UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

October 20, 1980

Docket No. 50-344

FACILITY: Trojan Nuclear Plant

LICENSEE: Portland General Electric Company (PGE)

SUBJECT: SUMMARY OF MEETING HELD ON SEPTEMBER 30, 1980 WITH PGE/WESTINGHOUSE TO DISCUSS INTERIM LABORATORY EXAMINATION RESULTS OF STEAM GENERATOR ROW 1 U-BEND TUBE SAMPLES REMOVED FROM TROJAN

On September 30, 1980, the NRC staff met with representatives of PGE and Westinghouse to discuss the results obtained thus far from the laboratory examination of steam generator rows 1 and 2 U-bend tube samples removed from Trojan. A list of attendees is contained in Attachment 1. A summary of the technical material presented at the meeting is contained in Attachment 2, which includes the viewgraphs and slides presented at the meeting.

PGE/Westinghouse removed 26 row 1 and 3 row 2 steam generator tube U-bends from Trojan during a refueling outage this spring. PGE had been experiencing leakage in row 1 tubes in all 4 steam generators. Tube samples were removed to gain a better understanding of the cause of tube leakage.

PGE/Westinghouse has submitted two reports of the investigations thus far:

July 11, 1980 - nondestructive examination (interim results)

August 15, 1980 - destructive examination (interim results)

The purpose of the meeting was to gain a better understanding of these reports and results obtained to date.

Axially-oriented cracks originating from the tube I.D. have been found in the vicinity of the transition zone between the U-bend and the straight section. Details are contained in Attachment 2.

A further meeting with PGE/Westinghouse will be held in mid-December, when final examination results will be available and discussed.

There appear to be three corrective action options with respect to row 1 tubes at this point:

1. plug all row 1 tubes

2. plug selected row 1 tubes (those susceptible to cracking)

3. leave row 1 tubes unplugged if it can be shown that large tube ruptures are unlikely (i.e., small leaks only, as has been seen thus far).

Corrective action will be decided when the examination has been completed.

Charles M. Trammell

Charles M. Trammell, Project Manager
Operating Reactors Branch #3
Division of Licensing

Attachments:
1. List of Attendees
2. Viewgraphs and Slides

cc: w/attachments
See next page

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Portland General Electric Company

cc: Mr. J. W. Durham, Esquire
Vice President and Corporate Counsel
Portland General Electric Company
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Robert M. Hunt, Chairman
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Columbia County
St. Helens, Oregon 97051

Director, Technical Assessment Division
Office of Radiation Programs (AW-459)
U. S. Environmental Protection Agency
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Arlington, Virginia 20460

MEETING SUMMARY DISTRIBUTION

Licensee: Portland General Electric Company

* Copies also sent to those people on service (cc) list for subject plant(s).

Docket File
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DCrutchfield
RAClark
ORB Project Manager - CTrammell
Licensing Assistant - PMKreutzer
OELD
AEOD - JHeltemes
IE-3
SShowe (PWR) or CThayer (BWR), IE

RFraley, ACRS (16)
Program Support Branch
GZech
JOlshinski
BGrimes
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FPagano
Emergency Preparedness Development Branch
Mtg. Summary Dist.
NRC Participants

BTurovlin	LFrank	LKintner
PWu	DHuang	ASchwencer
WHazelton	DESmith	FMariliga
BDLiaw	PMatthews	BJYoungblood
SPawlicki	CStahle	ADromerick
EMurphy	JKerrigan	
RAClark	RBirkel	

8011060253

Attachment 1

LIST OF ATTENDEES

PGE/WESTINGHOUSE MEETING

SEPTEMBER 30, 1980

NRC
C. Trammell
B. Turovlin
P. Wu
W. Hazelton
B. D. Liaw
S. Pawlicki
E. Murphy
R. A. Clark
L. Frank
D. Huang
D. E. Smith
P. Matthews

PGE
J. Carter
G. Zimmerman

W
R. Aspden
C. Hirst
R. Bagby
E. Murphy

Brookhaven
J. Weeks
D. Van Rooyen

Attachment 2

INTRODUCTION

The Trojan Nuclear Plant is a four loop Westinghouse Pressurized Water Reactor facility with a Namplate Rating (Gross MWe) of 1216 and Maximum Dependable Capacity (Net MWe) of 1080. The initial power generation took place in Dec. 1975, and the plant was declared commercial in May, 1976.

STEAM GENERATOR CHARACTERISTICS

The four steam generators designated "A", "B", "C", and "D" are Westinghouse Series 51 units, and were fabricated in the Tampa facility. The 3388 0.875" OD X 0.050" wall Inconel 600 u-bend tubes in each generator were produced at the Westinghouse-Blairsville mill. The tubes were shop rolled into the tube plate and later Wextex explosively expanded in the field.

The nominal primary pressure is 2235 psig. Primary inlet and outlet temperatures for the steam generators are 616.8°F and 552.3°F respectively, and the nominal secondary temperature is 533.3°F.

Typical mill properties for the Inconel 600 tubing can be characterized by those for the three defective tubes to be discussed later. These are:

Heat No.	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Co
5889	.03	.21	6.37	.007	.15	.01	77.74	15.46	.27	.34	.01
2652	.03	.13	7.33	.007	.21	.22	76.78	15.27	.18	.28	.03
2834	.04	.19	8.16	.007	.28	.47	75.86	14.97	.19	.23	.04

Heat No.	YS;ksi	UTS, ksi	ELONG. %	Rb
4889	57,58,56	103,104,102	58,36,37	77,86,82
2652	57,59,59	103,102,107	39,41,40	89,88,87
2834	57,56,59	102,111,103	40,41,39	87,86,87

The operating history of the plant is summarized in the attached charts. Maintenance and refueling shutdowns are generally timed to coincide with the spring runoff and available hydropower. Other outages of any duration are explained on the charts.

PRIMARY WATER CHEMISTRY

Primary water chemistry has been within normal Westinghouse specifications except for the following.

1. H_2 was about 15 cc/Kg H_2O for about a two month period during startup. It has since been in the 25 to 35 cc/Kg H_2O range.
2. While there is no specific limit on SiO_2, the plant experienced a high initial SiO_2 level thought to be due to residual blasting sand in a storage tank. This level (~1.5 ppm) was gradually reduced during operation.
3. Li^7OH concentration during the period from June 1977 - March 1978 was maintained at the low level of .2-.5 ppm Li^7 as part of a joint experiment with Westinghouse.

STEAM GENERATOR INSPECTIONS

The first figure summarizes the results of the steam generator eddy current inspections performed to date. All relevant indications (not found during pre-service inspection) have been located in the Row 1 U-bends, of which there are 94 per generator. The next figure shows the configuration of the U-bend region for the Row 1 U-bends.

Returning to our summary, initial leakage was detected in January, 1978, after about 10,000 hours of operation. Note that this leak in the "B" steam generator was not found with the equipment then available. Pressurization of the secondary system revealed the leak to be in the cold leg. This leak was plugged, and a long outage due to seismic deficiencies in the control building occurred. Leakage was again detected in January, 1979 (~12,000 hours of operation). Upon shutdown in October, 1979, all Row 1 tubes in all four generators were inspected. Operating time at the point was over 17,000 hours, and a maximum leak rate of about 150 gpd had been observed prior to shutdown. Five leakers and four indications in Row 1 U-bends were found.

Leakage was again observed soon after startup in January, 1980, and increased to a maximum of 68 gpd just prior to shutdown in April, 1980 at about the 20,000 hour mark. Leak checks of the "A", "B", and "C" generators revealed five leakers. Eddy current inspection of all Row 1 tubes found five indications. The two indications in the "D" steam generator may or may not have been leakers. In addition to the indications found in this inspection, R1, C7, which was not inspected prior to removal, had an indication in the cold leg tangent region upon laboratory examination.

The next figure summarizes the overall history of leakers and eddy current indications found. The rough balance between hot leg and cold leg occurrences is of interest. It is also interesting to note that if one marks the column numbers off on a tube sheet diagram, no particular pattern is observed. Some tube marks are displaced one tube because of duplication among the generators. Eighty percent of the occurrences are located adjacent to flow slots, which happen to be adjacent to eighty percent of the tubes.

TUBE REMOVAL OPERATION

Pursuant to an agreement with the NRC, it was decided to remove 26 Row 1 tubes (C1 - C26) and 3 Row 2 tubes (C1 - C3) from the "D" steam generator. This provided one known leaker (R1, C6) and one indication (R1, C26) plus comparison tubes from Row 2. Subsequent identification of R1 - C7 as a defective tube was a bonus of sorts.

Tube removal procedures and tooling were developed by Westinghouse -NSD whose personnel supervised the operation. After drilling a pilot hole to verify location, a weld-deposited buildup was applied and machined to accommodate a flanged cover for this field installed hand hole. The buildup was post-weld heat treated to satisfy applicable pressure vessel code requirements. A six-inch hand hole was then cut in the steam generator vessel and the tube bundle wrapper just above the seventh support plate.

After measuring the leg spacing on each tube, the tube was cut above the seventh support plate by a plasma arc TIG torch. The tube ends were sealed with tape to prevent loss of contamination from the inside. Photographs were taken of the tubes, and they were crated for shipment. A typical field photograph is shown in the next figure, followed by a figure showing a general view of the situation after cutting of the Row 1 tubes.

NONDESTRUCTIVE EXAMINATION

Upon arrival at Westinghouse - Forest Hills, the tubes were uncrated and photographed. A photograph of R1-C6 is shown as the next figure. Following this documentation, the tubes were eddy current tested, radiographed in several rotations, and limited dimensional measurements taken. The leg spacing, before and after cutting of each Row 1 bend and the maximum ovality measured, after removal, at the apex of the bends and at the hot and cold leg tangent points are summarized in the next figure. Also included are the NDE findings. It should be noted that there is an uncertainty associated with the pre and post leg spacing values due both to the difficulties inherent in making the measurements in the steam generator prior to cutting and in duplicating the location for the measurement afterward. Assuming that the reported values are reasonably correct, it appears that R1C6, the leaking tube, and R1C7, reported by radiography and eddy current to be cracked, have the smallest leg spacing, prior to cutting of any of the Row 1

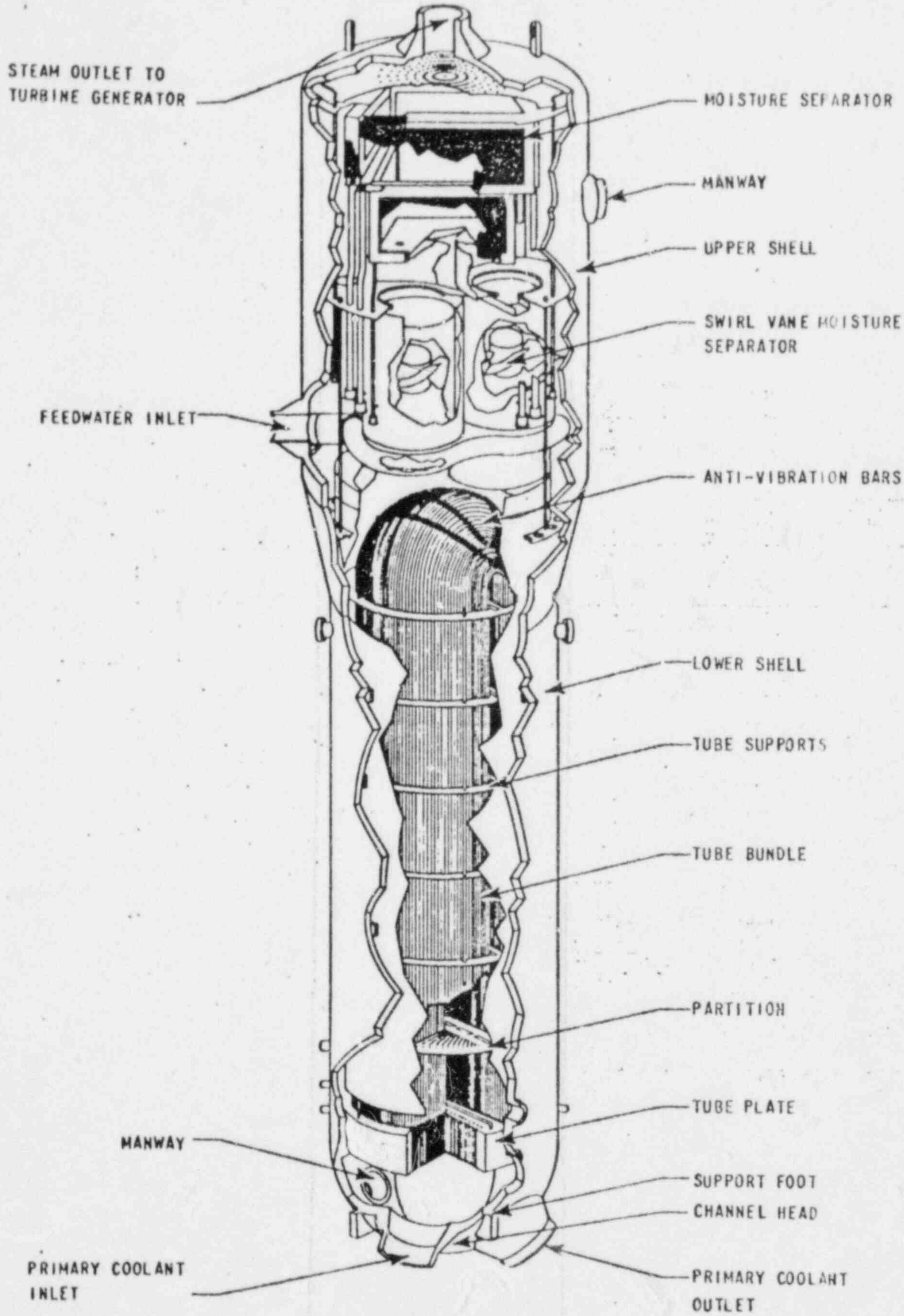
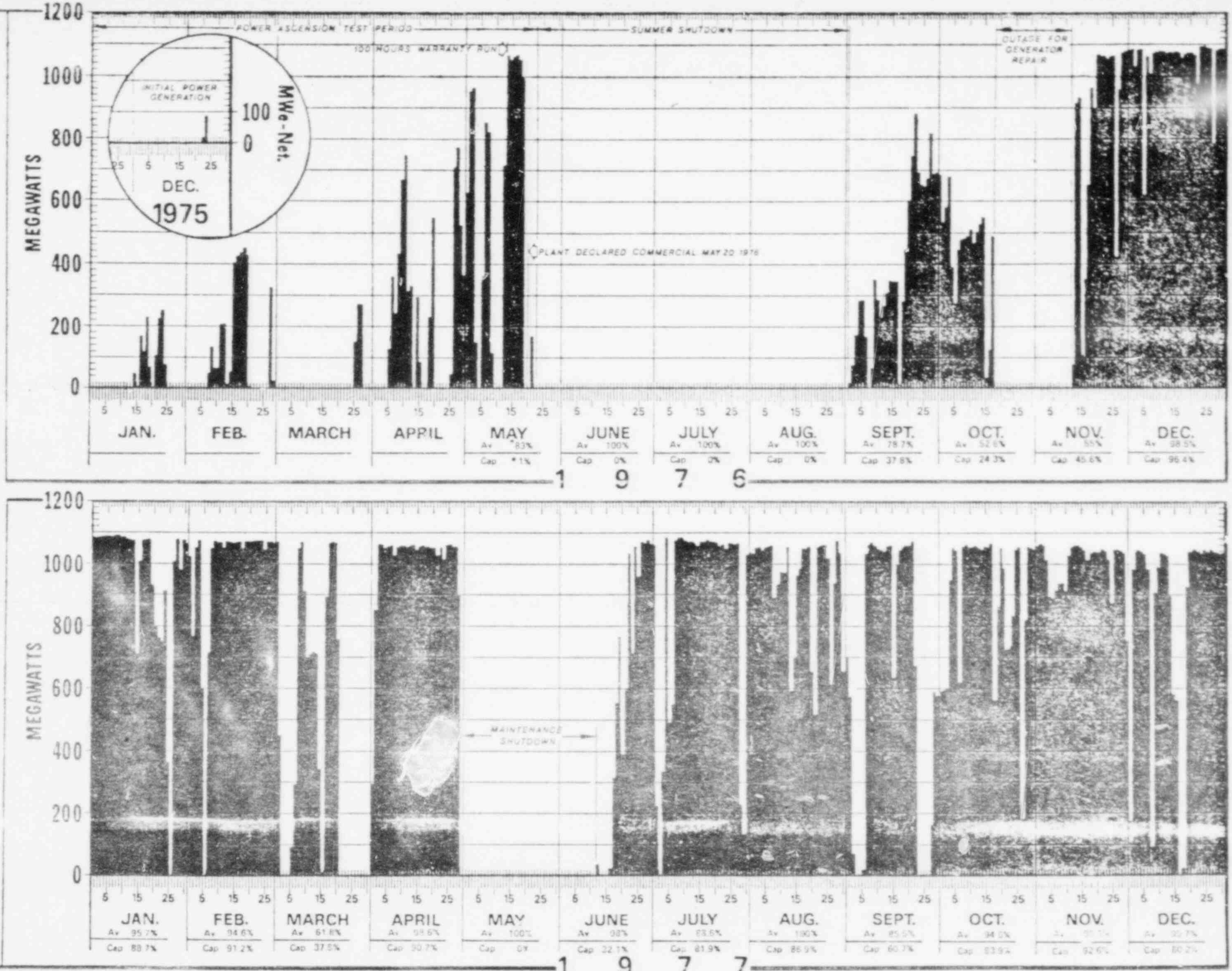


