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

R. Martin

July 14, 1982

Docket No. 50-289

FACILITY: Three Mile Island, Unit No. 1 (TMI-1)

LICENSEE: GPU Nuclear Corporation (GPUN)

SUBJECT: SUMMARY OF MEETING WITH GPUN ON JUNE 28 and 29, 1982 CONCERNING GPUN'S STEAM GENERATOR RECOVERY PROGRAM

Background

In late November 1981, while the plant was in a cold shutdown condition, primary to secondary leakage was detected in the Once Through Steam Generators (OTSGs). GPUN has conducted an extensive program in the areas of failure analysis, tube repair techniques, inspection for the corrosion of other Reactor Coolant System (RCS) components, and Eddy Current Testing (ECT). The purpose of the June 28 and 29, 1982 meetings was to update the NRC staff and their consultants on GPUN's current progress with these programs. The June 28th meeting was a working level meeting to discuss the results of GPUN's RCS inspection and metallurgical examination results of removed steam generator tubes. At the June 29th meeting, GPUN briefed the staff and consultants on qualification status of the explosive expansion tube repair technique to be used to repair defective tubes within the Upper Tube Sheet (UTS). Copies of GPUN's presentations and a list of attendees are enclosed.

Discussion

1. RCS Inspection Results

GPUN presented the results of their inspection of RCS components which was conducted in April and May 1982. A total of 22 different inspections and tests which involved over 1,000 selected components were conducted with no evidence of an intergranular stress corrosion (IGSC) problem. Prior to conducting the inspections and tests, all RCS materials were categorized as to their susceptability to IGSC and representative materials were selected for inspection and/or testing. Various Non Destructive Examination (NDE) techniques were employed including ECT, dye penetrant testing, radiograph testing, ultrasonic testing and video. Additionally, three components of materials considered highly susceptible to IGSC were destructively examined using metallographic techniques. Functional tests of incore detectors and reactor vessel vent valves were also conducted. No significant problems were found on any of the tests and inspections. The RCS inspection plan and results are documented in BAW 1727 dated April 16, 1982 and GPUN Technical Date Report No. 343 dated June 11, 1982.

The primary repair criteria is to establish as low as reasonably achievable allowable primary to secondary leakage with a seal able to sustain with adequate margins, the design basis loads. The largest design basis axial load is achieved during a Main Steam Line Break (MSLB) where tensile loads may reach 3140 pounds.

Foster Wheeler, under direction of GPUN and B&W, will conduct the expansions. Qualification testing conducted to date indicates that an 8 inch expandion is able to withstand pullout loads greater than 4500 pounds. It is highly possible that the expansions will be conducted in two steps; one detonation to expand the tube and the other to tightly seal the tube against the UTS. Additionally, it is presently planned that the expansions will be done one row in the OTSG at a time. Additional testing for pullout strength, effect of neighboring detonations, effect of corrosion, leak rate testing and thermal cycling testing is ongoing, but the interim results are encouraging. GPUN has also planned a full scale test at the B&W OTSG in Mount Vernon, Indiana which will be conducted in late July. Assuming no major delays, it is estimated that sufficient qualification testing will have been completed by mid August to permit commencement of repairs in the OTSG at that time. Under this schedule, GPU estimates that the OTSGs could be repaired and the plant ready for service in November 1982.

Richard Jacobs, Project Manager
Operating Reactors Branch #4
Division of Licensing

Enclosures:
1. List of attendees
2. GPU presentation

ORB#4:DL

MEETING SUMMARY DISTRIBUTION

Licensee: GPU Nuclear Corporation

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

Docket File
NRC PDR
L PDR
ORB#4 Rdg
TNovak
JStolz
Project Manager-RJacobs
Licensing Assistant-RIngram
OELD
Heltemes, AEOD
IE
SShowe (PWR) or CThayer (BWR), IE
Meeting Summary File-ORB#4
RFraley, ACRS-10
Program Support Branch

ORAB, Rm. 542
BGrimes, DEP
SSchwartz, DEP
SRamos, EPDB
FPagano, EPLB

Meeting Participants Fm. NRC:

HDenton
GLainas
RBosnak
CMcCracken
KWichman
RConte-Region I
HGray-Region I
EMurphy
RMartin
JRajan
MWilliams
CCheng
EBrown
CSchulten
WCollins
PWu

PGrant
MGarrington
SBajwa
LFrank
CSellers
HConrad
PMatthews

Enclosure 1

LIST OF ATTENDEES - MEETING WITH GPUN

JUNE 29, 1982

TMI-1 STEAM GENERATOR RECOVERY PROGRAM

NRC
HDenton
TNovak
GLainas
JStolz
RBosnak
CMcCracken*
RJacobs*
KWichman
RConte (Reg. 1)
HGray (Reg. 1)
EMurphy
RMartin
JRajan*
MWilliams
CCheng*
EBrown
CSchulten*
WCollins
PWu*
PGrant
MGarrington
SBajwa*
LFrank
CSellers**
HConrad**
PMatthews**

GPUN
RWilson
DSlear*
EWallace
FGiacobbe*
JColitz
DBedell
MGraham*
RNeidig
WWilkerson**
NKazanas**

NRC Concultants
JWeeks, BNL*
CDodd, ORNL
CAverbacn, BNL
RNewman, BNL*
RBandy, BNL
D. Van Rooney, BNL*
RDillon, PNL*
TShook, FRC*
EMucha, FRC*
ULuk, FRC*
LLeonard, FRC*
CDavey, FRC*

