1. Abnormal Occurrence Report No. 50-313/74-11A

2. Report Date: January 22, 1975 3. Occurrence Date: November 7, 1974

4. Facility: Arkansas Nuclear One-Unit 1
Russellville, Arkansas

5. Identification of Occurrence:

See AOR 50-313/74-11 dated 11/18/74

6. Conditions Prior to Occurrence:

Steady-State Power	____	Reactor Power	0 MWth
Hot Standby	____	Net Output	0 MWe
Cold Shutdown	X	Percent of Full Power	0 %
Refueling Shutdown	____		
Routine Startup Operation	____		
Routine Shutdown Operation	____		

Load Changes During Routine Power Operation ____

Other (Specify) ____

7. Description of Occurrence:

See AOR 50-313/74-11

8004170527

8. Designation of Apparent Cause of Occurrence:

Design		Procedure	
Manufacture		Unusual Service Condition Including Environmental	
Installation/ Construction		Component Failure	
Operator			
Other (Specify)	X		

Not determined at this time. See attached report.

9. Analysis of Occurrence:

See attached report.

10. Corrective Action:

See attached report.

11. Failure Data:

See AOR 50-313/74-11

12. Reviews and Approvals:

Reviewed and Approved by: Plant Safety Committee Yes (X) No ( )

Plant Superintendent Yes (X) No ( )

Reference: JWA-825 Date: 1/29/75

Reviewed by: Donald A. Rueter Date: 2/3/75
Licensing Supervisor

Approved by: [signature] Date: 2-4-75
Safety Review Committee

Approved by: William Cavanaugh Date: 2/3/75
Manager of Nuclear Services

Approved by: [signature] Date: 2-4-75
Director of Power Production

Approved by: [signature] Date: 2-5-75
Senior Vice President

ATTACHMENT TO AOR 50-313/74-11A

On November 7, 1974, a leak was discovered in a Reactor Building Spray System pipe of Arkansas Nuclear One-Unit 1. The plant was being shut down following hot functional test of the primary coolant drain line, and was going into decay heat mode at the time the leak was detected. The leak was located adjacent to a weld in line HCB-6-1. A segment of the system, including the leak, was replaced and the plant returned to operation. On November 13 a second leak was detected adjacent to a new weld which was made in the original pipe as part of the original repair. Subsequent leaks were also discovered in the spray pumps suction crossover line between valves BW7A and BW7B. These leaks (labeled #3, #4 and #5 in this report) were not considered to be abnormal occurrences since that section of the pipe is isolated under normal modes required for spray system operation. Leak #4 was found in the weld made for the repair of leak #3. Figure 1 is a simplified isometric showing the location of the first 4 leaks and figure 2 of leak #5. Samples of the pipe containing each of the first three pipe leaks have been forwarded to Bechtel's Materials, Fabrication and Quality Control Services Laboratory for Metallurgical Analysis.

The following discussion describes the investigations made to date and the results. All failures except cracks #4 and #5 have been repaired by replacing a section of the pipe. Cracks #4 and #5 have not been repaired because they are located in the non-essential crossover line and plans have been made to eliminate this line. The crossover line is currently isolated.

Upon examination, the three leaking pipe sections showed very similar crack morphologies. All three exhibited intergranular cracking roughly parallel to circumferential butt welds in the continuous sensitized region of the Heat Affected Zone (HAZ). In all cases the cracking began on ID surfaces, approximately 1/4 inch from the root of the weld. The microstructure of the pipe showed carbide precipitation. Both surfaces exhibited a continuous network of intergranular attack approximately 0.001 inch deep.

Intergranular stress-assisted corrosion cracks (IGSACC) of TP-304 stainless steels at temperatures near atmospheric ambient are rare. Very specific conditions and chemical species are generally required to provide IGSACC in sensitized TP-304 at ambient temperature. Sensitized stainless steels are susceptible to IGSACC in nitric, sulphuric, phosphoric, hydrochloric, hydrofluoric and naphthenic acids, in addition to certain ratios of $SO_4^{=}/Cl^{-}$, aqueous ammonium chloride solutions and dissolved O_2. Most of the chemical species mentioned are outside the range of water chemistry expected in the containment spray system. Pickling is known to have a detrimental effect on the intergranular stress-assisted corrosion cracking susceptibility of sensitized TP-304 stainless steel. Pickling of sensitized stainless steel provides potential crack starters in the form if intergranular attack.

The various factors in this investigation are discussed below with an estimation of their probable effect in the cracking of pipe sections.

1. Pipe Material:

   The piping material is ASTM A-358, TP-304. By specification, "all pipe shall be furnished in the heat treated condition. The heat treatment procedure shall consist of heating the material to a minimum of 1900°F and quenching in water or rapidly cooling by other means." Extensive microstructural examination of the cracked pipe sections revealed some sensitization. The heat treat condition is a significant contributor to the intergranular stress-assisted corrosion cracking. The examination also revealed a continuous network of intergranular attack on both ID and OD surfaces of the piping. The attack was on the order of 0.001 to 0.002 inches deep and was probably caused by pickling after heat treatment. The fact that the attack on the outside and inside surfaces is the same is significant in that it indicates the attack existed prior to installation and was not caused by the service environment. This type of intergranular attack is believed to hasten cracking of sensitized stainless steels and to provide retention of fluoride ions from the pickling solution. Fluoride ion in very small concentrations, 1 to 400 ppm, is known to cause IGSACC in sensitized TP-304 stainless at or near atmospheric ambient temperature.

2. Stress:

   It is assumed that the stress component for IGSACC was due to fit-up and welding because the cracking observed has all been near welds.

3. Water Chemistry:

   The chemistry of the water to which the piping was exposed during normal operation and prior to failure will be presented in our final report. The fluid is primarily borated water of varying concentrations.

The investigations included visual observations, microstructural examinations, scanning electron microscope examination of fracture surface and chemical analysis.

The results of the investigations are summarized here without reference to specific photomacrographs or photomicrographs. A pictorial review of the three cracks is presented in Appendices 1, 2 and 3. The photomacrographs and photomicrographs of the appendices are supported by commentary.

1. Visual Observations:

The three pipe sections which leaked were examined visually with magnification aid to 30X. The three sections contained cracks parallel to the circumferential butt welds. The cracks were approximately 1/4" from the root of the weld. All cracks were within the HAZ as determined by the welding heat tinting. The cracks were longer, with wider openings on the ID surfaces, indicating that they originated on these surfaces. Three additional cracks originated on the ID surface which did not go all the way through the wall. Examination of both ID and OD surfaces at 30X revealed a "dried mud cracked" appearance. At crack #1, the pipe had been deformed to match the adjacent pipe fitting. Visual examination of all three pipe sections revealed that there was a similarity of location (in HAZ), orientation (parallel to weld), appearance (intergranular) and origin (ID surface).

The cracks on the pipe perimeters are located as follows:

Looking into the pipe from the circumferential butt weld side, crack #1 was located at 12:00 o'clock, crack #2 at 7:00 o'clock, and cracks on pipe #3 were located at 1:00 o'clock, 5:00 o'clock, 7:00 o'clock and 9:00 o'clock. Those at 5:00, 7:00 and 9:00 o'clock did not penetrate the wall.

2. Microstructural Analysis:

Cross sections of all cracks and pipe base metal away from the circumferential welds were examined on a metallurgical microscope with magnifications up to 1000X. The results were very similar for all three pipe sections examined.

a. The cracks originated on the ID surfaces and progressed through the pipe thickness in an intergranular manner. There was no evidence of transgranular or mixed mode cracking.

b. The cracking occurred in the heat-affected zone of continuous carbide precipitation at the grain boundaries.

c. The cracking was branched with secondary cracking.

d. The weld appeared sound with no suggestion of any objectionable features.

e. The longitudinal welds on all pipe sections appear to have been solution treated after planishing. There was no evidence of a heat-affected zone near these welds.

f. The base metal of all pipe sections contained continuous and semi-continuous carbide precipitation at the grain boundaries, indicating an inadequate cooling rate from the solution heat treating temperature. The carbide precipitation was heavier in the center of the pipe thickness than at either surface.

g. On both ID and OD surfaces throughout the pipe lengths, there was a network of intergranular attack at the grain boundaries. This intergranular attack extended to a depth of 0.001 to 0.002 inch. This attack was most probably caused by pickling subsequent to heat treating.

3. Fractographic Analysis:

The fracture surface of crack #1 was examined on a scanning electron microscope. This examination confirmed the intergranular mode of fracture. The fracture features were sharp, indicating fracture was accompanied by very little corrosion.

4. Chemical Analysis:

A sample from pipe containing crack #1 was subjected to chemical analysis to specification requirements. The analysis shows all specification requirements for chemistry were met, although the carbon content is near the maximum permitted. The rare earth metals, Cesium, Cerium and Lanthanum were present in small quantities.

5. Water Analysis:

A chemical analysis of water from the containment spray and decay heat systems will be presented in our final report.

6. Deposit Analysis:

A wipe sample of the ID surface of pipe section containing crack #2 was obtained before the line was decontaminated. The analysis of this sample is not complete.

7. Field Investigation:

A random sample of areas adjacent to 46 welds in the building spray and decay-heat systems was examined by ultrasonic and radiographic methods. Of these areas, five showed crack-like indications in the radiographs. It was concluded that ultrasonic testing was not a satisfactory method of examining pipe for the suspected defect and that radiography was the more satisfactory method of examination.

The following work remains to be done:

1. Obtain a chemical analysis of water samples and crud from the system.

2. Perform modified Strauss tests on samples of the pipe to determine the effect of carbide precipitation.

3. Field investigation of all schedule 10 stainless steel piping to identify pipe with excessive pickling attack.

4. Metallurgical examination of cracks #4 and #5 and RT indications following removal of crossover pipe.

Item 1. has been delayed due to non-availability of legal shipping containers. No date is available for completion. Items 2. through 4. depend on removal of the section of crossover pipe. This removal will be accomplished during a planned shutdown in the spring of this year. The exact date of the planned shutdown is not yet known.

