GPU Nuclear

TECHNICAL DATA REPORT

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PROJECT: Oyster Creek Nuclear Generating Station

DOCUMENT TITLE: Isolation Condenser System Piping Cracked Welds - Repair and Failure Analysis

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ABSTRACT:

Statement of Problem

Twenty-seven welds containing crack-like indications were discovered in the Isolation Condenser system piping outside containment. Determine the cause of the indications and repair the welds in a manner which will permit the system to be returned to service.

Summary of Key Results

1. Three welds were removed and destructively evaluated. The failure mechanism was concluded to be indicative of intergranular stress corrosion cracking. (IGSCC).

2. Nine of the affected welds were replaced; the remaining eighteen were repaired with weld overlay.

Conclusions

1. The Isolation Condenser system may be returned to service. The repair methods used will not adversely affect the system's operability and will not reduce safety margins.

Actions To Be Taken

1. Evaluate the use of the system piping as-repaired for more than one fuel cycle.

2. Perform augmented inspections, during the next scheduled outage, of stainless steel piping welds in systems susceptible to IGSCC.

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DOCUMENT NO.
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TITLE Isolation condenser system cracked welds-repair and failure analysis

REV	SUMMARY OF CHANGE	APPROVAL	DATE
1	1. The tense was changed from present and future to past on the following pages: 1-3 places 15-2 places 5-2 places 17-1 place 11-4 places 18-1 place 14-4 places 19-2 places	B.D. Elam R.T. DeMuth	9/11/84 9/11/84
	2. Page 10, Para. 2.3.3 and page 22, para. 3.3.2-Revised to include current information provided by Brookhaven. Also, identified that BNL report will be sent directly to NRC.	D.K. Croneberger	9.17.84
	3. Page 15, para. 2.4.3.3-Revised last sentence to reflect actual sequence of inspections.		
	4. Page 19, para. 2.5.2.3-Added results of evaluation of actual weld overlay shrinkage effects.		
	5. Pages 84-110, Appendix B-Final GE report on weld overlay design.		
	6. Page 91, Appendix B-Added " $\sqrt{\quad}$ " 2 places. Editorial correction.		
	7. Page 92, Appendix B-Added 3.6 to provide information requested by NRC.		
	8. Page 93, Appendix B-Added results of evaluation of actual weld overlay shrinkage.		
	9. Page 107, Appendix B-Added Table 7 summarizing information requested by NRC.		

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TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 This report describes GPUN's actions taken to return the Isolation Condenser system to service after the discovery of a leak in the Return Line piping outside containment.

1.2 Background

During a hydrost ic test of the "A" Condenser, water was seen dripping from the Return Line. The insulation was removed from the pipe in the area of the leak. The origin of the leak was from the pipe near weld NE-2-12. This pipe is 8-inch diameter, Schedule 80. All the piping in the Isolation Condenser system is made from Type 316 austenitic stainless steel.

1.3 Inspections

All piping welds in the Isolation Condenser system outside containment were inspected by ultrasonic testing (UT) techniques that have been shown to be capable of detecting intergranular stress corrosion cracking (IGSCC) and have been qualified to IE Bulletin 82-03.

Fifteen welds in the Isolation Condenser system inside containment and ten welds in the Reactor Water Cleanup system outside containment were ultrasonically inspected.

1.4 Inspection Results

There were 27 welds containing crack-like indications in the heat-affected zones in the Isolation Condenser system outside containment. A summary is shown below:

"A" Condenser

Supply Line - 8 welds

Return Line - 6 welds

"B" Condenser

Supply Line - 9 welds

Return Line - 4 welds

More detailed listings of these welds are provided in Tables I and II.

No crack-like indications were detected in welds in the Isolation Condenser system inside containment or in the Reactor Water Cleanup system outside containment.

1.5 Metallurgical Evaluations

Three of the affected welds, including the leaker, were removed from the Supply (NE-1-15, NE-1-61) and Return Lines (NE-2-12) and were sent to General Electric's Turbine Technology Laboratory and Brookhaven National Laboratory for metallurgical evaluation. The results of the evaluations revealed that the cracking was a result of intergranular stress corrosion.

1.6 Repairs

As a result of the inspections performed, it was decided to repair the welds containing crack-like indications by either replacement or weld overlay with the intent of returning the system to service without jeopardizing safety. Eighteen welds were repaired using the weld overlay method, and the remaining nine welds were removed and replaced with new piping material.

1.7 Overall System Evaluation

The performance and availability of the Isolation Condenser system is not altered by this repair process. Since the piping used for replacement and the welding techniques are superior to those originally used, and since the weld overlay repair restores the structural integrity of the pressure boundary, the overall system availability and reliability has actually been enhanced.

1.8 Conclusions

a) The cracking was a result of intergranular stress corrosion.

b) The repair methods used to correct the Isolation Condenser piping indications due to IGSCC are adequate to support system performance in a safe manner for at least one additional fuel cycle.

1.9 Actions to be Taken

a) Evaluate the adequacy of the repaired piping for service beyond one fuel cycle.

b) Perform augmented inspections, during the next scheduled outage, of stainless steel piping welds in systems susceptible to IGSCC.

c) Plant operating procedures will be reviewed and revised as necessary to preclude the potential for water hammer in the steam lines and to minimize the thermal cycle loading on Isolation Condenser system.

2.0 METHODS

2.1 Introduction

This section describes the methods used to perform 1) inspection of welds, 2) metallurgical evaluations, 3) repairs of cracked welds, and 4) overall evaluation of the repaired system.

2.2 Inspections

2.2.1 Sampling

2.2.1.1 Isolation Condenser System

After the leak was detected, ultrasonic inspections were performed on 100% (124) of the butt welds outside containment and 32% (15 of 47) of the butt welds inside containment. The number of welds inspected inside containment is consistent with the sampling requirements of the ASME Code and the NRC.

2.2.1.2 Other Systems

Ten welds in the Reactor Water Cleanup system piping outside containment were inspected. Six welds were located in the inlet line;

four were located in the return line. This system was inspected since it is environmentally similar (temperature, pressure) to the Isolation Condenser System.

2.2.2 Inspection Methods

The welds were inspected using ultrasonic techniques (Reference 1) shown to be capable of detecting IGSCC in austenitic stainless steel and qualified to IE Bulletin 82-03.

Radiography was also used to evaluate indications detected by ultrasonics.

2.2.3 A report of the inspection methods is provided in Reference 2.

2.3 Metallurgical Evaluations

2.3.1 Introduction

GPUN removed three spool pieces containing crack-like indications from Isolation Condenser system piping for shipment to laboratories for metallurgical evaluation.

One piece contained welds NE-2-12 (the leaker) and NE-2-13 from the "A" Return Line. Another contained weld NE-1-15 from the "A"

Supply Line. The last piece contained weld NE-1-61 from the "B" Supply Line. The locations of these samples in the system are shown in Figures 2, 3, and 4.

Weld NE-2-12 (the leaker) contained one through-wall crack and one crack-like indication (Figure 1).

Welds NE-1-61 and NE-2-12 were identified to be field welds; NE-1-15 and NE-2-13 were identified to be shop welds.

General Electric's (GE) Turbine Technology Laboratory, GPUN's contractor, evaluated NE-1-15, NE-2-15, and the bottom half of NE-2-12.

Brookhaven National Laboratory (BNL), the NRC's contractor, evaluated NE-1-61 and the top half of NE-2-12.

2.3.2 GE Evaluation

Samples from NE-1-15 and NE-2-12 were examined using Scanning Electron Microscopy (SEM) and metallography.

NE-2-13 was liquid penetrant inspected on the inside surface.

Chemical analysis was performed on one sample, each, removed from wrought material adjacent to NE-1-15 and NE-2-12.

Details of the GE evaluation can be found in Appendix A.

2.3.3 BNL Evaluation

BNL is performing fractographic and metallographic evaluations of samples from NE-1-61, the top half of NE-2-12, and the bottom half of NE-2-12 (the leaker, forwarded from GE). Sensitization tests of the base material per ASTM A262 and EDS scans of the fracture faces for contaminants are also being performed.

A formal report detailing BNL's evaluation methods will be released directly to the NRC.

2.4 Repairs

2.4.1 Introduction

Based on the metallurgical evaluation and the nondestructive testing performed on the Isolation Condenser system piping, it was decided to repair all the welds containing crack-like indications with the intent of returning the system to service for at least one fuel cycle without sacrificing safety. The entire piping system outside the drywell will be evaluated before and during next refueling outage to determine the adequacy of the repair beyond one cycle.

There were a total of 27 welds containing crack-like indications, 17 in the Supply lines and 10 in the Return lines, all of which were repaired by either replacement or weld overlay. Based on the samples removed and weld locations, 18 welds were repaired using the weld overlay process and the remaining 9 welds were physically removed and replaced by new piping or fittings, as necessary.

Of the eighteen welds that were overlaid, six are pipe-to-pipe and twelve are pipe-to-elbow butt welds.

2.4.2 Replacement

Replacement piping and fittings were ordered to lower than normally allowable carbon content for the original material used. The original piping was bought in accordance with Burns and Roe Specification 2299-S60 and was ASTM A 312 or 376 Grade 316. Piping replacement was purchased to ASME SA-312 Type 316 seamless with carbon content not to exceed 0.05%. Fittings were also purchased to ASME standards (ASME SA-403 Type 316) with 0.05% max. carbon. Additionally, 12" pipe was purchased to ASME SA-358 Type 316 (nuclear grade stainless steel with 0.02% maximum carbon content).

The welding process used for the repair defined low heat input welding which, together with the lower than previously specified carbon content, minimizes the possibility of IGSCC. Additionally, the welding procedures included the requirements of the NRC Regulatory Guides 1.31 and 1.44.

The original piping design code appears to be Section I of ASME per B&R specification 2299-S60, whereas the replacement piping is to be in accordance with ASME Section III Subsection NC(Class 2) which is considered superior to original code.

2.4.3 Weld Overlay

2.4.3.1 Introduction

The weld overlay is a repair method by which filler metal compatible with the matching pipe is deposited on the pipe outside diameter to restore the piping structural integrity.

2.4.3.2 Design

The weld overlay is an NRC-accepted piping repair* method and is designed in accordance with ASME Section XI paragraph IWB-3640. The design was conducted by General Electric under contract from GPUN and the design/stress analysis is documented in Appendix B.

* Inspection of BWR Stainless Steel Piping (Generic letter 84-11) dated April 19, 1984

The weld overlay designs for repair of the Isolation Condenser system piping were determined based on maintaining the ASME Code required factor of safety against net section collapse of the overlaid welds. The minimum required weld overlay thicknesses were obtained assuming the flaws to be fully circumferential and to extend through the original pipe wall. The applied primary loads used in the thickness calculations were enveloped to provide further conservatism and generality in the designs. The minimum thicknesses do not include the first weld layer, which must pass liquid penetrant examination, or possibly the second layer if the first has a measured ferrite number of less than 8FN. The overlay widths were sized to optimize the amount of welding time and material necessary to provide the required structural reinforcement of the flawed weld regions.

The criterion used in design of the weld overlays for the Isolation Condenser system piping was to provide full structural reinforcement of the cracked region. In evaluation of the overlay designs, it was conservatively assumed that the flaws are fully circumferential and extend through the susceptible material of the original pipe wall. With this assumption, no credit was taken for the beneficial compressive residual stresses induced by the heat sink weld overlay process that would oppose crack extension through the thickness. The postulated through-wall cracks also provide assurance that the overlay design is independent of the crack size as determined by the ultrasonic testing. IGSCC propagation into the weld overlay material beyond the first layer is considered to be unlikely since the weld material (low carbon, high ferrite) beyond the first layer is resistant to IGSCC.

Detail design analysis, assumptions and results are documented in Appendix B.

2.4.3.3 Application

The weld overlay process was implemented via Reference 3 at Oyster Creek. To minimize weld shrinkage resulting from the overlay process and, therefore, reduce stress, cooling water is flowed through the pipe. An actual field mock-up test verification was set up to insure that cooling water flow rates obtainable in the field were sufficient to insure adequacy of the weld overlay process and resultant shrinkage.

All weld overlays were applied in accordance with a procedure qualified in accordance with ASME Code Sections IX and XI. The effective overlay thickness was deposited after the first overlay layer having a ferrite number of 8FN, or higher, as determined with an instrument meeting the requirements of AWS A4.2 (Reference 4). The overlay dimensions and shrinkage were determined with before-and-after dimensional measurements. Liquid penetrant examination was performed on the pipe surface, before welding, the first layer with a ferrite number of 8FN or higher, and the last layer of the overlay. Radiography was performed on the finished weld overlays to verify their integrity.

2.5 Overall System Evaluation

2.5.1 System Performance

The repair process does not affect, in any way, the operation of the Isolation Condenser system, since the piping is replaced with similar material and pipe schedule and the overlay is applied to the piping outside diameter. The amount of shrinkage expected due to the overlay process is considered insignificant in affecting the flow through the piping in an accident mitigation function. Valve operability (containment isolation) and condenser performance are not affected by this modification.

2.5.2 Stress Analysis

2.5.2.1 Overall Discussion

The original system stress analysis was performed by the architect engineer (Burns & Roe) and included the then defined seismic loading in addition to the normal deadweight and thermal loads. It is apparent from the design drawings that cold spring was used to improve the stress characteristics of the system, yet the calculations did not take credit for them, nor were they found when the sample spool pieces were removed.

Subsequently, EDS Nuclear performed another stress evaluation of the Isolation Condenser system piping and found it to be adequate (Reference 5).

As a result of the indications found, the repair process, the above mentioned cold spring question, and the revised (higher) seismic loads as a result of the Systematic Evaluation Program (SEP) for Oyster Creek (Reference 5), GPUN's consultant, MPR, performed a new analysis on the entire Isolation Condenser system outside the drywell (Reference 6).

The analysis was based on deadweight, design pressure (1250 psig), thermal loads (70°F to 550°F), anchor displacements due to drywell penetration movement, and seismic loads based on the SEP criteria (Reference 7) using Reg. Guide 1.61 damping values for OBE and SSE.

The load combination used was based on ASME Section III, NC-3650 equations 8, 9 and 10 respectively, and the resulting stresses still meet ANSI B31.1 code allowable stress.

Waterhammer loads were specifically not included for two distinct reasons:

1) No evidence of waterhammer was evident from the operational data at Oyster Creek, and

2) Procedural guidance is provided to the operators to maintain shell side emergency condenser water level within a given band, such that the probability of waterhammer is minimized.

The results of the analysis concluded that the Isolation Condenser system piping is adequate "as is" without any modifications and without need of any cold springs and, therefore, was reinstalled without adding cold spring (for replacement piping).

2.5.2.2 Cycle Fatigue

An analysis (Reference 8) was performed prior to the destructive testing of the metallurgical sample to try to determine the cause of the leakage in the NE-2-12 joint. Cycle fatigue was considered as one of the possible causes. However, the analysis concluded that the Isolation Condensers were used 33 times (A) and 36 times (B). The exact number of cycles used each time the condenser was put into service is not known since it would require a large amount of time to evaluate the strip charts from plant initial operation to present, but even if 100 cycles per use is conservatively assumed the total number of cycles is still less than the 7000 cycles identified by ANSI B31.1 as not being considered significant in the stress analysis (i.e. stress range reduction factor = 1.0 per ANSI B31.1 Table 102.3.2(c)). Therefore, cycle fatigue is not considered a contributor to the leakage.

2.5.2.3 Cold Spring

As discussed above, the original design drawings show various degree of cold spring being applied to the Isolation Condenser system piping for both Supply and Return lines outside the drywell; however the AE analysis did not consider it in their analysis. A re-analysis without cold spring performed by MPR concluded that cold spring is not required, and the replacement piping was installed without any cold spring. It appears that cold spring was not a contributor to the piping cracks. No credit was taken for the beneficial compressive residual stresses induced by the heat sink weld overlay process that would oppose crack extension through the thickness.

2.5.2.4 Shrinkage Stress Due to Weld Overlay Application

Application of a weld overlay produces an axial contraction of the pipe which is a function of the pipe size and the overlay thickness and width. This shrinkage imposes stresses on the entire piping system. The amount of shrinkage was estimated by GE based on typical shrinkages observed in similar weld overlay applications performed by GE. The shrinkage effect was simulated by forcing thermal contractions at the weld overlay locations equivalent to the assumed overlay shrinkage. The shrinkage stresses obtained were low due to the overall flexibility of the piping system; the piping is supported mainly through hangers and snubbers. The actual weld overlay shrinkages were measured and compared to the assumed values. Variations were re-evaluated to determine the significance of the deviation from the assumed shrinkages. It was concluded that the actual shrinkage had no adverse effect on the system piping.

2.5.2.5 Weight Effects of Weld Overlays

The effects of the weld overlay weight on the stress analysis, including seismic, is considered insignificant since the weight added is of the same magnitude or less than, the pipe fabrication weight tolerance and is very localized over a narrow area.

3.0 RESULTS

3.1 Introduction

This section provides the results of the various efforts described in Section 2.

3.2 Inspections

3.2.1 Isolation Condenser System

Outside containment, ultrasonic inspection revealed that 27 (22%) welds contained crack-like indications. Of these, 19 were confirmed by additional ultrasonic examination and/or radiography. The remaining eight (8) were classified as "suspect", because they could not be either confirmed as cracks or classified as geometric reflectors.

Tables I ("A" Condenser) and II ("B" Condenser) list the defective welds and other pertinent information.

Figures 2, 3, 4, and 5 show the locations of the defective welds.

Inside containment, none of the welds inspected contained crack-like indications.

3.2.2 Other Systems

None of the welds inspected in the Reactor Water Cleanup system contained crack-like indications.

3.2.3 A report of the inspection results is provided in Reference 2.

3.3 Metallurgical Evaluations

3.3.1 General Electric

Fractography of the crack surface of welds NE-2-12 (the leaker) and NE-1-15 revealed an intergranular surface on both.

Metallography of NE-2-12 and NE-1-15 revealed that both had cracks that were intergranular and adjacent to the weld bead. And, in NE-2-12, metallography revealed a second crack in the base material between the weld bead and the leaking crack. All the cracks were located within the heat-affected zone of the weld.

Liquid penetrant examination on the ID surface of NE-2-13, a "suspect" weld, revealed no indication in the region of the ultrasonic indication.

Chemical analysis of wrought material adjacent to NE-2-12 and NE-1-15 verified the material as being Type 316 stainless steel.

Details of the results, including photographs, are provided in Appendix A.

3.3.2 BNL

BNL has not yet completed their evaluations. However, BNL reported that EDS scans of the fracture face of the leaker (bottom half of NE-2-12) revealed no contaminants considered to be contributory to IGSCC.

BNL's results will be provided in a formal report released directly to the NRC.

3.4 Repairs

The repair process used, replacement or weld overlay, is considered adequate for safe operation of the Isolation Condenser system at Oyster Creek for at least one fuel cycle without any loss in factors of safety.

The nondestructive examinations performed on the existing and repaired pipe together with the repair process assures safe plant operation.

3.5 Overall System Evaluation

The repair process did not and will not affect system performance and availability. As a matter of fact, the repair process together with the additional NDE and piping support verification, provide additional assurance of system reliability and availability.

4.0 CONCLUSIONS

4.1 Repair Effort

The repair effort, replacement and weld overlay, is a satisfactory method to return the Isolation Condenser system to service in a safe and reliable way.

4.2 Metallurgical Evaluation

4.2.1 The cracking was circumferentially oriented intergranular stress corrosion in the weld heat-affected zone.

4.2.2 No firm conclusions regarding the eight "suspect" welds could be reached. For conservatism, we treated these welds as being cracked welds and repaired each one.

4.3 Overall System Evaluation

The overall Isolation Condenser system performance and availability are not being lessened by the repair process but, in fact, are enhanced since the probability of system unavailability due to IGSCC-induced leakage has been reduced.

5.0 ACTIONS TO BE TAKEN

1) Evaluate the piping in the Isolation Condenser system outside the drywell before and during the next refueling outage for adequacy for service beyond one fuel cycle.

2) Perform augmented inspections, during the next scheduled outage, of stainless steel piping welds in piping systems susceptible to IGSCC.*

* A response to Generic Letter 84-11 addressing these examinations is in preparation.

3) Plant personnel shall be instructed to minimize the use of emergency condensers to emergency use only and not for normal plant cooldown such that the cyclic loading is minimized.

4) Verify plant procedures to ensure that the probability of waterhammer is minimized by controlling the water level in the emergency condensers.

6.0 REFERENCES

1) GPUN Procedure MTIS-008 Rev. 4: "Ultrasonic Examination of Piping Welds 0.2" - 6.0" in Thickness."

2) GPUN Report No. 6153-ISI-84-001: "Oyster Creek Isolation Condenser System Augmented Examination Program" (to be issued).

3) GE Process Specification P50YP225 Rev. 1: Thin Weld Overylay for Austenitic Stainless Steel Piping Welds; with ECN NH18401.

4) AWS A4.2-1974: "Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austentic Stainless Steel Weld Metal."

5) Oyster Creek Isolation Condenser System Piping Stress Report, prepared by EDS Nuclear, November 1979, EDS Report No. 02-0370-1021

6) MPR 830: "Analysis of Emergency Condenser Piping Outside Containment", dated July 1984.

7) NUREG/CR-1981 "Seismic Review of the Oyster Creek Nuclear Power Plant as Part of the Systematic Evaluation Program", dated April 1981

8) MSS-84-166 "Oyster Creek Emergency Condenser Leakage Investigation", dated April 17, 1984

7.0 TABLES

Table I

"A" Condenser Piping Welds with Crack-like Indications

Weld Number	Supply(S) or Return (R) Line	Pipe Diameter (In)	Weld Type (1)	Component Type (2)	Repair Method (3)
NE-1-2(*)	S	16	S	P-P	O
NE-1-11	S	12	F	P-E	O
NE-1-13	S	12	S	P-P	O
NE-1-15	S	12	S	P-E	R
NE-1-20(*)	S	12	S	P-P	O
NE-1-25	S	12	S	P-P	O
NE-1-29	S	12	S	P-P	O
NE-1-32	S	12	S	P-E	O
NE-2-4(*)	R	8	S	P-E	O
NE-2-8	R	8	F	P-E	O
NE-2-12	R	8	F	P-E	R
NE-2-13(*)	R	8	S	P-E	R
NE-2-17(*)	R	8	S	P-E	O
NE-2-28	R	8	F	P-E	O

* - "Suspect" (see 3.2.1)

Notes:

1) S = Shop, F = Field
2) P = Pipe, E = Elbow
3) O = Overlay, R = Replace

Table II

"B" Condenser Piping Welds with Crack-like Indications

Weld Number	Supply(S) or Return (R) Line	Pipe Diameter (In)	Weld Type (1)	Component Type (2)	Repair Method (3)
NE-1-37	S	16	S	P-R	R
NE-1-38	S	16	S	P-P	R
NE-1-39A	S	16	(4)	P-P	R
NE-1-40	S	16	S	P-E	R
NE-1-41	S	16	S	P-E	R
NE-1-46	S	12	S	P-E	O
NE-1-51	[illegible]	12	F	P-E	O
NE-1-54A	S	12	(4)	P-P	O
NE-1-61	S	12	F	P-E	R
NE-2-80(*)	R	8	S	P-E	O
NE-2-91(*)	R	8	S	P-E	O
NE-2-98	R	8	S	P-E	O
NE-2-103(*)	R	10	S	P-P	O

* - "Suspect" (see 3.2.1)

Notes:

1) S = Shop, F = Field
2) P = Pipe, E = Elbow, R = Reducer
3) O = Overlay, R = Replace
4) Weld type is unknown. Weld records cannot be located. Most likely, these two welds are field welds.