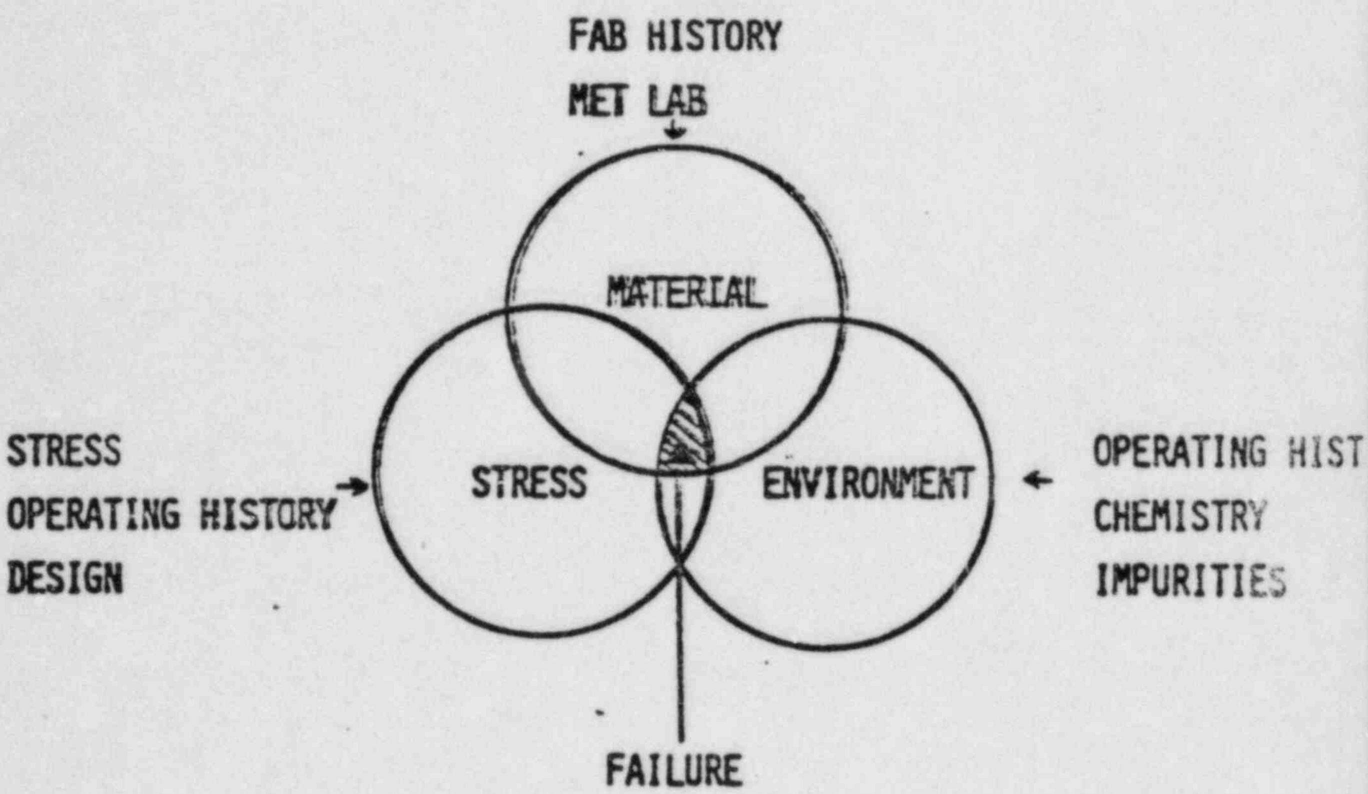
GPUN Consultants
JPearsen, B&W
RKosiba, B&W
RCoe, B&W
BBarrat, FWEA
SWeems, MPR, Assistant
HBehnke, B&W**

Other
AManik, PANE
MLewis
LConner, NRC Calendar
JBergan, EPRI**

* Also attended June 28, 1982 meeting
** Only attended June 28, 1982 meeting

TMI-1 STEAM GENERATORS

GENERAL INTERGRANULAR STRESS CORROSION CRACKING



MUST EXPLAIN - TIMING OF CRACKING
- MATERIAL FAILURE MODE, I.E., INTERGRANULAR
- CONTAMINANT SOURCE FORM
- AXIAL/RADIAL CRACK DISTRIBUTION