In addition to the above work, Southwest Research Institute has been retained to do the following:

a. Review the analysis performed in the Bechtel Lab and issue a report on their findings;

b. Perform, by microprobe technique, an analysis to identify any corrodent;

c. Establish a program to examine, in the field, pipe surface conditions to identify pipe that has experienced chemical attack due to excessive pickling;

d. Perform an independent metallurgical examination of cracks #4 and #5 and RT indications following removal of the crossover pipe;

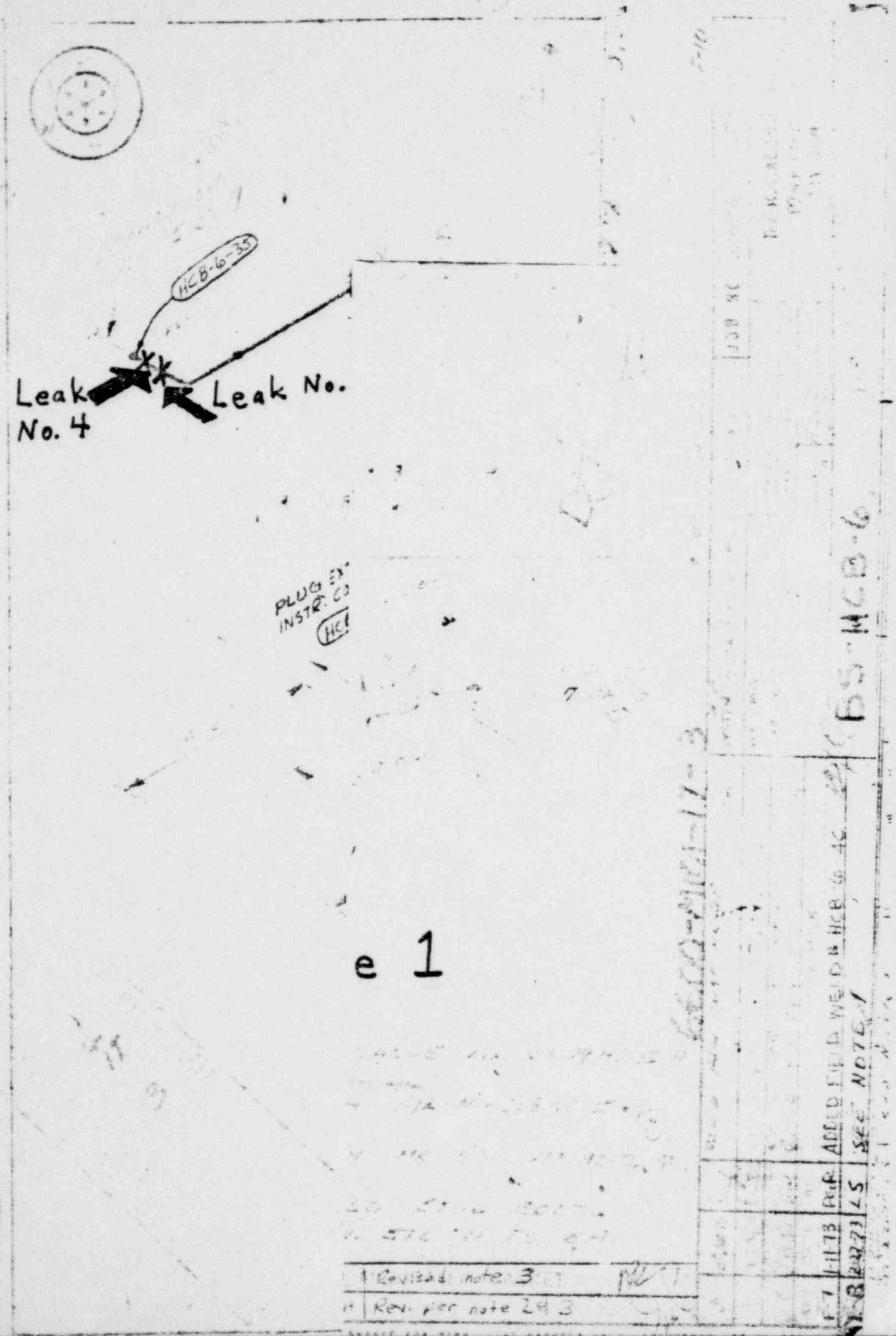
e. Examination of the surface of the pipe in the field for carbide precipitation by a surface replica technique;

f. Propose additional investigations they believe would be advisable.

Item c has been completed. Our review of the program has not been completed at this time. The other items depend on the planned shutdown this spring.

In the interim, we have increased our surveillance of this system to include a once-a-shift walk thorough examination for leaks.

Final results, conclusions and corrective action will be reported when all investigations are complete. The schedule for this final report necessarily depends on the planned spring shutdown for which an exact date is impossible to determine at this time.

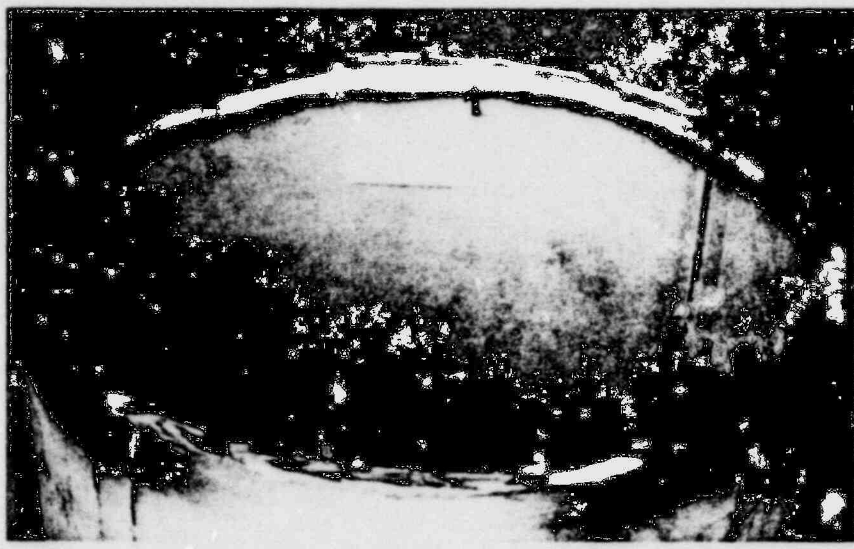

HCB-6-35
Leak No. 4
Leak No.
PLUG EX
INSTR. CO
e 1
Revised note 3
Rev. per note 2 & 3
BS-HCB-6
ADDED FIELD WELD # HCB-6-46
SEE NOTE 1

APPENDICES

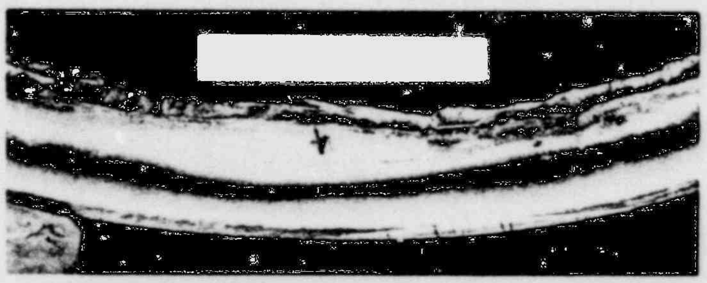
Appendix 1 is a pictorial review of crack #1. Cracks #2 and #3 are similar to crack #1. Appendicies 2 and 3 are a pictorial documentation to show this similarity. The Metallographic examination confirmed the Morphology of the cracks to be identical in nature.

APPENDIX 1

PICTORIAL REVIEW OF CRACK No. 1



(a)

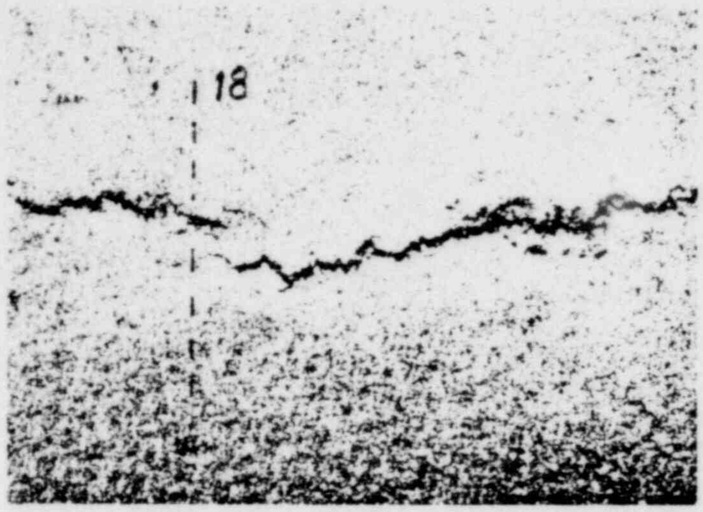


(b)

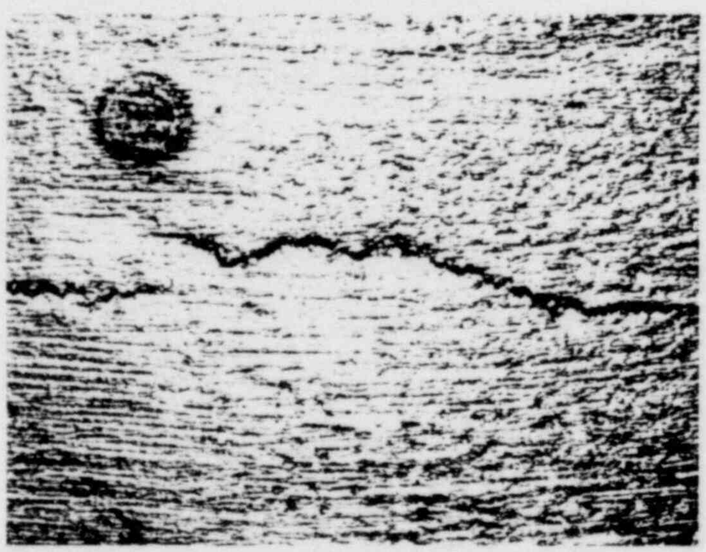
(c)

Sample No. 1

Fig. 1-1 (a) The failed end of sample No. 1 with cracks marked by the arrow.
(b) The inside surface of the crack area.
(c) The outside surface of the crack area.



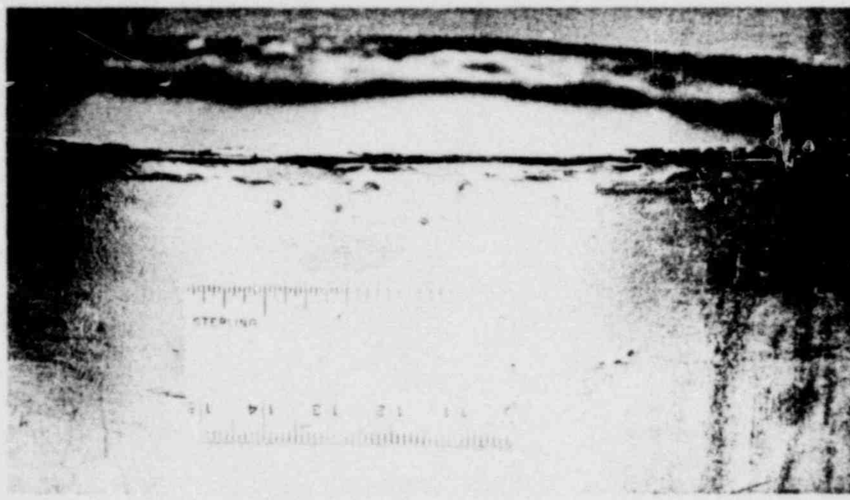
(a) Inside Surface 10X



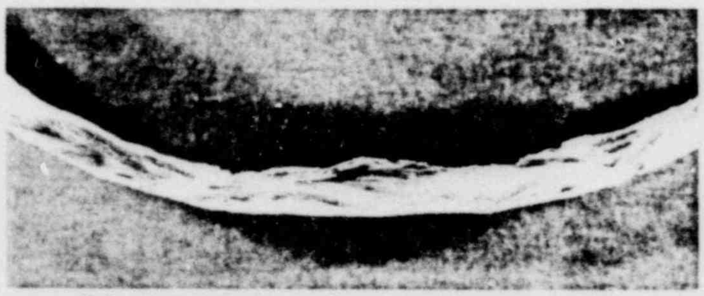
(b) Outside Surface 10X

Sample No. 1

Fig. 1-2 Closeup views of the inside and outside surfaces showing the crack marked by the arrows in Fig. 1-1 (b) and (c).



