratio	Z	A	F	ZAF	Atom%	Wt%
Si-K	0.002	0.918	2.136	0.999	1.957	0.81	0.40
Nb-L	0.019	1.083	1.349	0.998	1.457	1.71	2.79
Ti-K	0.003	1.016	1.053	0.928	0.993	0.30	0.26
Cr-K	0.217	1.016	1.024	0.927	0.964	22.87	20.88
Fe-K	0.028	1.011	1.042	0.880	0.927	2.69	2.64
Ni-K	0.680	0.992	1.028	1.000	1.020	67.22	69.33
Al-K	0.002	0.945	2.768	0.999	2.615	1.09	0.51
Mn-K	0.034	1.032	1.015	0.900	0.943	3.31	3.19
						Total=	100.00%

Figure 3-5. EDS Results from Weld Sample #1.



SQ: QUANTIFY

PALISADES WELD SAMPLE #2
Standardless Analysis
20.0 KV   40.0 Degrees

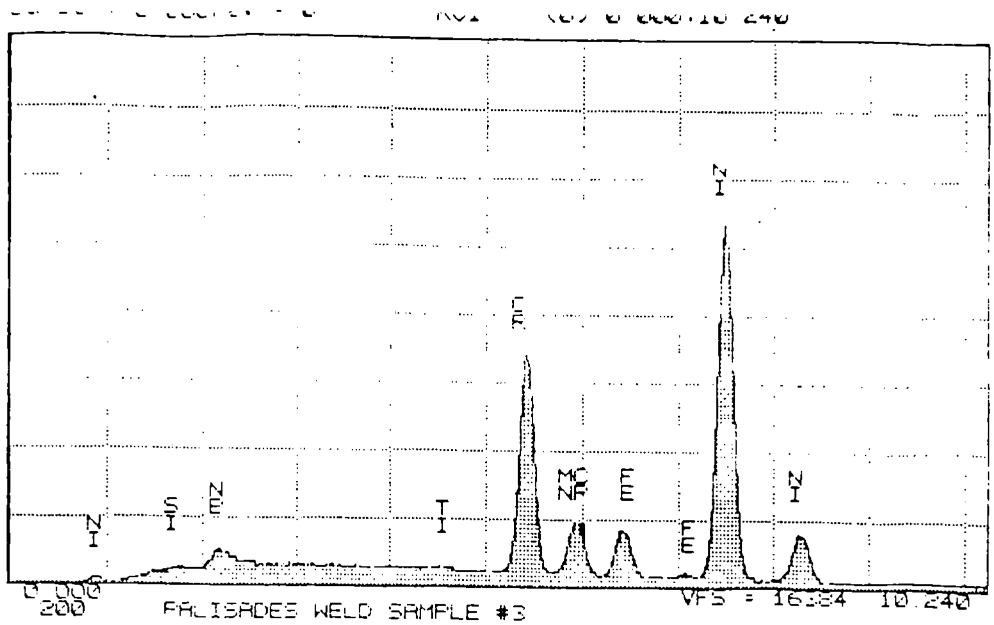
Chi-sqd = 5.19

Element	Rel. K-ratio	Net Counts
Ni-L	0.34120 +/- 0.01295	3347 +/- 127
Si-K	0.00123 +/- 0.00022	1651 +/- 295
Nb-L	0.01583 +/- 0.00074	14834 +/- 694
Ti-K	0.00209 +/- 0.00037	2106 +/- 369
Cr-K	0.14912 +/- 0.00097	118981 +/- 772
Fe-K	0.01838 +/- 0.00068	11903 +/- 440
Ni-K	0.44891 +/- 0.00202	214195 +/- 964
Mn-K	0.02323 +/- 0.00082	16589 +/- 584

ZAF Correction 20.00 KV 40.00 deg
No.of Iterations = 2

Element	K-ratio	Z	A	F	ZAF	Atom%	Wt%
Si-K	0.002	0.917	2.124	0.999	1.944	0.73	0.36
Nb-L	0.024	1.082	1.343	0.998	1.449	2.12	3.43
Ti-K	0.003	1.016	1.053	0.928	0.993	0.37	0.31
Cr-K	0.223	1.014	1.024	0.929	0.965	23.77	21.54
Fe-K	0.028	1.010	1.044	0.883	0.931	2.63	2.56
Ni-K	0.672	0.991	1.029	1.000	1.020	66.95	68.51
Mn-K	0.035	1.031	1.015	0.902	0.944	3.43	3.28
						Total=	100.00%

Figure 3-6. EDS Results from Weld Sample #2.



SC: QUANTIFY

PALISADES WELD SAMPLE #3 FILE 23 DISK 13
Standardless Analysis
20.0 kV 40.0 Degrees

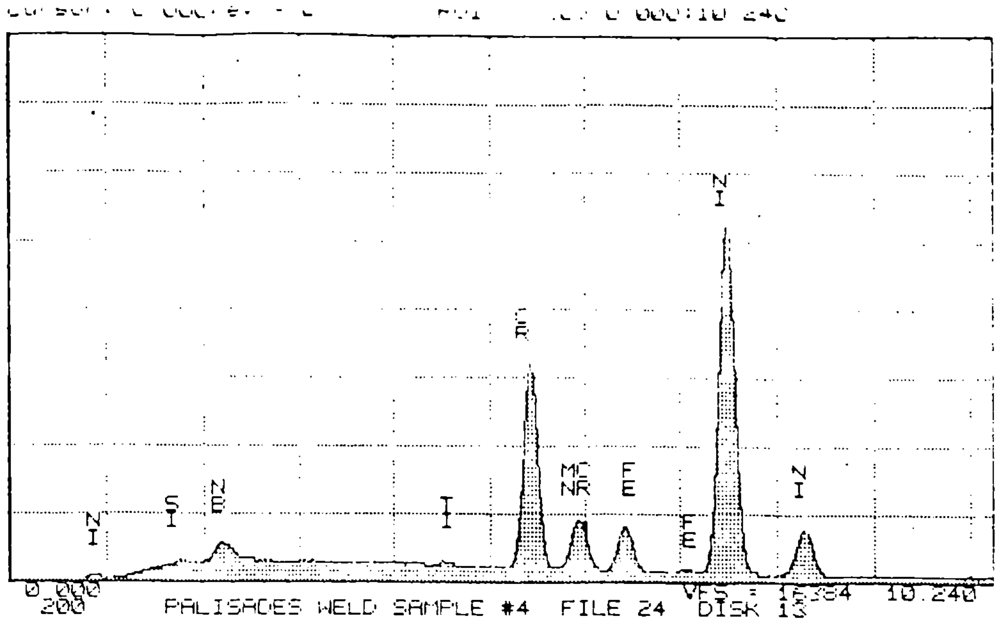
Chi-sqd = 5.55

Element	Rel. K-ratio	Net Counts
Ni-L	0.27555 +/- 0.01208	2716 +/- 119
Si-K	0.00087 +/- 0.00021	1170 +/- 285
Nb-L	0.01303 +/- 0.00072	12265 +/- 677
Ti-K	0.00250 +/- 0.00038	2532 +/- 385
Cr-K	0.15987 +/- 0.00100	128152 +/- 805
Fe-K	0.04370 +/- 0.00081	28426 +/- 530
Ni-K	0.48139 +/- 0.00211	230769 +/- 1012
Mn-K	0.02309 +/- 0.00085	16565 +/- 610

ZAF Correction 20.00 kV 40.00 deg
No.of Iterations = 2

Element	K-ratio	Z	A	F	ZAF	Atom%	Wt%
Si-K	0.001	0.917	2.129	0.999	1.950	0.47	0.23
Nb-L	0.018	1.082	1.344	0.998	1.450	1.59	2.58
Ti-K	0.003	1.016	1.052	0.928	0.991	0.41	0.34
Cr-K	0.218	1.015	1.023	0.927	0.962	23.13	21.01
Fe-K	0.060	1.010	1.042	0.887	0.934	5.71	5.57
Ni-K	0.658	0.991	1.032	1.000	1.022	65.58	67.27
Mn-K	0.032	1.031	1.014	0.906	0.947	3.11	2.99
						Total=	100.00%

Figure 3-7. EDS Results from Weld Sample #3.



SC: QUANTIFY

PALISADES WELD SAMPLE #4 FILE 24 DISK 13
Standardless Analysis
20.0 kV 40.0 Degrees

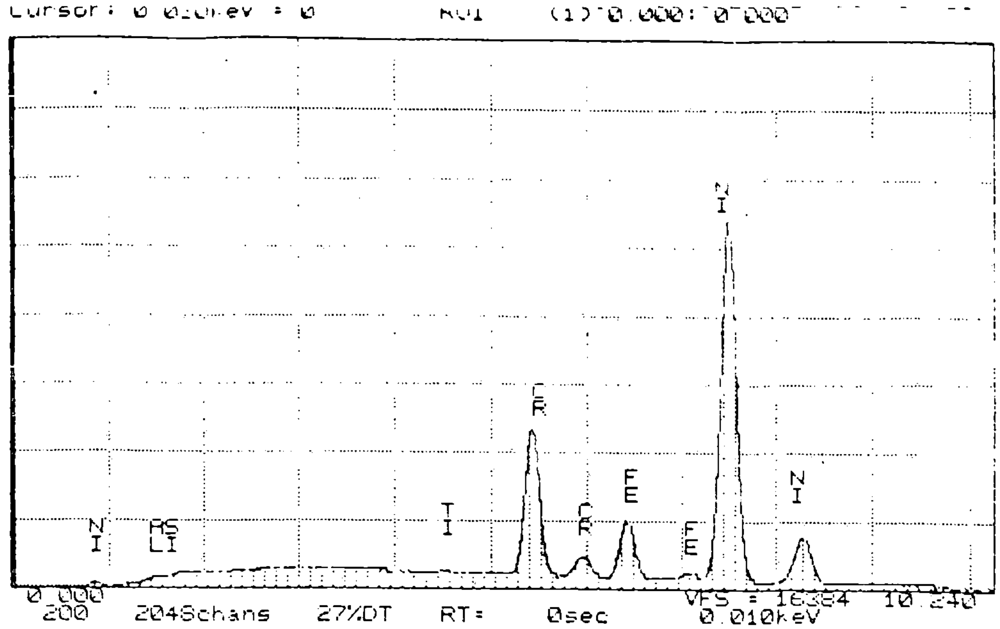
Chi-sqd = 4.80

Element	Rel. K-ratio	Net Counts
Ni-L	0.32617 +/- 0.01265	3352 +/- 130
Si-K	0.00128 +/- 0.00021	1791 +/- 298
Nb-L	0.01538 +/- 0.00071	15104 +/- 696
Ti-K	0.00253 +/- 0.00036	2667 +/- 379
Cr-K	0.14432 +/- 0.00093	120638 +/- 781
Fe-K	0.03828 +/- 0.00076	25965 +/- 517
Ni-K	0.45071 +/- 0.00199	225308 +/- 995
Mn-K	0.02134 +/- 0.00080	15968 +/- 595

ZAF Correction 20.00 kV 40.00 deg
No.of Iterations = 2

Element	K-ratio	Z	A	F	ZAF	Atom%	Wt%
Si-K	0.002	0.917	2.125	0.999	1.945	0.74	0.36
Nb-L	0.023	1.082	1.343	0.998	1.449	2.02	3.27
Ti-K	0.004	1.016	1.053	0.929	0.994	0.44	0.37
Cr-K	0.211	1.014	1.024	0.927	0.963	22.46	20.36
Fe-K	0.056	1.010	1.042	0.885	0.932	5.36	5.22
Ni-K	0.660	0.991	1.031	1.000	1.021	65.89	67.45
Mn-K	0.031	1.031	1.015	0.905	0.947	3.09	2.96
						Total=	100.00%

Figure 3-8. EDS Results from Weld Sample #4.