Figure 5.5-4 Steam Generator

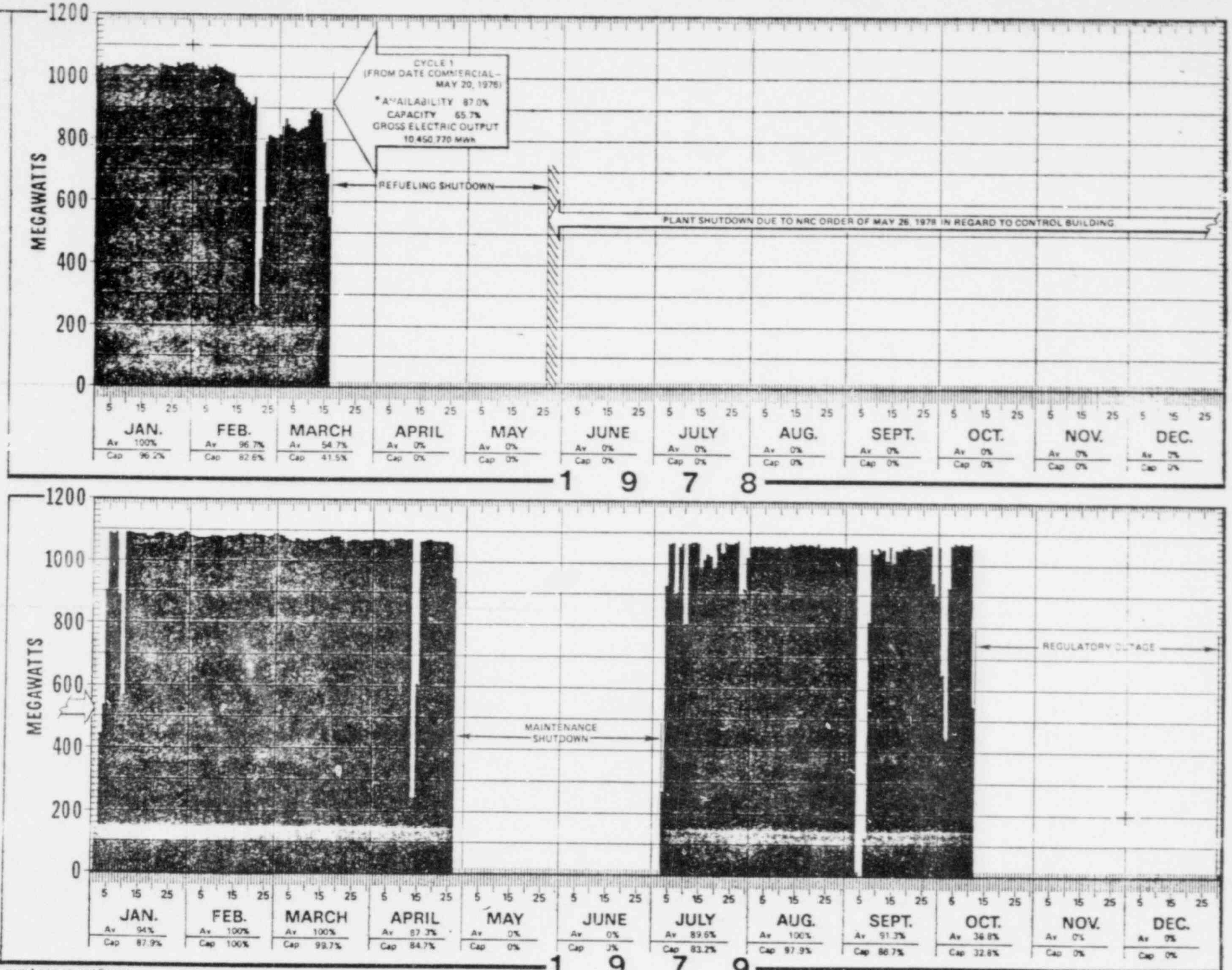
TROJAN NET ELECTRIC GENERATION



*Monthly Average Availability and Capacity Factors from Date of Commercial Operation

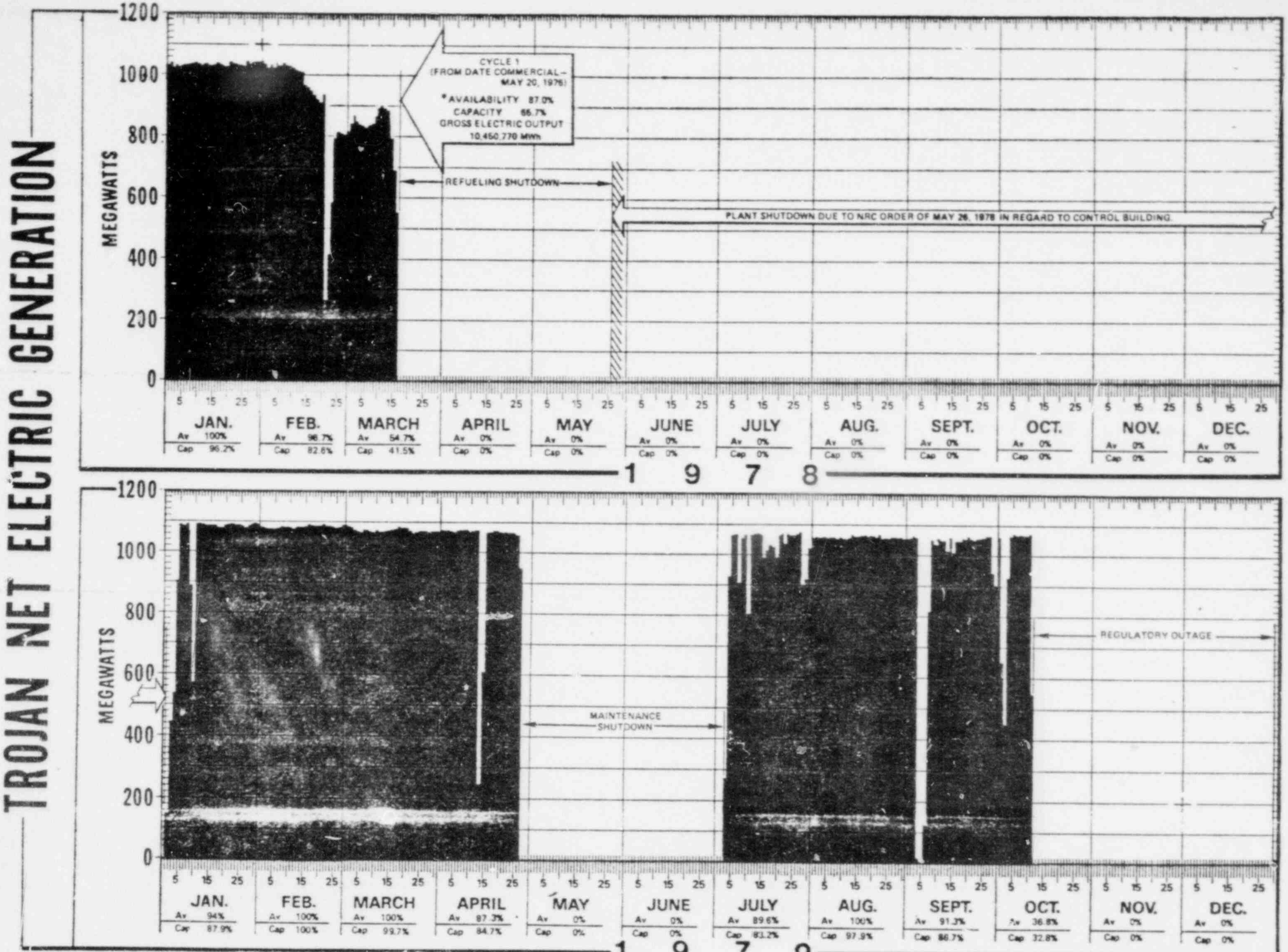
RATED CAPACITY NET MWe 1080

TROJAN NET ELECTRIC GENERATION



*Monthly Average Availability and Capacity Factors from Date of Commercial Operation

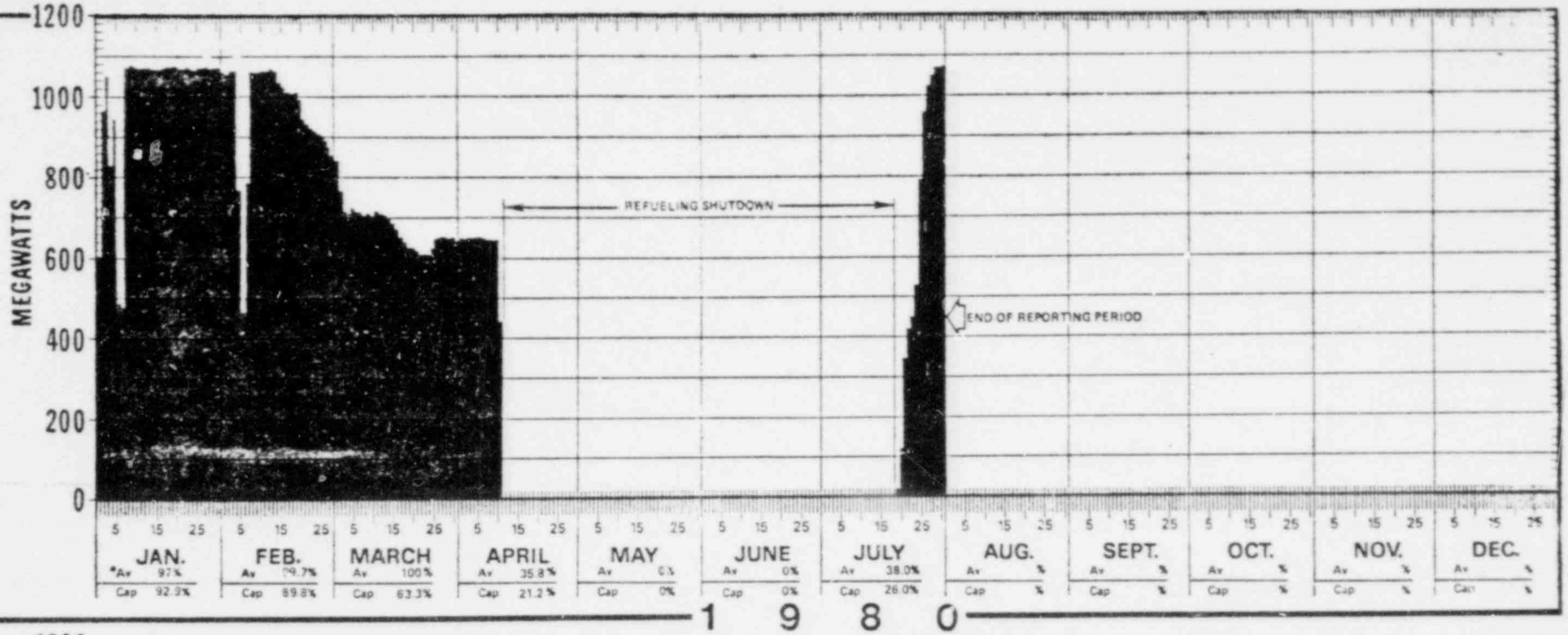
MAXIMUM DEPENDABLE CAPACITY, NET MWe 1080

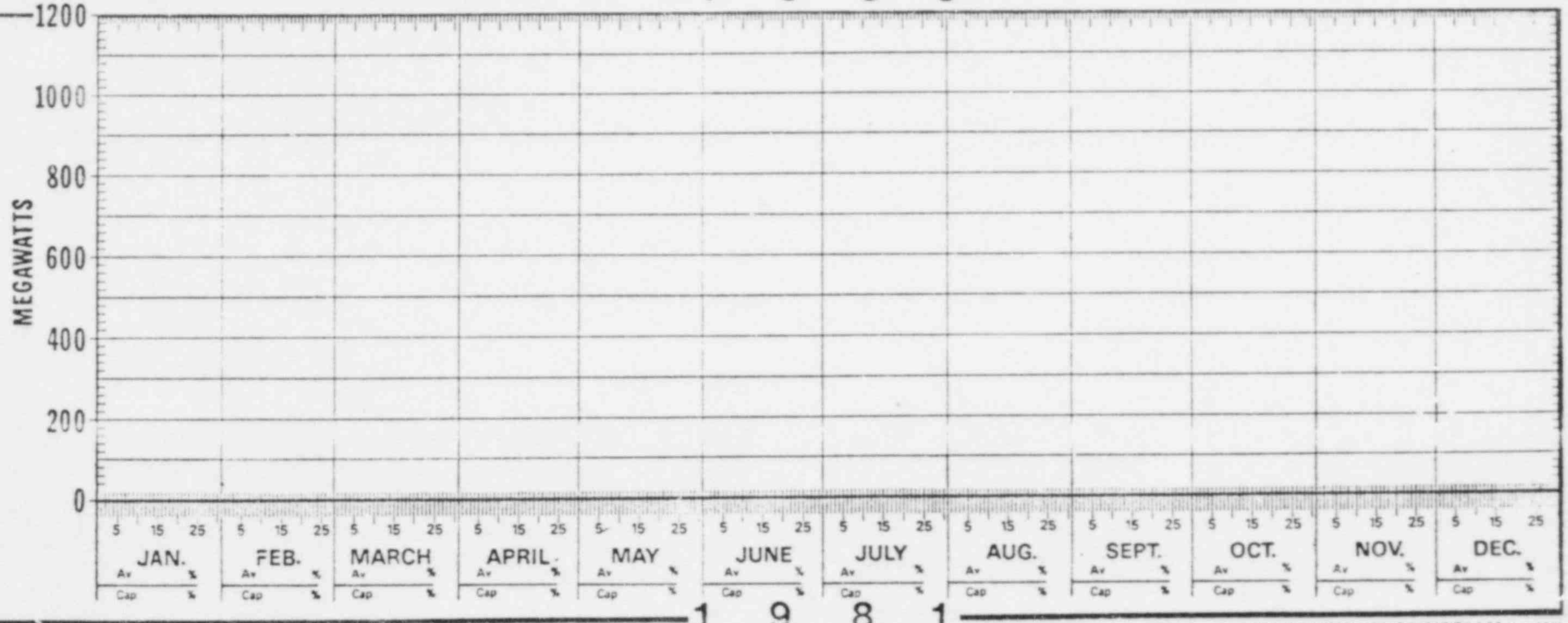


*Monthly Average Availability and Capacity Factors from Date of Commercial Operation

MAXIMUM DEPENDABLE CAPACITY, NET MWe 1080

TROJAN NET ELECTRIC GENERATION





*Monthly Average Availability and Capacity Factors from Date of Commercial Operation

MAXIMUM DEPENDABLE CAPACITY, NET

TROJAN

STEAM GENERATOR INSPECTIONS

SUMMARY

PRE-SERVICE: April, 1975

100% of "accessible" tube area; 400 kHz

APRIL, 1978: SG/B

507 tubes @ 400 kHz around U-bend.

68 tubes - small radius 400 kHz.

27 tubes @ 100 kHz.

Leak @ R1C57 not located by eddy current.

OCTOBER, 1979: All Steam Generators

94 tubes (all row 1)/SG @ 100 kHz absolute.