(a) Cracked side

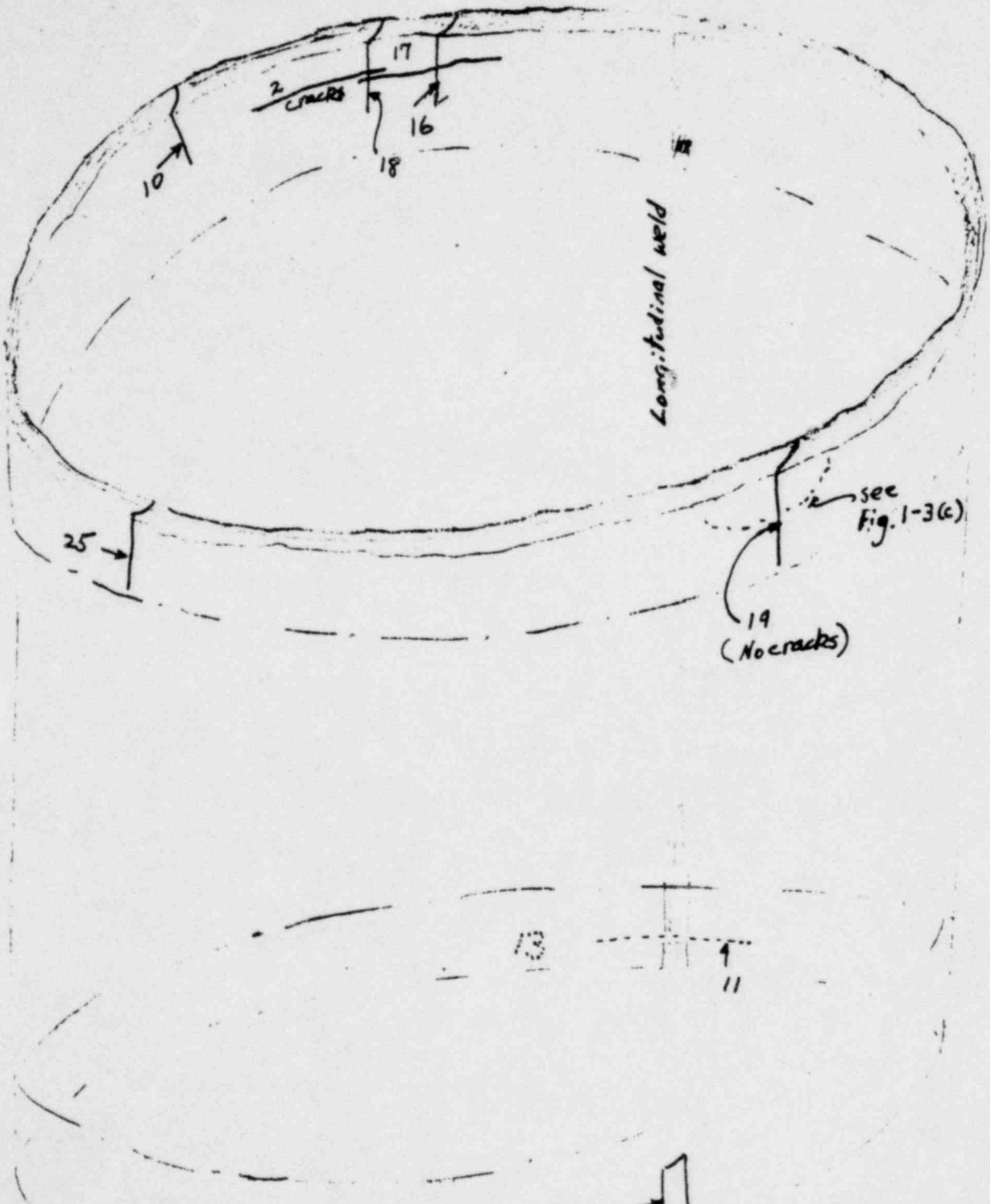


(b) Top view of the cracked region

(c) Opposite side

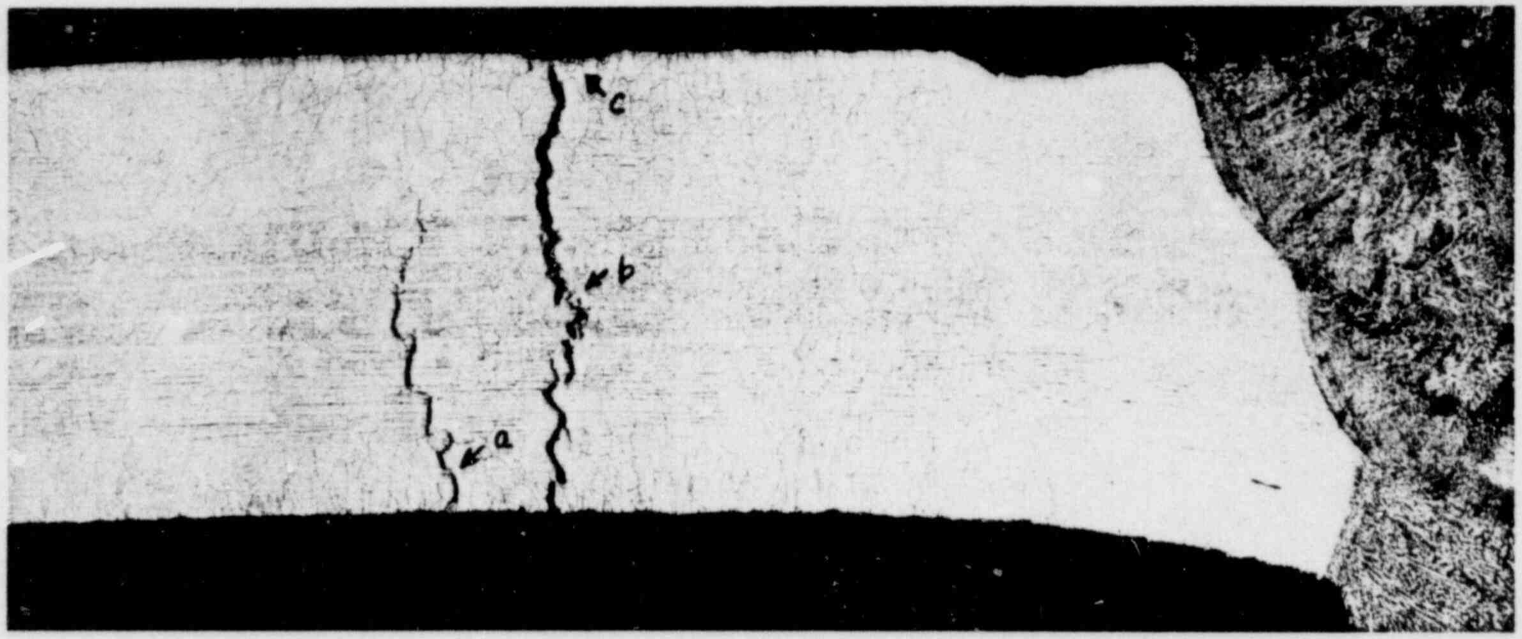
Sample No. 1

Fig. 1-3 (a) The crack on the outside surface.
(b) The top view of the cracked region showing flattened circumference.
(c) A semi-circular mark on the outside surface about 170° away from the crack. This area was also flattened to about the same extent as in (b).



Sample No. 1

Fig. 1-4 A sketch showing the locations of metallographic specimens.

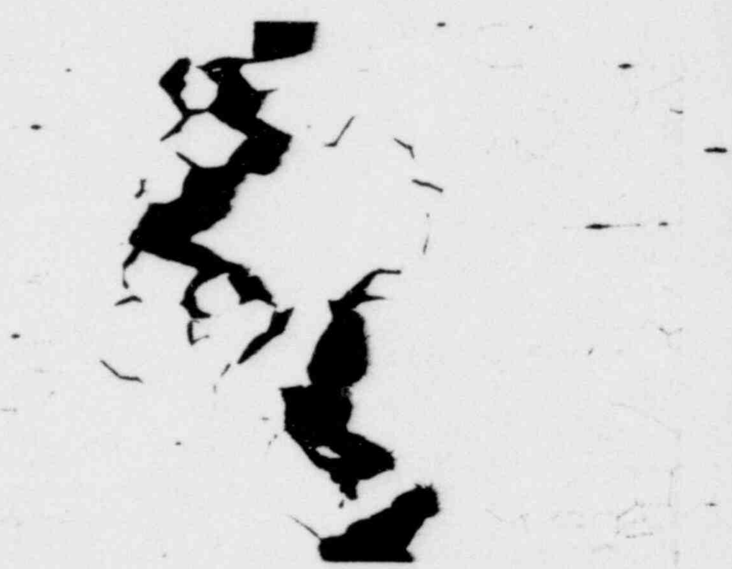


Electrolytic etch in 10% oxalic acid 15X

Specimen No. 18 (Sample No. 1)

Fig. 1-5 Macrograph of specimen No. 18 showing a section through the crack as marked by the line in Fig. 1-2 (a) and a dotted line in Fig. 1-4. Note relationship of cracking with the weld HAZ.

(a) Inside 100X



(b) Middle 100X

Specimen No. 18 (Sample No. 1)

Fig. 1-6 Micrographs showing the intergranular cracks marked by the arrows a and b in Fig. 1-5.