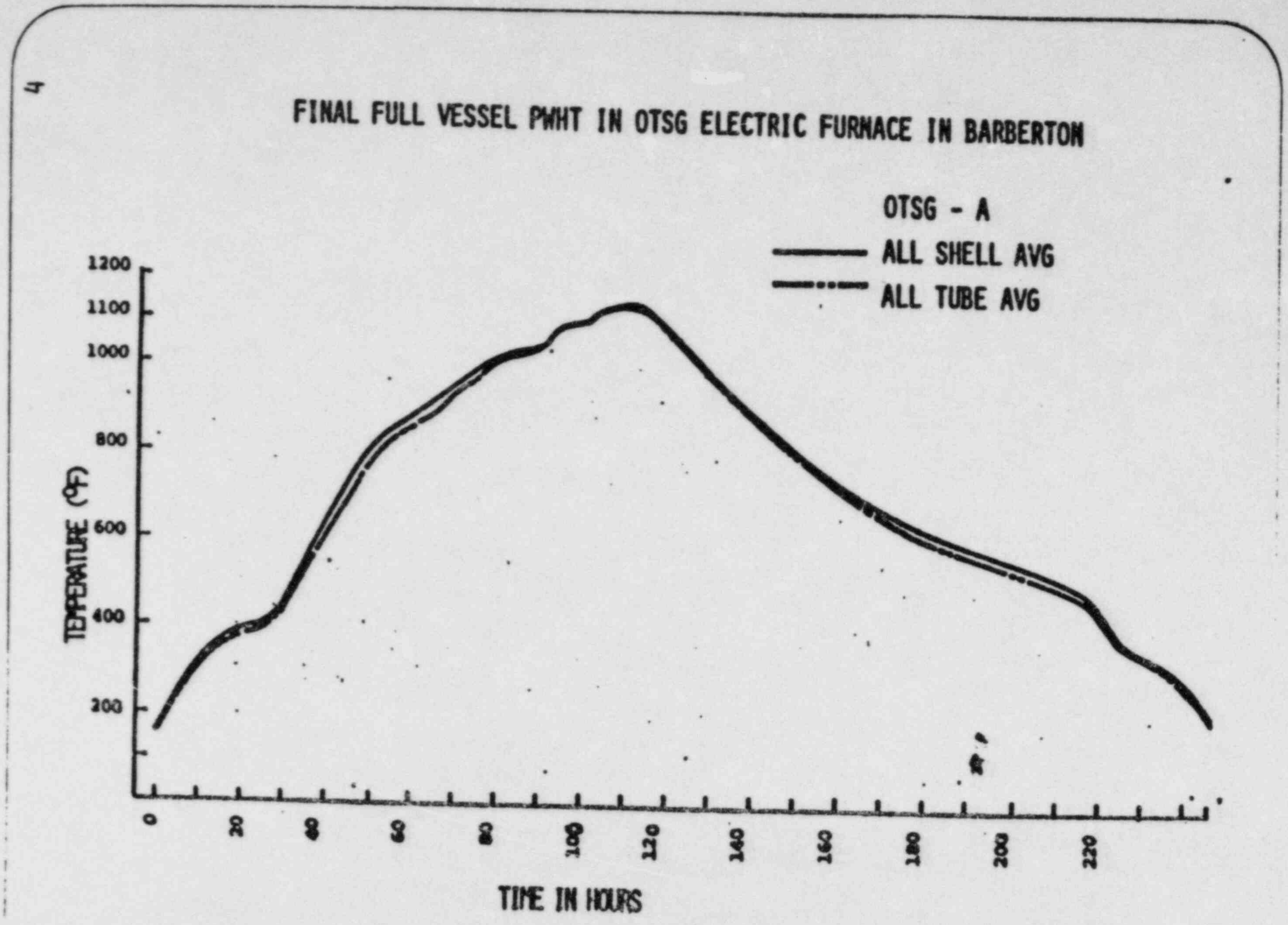
TMI-1 OTSG TUBE MAKING PROCESS

- ALL TUBES MANUFACTURED BY PATCO
  - NO FORMAL PATCO RECORDS AVAILABLE
  - GPUN/B&W REPS VISIT TO PATCO (1982)
  - MPR TRIP REPORT TO PATCO (1968)
  - GPUN/B&W REPS VISIT B&W TUBULAR PRODUCTS DIVISION (1982)
- BASE MATERIAL SUPPLIED BY B&W TUBULAR PRODUCTS
- GENERAL PROCESS
  - BASE MATERIAL - ROUND HOLLOW BARS ~2" OD, ~0.088" WALL
  - ONE COLD DRAW THRU ROCKER TYPE REDUCER DIE TO ~1¼" OD, ~0.088" WALL
  - FOUR COLD DRAWS OVER FLOATING MANDRELS THRU A DIE TO ~0.625" OD, ~0.034" WALL
  - TUBES CLEANED, ANNEALED IN HYDROGEN ENVIRONMENT IN TWO ZONE FURNACE (1800°F AND 2000°F); 40 - 50 INCH/MIN TRAVEL
  - TUBES STRAIGHTENED AND CENTERLESS GROUND - MINIMUM WALL IS 0.034"
- OTHER DATA
  - EXTREME CARE TO PREVENT CONTAMINANT CONTACT WITH TUBE
  - NDE TESTS INCLUDED UT, PT, EC, HYDRO, METAL COMPARATOR CHECK
  - INTERMEDIATE CLEANING, ANNEALING AFTER EACH DRAWING OPERATION, IN 1750° BRIGHT ANNEALING FURNACE AT 1750°F, 18 INCH/MIN TRAVEL

~80%

4/23/82

4


FINAL FULL VESSEL PWHT IN OTSG ELECTRIC FURNACE IN BARBERTON
OTSG - A
ALL SHELL AVG
ALL TUBE AVG
TEMPERATURE (°F)
1200
1100
1000
800
600
400
200
0
20
40
60
80
100
120
140
160
180
200
220
TIME IN HOURS

RESULTS OF ANALYSIS OF STRESS RELIEF DATA

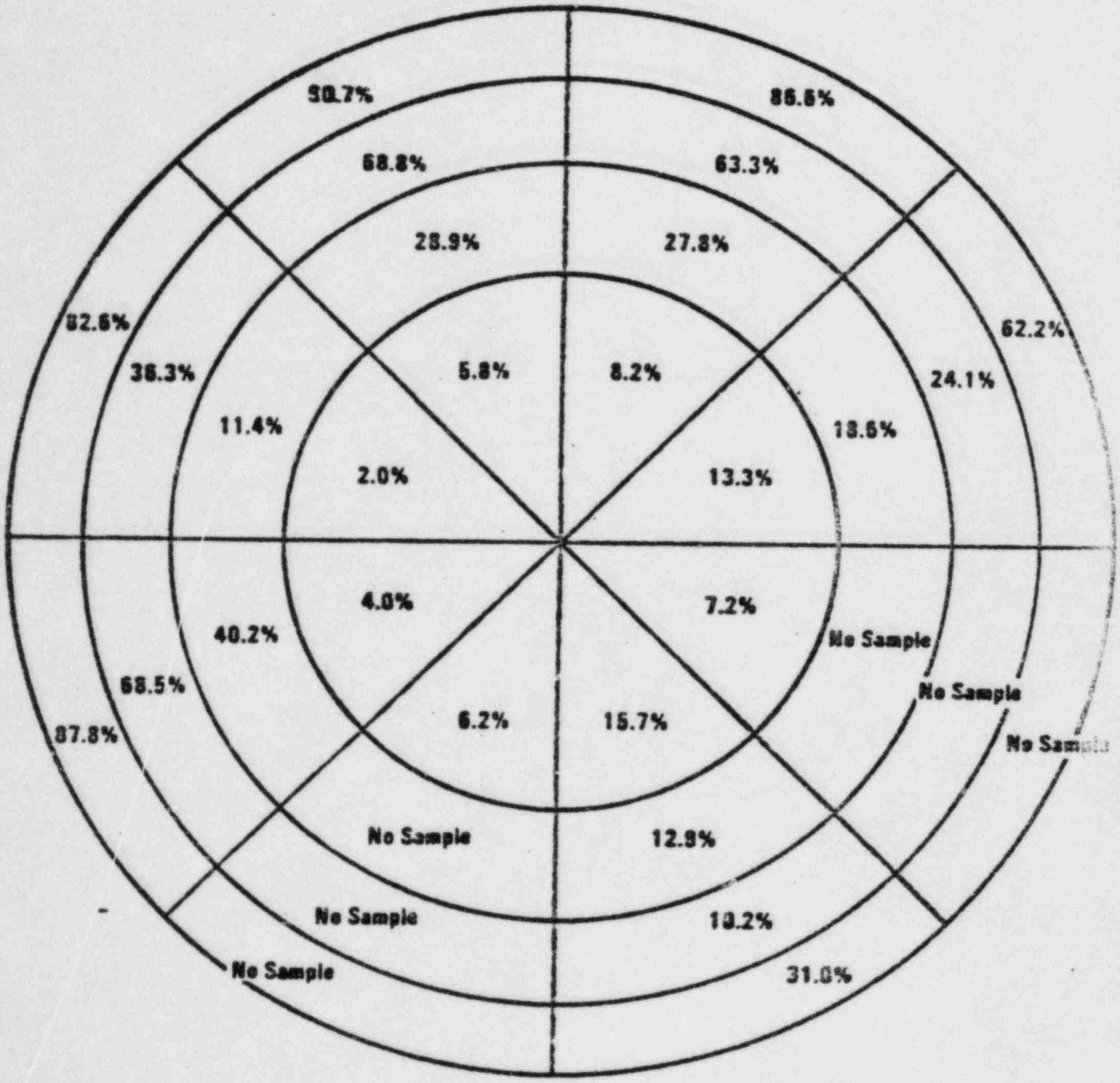
- A-OTSG STRESS RELIEF CYCLE WAS LONGER DUE TO SLOWER HEATUP RATES. HOLD TIMES AND COOLDOWN RATES WERE VIRTUALLY IDENTICAL BETWEEN OTSGs.

