GPU Nuclear
TECHNICAL DATA REPORT

TITLE: CRACK GROWTH AND LEAK RATE ASSESSMENT OF THE OYSTER CREEK EMERGENCY CONDENSER SYSTEM PIPING OUTSIDE CONTAINMENT BELOW THE 95 FOOT ELEVATION.

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GPU Nuclear **TECHNICAL DATA REPORT**	**TDR NO.** 467	**REVISION NO.** 1
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DOCUMENT TITLE: CRACK GROWTH AND LEAK RATE ASSESSMENT OF THE EMERGENCY CONDENSER SYSTEM PIPING OUTSIDE CONTAINMENT BELOW THE 95 FOOT ELEVATION

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ABSTRACT:

STATEMENT OF PROBLEM

Justify the use of visual surveillance as the means by which leak detection will be performed under predefined crack growth criteria on the Oyster Creek Emergency Condenser System supply (steam) and return (condensate) lines outside containment below the 95 foot elevation.

SUMMARY

One weld per pipe size (below the 95 foot elevation) was analyzed for crack growth and leak rate assuming an initial through-wall circumferential crack length of 2 wall thicknesses (2t). Plastic instability was assumed to occur when the crack length exceeded 90° of the pipe circumference.

Under normal operating conditions, the shortest time for a crack to grow from 2t to 90° was calculated to be 18 months. Leakage from both the supply and return lines would be readily detected by visual means.

CONCLUSIONS

1) Visual surveillance of this piping will enable detection of leakage from a crack well before a crack would reach an unstable length.

2) There is sufficient time to take appropriate actions (i.e., shut down or isolate the affected condenser) between leak detection and the time that a crack reaches an unstable length.

ACTIONS TO BE TAKEN

The Oyster Creek Technical Specification will be revised to require a visual surveillance of the subject lines once every 24 hours.

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REV	SUMMARY OF CHANGE	APPROVAL	DATE
1	Substantially revised because of recent cracking event and changes in basis and methodology.	R. T. DeMuth	8/15/84
		for E. S. Giacobbe	8/15/84
		for G. E. Von Nieda	8/15/84
		D. K. Croneberger	8-15-84

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Executive Summary

In 1979, Jersey Central Power & Light Company (JCP&L) performed a high energy line break (HELB) evaluation of the Oyster Creek Emergency Condenser System (ECS) outside containment. The conclusion was that a pipe break could result in damage to the ECS isolation valves and controls.

In 1982, the NRC-SEP issued criteria, commonly referred to as the "Palisades Criteria", which permitted licensees to perform a safety assessment as an alternative to system modifications or alterations. Based upon these criteria, GPUN performed an analysis of the HELB locations identified in the 1979 evaluation and concluded that no system changes were required provided that a periodic visual inspection of the area was performed. The NRC-SEP accepted the conclusion reached on system modifications; however, the NRC-SEP considered that an automated leak detection method was necessary to detect low level leakage in the order of 0.1 gallon per minute (gpm) to protect piping integrity. GPUN stated that it would analyze crack growth and resultant leak rates to justify the use of visual monitoring.

This report describes the methods used to estimate the crack growth and leak rates from each of three locations in the ECS (one location per pipe size) below the 95 foot elevation outside containment. The piping is Type 316 austentic stainless steel 8-, 10-, and 16-inch diameter. Cracks in this material will develop and grow primarily due to intergranular stress corrosion cracking (IGSCC) in the heat-affected zones of the girth welds.

Only environmentally (IGSCC) controlled growth was evaluated; the contribution of fatigue to crack growth is negligible in these lines. Both supply (steam) and return (condensate) lines were evaluated. For all cases the calculations were perfomed for one month intervals, assuming an initial through-wall crack length of 2t, where t is the nominal wall thickness, until the crack length exceeded 90° of the pipe circumference (assumed instability).

The results of the calculations show that the leak rates from the cracks are sufficiently high to be detectable by visual means. Additionally, sufficient time exists to take appropriate actions (i.e., shut down or isolate the affected condenser) between the time of leak detection and the time that a crack would grow from that point to an unstable length.

The results support the use of visual monitoring as an acceptable method of leak detection.

The Oyster Creek Technical Specification will be revised to require visual surveillance to be performed once every twenty-four (24) hours. Additionally, selected welds will be left exposed (i.e., without insulation) to facilitate leak detection.

1.0 INTRODUCTION

1.1 Purpose

The purpose of this report is to determine crack growth rate and leak rate to justify the use of visual surveillance to detect leakage from the Oyster Creek Emergency Condenser System (ECS) piping outside containment below the 95 foot elevation and that adequate time between leak detection and the onset of crack instability exists to take appropriate actions. A system description is provided in Appendix A.

1.2 Background

In 1979, Jersey Central Power and Light Company (JCP&L) performed a high energy line break (HELB) analysis of the Oyster Creek ECS piping outside containment below the 95 foot elevation and concluded that a pipe break could cause damage to the ECS isolation valves and controls [1]. JCP&L provided this conclusion to the NRC. The NRC (SEP Branch) performed an on-site inspection, confirmed JCP&L's findings, and requested modifications to the ECS to provide adequate protection against the effects of a postulated HELB. JCP&L performed engineering studies of various modifications and concluded that none could be made on a retrofit basis that would effectively resolve all the potential problems and not impose significant limitations on access for inspection and maintenance. JCP&L notified the NRC of these conclusions and stated that they would perform an analysis to demonstrate that the ECS piping would leak before a significant break could occur.

The NRC had developed criteria [2], often called the "Palisades Criteria", which permitted licensees to perform a safety assessment based upon fracture mechanics or an augmented inservice inspection (ISI) program as alternatives to system modifications. GPUN used these criteria to perform the safety analysis.

1.3 NRC Alternative Safety Assessment Criteria (Palisades Criteria)

1.3.1 Detectability Requirements

A leak detection system is to be provided to detect through-wall cracks, both longitudinal and circumferential, of a length of twice the wall thickness for minimum flow rates associated with normal (Level A) ASME B & PV Code operating conditions.