Electrolytic etch in 10% NaCN 14X

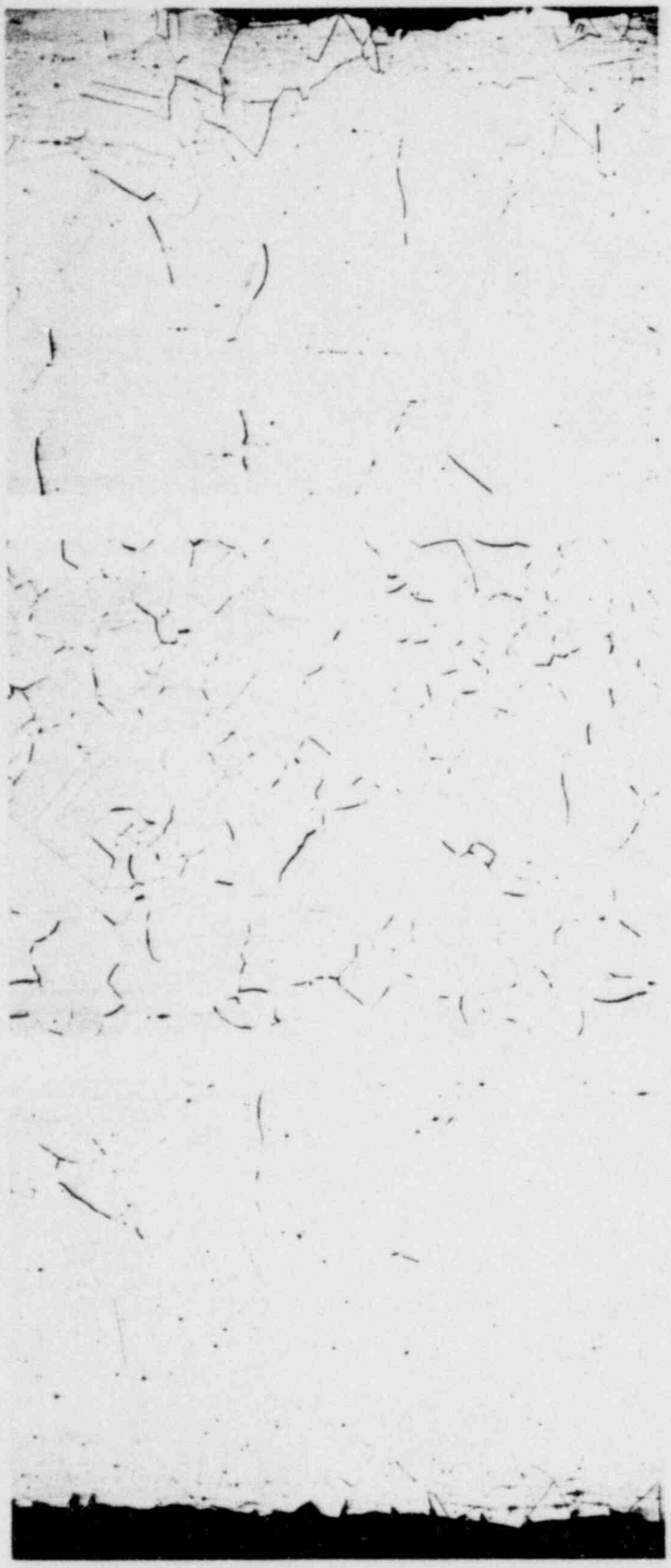
Specimen No. 16 (Sample No. 1)

Fig. 1-7 Macrograph of specimen No. 16 showing another section through the crack as marked by a line in Fig. 1-4. The bottom edge is a profile of the inside surface.

Electrolytic etch in 10% NaCN 30X

Specimen No. 16 (Sample No. 1)

Fig. 1-8 A composite micrograph showing the crack in the far side of the carbide precipitation zone from the weld. The upper edge is a profile of the outside surface of the pipe.

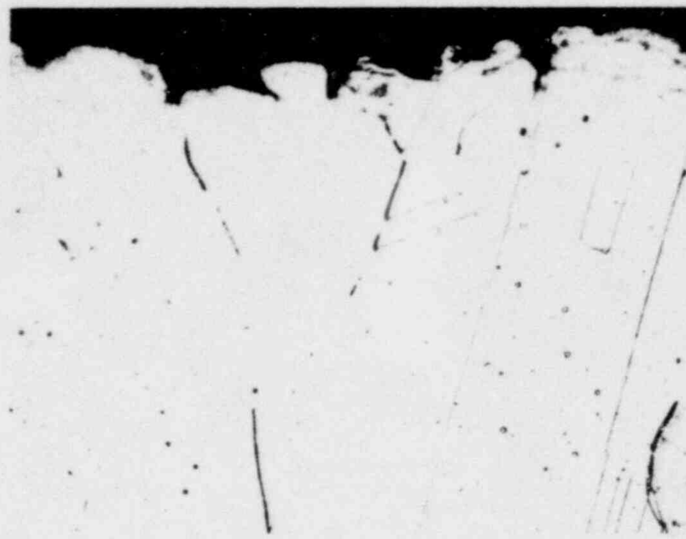


Electrolytic etch in 10% oxalic acid 100X

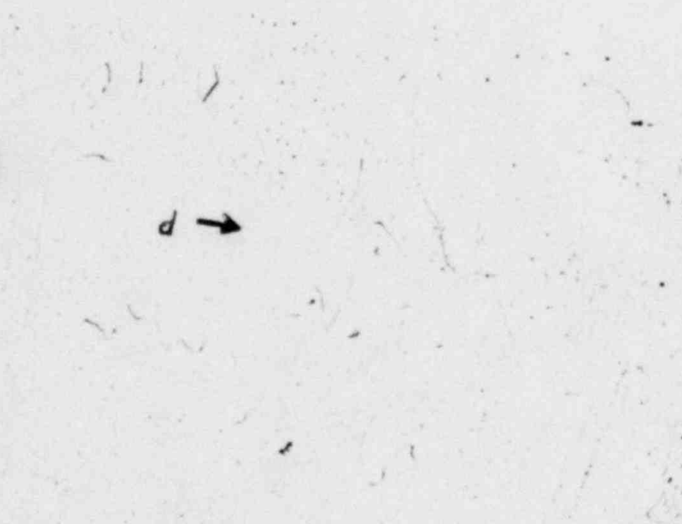
Specimen No. 21 (Sample No. 1)

Fig. 1-9 The carbide precipitation in the base metal away from both the circumferential and the longitudinal welds. Note the surface intergranular penetration probably from pickling.

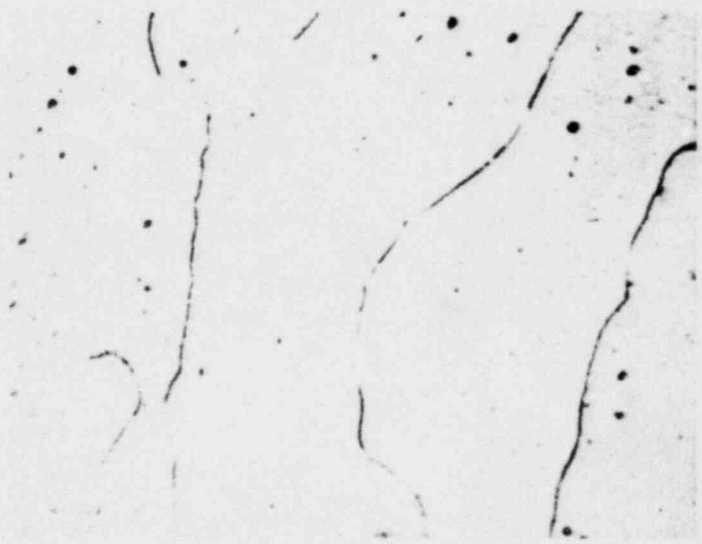
(a) Outside 100X



(b) Outside 500X



(c) Middle 100X



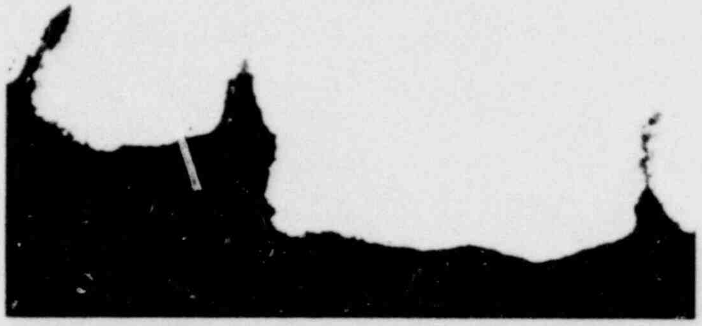
(d) Middle 500X

Specimen No. 11 (Sample No. 1)

Fig. 1-10 The microstructure of the longitudinal weld showing recrystallized grains, carbide precipitation and intergranular surface attack by pickling. Electrolytic etching in 10% oxalic acid.

These pictures indicate the pipe was solution treated after seam welding.

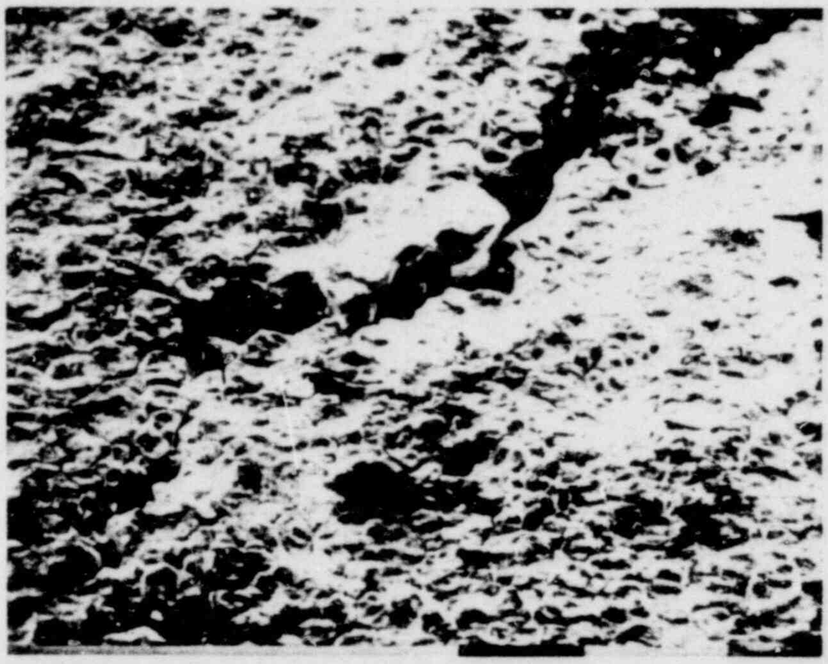
(a) 1000X



(b) 1000X

Specimen No. 10 (Sample No. 1)

Fig. 1-11 Micrographs showing oxidation (or corrosion) products at the bottom of ditches on the inside surface. As polished.



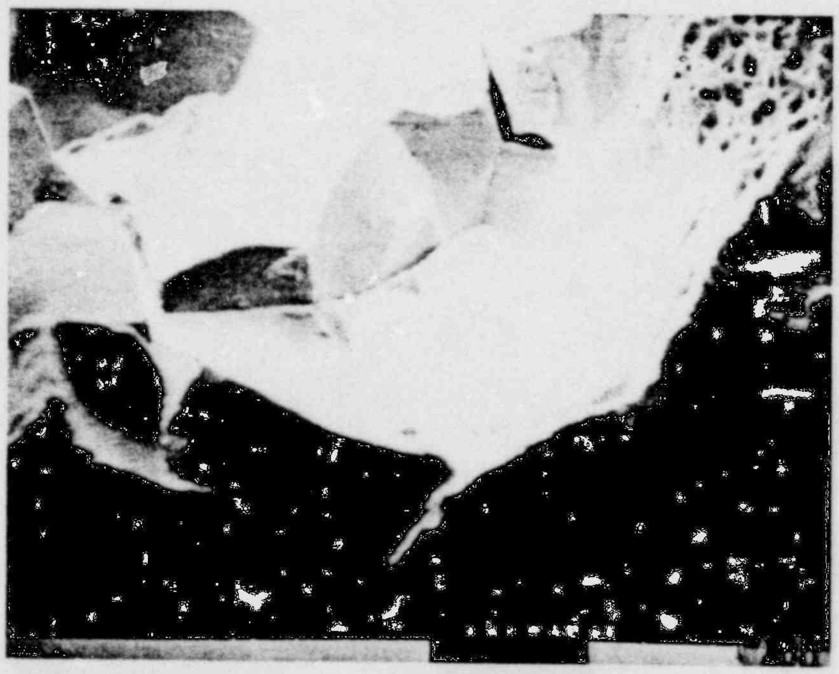
(a) 85X

(b) 420X

<u>Specimen No. 17 (Sample No. 1)</u>

Fig. 1-12 Scanning electron micrographs of the crack as viewed from the inside surface. (b) shows the area marked by the arrow in (a).