5 leakers: One (1) in SG/A; four (4) in SG/D
One (1) indication in each SG.

720 mil ball gauging in Row 1, SG/D: All tubes passed.

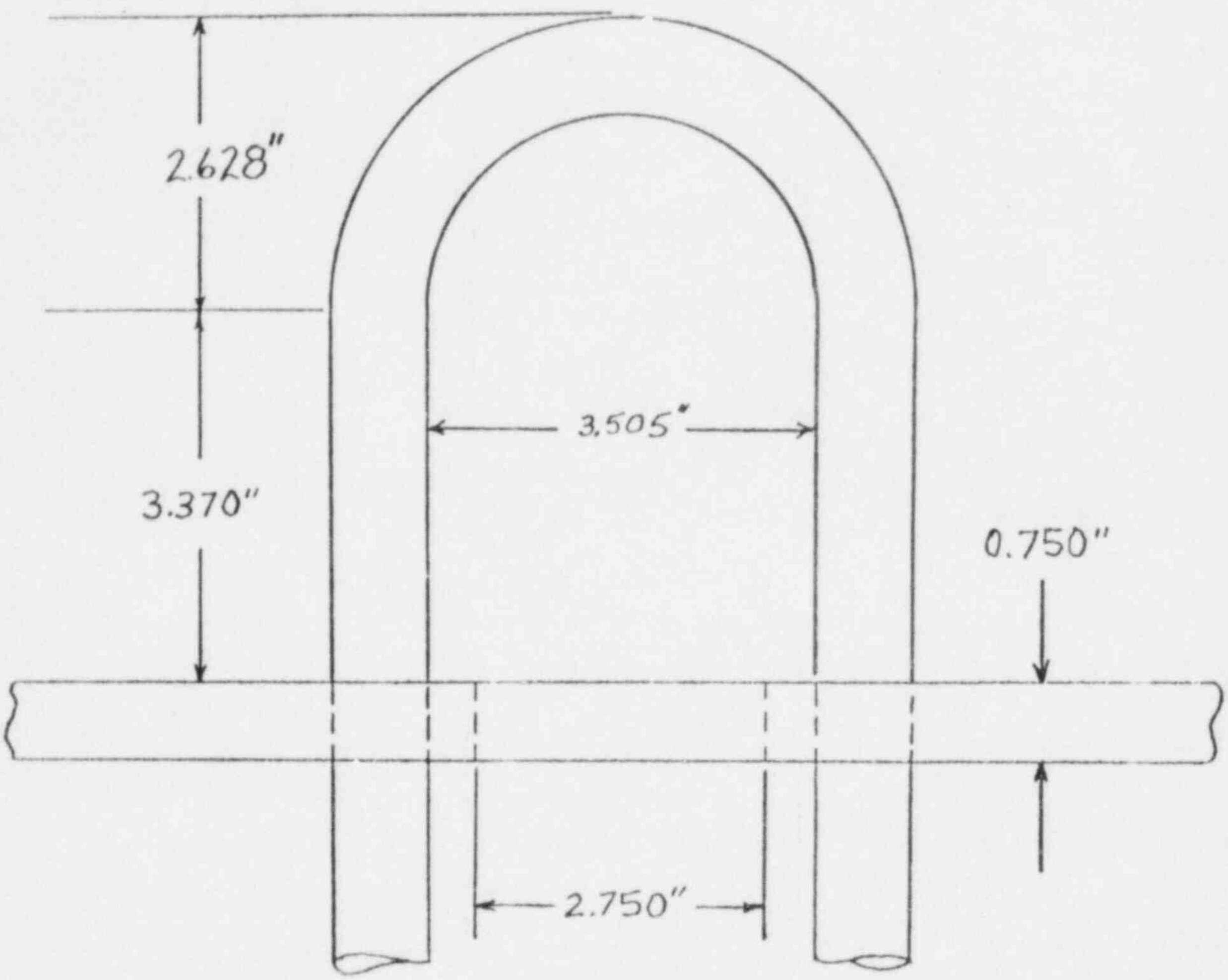
JUNE, 1980: All Steam Generators

Row 1 in all four (4) SG's.

Reg. Guide Program in SG/D.

5 leakers: Three (3) in SG/A; Two (2) in SG/B.

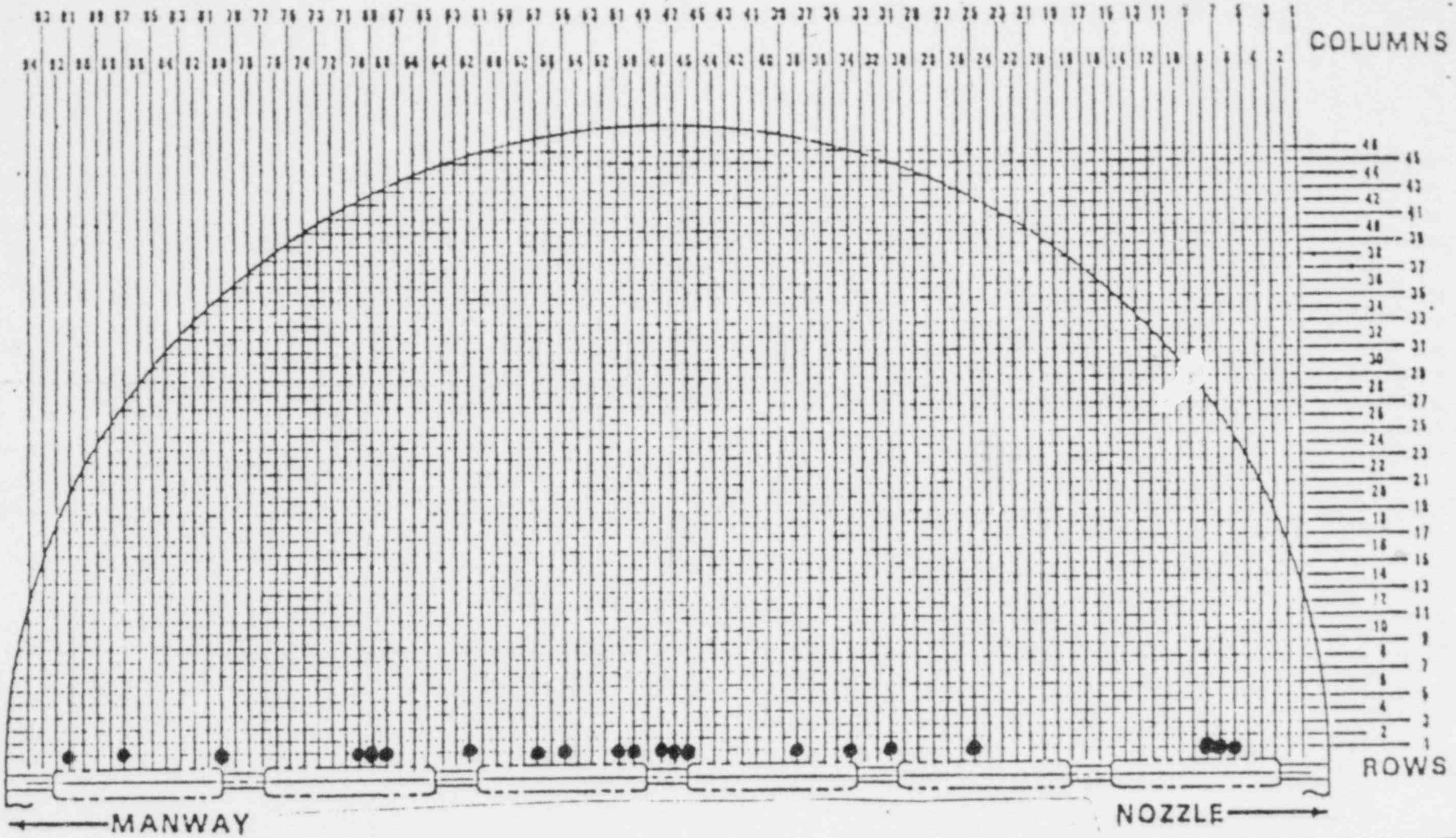
EC Indications: One (1) each in A,B,C;
Two (2) in SG/D. (possibly leakers)


2.628"
3.505"
3.370"
0.750"
2.750"

SG	Column	Elevation	Finding	Date Plugged
A	68	CL-Tangent	L	11/79
A	38	HL-Tangent	I	11/79
A	48	CL-Tangent	L	6/80
A	80	CL-Tangent	L	6/80
A	87	CL-Tangent	L	6/80
A	7	HL-Tangent	I	6/80
B	57	CL-Unknown	L	6/78
B	47	CL-Tangent	I	11/79
B	48	HL-Tangent	L	6/80
B	51	HL-Tangent	L	6/80
B	50	HL-Tangent	I	6/80
C	34	HL-Tangent	I	11/79
C	68	CL-Tangent	I	6/80
D	6	CL-Tangent	L	11/79
D	62	HL-Tangent	L	11/79
D	70	HL-Tangent	L	11/79
D	91	CL-Unknown	L	11/79
D	26	CL-Tangent	I	11/79
D	31	CL-Tangent	I,L?	6/80
D	55	HL-Tangent	I,L?	6/80
D	7	CL-Tangent	I	*

*Not inspected prior to removal - laboratory finding

12 Cold Leg - 9 Hot Leg


COLUMNS
ROWS
MANWAY
NOZZLE

STEAM GENERATOR TUBE DIMENSIONAL MEASUREMENTS AND NDE RESULTS

Tube Number	Leg Spacing (Inches) Pre	Post	Δ	Percent Ovality (Maximum) CL	Apex	HL	NDE Results
R1-C1	3.505	3.457	-.048	4.8	2.06	1.71	OK
R1-C2	3.481	3.480	-.001	4.23	1.37	2.40	OK
R1-C3	3.483	3.566	+.083	1.71	3.54	4.57	OK
R1-C4	3.483	3.479	-.004	1.26	2.06	0.57	OK
R1-C5	3.476	3.489	+.013	2.17	2.74	4.11	OK
R1-C6	3.447	3.495	+.048	3.66	1.60	4.80	Crack in cold-leg transition per RT and ET
R1-C7	3.452	3.474	+.022	2.17	2.40	2.06	Crack in cold-leg transition per RT and ET
R1-C8	3.465	3.435	-.030	2.06	2.97	2.40	OK
R1-C9	3.473	3.466	-.007	1.23	2.29	3.20	OK
R1-C10	3.501	3.450	-.015	2.06	1.71	4.57	OK
R1-C11	3.493	3.478	-.051	4.80	2.97	2.17	OK
R1-C12	3.479	3.466	-.013	2.51	1.37	2.97	OK
R1-C13	3.481	3.463	-.018	2.06	1.71	5.14	OK
R1-C14	3.497	3.480	-.017	4.91	2.74	1.37	OK
R1-C15	3.481	3.420	-.061	4.11	2.17	2.40	OK
R1-C16	3.478	3.470	-.008	3.31	2.17	3.09	OK
R1-C17	3.471	3.417	-.054	2.74	2.06	3.54	OK
R1-C18	3.513	3.535	+.022	4.34	3.26	1.66	OK
R1-C19	3.483	3.450	-.033	3.09	2.06	1.14	OK
R1-C20	3.503	3.556	+.053	4.91	2.97	2.51	OK
R1-C21	3.506	3.534	+.028	4.69	3.20	1.26	OK
R1-C22	3.507	3.510	+.003	4.69	3.77	1.26	OK
R1-C23	3.502	3.535	+.033	2.86	3.31	0.97	OK
R1-C24	3.503	3.542	+.059	4.23	3.09	1.03	OK
R1-C25	3.495	3.466	-.029	2.17	2.51	5.37	OK
R1-C26	3.503	3.509	+.006	2.63	2.40	2.57	Crack in cold-leg transition per RT and ET

NONDESTRUCTIVE EVALUATION OF STEAM GENERATOR D TUBE U-BEND SECTIONS

Tube Number	Visual Examination	Radiography[a]	Eddy Current Examination[b]
R1C1	No indications (NI)	No discontinuity (ND)	No indications (NI)
R1C2	NI	ND	NI
R1C3	NI	ND	NI
R1C4	NI	ND	NI
R1C5	NI	ND	Indication - hot leg
R1C6	1 indication - OD 3 indications - ID	One axial crack (3 segments) at cold-leg transition on extrados, total length 0.75-in.	Large indication - cold leg
R1C7	No indication - OD 1 indication - ID	One axial crack at cold-leg transition near extrados, total length 0.5 to 0.625-in.	Indication - cold leg
R1C8	NI	ND	NI
R1C9	NI	ND	NI
R1C10	NI	ND	NI
R1C11	NI	ND	NI
R1C12	NI	ND	NI
R1C13	NI	ND	NI
R1C14	NI	ND	NI
R1C15	NI	ND	NI
R1C16	NI	ND	NI
R1C17	NI	ND	NI

[a] W RT analysis at 150 kV (6-26-80)
[b] W ET analysis with Zetec probe (6-12-80)

NONDESTRUCTIVE EVALUATION OF STEAM GENERATOR D TUBE U-BEND SECTIONS

Tube Number	Visual Examination	Radiography[a]	Eddy Current Examination[b]
R1C1	No indications (NI)	No discontinuity (ND)	No indications (NI)
R1C2	NI	ND	NI
R1C3	NI	ND	NI
R1C4	NI	ND	NI
R1C5	NI	ND	Indication - hot leg
R1C6	1 indication - OD 3 indications - ID	One axial crack (3 segments) at cold-leg transition on extrados, total length 0.75-in.	Large indication - cold leg
R1C7	No indication - OD 1 indication - ID	One axial crack at cold-leg transition near extrados, total length 0.5 to 0.625-in.	Indication - cold leg
R1C8	NI	ND	NI
R1C9	NI	ND	NI
R1C10	NI	ND	NI
R1C11	NI	ND	NI
R1C12	NI	ND	NI
R1C13	NI	ND	NI
R1C14	NI	ND	NI
R1C15	NI	ND	NI
R1C16	NI	ND	NI
R1C17	NI	ND	NI

[a] W RT analysis at 150 kV (6-26-80)
[b] W ET analysis with Zetec probe (6-12-80)

Tube Number	Visual Examination	Radiography[a]	Eddy Current Examination[b]
R1C18	NI	ND	NI
R1C19	NI	ND	NI
R1C20	NI	ND	NI
R1C21	NI	ND	NI
R1C22	NI	ND	NI
R1C23	NI	ND	NI
R1C24	NI	ND	NI
R1C25	NI	ND	NI
R1C26	NI	Two axial cracks at cold-leg transition on extrados, total length 0.625-in.	Indication - cold leg
R2C1	NI	ND	NI
R2C2	NI	ND	NI
R2C3	NI	ND	NI

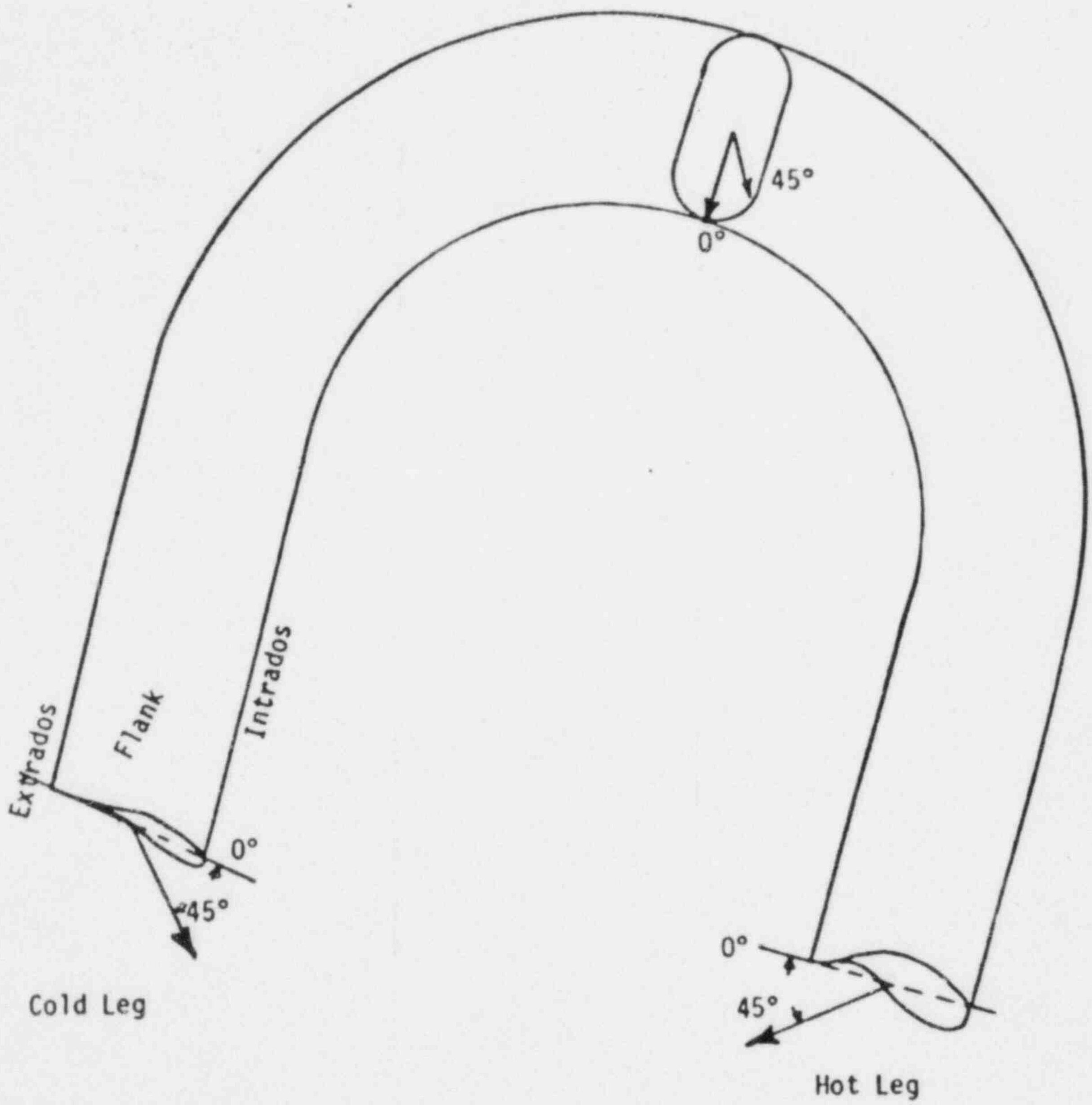


Figure 1. Definition of angular positions.

