Report Issued: AUG 2 6 1977

Report 411-77.55

PACIFIC GAS AND ELECTRIC COMPANY
DEPARTMENT OF ENGINEERING RESEARCH

FAILURE ANALYSIS OF CRACKED FIELD WELD NO. 212
DIABLO CANYON UNIT 1, STEAM GENERATOR 1-2
NOZZLE-TO-PIPE WELD

Prepared By:

S. G. FRIEDRICH, Engineer

S. T. IVY, Engineer

Approved By:

W. C. HAM, Sr. Metallurgical Engr.

C. J. REINBERG, Supv. Engineer

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SCOPE

This report covers the metallurgical investigation of a crack found in the pipe-to-nozzle weld of feedwater line of Steam Generator 1-2 at Diablo Canyon Power Plant. Based on the findings of this investigation, recommendations are made for modification of the welding procedures, fabrication practices, and inspection of future welds made in P-3 nozzle materials.

INTRODUCTION

On March 17, 1977, during heat-up for hot functional testing of Unit 1, a leak was discovered in the nozzle-to-pipe butt weld joining the 16-inch diameter feedwater pipe to the No. 4 nozzle of Steam Generator 1-2 (Field Weld No. 272, Line K16-555-16IV). The line temperature and pressure at this time was approximately 300°F and 90 psi, respectively. Visual observation at this time revealed an intermittant linear indication approximately 3/8-inch long running in the circumferential direction near the center of the weld. During grinding of the weld crown flush with the pipe surface the length of this linear indication increased to approximately two inches. Subsequent nondestructive examination by radiography and ultrasonics revealed a crack with a total length of approximately six inches.

As a result of the above findings, a spool piece containing a major portion of the weld, a small section of the nozzle I.D. adjacent to the weld root, and several inches of pipe were removed for analysis. Figure 1 is a sketch of the spool piece received for analysis; included is the crack path and a sketch of the shape of the crack.

FABRICATION AND SERVICE HISTORY

Material Specifications

The steam generator nozzle is fabricated of ASME SA508 Class 2 material. A copy of the original Material Test Report and a chemical analysis performed on the nozzle material adjacent to the crack are included in Appendix I. The chemical and physical properties for this material are within the limits for SA508 Class 2 material.

The feedwater line piping is fabricated from ASTM A106 Grade B material. A copy of the chemical analysis performed on this material adjacent to the crack are included in Appendix I. This analysis shows that the pipe material meets the chemical requirements of ASTM A106 Grade B.

Welding was performed using E8018 C-3 electrode. A copy of the original Certificate of Analysis for the three electrode lots used and a check analysis taken adjacent to the crack are included in Appendix I. These analyses show the material to within the chemical requirements of E8018 C-3.

Welding and Heat Treating History

Welding on Field Weld 212 was done in accordance with M. W. Kellogg Procedure 200. The weld traveller and other Q.C. documents were checked along with the temperature records for preheating and postweld heat treatment for compliance with this procedure; no deviations were noted. The weld root was placed using the tungsten inert gas method (TIG) with a consumable insert and inert gas backing. Two TIG fill passes were put in and the weld was completed using shielded metal arc weld. The weld preparation was preheated to 200°F prior to welding. Welding on FW 212 was done over a time period of several weeks; Table 1 is an outline of this welding history.

Postweld heat treatment was performed at 1150°F; metal temperatures were monitored on both the pipe and nozzle sides of the weld with a thermocouple placed several inches from the centerline of the weld. The temperature records were reviewed, and during heat-up there was an uneven heating rate between the pipe and the nozzle, resulting in a maximum temperature differential of 260°F, where the pipe was at a temperature of 680°F when the nozzle was at 420°F. This temperature differential was rectified and no further problems were encountered throughout the postweld heat treatment.

Radiography of this weld was performed after completion of welding but prior to postweld heat treatment, an acceptable practice under the governing construction code, USAS B31.1.0-1967. Review of the radiographs showed a slight density gradient in the region where the crack occurred, but it was not judged to be rejectable nor would it be interpreted as such now. If this indication in actuality is a crack, it is at the limit of detectability.

Service History

Prior to making FW 212, a cap was welded onto the feedwater nozzle of SG 1-2, and a hydro test of the steam generator was performed. Subsequently, the piping was attached and two more hydro test cycles were performed, followed by a hot functional test program. A second hot functional was underway when the leak occurred. This sequence of events is summarized in Table 1, the hot functional testing summary is in Appendix II.

During the period between the hydro test following weld completion, August 29, 1975, and the time the leak occurred, March 17, 1977, the system was filled with water under chemical control to limit corrosion or other damage to the piping or steam generator internals. The water chemistry records were reviewed and no abnormal conditions were noted.

RESULTS OF METALLURGICAL EXAMINATION

The surface of the main fracture was almost flat, originated along the edge of a weld bead, grew approximately perpendicular to the surface and contained markings that ran parallel to the original edge, Figures 2 and 3. These markings appeared to be "beachmarks" denoting positions of the crack during its growth. The fracture surface appeared to be oxidized and was dark in color near the origin edge. Using SEM, the main fracture surface was found to be oxidized, to exhibit some evidence of mechanical damage (rubbing) and, at a distance from the origin, to contain secondary cracks, Figure 4. The presence of the visual beachmarks and the secondary cracks indicate that cylic loading had a role in the generation of the fracture.

Examination of several polished cross-sections taken through the crack showed the fracture initiated in small regions of lack of fusion along the fusion zone and in small, up to 0.015-inch deep, cracks at the root of grinding scratches adjacent to the fusion zone on the nozzle side of the weld. The crack propagated through the heat-affected zone and then through the weld metal in the V-shaped section of the weld, Figure 5. The crack cross-section in the heat-affected zone was very flat and straight, indicating little ductility; once into the weld the crack tended to branch and wander, indicating a material with more ductility. The heat-affected zone in both pipe and nozzle materials was tempered martensite, the pipe material away from the weld was mixed pearlite and ferrite, and the weld material was tempered martensite. Microhardness tests in these various regions, converted to Rockwell hardness values, were as follows: nozzle, away from HAZ, R_B96; nozzle HAZ, R_C 34; weld root, R_C23; pipe base material, R_B88.

Examination of the small cracks adjacent to the main fracture, Figures 6, 7, and 8, illustrated that the cracks originate in slight depressions in the surface, grew perpendicular to the surface and at an oblique angle to the rolling direction (as revealed by the inclusion stringers), were filled with oxide, were transgranular, and exhibited some crack branching. No evidence of plastic deformation was observed. EDXA microprobes verified that the material in the cracks was probably oxide, that the base metal was carbon steel, and that the inclusion stringers were manganese sulfide, Figures 10-12.

Two small cracks were opened up for examination by impacting them at liquid nitrogen temperatures (Specimens 2 and 3). The fracture surfaces had a dark layer of oxide patches along the outer edge, Figure 9, and were in close proximity to weld beads. Each crack was actually the result of the coalescence of many cracks each having its own origin. The origin edges of the fracture surfaces were covered with a relatively uniform oxide layer. The oxide layer was present all the way to the tip of the prior existing crack.

Using the plastic/carbon replica technique, the details of the main fracture surface were examined in the TEM. The surface was again found to be completely oxidized; however, in some areas, the oxide formed parallel ridges which could possibly suggest prior fatigue striations. In some areas, large block-like oxide growth was found.

Extraction replicas were examined in the TEM to obtain the diffraction pattern of the oxide. The patterns obtained were analyzed, Appendix II, and found to be composed of α-Fe_2O_3. This oxide forms at about 300°C (570°F).

CONCLUSIONS

The characteristics of the small cracks and the major fracture surface are similar in regularity, orientation, oxidation, and degree of crack branching. The oxide extended to the tip of the advancing cracks indicating that oxidation and/or corrosion was an inherent part of the crack growth process. The characteristics of the fracture process; i.e., transgranular, oxidized, no plastic deformation, with some crack branching, indicated that the crack growth mode was either corrosion fatigue or thermal fatigue.

The oxide resulting from corrosion fatigue would probably be hydrated and a lower temperature form than found on the crack surfaces in this study. Based on this and the closely regulated water purity, it is believed that it is more likely that the cracks in the feedwater line of Diablo Canyon Unit 1 steam generator resulted from thermal fatigue. The cracks initiated in elongated depressions in the surface of the steel which are believed to be grinding marks, and apparently acted as local stress risers, and at minor regions of lack of fusion in the weld root.

It is believed that small cracks initiated on the I.D. of the nozzle, weld, and pipe during the thermal cycling that occurred during preheating. These small cracks originated at convenient stress risers such as grinding scratches and regions of lack of fusion and weld bead, rollover. At the time of acceptance radiography, prior to postweld heat treatment, these cracks were below the limits of detectability for radiography. Upon heat-up for the postweld heat treatment thermal stresses from the uneven heat-up between the pipe side and nozzle side of the weld caused several of these small cracks to link up and grow to some substantial size, most likely through the heat-affected zone (HAZ) and into the weld metal. The HAZ at this time, prior to postweld heat treatment (PWHT), would have consisted of untempered martensite, and have a hardness of about R_c45. The HAZ would have quite low ductility in this condition and easily propagate an existing crack when subjected to differential thermal stresses. Once this crack had propagated to a substantial size during PWHT it propagated to failure by fatigue as a result of subsequent hydro test and hot functional test stresses.

Since postweld heat treatment of the weld has tempered the heat-affected zone, this high hardness, low ductility condition no longer exists. The heat affected-zone now has a hardness of R_c 30-35, and would not be expected to be subject to the rapid crack growth that is believed to have occurred during PWHT.