8.0 FIGURES

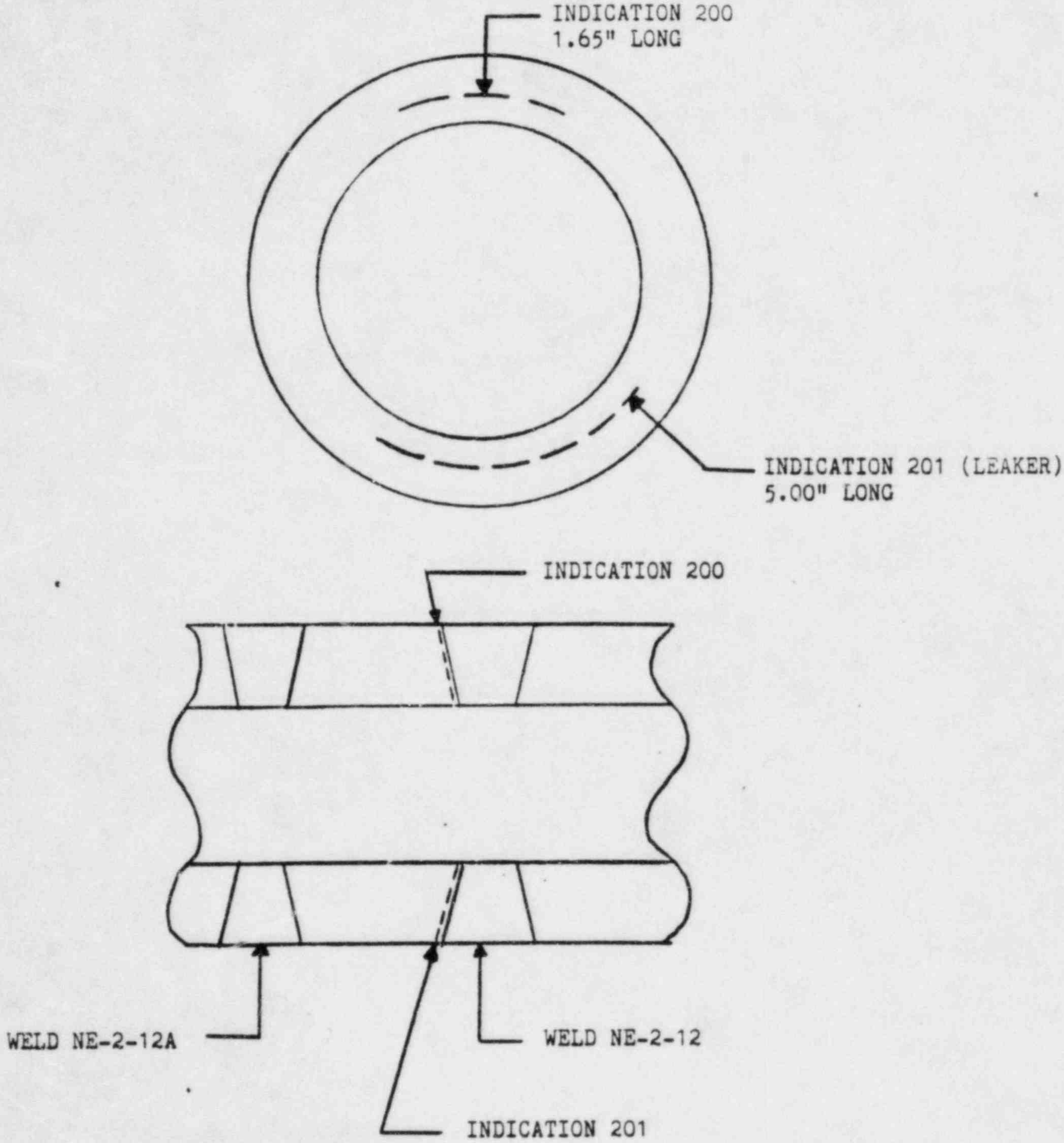

FIGURE 1- Defects in Weld NE-2-12

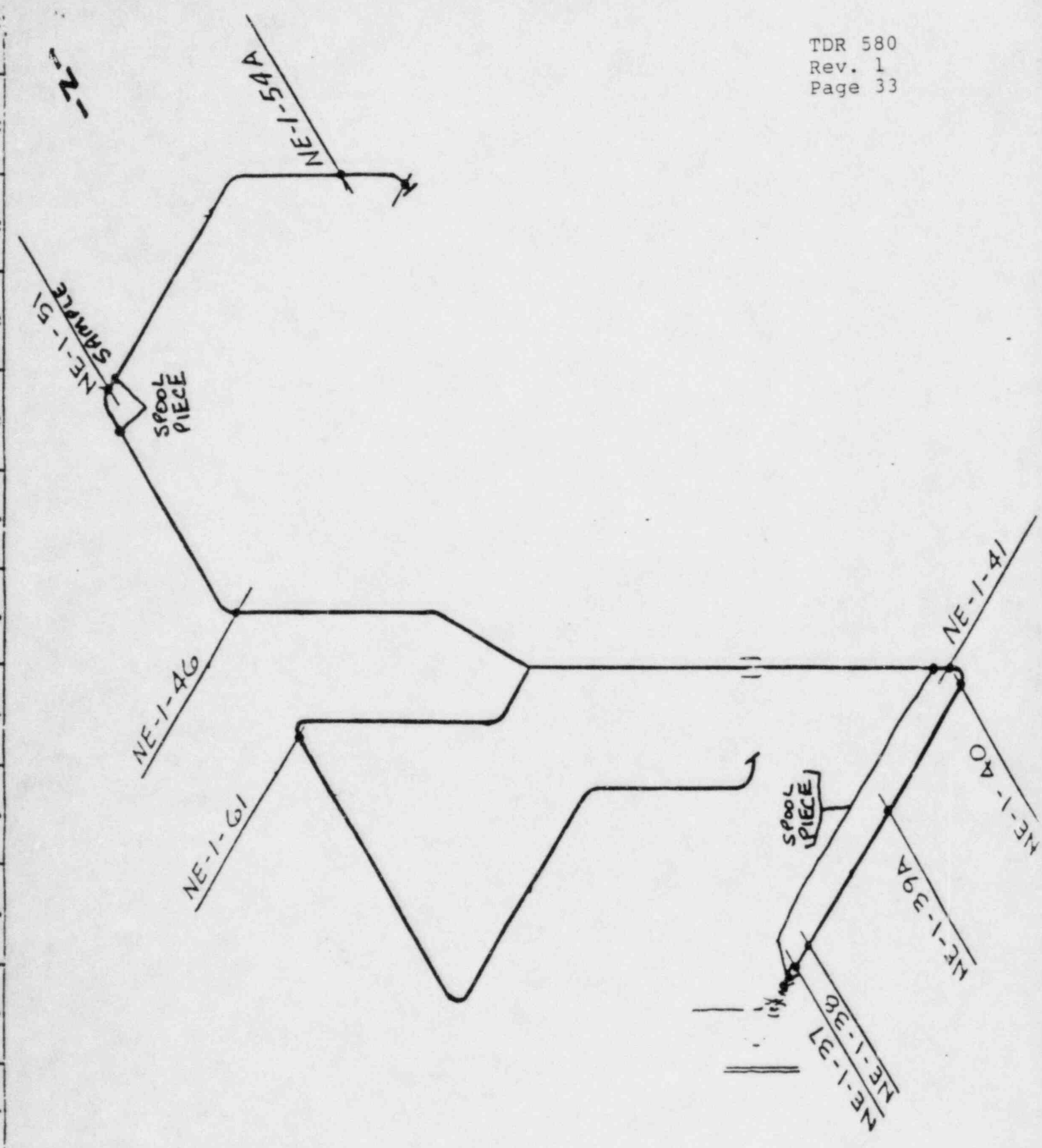

FIGURE 2- 'A' Supply Line, Defective Welds

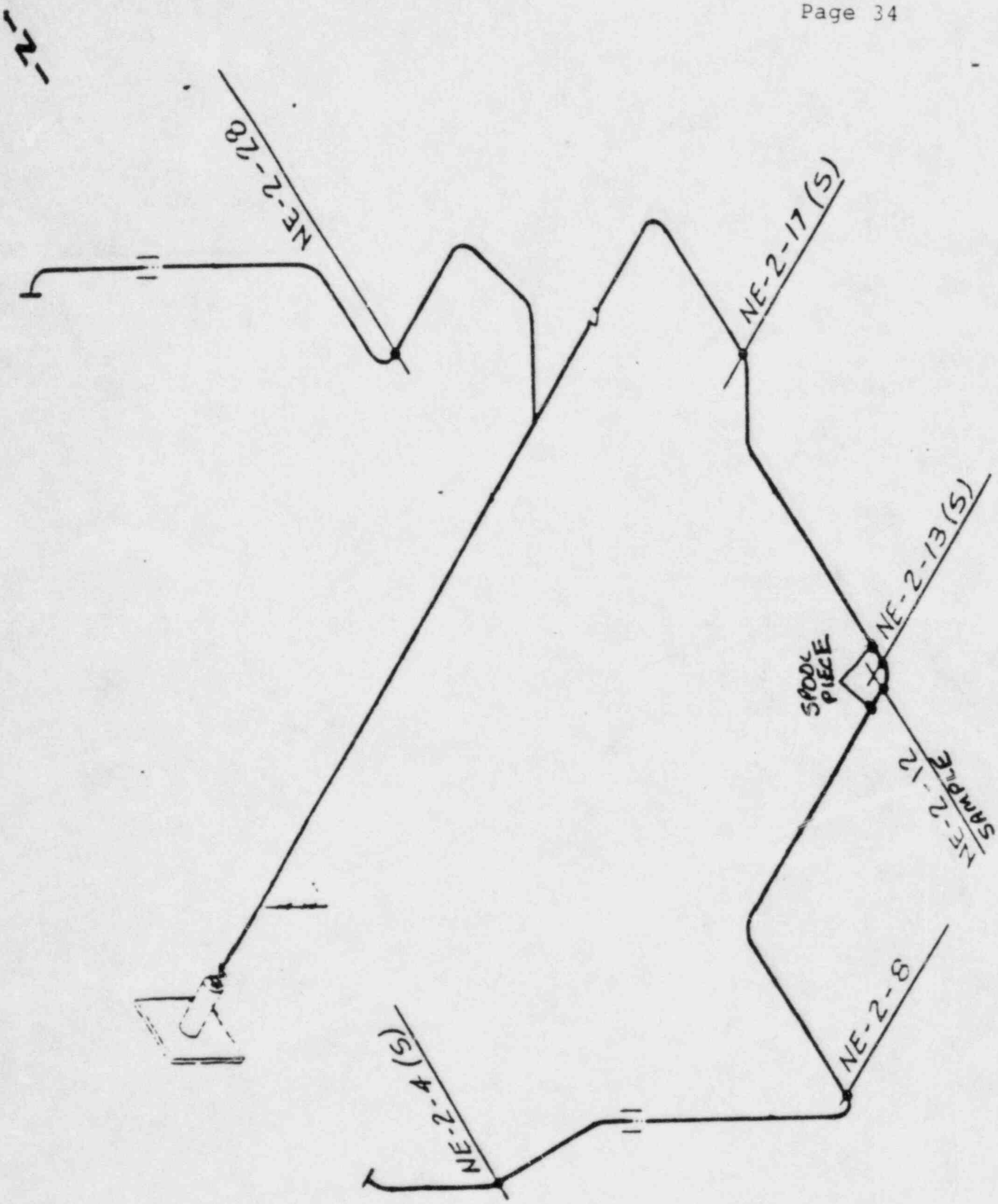

FIGURE 3- 'A' Return Line, Defective Welds

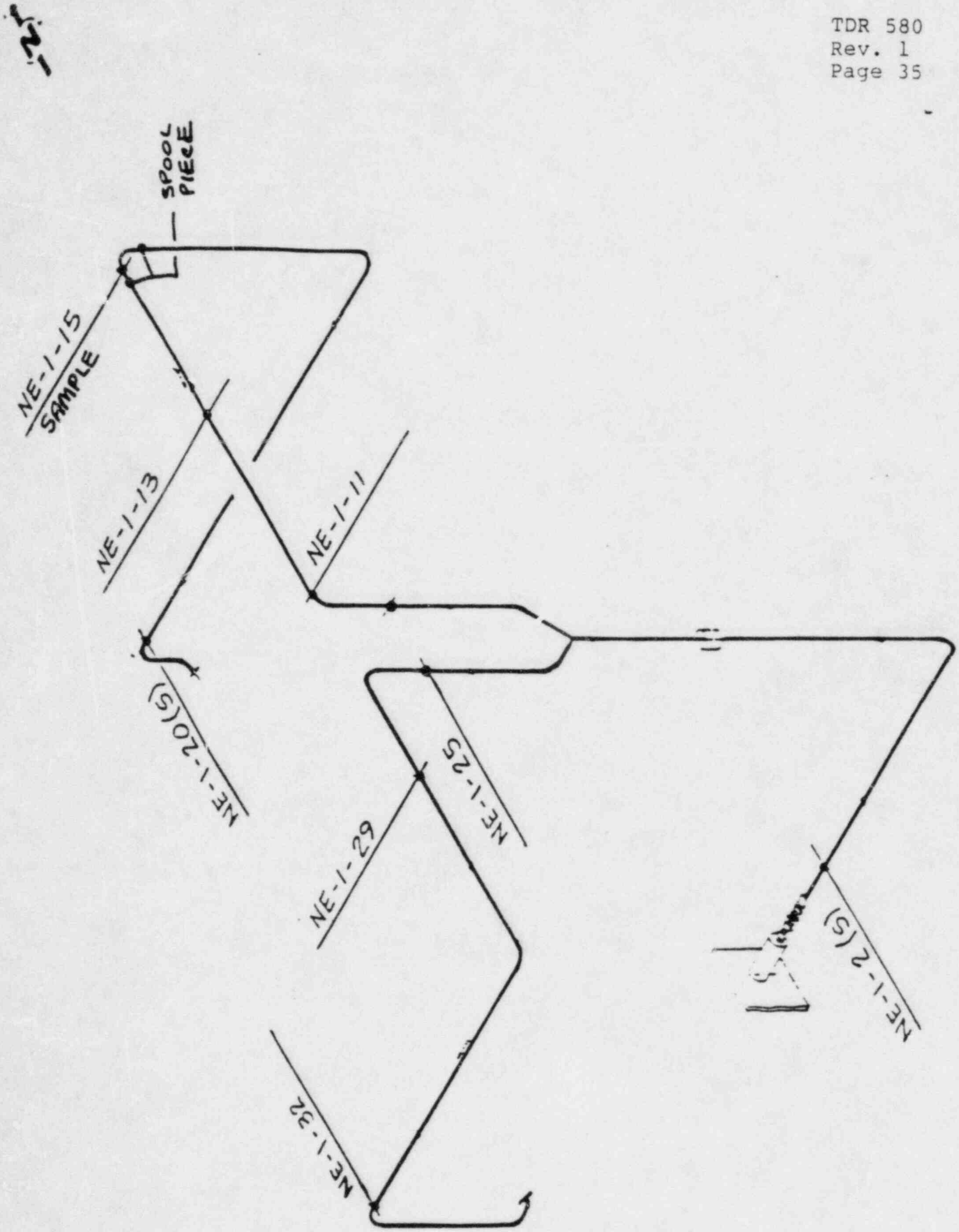

FIGURE 4- 'B' Supply Line, Defective Welds

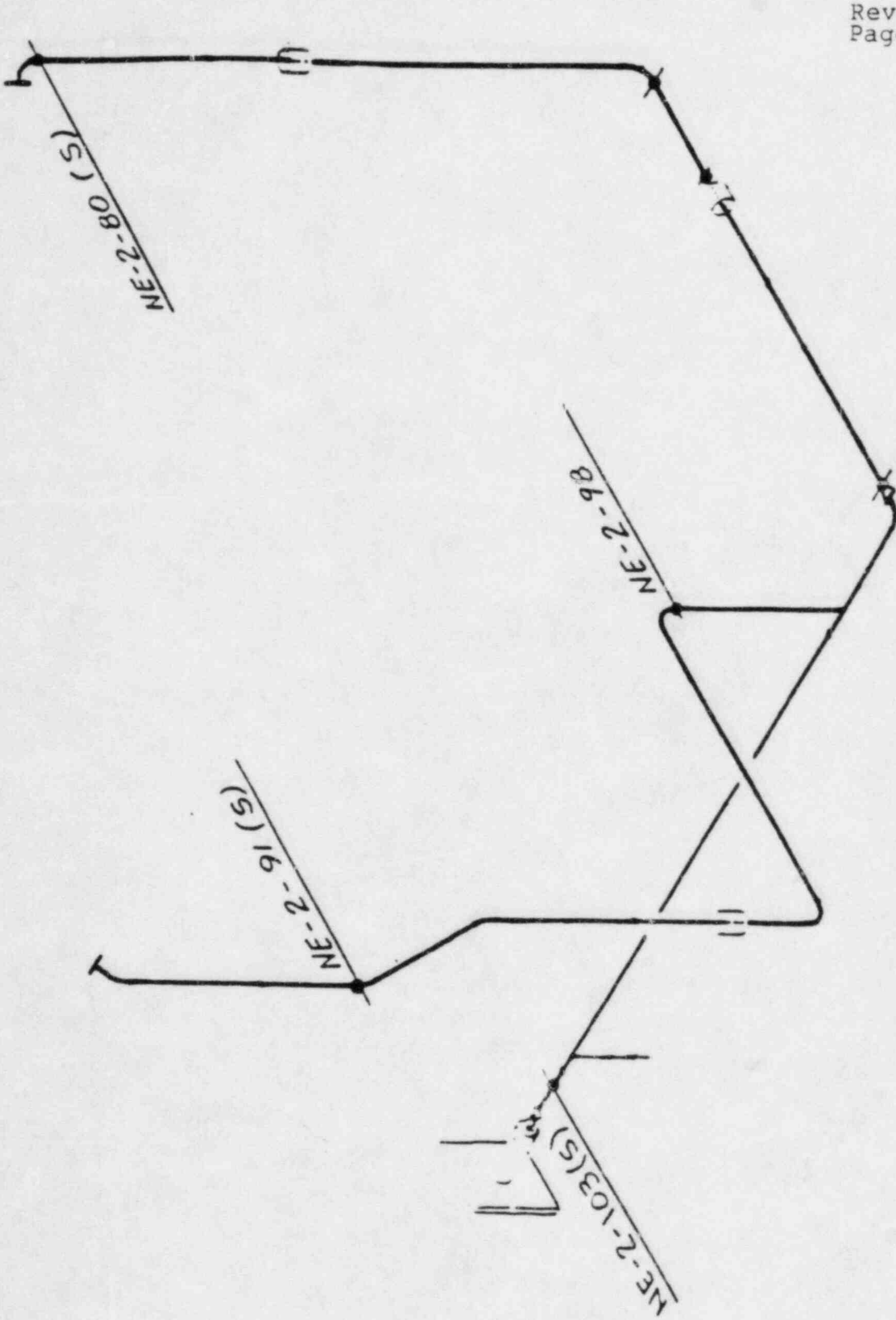

FIGURE 5- 'B' Return Line, Defective Welds

9.0 APPENDICES

A - GE Metallurgical Evaluation Report
B - GE Weld Overlay Design Report

Appendix A

GE Metallurgical Evaluation Report

NUCLEAR ENERGY
BUSINESS OPERATIONS

GENERAL ELECTRIC

P.M.T. TRANSMITTAL
NO. 178-84-015

DRF NO.

PLANT MATERIALS TECHNOLOGY

FAILURE ANALYSIS OF OYSTER CREEK ISOLATION CONDENSER PIPING

DATE: June 25, 1984

PREPARED BY: C.S. Hodgefor
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INTRODUCTION

During a recent hydro test performed on the Oyster Creek isolation condenser piping return line (A loop), a leak was noticed near an isolated elbow on the condensate piping, downstream of the condenser. The insulation was removed to reveal a crack near weld NE-2-12. The weld was examined ultrasonically, which pinpointed the existence of two through-wall cracks. An inspection of both A and B loop isolation condenser piping (steam and condensate side) has been performed. A total of 27 welds have been found with crack indications, all outside the drywell isolation valves. Two sections of piping were sent to the General Electric Turbine Technology Laboratory to determine the nature of the defects. One piece of pipe was an 8" diameter Schedule 80 elbow from the A loop which contained the through-wall crack (weld NE-2-12). The second section of pipe was a 12" diameter Schedule 80 spool piece from the supply line (B loop) containing weld NE-1-15.

The attached report, "Investigation of Pipe Cracks Found in Oyster Creek Piping" (Memo Report CI-1108), describes the results of the radiographic and metallographic inspection of the two pieces of AISI 316 stainless steel pipe from Oyster Creek.

RESULTS

A total of three cracks were found, all beginning at the inside pipe wall and propagating intergranularly in a heat affected zone. The material composition was found to be within the AISI 316 stainless steel composition range, with a carbon content high enough to promote a sensitization zone after welding (A loop section - 0.046%C, B loop section - 0.060%C). The defects are typical of intergranular stress corrosion cracks.

Memo Report CI-1108

Chemistry and Electrical Insulation Subsection

Turbine Technology Laboratory
Schenectady, New York

INVESTIGATION OF PIPE CRACKS FOUND IN OYSTER CREEK PIPIN

- by -

G.C. GOULD

June 20, 1984

Abstract: The results of radiographic and metallographic inspection of two pieces of AISI 316 stainless steel pipe are presented. Three different cracks were found, all beginning at the inside pipe wall and propagating intergranularly.

Memo Report CI-1108

INVESTIGATION OF PIPE CRACKS FOUND IN OYSTER CREEK PIPING

- by -

G.C. GOULD

INTRODUCTION

Two separate pieces of pipe were sent from Oyster Creek to the Turbine Technology Laboratory for investigation into the nature of defects that were uncovered by NDT while the piping was in place.

One piece of pipe was an 8" Schedule 80 elbow contained in the isolation condenser system "A" return line, while the second, received at a later date, was a 12" diameter Schedule 80 spool piece from the isolation condenser "B" supply line containing weld NE-1-15.

The results of the investigation will be presented in two parts, one pertaining to each piece of pipe.

PART I: INVESTIGATION OF THE LEAKING INDICATION IN THE 8" SCHEDULE 80 PIPE, NE-2-12 FROM ISOLATION CONDENSER "A" RETURN LINE

The 8" Schedule 80 pipe elbow was received at 1:00 a.m. May 19, 1984. The level of radiation was 70 mR/hour at contact on the interior surface and less than 2 mR/hour at three feet.

The sample, as-received, is shown in Figure 1. The first operation was to cut the weld, NE-2-12, out as indicated in Figure 1.

This smaller, ring-like specimen was radiographed around the full circumference of the weld, and a defect was found "intermittent 360^{o}". Prints taken from these radiographs are included as Appendix I.

The ring specimen was split axially with half being forwarded to Carl Czajkowski at Brookhaven National Laboratory in Upton, New York.

The remaining half of the specimen containing the leaking indication 201 in NE-2-12 was sectioned as shown in Figure 3. Figure 4 is a photograph of the pipe section, with Figure 5 showing the leak from the outside.

Chemical analysis by X-ray fluorescence was done in the piece marked "1" in Figure 3, and subsequently, chips were removed for a carbon determination from the same piece.

Scanning electron microscopy was performed on the piece marked "2" in Figure 3. The long piece was sawed out and placed in a vise and broken open (by hand) and the fracture surface cleaned by ultrasonic agitation in a detergent water solution.

The part of the leaking crack adjacent the scanning electron microscope specimen was labeled "3" and removed with both sides of the crack intact, mounted in epoxy resin, and prepared metallographically. While being inspected, the weld bead was identified and photographed, and later, at a higher magnification, the crack was photographed. A second crack, nearer the weld bead, was found during this microscopic inspection and photographed.

A red dye penetrant inspection was performed on weld NE-2-13 on the inside pipe surface.