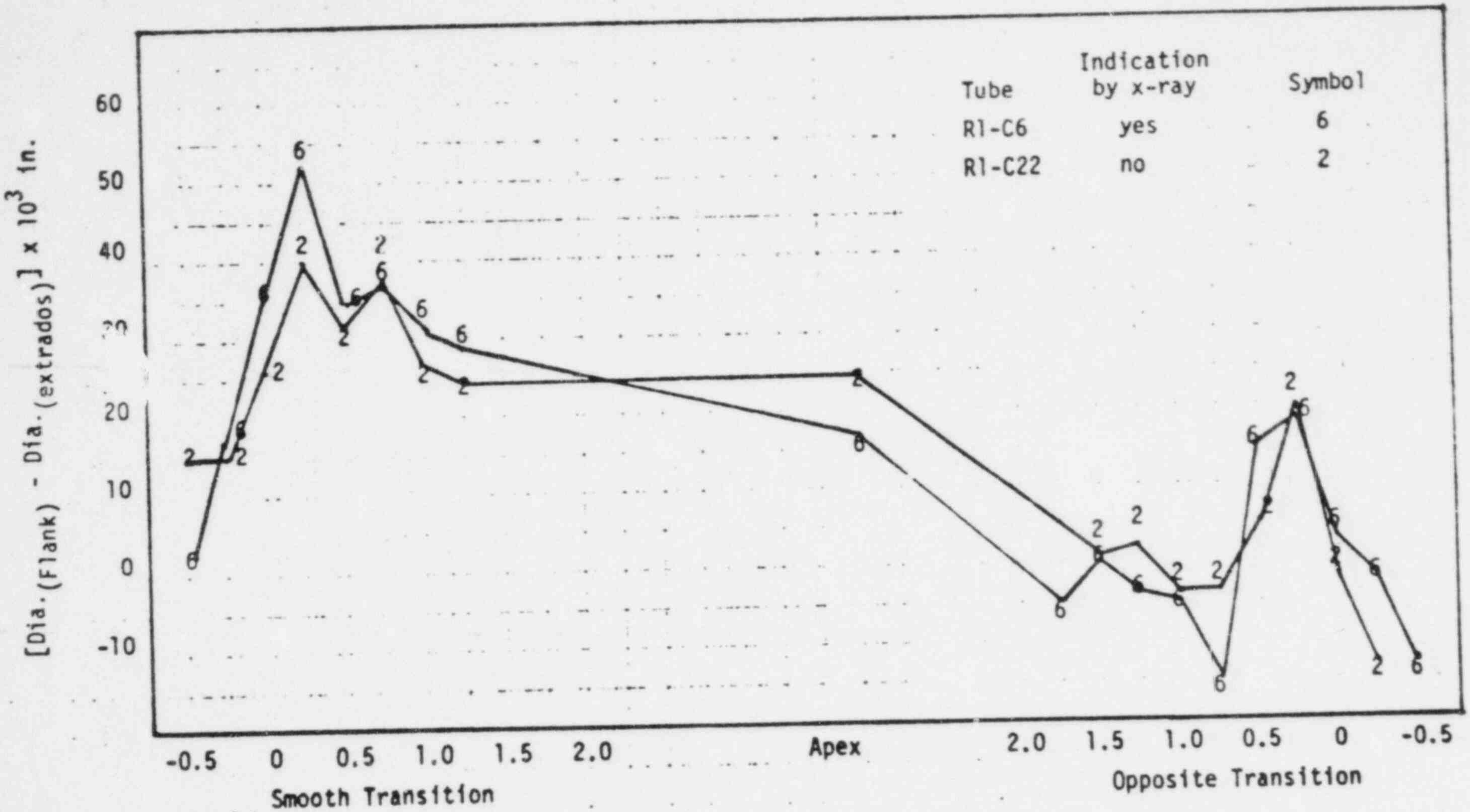


Figure 2. Ovality for tubes R1-C6 and R1-C22 at the smooth transition, apex and opposite transition. Zero positions correspond to intrados transitions.

2a

Table 1. Diametral data at the apex on 3 U-bends with indications by x-ray and on 5 without indications (values are deviations from 0.875 in mils)

	Angular Position 0	45	90	135°	(Dia @ 90° - Dia @ 0°)	Difference in Values
R1-C4	-13.0	- 4.0	1.6	- 6.8	14.6	
	-13.5	- 8.0	0.8	- 5.0	14.3	.3
R1-C6	-14.2	- 7.9	- 1.7	- 8.2	12.5	
	-14.8	- 9.2	0.4	- 6.5	15.2	2.7
R1-C7	-14.9	- 9.1	1.1	- 7.2	16.0	
	-14.7	- 7.8	1.6	- 6.0	15.3	.7
R1-C10	- 0.8	- 9.3	2.5	- 4.2	3.3	

R1-C13	-15.9	-11.3	- 2.0	- 9.8	13.9	
	-15.0	-11.1	- 1.0	-11.0	14.0	.1
R1-C18	-12.3	- 4.3	13.2	- 2.7	25.5	
	-12.4	- 6.2	11.5	- 4.1	23.9	1.6
R1-C22	-13.3	- 3.5	13.0	- 4.0	26.3	

R1-C26	-11.5	- 2.5	10.6	-12.3	22.1	
	-11.7	- 7.3	12.4	- 3.7	24.1	2.0

Table 2. Comparison of wall thickness (mils) and Knoop Hardness (500g) for three tubes with x-ray indications and three without at various approximate angular positions on a straight leg.

Tube/Leg		Wall Thickness 135°	180 (Extrados)	225	Avg.	Hardness (mid-wall) 90	135	180 (Extrados)	225	270	Avg.
R1-C6 Cold*	x-ray indication	57	55	54	55.3	219.8	233.9	245.0	234.7	216.7	230.0 (Rb = 93)
R1-C7 Hot**	x-ray indication	57	57	55	56.3	186.7	187.3	178.2	178	183.2	182.7
R1-C26 Hot**	x-ray indication	56	57	56	56.3	199.6	190.4	185.2	201.8	206.3	196.6
R1-C10 Cold*	no x-ray indication	59	60	57	58.66	179.1	186.4	183.1	180.4	186.1	183.0
R1-C13 Hot**	no x-ray indication	52	52	54	52.7	187.8	183.1	187.8	186.5	190.8	187.2
R1-C22 Cold**	no x-ray indication	59	57	55	57.0	181.3	185.2	183.5	176.8	181.3	181.6 (Rb = 83

* Opposite Transition
** Smooth Transition

Table 3. Comparison of ovality measurements obtained from as-polished transverse cross-sections at the apex with those from diametral valves measured with a vernier caliper.

Tube	Ovality ($Dia._{Flank} - Dia._{Extrados}$) Metallography	Caliper
R1-C6	9.0 mils	12.5
		15.2
R1-C1D	0.0	3.3
R1-C22	28.4	26.3

4
CDEF

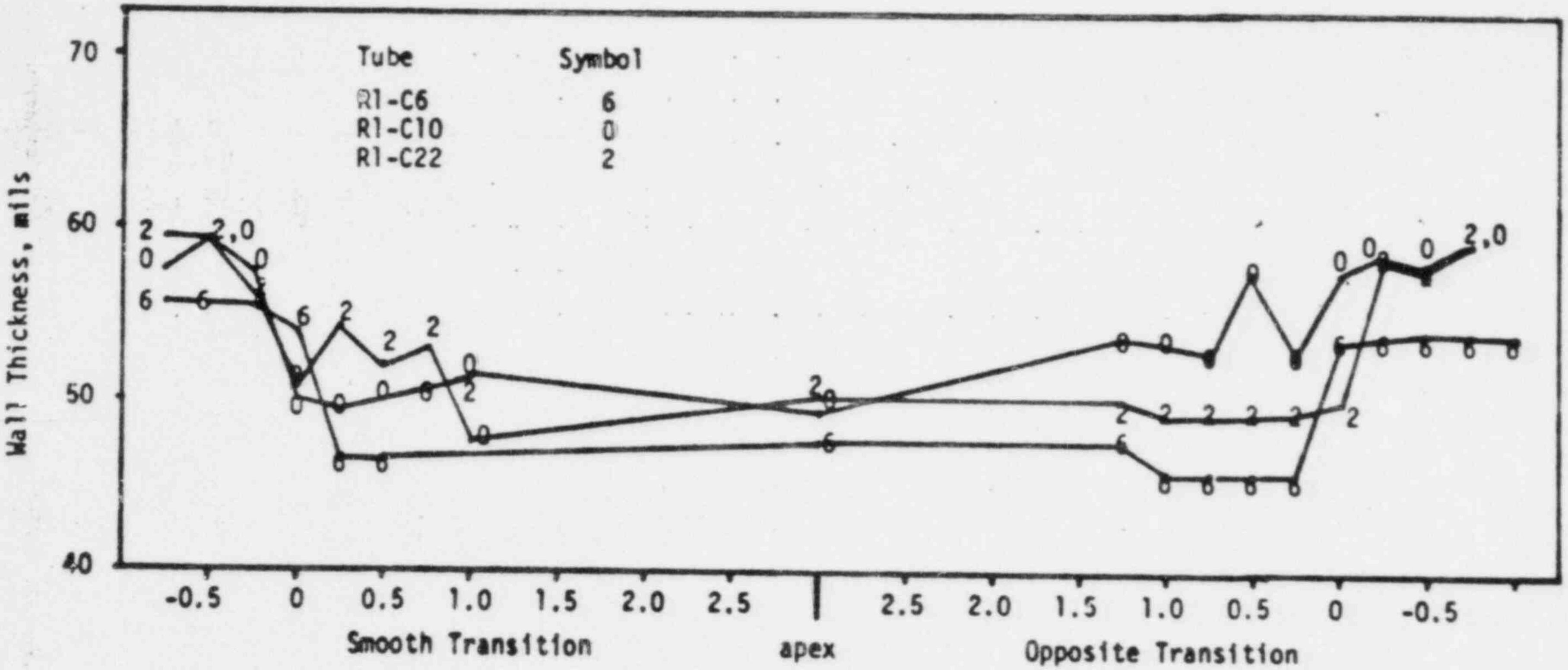


Figure 9. Wall thickness measurements at the extrados (180°) for the smooth transition, apex, and opposite transition. Zeros correspond to extrados transitions.

SUMMARY OF THE PRINCIPAL FACTS

1. DOUBLE WALL X-RAY RADIOGRAPHS IDENTIFIED THREE TUBES WITH INDICATIONS OUT OF 26 ROW 1 TUBES.

2. THESE INDICATIONS OCCURRED AT THE TRANSITION WITH WELL DEFINED EXTRADOS AND INTRADOS TRANSITIONS AND ON THE EXTRADOS JUST BELOW THE EXTRADOS TRANSITION AND IN THE STRAIGHT LENGTH SECTION.

3. THE INDICATION ON TUBE R1-C6 CONSISTED OF INTERGRANULAR CRACKS WHICH RESULTED FROM MULTIPLE INITIATIONS ON THE I.D.

4. THE HARDNESS OF R1-C6 TUBE WAS HIGHER THAN FOR TWO OTHER TUBES WITH INDICATIONS AND FOR THREE OTHER TUBES WITH NO INDICATIONS.

Programs Underway

TROJAN

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2. Examination of R1-C26 (indication) and one without indication
   a) microstructures and hardnesses at smooth and opposite transitions and apex
   b) microanalyses of fracture surface
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5. Chemical analyses of tubes
6. Distribution of carbides in the grain boundaries and degree of sensitization

TURKEY POINT No. 4, SURRY I and SURRY II U-bends

1. Eddy current characterization and double wall X-ray radiography
2. Diametral data, metallography, and hardness data on opposite transitions
3. Residual stress measurements

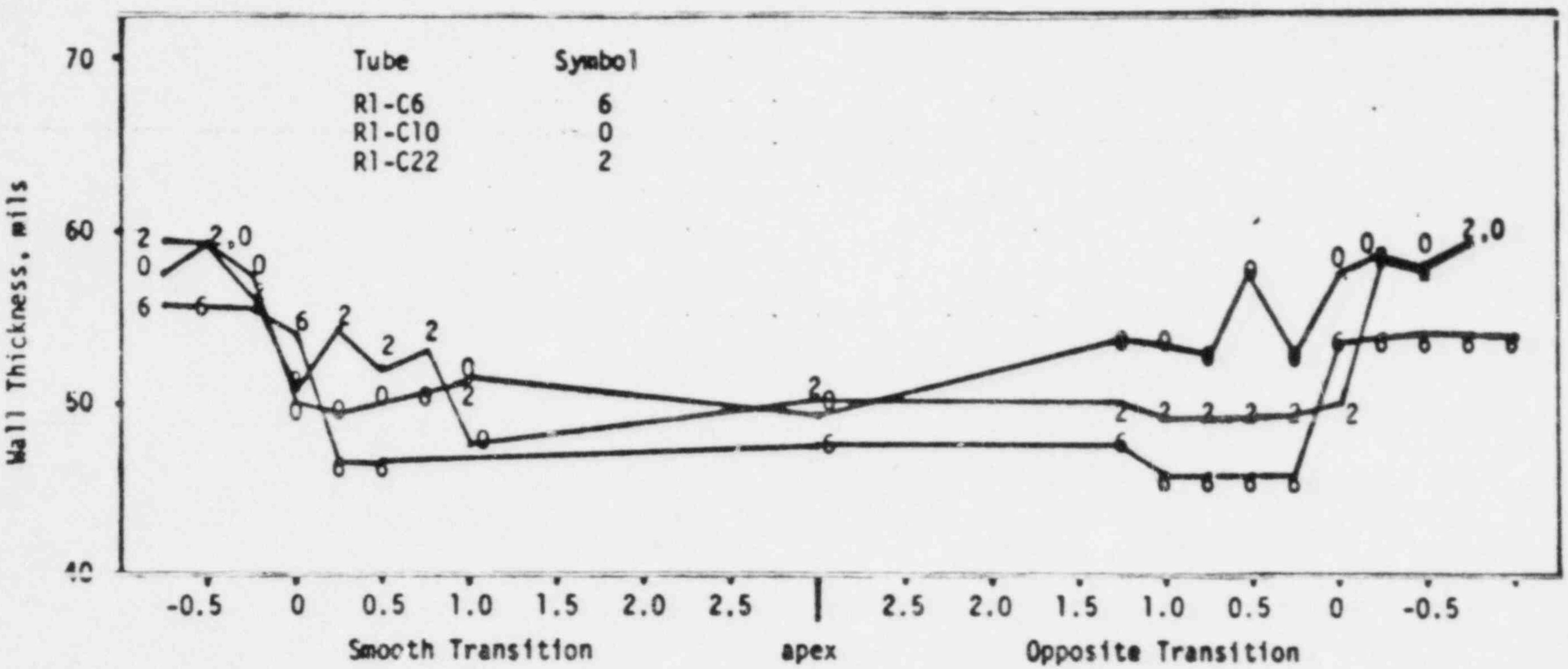

Figure 9. Wall thickness measurements at the extrados (180°) for the smooth transition, apex, and opposite transition. Zeros correspond to extrados transitions.