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RECOMMENDATIONS

Based on the findings of this investigation, following recommendations are made for future welds made in P-3 materials:

1. Specify a minimum preheat temperature of 250°F; a maximum interpass temperature of 550°F should also be specified.

2. Maintain the preheat temperature throughout the weld and until postweld heat treatment can be initiated. If a long delay during welding or between welding and PWHT is unavoidable, maintain the preheat for at least eight hours after welding stops, and then slowly cool to room temperature.

3. Care should be exercised in avoiding large temperature differentials during preheating and postweld heat treatment.

4. Final radiography should be done after postweld heat treatment.

TABLE 1

Fabrication and Service History (Summary)

1-14-73	Preheat to attach lugs
1-14-73	Preheat to weld cap
1-15-73	Preheat to weld cap
2-19-73	Hydro, 1356# at 106°F
4-8-74	Preheat to remove cap
4-9-74	Preheat to remove cap
5-18-74	Preheat for nozzle-pipe weld
5-21-74	Preheat for nozzle-pipe weld
5-22-74	Preheat for nozzle-pipe weld
5-23-74	Preheat for nozzle-pipe weld
5-24-74	Preheat for nozzle-pipe weld
6-15-74	Radiograph finished weld
6-24-74	PWHT weld
[illegible]8-74	PWHT adjacent weld (15" away)
8-29-75	Second hydro, 1320# at 88°F
8-29-75	Third hydro, 1356 at 88°F
12-13-75 to 2-10-76	First hot functional
3-16-77	Second hot functional

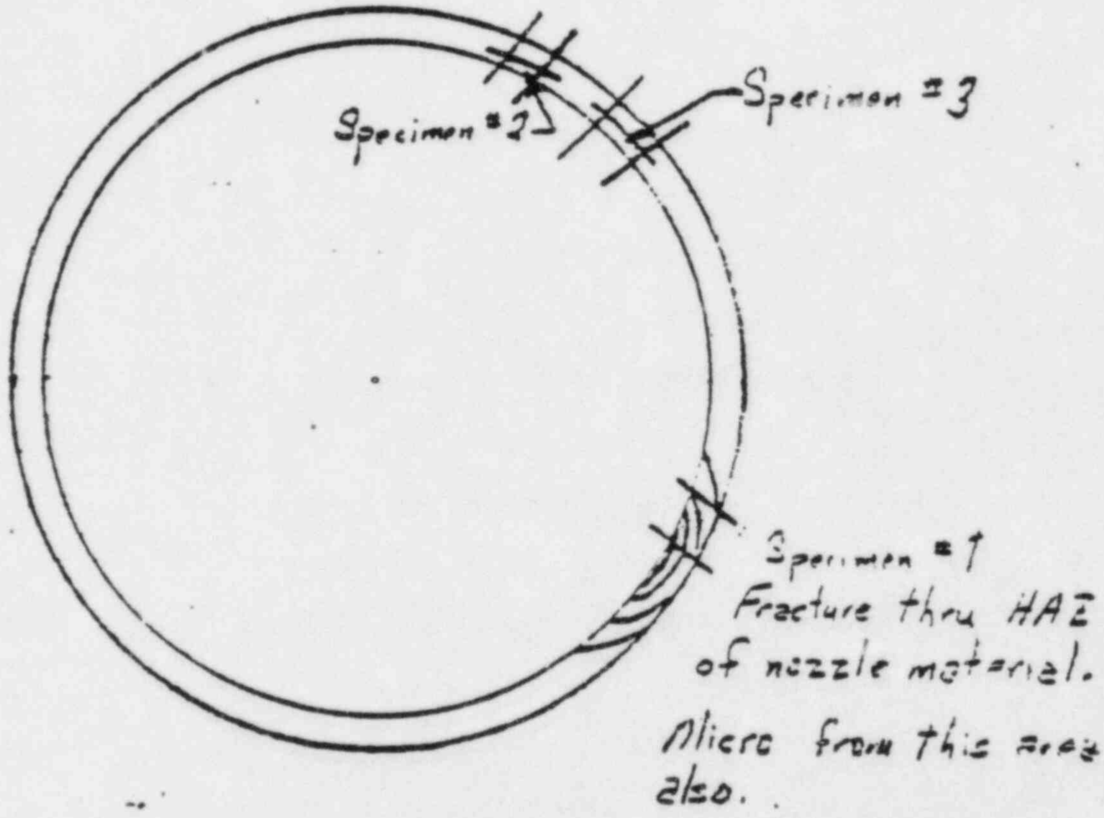


Figure 1. Schematic diagram of failed nozzle illustrating the locations from which samples were removed.

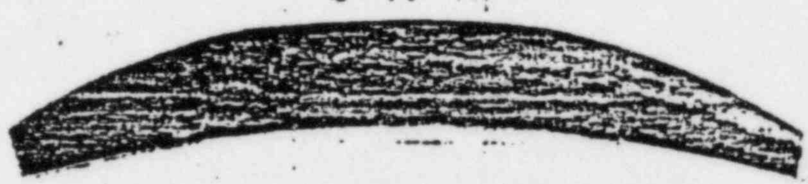
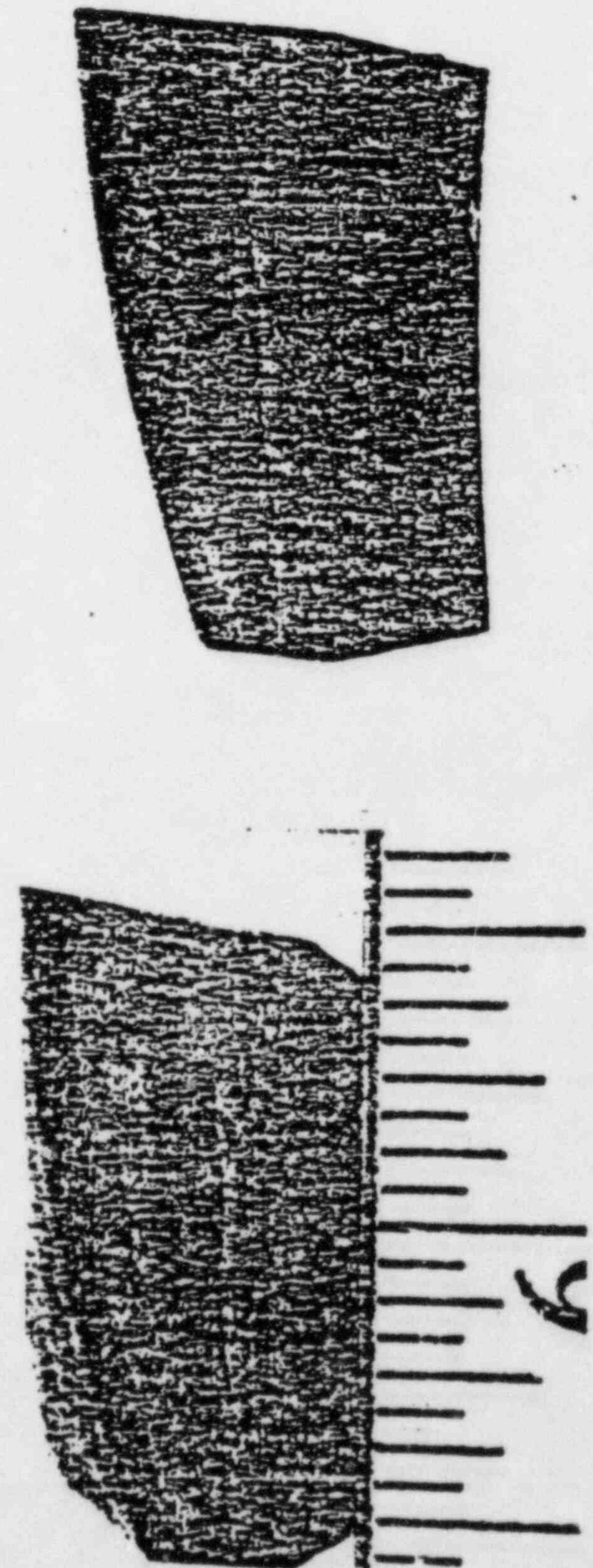