SQ: QUANTIFY

PALISADES BASE METAL
Standardless Analysis
20.0 kV 40.0 Degrees

Chi-sqd = 4.75

Element	Rel. K-ratio	Net Counts
Ni-K	0.52137 +/- 0.00227	230753 +/- 1005
Fe-K	0.06073 +/- 0.00089	36478 +/- 534
Cr-K	0.11677 +/- 0.00092	86422 +/- 682
Ni-L	0.29403 +/- 0.01253	2675 +/- 114
Al-K	0.00156 +/- 0.00031	1396 +/- 280
Si-K	0.00129 +/- 0.00028	1603 +/- 343
Ti-K	0.00153 +/- 0.00039	1429 +/- 362
Mn-K	0.00271 +/- 0.00074	1798 +/- 488

ZAF Correction 20.00 kV 40.00 deg
No.of Iterations = 1

Element	K-ratio	Z	A	F	ZAF	Atom%	Wt%
Ni-K	0.736	0.996	1.025	1.000	1.021	72.52	75.12
Fe-K	0.086	1.015	1.032	0.861	0.903	7.85	7.74
Cr-K	0.165	1.020	1.021	0.910	0.947	17.02	15.61
Al-K	0.002	0.949	2.853	1.000	2.706	1.25	0.59
Si-K	0.002	0.921	2.192	0.999	2.017	0.74	0.37
Ti-K	0.002	1.020	1.052	0.934	1.002	0.26	0.22
Mn-K	0.004	1.036	1.013	0.888	0.932	0.37	0.35
						Total=	100.00%

Figure 3-9. EDS Results from Base Metal Sample.

Table 3-1

WELD METAL ANALYSIS RESULTS (wt.%)*

	Weld Sample Location				1968 Code	
Element	1	2	3	4	SB-304 (I-82)	SB-195 (I-182)
Ni	74.25	74.90	69.89	69.77	67 min.	Rem
Cr	19.92	20.23	20.62	20.88	(20**)	13-17
Fe	2.99	5.30	3.84	6.71	<3.0	6.0-10.0
Mn	2.92	3.13	2.35	2.58	2.25-3.5	5.0 to 9.5
Si	0.12	0.14	0.11	0.18	<0.5	<1.0
Cu	0.06	0.06	0.05	0.09	<0.05	<0.50
Al	0.05	0.06	0.05	0.06	-	-
P	0.037	0.037	0.029	0.030	-	-
S	0.031	0.012	0.025	0.018	<0.015	<0.015
Ti	0.02	0.02	0.02	0.02	-	<1.0
C	0.012	0.051	0.020	0.056	<0.10	<0.10
Co	0.01	0.02	0.02	0.04	(with Ni)	-
Cb					-	1.0 to 2.5 (Cb+Ta)

* ICP Analysis except for carbon
** Nominal, no amount specified

Table 3-2

ALLOY 600 BASE METAL ANALYSIS RESULTS (wt.%)*

Element	Base Metal Analysis	1965 ASME Code SB-166 Bar
Ni	75.92	72.0 min.
Cr	16.17	14.0 to 17.0
Fe	7.43	6.0 to 10.0
Mn	3.32	1.0 max.
C	0.131	0.15 max.
Cu	0.11	0.5 max.
Si	0.13	0.5 max.
S	<0.001	0.015 max.

* ICP Analysis Except for Carbon

Section 4.0

FRACTURE SURFACE SAMPLE

4.1 GENERAL

A portion of the Inconel 600 half of the safe-end fracture, shown in Figure 4-1 was sent to ABB/CE for characterization. The fracture surface had been replicated and some of the replicating material remained on the surface. The sample was cleaned in an ultrasonic bath of acetone to remove the replicating material so that it wouldn't charge up in the SEM. By cutting axially in 2 locations the sample was divided into essentially 3 equal size pieces. A sketch is provided in Figure 4-1 detailing the sectioning scheme. A photo-montage was recorded for each third of the fracture surface. Single SEM views along with EDS results were obtained on several locations on the center piece of the fracture. The locations of the micrographs and EDS spectra are shown on the sketch in Figure 4-1 and the results for the identified locations are shown in Figures 4-2 through 4-5 respectively.

Figure 4-2 shows a region on the fracture surface near the inner wall of the pipe. At lower magnification (about 10X) this region was unusual in that it had the appearance of a ductile fracture, but upon closer examination it does not have ductile dimpling typical of ductile tearing. The appearance of the grains are unusual and do not clearly resemble any one known fracture of Alloy 600. Their appearance suggests intergranular fracture followed by abrasion of some sort which rounded off the sharp edges of the "rock candy" shaped fracture grains. EDS analysis of this region shows a typical Alloy 600 spectra.

Figure 4-3 shows an example of what most of the fracture surface looked like. It shows a typical intergranular fracture "rock candy" appearance. Figure 4-4 shows a closeup of one of the grain facets. The grain surface has a rough appearance, suggesting an older surface.

Figure 4-5 shows a region near the OD which was out of the fracture plane and did not appear as an intergranular fracture. This region may represent a portion of the crack that extended into the weld, although the EDS spectra shown in Figure 4-5 closely resembles that of Alloy 600.

4.2 MICROHARDNESS SURVEY

A longitudinal section near the midline of the center section of the fracture sample was prepared and Knoop microhardness transverses were taken in the HAZ and base metal regions across the thickness of the sample from ID to OD. Indentations were made on a Shimadzu Type M78328 microhardness tester, using a Knoop indenter, under a 300 grain load for 15 seconds. Indentations were measured at a magnification of 400X in microns, and converted to HK_{300} in accordance with ASTM E384. The results of these traverses are shown in Figure 4-6. The base metal traverse was made about 1/2 inch from the fracture. Readings in the HAZ were taken as close to the fracture as deemed feasible, ie., about 5 to 10 mils away. There is a great deal of variability in the microhardness across the nozzle wall, however the general trends show that the microhardness near the HAZ was less than that of the bulk alloy. The microhardness values are very high, especially near the periphery of the bulk metal. Pressurizer instrumentation nozzles made of SB-166 forged bar stock from Calvert Cliffs 2 had a bulk metal microhardness of about 175 HK_{300} and about 210 HK_{300} near its cracks. A rough correlation of material strength and hardness would suggest that the bulk metal has an ultimate strength of 135 KSI (at 300 HK_{300}) and 105 KSI (at 230 HK_{300}) near the HAZ. The yield strength of the material is not related to the microhardness, since the diamond indenter penetrates and plasticly deforms the metal. The ultimate strength of the material as listed in the original material certification report was 114 KSI.

4.3 DUAL ETCH METALLOGRAPHY

The microstructure of the material was evaluated by performing a dual etch on longitudinal sections. In the dual etch, areas from each section are etched first with orthophosphoric acid to reveal the location and distribution of carbides. The same areas are then examined after a nital etch to show the grain boundary network. This permits an assessment of carbide distribution with respect to the grain boundary network. A microhardness indent is used to assist in the identification of areas to be examined.

Dual etch metallography was performed on the HAZ and on the base metal. In each case a micrograph set was obtained near the ID surface, mid-wall and near the OD surface. These dual etch sets can be seen in Figures 4-7 through 4-12.

These photomicrographs show good correspondence between carbides and grain boundaries. The grains are very large, mostly ASTM size 00. The orthophosphoric acid etch photomicrograph shown in Figure 4-12 clearly shows the HAZ, a region having absolutely no intragranular indications. The HAZ is about 30 mils wide. The orthophosphoric acid etch revealed indications that appeared to line up in three directions. These are not carbides but rather are etch pits due to stress relaxation. The structure is similar to that of a failed SONGS-3 pressurizer nozzle, having large grains and numerous intergranular carbides.

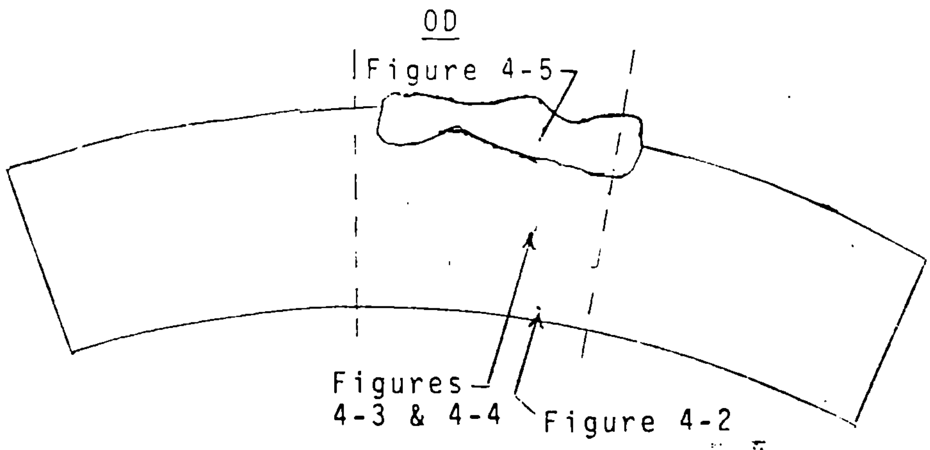
An attempt was made to resolve the grain boundary particles employing higher magnification and the H_3PO_4 etch. The results are shown in Figures 4-13 and 4-14 for the base metal and HAZ respectively. In both cases the carbides are extremely fine.

4.4 SENSITIZATION TEST

A section from the center third of the overall fracture sample was modified Huey tested, mounted, polished and etched in Glycerigia to assess the degree of attack. The micrograph in Figure 4-15 shows the attack to be fairly equal on the ID and OD surfaces but slightly deeper at the fracture surface. The Modified Huey test is a 25% boiling HNO_3 acid exposure for a period of 48 hours.

4.5 AXIAL CRACK CHARCTERIZATION

An axial intergranular crack was observed on the ID surface during the SEM examination of the fracture surface. This crack was observed running from the fracture surface into the Inconel base metal and is shown in Figure 4-16. These SEM micrographs also show a closeup of a narrow circumferential groove on the inner surface. This groove also has a spherical droplet of weld metal on it. EDS analysis of this material showed that it had the same composition as the original I-82 weld material. The axial crack seems to be unrelated to the groove or the droplet. This crack was examined in metallographic mounts and was found to be 0.065" long (radial view) and 0.085" into the wall dimension (axial view as shown in Figure 4-17).