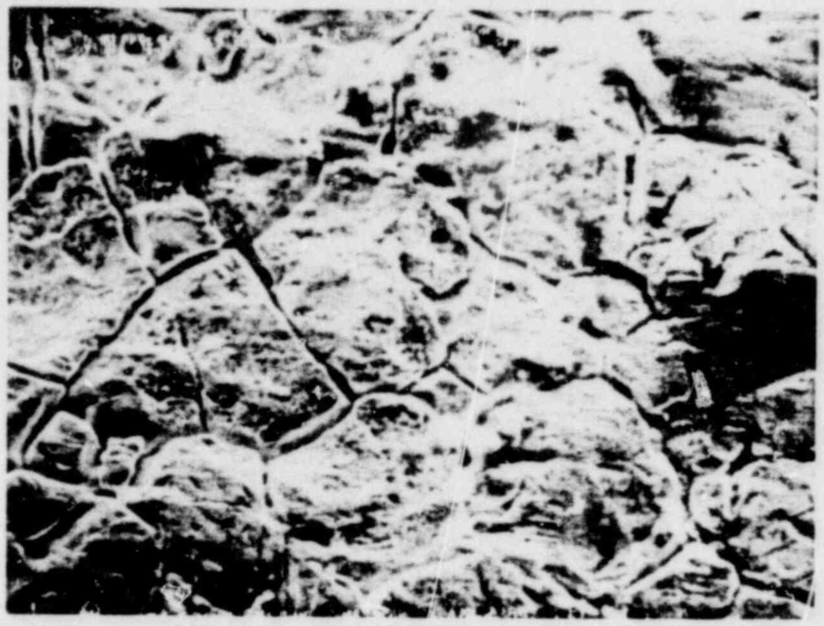
(a) Middle 1000X



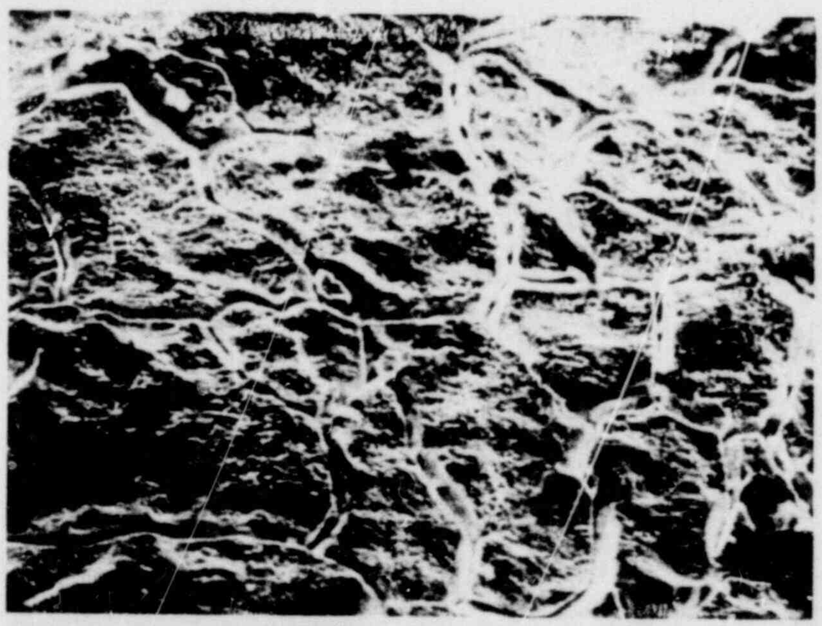
(b) Outside edge 530X

Specimen No. 17 (Sample No. 1)

Fig. 1-13 Scanning electron micrographs of the fracture facets in the mid-thickness and near the outside surface.



(a) Outside surface 420X

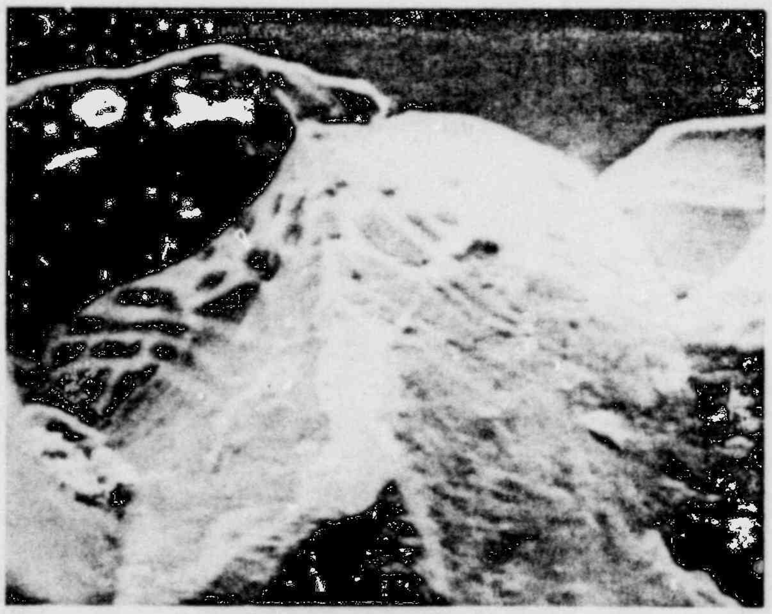


(b) Inside surface 350X

Specimen No. 13 (Sample No. 1)

Fig. 1-14 Scanning electron micrographs showing intergranular ditches on both inside and outside surfaces. This is "dried mud cracked" surface apparent at 6X.

(a) Viewed from inside 500X



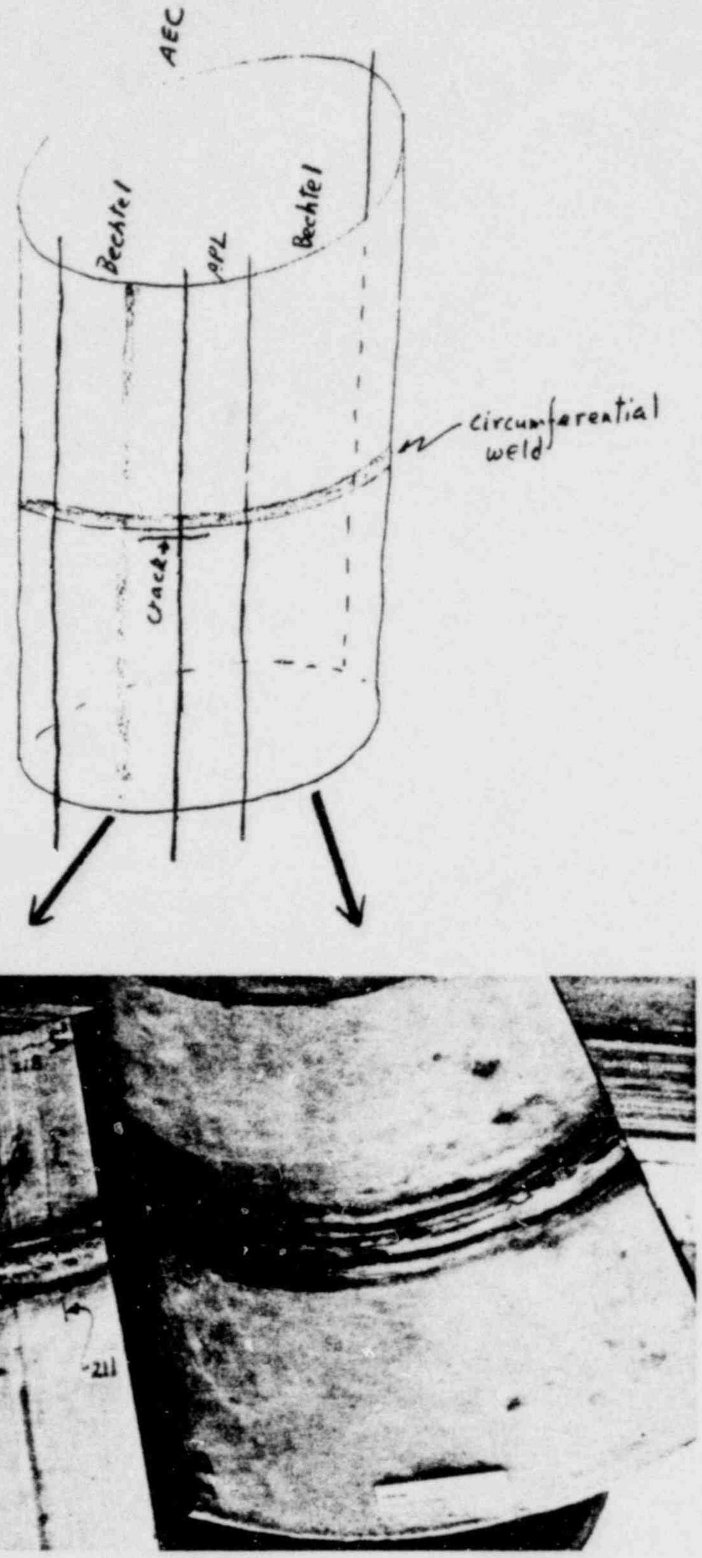
(b) Viewed toward inside 1050X

Specimen No. 17 (Sample No. 1)

Fig. 1-15 Scanning electron micrographs showing deposit on the fracture facets along the inside surface.