G→0

Table 1. Diametral data at the apex on 3 U-bends with indications by x-ray and on 5 without indications (values are deviations from 0.875 in mils)

	Angular Position 0	45	90	135°	(Dia @ 90° - Dia @ 0°)	Difference in Values
R1-C4	-13.0	- 4.0	1.6	- 6.8	14.6	
	-13.5	- 8.0	0.8	- 5.0	14.3	.3
R1-C6	-14.2	- 7.9	- 1.7	- 8.2	12.5	
	-14.8	- 9.2	0.4	- 6.5	15.2	2.7
R1-C7	-14.9	- 9.1	1.1	- 7.2	16.0	
	-14.7	- 7.8	1.6	- 6.0	15.3	.7
R1-C10	- 0.8	- 9.3	2.5	- 4.2	3.3	---
R1-C13	-15.9	-11.3	- 2.0	- 9.8	13.9	
	-15.0	-11.1	- 1.0	-11.0	14.0	.1
R1-C18	-12.3	- 4.3	13.2	- 2.7	25.5	
	-12.4	- 6.2	11.5	- 4.1	23.9	1.6
R1-C22	-13.3	- 3.5	13.0	- 4.0	26.3	---
R1-C26	-11.5	- 2.5	10.6	-12.3	22.1	
	-11.7	- 7.3	12.4	- 3.7	24.1	2.0

Table 3. Comparison of ovality measurements obtained from as-polished transverse cross-sections at the apex with those from diametral valves measured with a vernier caliper.

Tube	Ovality ($Dia._{Flank} - Dia._{Extrados}$)	
	Metallography	Caliper
R1-C6	9.0 mils	12.5
		15.2
R1-C1D	0.0	3.3
R1-C22	28.4	26.3

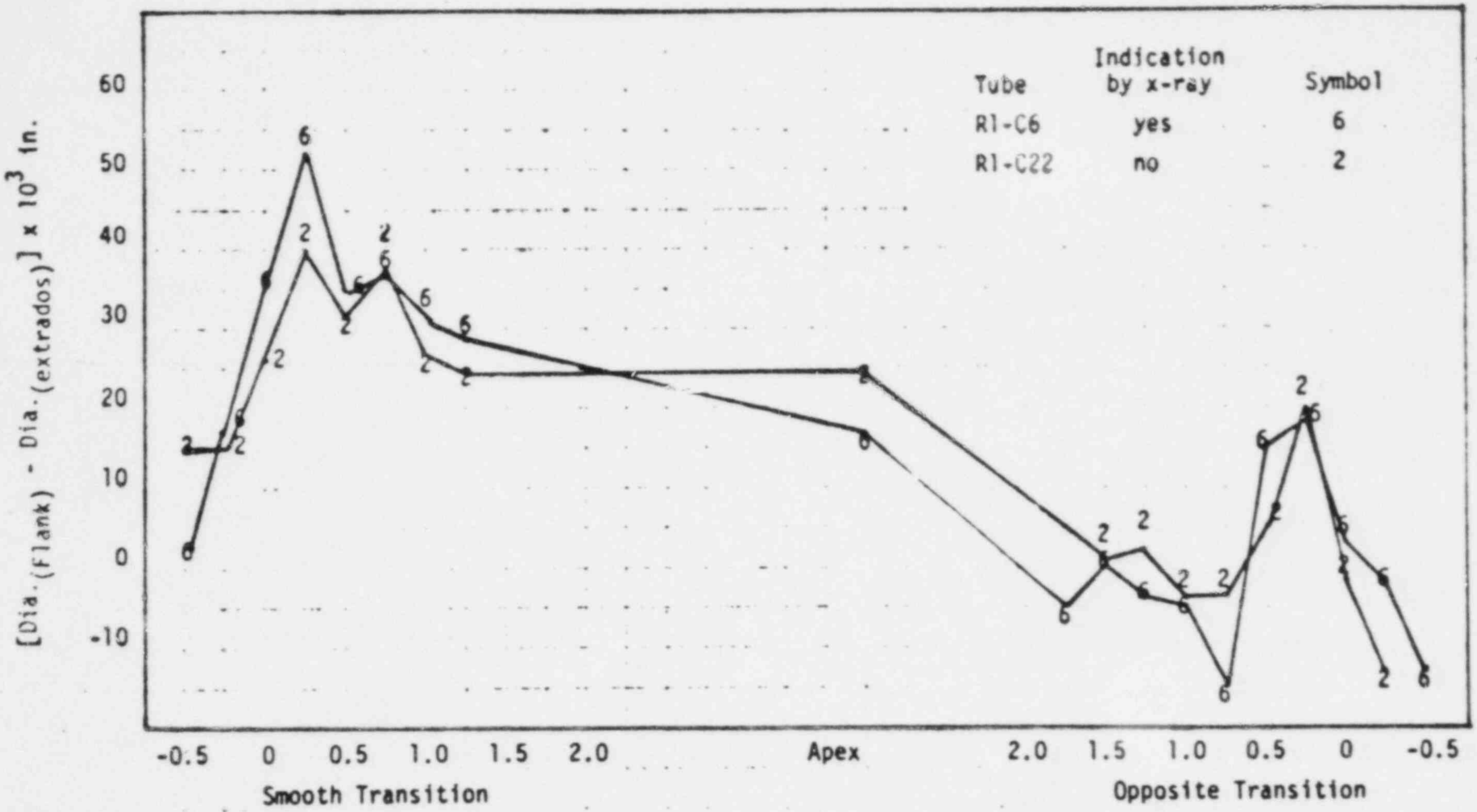

Figure 2. Ovality for tubes R1-C6 and R1-C22 at the smooth transition, apex and opposite transition. Zero positions correspond to intrados transitions.

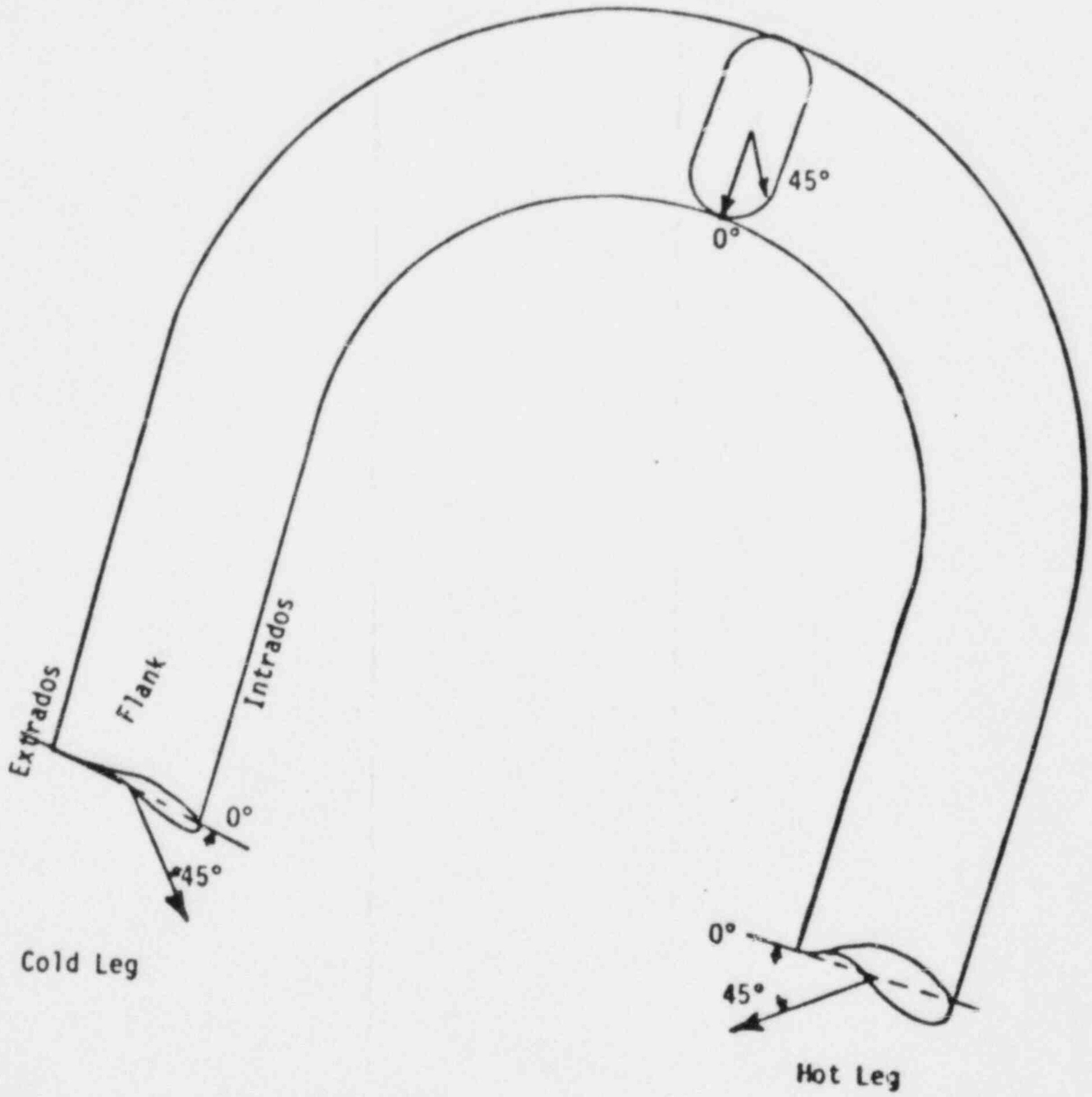

Figure 1. Definition of angular positions.

Table 2. Comparison of wall thickness (mils) and Knoop Hardness (500g) for three tubes with x-ray indications and three without at various approximate angular positions on a straight leg.

Tube/Leg	Group	Wall Thickness 135°	Wall Thickness 180 (Extrados)	Wall Thickness 225	Wall Thickness Avg.	Hardness (mid-wall) 90	Hardness (mid-wall) 135	Hardness (mid-wall) 180 (Extrados)	Hardness (mid-wall) 225	Hardness (mid-wall) 270	Hardness (mid-wall) Avg.
R1-C6 Cold*	x-ray indication	57	55	54	55.3	219.8	233.9	245.0	234.7	216.7	230.0 (Rb = 93)
R1-C7 Hot**	x-ray indication	57	57	55	56.3	186.7	187.3	178.2	178	183.2	182.7
R1-C26 Hot**	x-ray indication	56	57	56	56.3	199.6	190.4	185.2	201.8	206.3	196.6
R1-C10 Cold*	no x-ray indication	59	60	57	58.66	179.1	186.4	183.1	180.4	186.1	183.0
R1-C13 Hot**	no x-ray indication	52	52	54	52.7	187.8	183.1	187.8	186.5	190.8	187.2
R1-C22 Cold**	no x-ray indication	59	57	55	57.0	181.3	185.2	183.5	176.8	181.3	181.6 (Rb = 83)

* Opposite Transition
** Smooth Transition

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Tube/Leg		Wall Thickness				Hardness (mid-wall)					
		135°	180 (Extrados)	225	Avg.	90	135	180 (Extrados)	225	270	Avg.
R1-C6 Cold*	x-ray indication	57	55	54	55.3	219.8	233.9	245.0	234.7	216.7	230.0 (Rb = 93)
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R1-C13 Hot**	no x-ray indication	52	52	54	52.7	187.8	183.1	187.8	186.5	190.8	187.2
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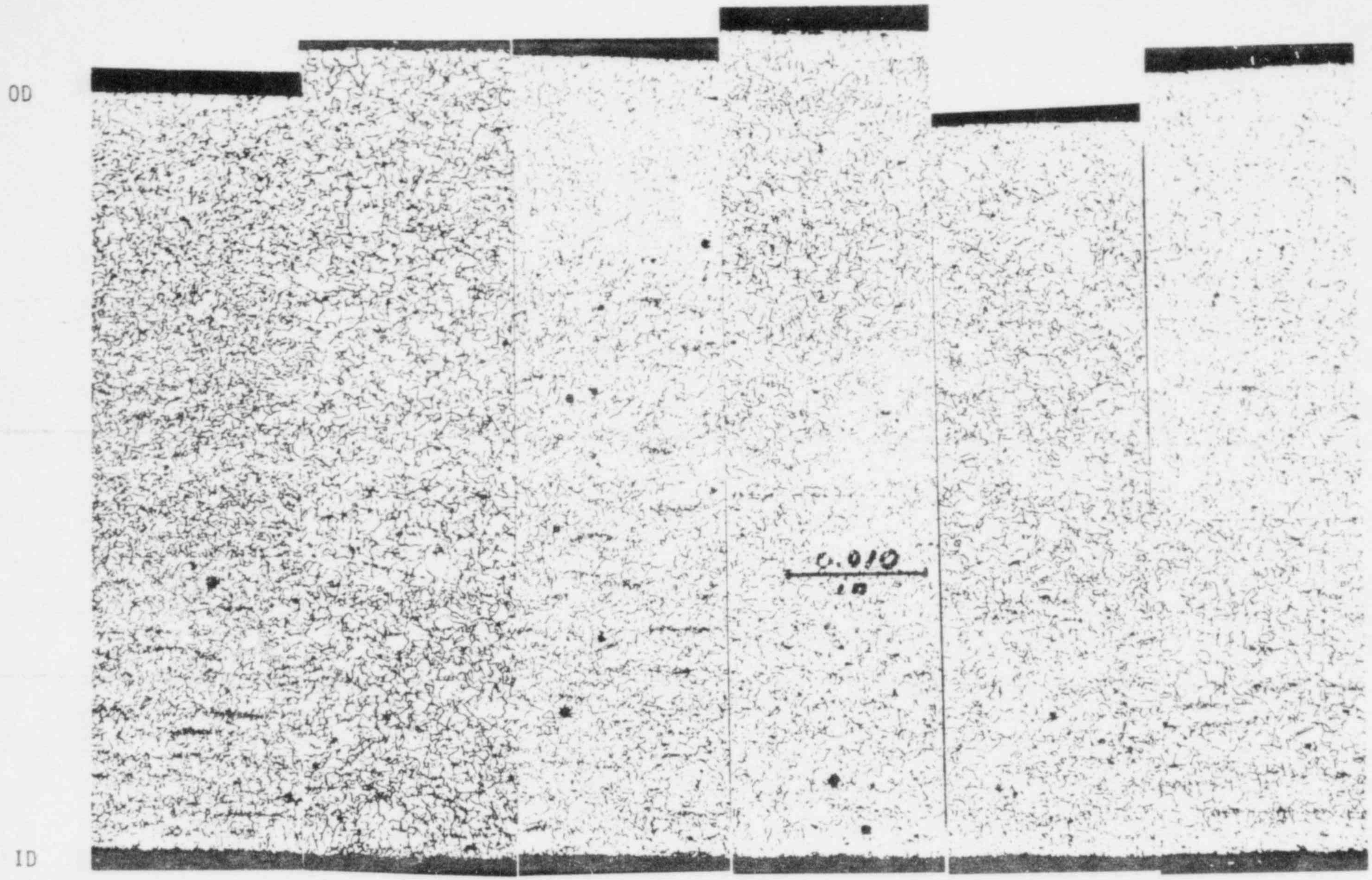


	x-ray indication			no x-ray indication		
Tube :	R1-C6	R1C-7	R1-C26	R1-C10	R1-C13	R1-C22
Section:	E6A	E7A	E26A	E10A	C13A	E22A
Angle :	150°	180°	205°	160°	180°	205°

Figure 3. Comparison of straight section through wall microstructures for 3 tubes with and three tubes without x-ray indications.