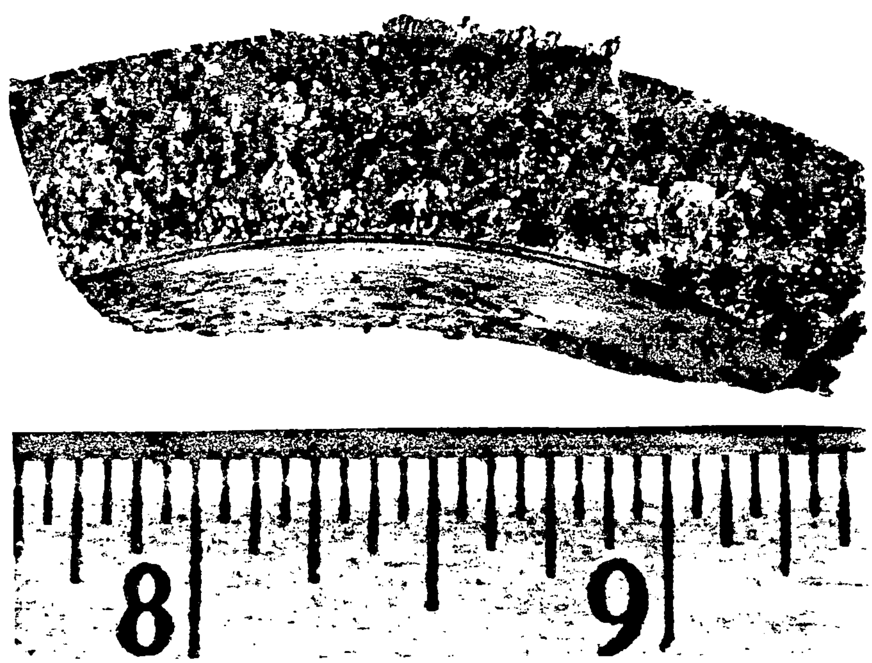


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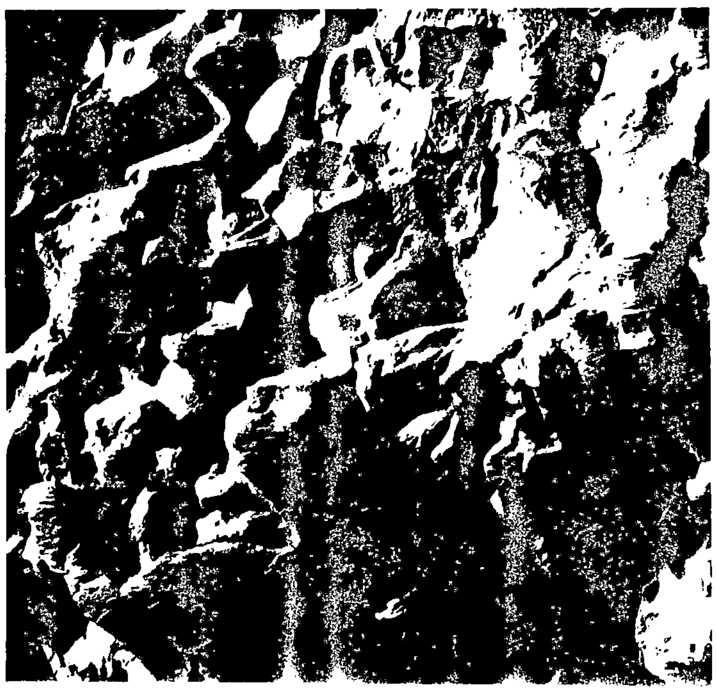
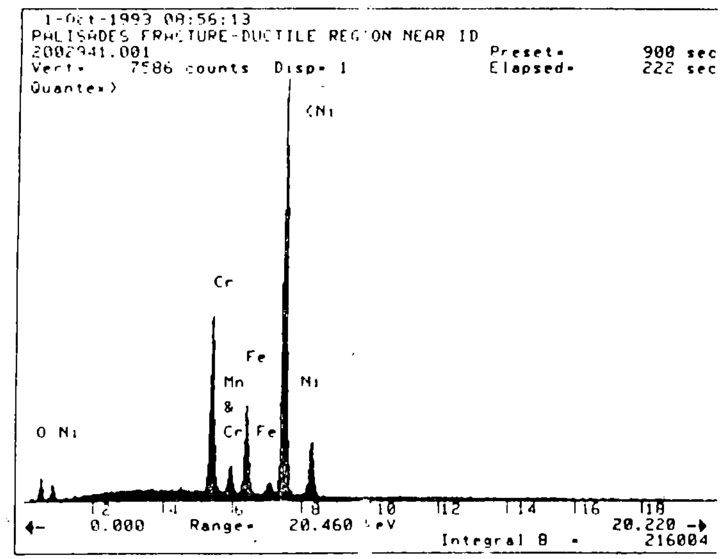
Figure 4-1. Inconel 600 Half of Safe-End Fracture.



107406 100X



EDS Spectra

Figure 4-2. Fracture Surface Near ID and EDS Spectra.

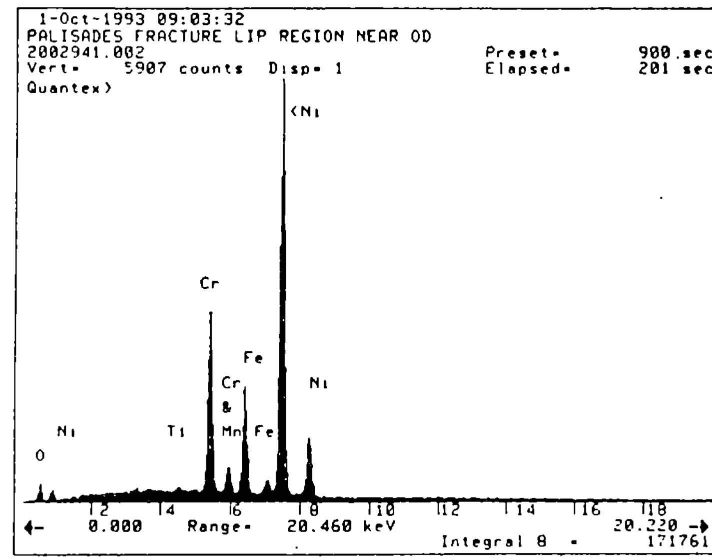
107418 50X

Figure 4-3. Center of Fracture Surface, Typical of Most of Fracture, Showing "Rock Candy" Appearance of Intergranular Fracture.

107407 200X

Figure 4-4. Closeup of Grain Facet.

107409 50X



EDS Spectra

Figure 4-5. Fracture Lip Region Near OD.

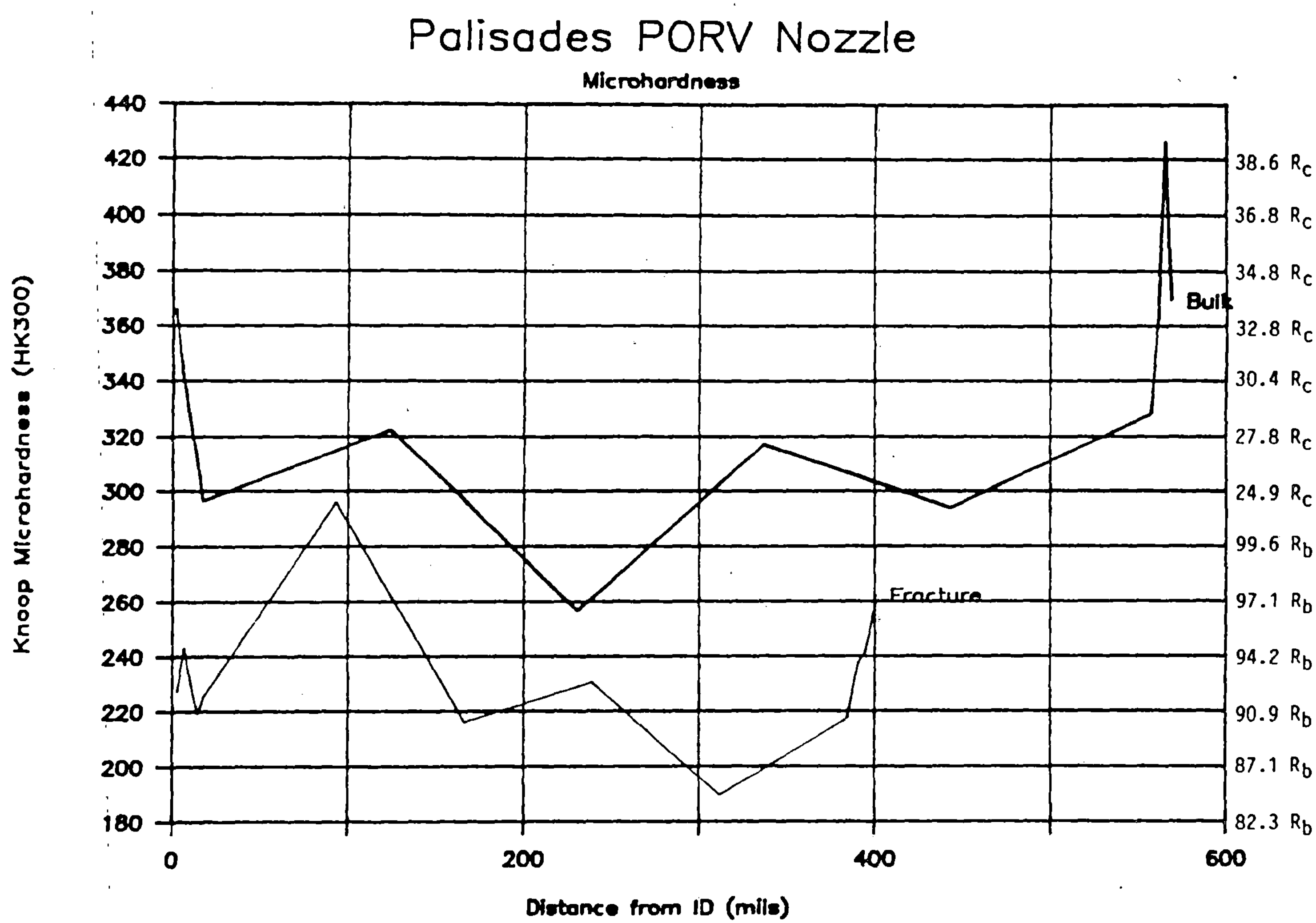
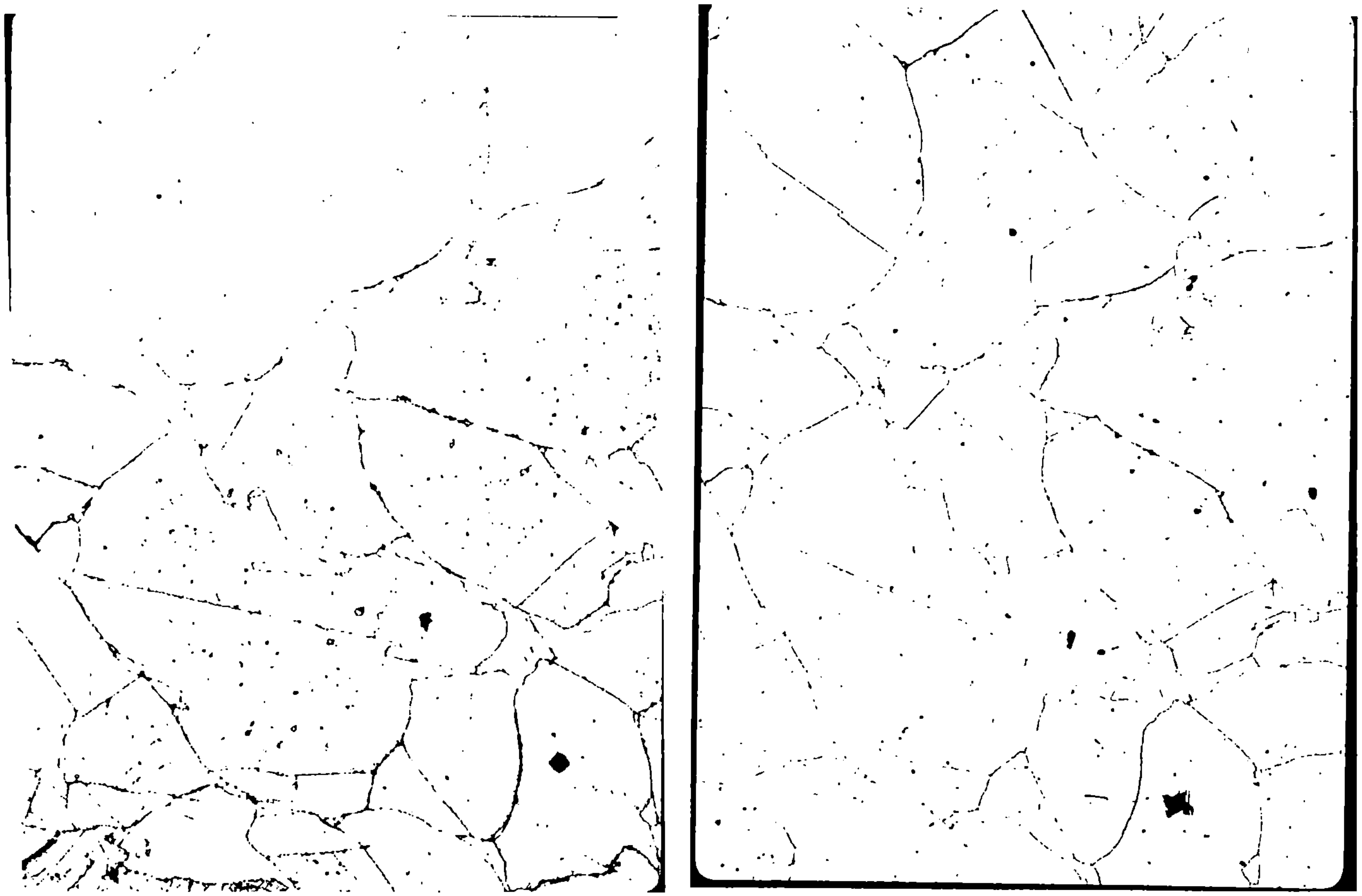