RESULTS

The results of the chemical analysis done on piece "1" of Figure 3 are shown in Table I.

The carbon content, 0.046 percent, is sufficiently high to allow sensitization in the heat affected zone of the weld.

The scanning electron micrographs taken from the "2" location in Figure 3 (indication 201, leaker) appear in Figure 6. The result of a complete scan of the fracture surface showed only an intergranular surface with some variation in the amount of oxide on the fracture surface. As mentioned in the Procedure section, a ten minute exposure to ultrasonic agitation while immersed in a water/detergent solution was employed to reduce the fracture surface oxide and improve the clarity of the SEM pictures.

Metallography carried out on indication 201 "leaker" is shown in Figures 7 through 9. The location of this specimen is shown as "3" in Figure 3.

Figure 7 shows the weld bead at 8X and the location of the leaking crack adjacent to the weld bead. In addition, there is a second crack visible very close to the weld bead. This second crack extends only slightly past the midwall thickness of the pipe, penetrating about 60 percent of the wall thickness.

Figures 8 through 10 show the leaking crack at the inside wall, midwall, and at the outside of the pipe.

Figures 11 and 12 show the second, non-penetrating crack at its origin on the inside wall and at the midwall location.

All cracks are judged to be intergranular along the austenite grain boundaries. Neither of the cracks in the 8" pipe are observed propagating into the weld bead. A Magnagage reading on this weld showed a ferrite number between 3 and 4.

A red dye penetrant inspection was performed on the I.D. of weld NE-2-13. Figures 13 and 14 show the 8" pipe looking at NE-2-13 toward NE-2-12. Note the axial weld bead for orientation in Figure 13 and the linear indication approximately 230° from the axial weld. Figure 14 shows a close-up of the red dye indication found in weld NE-2-13. In-service, the axial weld is at 5 o'clock looking from NE-2-13 toward NE-2-12.

CONCLUSIONS

1. The fracture path of the leak and a second crack found just adjacent the weld bead are unambiguously intergranular.

2. The material composition is within the composition range of AISI 316 stainless steel, and the carbon content is high enough to allow heat affected zone sensitization.

3. The cracking is most probably intergranular stress corrosion cracking of the weld heat affected zone.

PART II: INVESTIGATION OF THE 12" SCHEDULE 80 PIPE SPOOL FROM ISOCONDENSER "B" SUPPLY LINE

The 8" long section of 12" diameter pipe was received May 20, 1984, at approximately 9:00 p.m. The level of radiation measured was about 110 mR/hour at contact on the inside surface and 6 mR/hour at three feet. The sample as-received is shown in Figure 15. A slice of the 12" pipe wall was cut from the spool piece as shown in the sketch in Figure 16.

Radiography was done on the circumferential weld, and prints of the radiographs and their location are shown in Appendix II.

Figure 17 shows the piece removed from the 12" spool piece and the location of the pieces used for each of the subsequent examinations.

Chemical analysis was performed on piece "4" by X-ray fluorescence, and the results are shown in Table II.

Scanning electron microscopy was performed on piece "3" in Figure 17, and in this case, a heavy coating of oxide necessitated the use of ultrasonic agitation for two ten-minute periods in a 5 percent H_2SO_4 solution containing catechol.

The piece marked "5" in Figure 17 was mounted in epoxy resin and ground, polished, and etched with Kalling's etchant prior to being photographed. The weld bead was photographed at 8X while the crack was done at 50X. The location of the 50X pictures is given on the 8X picture.

A Magnagage was used to measure the ferrite content of the circumferential weld on the 12" diameter pipe.

RESULTS

The results of the chemical analysis by X-ray fluorescence appear in Table II. The location of the chemical analysis specimen is shown in Figure 17 as piece "4".

The results of the scanning electron microscope fractography are shown in Figures 18 and 19. The fractographs shown in Figure 18 are taken near the inside wall of the pipe near the crack origin and have a thicker coating of oxide on them than those in Figure 19, taken at midwall location near the growing end of the crack, or crack tip.

Figure 20 is a montage of microphotographs showing the weld bead, the crack, and the location of the photomicrographs that make up Figures 21 through 23. The crack has penetrated about 54 percent of the pipe wall.

Notice the surface weld beads on the right outside surface in Figure 20. These beads make the weld appear larger than it is, in fact, from the outside pipe surface and undoubtedly led to NDT conclusion of a midbead or centerline defect when, in fact, the crack is located in wrought material.

Figures 21 through 23 show the crack at the inside wall (origin), midwall at the Y of the weld bead, and at the growing branching end past midwall.

It can be seen that the crack grows into the weld bead and arrests on several occasions, albeit not very far. Magnagage readings gave a ferrite number between 12 and 13 for this weld.

CONCLUSIONS

1. The cracking is wholly intergranular initiating at the inside pipe wall in the heat affected zone.

2. The composition of the steel falls within the specified range of AISI 316 with the carbon content 0.060 percent, high enough to allow sensitization in the weld heat affected zone.

3. The most probable cause for the cracking in intergranular stress corrosion cracking in the weld heat affected zone.

Table I

CHEMICAL ANALYSIS OF WROUGHT MATERIAL DONE ON 8" DIAMETER SCHEDULE 80 PIPE FROM OYSTER CREEK*

Weight Percent

Cr	Ni	Mo	C
17.0	11.1	2.20	0.046

*Location of the chemical analysis sample defined as "1" in Figure 3.

Table II

CHEMICAL ANALYSIS OF WROUGHT MATERIAL DONE ON 12" DIAMETER PIPE FROM ISOCONDENSER B*

Weight Percent			
Cr	Ni	Mo	C
16.9	13.1	2.26	0.060

*Location of specimen defined in Figure 17 as part "4".

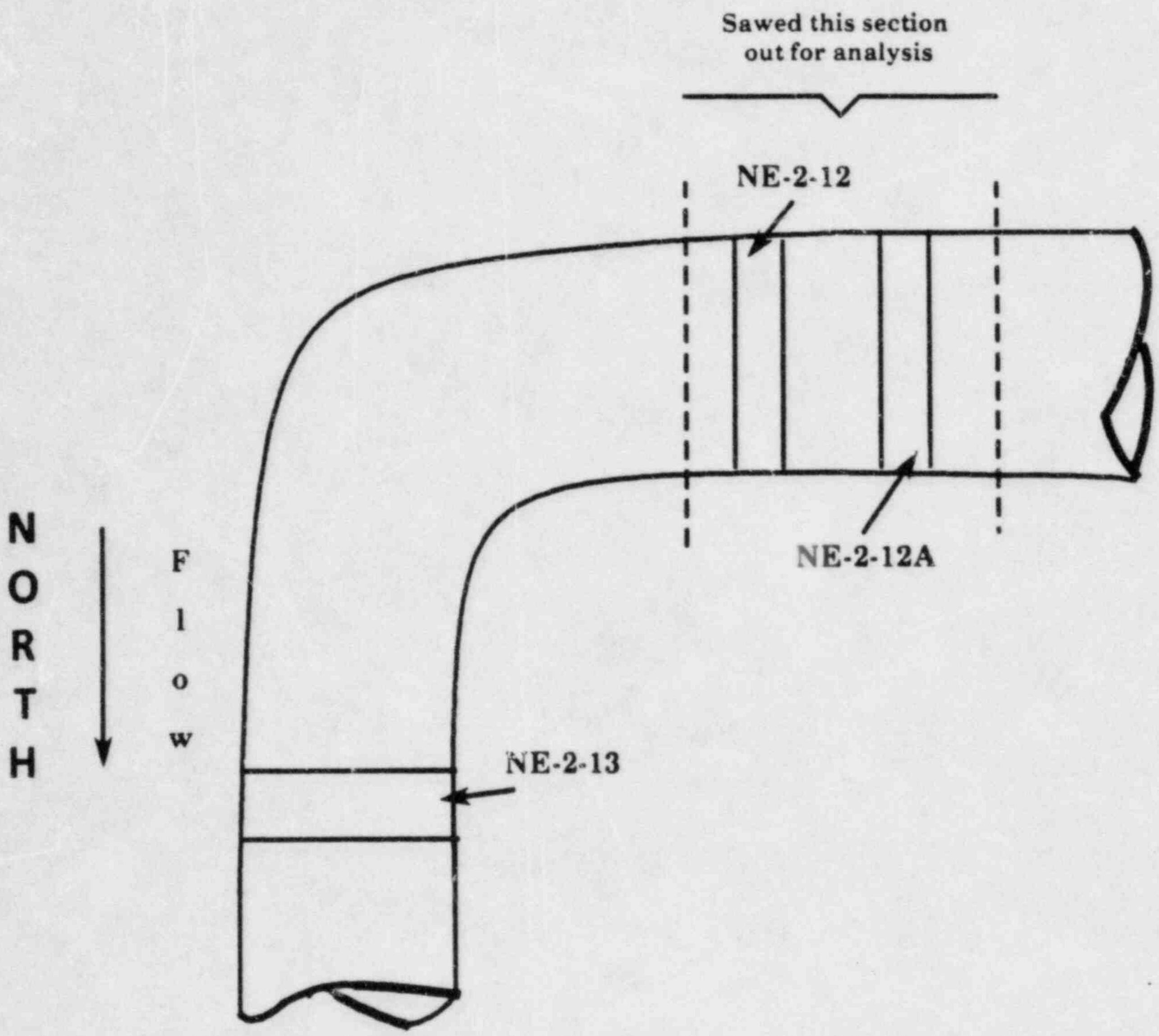


Figure 1: 8" Dia. schedule 80 pipe received from Oyster Creek

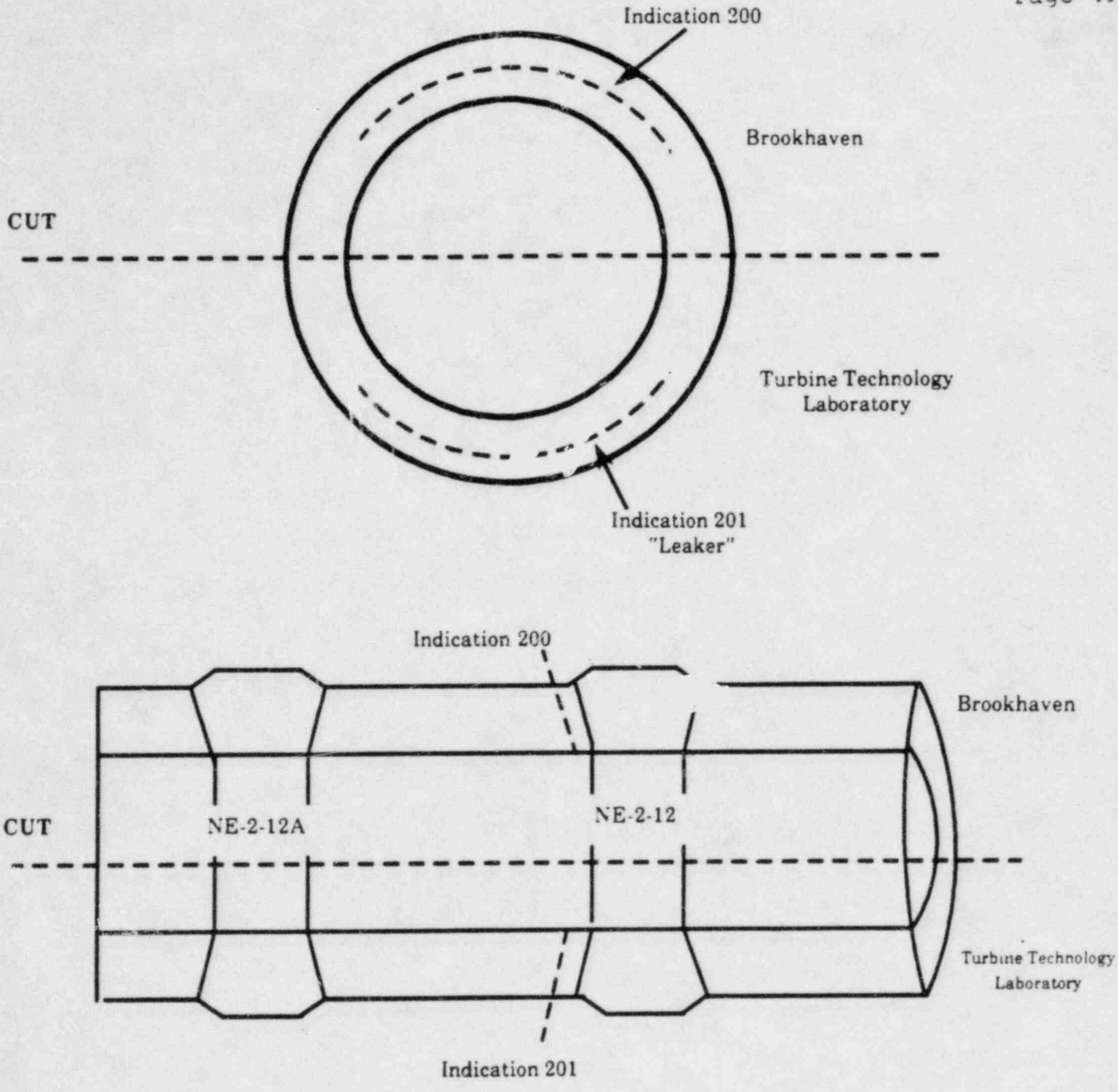
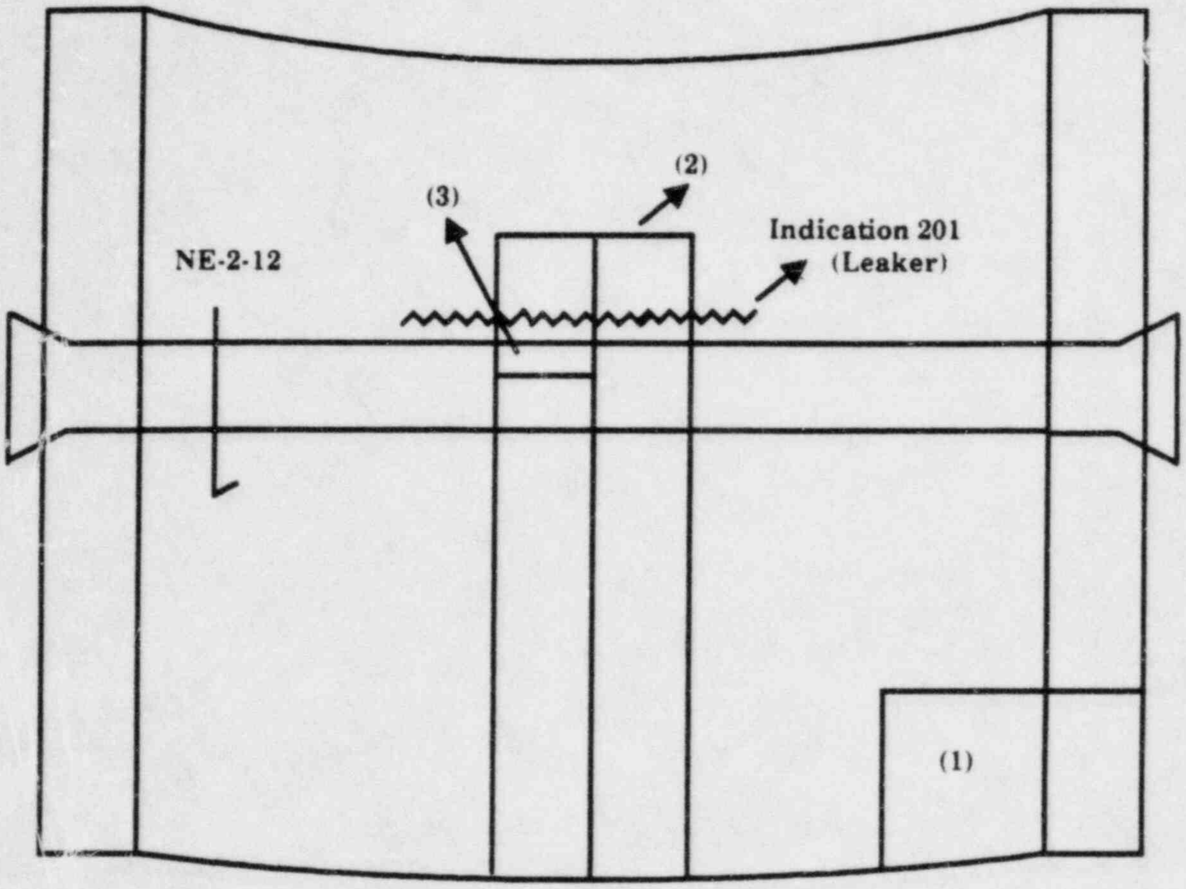


Figure 2: **Axial cut to divide NE-2-12 (and NE-2-12A) between Brookhaven National Laboratories and Turbine Technology Laboratory**

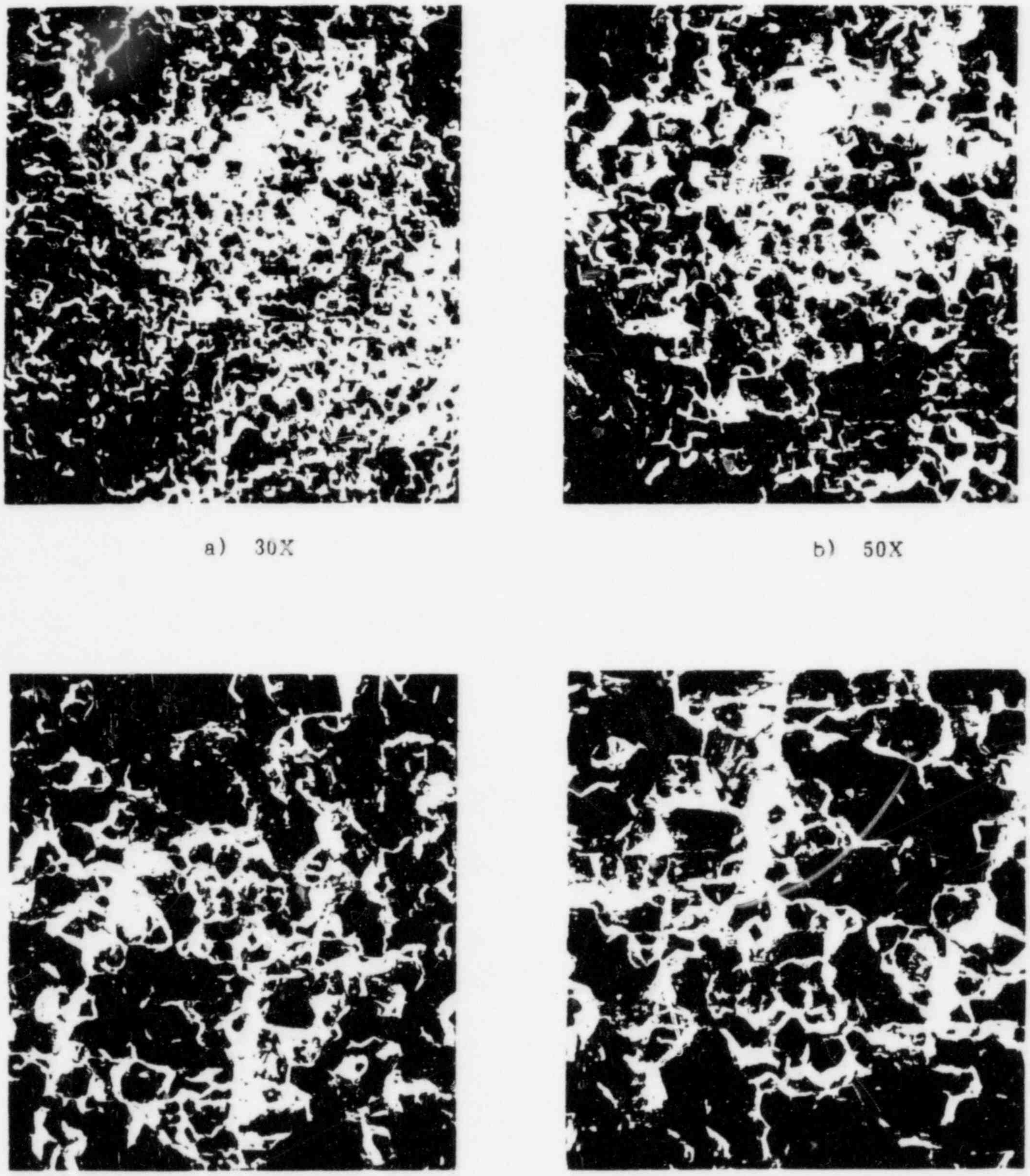


(1) Chemical Analysis Sample
(2) Sem Fractographic Sample
(3) Metallographic Sample

Figure 3: **The half of the pipe kept for analysis at Turbine Technology Laboratory. The other half to Brookhaven National Laboratory.**

Figure 4 - Macrophotograph of 8 inch pipe weld NE-2-12 and NE-2-12A
Neg. No. 4-1461 .93X

Figure 5 - Closeup of leak in weld NE-2-12
Neg. No. 4-1461 2.2X



a) 30X

b) 50X

c) 70X

d) 100X

Figure 6 - Scanning electron microscope fractographs of the leaking indication (201) on 8 inch pipe

Figure 7 - Weld bead and two cracks found in NE-2-12 8 inch - Oyster Creek
Neg. No. 4-1481F-4 8X
Kallings

Figure 8 - Leaking crack in weld NE-2-12 8 inch diameter pipe.
Crack origin inside wall. 50X
Neg. No. 4-1481F-1 Kallings

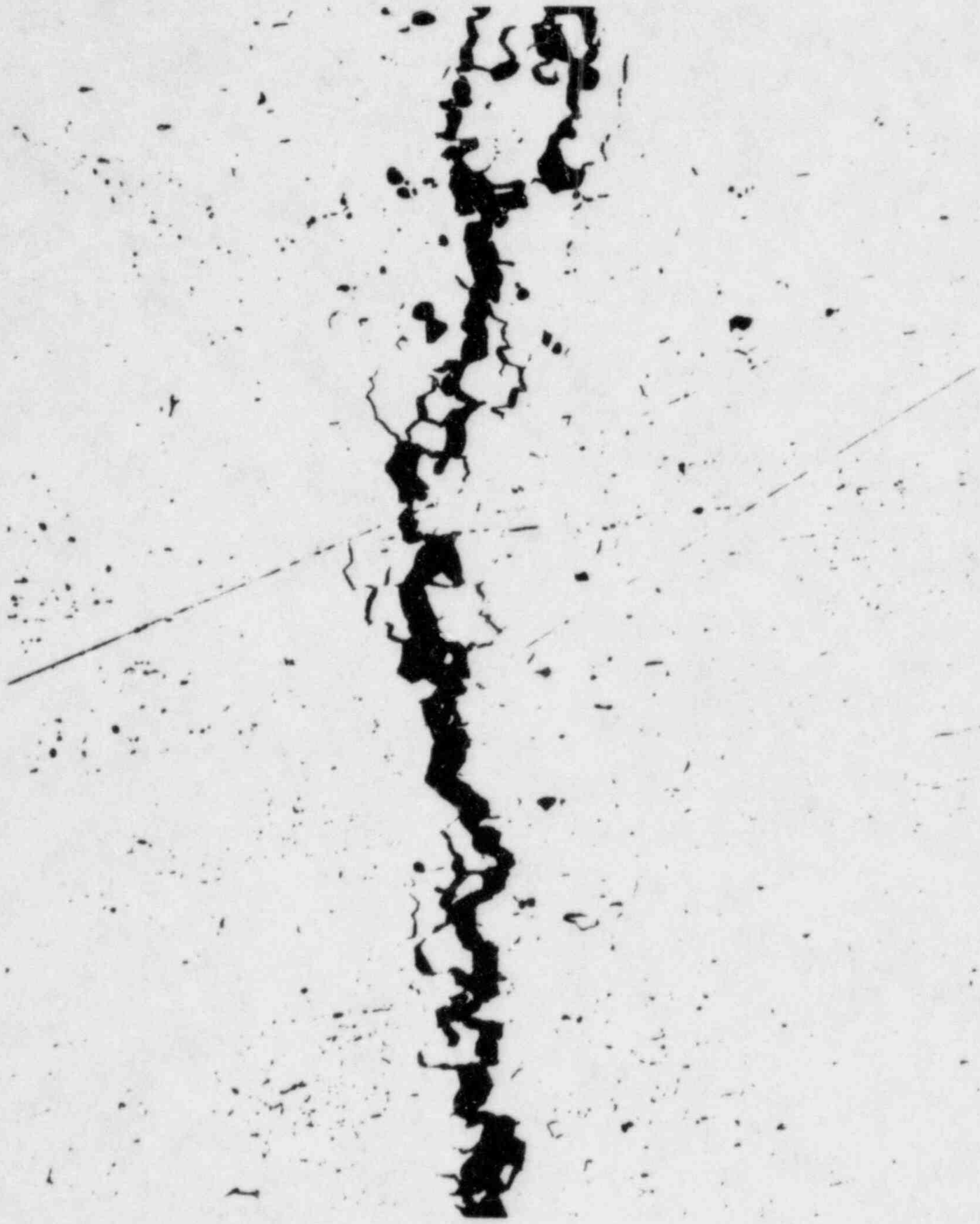


Figure 9 - Leaking crack in weld NE-2-12 8 inch diameter pipe.
Midwall location. 50X
Neg. No. 4-1481F-2 Kallings