- ONLY SLIGHT VARIATIONS EXISTED BETWEEN UPPER AND LOWER TUBESHEETS AND FROM CENTER TO OUTER PERIPHERY OF A PARTICULAR TUBESHEET.

- BASED ON COMPARISON WITH EPRI WORK, ALL TUBES ARE EXPECTED TO BE UNIFORMLY SEVERELY SENSITIZED.

- PREDICTION OF UNIFORM SEVERE SENSITIZATION CORRELATES WITH RESULTS OF ACTUAL TESTS (STEM, EPR, MODIFIED HUEY).

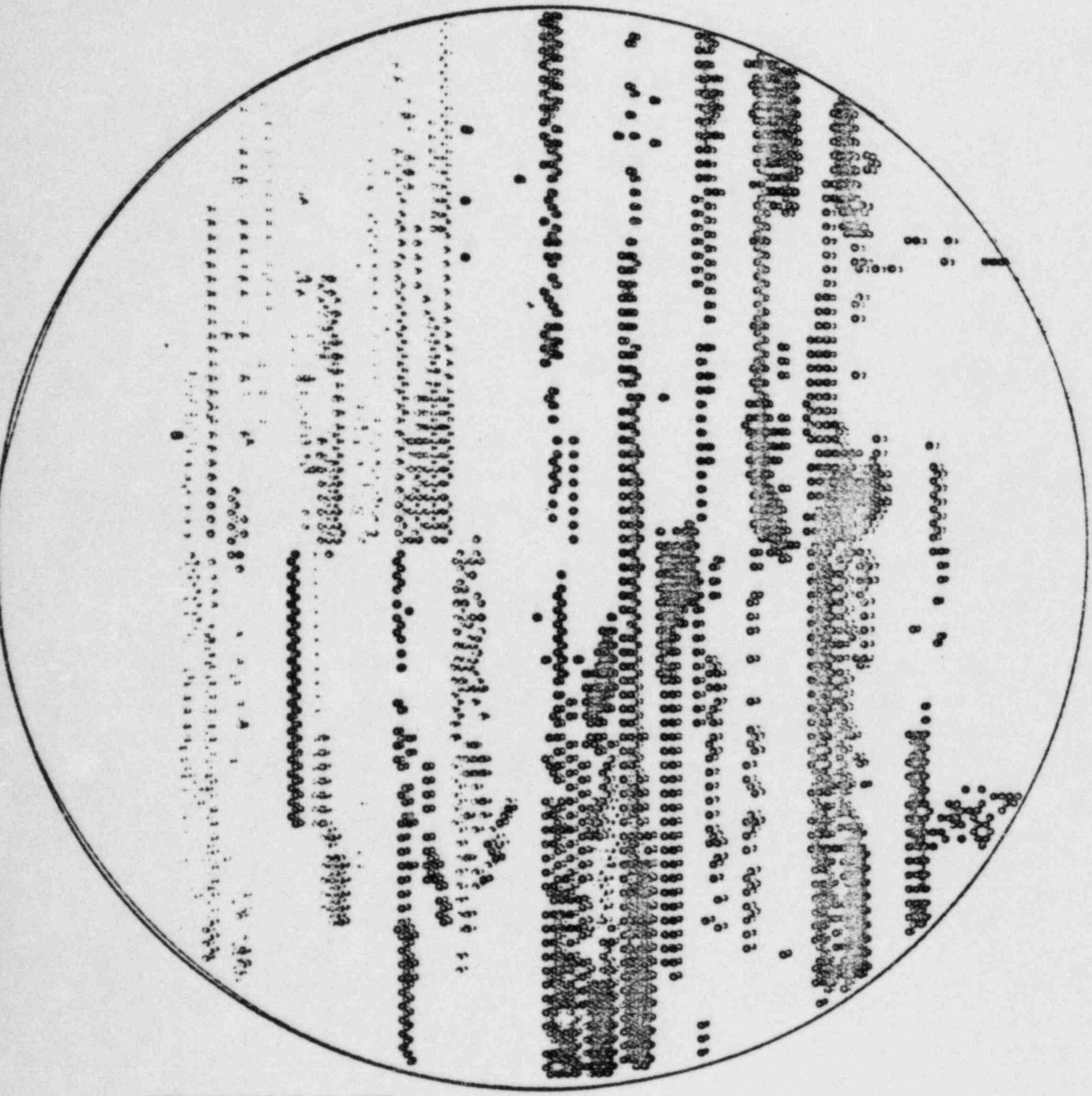
Three Mile Island Nuclear Generating Station Unit 1 Steam Generator A