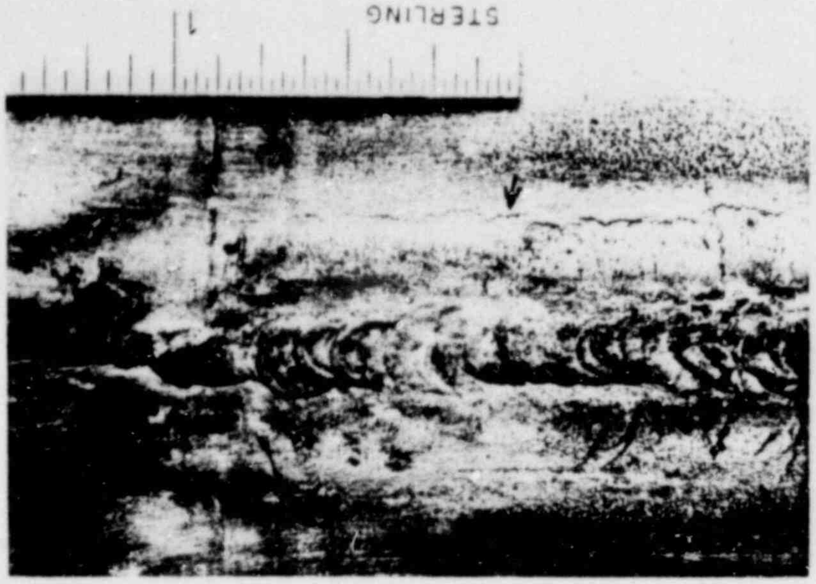
APPENDIX 2

PICTORIAL REVIEW OF CRACK No. 2



Sample No. 2

Fig. 2-1 Sketch showing the locations of the samples received and the locations for the metallographic specimens.



(a)

(b)

(c) 4X

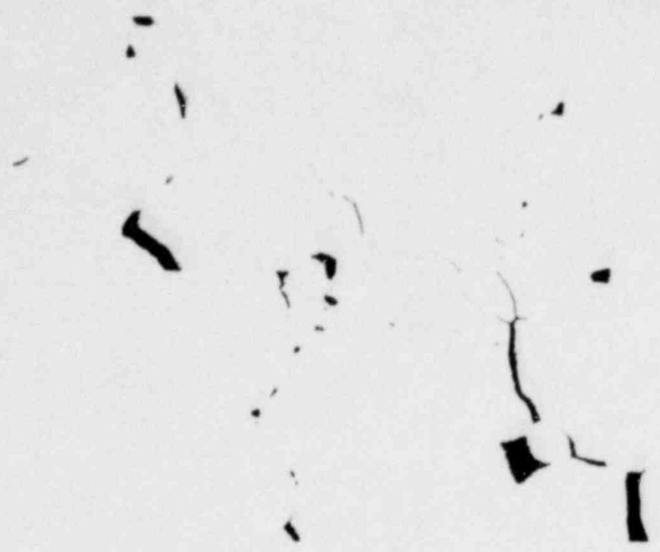
Sample No. 2

Fig. 2-2 The crack in sample No. 2. The arrows in (a) and (c) show the same area. (b) is a side view of (a).

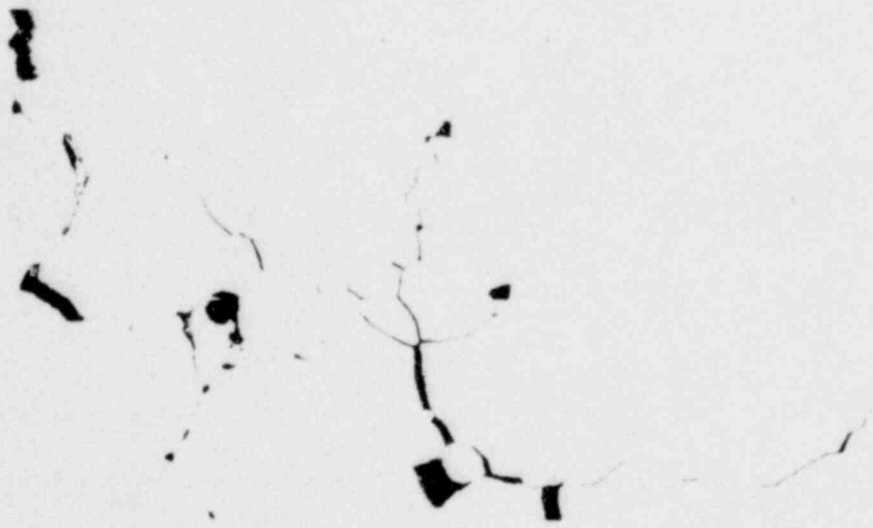
Electrolytic etch in 10% oxalic acid 15X

Specimen No. 211 (Sample No. 2)

Fig. 2-3 Macrograph of a section through the crack shown in Fig. 2-2.



(a) As polished 100X



(b) Light electrolytic etch in 10% NaCN 100X

Specimen No. 211 (Sample No. 2)

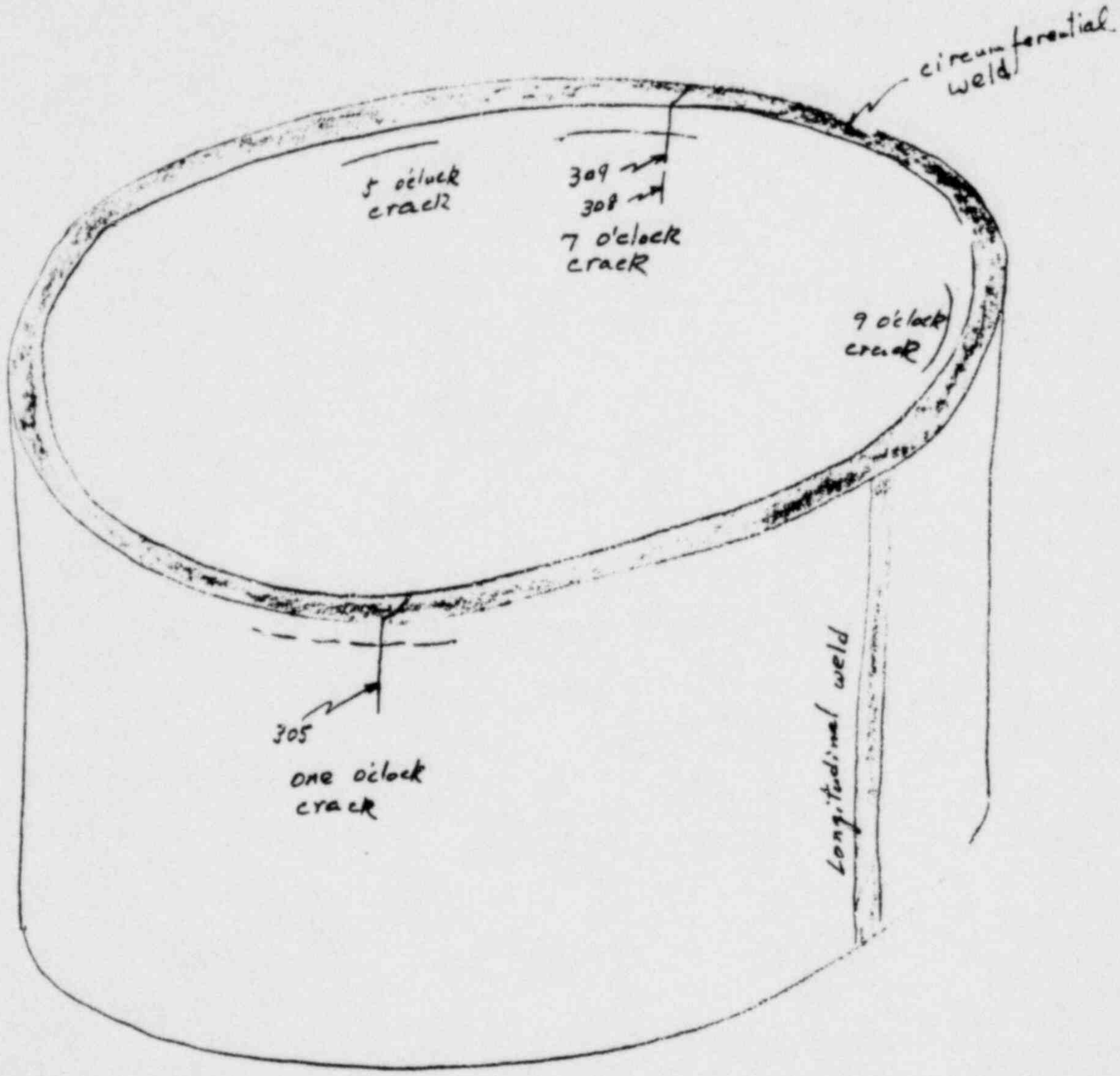
Fig. 2-4 Micrographs showing intergranular cracks marked by the arrow in Fig. 2-3.

Specimen No. 218 (Sample No. 2)

Fig. 2-5 Micrographs showing carbide precipitates in the base metal. Electrolytic etch in 10% oxalic acid.

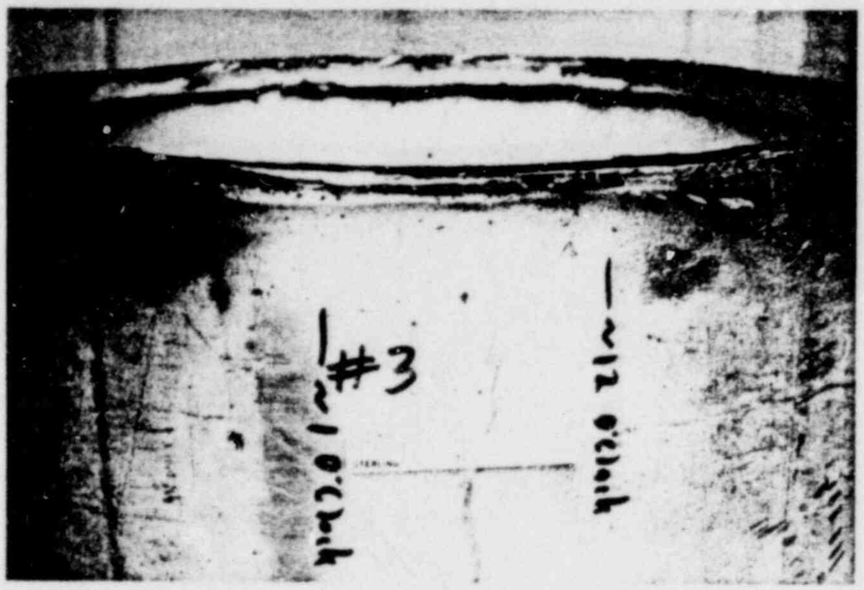
APPENDIX 3

PICTORIAL REVIEW OF CRACK No. 3

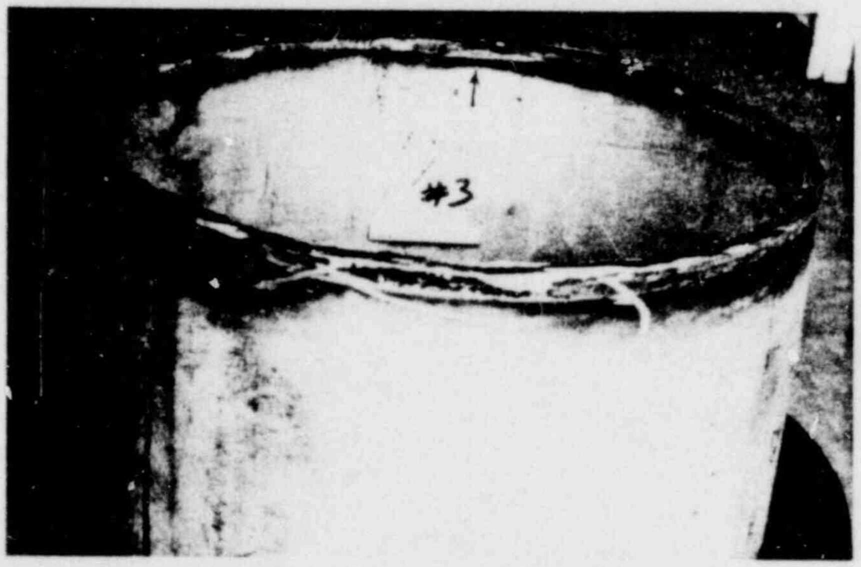


Sample No. 3

Fig. 3-1 Sketch showing the locations of cracks and metallographic specimens.