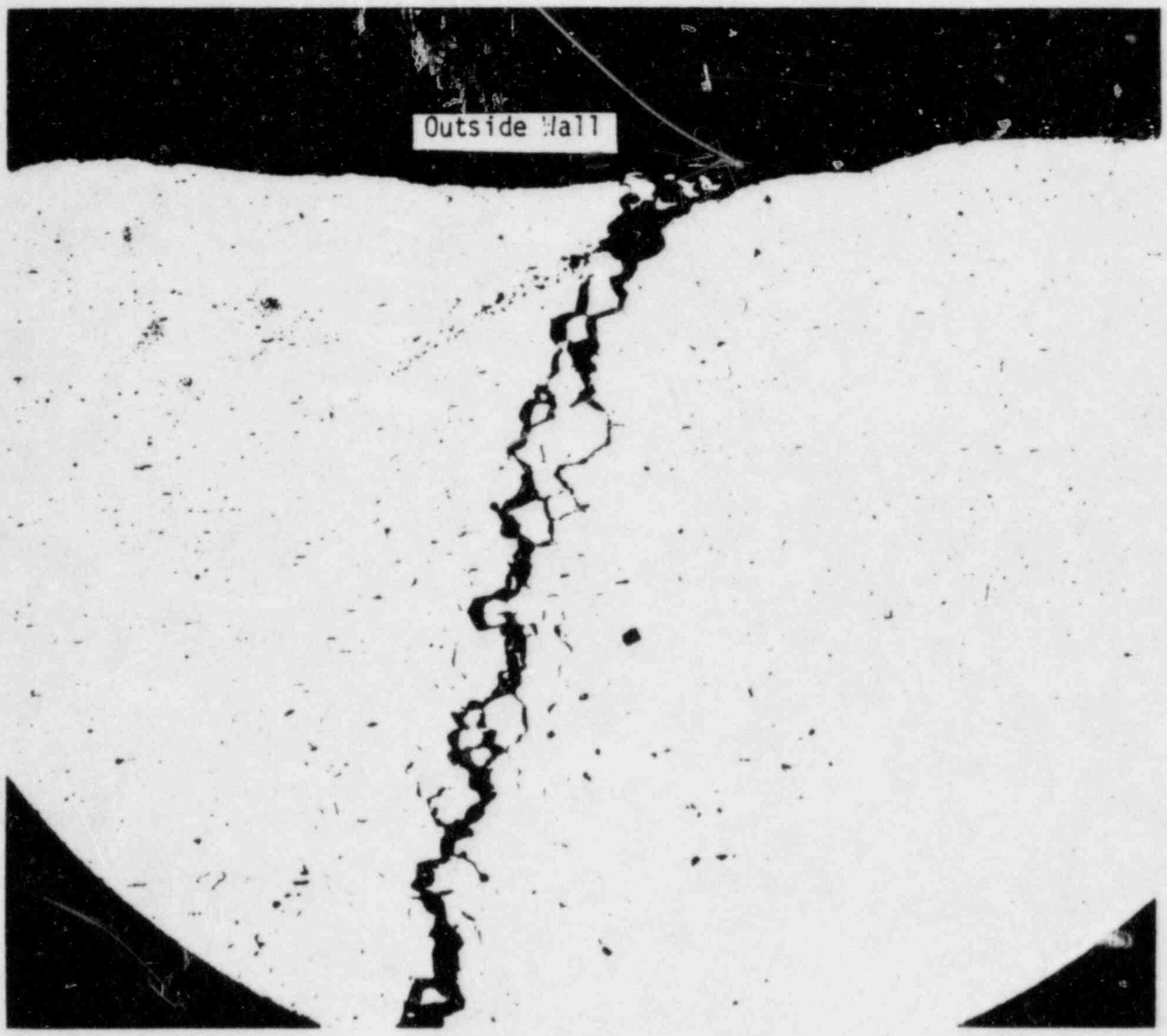


Figure 10 - Leaking crack in weld NE-2-12 8 inch diameter pipe.
Outside wall. 50X
Beg. No. 4-1481F-3 Kallings

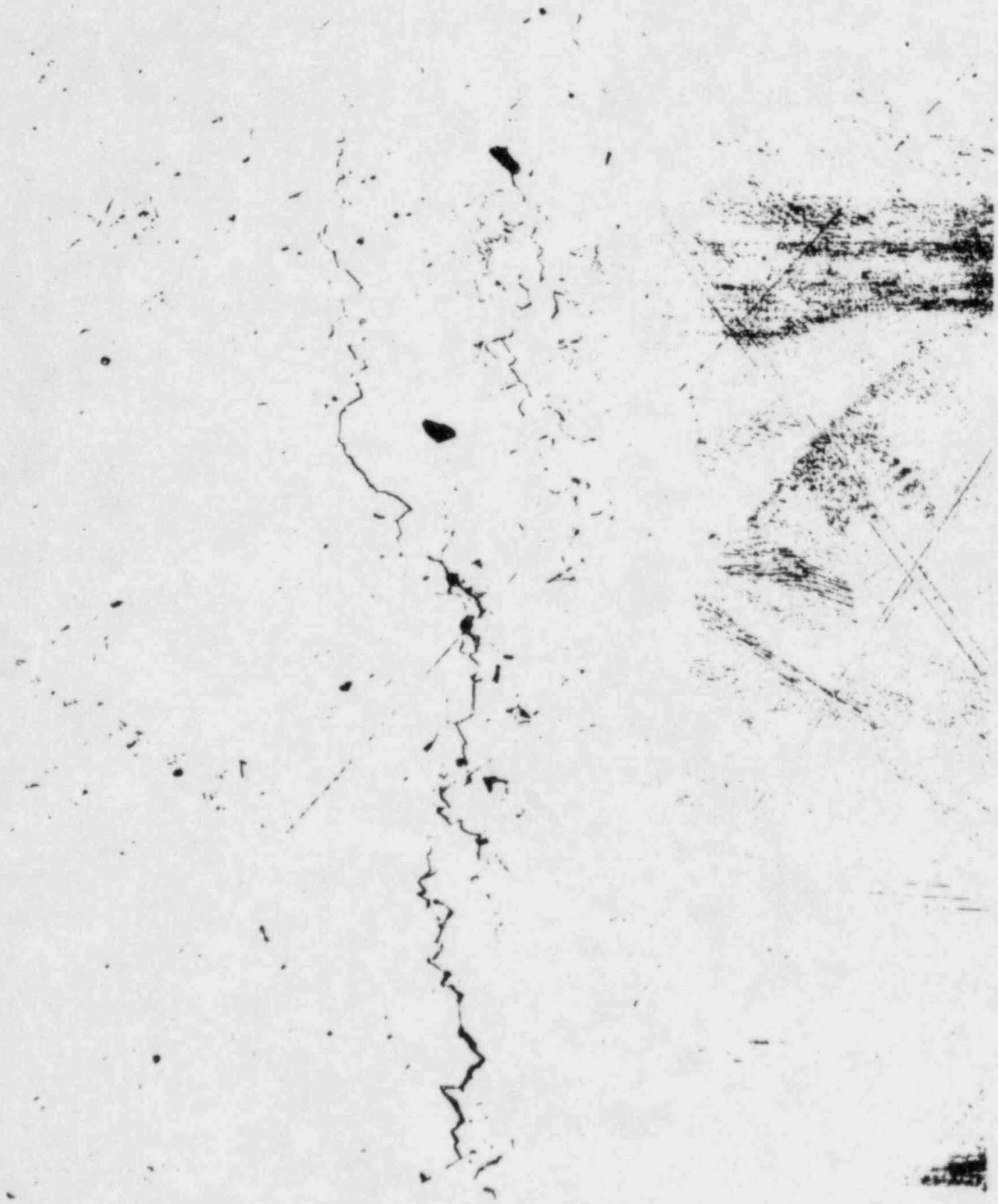


Figure 12 - Second crack found in NE-2-12 8 inch diameter pipe.
Midwall location "Growing End".
Neg. No. 4-1481F-5 50X
Kallings

TOP

Figure 13 - Eight inch diam..r pipe looking from NE-2-13 toward NE-2-12. Red dye inspect..on of weld NE-2-13. Note axial weld for orientation.
Neg. No. 4-1461 .81X

Figure 14 - Red dye indication in weld NE-2-13 225° clockwise from axial weld.
Neg. No. 4-1461 2X

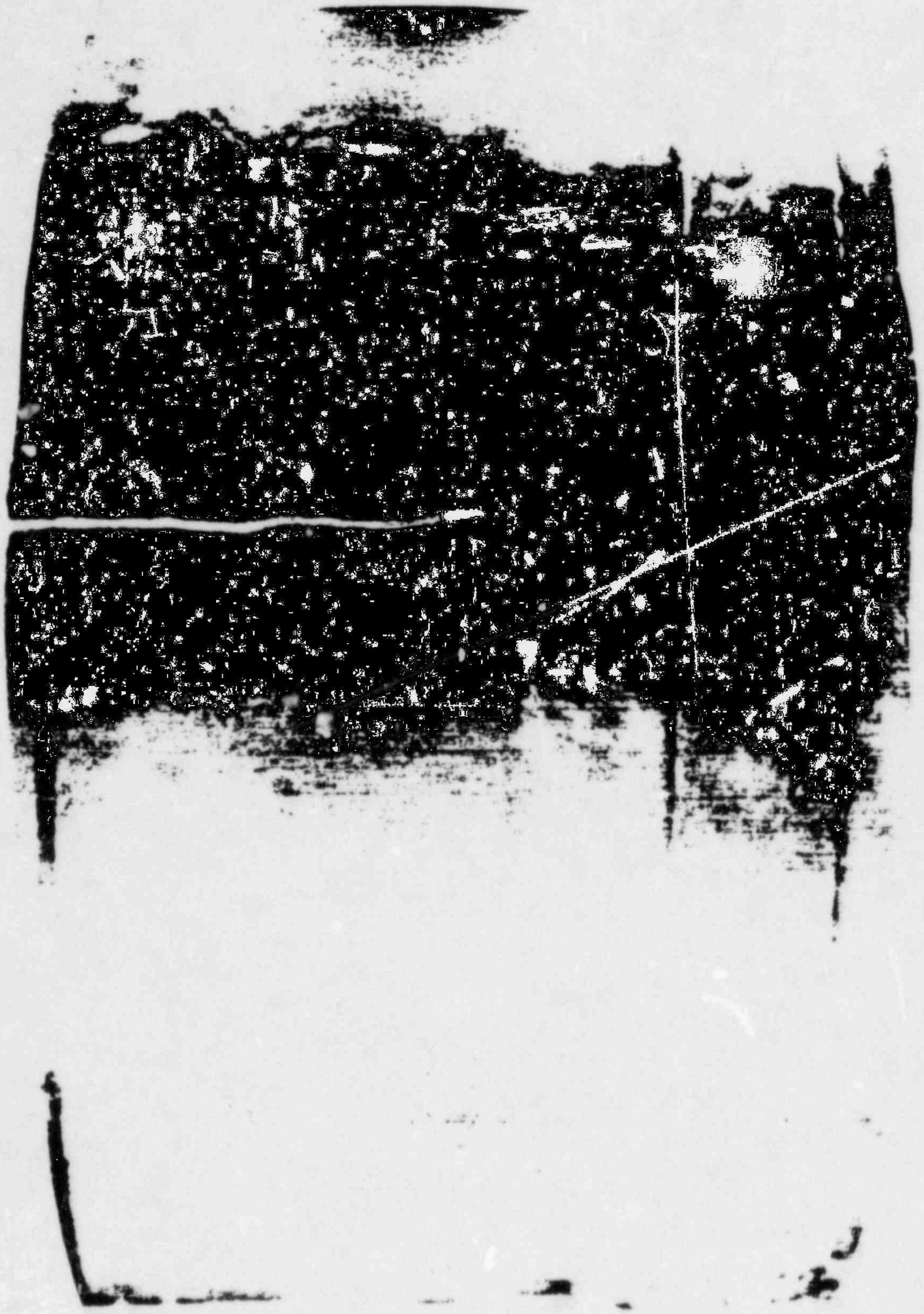


Figure 15 - Weld NE-1-15 in 12 inch spool piece from Oyster Creek
Neg. No. 4-1461 0.6X

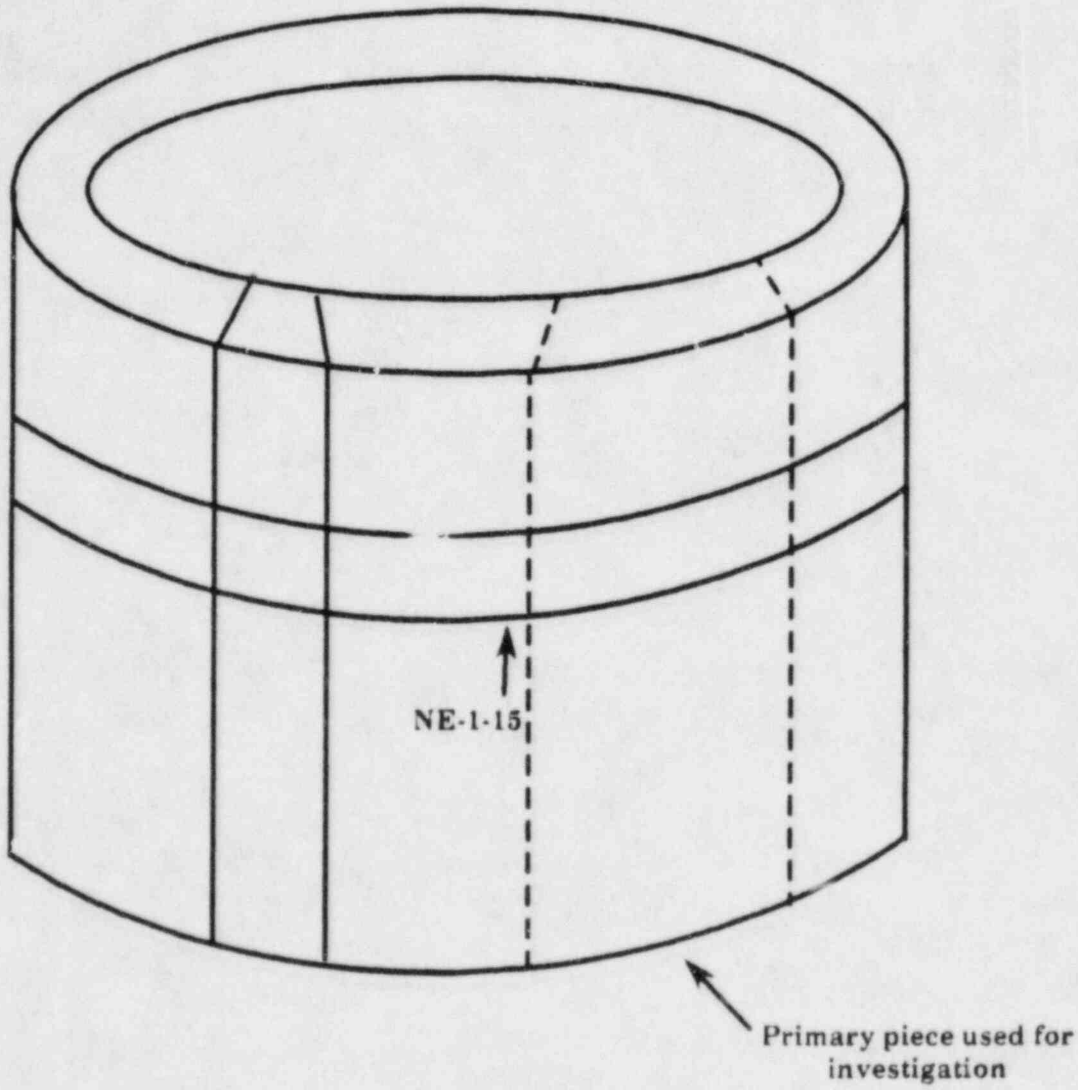


FIGURE 16: Sketch of 12 inch diameter spool piece showing ↑NE-1-15 and axial weld in addition to the piece removed for examination.

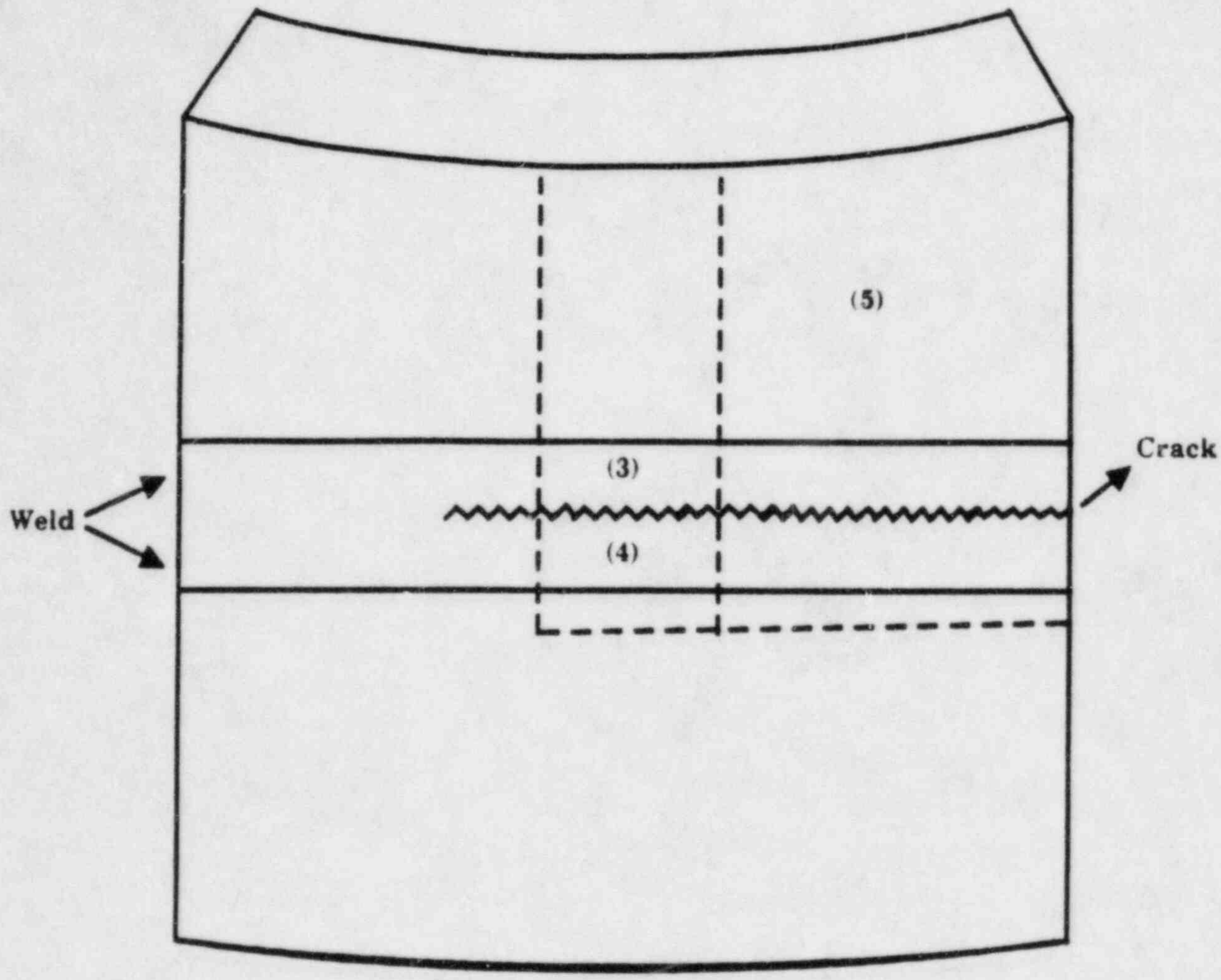
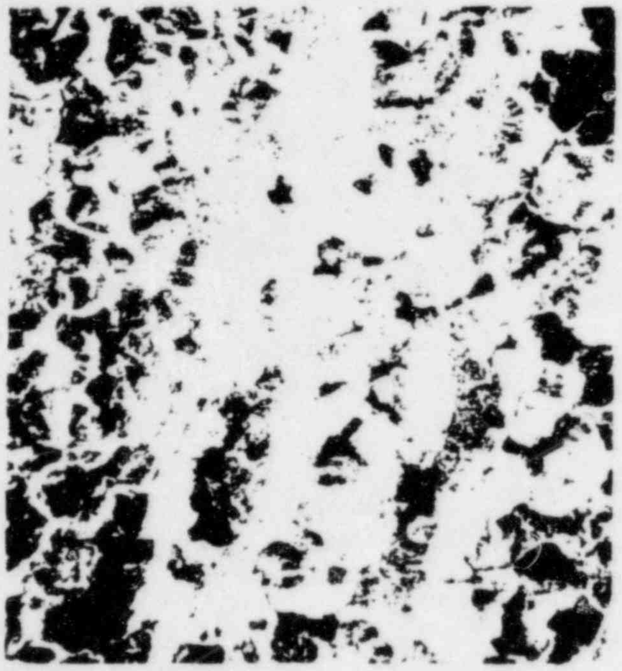
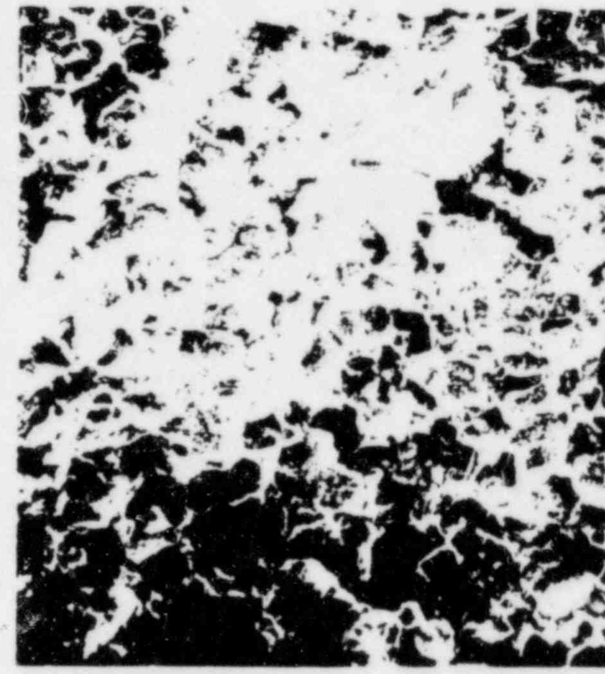


Figure 17: Piece removed from 12 inch spool piece and the location of fractographic specimen (3); metallographic specimen (5); chemical analysis specimen (4).