1.3.2 Integrity Requirements

1.3.2.1 Level D Loads

Show that circumferential or longitudinal through-wall cracks of four wall thicknesses in length subjected to Level D loading conditions exhibit stable crack growth and ensure that local or general plastic instability does not occur from Level D loads and the specified crack lengths.

1.3.2.2 Extreme Conditions

Demonstrate the stability of a circumferential through-wall crack of a length equal to the greater of 4 wall thicknesses or 90° circumferential length under fully plastic bending loads; hanger effects are to be neglected; snubbers are to be assumed as ineffective.

1.3.1.3 Material Properties

Lower-bound material properties are to be used and justified.

1.3.3 Sub-Critical Crack Growth

Consideration shall be given to the types of sub-critical cracks which may exist in the piping.

1.3.4 Augmented ISI

Piping systems shall be volumetrically inspected to the ASME Code Section XI for Class 1 Systems regardless of the actual classification if corrective measures are not practicable.

GPUN adopted the Palisades Criteria, with the exception of automated leak detection devices, and used them for a leak-before-break analysis.

1.4 Leak Before Break Analysis

It was concluded that: 1) the ECS A and B supply and return lines all exhibited crack stability (i.e. would leak before break) and, therefore, no system modifications were necessary and 2) visual surveillance may be used for leak detection since all the lines exhibited excellent stability for 90° circumferential length through-wall cracks under both Level D and extreme conditions [3].

The NRC-SEP accepted this position on stability; however, the NRC-SEP considered an automated leak detection system was still necessary. GPUN responded by stating that it would perform a crack growth analysis to justify that the resultant leak rates would be sufficiently high so that visual monitoring is an acceptable method of leak detection.

1.5 Leak Rate Analysis

GPUN has performed a leak rate analysis on each of three locations (one location per pipe size) identified in [4] as the most highly-stressed weld. Each line is fabricated from Type 316 austentic stainless steel. Welding of these lines resulted in circumferentially oriented, sensitized heat affected zones which will promote IGSCC. The analysis was performed assuming that a

2t-long circumferential through-wall crack was present at each location. The crack growth rate and resultant leak rate were calculated for one month intervals until the crack length exceeded 90° of the pipe circumference. The effects of fatigue on the crack growth rate were not included since their contribution to crack growth on these lines is negligible; therefore, only environmentally (IGSCC) controlled growth under steady-state conditions was evaluated.

2.0 METHODS

2.1 Introduction

To determine leak rates as a function of time, one requires the following information for each location analyzed:

- a) Operating Stresses
    - 1) Tensile (pressure)
    - 2) Bending
        - a) Gravitational (deadweight)
        - b) Thermal
- b) Crack Orientation
- c) Crack Geometry
- d) Stress Intensity at the Crack Tip
- e) Crack Growth Rate
- f) Leak Rate Calculation Methodology.

Each of these items is discussed in this section.

2.2 Operating Stresses

GPUN reviewed the stress analysis [4] and selected the most highly stressed point for each pipe size outside containment and below the 95 foot elevation. Only steady-state stresses were evaluated since a seismic event is of such short duration that it will not significantly contribute to IGSCC propagation. The stresses for each pipe size evaluated are shown in Table I.

The effects of weld induced through-wall residual stresses were not included for this analysis. For purposes of analysis of crack growth, the residual stress pattern for welds under one inch thick, which is appropriate for the ECS piping, has been idealized as being asymmetrical around the mid-point of the wall thickness (i.e. $\sigma_{rod} = -\sigma_{rid}$ [9], where σ_{rod} is the residual stress at the outside of the pipe wall and σ_{rid} is the residual stress at the inside of the pipe wall.

In other words, the average residual tensile stress driving the crack to grow is equal to the average residual compressive stress that inhibits crack growth. Therefore, residual stress is not used as a factor in the circumferential growth of a through-wall crack [7,8]. This is a conservative approach since at discrete locations within the wall, the compressive force will, in fact, act to retard crack growth; therefore, the calculated crack growth rate, neglecting residual stress influences, will be greater than that realized in actual cases.

For crack growth calculations, design pressure and calculated deadweight stresses were used for both the supply and return lines. Thermal stresses were used only for the supply line calculations; the return lines are at ambient temperature because the return line valve just outside containment is kept closed during normal operation.

For leak rate calculations, Level A (normal operating) pressures were used since this is operating condition for which leak detection is required [2].

Additionally, shrinkage stress resulting from the application of weld overlays [14] to the system piping were included in the crack growth analysis. A value of 3000 psi (twice the maximum value assumed in the analysis of the overlay shrinkage stress [14]) was assumed regardless of each analyzed location's proximity to any overlay.

2.3 Crack Orientation

Circumferentially oriented cracks were selected for analysis based upon a combination of factors. For all the points selected except one, the axial stress exceeds the circumferential (hoop) stress; therefore, the crack driving force will drive the crack tip in the circumferential direction. Also, field experience has been that axial IGSCC growth occurs only in furnace sensitized piping; the Oyster Creek ECS piping is girth-weld sensitized.

2.4 Crack Geometry

The crack growth and leak rate analyses were performed assuming that a 2t circumferential length through-wall crack existed at each point selected. The crack shape was assumed to be semi-elliptical with an I.D. to O.D. length ratio typical of circumferential cracks caused by IGSCC in the sensitized heat affected zone of girth-welded stainless steel piping experienced in the ECS piping at Oyster Creek.

In [3], GPUN showed that cracks in all three pipe sizes exhibited excellent stability even when the crack length equalled 90° of the pipe circumference. For the purpose of this analysis, it was conservatively assumed that crack instability will occur when the crack length exceeds 90° of the pipe circumference. By selecting an initial crack length of 2t, the margin between the time of leak detection and the time of the onset of assumed crack instability is easily identified.