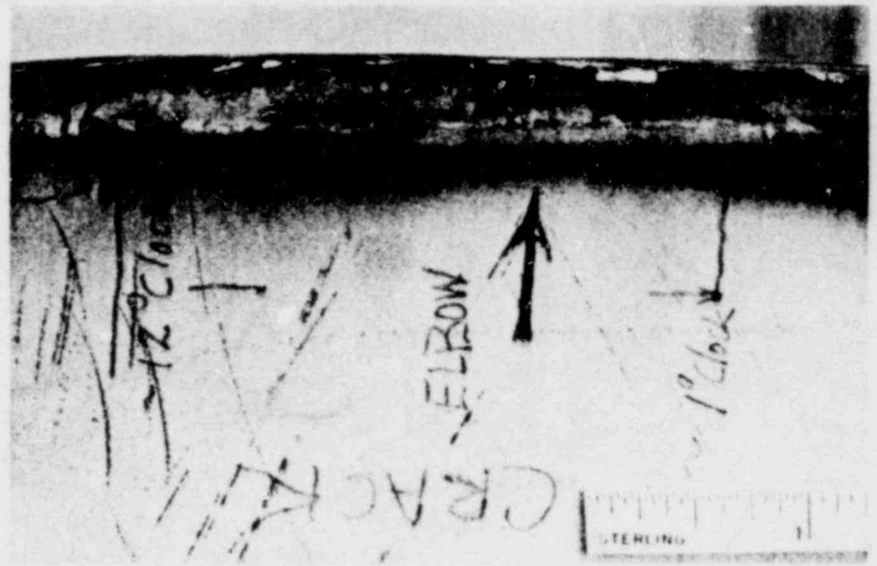
(a)



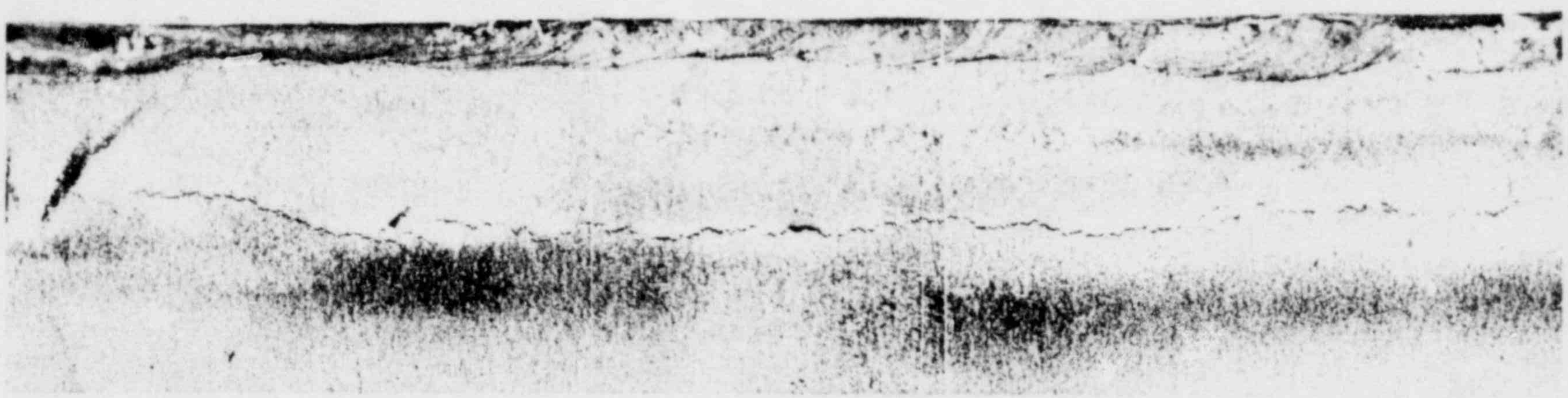
(b)

<u>Sample No. 3</u>

Fig. 3-2 The failed end of sample No. 3. (a) shows the same orientation as Fig. 3-1. (b) is a view from the opposite side. The arrows mark the through crack at the one o'clock position. Both the 12 o'clock and the 7 o'clock positions were flattened.



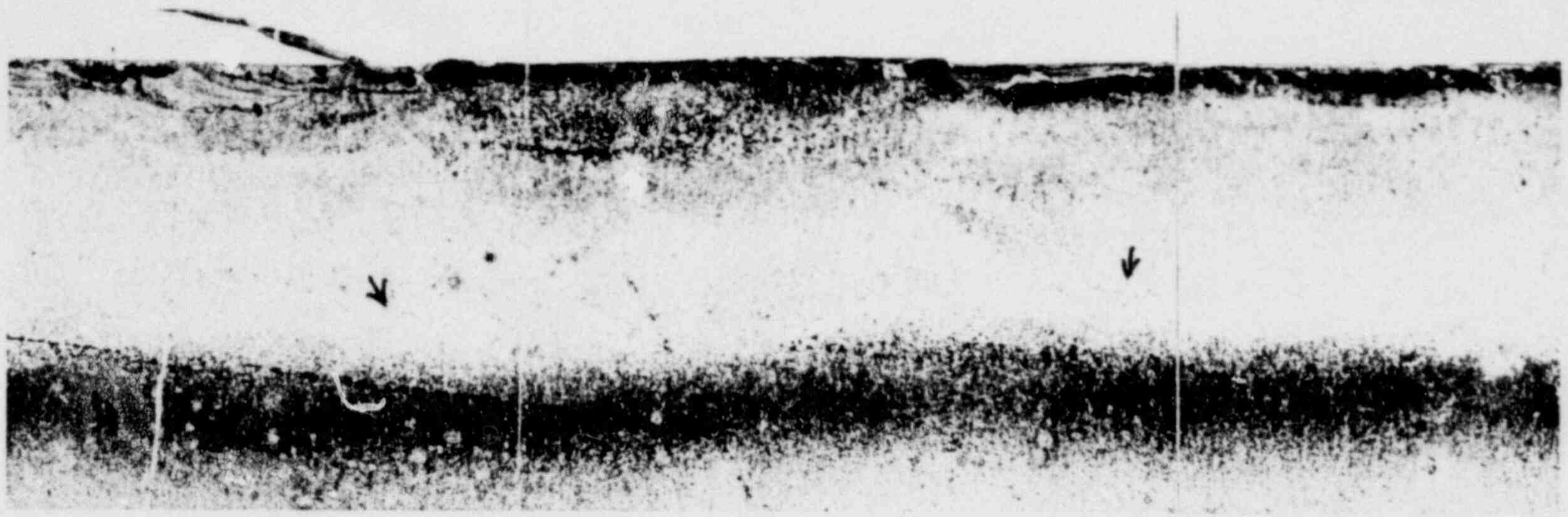
(a) One o'clock 1.5X



(b) One o'clock 4X

Specimen No. 301 (Sample No. 3)

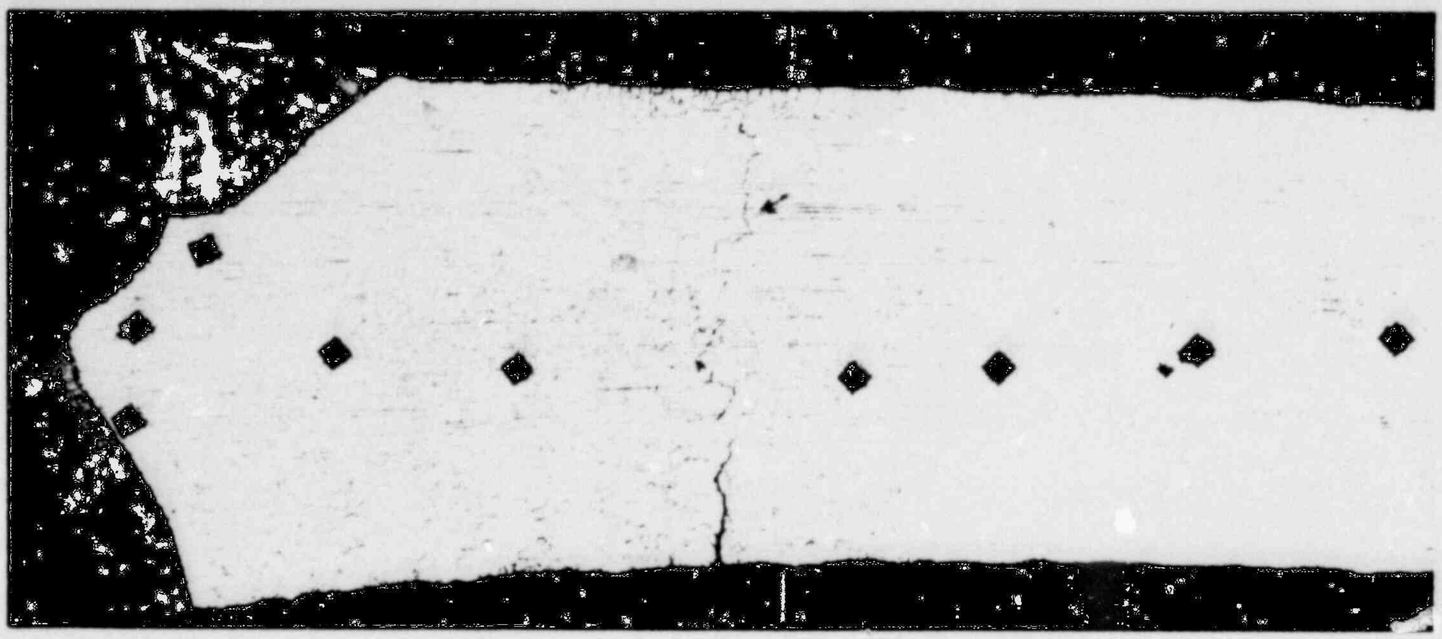
Fig. 3-3 The crack at one o'clock in sample No. 3 as viewed on the inside surface. This crack propagated through the wall.