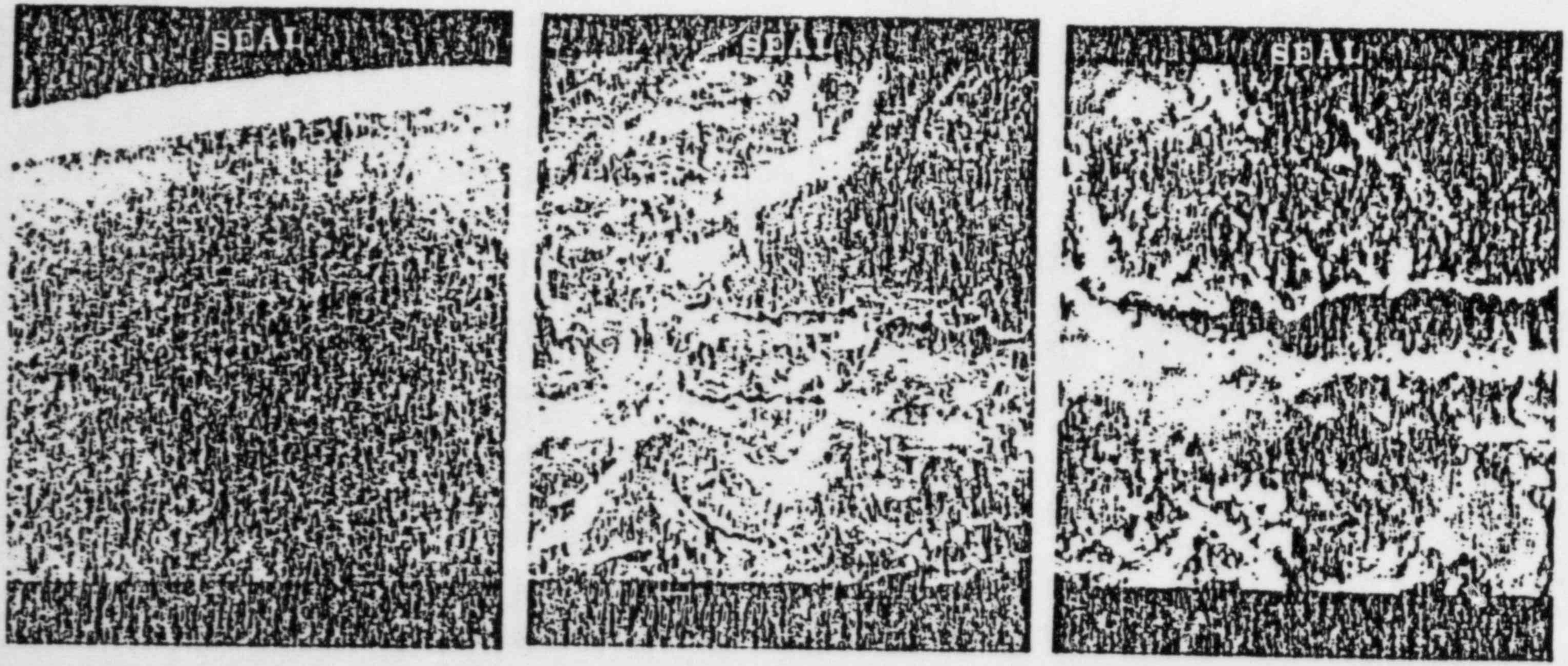
Figure 2. Overall view of fracture surface.



a.

b.

Figure 3 Specimen #1, showing fracture surface with parallel markings originating along one side of weld bead; 3X.



a. b. c.

Figure 4. Surface of main fracture which was in the heat affected zone (HAZ) of the nozzle, Specimen #1, showing oxidized surface with crack branching. a. 20X (50595). b. 500X (50594). c. 2000X.

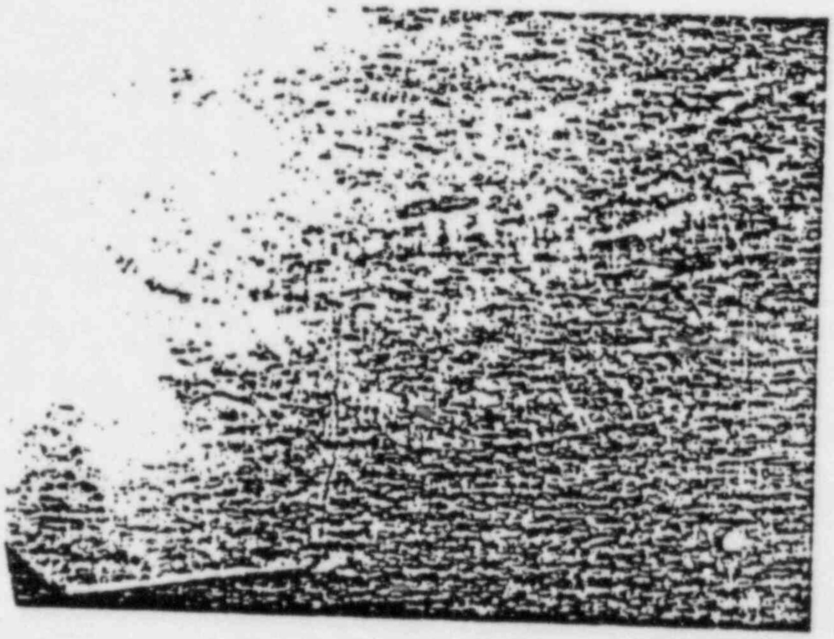
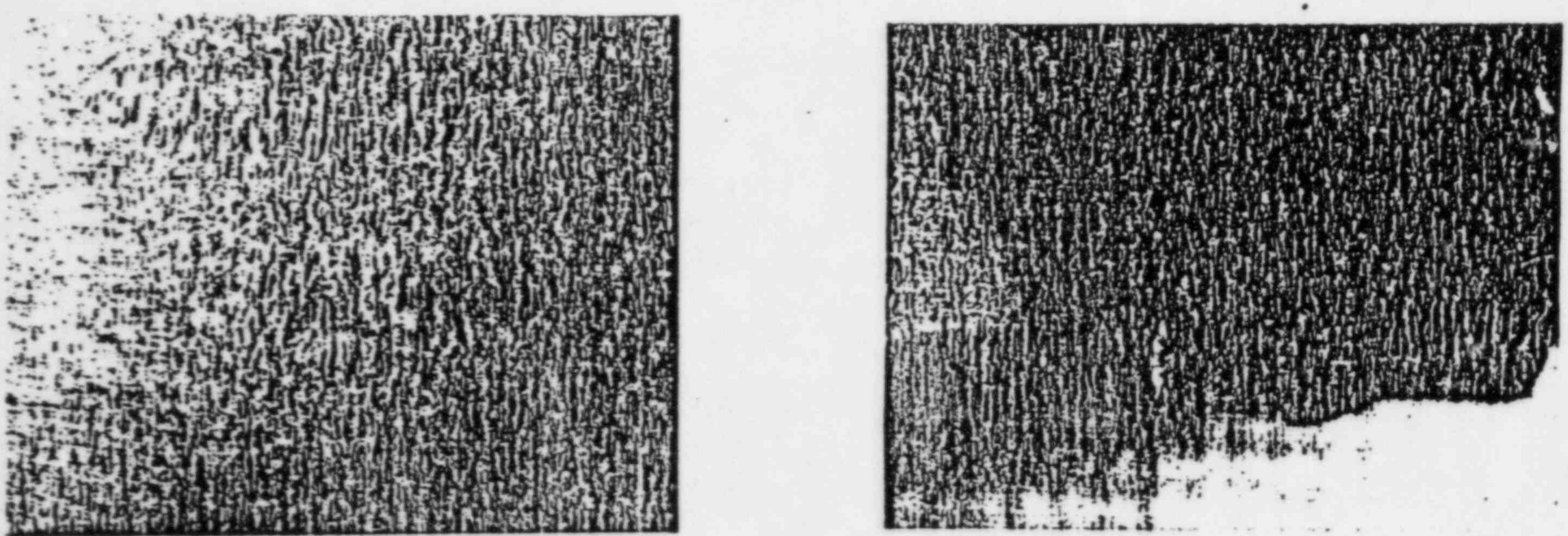


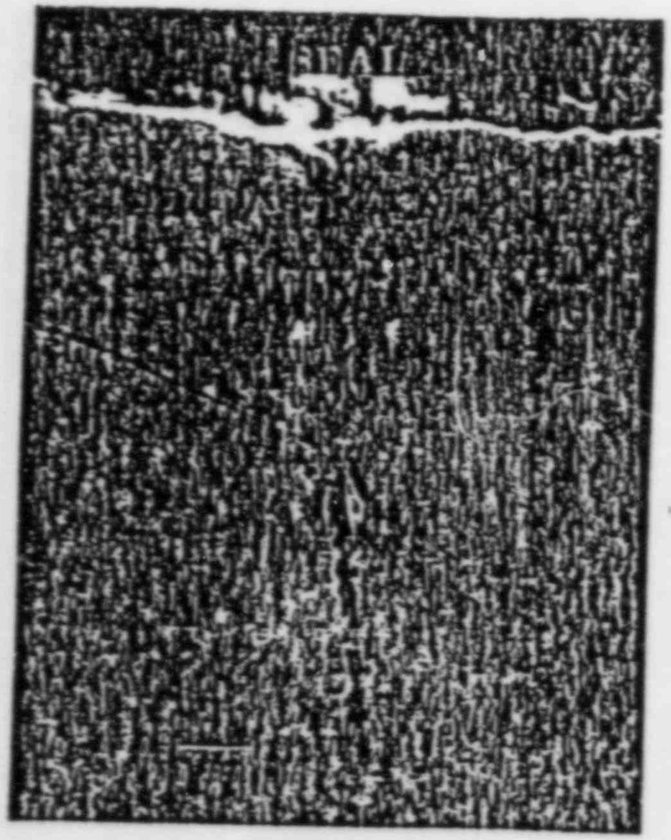
Figure 5. Polished cross section of the main fracture. The pipe is on the bottom left, the weld root is bottom center and the nozzle is bottom right. The bottom of the picture is the pipe I.D. The small bright dots are micro hardness indentations. 7 x magnification.



a. b.

Figure 6. Cross section of Specimen #3, Figure 1, which shows small secondary cracks similar to those noted adjacent to the main fracture. The tilted view shows the coincidence of the cracks with grinding marks on the pipe and nozzle I. D., as well as in the unground weld.

Figure 7. Polished cross section from main fracture area showing a crack, filled with oxide, with crack branching and sulfide inclusion stringers; 450X.



a.

b.

Figure 8. Details of polished cross section shown in Figure 7 a. 1000X. (51136). b. 5000X (51138).