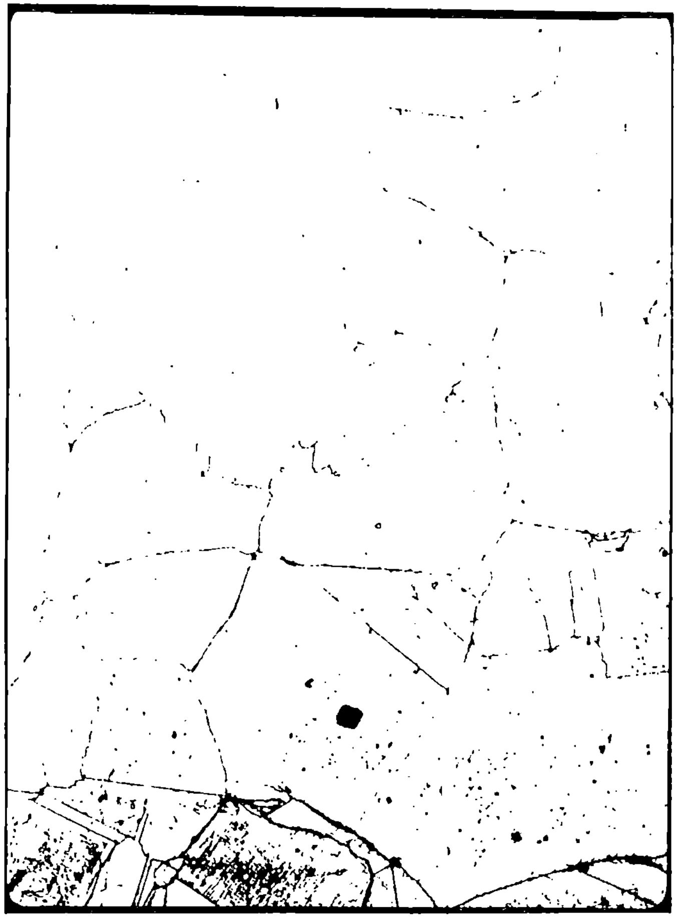
Figure 4-6. Plot of Microhardness Results from HAZ and Base Metal.



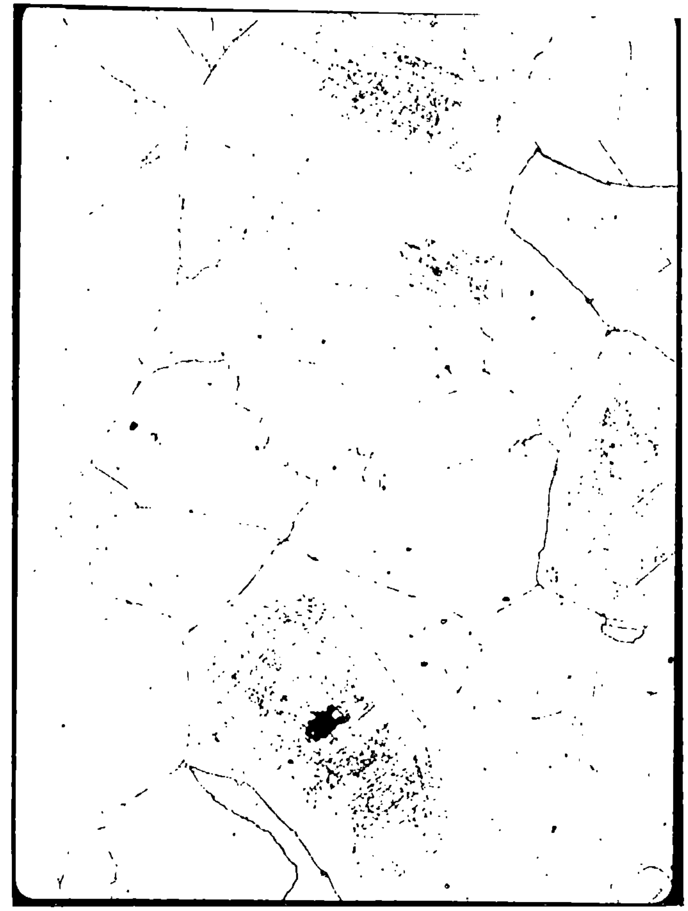
107435 HNO_3 75X

107434 H_3PO_4 75X

Figure 4-7. Dual Etch Metallography on Base Metal Near ID.

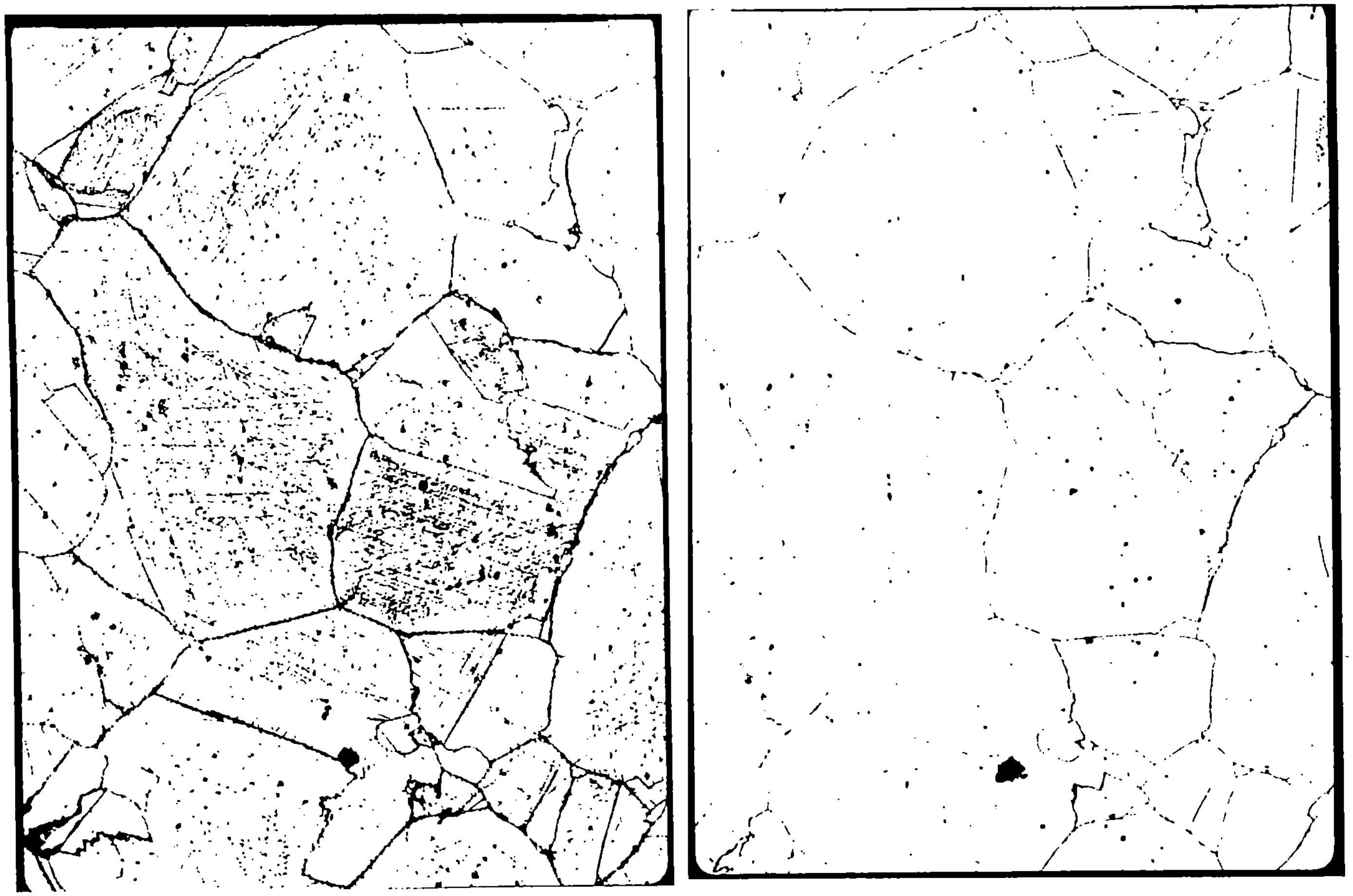


107436 HNO_3 75X



107437 H_3PO_4 75X

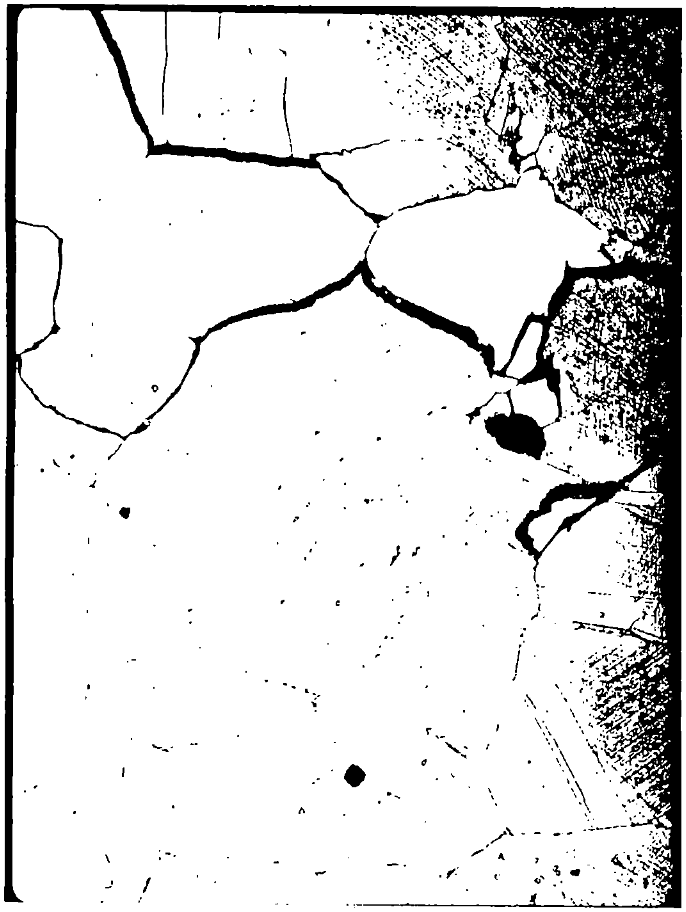
Figure 4-8. Dual Etch Metallography on Base Metal at Mid-Wall.