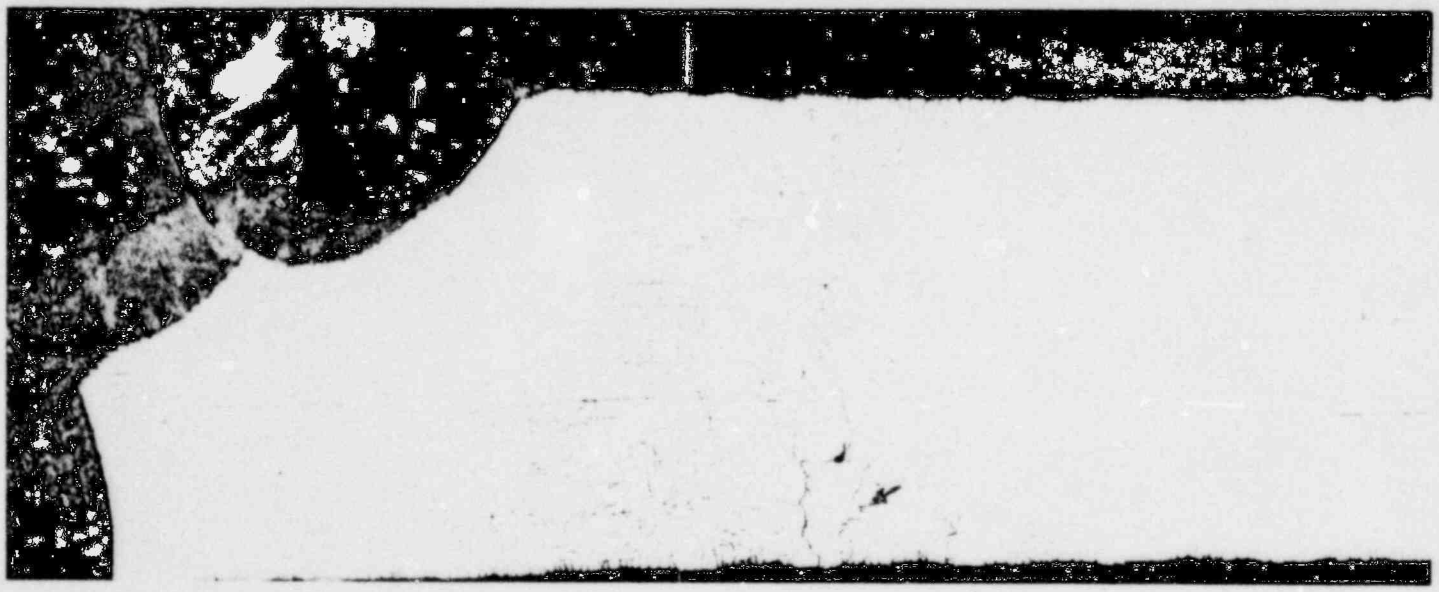
7 o'clock 4X

Specimen No. 303 (Sample No. 3)

Fig. 3-4 The tight crack at the 7 o'clock position as viewed on the inside surface. This crack did not propagate through the wall.



(a) Specimen No. 305 15X

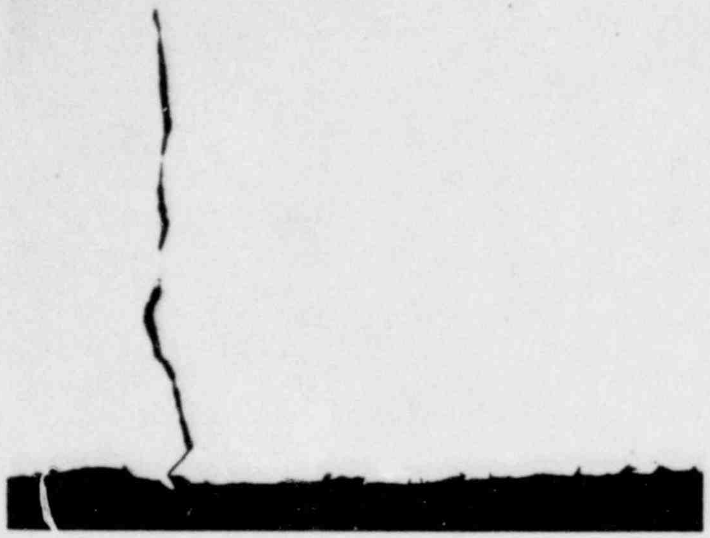


(b) Specimen No. 309 15X

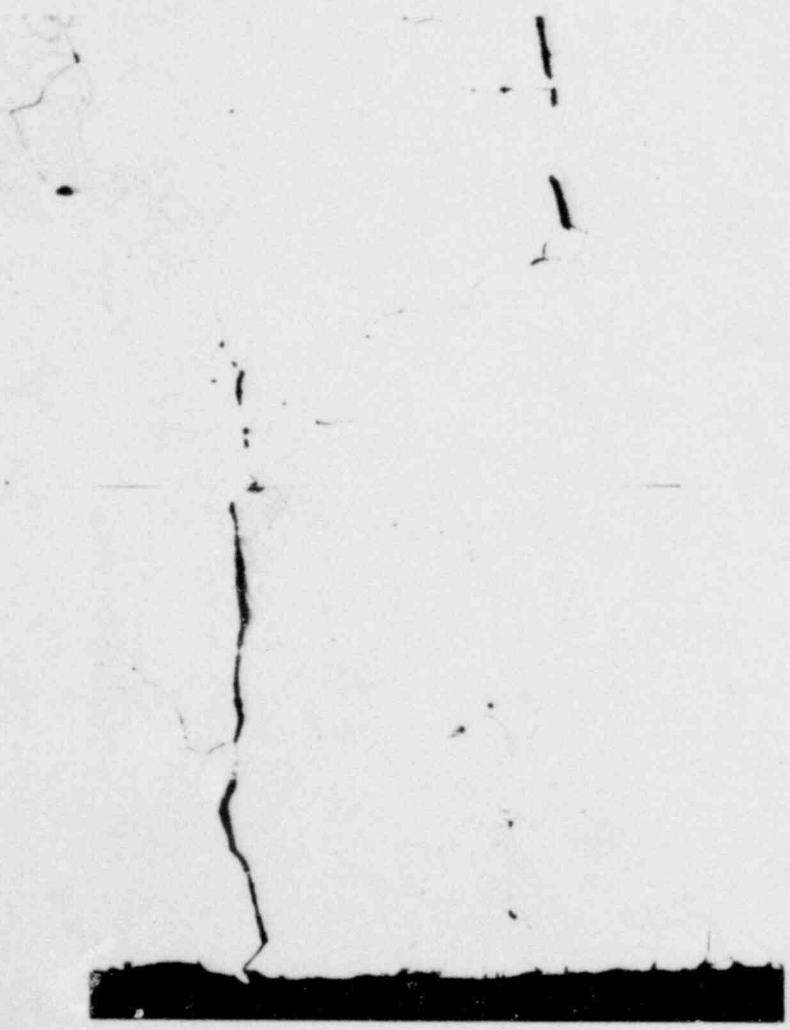
Sample No. 3

Fig. 3-5 (a) Macrograph showing a section through the crack in Fig. 3-3.

(b) Macrograph showing a section through the crack in Fig. 3-4. Both electrolytically etched in 10% oxalic acid.



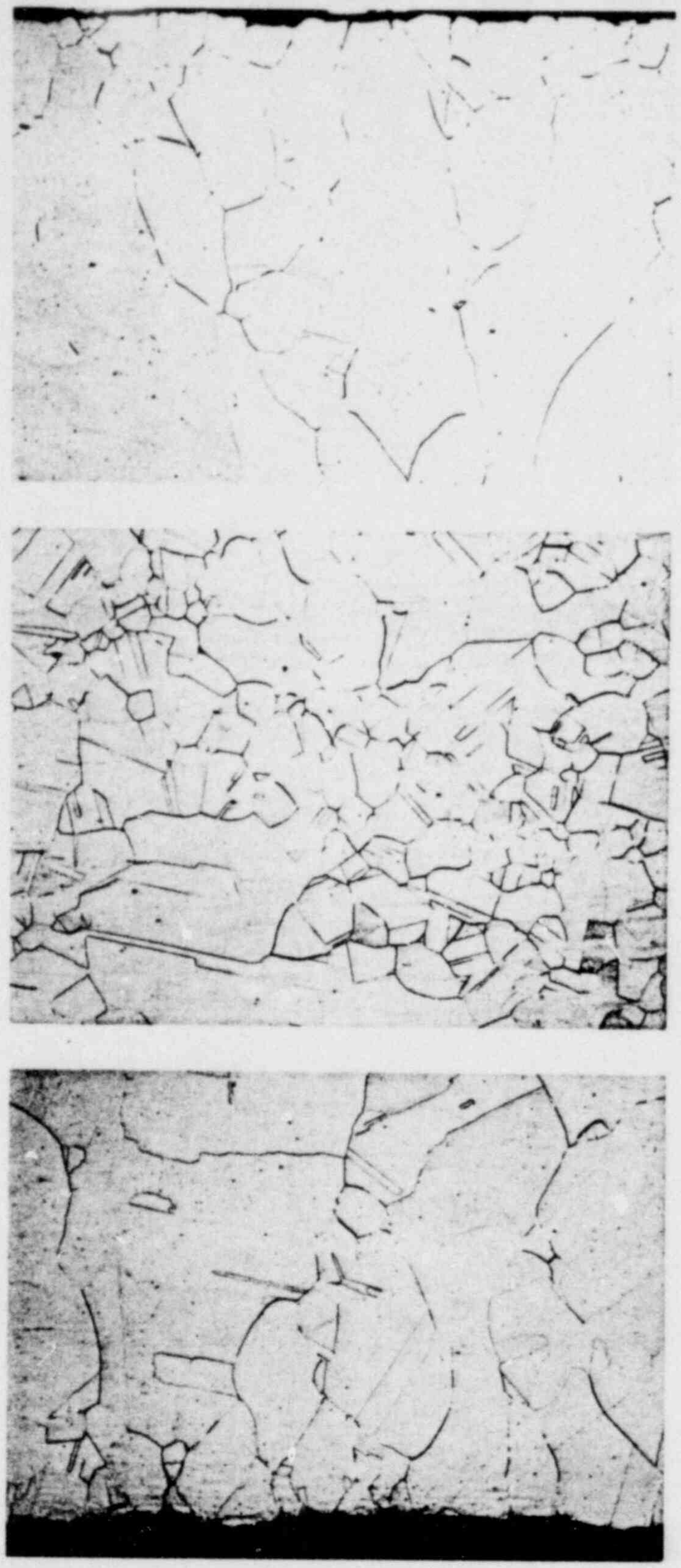
(a) As polished 100X



(b) Light etch in oxalic acid 100X

Fig. 3-6 Specimen No. 309 (Sampl- No. 3)

Micrographs showing the intergranular cracks marked by the arrow in Fig. 3-5 (b) after repolishing. The interference pattern in (b) was formed by the etchant that came out of the cracks.



Outside surface

Middle

Inside surface

100X

Specimen No. 323 (Sample No. 3)

Fig. 3-7 Micrographs showing carbide precipitates in the base metal. Etched electrolytically in 10% oxalic.