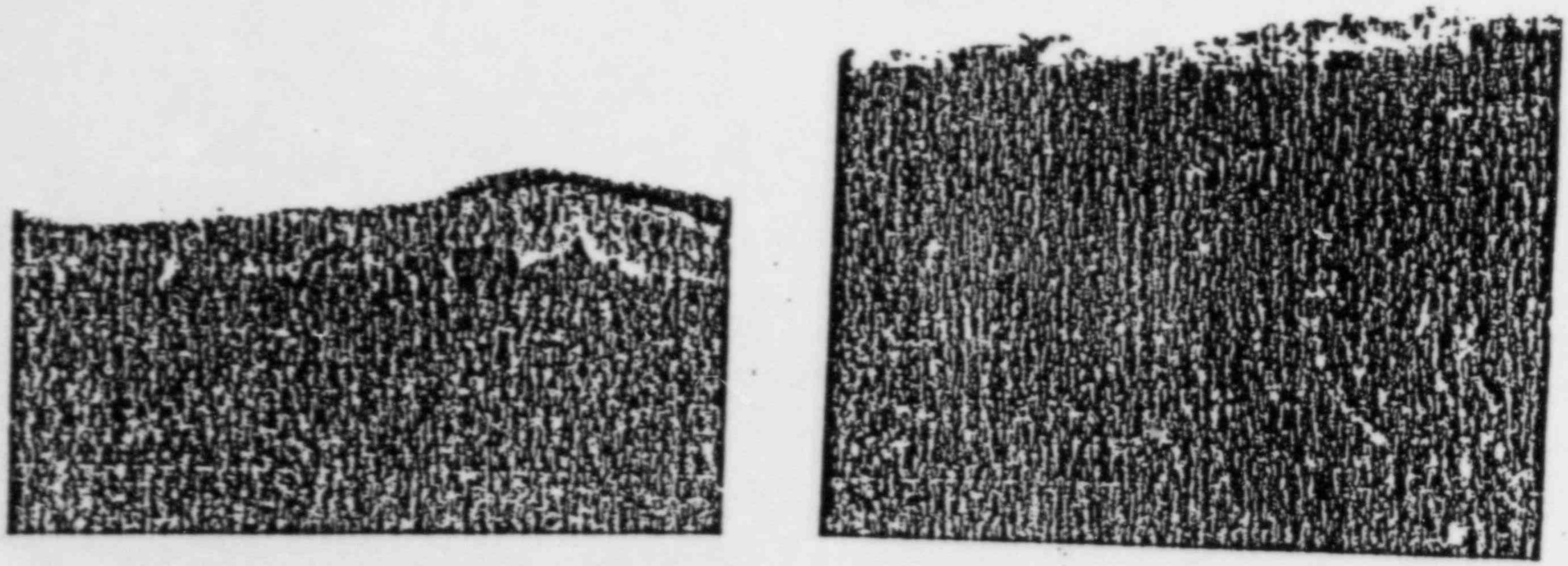


Figure 9. Opened crack along weldment on Specimen 2 showing several fracture plateaus indicative of multiple cracks and multiple origins. a. 3X. b. 12X.

Figure 10. EDXA microprobr spectrum obtained from steel matrix in Figure 8.

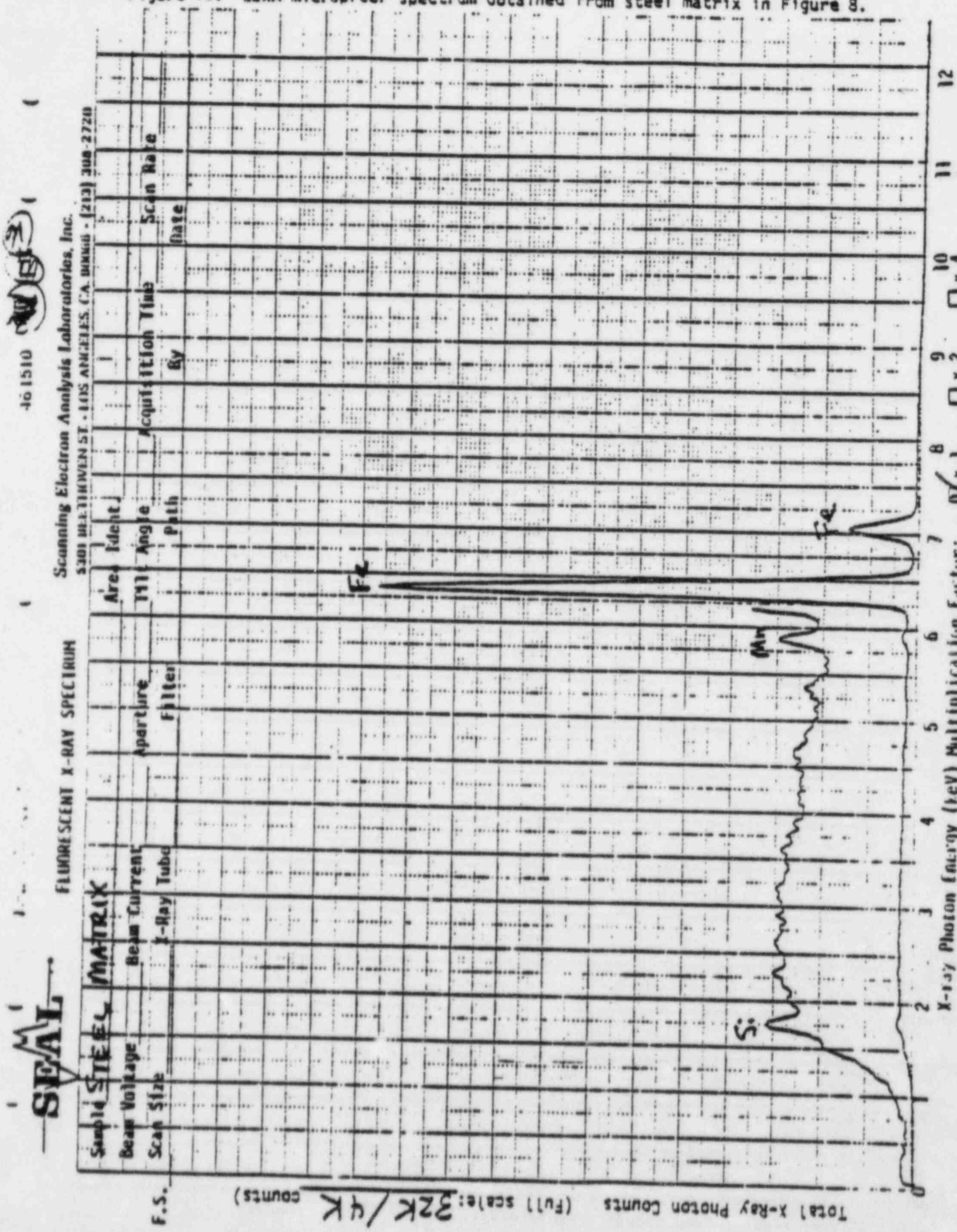


Figure 11. EDXA microprobe spectrum obtained from oxide in crack in Figure 8.