107433 HNO_3 75X

107432 H_3PO_4 75X

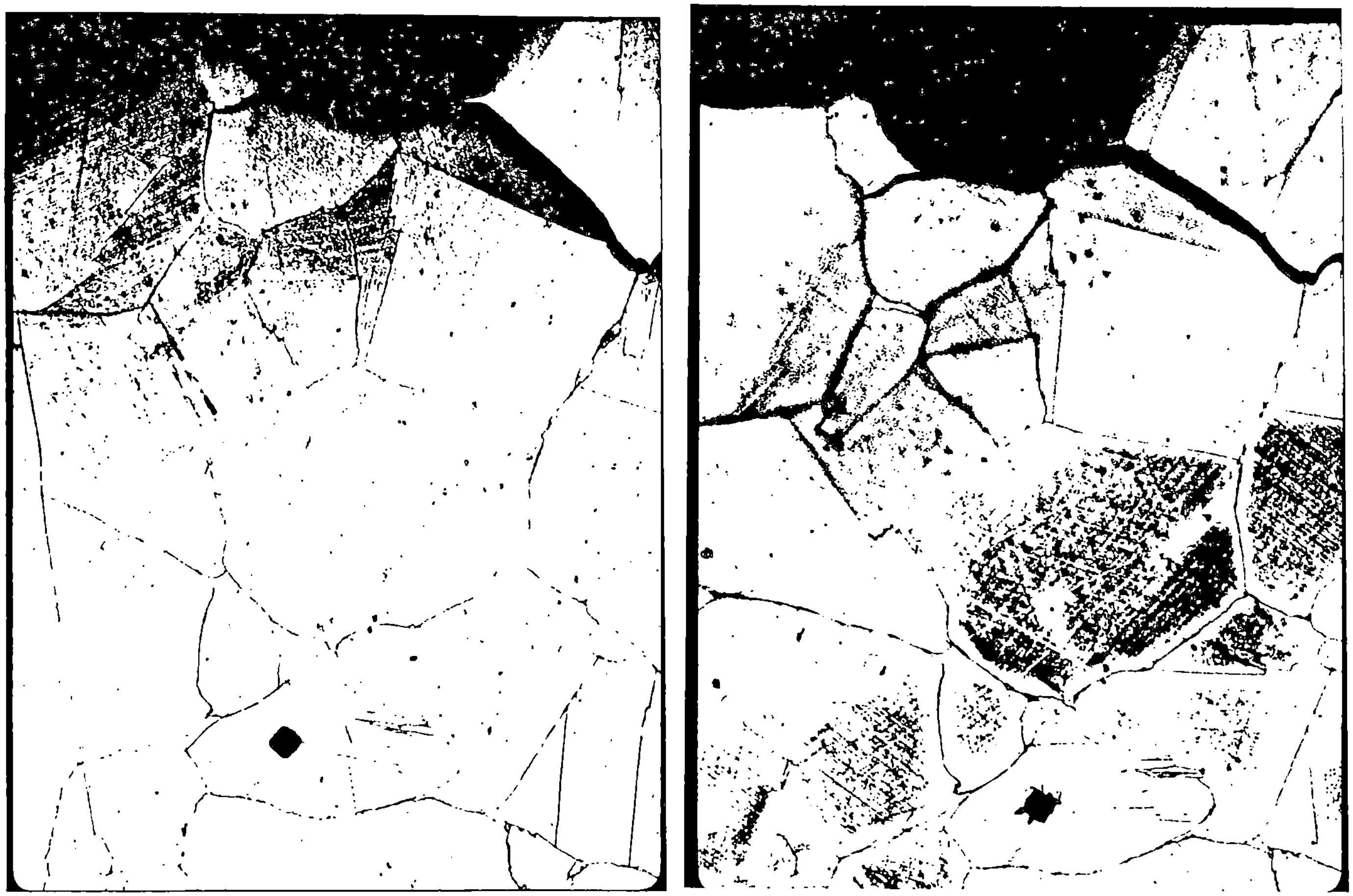
Figure 4-9. Dual Etch Metallography on Base Metal Near OD.



107438 HNO_3 75X

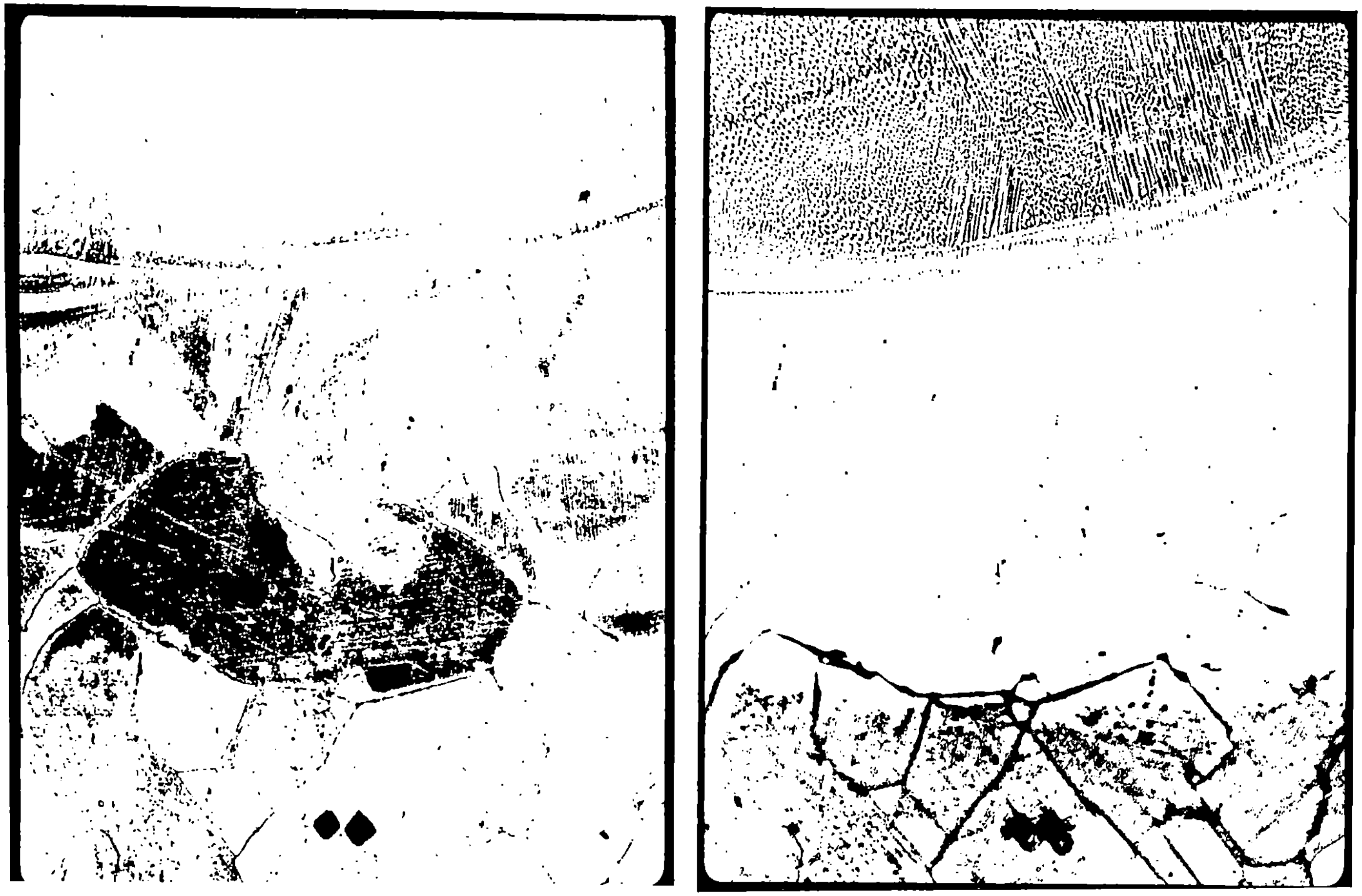
107439 H_3PO_4 75X

Figure 4-10 Dual Etch Metallography on HAZ Near ID.



107441 HNO_3 75X 107440 H_3PO_4 75X

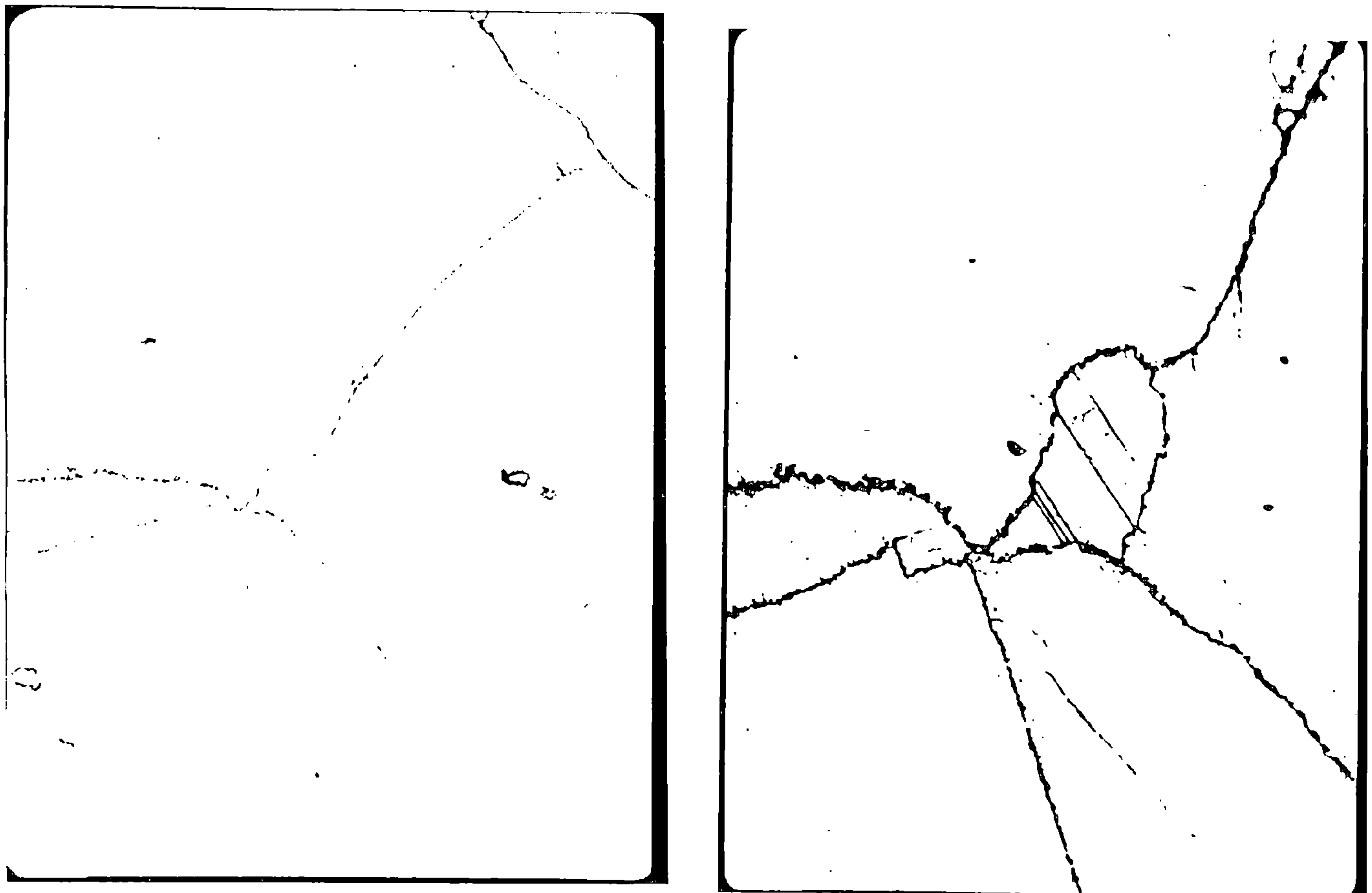
Figure 4-11. Dual Etch Metallography on HAZ at Mid-Wall.