2.5 Stress Intensity Factor at the Crack Tip

The formula for the stress intensity factor at the crack tip in tension and bending is given by

$$K = \sigma_t \sqrt{\pi a}\, F_t + \sigma_b \sqrt{\pi a}\, F_b \qquad [5]$$

where σ_t and σ_b are the tension and bending stresses, respectively, 2a is the length of the through-wall crack on the O.D. surface, and F_t and F_b are dimensionless functions of a. This formula represents the stress intensity factor at the tip of an edge crack in an infinitely long plate subjected to remote tension and bending and is based upon linear-elastic fracture mechanics (LEFM). Values and formulas for F_t and F_b are provided in several documents (e.g., [5, 6, 13]). GPUN performed an engineering assessment of published solutions for F_t and F_b and selected appropriate values for each.

2.6 Crack Growth Rate

The formula for calculating crack growth rate is given by: $da/dt = C(K)^n$, where $K = K_{max}$ or K_{eff} and C and n are empirically derived constants. K_{max} was used and the values used for C and n were 5.65×10^{-9} and 3.07, respectively [10]. C and n were derived from fitting a straight line on experimental data points to give the best estimate of crack growth for furnace sensitized Type 304 stainless steel in low oxygenated water under constant stress.

The effects of fatigue, primarily from heatup and cooldown, were not included since the number of cycles is in the order of one to 10 per year. Extrapolation of fatigue curves to extremely low cyclic values indicates that the contribution of fatigue to crack growth in these lines is negligible; therefore, only environmentally (i.e., IGSCC) controlled growth under steady-state conditions is evaluated [10].

For all points the crack growth was calculated in one month intervals.

2.7 Leak Rate Calculations

The leak rate calculations were performed using a research computer program developed under EPRI sponsorship. Given the upstream thermodynamic conditions and the crack geometry, the estimated leak rate through the crack can be calculated. The analytical model is a modified version of the Henry non-equilibrium two-phase critical flow model. The details of the model and the assumptions are provided in [11]. The program was run for the Duane Arnold safe-end leak [12] in order to obtain a benchmark result. The rate calculated was 3.25 gallons-per-minute (gpm) versus an actual leak rate of approximately 3 gpm. This shows good agreement between the calculated and actual leak rates. However, for conservatism, the calculated results were reduced by a factor of 2 for the purpose of evaluating detectability.

3.0 RESULTS

3.1 Results

The results of the calculations are tabulated in Tables II through IV. Figures 1 through 3 are plots of crack length and leak rate versus time.

3.2 Discussion

3.2.1 General

The most highly stressed point is the location that will most likely exhibit the shortest time to failure (instability) once a through-wall crack has developed. This is because the crack growth rate is dependent upon stress intensity factor (K) which, in turn, is dependent upon the stresses to which the point is subjected, and the crack length. The result of these dependencies is that there will be little crack growth for a period of time and then crack growth will occur at an increasingly rapid although stable, rate until the unstable length is reached. The leak rate from a growing crack will increase accordingly.

3.2.2 Return Lines

Calculations show that a 2t-long crack will grow to 90°F of the pipe circumference in approximately 4 years, minimum. The leak rates from these cracks are high enough to be readily detected at an early stage of crack growth. For example, the leakage from a 2t-long crack in the 8-inch return line is approximately 3/4 of a gallon-per-minute. This results in the leakage of approximately 1100 gallons of water in a 24 hour period. This quantity of water would be readily detected. Even if surveillance were not able to detect the leakage from the piping, the water accumulating on the floor would be readily observed. Also, if surveillance on one day were to miss detection of leakage, it is highly unlikely that surveillance on the next day would not detect leakage.

The results also show that crack growth is slow enough to be able to take appropriate action (shut down the plant or isolate the affected condenser) long before a crack would reach an unstable length.

A through-wall crack was detected in the "A" Return line in March 1984. A leak was visually detected during a hydrostatic test of the "A" condenser. Destructive evaluation led to the conclusion that the crack was a result of IGSCC. A major inspection and repair effort followed [14]. Several welds were replaced and others were repaired with weld overlays.

The crack growth calculations perfomed for this evaluation appear to be conservative when compared to the actual cracking experienced. Oyster Creek had been in operation for approximately 13 years before the cracks were detected. The fracture surfaces of the destructively evaluated cracks were heavily oxidized indicating that they had existed for a long period of time. Crack growth calculations, both through-wall and circumferential, predict failure in a much shorter period of time.

3.2.2 Supply Line

A supply line leak will be detectable by both visual and audible means. The points of interest on both the A and B supply lines are located just downstream of two valves located outside containment (see Figures 1 and 2 of

Appendix A). Packing leaks in these valves have been readily detected both visually and audibly. The temperature of the area in which these lines are located is near ambient; therefore, condensation of the steam will form rapidly and will be readily detected by visual means.

4.0 CONCLUSIONS

It has been shown that leakage from the subject lines can be easily detected by audible and/or visual means well before unstable crack extension will occur in the subject lines. The methods and assumptions used yielded conservative results in that the calculated crack growth rate is higher and the calculated leak rate is lower than what would be expected under actual plant conditions.

5.0 ACTIONS TO BE TAKEN

The Oyster Creek Technical Specification will be revised to require a visual surveillance of the Emergency Condenser System area, both on the 95' elevation and 75' elevation of the Reactor Building once every twenty-four hours. The operator shall visually monitor the general areas around and under the Emergency Condensers, the supply and return piping including any valves or other system components. He shall look for, listen for and report any evidence of water leaking from the return lines, steam leaking from the supply lines, or any leakage from other system components. To facilitate the surveillance and leak detection, the sheet steel and insulation is wrapped around the piping will be removed for a distance of approximately two inches on each side of selected welds in the system. The most highly stressed weld per pipe size, per condenser on the 75 foot elevation will be exposed.