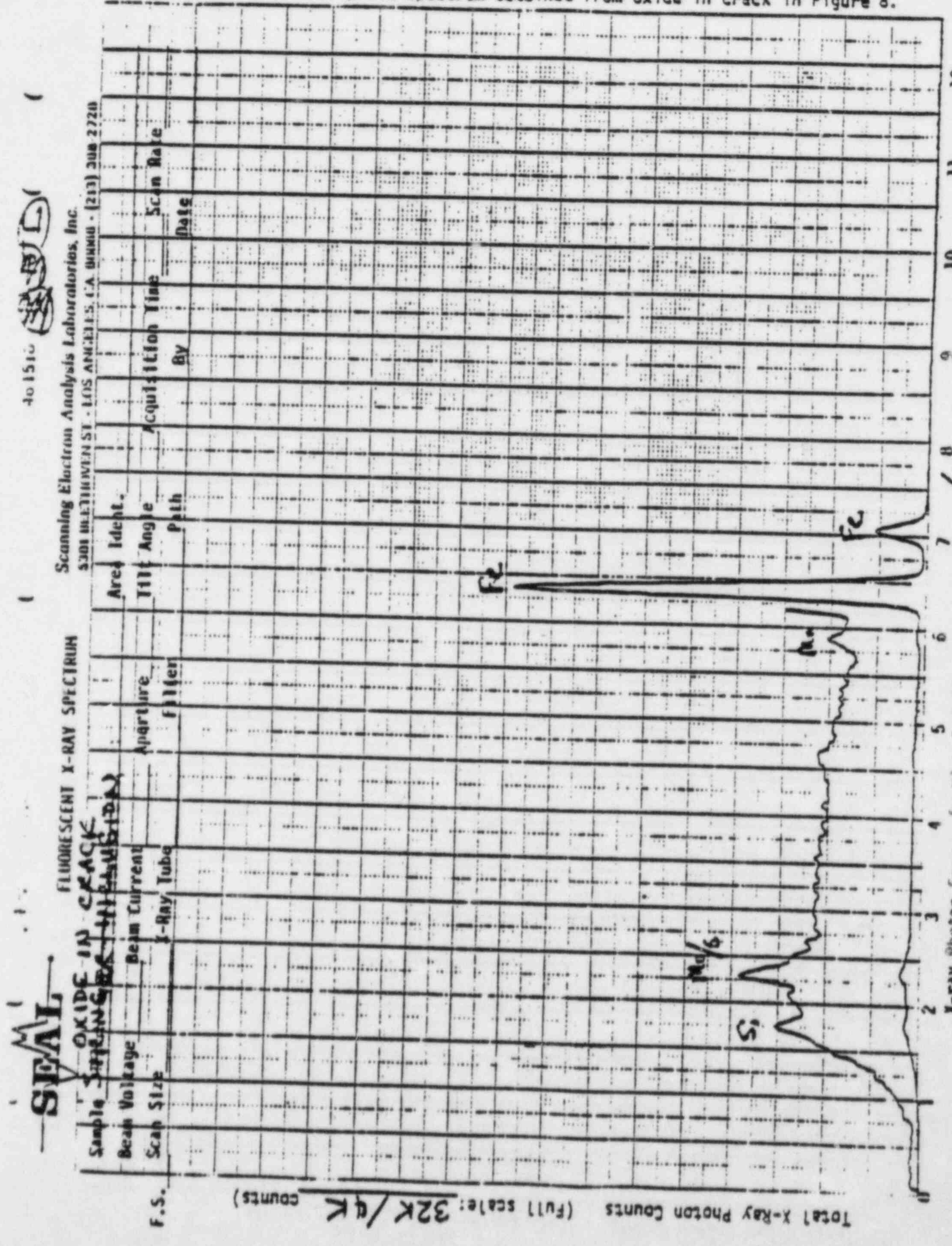
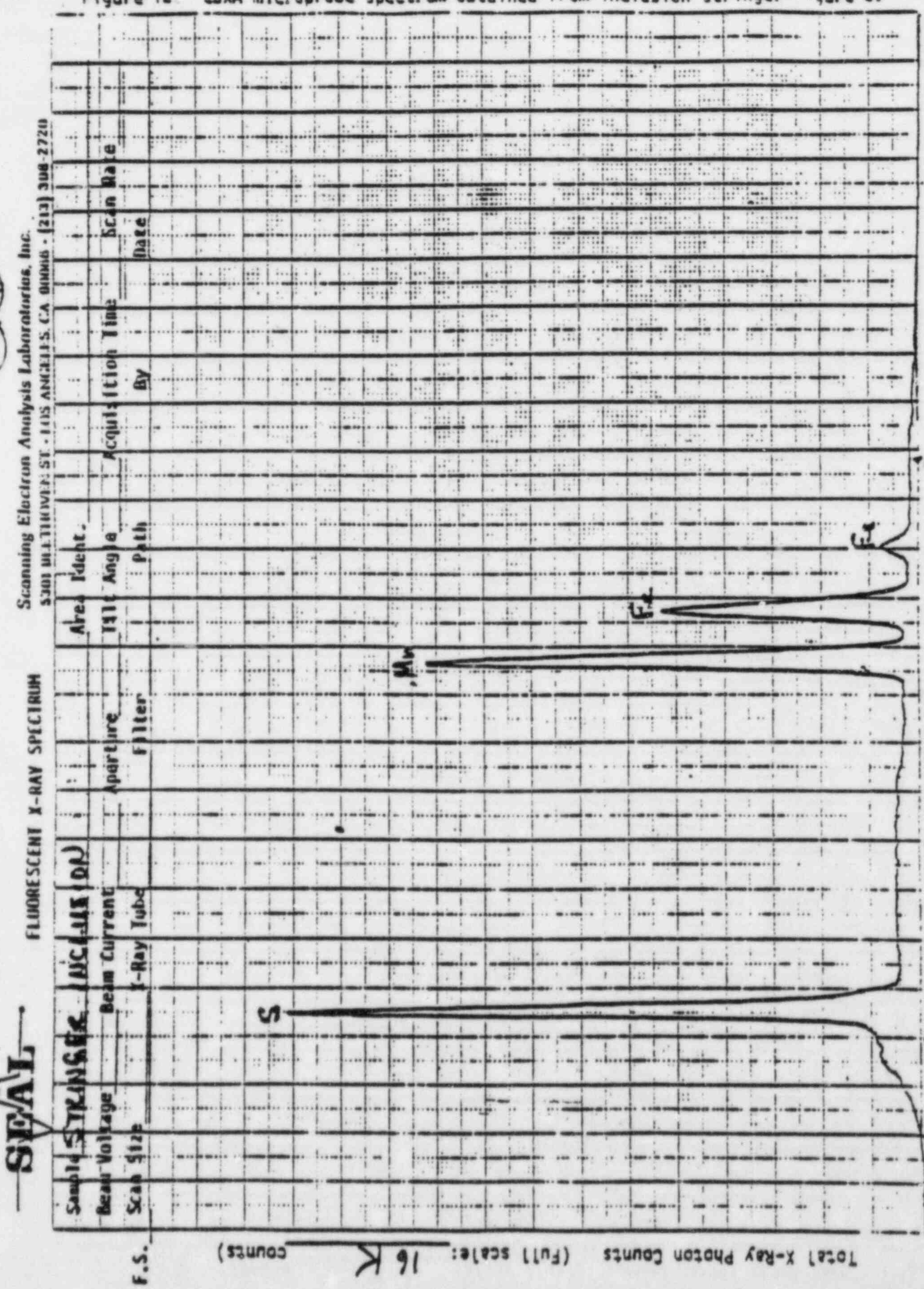


Figure 12 EDXA microprobe spectrum obtained from inclusion stringer Figure 8.



APPENDIX I

Material Specifications and Welding Procedure

411-77.55

Boonty Forge & Foundry Inc.

MATERIAL TEST REPORT

S.O. No. ______

Purchaser Westinghouse Electric Corp.

Distributor C.I. Grais Co, Inc.

DATE June 20, 1968

Purchaser's Order No. 54-S-1048-E90

Distributor's Order No. ______

ITEM NO.	QTY.	PRODUCT	SPEC.	HEAT OR CODE NO.	FORGING NO.	HEAT TREATMENT	PCR. CHARTS ATTACHED YES	NO
1	1	14.75" I.D. Insert Stud Feedwater Nozzles per/Dwg. 870C217 T-00784	SA508-2	Q2Q3VW	401R4	1650°F± 25°F.1Hr/in Air Cooled. 1560°F± 25°F.1Hr/in Water Quench 1290°F± 25°F.1Hr/in Air Cooled. 1560°F± 25°F.1Hr/in Water Quench 1290°F± 25°F.1Hr/in Air Cooled. Tests Stress Relieved At: 1125°F± 25°F. For 20 Hours.		X

CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES

FORGING NO.	HEAT NO.	C	MN	P	S	SI	CR	NI	MO	V			NDT REPORTS ATTACHED U.T.	M.P.	D.P.	REMARKS
401R4	Q2Q3VW	.21	.79	.012	.012	.27	.34	.80	.68	.05	Ladle		X	X		
		.209	.79	.005	.015	.29	.37	.80	.57	.04	Check					

FORGING NO.	HEAT NO.	TEST TEMP.	TENSILE PSI x 1000	YIELD PSI x 1000	ELONG. % in 2"	R.A. %	B.H.N.	(V-Notch at + 10° F.) IMPACT TESTS (Keyhole @) ENERGY (ft-lbs)	LATERAL EXP. (in.)	% SHEAR
401R4	Q2Q3VW	Room Temp.								
		0°	93.000	72.500	21.5	64.9		92-109-114	.067-.078-.080	80-90-90
		180°	93.100	73.400	21.5	60.9		108-104-103	.074-.076-.073	85-90-85

Guy de la Rigaudiere

We hereby certify the above results to be correct as contained in the records of the Company

Report 411-77.55

417

CHEMETRON CORPORATION

WELDING PRODUCTS DIVISION

Certificate of Analysis

M. W. Kellogg Co.
c/o Pacific Gas & Elect. Co.
Daiblo Canyon Power Plant
Avila Beach, California 93424

Customer Order No. N/A

Order No. 62853

Shipped 6-6-73

This material conforms to Specification AWS A 5.5-69
Test No. 415
X-Ray Satisfactory
F-7177-1269 Item A

Type E 8018 C-3

Trade Name:	Atom Arc 8018
Diameter Size:	1/8"
	1,000 lb.
Lot Number:	C315C3AD
Heat Number:	402K9921
Carbon	.05
Manganese	1.01
Chromium	Nil
Nickel	.96
Silicon	.58
Columbium	
Tantalum	
Molybdenum	.12
Tungsten	
Copper	
Titanium	
Phosphorus	.017
Sulphur	.018
Vanadium	.02
Iron	
Ferrite	

Moisture @ 1800°F. 0.2%

Concentricity 3%

Type Steel A-285

Test No.	Full	Split	Volts	Amps
Tensile & Impacts	1	6	22	140

Test Results:	AS Welded
Yield	76,400
Tensile	87,500
Elongation	31%
Red. of Area	76.7%

Charpy V-Notch Impacts Tested @ -40°F.

Impacts	79
Impacts	84
Impacts	87

APPROVED
M. W. KELLOGG
Q. A.
P.G.&E. Diablo Canyon Project
TW 6-27-73
INITIALS

State of Penna.) SS
County of York)

Subscribed and sworn to before me this 22nd day of June 19 73

[signature]
Notary Public

My commission expires: 4-12-76

The undersigned certifies that this report is correct and that no significant change has been made in any of the elements described in the qualification approval.