107431 HNO_3 75X

107430 H_3PO_4 75X

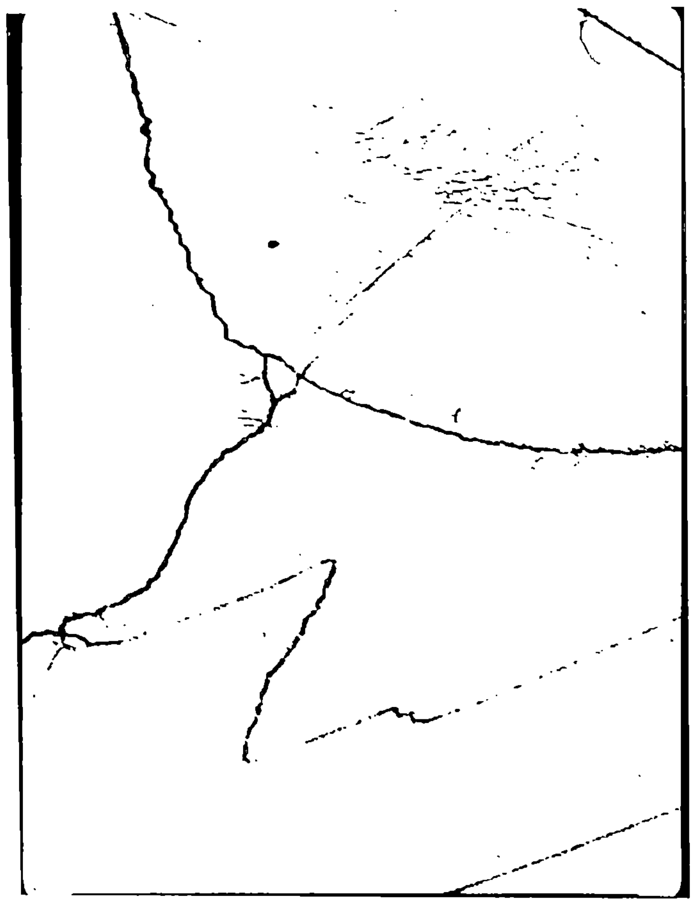
Figure 4-12. Dual Etch Metallography on HAZ near OD.



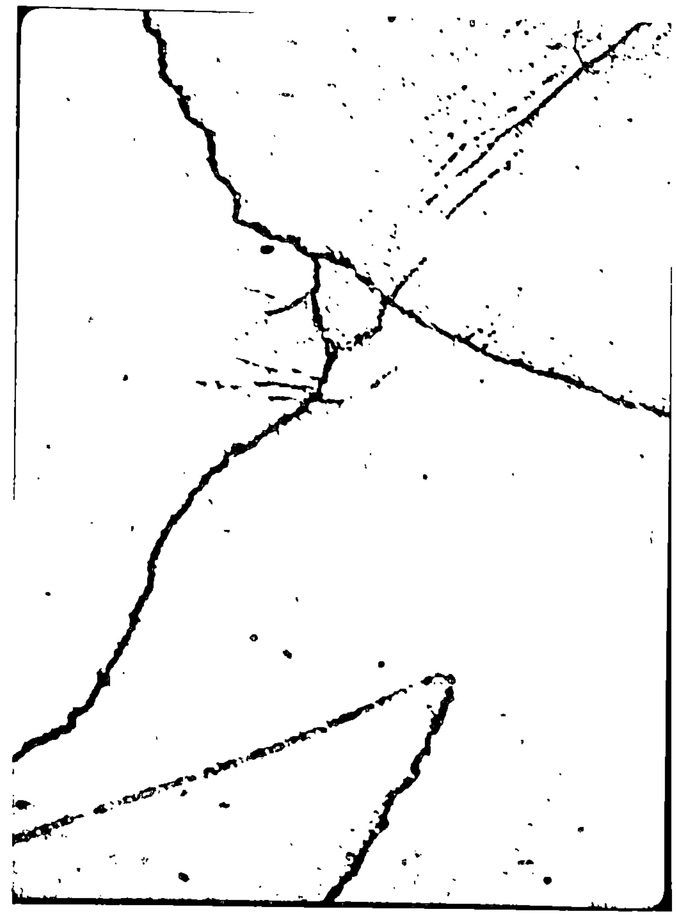
107305 500X

107300 1250X

Figure 4-13. High Magnification Micrograph of Base Metal Boundary Carbides H_3PO_4 Etch.



107298 500X

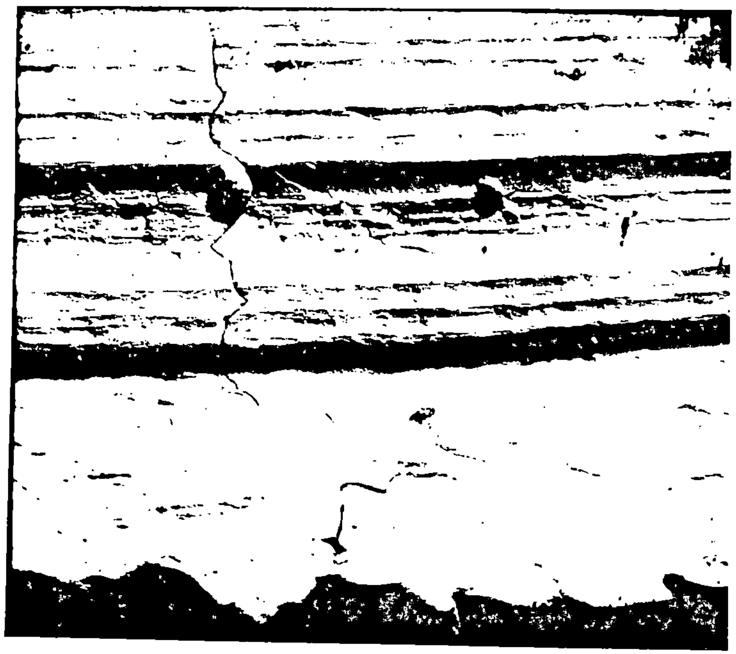


107449 1250X

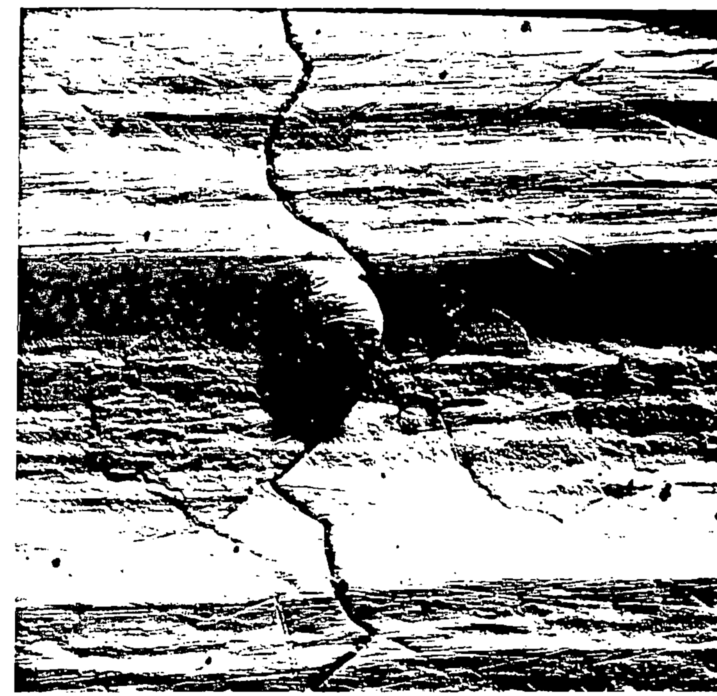
Figure 4-14. High Magnification Micrograph of HAZ Boundary Carbides H_3PO_4 Etch.

107429 50X

Figure 4-15. Polished and Etched Section of Modified Huey Test Sample.



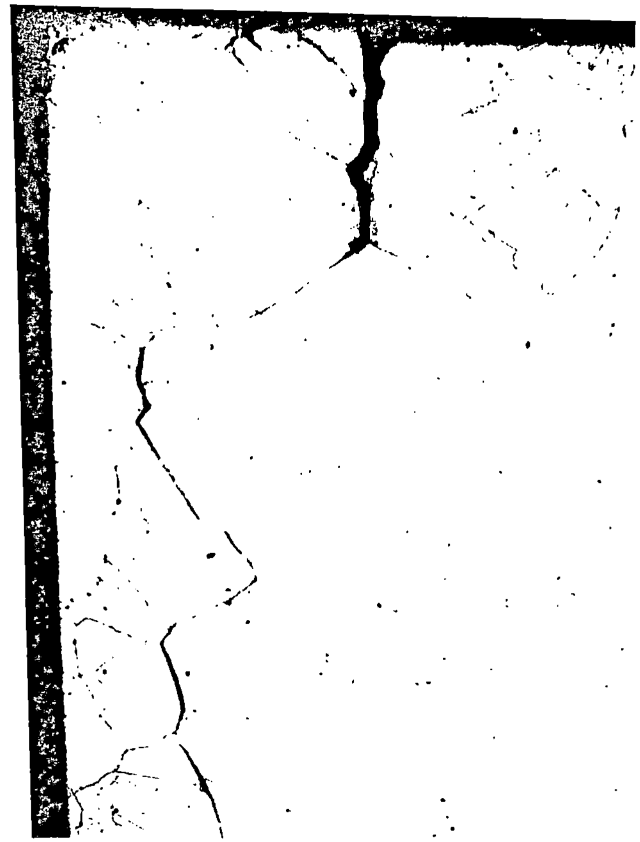
107411 20X



107414 60X

Figure 4-16. ID Surface Axial Crack.

107445 Radial View 50X



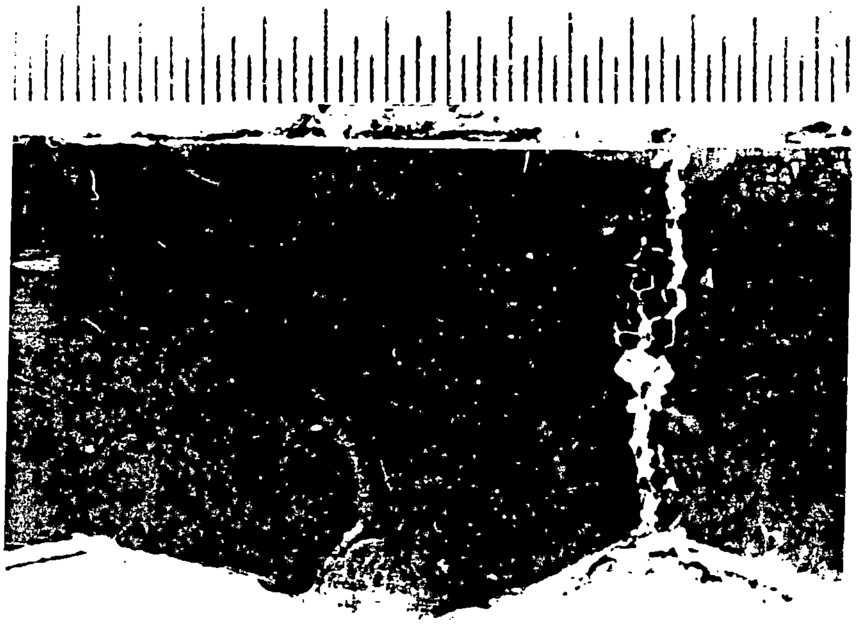
107442 Axial View 50X

Figure 4-17. View of ID Surface Axial Crack.