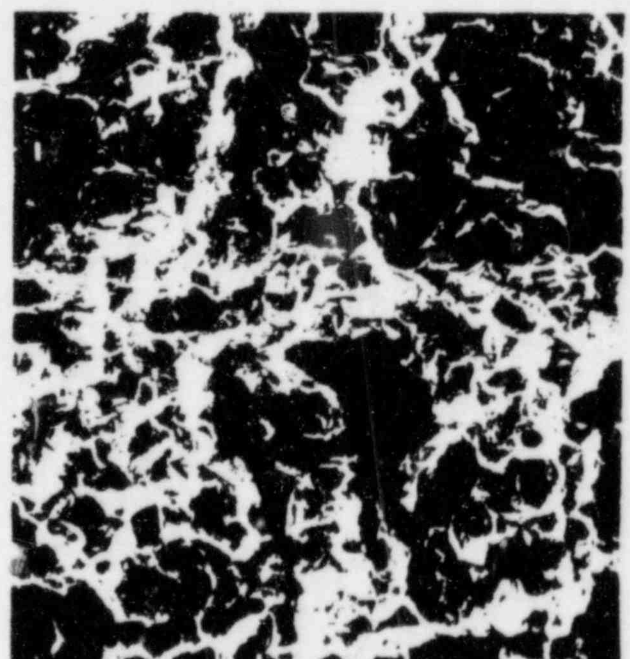


a) 50X



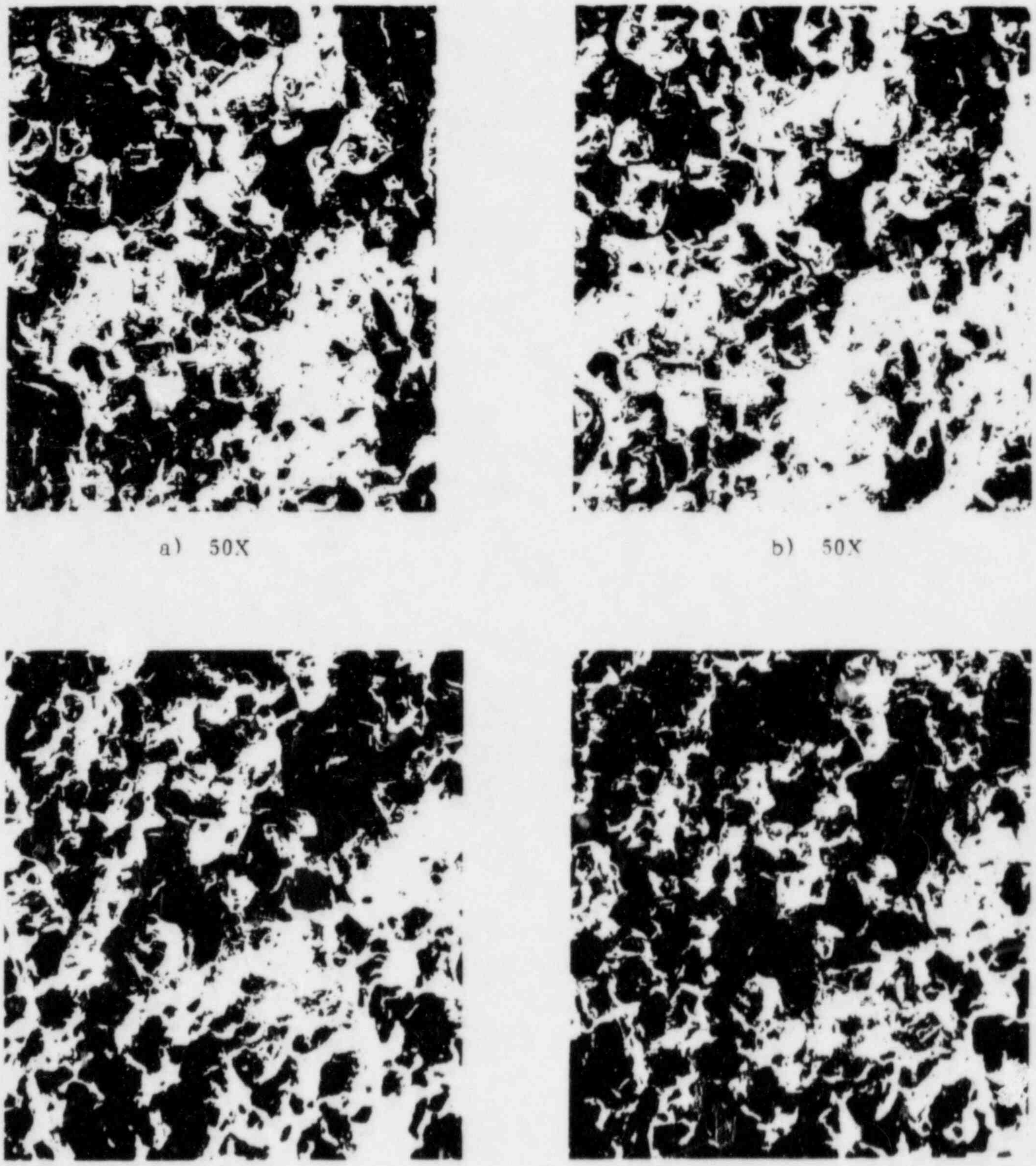
b) 50X

c) 50X



d) 50X

Figure 18 - Scaning electron microscope fractographs at the inside pipe wall of the 12 inch pipe



a) 50X

b) 50X

c) 50X

d) 50X

Figure 19 - Scanning electron microscope fractographs at the mid wall location - near the crack end 12 inch pipe

Figure 20 Twelve Inch Diameter Pipe Weld Bead and Associated Crack
Neg. No. 4-1480F1-3 8X
Kallings

**Figure 21 - Twelve inch diameter pipe crack at the inside surface; origin.
Neg. No. 4-1480F-4 50X
Kallings**

Figure 22 - Twelve inch diameter pipe crack at mid wall. Note the change in direction.
Neg. No. 4-1480-5 50X
Kallings

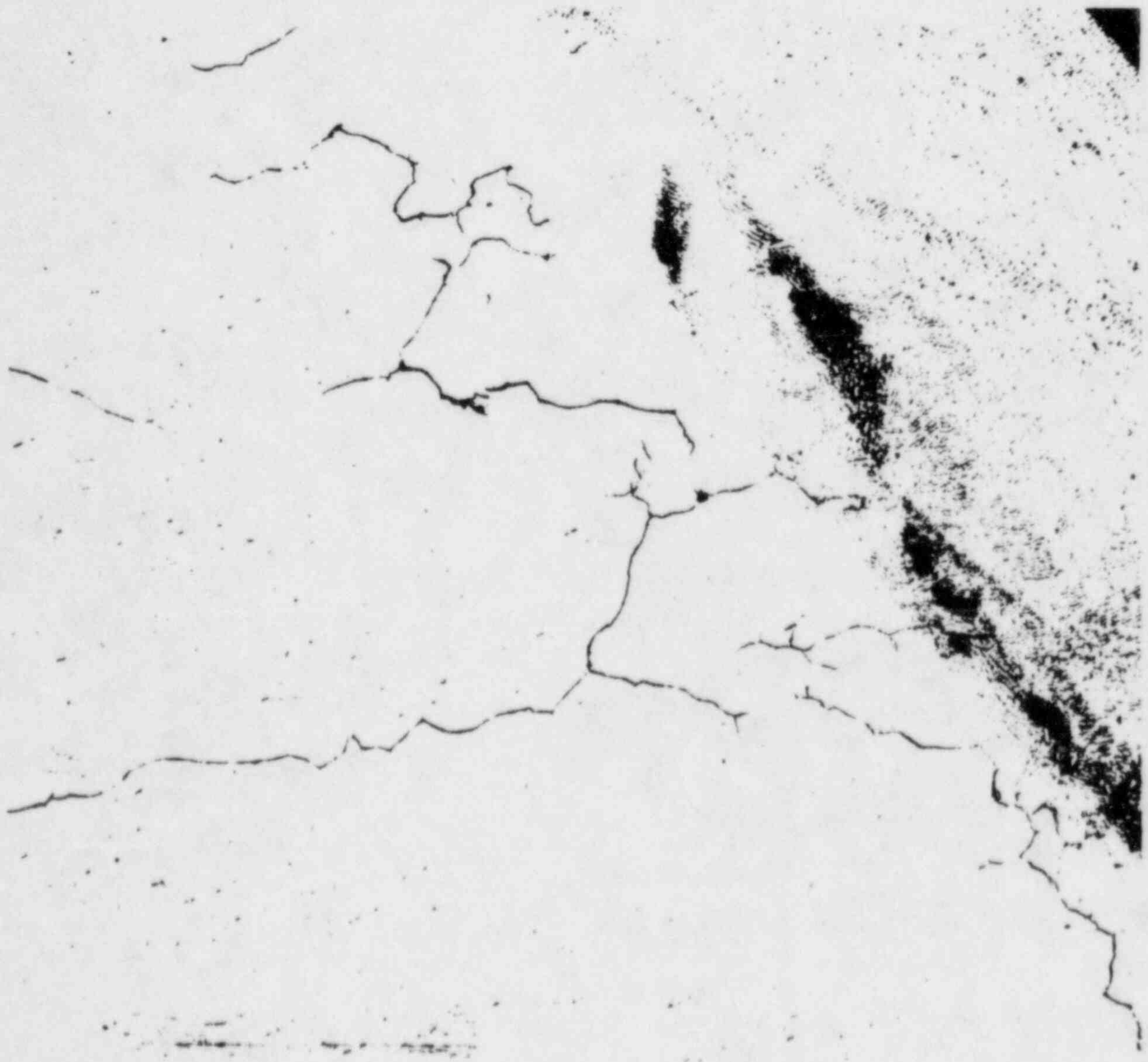
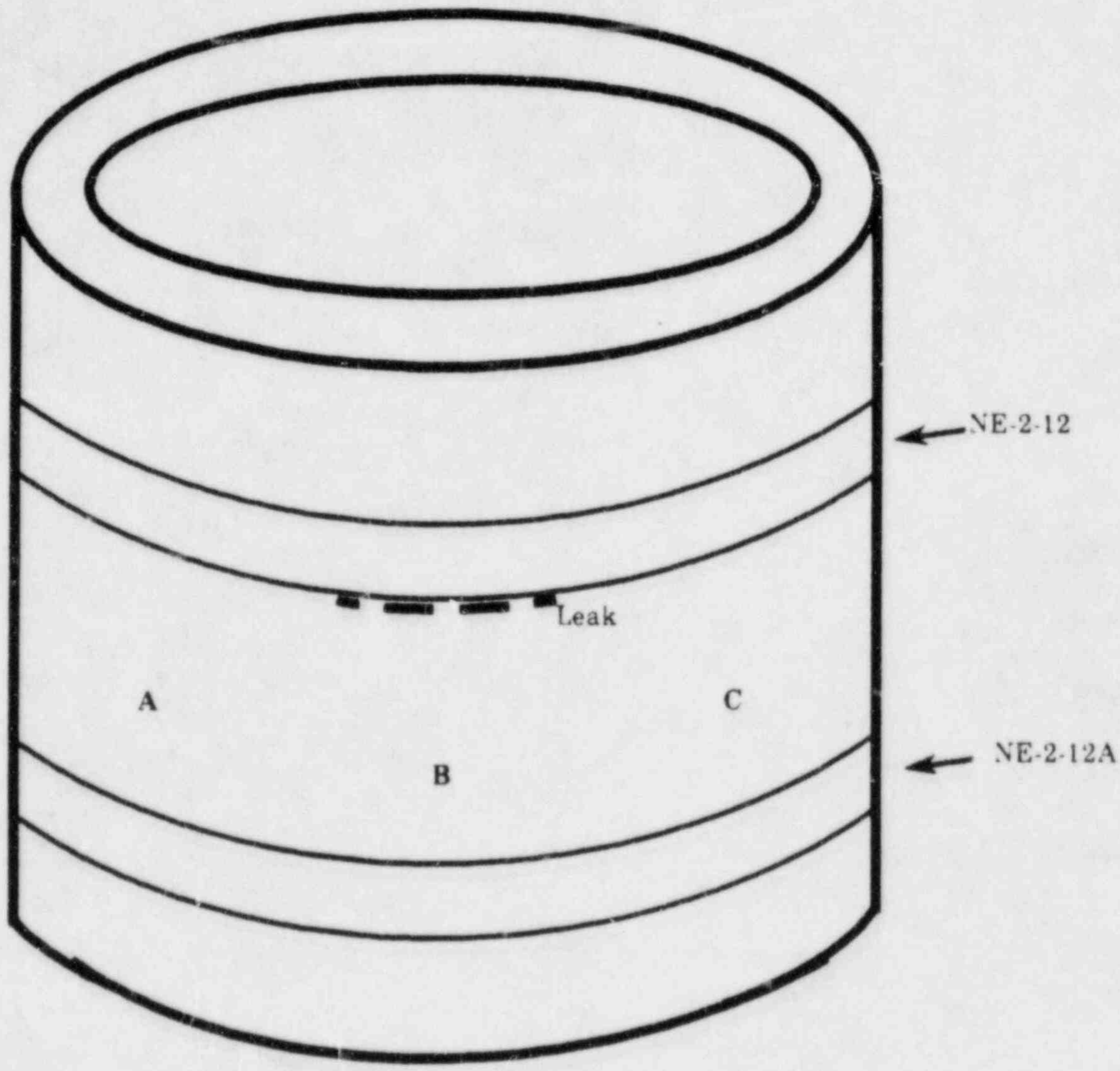
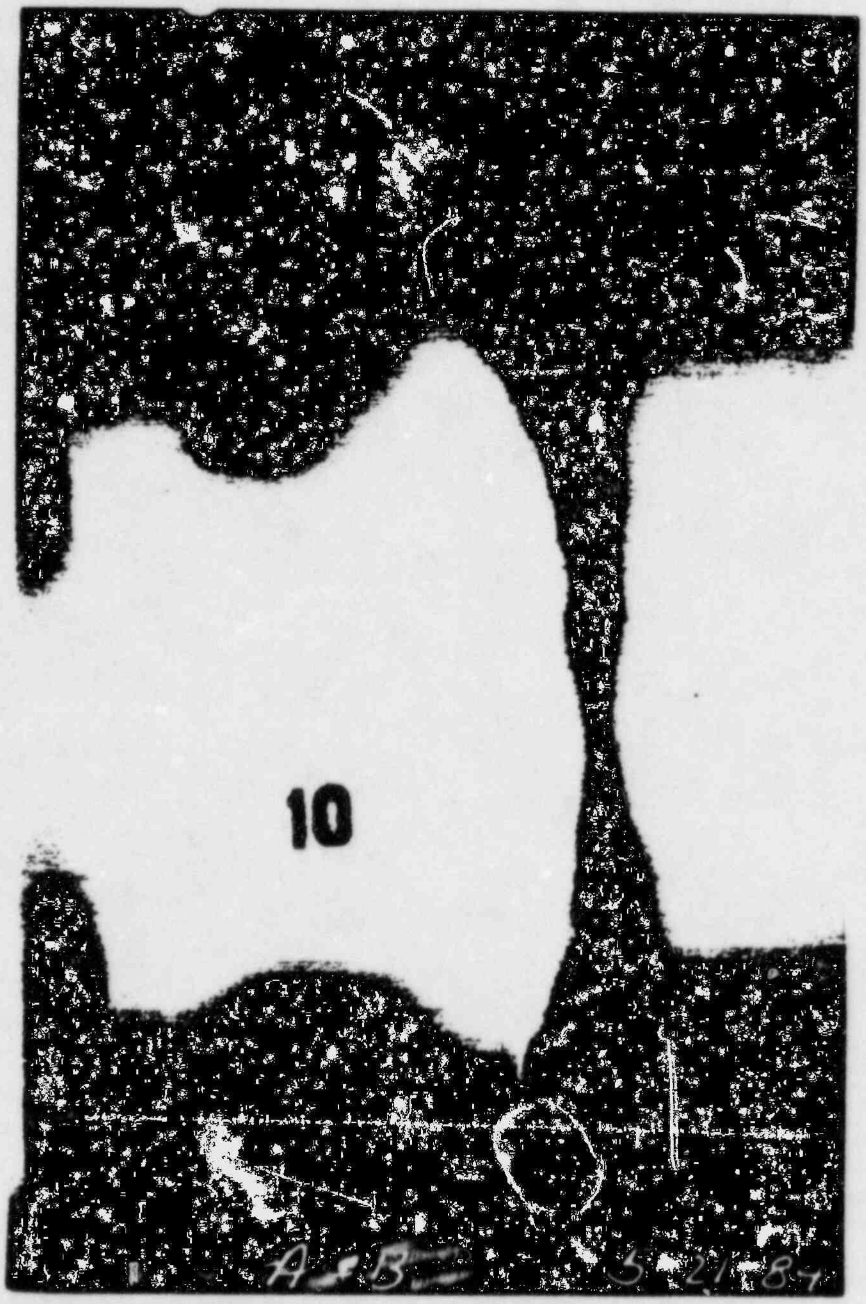
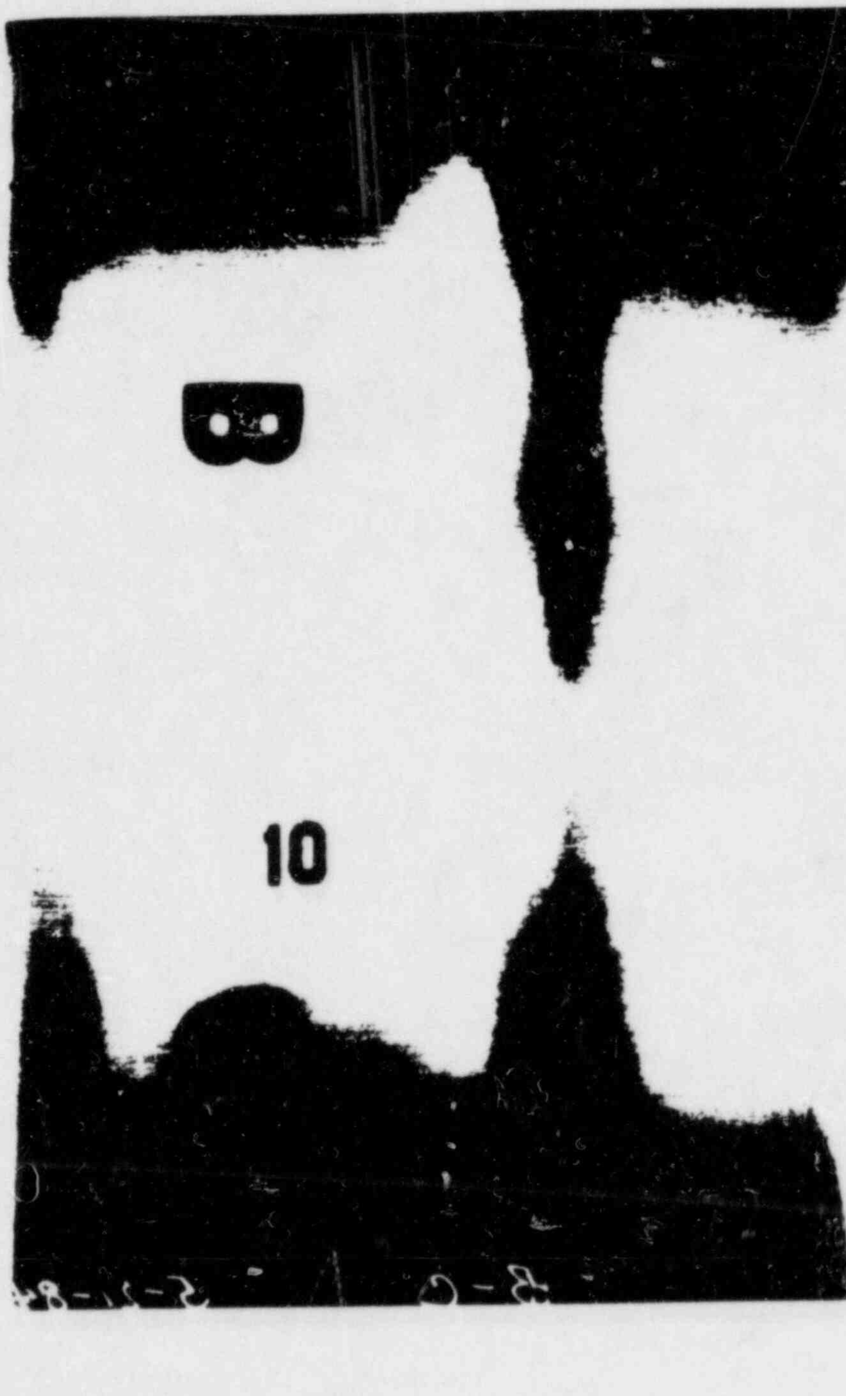


Figure 23 - Twelve inch diameter pipe crack at the "growing" end.
Neg. No. 4-1480F-6 50X
Kallings



APPENDIX I: Location of the radiographs on NE-2-12 in the 8 inch pipe.