CHEMETRON CORPORATION
WELDING PRODUCTS DIVISION

BY [signature]
R. J. Stallman

Report 411-77.55

(520)

CHEMETRON CORPORATION
WELDING PRODUCTS DIVISION

Certificate of Analysis

M. W. Kellogg Company
c/o Pacific Gas & Electric
Power Plant
7 Miles N. of Avila Beach
Avila Beach, California 93424
7177-1505

Customer Order No. 6520

Order No. 65365

Shipped 9-21-73

This material conforms to Specification AWS A 5.5-69
Test No. 650
X-Ray Satisfactory

Type E 8018-C3

Trade Name: Atom Arc 8018
Diameter Size: 1/8"
400 lb.
Lot Number: B328C3AD
Heat Number: 627233

Carbon	.05
Manganese	.93
Chromium	.05
Nickel	1.07
Silicon	.40
Columbium	
Tantalum	
Molybdenum	.15
Tungsten	
Copper	
Titanium	
Phosphorus	.014
Sulphur	.022
Vanadium	.02
Iron	
Ferrite	

Moisture @ 1800°F. 0.2%
Concentricity 3%
Type Steel A-285

Test No.	Full	Split	Volts	Amps
Tensile & Impacts	1	6	22	130

Test Results: As Welded

Yield	72,400
Tensile	86,000
Elongation	31%
Red. of Area	75.0%

Charpy V-Notch Impacts Tested @ -40°F

Impacts	76
Impacts	77
Impacts	78

Fillets: OK Vertical 1 Overhead

APPROVED
M. W. KELLOGG
Q. A.
P.G.&E. Diablo Canyon Project
MW 10-3-73
INITIALS

State of Penna.)
County of York) SS

Subscribed and sworn to before me this 25th day of Sept. 1973

SEAL [signature]
Notary Public

My commission expires: 4-12-76

The undersigned certifies that this report is correct and that no significant change has been made in any of the elements described in the qualification approval.

CHEMETRON CORPORATION
WELDING PRODUCTS DIVISION

BY [signature]

Report 411-77.55 (979)

CHEMETRON CORPORATION

WELDING PRODUCTS DIVISION

Certificate of Analysis

M. W. Kellogg Co.
c/o Pacific Gas & Electric
Diablo Canyon Power Plant
Mark: PO F7177-2373
7 Miles North of
Avila Beach, California

Customer Order No. F 7177-2373

Order No. 78322

Shipped 2-20-75

This material conforms to Specification AWS A 5.5-69 & M. W. Kellogg Spec. B31.7 SFA 5.5 Class I1

Test No. 558

X-Ray Satisfactory

Type E 8018-C3

Trade Name:	Atom Arc 8018
Diameter Size:	3/32" 200 lb.
Lot Number:	L416F3AC
Heat Number:	640912
Carbon	.04
Manganese	.75
Chromium	.03
Nickel	.91
Silicon	.20
Columbium	
Tantalum	
Molybdenum	.04
Tungsten	
Copper	.03
Titanium	
Phosphorus	.016
Sulphur	.015
Vanadium	.02
Iron	
Ferrite	

Moisture @ 1800°F. 0.2%
Concentricity 4%
Type Steel A-285

Test No.	Full	Split	Volts	Amps
Tensiles & Impacts	1	7	21	140

Test Results:	AS Welded	Stress Relieved 8 hrs. @ 1125°F.
Yield	72,100	68,500
Tensile	84,500	82,100
Elongation	30%	32%
Red. of Area	77.5%	79%

Charpy V-Notch Impacts Tested @ -20°F.

Impacts	96-109-110-113-117	85-99-100-10[illegible]-
Lat.Exp.	73-76-83-79-77	71-84-79-78-7
% Shear	90-85-90-85-90	75-70-80-80-7.

Fillets: OK Vertical 1 Overhead 1

State of Penna.) SS
County of York)

Subscribed and sworn to before me this 25th day of Feb. 1975

APPROVED
M. W. KELLOGG
Q. A.
P.G.&E. Diablo Canyon Project
3-18-75

The undersigned certifies that this report is correct and that no significant change has been made in any of the elements described in the qualification approval.

CHEMETRON CORPORATION
WELDING PRODUCTS DIVISION

SEAL [signature]
Notary Public

My commission expires: 8-21-78

BY [signature]
R.W. Boyer

LABORATORY CERTIFICATE

Anamet Laboratories, Inc.

ANALYTICAL
CHEMICAL
METALLURGICAL
HIGH TEMPERATURE
GAS AND PRESSURE
PHYSICAL TESTING

May 25, 1977

LABORATORY NUMBER: 577.329 P.O. No. LO-879806

SAMPLE: One (1) Sample for Chemical Analysis

MARK: P-12 B
DCPP #1 Steam Generator
Nozzle Failure Analysis

DATE SUBMITTED: May 24, 1977

REPORT TO: Pacific Gas & Electric Company
3400 Crow Canyon Road
San Ramon, California 94583
Attn: Mr. Steve Ivy

CHEMICAL ANALYSIS

			Requirements A-508 Cl. 2 Min.	Max.
Carbon	(C)	0.23%	-	0.27%
Chromium	(Cr)	0.40%	0.25%	0.45%
Manganese	(Mn)	0.81%	0.50%	0.90%
Molybdenum	(Mo)	0.58%	0.55%	0.70%
Nickel	(Ni)	0.80%	0.50%	0.90%
Phosphorus	(P)	0.009%	-	0.025%
Silicon	(Si)	0.28%	0.15%	0.35%
Sulfur	(S)	0.012%	-	0.025%
Vanadium	(V)	0.05%	-	0.05%

Respectfully submitted,

ANAMET LABORATORIES, INC.

By ______________________
Siegfried Otto
Manager, Testing

3c
jm

29

LABORATORY CERTIFICATE

Report 4'1-77.55

Anamet Laboratories, Inc.

ANALYTICAL
CHEMICAL
METALLURGICAL
HIGH TEMPERATURE
APPLIED RESEARCH
PHYSICAL TESTING

May 25, 1977

LABORATORY NUMBER:	577.329 A	P.O. No. LO-879
SAMPLE:	One (1) Sample for Chemical Analysis	
MARK:	P-1 DCPP #1 Steam Generator Nozzle Failure Analysis	
DATE SUBMITTED:	May 24, 1977	
REPORT TO:	Pacific Gas & Electric Company 3400 Crow Canyon Road San Ramon, California 94583 Attn: Mr. Steve Ivy	

CHEMICAL ANALYSIS

			Requirements A-106 Gr. B Min.	Max.
Aluminum	(Al)	0.03%	Information	
Carbon	(C)	0.26%	-	0.30*
Chromium	(Cr)	0.14%	Information	
Copper	(Cu)	0.10%	Information	
Manganese	(Mn)	0.90%	0.29%	1.06%
Molybdenum	(Mo)	0.04%	Information	
Nickel	(Ni)	0.07%	Information	
Phosphorus	(P)	0.015%	-	0.048
Silicon	(Si)	0.25%	0.10%	-
Sulfur	(S)	0.033%	-	0.058
Titanium	(Ti)	0.003%	Information	
Vanadium	(V)	0.003%	Information	

Respectfully submitted,
ANAMET LABORATORIES, INC.

By [signature]
Siegfried Otto
Manager, Testing

jc
jm

Report 411-77.55

LABORATORY CERTIFICATE

Anamet Laboratories, Inc.

ANALYTICAL
CHEMICAL
METALLURGICAL
HIGH TEMPERATURE
APPLIED RESEARCH
PHYSICAL TESTING

May 25, 1977

LABORATORY NUMBER:	577.329 B	P.O. No. LO-879806
SAMPLE:	Two (2) Samples for Chemical Analysis	
MARK:	Weld - Side and Crown DCPP #1 Steam Generator Nozzle Failure Analysis	
DATE SUBMITTED:	May 24, 1977	
REPORT TO:	Pacific Gas & Electric Company 3400 Crow Canyon Road San Ramon, California 94583 Attn: Mr. Steve Ivy	

CHEMICAL ANALYSIS

		Side	Crown
Aluminum	(Al)	0.005%	0.004%
Carbon	(C)	0.08%	0.06%
Chromium	(Cr)	0.09%	0.06%
Copper	(Cu)	0.07%	0.08%
Manganese	(Mn)	1.17%	1.06%
Molybdenum	(Mo)	0.15%	0.12%
Nickel	(Ni)	1.00%	1.03%
Phosphorus	(P)	0.013%	0.012%
Silicon	(Si)	0.55%	0.60%
Sulfur	(S)	0.022%	0.022%
Titanium	(Ti)	0.01%	0.01%
Vanadium	(V)	0.03%	0.02%

Respectfully submitted,
ANAMET LABORATORIES, INC.

By Siegfried Otto
Manager, Testing

lc
jm

ROCEDURE SPECIFICATION FOR: Carbon Steel ing to Nickel Steel piping, insert weld- GTAW (root) and SMAW (weld out).

ASE METAL: The base metal shall conform the specifications for ASME, Section IX, 1B to P-1 materials.

LLER METAL: The filler metal shall con- to ASME Filler Metal Specifications Num- SFA-5.5 and SFA-5.18 for ferrous filler al in Group Number and F-6.

e chemical composition of the weld depos- shall fall within the limits of weld Metal ysis Number A-12b.

S FOR TORCH SHIELD: Nominal composition rgon, 99.995% minimum purity (for GTAW ess).

S FOR BACK-UP PURGE: Argon per Page 5 GTAW process).

CK WELDS FOR SET-UP: The GTAW process filler metal type listed on Page 2 may sed with or without back-up purge in 1/16, , or 1/8 inch diameter.

SITION: The welding may be done in all tions.

HEAT AND INTERPASS: 200° F - 300° F pre- for SMAW weld out only and 200° F minimum rpass.

ST HEAT TREATMENT: 1100° F - 1200° F, 1 per inch minimum (see job specifications cycle and thicknesses requiring post heat tment.

ACKING STRIP: None.

RAVEL SPEED: GTAW ½" - 6" per min.
SMAW 3" - 8" per min.