4 X 1 Eddy Current Results
Percent of Tubes with Defects

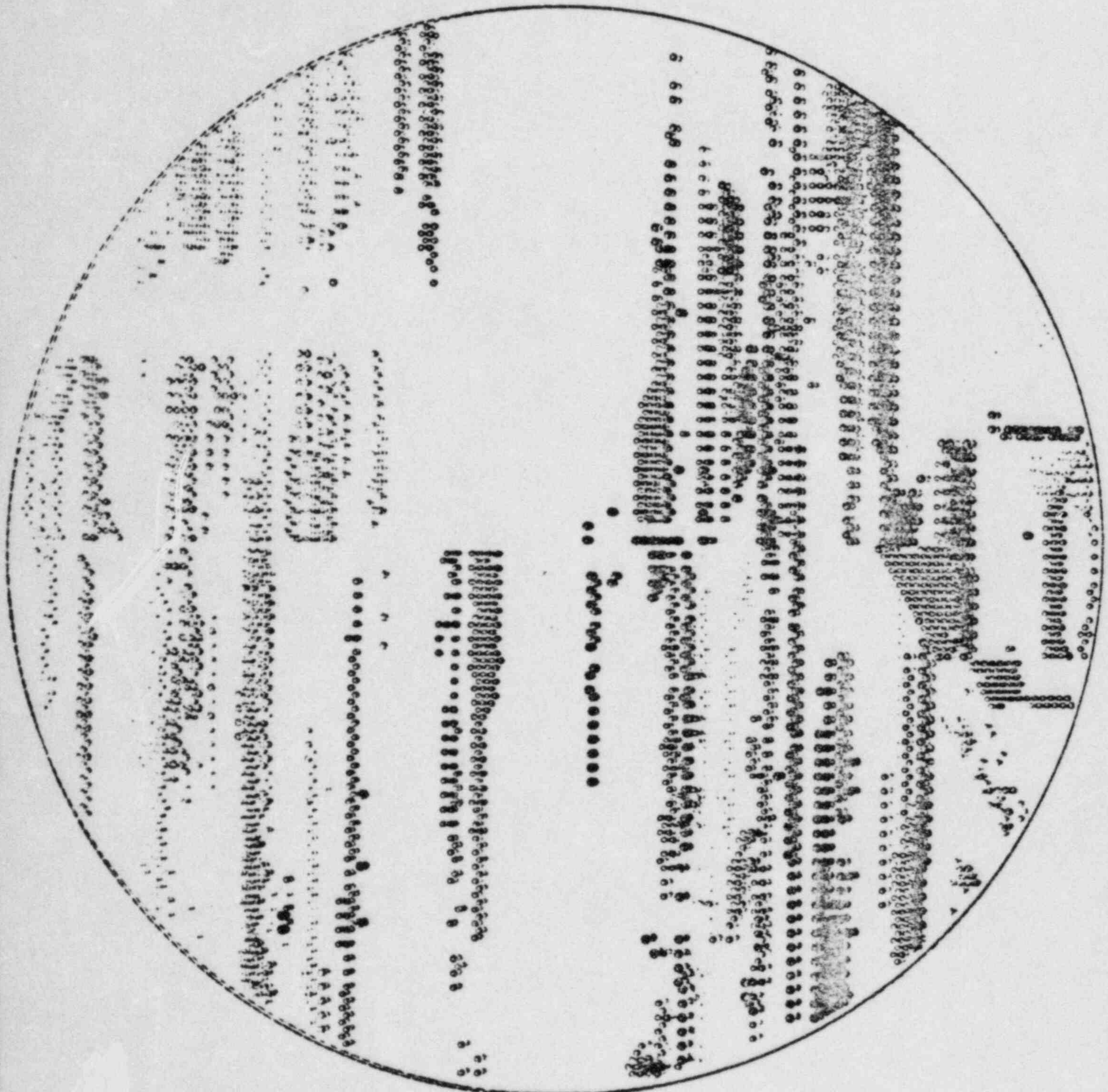
... - M 2345 | 741 | 15.0
Green - M 2352 | 445 | 4.1
Red - M 2562 | 326 | 5.2

THREE MILE ISLAND NUCLEAR
GENERATING STATION
UNIT 1 STEAM GENERATOR A



TUBE LOCATIONS OF ALL TUBES
FOR TUBE HEAT NUMBERS
M2328
M2346
[illegible]2
[illegible]

THREE MILE ISLAND NUCLEAR
GENERATING STATION
UNIT 1 STEAM GENERATOR B



TUBE LOCATIONS OF ALL TUBES
FOR TUBE HEAT NUMBERS
M2788
M2712
M2388
M2328

HEAT VS DEFECT CORRELATION
SUMMARY

- o TUBE FAILURES ARE ASSOCIATED WITH SPECIFIC LOCATIONS IN THE GENERATOR NOT HEAT RELATIONSHIPS.
- o THE DEFECT PATTERNS IN THE TWO GENERATORS APPEAR TO BE DIFFERENT AND THIS WILL NEED TO BE EXPLAINED BY A PARAMETER OTHER THAN HEAT NUMBER.
- o HEATS OF MATERIAL EXIST WHICH HAVE HIGH DEFECT FREQUENCIES IN BAD AREAS AND THE SAME HEATS WILL HAVE LOW DEFECT FREQUENCIES IN GOOD AREAS.