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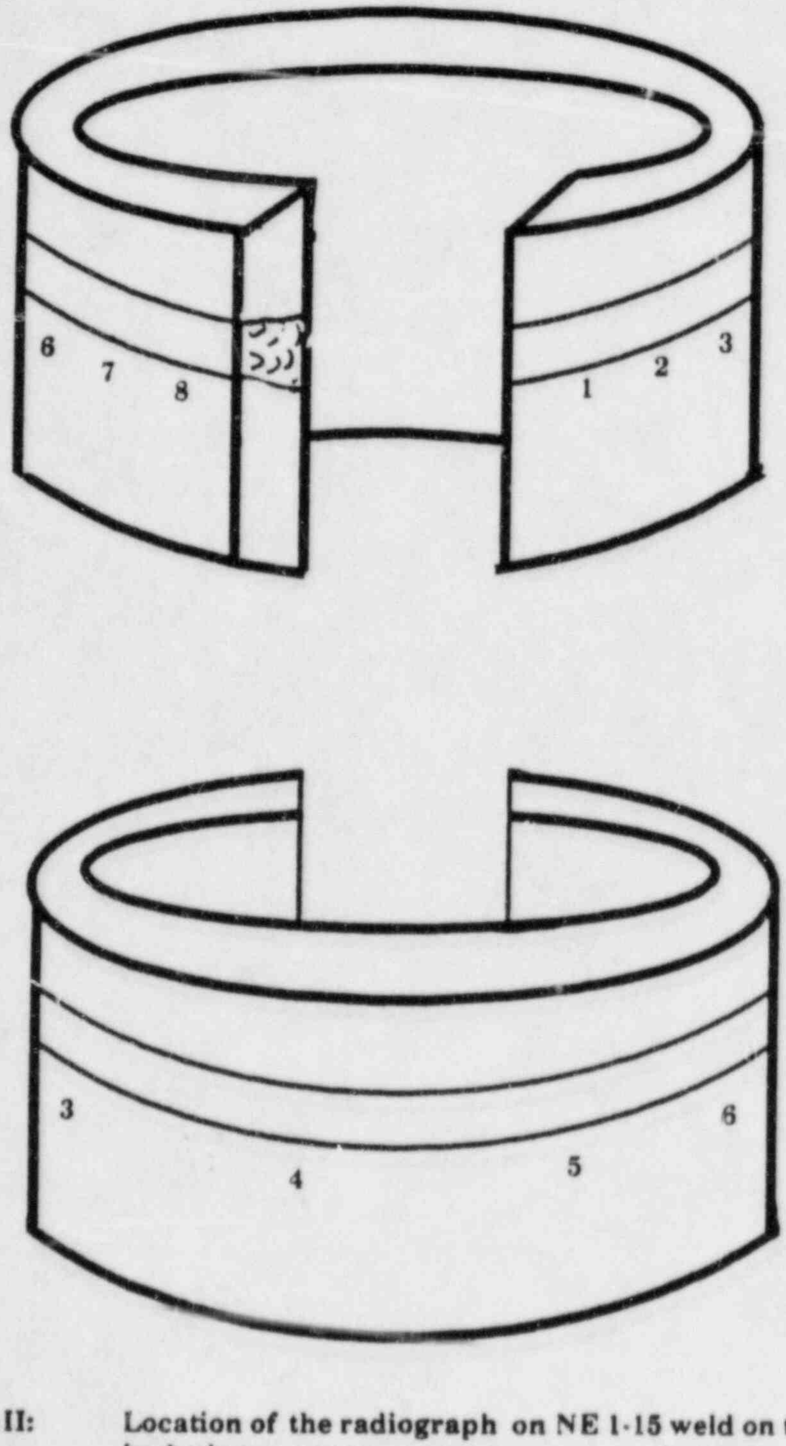
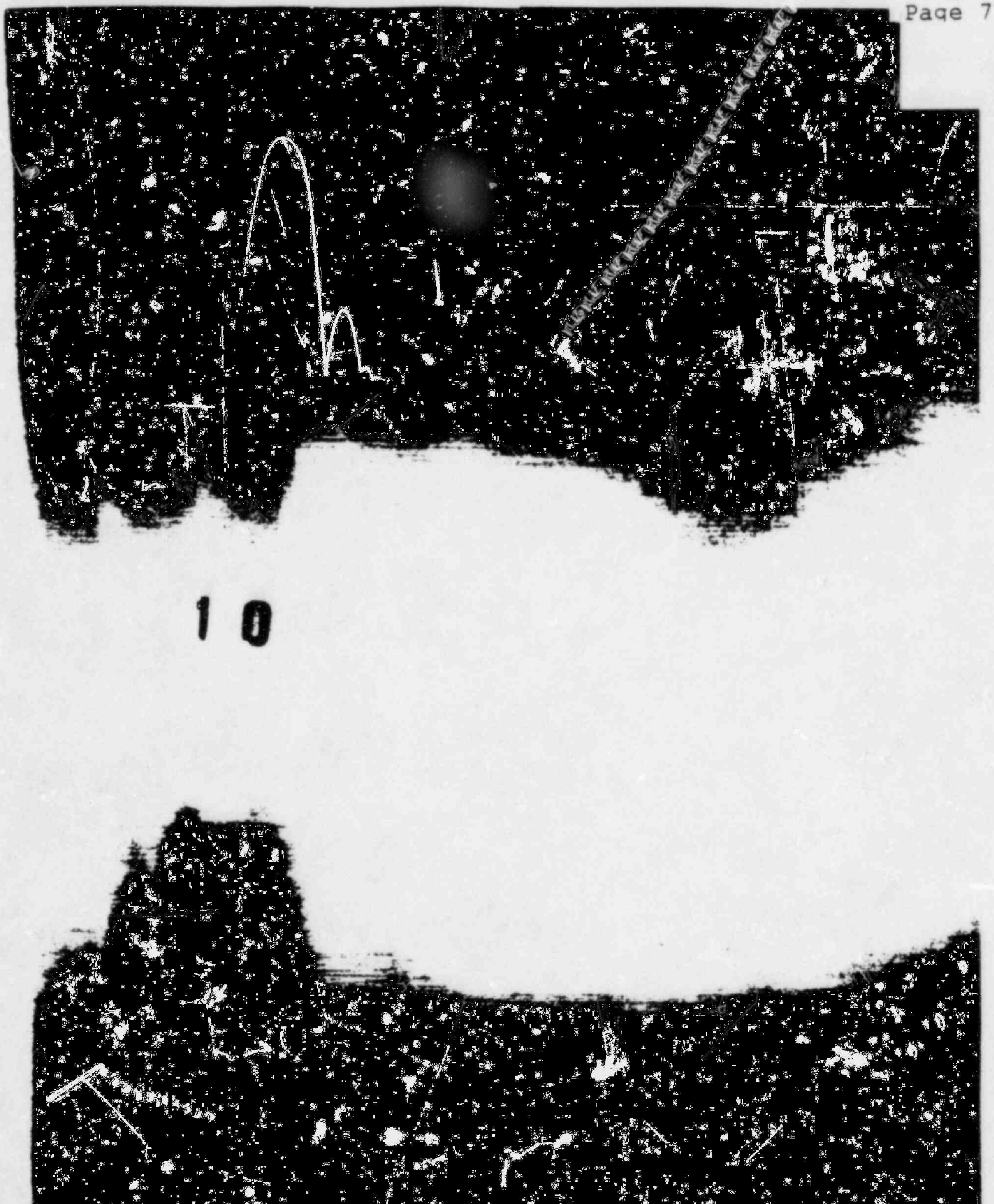
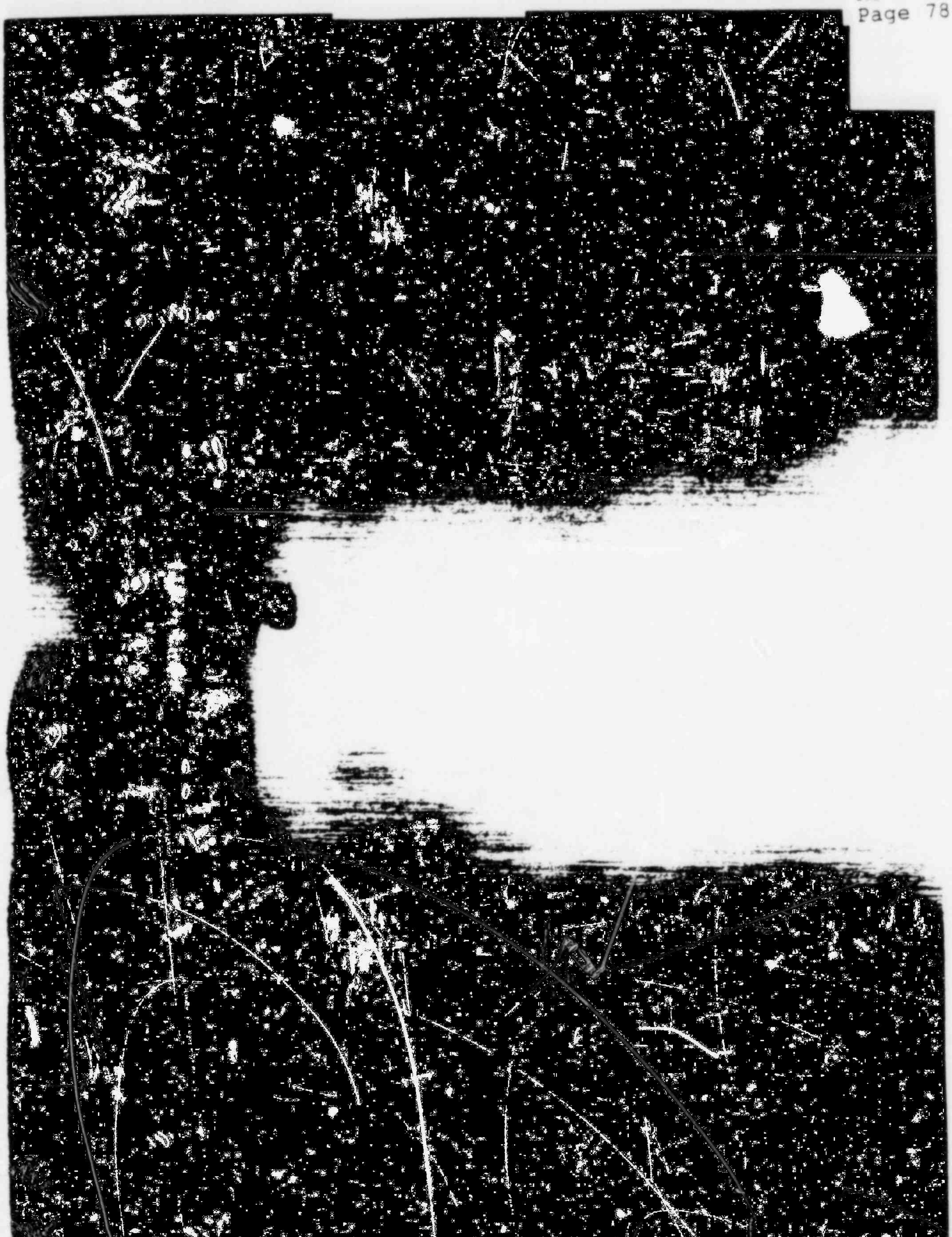
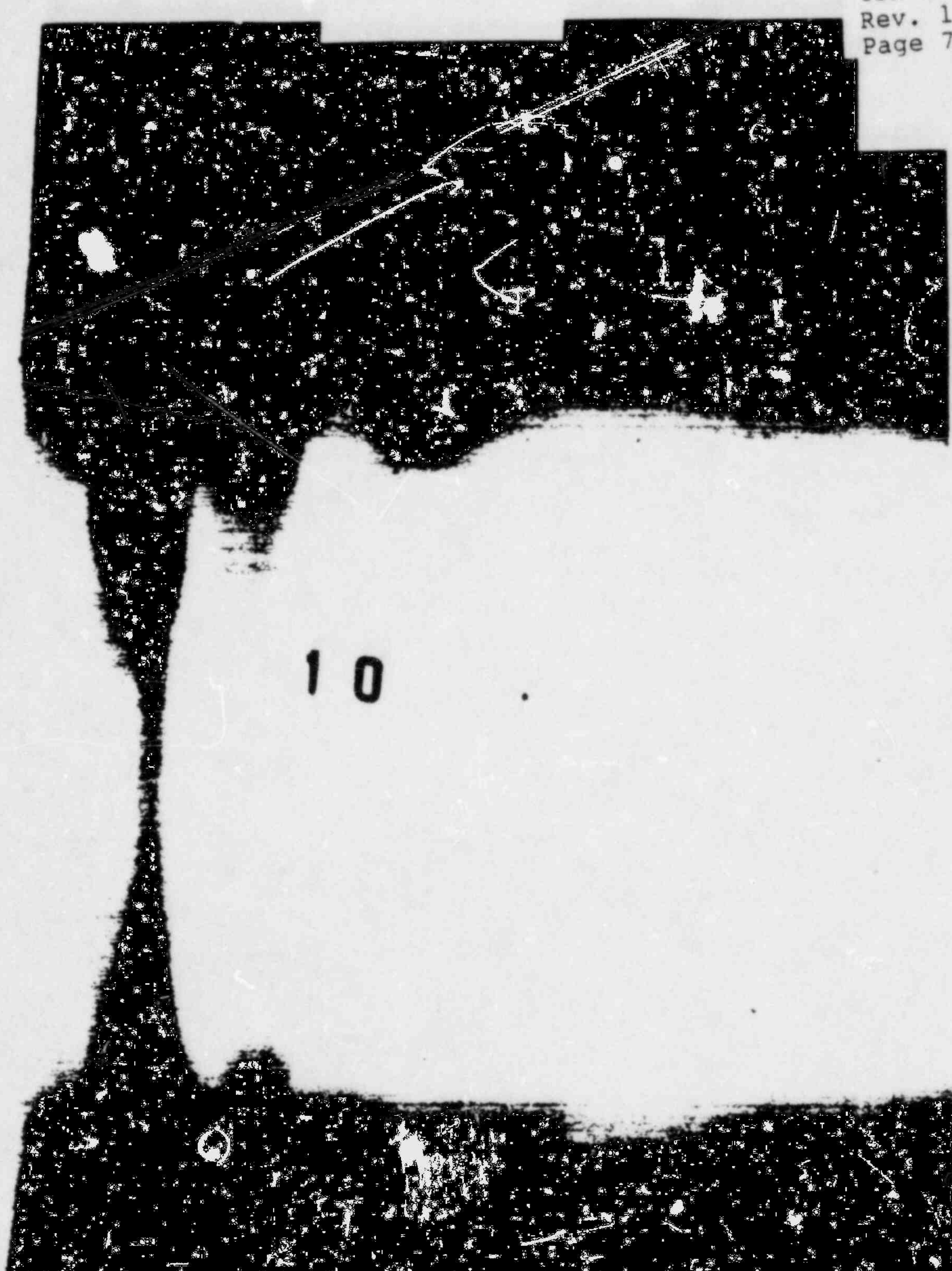


APPENDIX II: **Location of the radiograph on NE 1-15 weld on the 12 inch pipe.**


10



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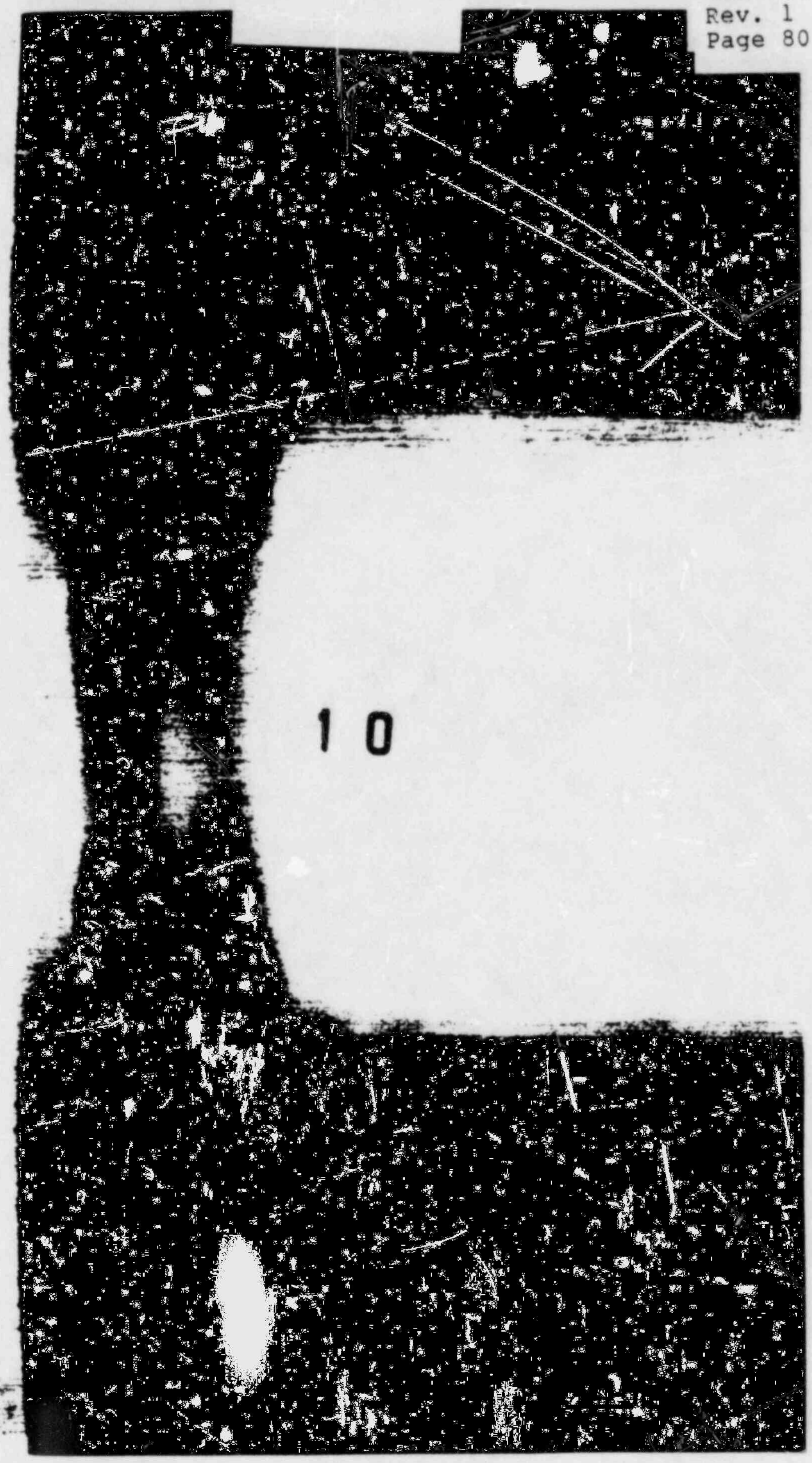

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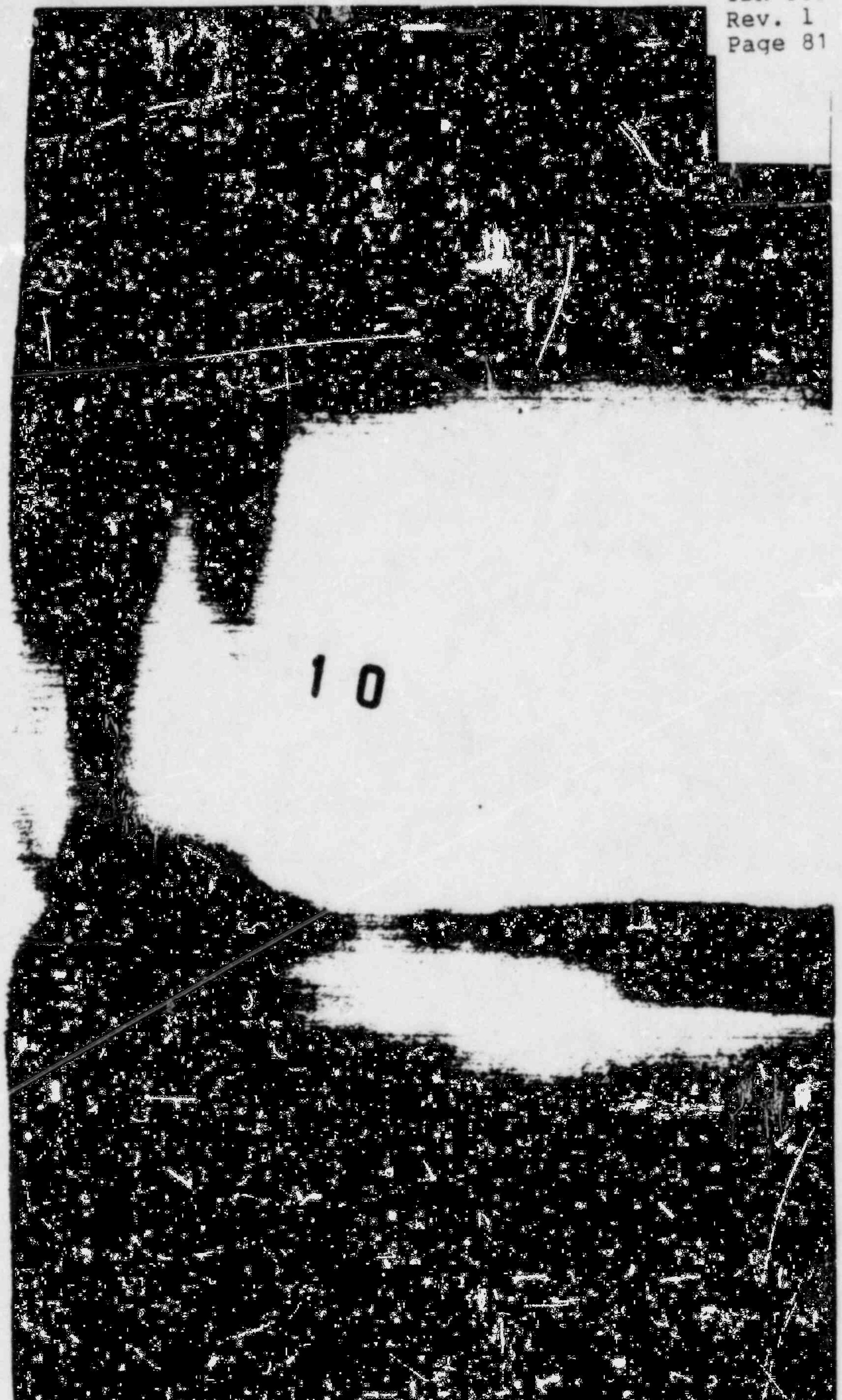
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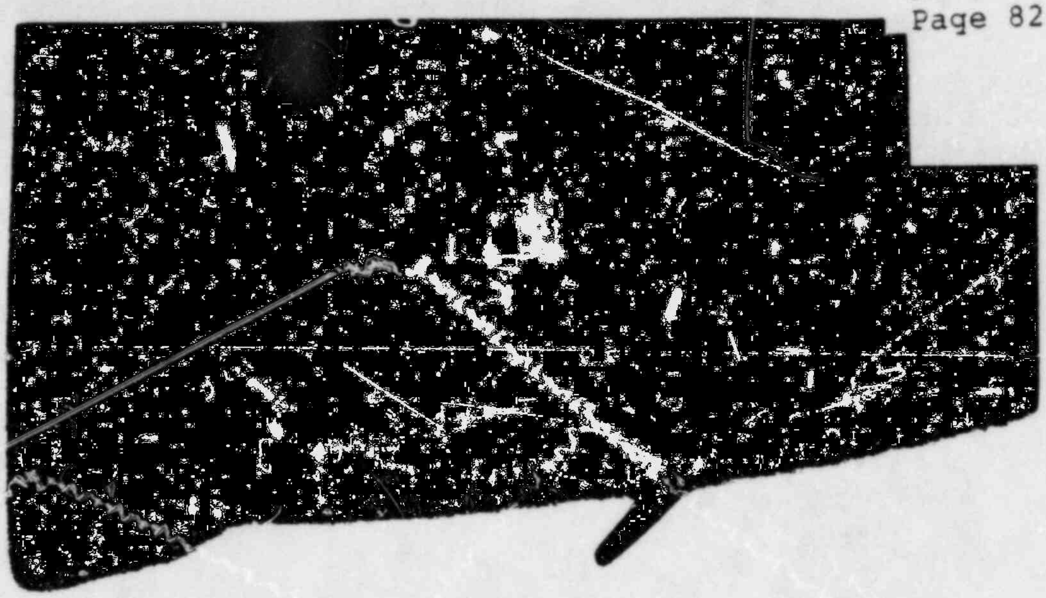


01

Appendix B

GE Weld Overlay Design Report

DRF #137-0010
MAR 84-17 Rev. 3
MAW03.DA

WELD OVERLAY DESIGNS
AND SHRINKAGE STRESS EVALUATION
FOR THE INDICATIONS IN THE
OYSTER CREEK ISOLATION CONDENSER SYSTEM PIPING

August 1984

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CONTENTS

1. INTRODUCTION

General Public Utilities (GPU) Nuclear performed an ultrasonic testing (UT) inspection of the Oyster Creek Isolation Condenser System piping in May 1984, for detection of Intergranular Stress Corrosion Cracking (IGSCC). The piping consists of two loops, A and B, each being made up of a supply line and a return line. Reportable indications were found at welds in each of the four lines, totaling twenty-seven. All of the indications were circumferential in orientation.

GPU Nuclear has decided to weld overlay repair eighteen of these welds and replace the remaining nine welds. The four pipe lines and the overlay locations are shown in Figures 1 through 4. Table 1 summarizes all of the welds and the respective pipe lines and pipe diameters. All but two of the indications were found in the 12-inch supply lines and the 8-inch return lines. The other two were at welds in a 10-inch return line and a 16-inch supply line. The overlays are to be designed to assure that the full structural margin intended by IWB-3640, Section XI [1], is maintained. This report provides recommendations for the design of the weld overlays to meet the Code safety margins and specific geometric considerations at each weld. The effects of axial shrinkage of the piping from application of the overlays is also examined in terms of the additional stresses imposed on the piping system.

2. SUMMARY AND RESULTS

The weld overlay designs for repair of the Isolation Condenser System piping were determined based on maintaining the ASME Code required factor of safety against net section yielding of the overlaid welds. The minimum required overlay thicknesses were obtained assuming the flaws to be fully circumferential and to extend through the original pipe wall. The applied primary loads used in the thickness calculations were enveloped to provide further conservatism and generality in the designs. The minimum thicknesses recommended here do not include the first weld layer. The overlay widths were sized to optimize the amount of welding time and material necessary to provide the required structural reinforcement of the flawed weld regions.