WELDING PROCESS: The welding shall be done by the GTAW insert root and SMAW weldout processes using manual equipment. The GTAW process may be used with the filler metal type listed on Page 2 for intermittent voids, look-in holes (peep holes) in the ring, or mismatch in the root set-up. If necessary, one complete pass may be made while holding the purge. GTAW Welding shall be done using a non-consumable electrode of 2% thoriated tungsten, EWTh-2.

BASE MATERIAL THICKNESS: This procedure is qualified to allow welding of material thickness between 3/16" and 1.5" (heat treated).

PREPARATION OF BASE MATERIAL: The edges or surfaces of the parts to be joined by welding shall be prepared by flame cutting, plasma arc, grinding, machining, or any combination of methods to essentially form the geometry of the weld shown on Page 2 as detailed on the attached sketches and shall be clean of all oil or grease and excessive amounts of scale or rust.

ELECTRICAL CHARACTERISTICS: The current used shall be DC: GTAW Straight Polarity
SMAW Reverse Polarity

JOINT WELDING PROCEDURE: The welding technique, such as electrode sizes, and voltages and currents for each electrode, size of the welding tip and filler rods, shall be substantially as shown on Page 2.

APPEARANCE OF WELDING LAYERS: The welding current and manner of depositing the weld metal shall be such that there shall be practically no undercutting on the side walls of the welding groove or the adjoining base material. See job specifications for specific undercutting limitations.

CLEANING: All slag or flux remaining on any bead of welding shall be removed before laying down the next successive bead of welding.

DEFECTS: Any cracks or blow holes that appear on the surface of any bead of welding shall be removed by chipping, grinding, or gouging before depositing the next successive bead of welding.

71-15-03

THE M. W. KELLOGG COMPANY
A DIVISION OF PULLMAN INCORPORATED
PIPING FABRICATION

RECOMMENDED FORM Q-1 MANUFACTURER'S RECORD OF WELDING PROCEDURE QUALIFICATION TESTS

* Heat Treated

Specification No. P12b-P1-K1-F4-SMAW-6G Date 12/28/73

Welding Process GTAW & SMAW Manual or Machine Manual

Material Specification A-508-CL2 to A-106-B of P-No. 12B to P-No. 1

Thickness (if pipe, diameter and wall thickness) 10" O.D. X 3/4" W

Thickness Range this test qualifies 3/16" thru 1½" wall thk, 3" IPS and over

Filler Metal Group No. F- 4 & 6

Weld Metal Analysis No. A- 12b

Describe Filler Metal if not included in Table Q-11.2 or QN-11.2 Root-E70S-2, weld out-E9018

For oxyacetylene welding—State if Filler Metal is silicon or aluminum killed.

FLUX OR ATMOSPHERE

Flux Trade Name or Composition None

Inert Gas Composition Argon

Trade Name --- Flow Rate 20 CFH

Is Backing Strip used? No

Preheat Temperature Range 200° F - 300° F

Interpass Temperature Range 200° F minimum

Postheat Treatment 400° F/hr from 600° to 1100° F, 1 hr at 1150° F, furnace cooled at 400° F/H to 600° A/C

WELDING PROCEDURE

Single or Multiple Pass Multiple

Single or Multiple Arc Single

Position of Groove 6G (See Pars. & Figs. Q-2 & Q-3, or QN-2 & QN-3)
(Flat, horizontal, vertical, or overhead; if vertical, state whether upward or downward)

FOR INFORMATION ONLY

Filler Wire—Diameter 1/8 x 5/32, 3/32, 1/8, 5/32

Trade Name ---

Type of Backing Argon

Forehand or Backhand ---

WELDING TECHNIQUES

Joint Dimensions Accord with See Sheet 2

amps -- volts -- inches per min.

Current D C Polarity GTAW Straight SMAW Reverse

REDUCED SECTION TENSILE TEST (Figs. Q-6 and QN-6)

Specimen No.	Dimensions Dia.		Area	Ultimate Total Load, lb.	Ultimate Unit Stress, psi	Character of Failure and Location
1	.498		.1948	14,000	71,900	Broke In Base Metal
2	.495		.1924	13,800	71,700	Broke In Base Metal

GUIDED BEND TESTS (Figs. Q-7.1, Q-7.2, QN-7.1, QN-7.2, QN-7.3)

Type and Figure No.	Result	Type and Figure No.	Result
1	Satisfactory	3	Satisfactory
2	Satisfactory	4	Satisfactory

Results of Filletweld Tests, Fig. Q-9(c) N/A

Welder's Name S. Selby Clock No. 35 Stamp No. 1

Who by virtue of these tests meets welder performance requirements.

Test Conducted by Magnaflux Corp. Laboratory—Test No. MWK B-1 *

per M. W. Kellogg

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

Signed The M. W. Kellogg Company
(Manufacturer)

Date 12/28/73

By R. G. Fink

Charpy "V" Notch Test Results:
H.A.Z. P12b = 66.5, 71.0, 71.0 = 69.5
Weld = 91.0, 85.0, 99.5 = 91.8
H.A.Z. P1 = 20.0, 27.0, 32.0 = 28.0

THE M. W. K[illegible]
A Division of [illegible] Incorporated
Piping Fabrication
Williamsport, Pa. 17701

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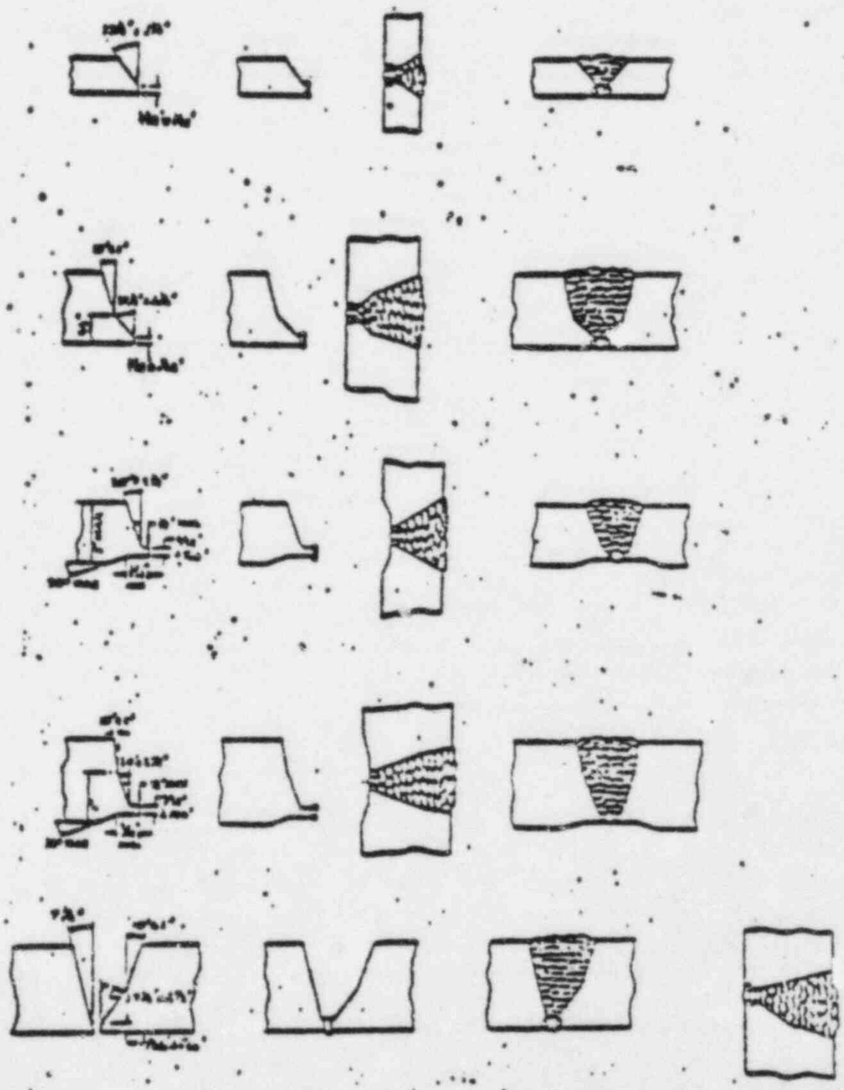
Weld Procedure C[illegible] No. 200
Spec. No. P12b-P1-K1-F4-SMAW-GG
Date 11/14/73
Revision Dates: 6-16-76



...S NO. ...ND ...CESS	FILLER METAL TYPE OPTIONAL	FILLER METAL SIZE OPTIONAL	AMPS	MAX. VOLTS	POLARITY	TORCH SHIELD & FLO RATE (MIN.)	TUNGSTEN SIZE AND POLARITY
...T ...AW	E70S-2, or -6	INSERT 1/8 X 5/32	55-175	21	straight	Argon 20 CFH	1/8 or 3/32 diameter straight
...CK TAW	E70S-2, or -6	1/16 3/32 1/8	60-120 70-150 100-[illegible]	14 17 20	straight	Argon 20 CFH	1/8 or 3/3[illegible] diameter straight
...LANCE ...W	E8018	3/32 1/8 5/32 3/16	65-110 100-165 140-220 180-275	27 31 34 36	reverse	—	—

*NOTE: 1/16", 3/32", or 1/8" E70S-2 or E70S-6 filler metal may be used as necessary for tacking, filling intermittent voids, look-in holes (peep holes), or mismatch in the root set-up. If necessary, one complete pass may be made while holding the purge.