6.0 REFERENCES

1) "Jersey Central Power and Light Company, Oyster Creek Nuclear Generating Station, Pipe Rupture Analysis of High Energy Emergency Condenser Lines Outside Containment Below the 95'-3" Elevation of the Reactor Building", EDS-Nuclear Inc., Report No. 02-0370-1021, Rev. 0, November 1979.

2) *Alternative Safety Assessment for Selected High Energy Pipe Break Locations at SEP Facilities*, Appendix 1 of Attachment to Enclosure 2, USNRC Letter to Consumer's Power, 12/4/81.

3) "Fracture Mechanics Analysis of the Oyster Creek Nuclear Generating Station Emergency Coolant System" Revision 1, Fracture Proof Design Corporation, 6/30/82.

4) "Analysis of Emergency Condenser Piping Outside Containment", MPR-830, MPR Associates, Inc., July 1984.

5) *Estimation of Stress Intensity Factors and the Crack Opening Area of a Circumferential and Longitudinal Through-Crack in a Pipe*, Appendix 2 of Attachment to Enclosure 2, USNRC Letter to Consumer's Power, 12/14/81.

6) "Elastic - Plastic Fracture Analysis of Flawed Stainless Steel Pipes", EPRI NP-2608-LD, September 1982.

7) Private communication with S. Ranganath (GE), 8/3/83.

8) Private communication with D. Norris (EPRI), 8/5/83.

9) "Guidelines for Flaw Evaluation and Remedial actions for Stainless Steel Piping Susceptible to Intergranular Stress Corrosion Cracking" (Draft), EPRI/SIA, April 1984.

10) "The Growth and Stability of Stress Corrosion Cracks in Large-Diameter BWR Piping", Volumes 1 and 2, EPRI NP-2472-SY, July 1982.

11) "Calculations of Leak Rates through Cracks in Pipes and Tubes", EPRI NP-3395, December 1983.

12) "Investigation and Evaluation of Stress-Corrosion Cracking in Piping of Light Water Reactor Plants", NUREG-0531, February 1979.

13) "Equations for Fracture Mechanics", K. E. Hoffer, Jr., Machine Design, February 1, 1968.

14) "Isolation Condenser System Piping Cracked Welds - Repair and Failure Analysis," GPUN TDR 580, August 1984.

7.0 TABLES

I. Stresses used for crack growth analyses.

II. Calculation results for crack growth and leak rate on 8" Return Line.

III. Calculation results for crack growth and leak rate on 10" Return Line.

IV. Calculation results for crack growth and leak rate on 16" Supply Line.

TABLE I

STRESSES USED FOR CRACK GROWTH ANALYSES

Line	Pipe Diameter	Stress (KSI)
Return	8"	11.07
Return	10"	10.24
Supply	16"	13.97

Table II

8″ Return Line

TIME (MONTHS)	CRACK LENGTH	LEAK RATE (GPM)
0	1.00	.78
3	1.08	.85
6	1.17	.92
9	1.28	1.00
12	1.40	1.10
15	1.54	1.21
18	1.70	1.34
21	1.88	1.47
24	2.10	1.65
27	2.36	1.85
30	2.67	2.10
33	3.05	2.40
36	3.52	2.77
38	4.10	3.22
42	4.85	3.81
45	5.82	4.58
47	6.64	5.22

Table III

10″ Return Line

TIME (MONTHS)	CRACK LENGTH	LEAK RATE (GPM)
0	1.19	.94
5	1.33	1.05
10	1.51	1.19
15	1.72	1.35
20	1.97	1.55
25	2.29	1.80
30	2.70	2.12
35	3.23	2.54
40	3.93	3.09
45	4.89	3.85
50	6.26	4.92
55	8.30	6.53