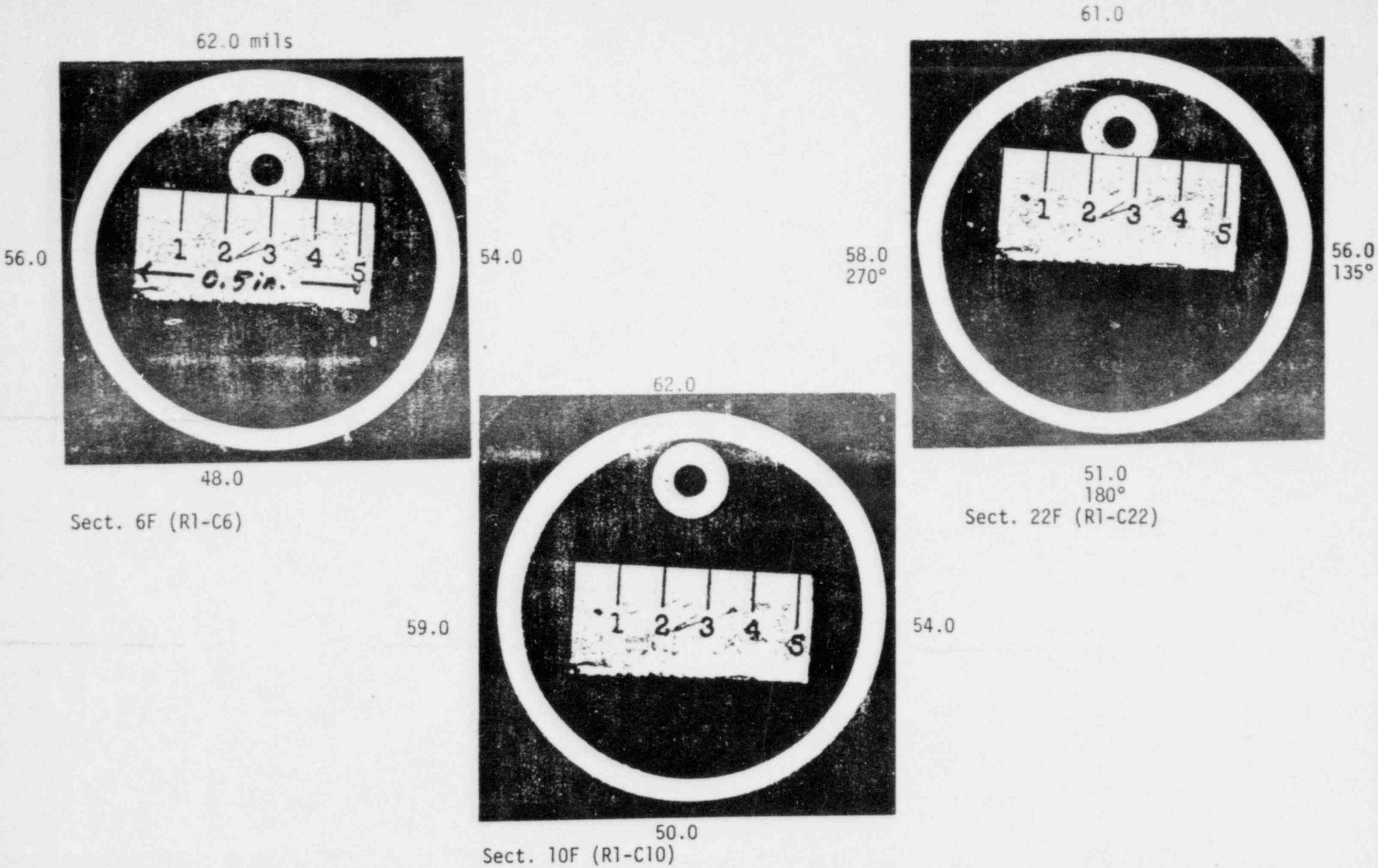


Figure 4. As-polished cross-sections at apex for tubes R1-C6, R1-C10, and R1-C22 showing variations in dimensions. Angular positions are given plus wall thicknesses in mils as-measured with thread micrometers prior to mounting.

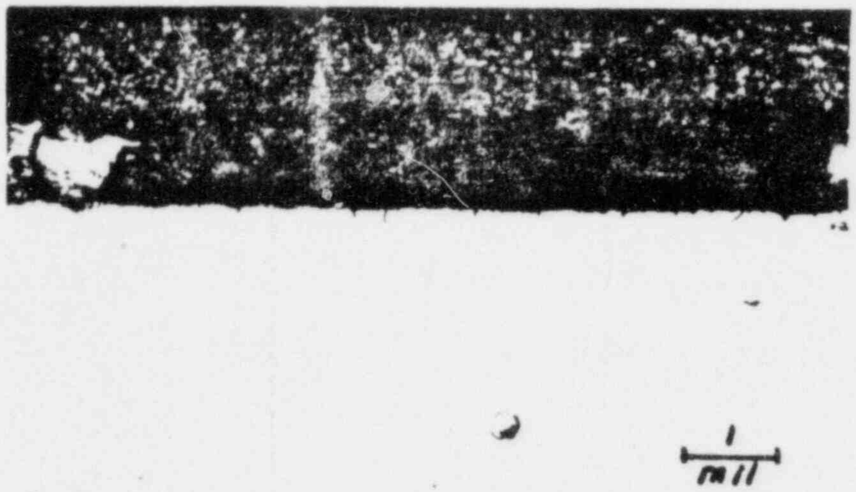


Figure 5. Shallow intergranular penetrations on the I.D. at the extrados on Section 6F (R1-C6). These were observed to a lesser extent at the flank (90°) and 0° positions.

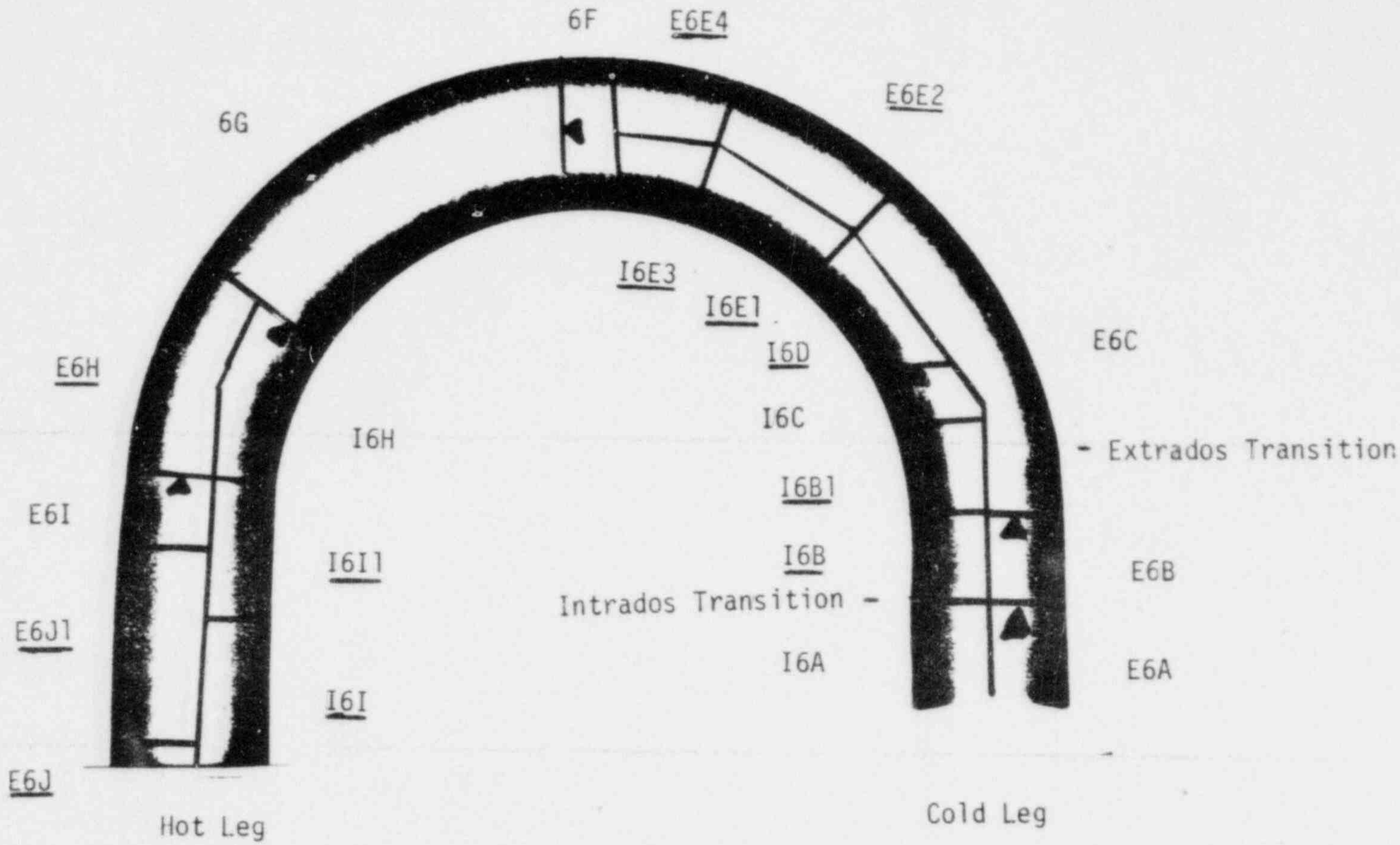


Figure 6. Print of double wall x-ray radiograph of RI-C6. Solid lines shown approximate locations of major cuts; sections are identified; surfaces polished for metallography are designated by ▲ . Underlined sections were flattened and their ID surfaces examined at 5X. Further cuts of E6C are given in next figure.

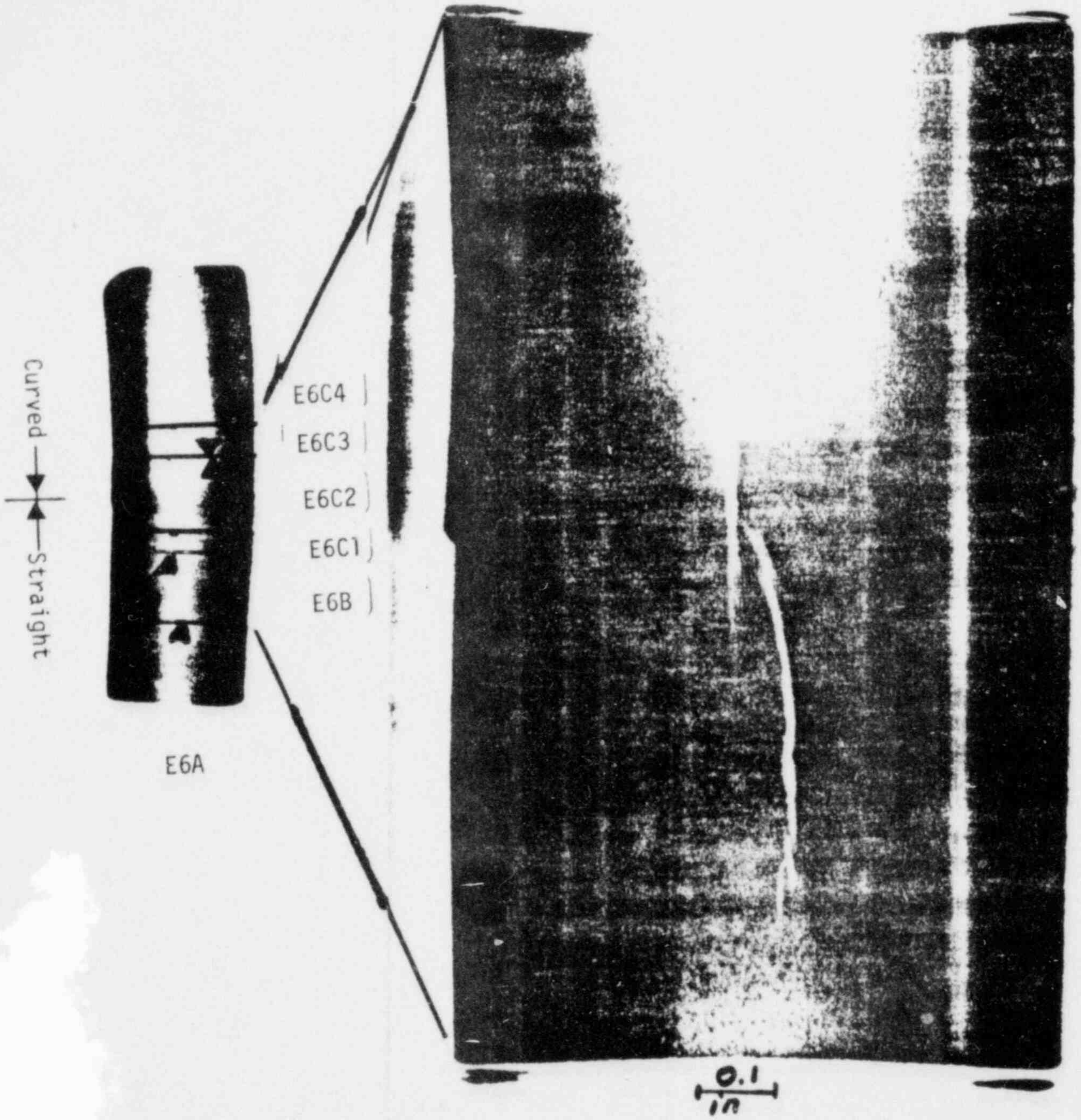
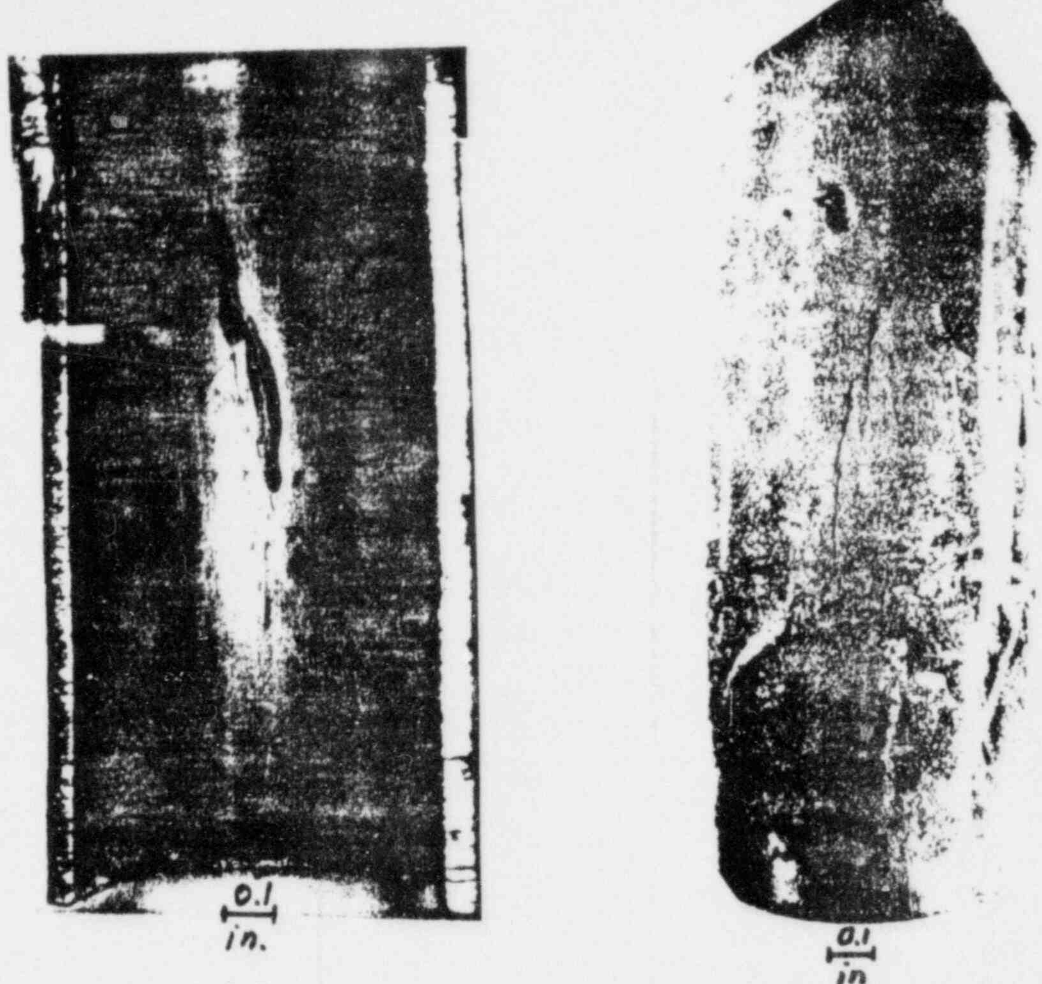


Figure 7. Prints of single wall x-ray radiographs of the cold leg of tube R1-C6 showing cracks at the extrados (180°) and near the transition from straight to curved. (Section was subsequently cut to form E6A, E6B and E6C.)