The stresses imposed on the Loop B supply and return lines from axial shrinkage of the overlays were calculated based on typical shrinkages. These stresses were found to be very low due to the overall flexibility of the piping. Loop A shrinkage stresses are expected to be of the same low magnitude.

3. WELD OVERLAY DESIGN ANALYSIS

The criterion used in design of the weld overlays for the Isolation Condenser System piping is to provide full structural reinforcement of the cracked region maintaining the ASME Code safety margins. In evaluation of the overlay designs, it is conservatively assumed that the flaws are fully circumferential and will extend through the susceptible material of the original pipe wall. With this assumption no credit is taken for the beneficial compressive residual stresses induced by the heat sink weld overlay process that would oppose crack extension through the thickness. The postulated through-wall cracks also provide assurance that the overlay design is independent of the crack size as determined by the ultrasonic testing. IGSCC crack growth into the weld overlay material beyond the first layer is not expected since the weld material away from the fusion line is not susceptible.

3.1 Methodology for Determining the Minimum Required Weld Overlay Thickness

The minimum weld overlay thickness necessary to achieve full structural reinforcement of the cracked section is that thickness which provides the appropriate factor of safety against net section collapse of the uncracked metal. For a fully circumferential crack, the depth at which net section collapse occurs is a funtion of the pipe material flow stress, the overall wall thickness including the weld overlay, and the primary membrane and bending stresses applied. The primary membrane stress is produced by pressure, and the primary bending stress is the sum of the dead weight and seismic bending stresses.

Paragraph IWB-3640 of Appendix X to Section XI, Reference 1, contains tables of the allowable circumferential flaw depth to pipe thickness ratios (a/t) for various applied primary stress ratios: $(P_m + P_b)/S_m$. The Isolation Condenser System piping welds are subjected to primary loads where the $(P_m + P_b)/S_m$ ratios are less than 0.6 after the weld overlay thickness adjustment (assuming a design stress intensity S_m of 17.5 ksi for 316 stainless steel). The tables of Reference 1 do not apply for these low stress ratios. Instead, the allowable flaw depth to thickness ratio must be calculated from the actual applied loads.

Assuming that the indications are fully circumferential, the method described in Reference 2 can be used. There, a relationship between the applied loads, the flow stress, and the critical crack depth to thickness ratio is defined by Equations (1) and (2).

$$\beta = \frac{\pi \left(1 - \frac{a}{t} - \frac{P_m}{\sigma_f}\right)}{2 - \frac{a}{t}} \qquad (1)$$

$$P_b = \frac{2\sigma_f}{\pi} \left(2 - \frac{a}{t}\right) \sin \beta \qquad (2)$$

where

σ_f = material flow stress,

P_m = primary membrane stress,

P_b = primary bending stress,

a = crack depth,

t = total thickness (pipe wall + weld overlay thickness), and

β = angle that defines location of neutral axis.

These equations cannot be solved directly for the allowable flaw depth to thickness ratio, so an iterative approach must be used. In the iteration scheme, a weld overlay thickness is assumed and the primary stresses are adjusted to the new total thickness. The allowable P_b corresponding to the new thickness and the adjusted primary membrane stress is calculated from Equations (1) and (2). The allowable $\left(\frac{P_m + P_b}{S_m}\right)$ ÷ Factor of Safety is then compared to the actual adjusted $\frac{P_m + P_b}{S_m}$. If the allowable is less than the actual, then the assumed weld overlay thickness is insufficient to provide full structural reinforcement and the procedure is repeated using a larger weld overlay thickness. The iteration is performed until the minimum required weld overlay thickness is determined. A factor of safety of 3.0 is used in accordance with the ASME Code, Section XI, Paragraph IWB-3640.

3.2 Applied Stresses at the Weld Overlay Locations

The deadweight and seismic stresses at the weld overlay locations were obtained from the Oyster Creek Isolation Condenser System piping stress report, Reference 3. The welds and the corresponding node numbers and stresses from this report are summarized in Table 2. The seismic stresses listed in this table are the greater of the two reported in Reference 3, corresponding to seismic analyses performed in two orthogonal horizontal directions.

A review of the deadweight and seismic stresses listed in Table 2 reveals considerable variation in each at the different weld locations. To obtain conservatism and generality in the weld overlay designs for the four different pipe sizes, the deadweight and seismic stresses were each enveloped based on the maximum stresses shown in Table 2. Thus, the enveloping deadweight stress is 3.3 ksi and the enveloping seismic stress is 5.1 ksi. The pressure used in calculating the primary membrane stress was 1090 psi. This is the technical specification limit for the opening of electro-mechanical relief valves.

In the IWB-3640 Tables [1], the implied factors of safety for normal/upset conditions are twice that for the emergency/faulted conditions (i.e., 2.8 versus 1.4). Therefore, the emergency/faulted condition primary loads are controlling only when they are more than twice the corresponding normal/upset condition loads. Since this was not the case for the subject isolation condenser line, the normal/upset condition loads stated in this subsection were used in the overlay design.

3.3 Weld Overlay Thickness Results

The iterative calculations described in Section 3.2 were performed for the four pipe sizes using the enveloping stresses. The flow stress σ_f was taken as 3 S_m. The results are provided in Tables 3 through 6. The thicknesses generated by this calculation are the minimum necessary for the overlay to maintain the required 3.0 factor of safety. They do not account for the various geometries specific to each weld, but serve only as the basis for the recommended design thicknesses.

3.4 Weld Overlay Widths

Unlike the thickness requirements for weld overlay designs, which are based on satisf-ing the safety margins of the ASME Code, there are no guidelines for determination of the weld overlay widths. General Electric has performed finite element studies which compared the stresses obtained in pipes with different weld overlay widths. Results showed that there is no significant difference between the stresses obtained for widths in excess of one attenuation length, $\sqrt{Rt}$, and it was concluded that the additional material of the wider overlay contributes little to the overall structural reinforcement of the weld. Therefore, minimum weld overlay widths of $\sqrt{Rt}$ are used here as the basis for the recommended overlay designs. This reduction in width greatly reduces the time required for application of the weld overlays. The minimum widths are included in Tables 3 through 6 also for each pipe size.

3.5 Weld Overlay Designs

The minimum weld overlay thicknesses and widths provided in Tables 3 through 6 were used as the basis for the individual weld overlay geometries. The specific overlay designs were also based on consideration of such factors as the relative thicknesses of the butt welding members, the weld crown geometry, the extent of the original heat affected zone, and the proximity to other pipe fittings such as elbows and attached piping. The slopes of the overlay ends were set to three-to-one (width-to-thickness) to reduce stress concentration effects.

A further consideration was weld metal-base metal dilution in the first weld overlay layer. The overlay-base metal mixing could result in a lessening of the weld material's resistance to IGSCC close to the fusion line. Thus an effective design thickness for overlay deposited after the first weld layer was specified in accordance with Reference 4.

Of the eighteen welds to be overlayed, six are pipe-to-pipe and twelve are pipe-to-elbow butt welds. A schematic of the overlay design geometries for the pipe-to-pipe welds and a summary of the overlay dimensions for each specific weld are provided in Figure 5. Similarly, for the pipe-to-elbow welds, Figure 6 summarizes the weld specific overlay design dimensions.

3.6 Safety Factors Evaluation

To demonstrate the conservatism built into the overlay design thickness calculations and to perform supplementary evaluations using thermal expansion stresses, a safety factor calculation for each weld overlay was performed and the results are shown in Table 7. The dead weight and seismic (OBE) stresses in Table 7 are the same as those in Table 2. The applied ($P_m + P_b$) stresses shown in the next column are the sum of the pressure, dead weight, and seismic stresses. The next column shows the calculated limit ($P_m + P_b$) of the overlays using Equations 1 and 2. This calculation was based on the recommended design thicknesses of overlays given in Figures 5 and 6. The safety factors, i.e., limit ($P_m + P_b$) over applied ($P_m + P_b$), were then calculated. It is seen that the factors of safety are in excess of 4.1.

In order to assess the impact of inclusion of thermal expansion stresses on the safety factors, a supplementary evaluation was performed and the results are shown in the last two columns of Table 7. The operating condition thermal expansion stresses at each weld are shown first. Note that these stress magnitudes, as are the others, do not include the stress intensification factors. This is consistent with the use of net section collapse theory in the overlay design. From an examination of the last column in Table 7, it is seen that even with the inclusion of thermal expansion stresses the safety factors are no less than 3.4. It is emphasized that this is only a supplemental calculation and does not imply that the thermal expansion stresses need be included in the overlay design. Moreover, available data on the TIG weldments of the type used in the weld overlays indicate that their toughness approaches that of wrought austenitic material for which the secondary stresses are of no concern.

4. WELD OVERLAY SHRINKAGE STRESS ANALYSIS

Application of a weld overlay produces an axial contraction of the pipe which is a function of the pipe size and the overlay thickness and width. This shrinkage imposes stresses on the entire piping system. The amount of shrinkage was estimated for the purpose of this analysis based on typical shrinkages observed in similar weld overlay applications. The 8- and 10-inch pipe overlays were assumed to shrink 1/4 inch, and the 12- and 16-inch pipe overlays were assumed to shrink 3/8 inch. A finite element analysis of the Loop B supply and return piping was performed to determine the magnitudes of the stresses due to these assumed shrinkages. This analysis was performed using the PISYS finite element code (Reference 5). The models are provided in Figures 7 and 8. The shrinkage effect was simulated by forcing thermal contractions at the weld overlay locations equivalent to the assumed 1/4- and 3/8-inch overlay shrinkages. A summary of the maximum shrinkage stresses obtained in the Loop B supply and return lines is provided in Table 8.

The shrinkage stresses obtained in Loop B are low due to the overall flexibility of the piping system: the piping is supported mainly through hangers and snubbers. The Loop A supply and return lines are very similar in configuration and support to Loop B and thus the stresses due to overlay shrinkage in these lines would be of the same low magnitude as calculated for the Loop B lines.

The actual shrinkage data from the field were unavailable at the time the shrinkage stress analysis was conducted. A review of the actual shrinkage data indicates that the maximum axial shrinkages are as follows: 8-inch pipe overlays, 0.465 inch; 10-inch pipe overlays, 0.33 inch; 12-inch pipe overlays, 0.36 inch; and 16-inch pipe overlays, 0.234 inch. Taking the worst deviation case from the assumed values, the 8-inch pipe overlay shrinkage is 1.86 times the value assumed in the stress analysis. The maximum shrinkage stress shown in Table 8 is 1487 psi. By conservatively multiplying this stress by 1.8, a maximum shrinkage stress of 2765 psi is obtained. This stress is well within the allowable value, which is equal to the material yield stress. Thus, the calculated weld overlay shrinkage stresses in the isolation condenser line are acceptable.

5. REFERENCES

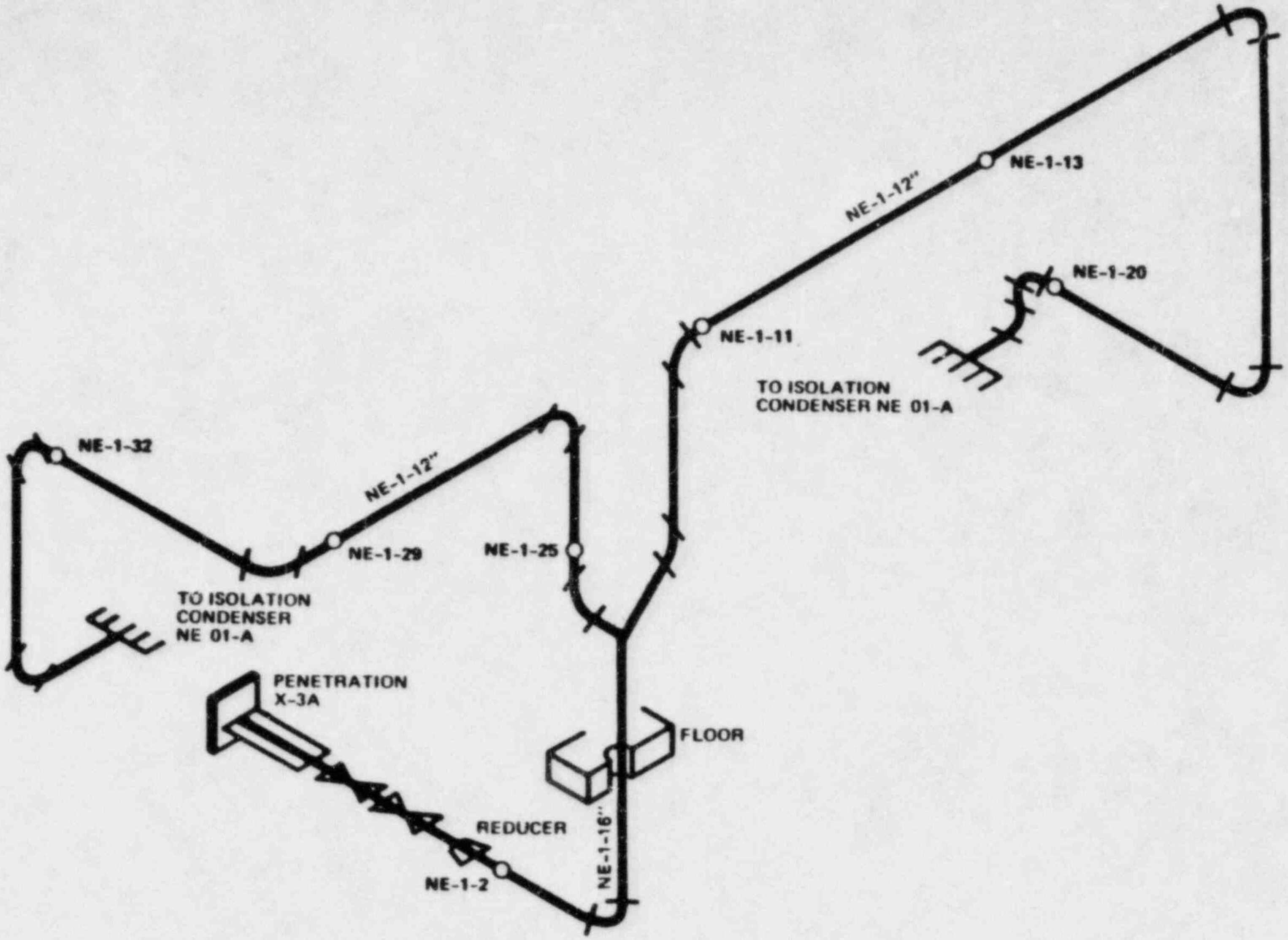
1. ASME Boiler and Pressure Vessel Code, Section XI, 1980 Edition, Winter 1983 Addenda.

2. Ranganath, S. and Mehta, H. S., 'Engineering Methods for the Assessment of Ductile Fracture Margin in Nuclear Power Plant Piping.' Elastic-Plastic Fracture: Second Symposium, Volume II--Fracture Resistance Curves and Engineering Applications, ASTM STP-803, 1983, pp. 309-330.

3. Oyster Creek Isolation Condenser System Piping Stress Report, prepared by EDS Nuclear, November 1979, EDS Report No. 02-0370-1021.

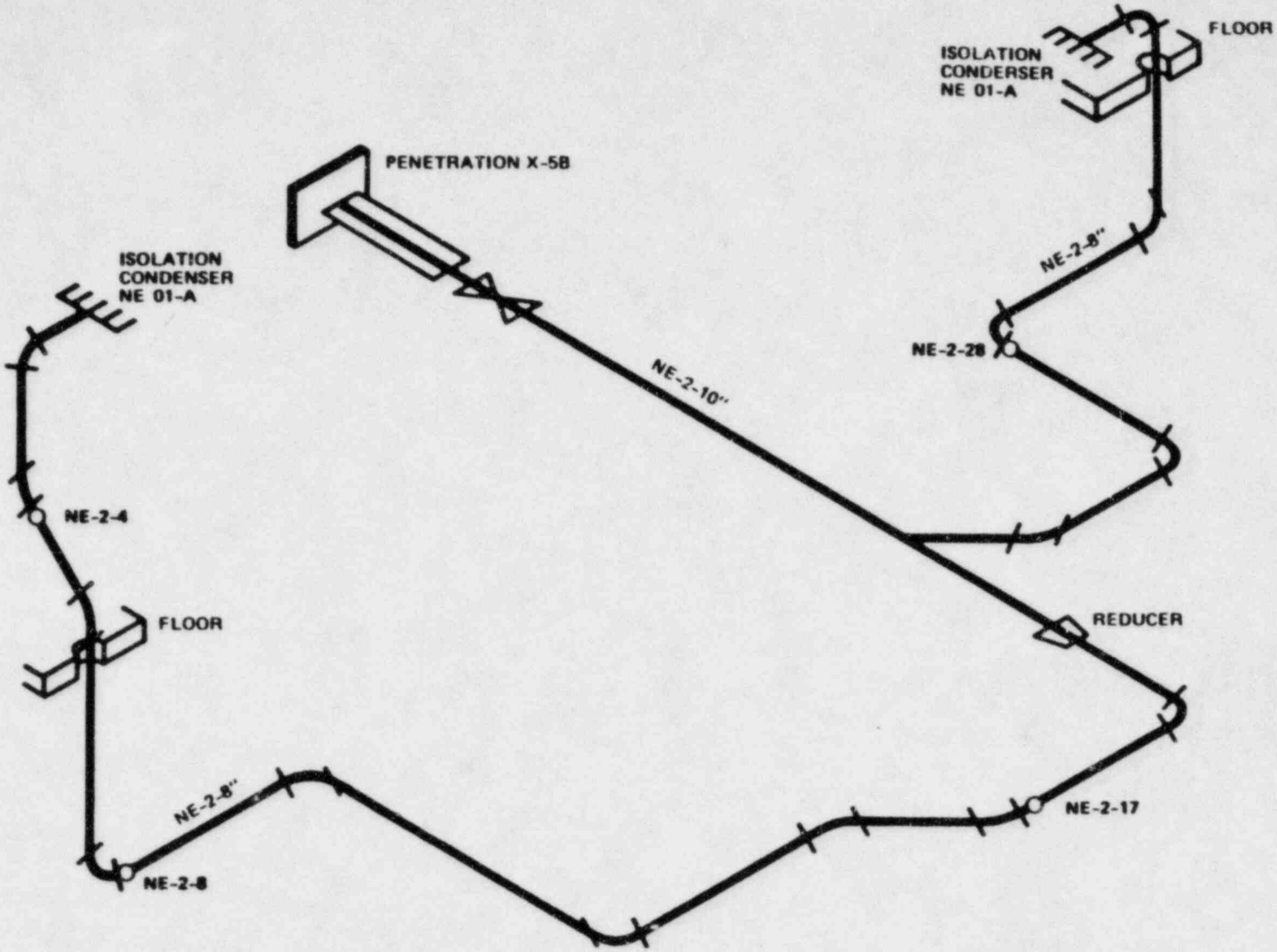
4. Letter from William J. Dircks, NRC to the Commissioners, NRC, 'Staff Requirements for Reinspection of BWR Piping and Repair of Cracked Piping.' November 7, 1983, SECY-83-267C.

5. PISYS05, GE Piping System Analysis Computer Program, NEDE-24077, January 1981.



Oyster Creek Isolation Condenser Piping Loop A Supply Line

Figure 1



Oyster Creek Isolation Condenser Piping Loop A Return Line

Figure 2

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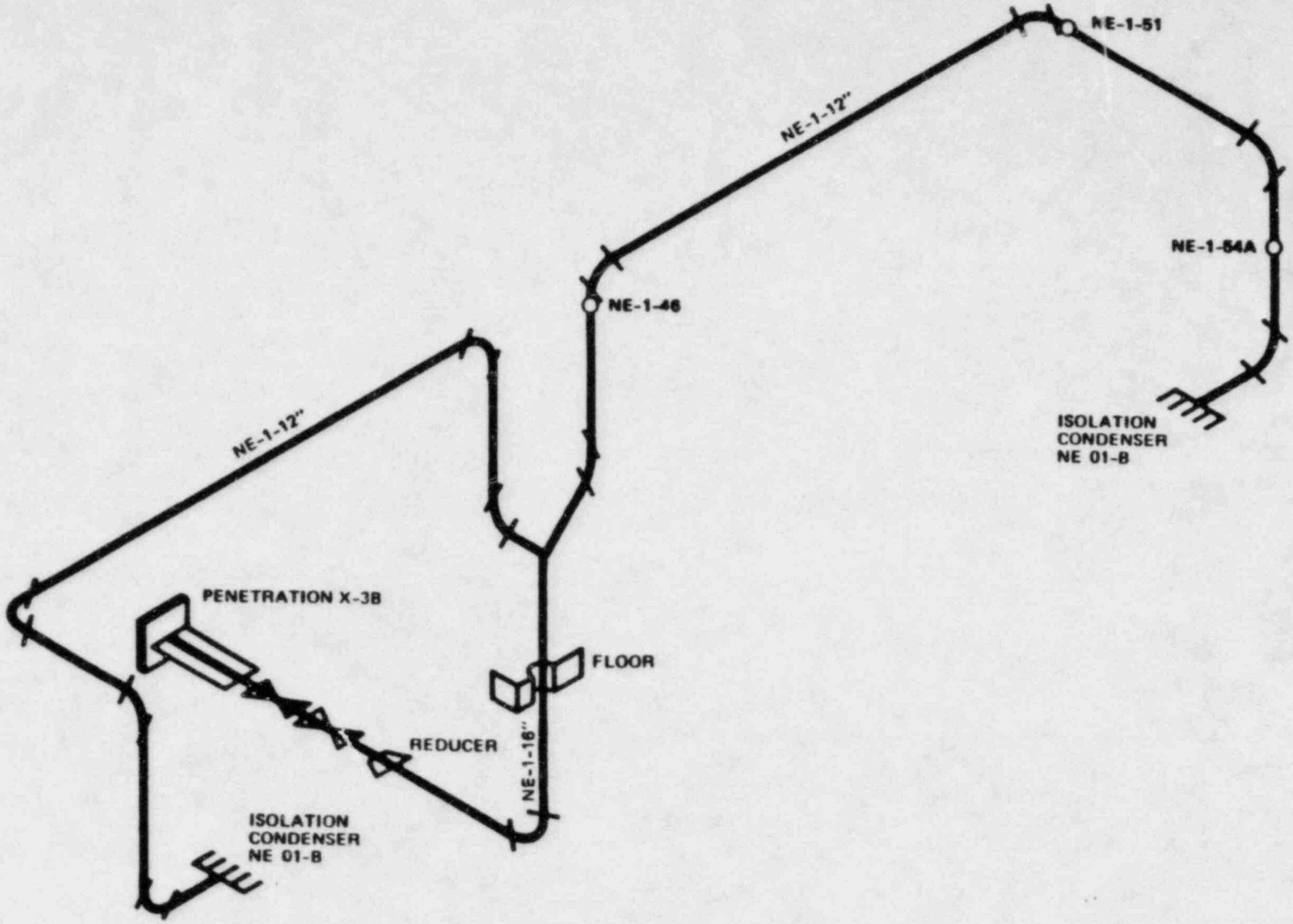
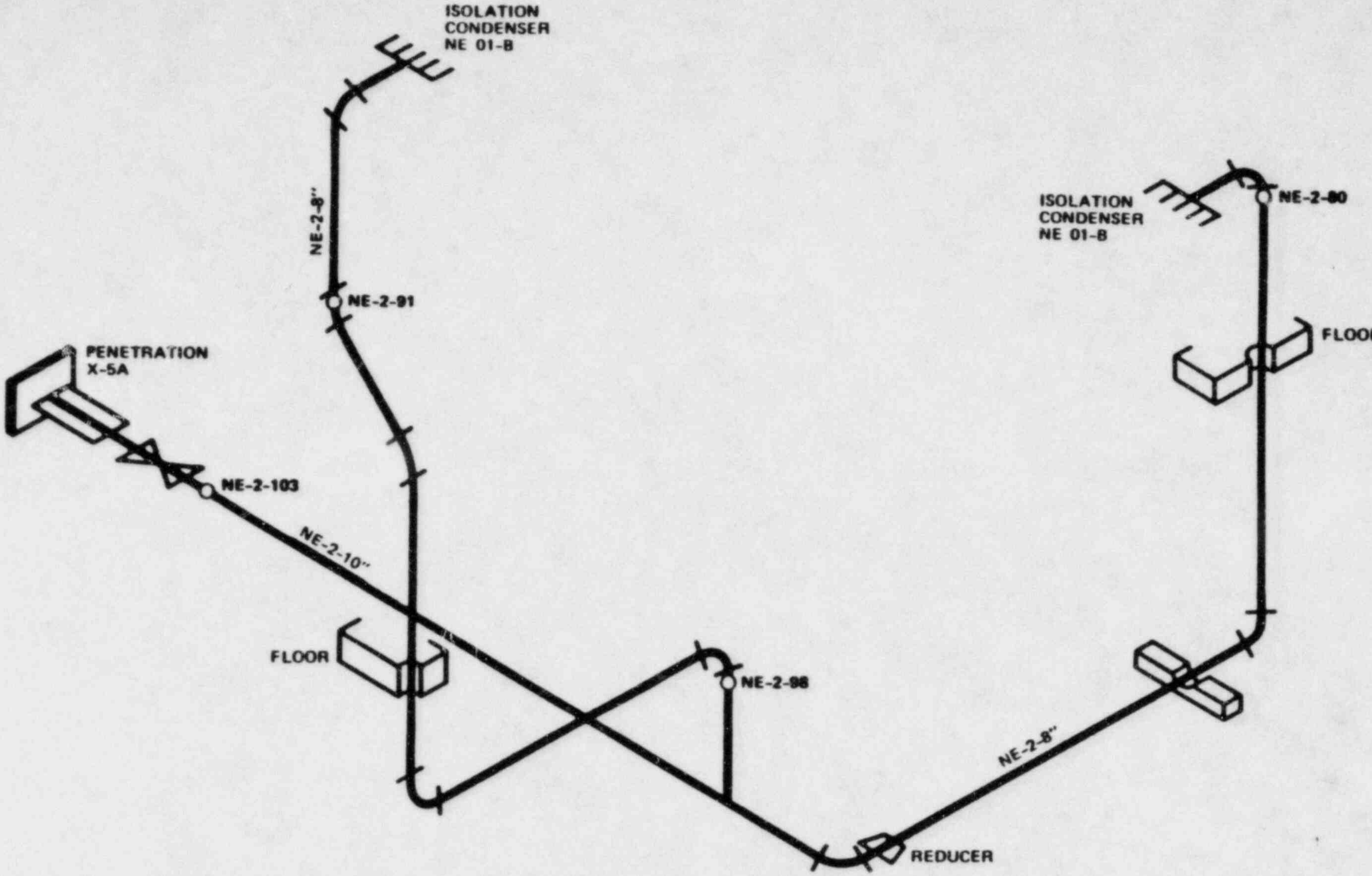