FOR STEAM GENERATOR AND PIPE WELDS ONLY — THE M.W. KELLOGG COMPANY

FIELD PROCESS SHEET

N/A = NOT APPLICABLE

CUSTOMER	NO & SYSTEM	ISOMETRIC DRAWING NO.	DETAIL DRAWING NO.	SHEET NO.
P. G. & E.	#3 FEEDWATER	500146	N/A	10 of [illegible]

PREPARED BY	JOB NO.	DATE	CODE	CLASS	MARK NO.
G.B.	7177	1/9/74	ASME SECTION I	SECTION I	N/A

OPER. NO.	OPERATION	HOLD FOR AUTH. INSP.	HOLD FOR NDE INSP.	PROC. NO.	OPER.	DATE COMP.	NDE INSP. & DATE	AUTH. INSP. & DATE
	FIELD WELD NO. T97 SEE DR-2450 ALSO Revisions							
1	CLEANING		✓	ESD 220	926	12/23/74	[illegible] 12/23/74	
2	FIT-UP	✓	✓	ESD 215	GX/126	[illegible]	[illegible]	[illegible]
3	WELD ROOT PASS			CODE 2014	GX	[illegible] Dec 74		/
4	PREHEAT SMAW ONLY (200° - 300°) USE CHART RECORDER	[illegible]	✓	CODE 2014	117	30 Dec 74		
5	WELD COMPLETE			CODE 2014	GX	30 Dec 74		
6	GRIND FOR R.T.			ESD 207	117	31 Dec 74		
7	VISUAL INSPECTION	✓	✓	ESD 215	[illegible]	[illegible]	[illegible]	[illegible]
8	R.T. FINISHED WELD	✓	✓	ESD 207	K	1/21/75	[illegible]	[illegible]
	STRESS RELIEVE - SEE Chart No - 341	✓	✓	ESD 218	117	2/4/75	[illegible] 2/4/75	[illegible]
	R.T. FINISHED WELD		✓	ESD 208	JC	2-11-5	[illegible] 2-11-5	[illegible]
	REMOVE DAMS	N/A [illegible]	✓	ESD 214				
	PT Finished Weld	✓	✓	ESD 211	[illegible]	[illegible]	DCB	
	FIELD WELD # 212 (Ring [illegible] 5/13/74 [illegible]) CUT OUT 5/21/74 Ring [illegible] 5/21/74 DCB				DCB			
1	CLEANING		✓	ESD 220	[illegible]	[illegible]	[illegible]	
2	FIT-UP	✓	✓	ESD 215	LB/[illegible]	[illegible]	[illegible]	[illegible]
3	WELD ROOT PASS	✓		CODE 200	LB	[illegible]	[illegible]	[illegible]
4	PREHEAT SMAW ONLY (200° - 300°) USE CHART RECORDER		✓	CODE 200	117	5/24/74	[illegible]	/
5	WELD COMPLETE			CODE 200	LB	[illegible]		
6	GRIND FOR R.T.			ESD 207	415	[illegible]		
7	VISUAL INSPECTION	[illegible]	✓	ESD 215	[illegible]	[illegible]	[illegible]	
8	R.T. FINISHED WELD	✓	✓	ESD 207	ES	[illegible]	[illegible]	[illegible]
	STRESS RELIEVE — Chart # 323	✓	✓	ESD 210	[illegible]	[illegible]	[illegible]	[illegible]
	R.T. FINISHED WELD	[illegible]		ESD [illegible]	GC	[illegible]	[illegible]	
11	REMOVE DAMS		✓	ESD 214	G71	[illegible]	[illegible]	

To: Steve Friedrich
From: MRT/RD Etzler

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PACIFIC GAS AND ELECTRIC COMPANY
STATION CONSTRUCTION DEPARTMENT
DIABLO CANYON PROJECT

HISTORY OF STEAM GENERATOR 1-2
DIABLO CANYON PROJECT

March 28, 1977

The following information is provided per your request to indicate tests and transient conditions which influenced temperature and pressure on the secondary side of steam generator 1-2:

HYDRO TESTS

2/19/74	1st hydro - 1 cycle to 1356 psig @ 106° F (main steam and feedwater nozzles capped at generator)
8/29/75	2nd hydro - 1 cycle to 1320 psig @ 88° F (RV's lifted and pressure had to be reduced)
8/29/75	With Present Piping 3rd hydro - 1 cycle to 1356 psig @ 88° F

HOT FUNCTIONAL TEST

12/13/75	RCS heatup	100° F to 150° F
12/15/75	RCS heatup	150° F to 240° F
12/23/75	RCS heatup	261° F to 340° F, 62 psig to 103 psig
12/30/75	RCS heatup	352° F to 450° F, 119 psig to 407 psig
12/31/75	RCS heatup	450° F to 571° F, 407 psig to 750 psig
1/1/76	RCS heatup	571° F to 547° F, 750 psig to 1010 psig
1/4/76	pressure dip	1000 psig - 940 - 1000 psig, ΔT < 10° F
1/4/76	pressure dip	1000 psig - 925 - 995 psig, ΔT < 10° F
1/4/76	temperature drop	545° F to 523° F, 980 psig to 810 psig
1/6/76	temperature dip	524° F - 497 - 524° F, 824 psig - 651 - 824 psig
1/7/76	temperature dip	531° F - 505 - 512° F, 900 psig - 695 - 750 psig
1/8/76	temperature increase	508° F to 546° F, 714 psig to 983 psig
1/9/76	temperature dip	545° F - 503 - 547° F, 983 psig - 677 - 1000 psig
1/10/76	temperature dip	548° F - 526 - 542° F, 1000 psig - 829 - 973 psig
1/12/76	RCS cooldown	536° F to 115° F, 908 psig to 0 psig
1/15/76	RCS heatup	139° F to 327° F, 0 to 84 psig
1/17/76	RCS heatup	327° F to 528° F, 84 psig to 860 psig
1/21/75	temperature dip	526° F - 472 - 546° F, 840 psig - 501 - 982 psig
1/23/76	turbine roll	546° F - 476 - 501° F, 1000 psig - 525 - 663 psig
1/24/76	temperature increase	501° F to 545° F, 680 psig - 985 psig
1/28/75	turbine roll	547° F to 482° F, 979 psig to 563 psig
1/28/76	RCS cooldown	482° F to 255° F, 563 psig to 20 psig
1/29/76	RCS heatup	255° F to 546° F, 20 psig to 989 psig
2/4/76	turbine roll	546° F - 477 - 546° F, 956 psig - 537 - 993 psig
2/5/76	turbine roll	546° F - 485 - 532° F, 987 psig - 595 - 857 psig

To: Spence Friedrich
From: MRT/RD Etzler
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HOT FUNCTIONAL TEST-continued

2/7/76	tested safeties	956 psig - 864 psig several times ΔT < 10° F
2/10/76	tested safeties (S.G.'s 1-3 and 1-4)	552° F - 531° F four times 1042 psig - 868 psig
2/10/76	RCS cooldown	549.5° F to 100° F, 1008 psig to 0 psig

NOTE: During the days not listed above, the temperature and pressure were relatively stable. A detailed picture of temperature and pressure is available at the site and a drawing of the entire hot functional program. Steam pressure shown on the drawing is downstream of the main steam isolation valves and does not always agree with steam pressure in the steam generator.

MINI-HOT FUNCTIONAL TEST

3/14/77	RCS heatup	115° F to 165° F
3/15/77	RCS heatup	165° F to 300° F, 0 psig to 52 psig
3/16/77	RCS heatup	300° F to 330° F, 52 psig to 88 psig
3/17/77	RCS cooldown	330° F to 100° F, 88 psig to 0 psig

FEEDWATER TO STEAM GENERATOR

During both Hot Functional and Mini-Hot Functional, the auxiliary feedwater system was used for makeup to the steam generator. Feedwater temperature varied from 90° F to 110° F and flow rate varied from 0 to 300 GPM. We understand you have obtained water chemistry results from the plant chemist.

THERMAL EXPANSION

During Hot Functional, thermal movement and potential component and piping interferences were closely monitored for each steam generator. Movement of steam generator 1-2 was in agreement with the movement of the remaining generators and acceptable by Engineering Department. However, insulation on the feedwater inlet line for steam generator 1-2 did come in contact with the missile barrier penetration, whereas feedwater lines on the other steam generators did not. The insulation cover was slightly indented, but not enough to induce a restriction to the movement of the feedwater line with the steam generator. Results of the thermal expansion test during Hot Functional are on file at the plant and General Office.

R. W. WOOD
Startup Department

RWWood:fgr
cc File

ANALYSIS OF ELECTRON DIFFRACTION PATTERNS

Gold Calibration for Camera Constant

Ring Dia. cm	dÅ	K
2.30	2.355	5.42
2.65	2.039	5.40
3.75	1.442	5.41
4.40	1.230	5.41

K = 5.41

Pattern From Extracted Oxide

Ring Dia. cm	dÅ	Intensity*
1.3	4.15	S
1.5	3.60	W
2.0	2.70	S
2.15	2.52	M
2.40	2.25	M
2.70	2.00	W
3.10	1.74	M
3.30	1.63	W
3.50	1.55	VS
4.00	1.35	S
4.40	1.22	W
4.70	1.15	M

*VS - Very Strong
S - Strong
M - Medium
W - Weak

* αFe_2O_3 Hematite

4-0755 MAJOR CORRECTION

d	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I/I_1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

d Å	I/I_1	hkl	d Å	I/I_1	hkl
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	111	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] (1979)

[illegible] (1956)

6-0502

d	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I/I_1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

d Å	I/I_1	hkl	d Å	I/I_1	hkl
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]