I.D.

O.D.

Figure 8. Photographs of I.D. and O.D. surfaces in the neighborhood of the crack on the cold leg of tube R1-C6. A bluish deposit color is evident on I.D. at location of crack. Distance of end of crack from cut tube-sheet-end was 0.71" on I.D. and 0.85" on O.D.

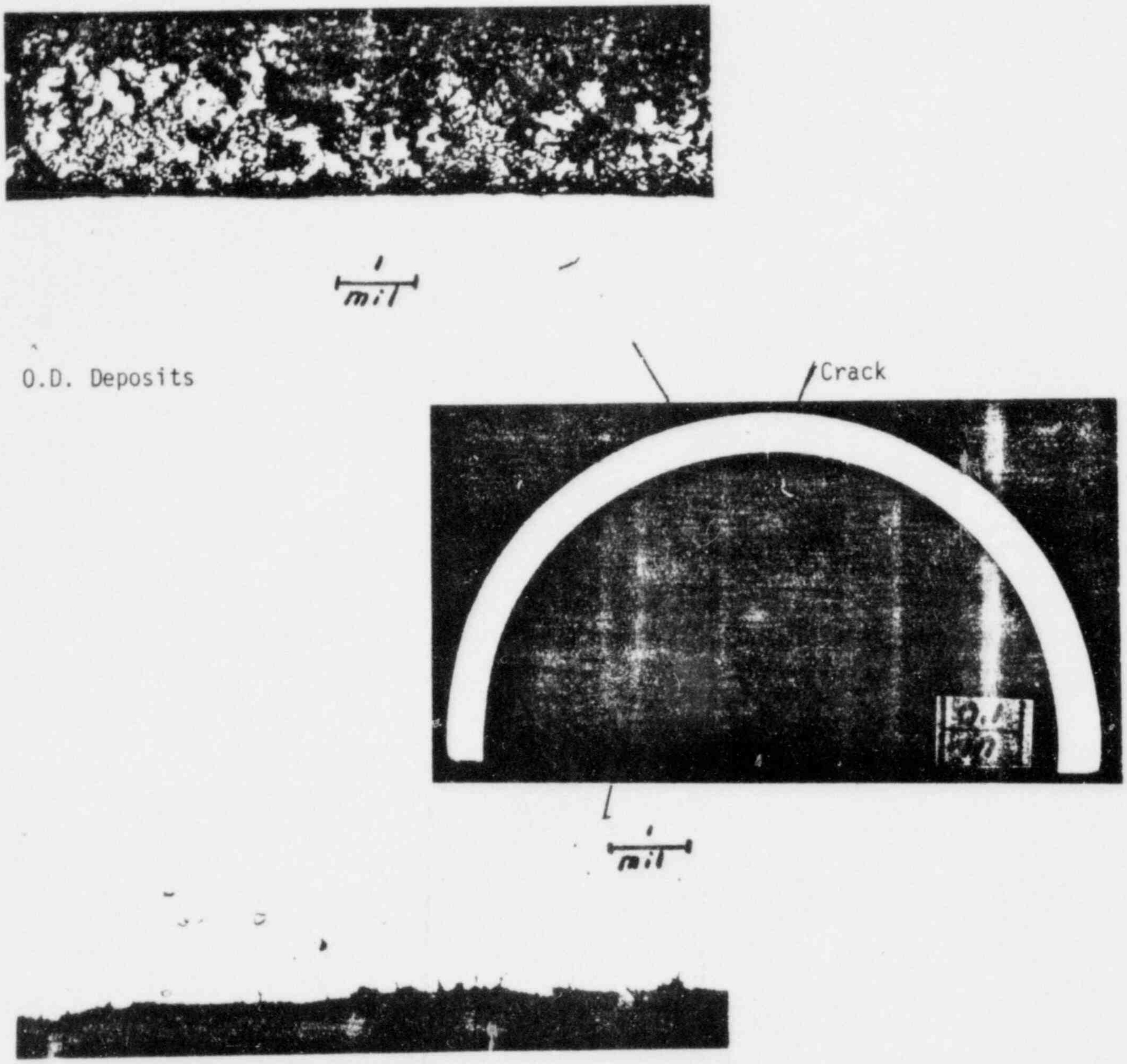


Figure 10. First plane of polish on section E6B showing through wall crack at extrados, 1.5 mils of deposits on O.D. and IG penetration on I.D.

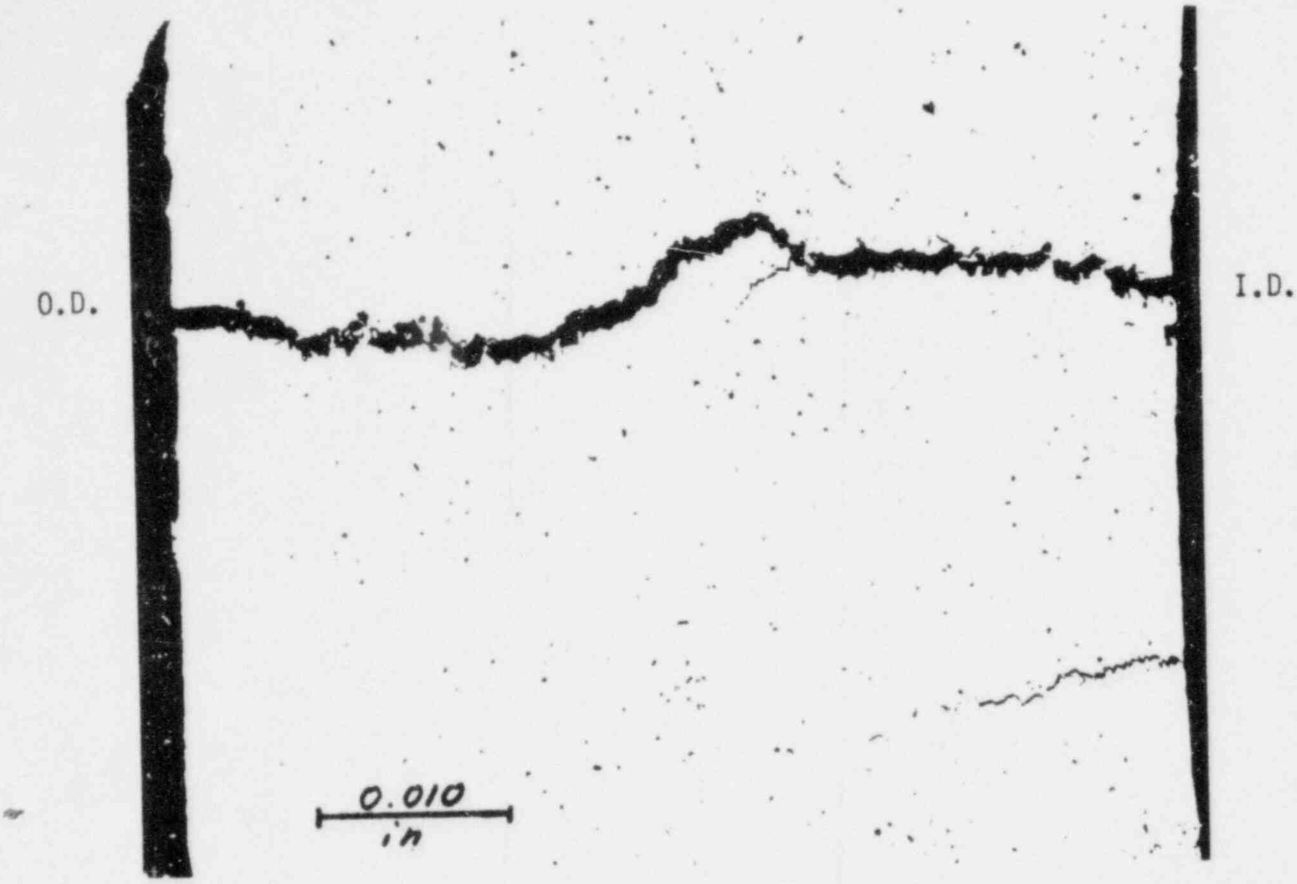
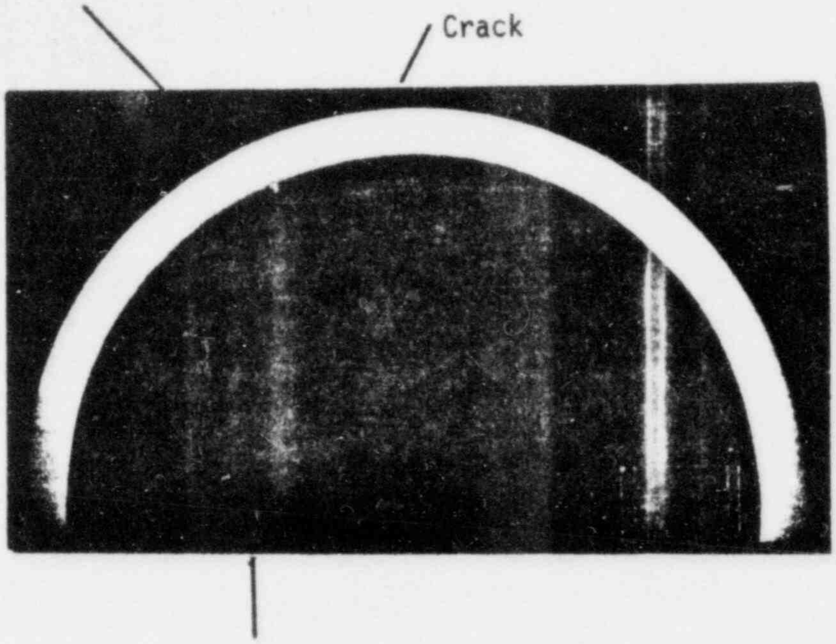


Figure 11. Through wall crack on first plane of polish on Section E6B; wall thickness is ~ 51.5 mils.

O.D. Deposits



IG penetrations on the I.D.

Figure 12. Second plane of polishing (45 mils below first plane) on Section E6B showing through wall crack, O.D. surface deposits, and shallow I.D. intergranular penetrations.

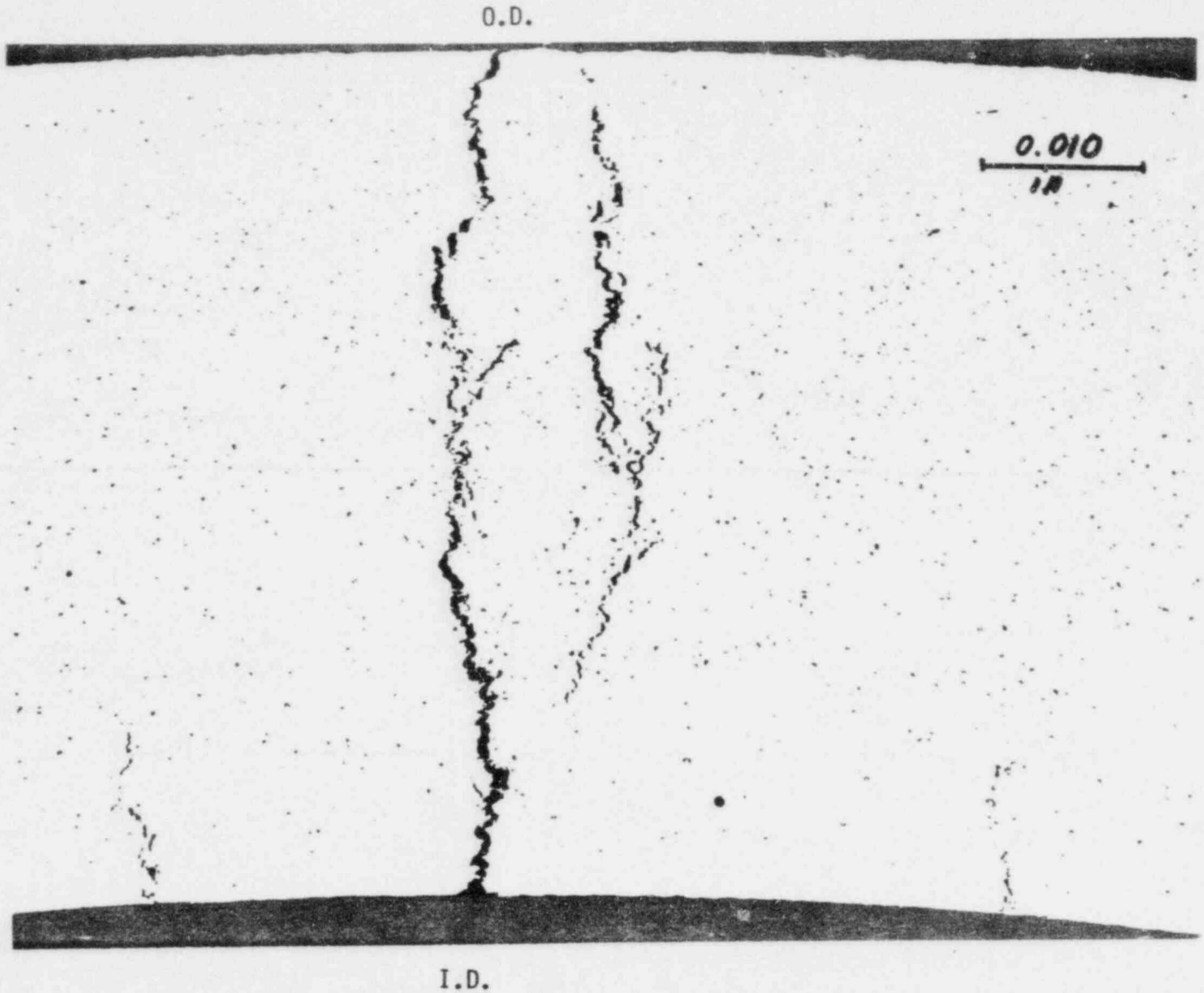


Figure 13. Through wall crack observed on second plane of polish of Sect. E6B.