Table IV

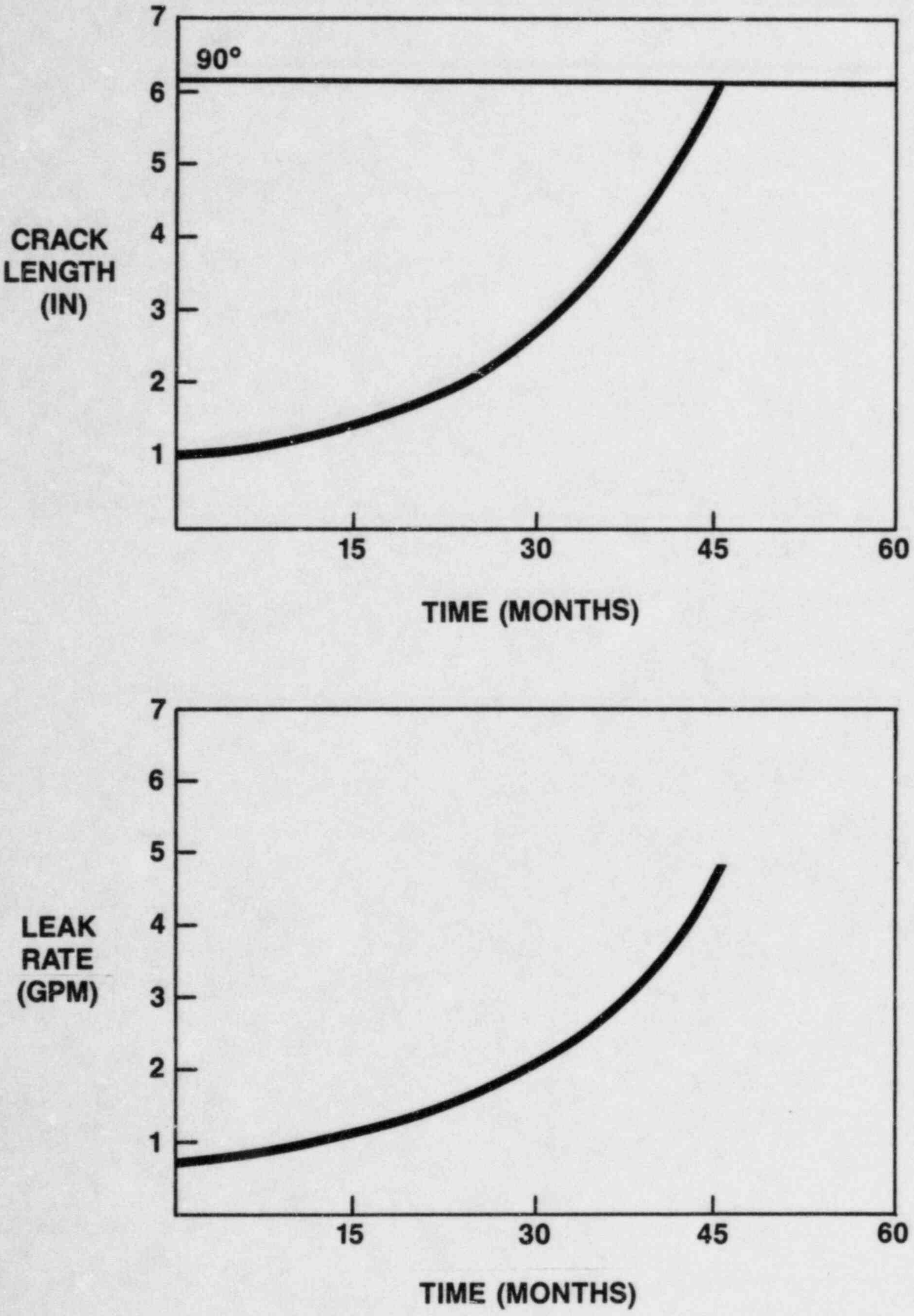
16″ Supply Line

TIME (MONTHS)	CRACK LENGTH	LEAK RATE (LBM/SEC)	EXIT PRESSURE (PSI)
0	1.69	.13	645
2	1.94	.15	645
4	2.26	.18	645
6	2.65	.20	645
8	3.16	.25	645
10	3.84	.30	645
12	4.75	.37	645
14	6.03	.47	645
16	7.89	.61	645
18	10.77	.84	645
19	12.81	1.00	645

8.0 FIGURES

1. 8" Return Line - Crack Length and Leak Rate vs. Time.
2. 10" Return Line - Crack Length and Leak Rate vs. Time.
3. 16" Return Line - Crack Length and Leak Rate vs. Time.