TUBE ANALYSIS SUMMARY

ROUND 1 & 2

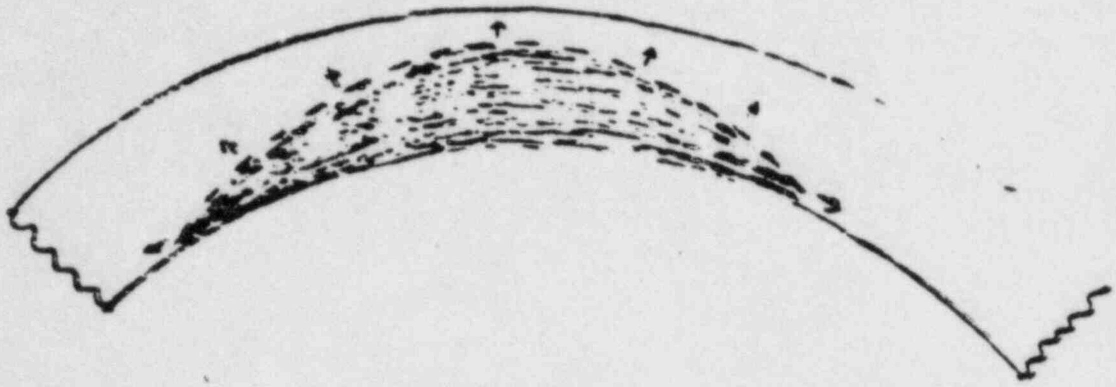
ANALYSIS	NO. OF TUBES	NO. OF SAMPLES
METALLOGRAPHIC	8	38
BEND TEST	15	19
SCANNING ELECTRON MICROSCOPY (SEM)	15	15
ENERGY DISPERSIVE X-RAY ANALYSIS (EDAX)	15	15
AUGER ELECTRON SPECTROSCOPY (AES)	5	7
ELECTRON SPECTROSCOPY FOR CHEMICAL ANALYSIS (ESCA)	5	6
SCANNING TRANSMISSION ELECTRON MICROSCOPY (STEM)	5	7
ELECTROCHEMICAL POTENTIOKINETIC REACTIVATION (EPR)	4	5
HUEY TEST	1	3
SECONDARY ION MASS SPECTROSCOPY (SIMS)	2	3
ELECTRON DIFFRACTION	1	1
TRANSMISSION ELECTRON MICROSCOPY (TEM)	2	2
TENSILE TEST	3	3
RESIDUAL STRESS	1	1
SODIUM AZIDE SPOT TEST	3	5

SUMMARY OF FAILURE ANALYSIS

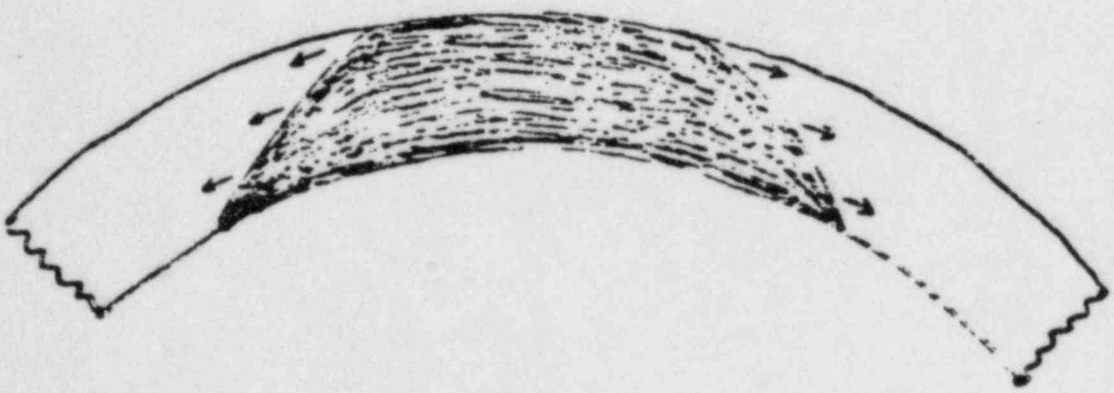
- ALL CRACKS ARE SULFUR INDUCED STRESS ASSISTED INTERGRANULAR CORROSION WITH INITIATION ON THE ID SURFACE
- EDDY CURRENT EXAMINATION HAS BEEN A RELIABLE INDICATOR OF CRACK LOCATION
- INCIPIENT CRACKS HAVE NOT BEEN DETECTED IN CLEAN SECTIONS (NO E.C. INDICATIONS) OF TUBING BY VISUAL AND DESTRUCTIVE EXAMINATION
- SMALL AREAS OF INTERGRANULAR CORROSION SEVERAL GRAINS DEEP HAVE BEEN OBSERVED ON THE ID AND OD SURFACES AT RANDOM LOCATIONS
- CARBON APPEARS AS THE MAJOR CONTAMINANT ON FRACTURE SURFACES. SULFUR AND CHLORINE ARE PRESENT AS SECONDARY CONTAMINANTS
- RESIDUAL STRESS MEASUREMENTS SHOW A PEAK AT THE ROLL TRANSITION AND A UNIFORM DISTRIBUTION THROUGH THE ROLL REGION.
- CHROMIUM LEVELS IN THE GRAIN BOUNDARIES VARY FROM 8 WT. % TO 20 WT. % INDICATING SOME AREAS ARE HIGHLY SENSITIZED
- THE INCONEL MICROSTRUCTURE APPEARS TYPICAL FOR STEAM GENERATOR TUBING WITH DISCRETE CHROMIUM CARBIDE PARTICLES IN THE GRAIN BOUNDARIES
- MECHANICAL TESTING OF UNCRACKED TUBES SHOW THAT THE MATERIAL EXCEEDS MINIMUM SPECIFICATION REQUIREMENTS
- NO RELATIONSHIP HAS BEEN ESTABLISHED BETWEEN MATERIAL HEATS AND DEFECTIVE TUBING