Section 5.0

REPAIR WELD - MOUNT NUMBER 3 SAMPLE

A metallographic mount identified as #3 was sent to ABB/CE for examination. The section includes what appears to be an ID repair weld. A low magnification SEM view of the repair weld is shown in Figure 5-1. EDS spectra were recorded in areas as noted on the micrograph in Figure 5-1. These spectra are shown in Figures 5-2 through 5-6 respectively. Table 5-1 summarizes the major elements in each of these EDS spectra. Table 5-1 shows that the repair weld has a composition between that of the original weld and the stainless steel. This difference in composition explains why this weld region etched differently than the other material.



107486 4X

107485 12X

Figure 5-1. Micrographs of Mount #3 Showing Repair Weld Region.

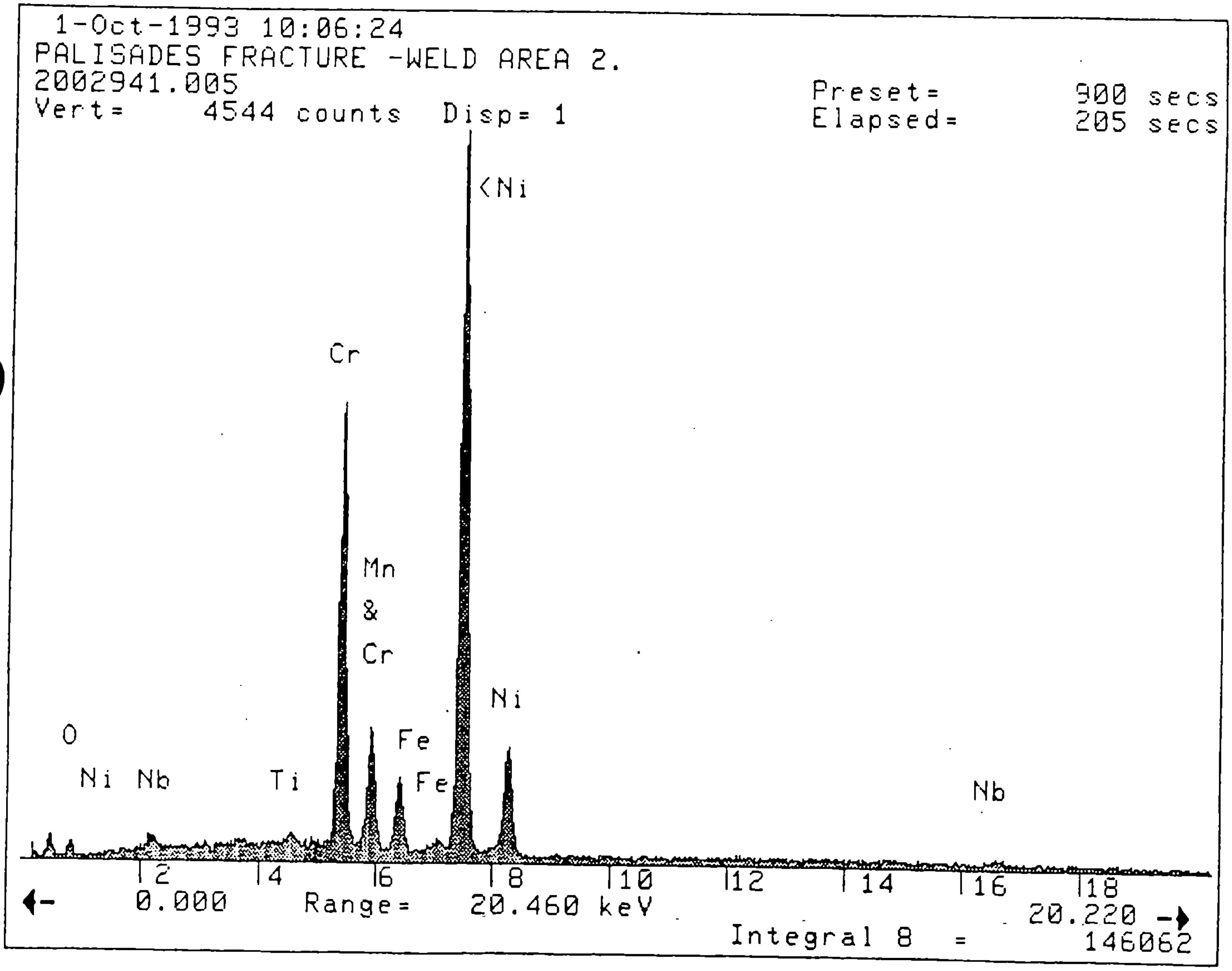


Figure 5-2. Original Weld EDS Spectra, Near ID.

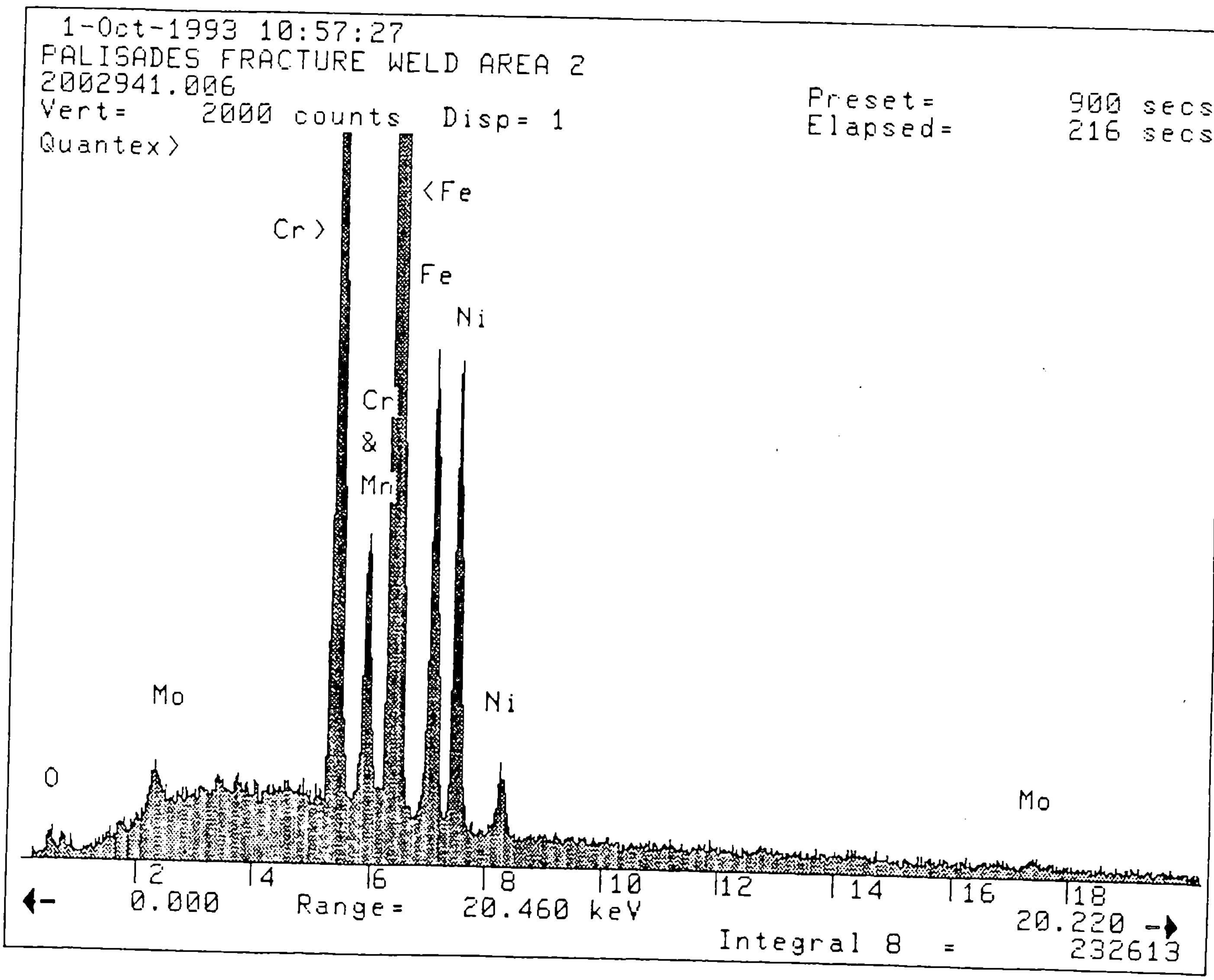


Figure 5-3. Stainless Steel EDS Spectra, Near Weld.

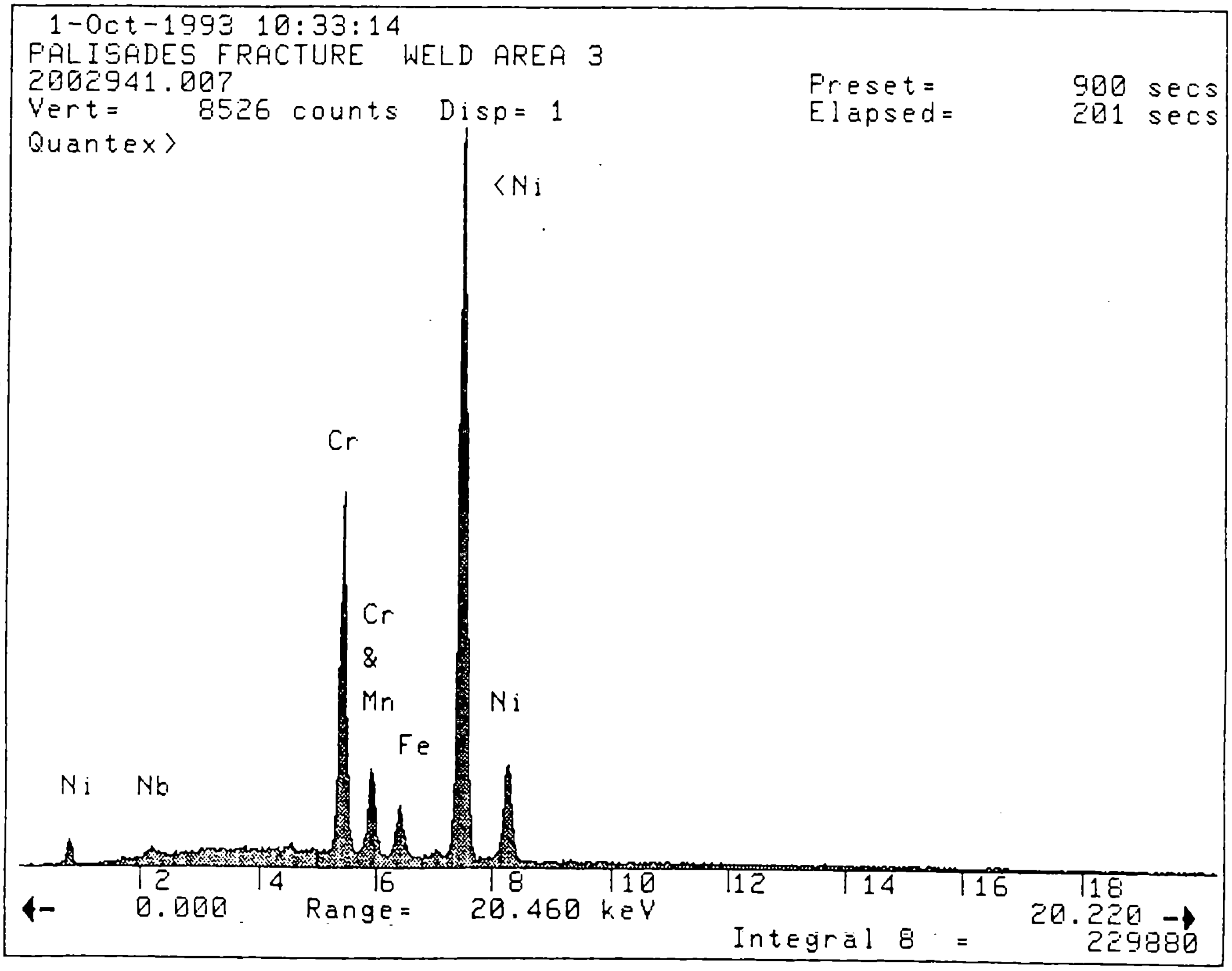


Figure 5-4. Original Weld EDS Spectra, Near Stainless Steel.