Figure 1 - 8″ Return Line



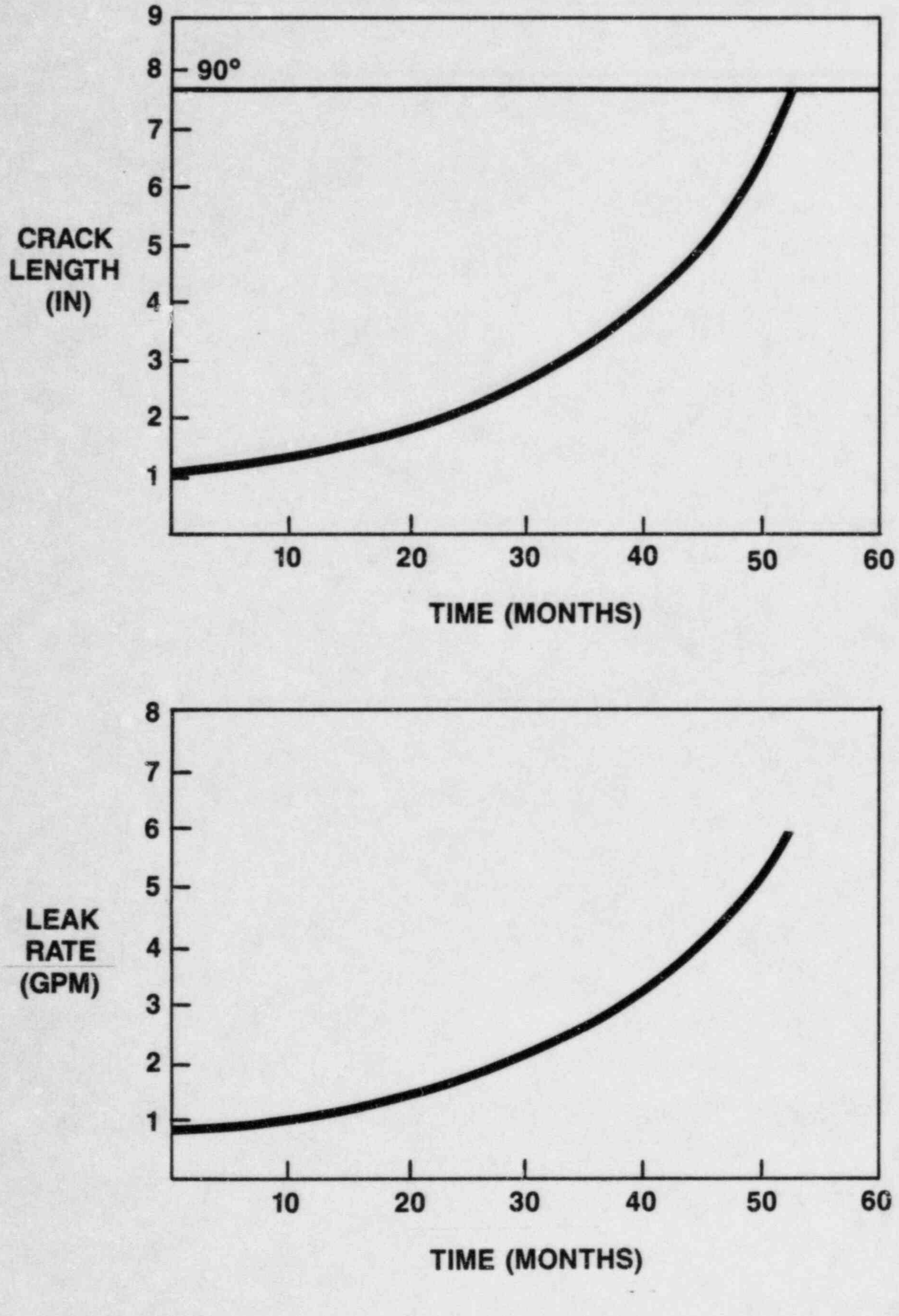
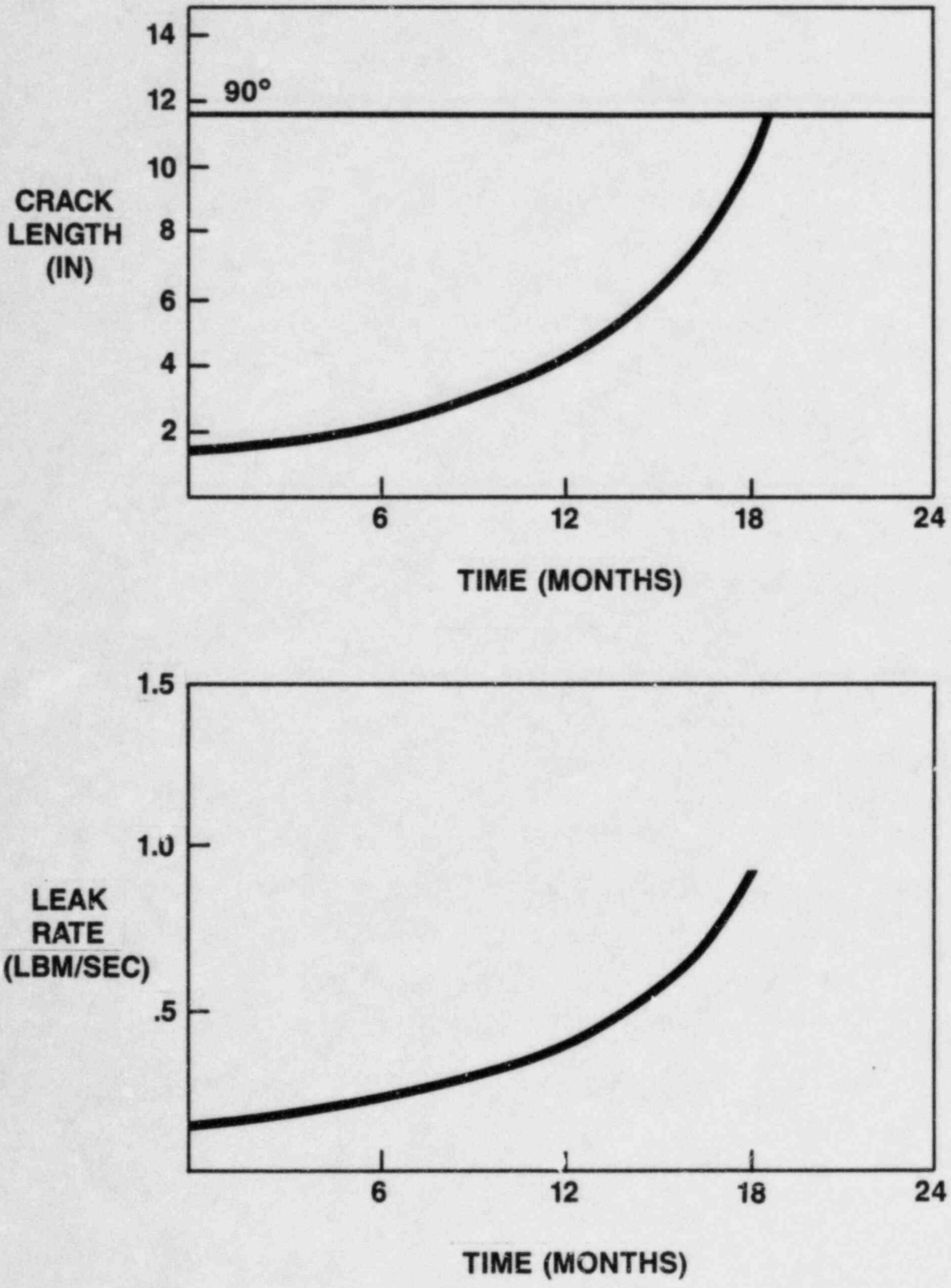


Figure 2 - 10″ Return Line

Figure 3 - 16″ Supply Line



9.0 APPENDICES

A. ECS System Description

APPENDIX A

EMERGENCY CONDENSER SYSTEM DESCRIPTION

The ECS piping runs from the reactor vessel to the two (2) isolation condensers. Portions of the piping are both in the drywell (inside containment) and outside the drywell (outside containment). The piping material is Type 316 stainless steel.