Oyster Creek Isolation Condenser Piping Loop B Supply Line

Figure 3



Oyster Creek Isolation Condenser Piping Loop B Return Line

Figure 4

TABLE 1

Welds at which Indications were Identified in the Oyster Creek Isolation Condenser System Piping

Weld ID	Piping Line	Nominal Pipe Size (inches)
NE-1-2	Loop A, Supply	16 Schedule 80
NE-1-11	''	12
NE-1-13	''	12
NE-1-20	''	12
NE-1-25	''	12
NE-1-29	''	12
NE-1-32	''	12
NE-2-4	Loop A, Return	8
NE-2-8	''	8
NE-2-17	''	8
NE-2-28	''	8
NE-1-46	Loop B, Supply	12
NE-1-51	''	12
NE-1-54A	''	12
NE-2-80	Loop B, Return	8
NE-2-91	''	8
NE-2-98	''	8
NE-2-103	''	10

TABLE 2

Summary of Deadweight and Seismic Stresses at Weld Overlay Locations Oyster Creek Isolation Condenser Piping

Weld ID	Finite Element Node #*	Deadweight (ksi)	Seismic (ksi)
NE-1-2	9	.211	.390
NE-1-11	46	.903	1.174
NE-1-13	52	1.205	1.346
NE-1-20	64	3.249	.594
NE-1-25	19	.604	.549
NE-1-29	28	.270	1.210
NE-1-32	33	.510	2.055
NE-2-4	40	1.114	.530
NE-2-8	33	2.293	.691
NE-2-17	18	2.330	1.871
NE-2-28	54	.846	5.021
NE-1-46	43	2.423	.629
NE-1-51	51	1.386	.406
NE-1-54A	55	1.571	.316
NE-2-80	32	.218	.823
NE-2-91	48	.326	2.241
NE-2-98	36	1.660	2.126
NE-2-103	6	.198	.411

*Node numbers correspond to the piping finite element models from Reference 3

Table 3

**Minimum Weld Overlay Dimensions
for Eight-Inch Isolation Condenser Piping**

WELD ID: 8 INCH

PIPE THICKNESS = 0.50 INCH
PIPE DIAMETER = 8.6 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 4.70 KSI
DEAD WEIGHT = 3.30 KSI
SEISMIC = 5.10 KSI

WOT	T / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.225	0.690	3.411	5.793	24.304	0.526	0.523

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.195
(PM+PB)/SM = 0.526

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.225 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 1.5 INCH

Table 4

Minimum Weld Overlay Dimensions for Ten-Inch Isolation Condenser Piping

WELD ID: 10 INCH

PIPE THICKNESS = 0.59 INCH
PIPE DIAMETER = 10.8 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 4.94 KSI
DEAD WEIGHT = 3.30 KSI
SEISMIC = 5.10 KSI

WOT	T / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.275	0.683	3.548	5.739	24.656	0.531	0.537

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.203
(PM+PB)/SM = 0.531

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.275 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 1.8 INCH

Table 5

**Minimum Weld Overlay Dimensions
for Twelve-Inch Isolation Condenser Piping**

WELD ID: 12 INCH

PIPE THICKNESS = 0.69 INCH
PIPE DIAMETER = 12.8 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 5.06 KSI
DEAD WEIGHT = 3.30 KSI
SEISMIC = 5.10 KSI

WOT	T / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.320	0.682	3.623	5.731	24.615	0.535	0.538

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.207
(PM+PB)/SM = 0.535

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.320 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 2.1 INCH

Table 6

Minimum Weld Overlay Dimensions for Sixteen-Inch Isolation Condenser Piping

WELD ID: 16 INCH

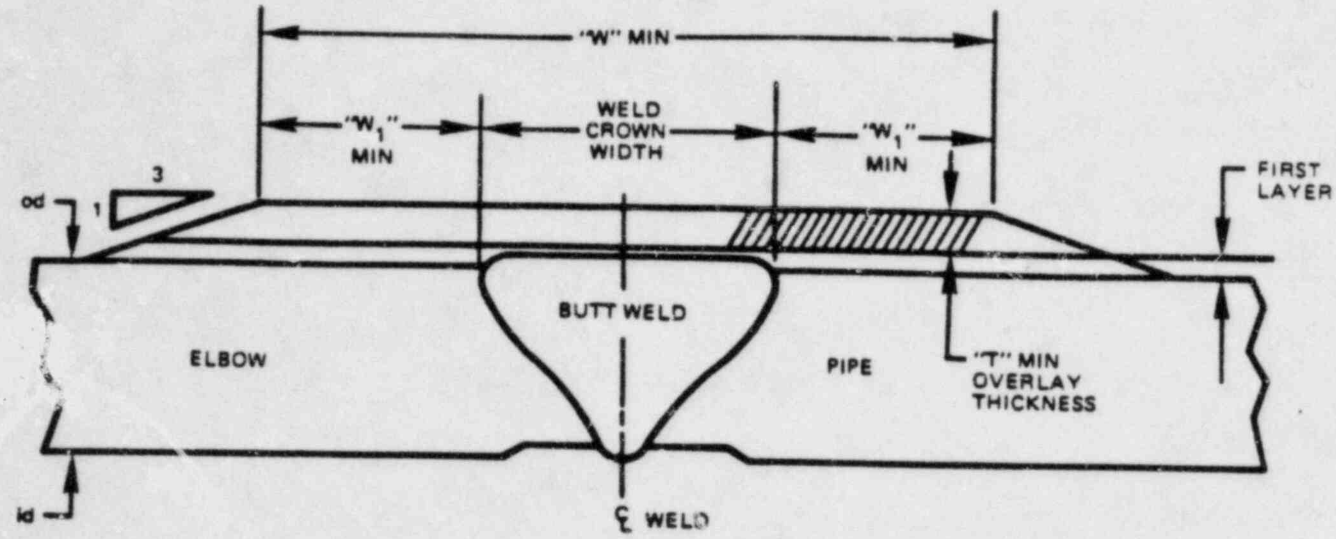
PIPE THICKNESS = 0.84 INCH
PIPE DIAMETER = 16.0 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 5.18 KSI
DEAD WEIGHT = 3.30 KSI
SEISMIC = 5.10 KSI

WOT	T / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	(PM+PB)/SM (ACTUAL)	(PM+PB)/3SM (CALC)
0.395	0.681	3.698	5.718	24.629	0.538	0.540

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.211
(PM+PB)/SM = 0.538

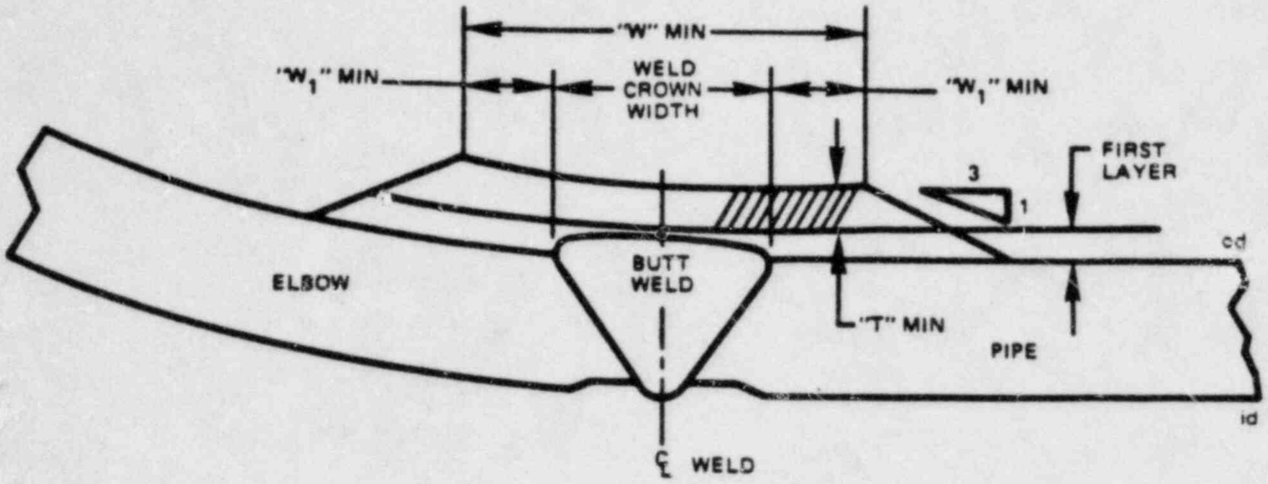
MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.395 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 2.6 INCH



PIPE-TO-PIPE

Weld No.	Loop	Pipe Size (inches)	Wall Thickness	T_{min}	W_1	W
NE-1-2	A	16	.843	.40	.75	3.3
NE-1-13	A	12	.687	.35	.60	3.0
NE-1-25	A	12	.687	.35	.60	3.0
NE-1-29	A	12	.687	.35	.60	3.0
NE-1-54A	B	12	.687	.35	.60	3.0
NE-2-103	B	10	.593	.30	.50	2.5

Figure 5 Design Dimensions for the Pipe-to-Pipe Weld Overlays Oyster Creek Isolation Condenser Piping



PIPE-TO-ELBOW

Weld No.	Loop	Pipe Size (inches)	Wall Thickness	T_{min}	W_1	W
NE-1-11	A	12	.687	.35	.60	3.0
NE-1-20	A	12	.687	.35	.60	3.0
NE-1-32	A	12	.687	.35	.60	3.0
NE-2-4	A	8	.500	.25	.50	2.1
NE-2-8	A	8	.500	.25	.50	2.5
NE-2-17	A	8	.500	.25	.50	2.2
NE-2-28	A	8	.500	.25	.50	2.3
NE-1-46	B	12	.687	.35	.60	3.0
NE-1-51	B	12	.687	.35	.60	3.0
NE-2-80	B	8	.500	.25	.50	2.7
NE-2-91	B	8	.500	.25	.50	2.4
NE-2-98	B	8	.500	.25	.50	2.3

Figure 6 Design Dimensions for the Pipe-to-Elbow Weld Overlays Oyster Creek Isolation Condenser Piping

Table 7

SAFETY FACTORS FOR OYSTER CREEK
ISOLATION CONDENSER WELD OVERLAYS

Weld ID	Piping Line	Nominal Pipe Size (inches)	Deadweight (ksi)	Seismic (ksi)	(P_m+P_b) (ksi)	Limit Load (ksi)	Safety Factor Based on Primary Stress	Thermal Expansion (ksi)	Safety* Factor w/ Thermal Expansion
NE-1-2	Loop A, Supply	16	.211	.390	5.78	41.5	7.2	0.5	6.6
NE-1-11	"	12	.903	1.174	7.14	43.2	6.1	3.9	3.9
NE-1-13	"	12	1.205	1.346	7.61	43.2	5.7	2.6	4.2
NE-1-20	"	12	3.249	.594	8.90	43.2	4.8	3.4	3.5
NE-1-25	"	12	.604	.549	6.21	43.2	6.9	2.7	4.8
NE-1-29	"	12	.270	1.210	6.54	43.2	6.6	3.7	4.2
NE-1-32	"	12	.510	2.055	7.62	43.2	5.7	2.4	4.3
NE-2-4	Loop A, Return	8	1.114	.530	6.34	42.8	6.7	0.1	6.6
NE-2-8	"	8	2.293	.691	7.68	42.8	5.6	0.2	5.4
NE-2-17	"	8	2.330	1.871	8.90	42.8	4.8	0.1	4.7
NE-2-28	"	8	.846	5.021	10.57	42.8	4.1	0.2	4.0
NE-1-46	Loop B, Supply	12	2.423	.629	8.11	43.2	5.3	4.7	3.4
NE-1-51	"	12	1.386	.406	6.85	43.2	6.3	2.4	4.7
NE-1-54A	"	12	1.571	.316	6.95	43.2	6.2	5.4	3.5
NE-2-80	Loop B, Return	8	.218	.823	5.74	42.8	7.4	0.8	6.5
NE-2-91	"	8	.326	2.241	7.27	42.8	5.9	0.4	5.6
NE-2-98	"	8	1.660	2.126	8.49	42.8	5.0	0.4	4.8
NE-2-103	"	10	.198	.411	5.55	43.4	7.8	0.4	7.3

*These safety factors are calculated for information purposes only. They do not imply that thermal expansion stresses be considered in weld overlay design.

Note: The P_m values are 4.70 ksi (8-inch pipe)
4.94 ksi (10-inch pipe)
5.06 ksi (12-inch pipe)
5.18 ksi (16-inch pipe)

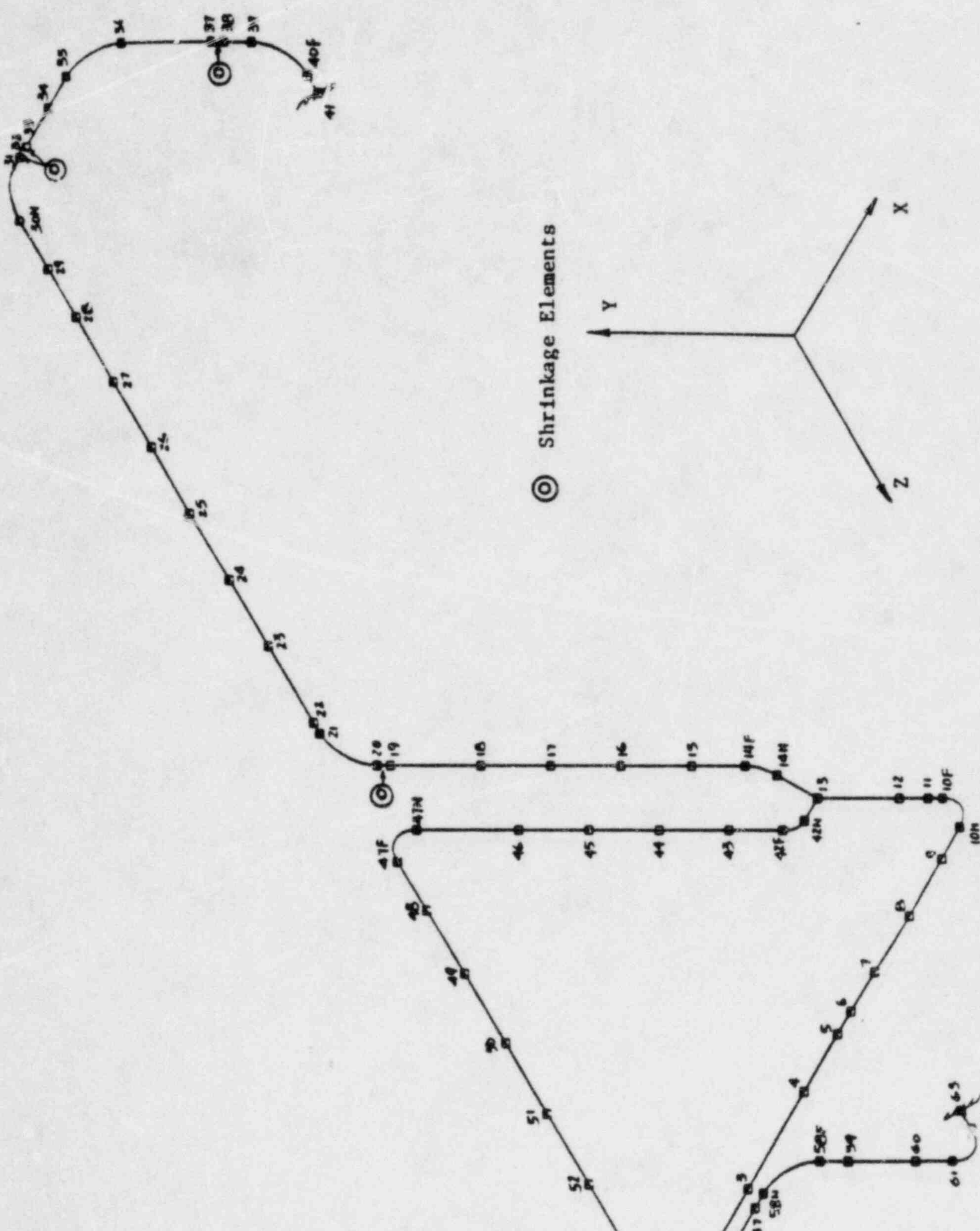


Figure 7

Isolation Condenser Piping Model for Shrinkage Stress Analysis--
Loop B Supply

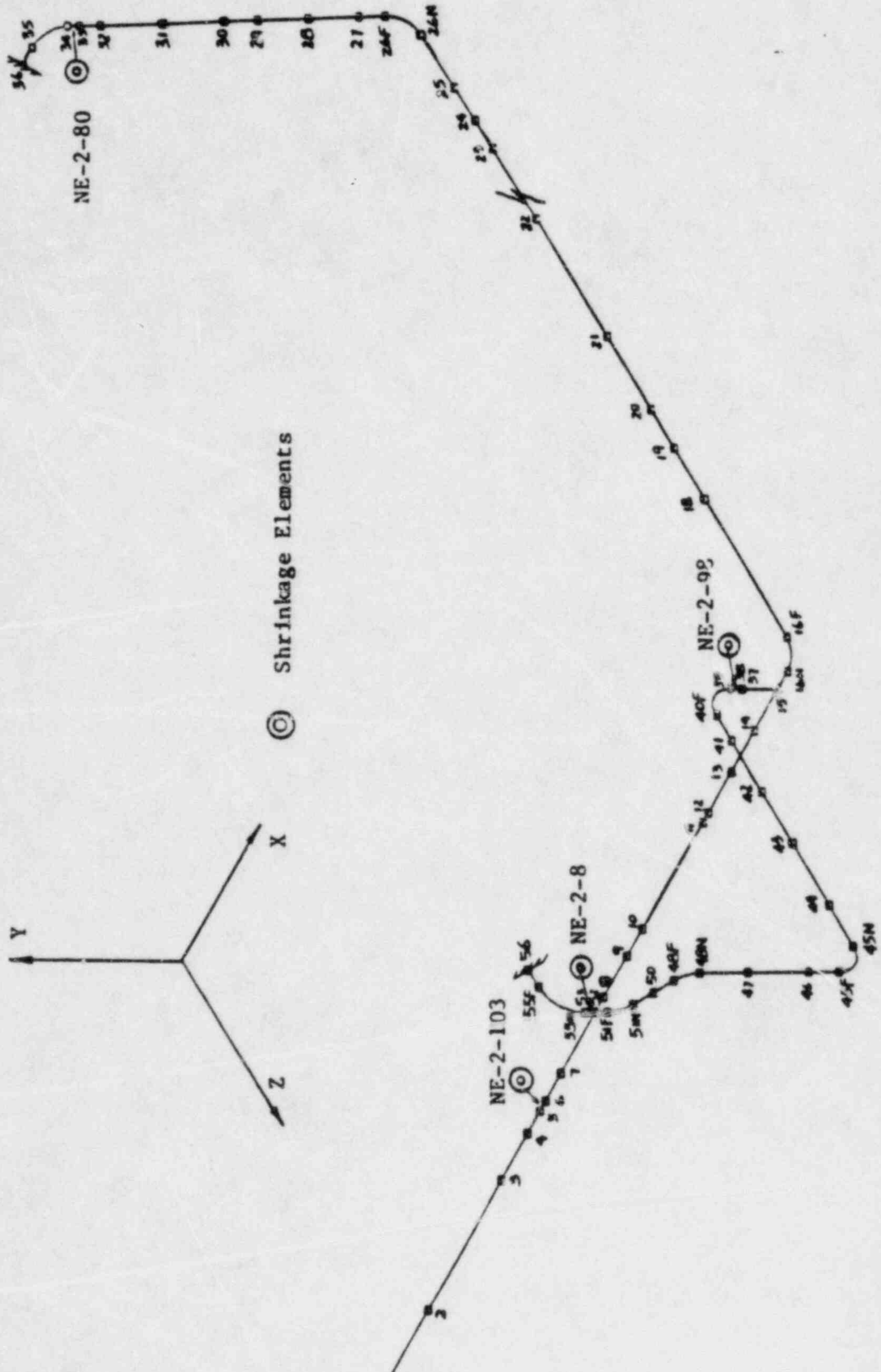


Figure 8

Isolation Condenser Piping Model for Shrinkage Stress Analysis--
Loop B Return

Table 8

Maximum Shrinkage Stresses
Isolation Condenser Piping—Loop B

Location	Pipe Line	Finite Element Node #	Moment	Section Modulus	Nominal Stress (psi)
Weld NE-1-40	Supply	10N	29,219	144.5	202
'Y' Reducer	Supply	13	29,153	74.5	391
Penetration X-5A	Return	1	67,712	45.6	1,487
Weld NE-2-98	Return	38	54,514	45.6	1,197