FIGURE VI - 1

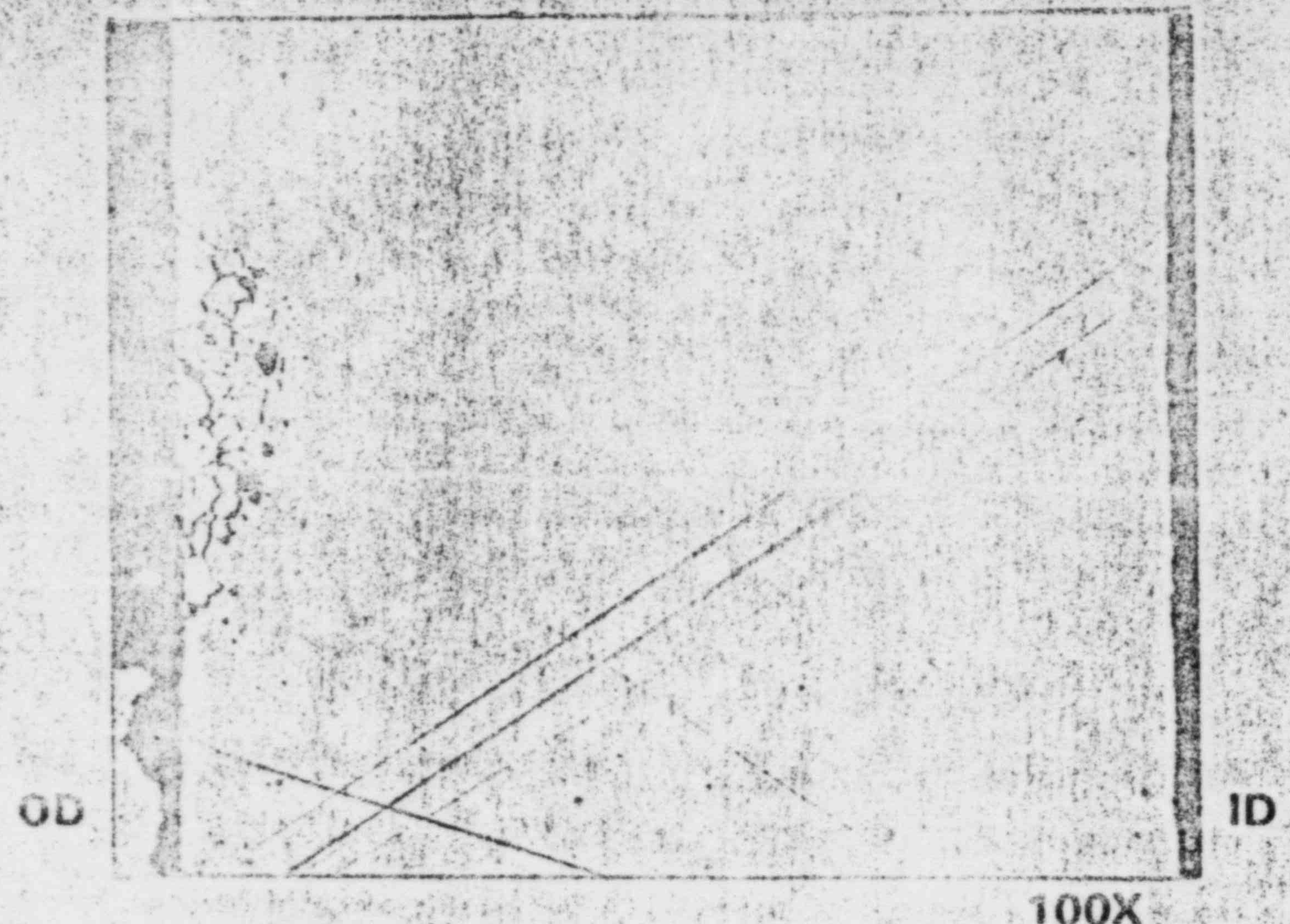
SKETCH OF TYPICAL CRACK SHAPES



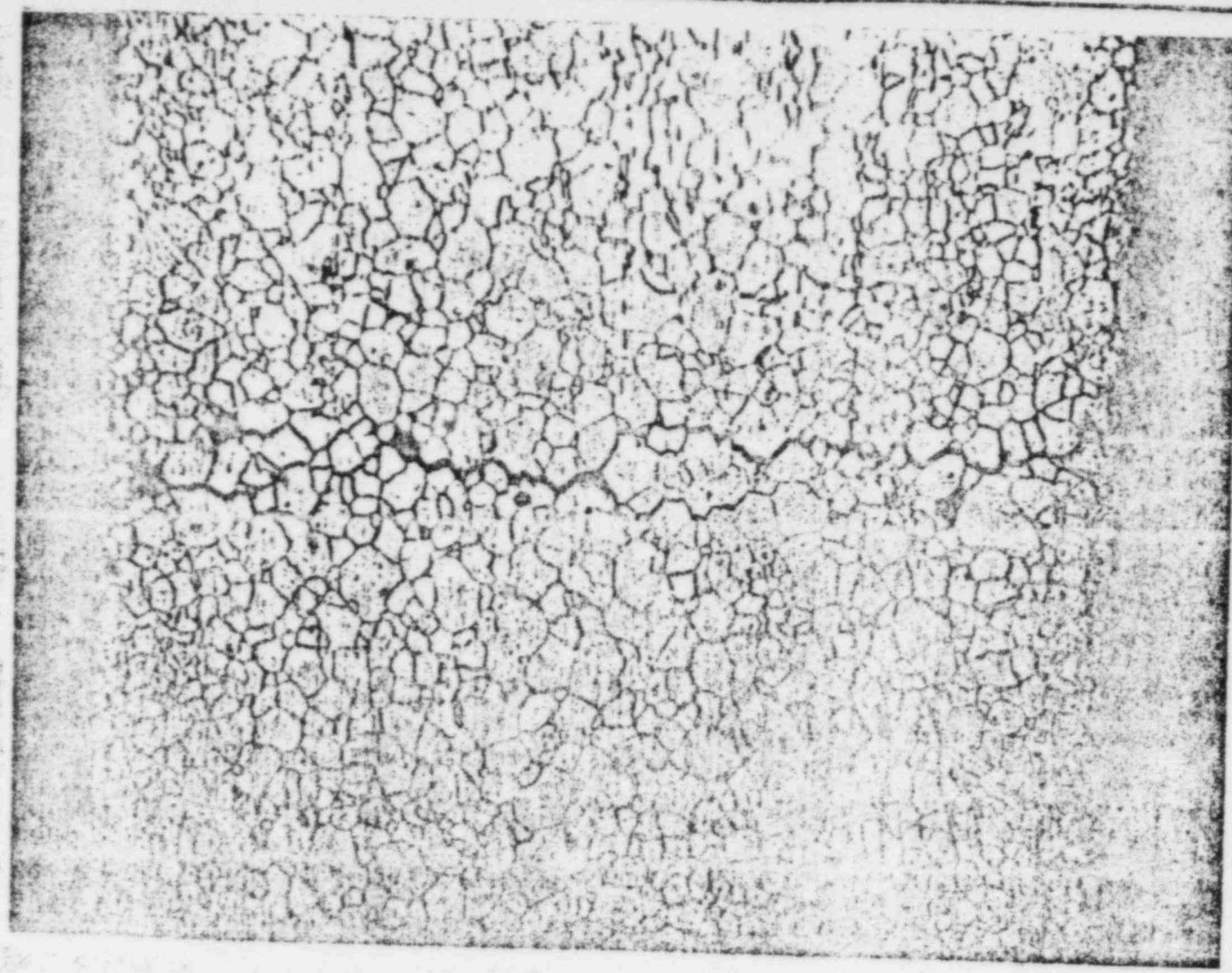
a) Advancing crack not yet through wall.