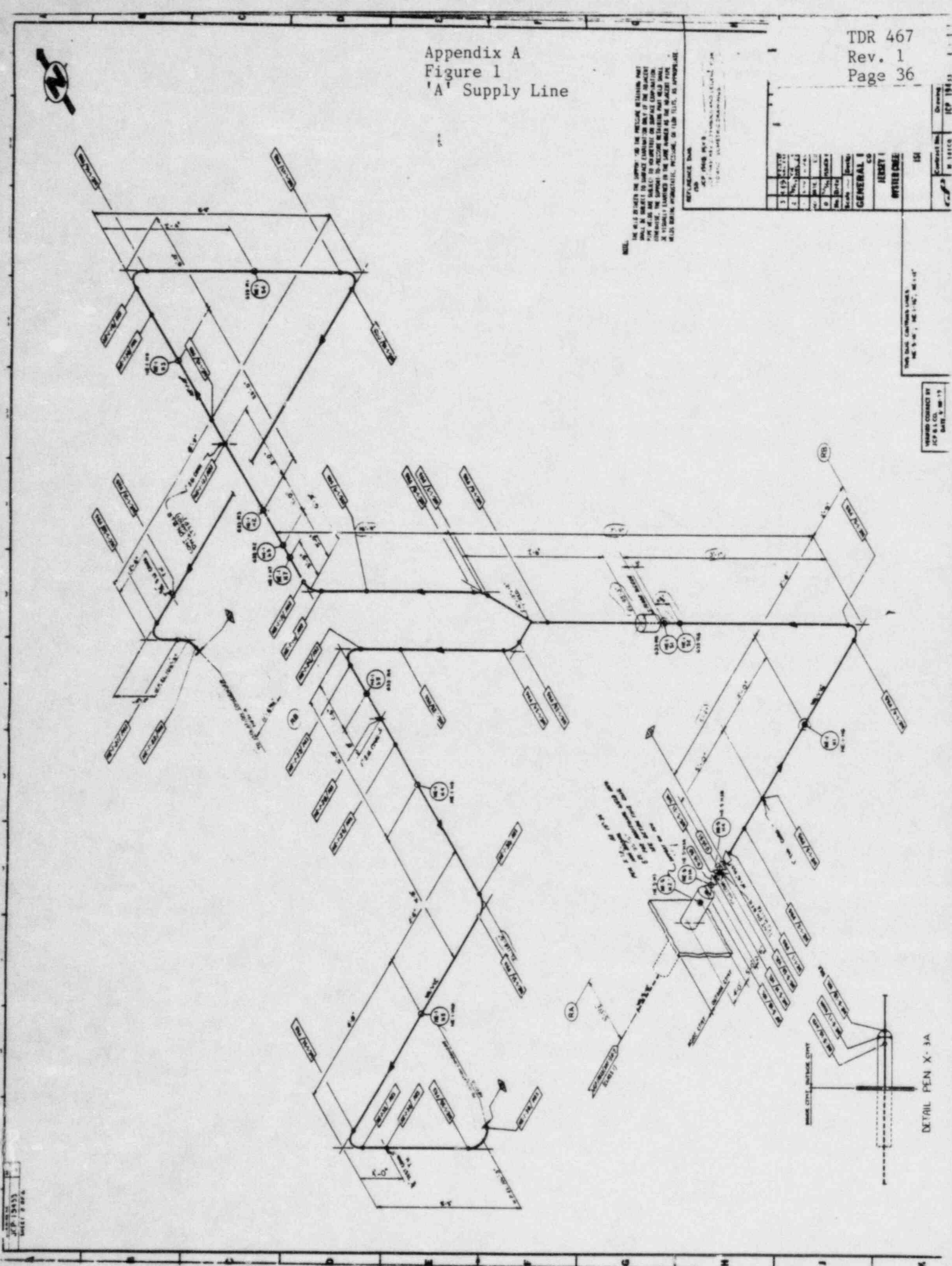
There are two (2) return (condensate) lines from each condenser. These lines are eight (8) inches in diameter and run down from the condenser through the 95 foot elevation floor to the 87 foot elevation where they run parallel to the ceiling until they join into a 10 inch diameter line. This line then joins in series with an isolation valve and the superpipe which penetrates the drywell at the 87 foot elevation.

The supply (steam) lines 10 inch diameter, penetrate the drywell at a 90 foot elevation, expands to 16 inch diameter, and runs parallel to this elevation until it turns upward and penetrates the 95 foot elevation floor. Above the 95 foot elevation, the 16 inch line branches into two 12 inch lines which eventually enter the ends of the condenser tanks.

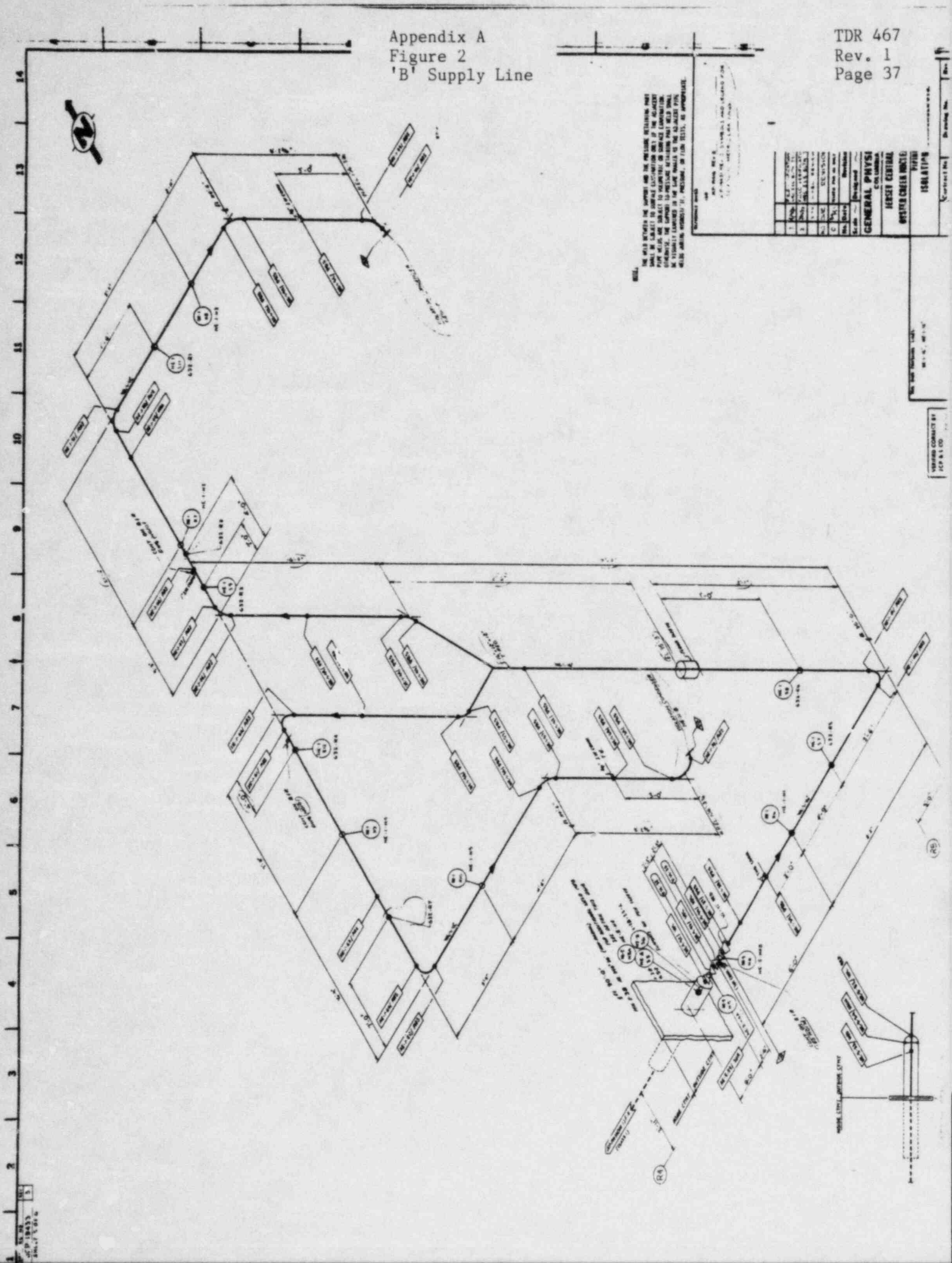
Piping isometrics of all four (4) lines are shown in Figures 1 through 4 of this Appendix. The break point identification is also shown with an arrow on these drawings.