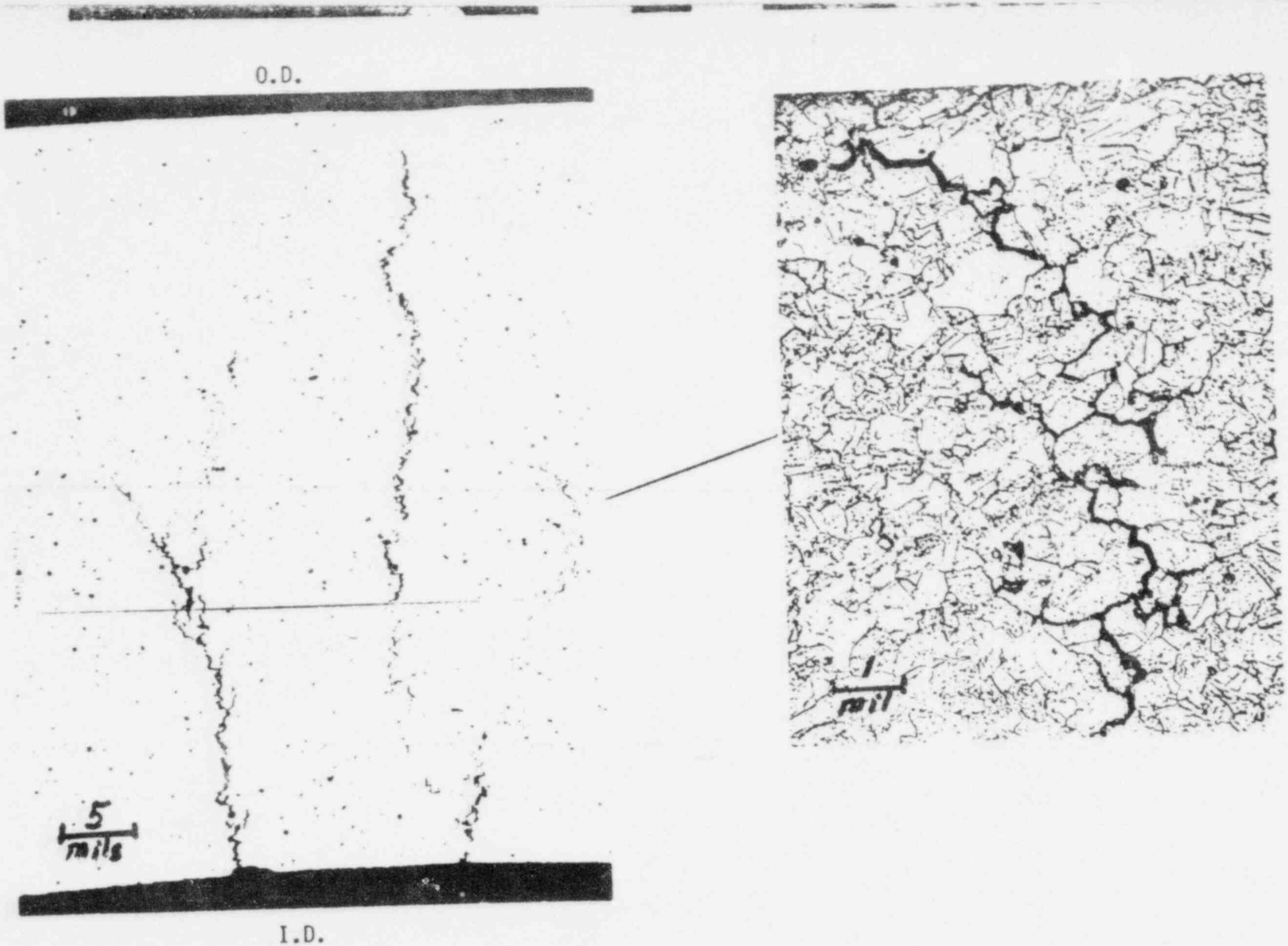
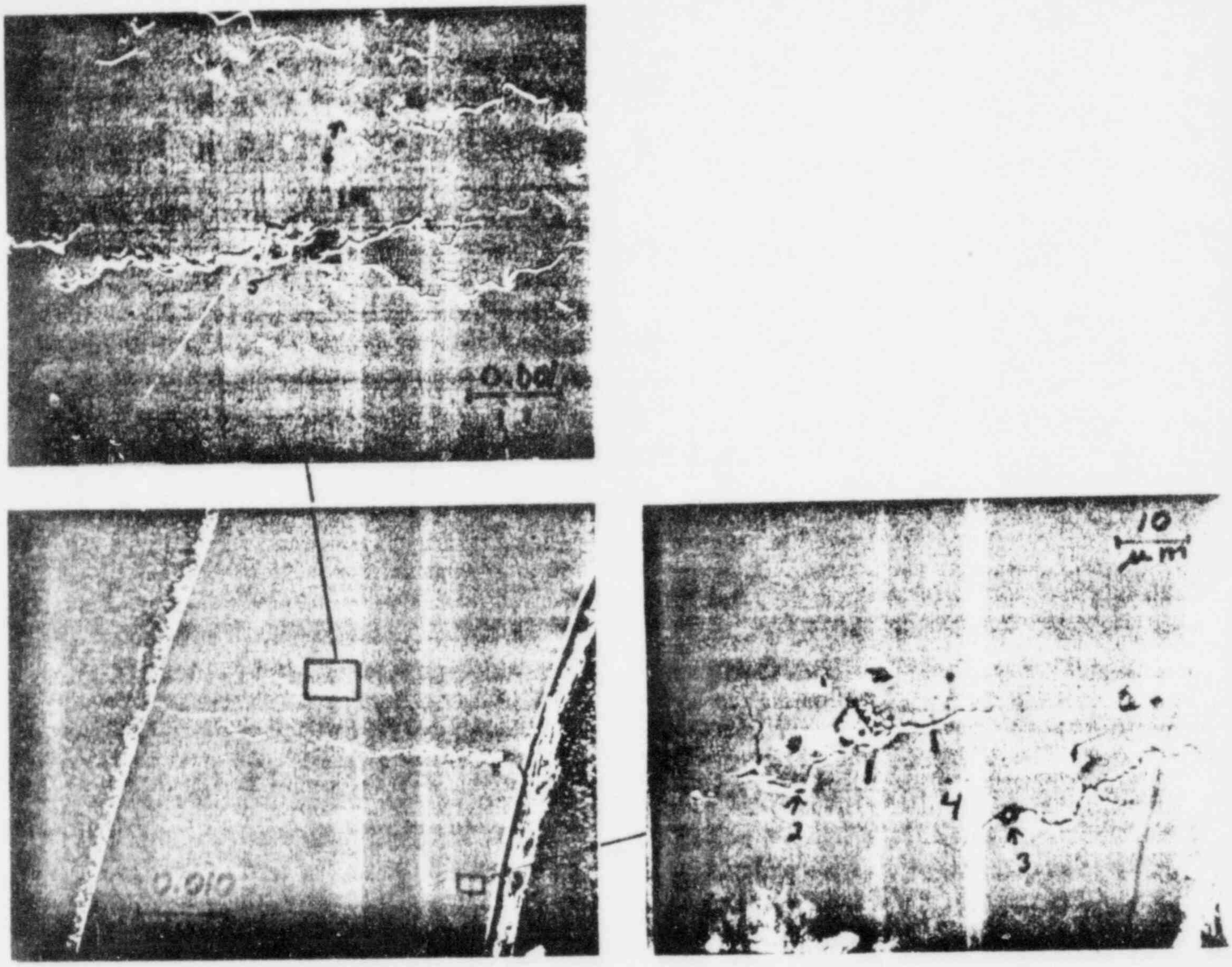


Figure 14. Third plane of polishing (33 mils below second plane) of Section E6B at the extrados.

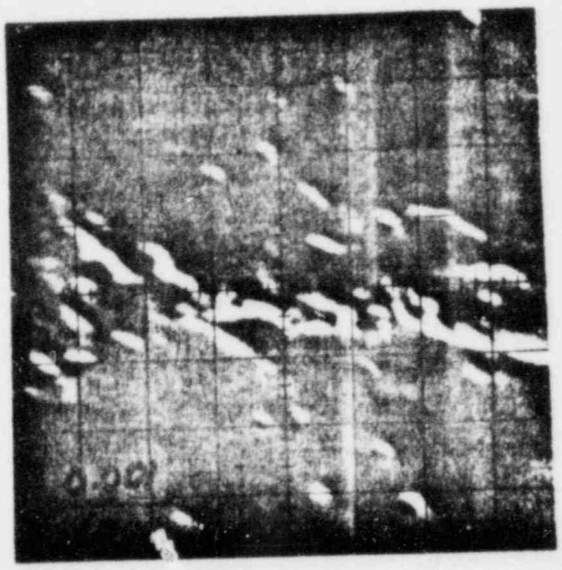


I.D.

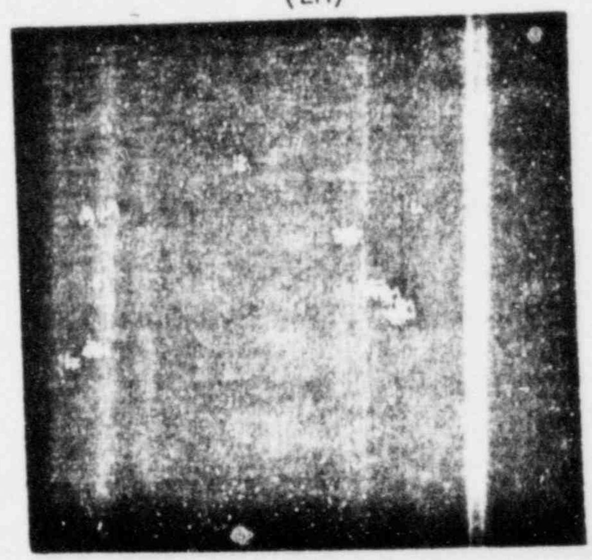
Figure 15. SEM micrographs of cracks in 2nd polished plane of sect. E6B (R1-C6 tube) showing areas examined with energy dispersive X-ray analyses (identified by numbers). Only Si and Na were identified as present plus alloying elements found in Inconel 600.

I.D.

(LM)



BSE



SiKα

Not Detected: P, S, Pb, K, Na and As

Figure 16. Two areas on the 2nd polished plane of E6B (R1-C6) were examined with Electron beam micro analysis for Si, P, S, Pb, K, Na and As, and are shown in the photograph obtained with the light microscope (LM). Similar results were obtained for both areas. Back scattered electron micrograph (BSE) is shown for Lower area. Si was detected in localized areas. None of the other elements was detected by area scans or by line traces through tight cracks.

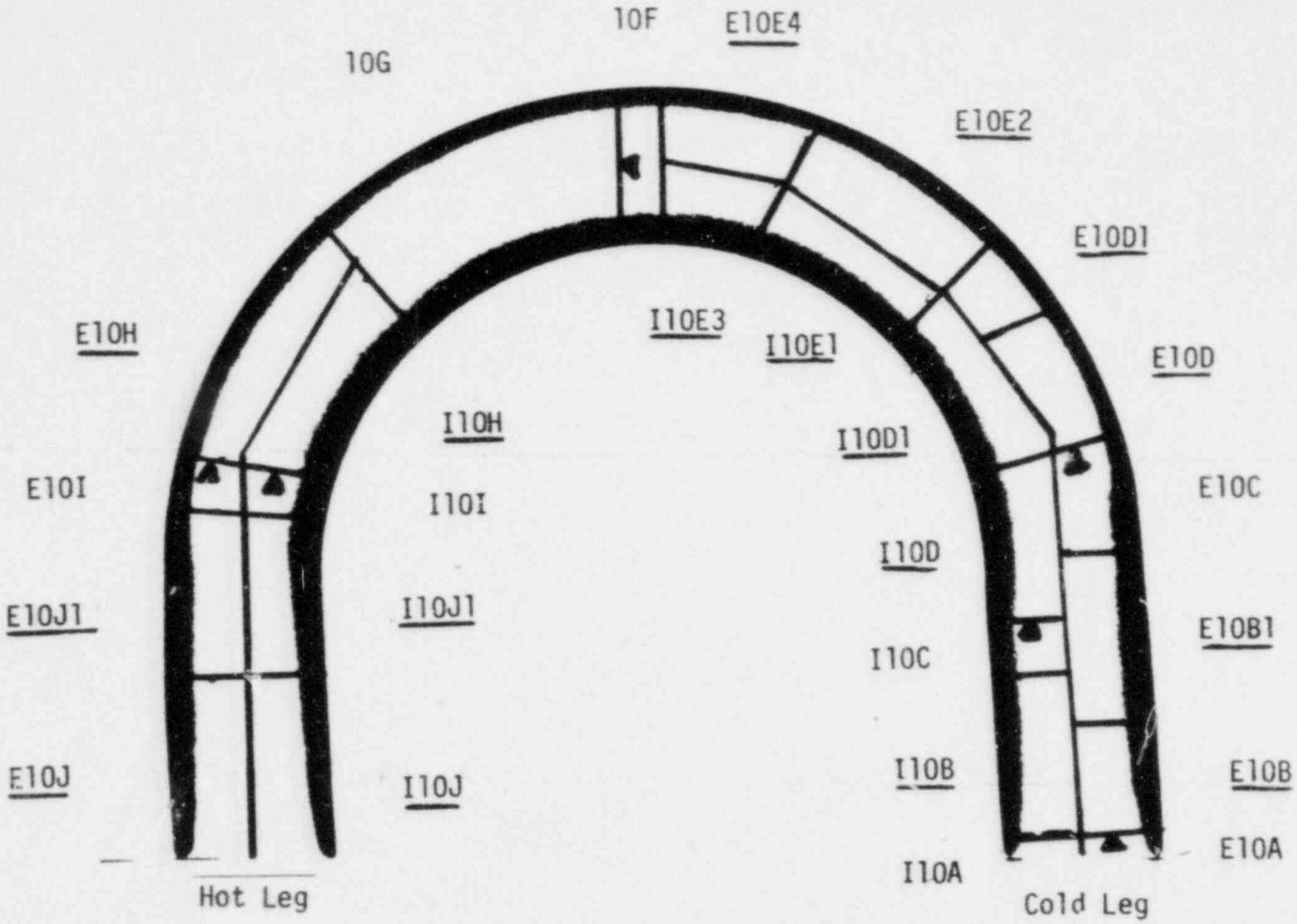


Figure 17. Print of double wall x-ray radiograph of tube R1-C10. Solid lines identify cuts; locations and identification of sections studied are given.

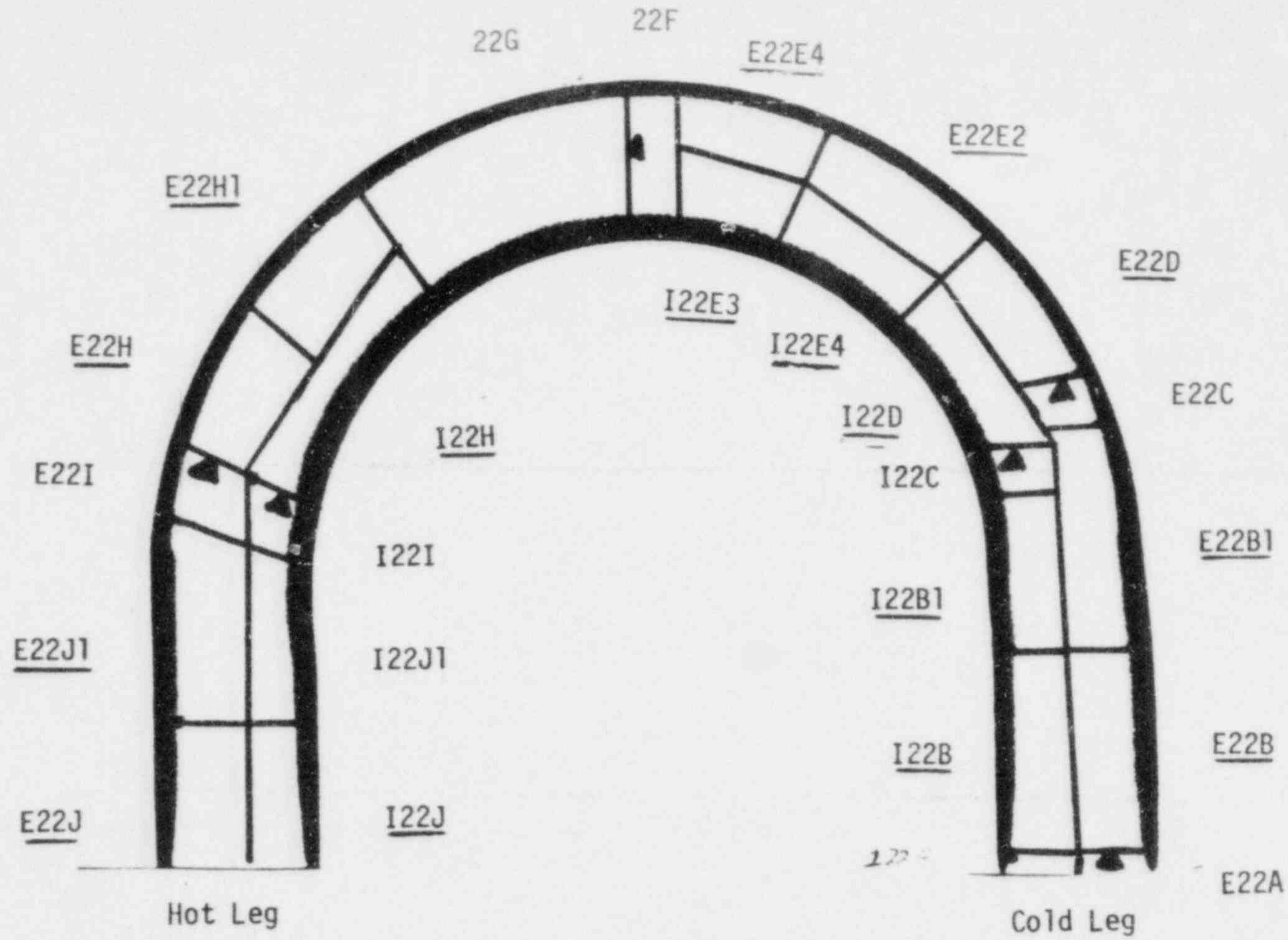


Figure 18. Print of double wall x-ray radiograph of R1-C22. Solid lines identify cuts; locations and identifications of sections studied are given.