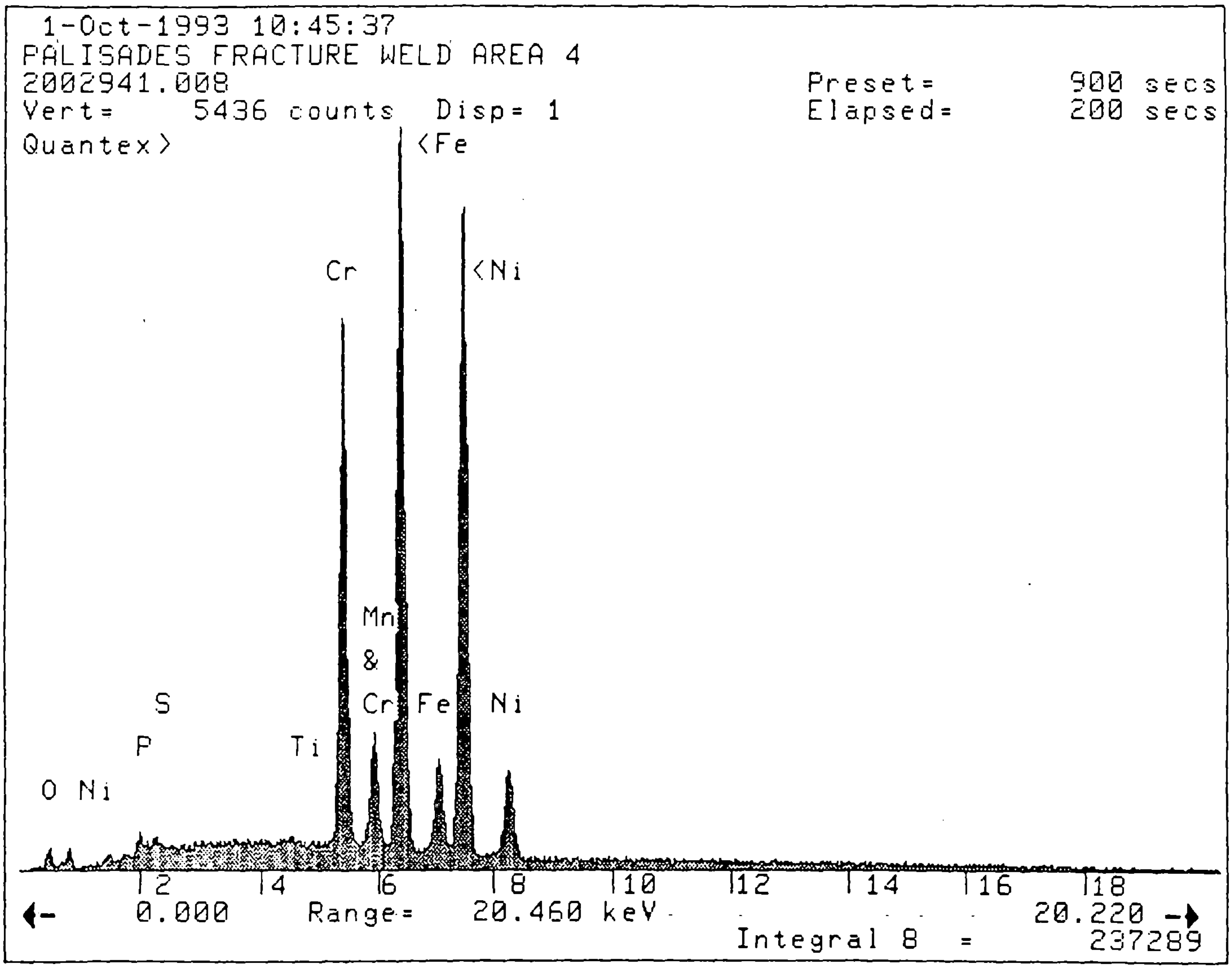


Figure 5-5. Repair Weld Near ID and Original Weld.

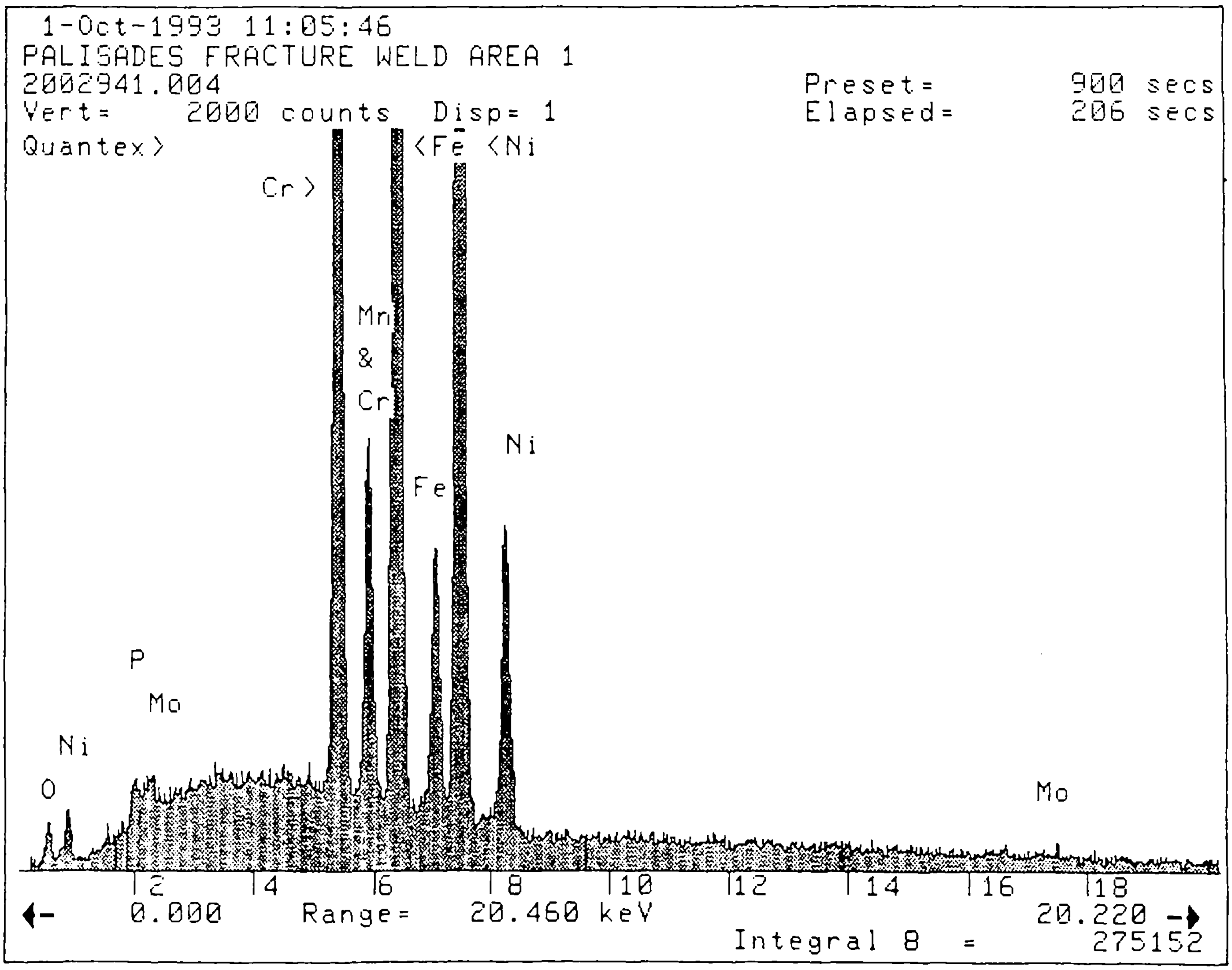


Figure 5-6. Repair Weld Near Stainless Steel.

Table 5-1

SUMMARY OF PRINCIPAL ELEMENTS FROM SEMI-QUANTITATIVE ANALYSIS OF EDS SPECTRUM - MOUNT #3

LOCATION	NICKEL	CHROMIUM	IRON
Figure 5-2 Original Weld	58.91	24.51	4.91
Figure 5-3 316 S/S	15.09	16.08	62.88
Figure 5-4 Original Weld	65.10	22.10	3.98
Figure 5-5 Repair Weld	41.93	17.54	32.38
Figure 5-6 Repair Weld	43.05	17.64	28.43

Section 6.0

DISCUSSION

In evaluating the bulk chemistry results it became evident that some form of contamination had occurred in generating the filings. Higher values than expected were recorded for manganese and sulfur. Carbon analysis results also exceeded the reported value on the CMTR for the safe-end.

To clarify this issue additional samples of the base metal were prepared and submitted to another laboratory for check analysis for carbon and manganese. These results were reported as 0.089% for carbon and 0.25% for manganese which is in reasonable agreement with the CMTR (see attachment 1).

The chemical analysis for the safe-end base metal is as expected. The results for the 4 locations analyzed in the weld indicate that a high nickel alloy filler metal was used in all cases.

The as-received fracture surface exhibited a light brown color and was very obviously an intergranular crack as evidenced by the large grains (rated as ASTM 00). By the nature of the submitted sample ABB/CE can not make any statements as to the origin of the crack (ID vs OD). Based on the crack length at the ID and OD Palisades has concluded that the failure was PWSCC.

The microhardness surveys were useful in documenting the softening that occurred in the HAZ. This is important because the crack initiated and propagated in the HAZ and not the harder base metal characterized by the 77.5 KSI yield strength on the CMTR. The resulting circumferential crack associated with the butt weld is dramatically different than in previously examined partial penetration welds of nozzles that exhibit axial cracking in the base metal and typically not in close proximity to the weld. The high values of hardness in the base metal surfaces, particularly the OD, could be due to straightening in bar form as well as nozzle machining.

The dual etch metallography performed in the HAZ and base metal indicates good correspondence. That is, there is little or no evidence of prior history "ghost" boundaries. Ghost boundaries are carbides that aligned with the grain boundaries of a previous structure. During annealing, new grain boundaries may form, but if the annealing temperature is not high enough, the carbides will not dissolve and will remain in the same position. However, in the case of the Palisades material, the annealing temperature was sufficiently high to dissolve these carbides, which then precipitated on the new grain boundaries upon cooling. As pointed out in Section 4 the grain boundary carbides are very fine but appear to be a continuous network.

Based on the attack shown in Figure 4-15 it appears that some degree of sensitization is present in the safe-end.

As pointed out in Section 4.5 a secondary crack, axial in nature, was observed to be present on the ID surface. Metallographic measurements indicated 20% penetration into the wall dimension of the safe-end.

Section 7.0

CONCLUSIONS

1. The Alloy 600 safe-end was welded to the PORV stainless line with high nickel alloy filler metal.

2. An intergranular crack was initiated and propagated in the "softened" HAZ.

3. The microstructure in the HAZ showed the presence of a fine continuous network of grain boundary carbides which is a desirable condition for PWSCC resistance.

4. Some degree of sensitization was present in the safe-end.

5. The ID repair weld, although showing dilution from the Type 316 stainless steel, was made with high nickel alloy filler metal.

ATTACHMENT 1

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CERTIFICATION

METALLURGICAL AND TESTING