During normal operation, the return line valve just outside containment is closed. All the remaining valves in the system are open. The pressure and temperature of the supply lines are 1034 psi and 548°F, respectively, and the pressure and temperature of the return lines are 1048 psi and 102°F, respectively. When the condensers are needed, one or both of the return line valves are opened and the pressure and temperature of the system will vary depended upon the length of condenser operation.

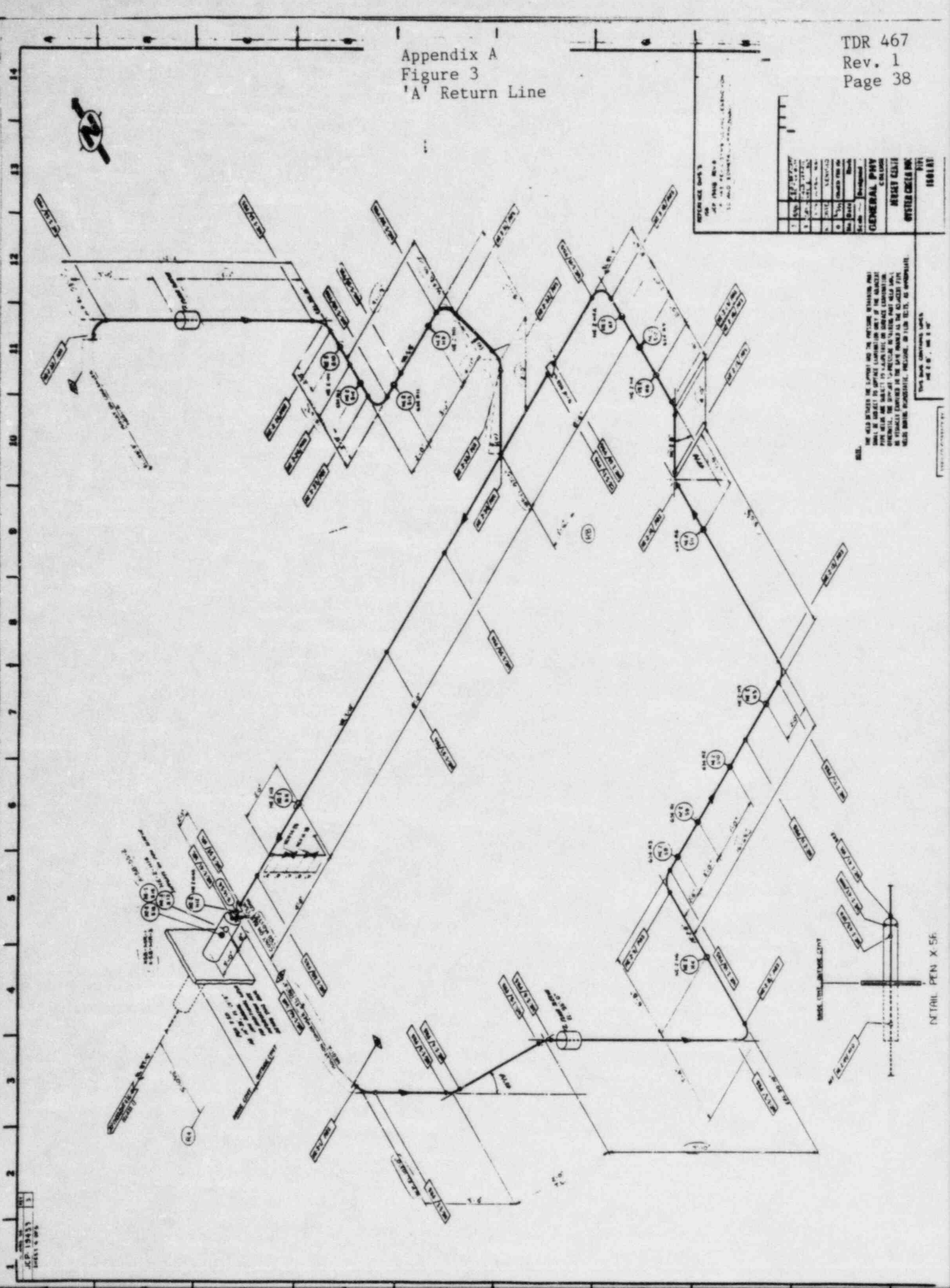
Appendix A
Figure 1
'A' Supply Line



Appendix A
Figure 2
'B' Supply Line



Appendix A
Figure 3
'A' Return Line



Appendix A
Figure 4
'B' Return Line