b) 100% through-wall crack continuing to grow.

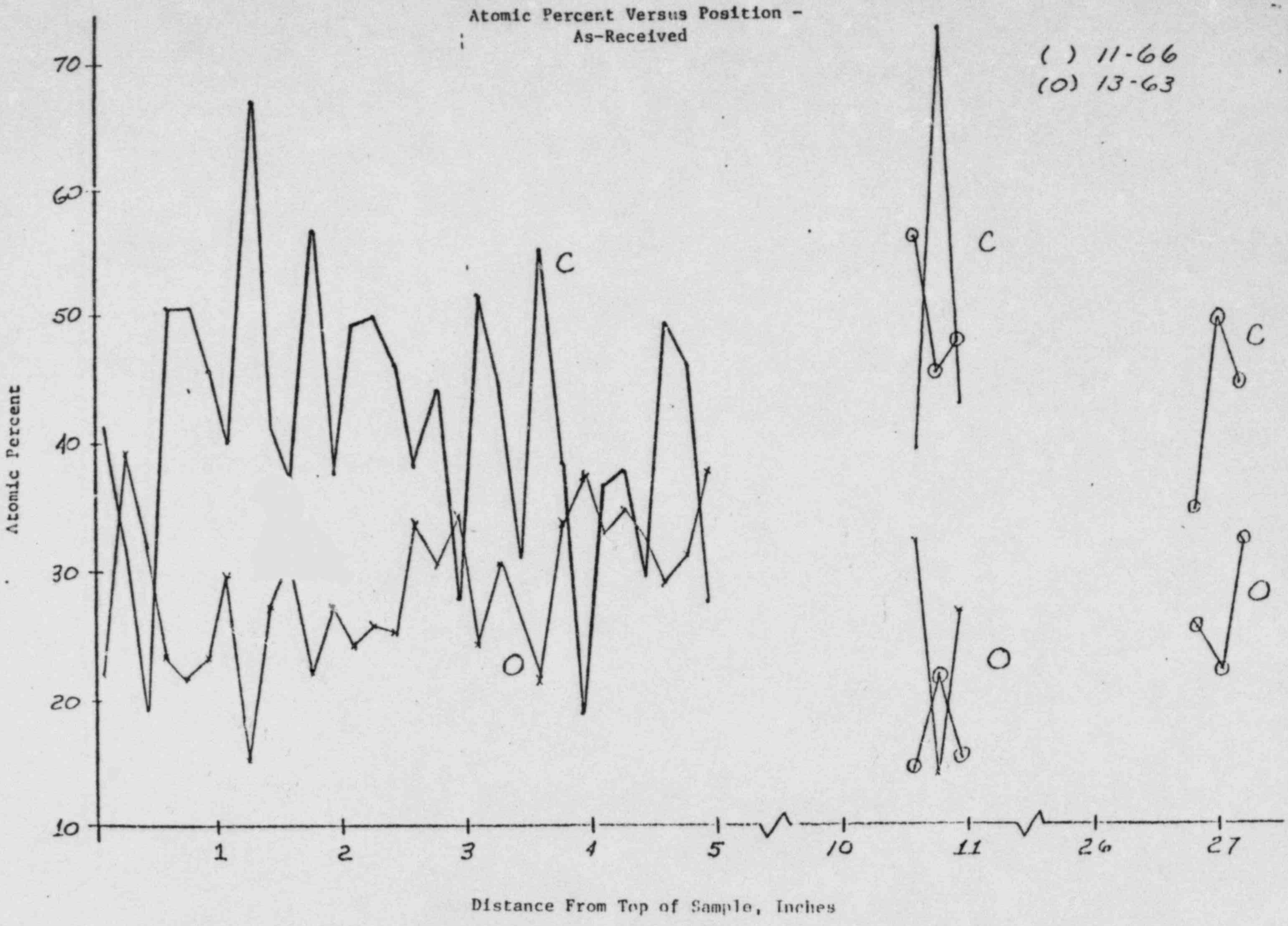


PHOTOMICROGRAPH OF IGA ON
SPECIMEN G FROM TUBE A-146-8



PHOTOMICROGRAPH OF THROUGH WALL IGC IN SPECIMEN C FROM TUBE A-146-6

Atomic Percent Versus Position -
As-Received



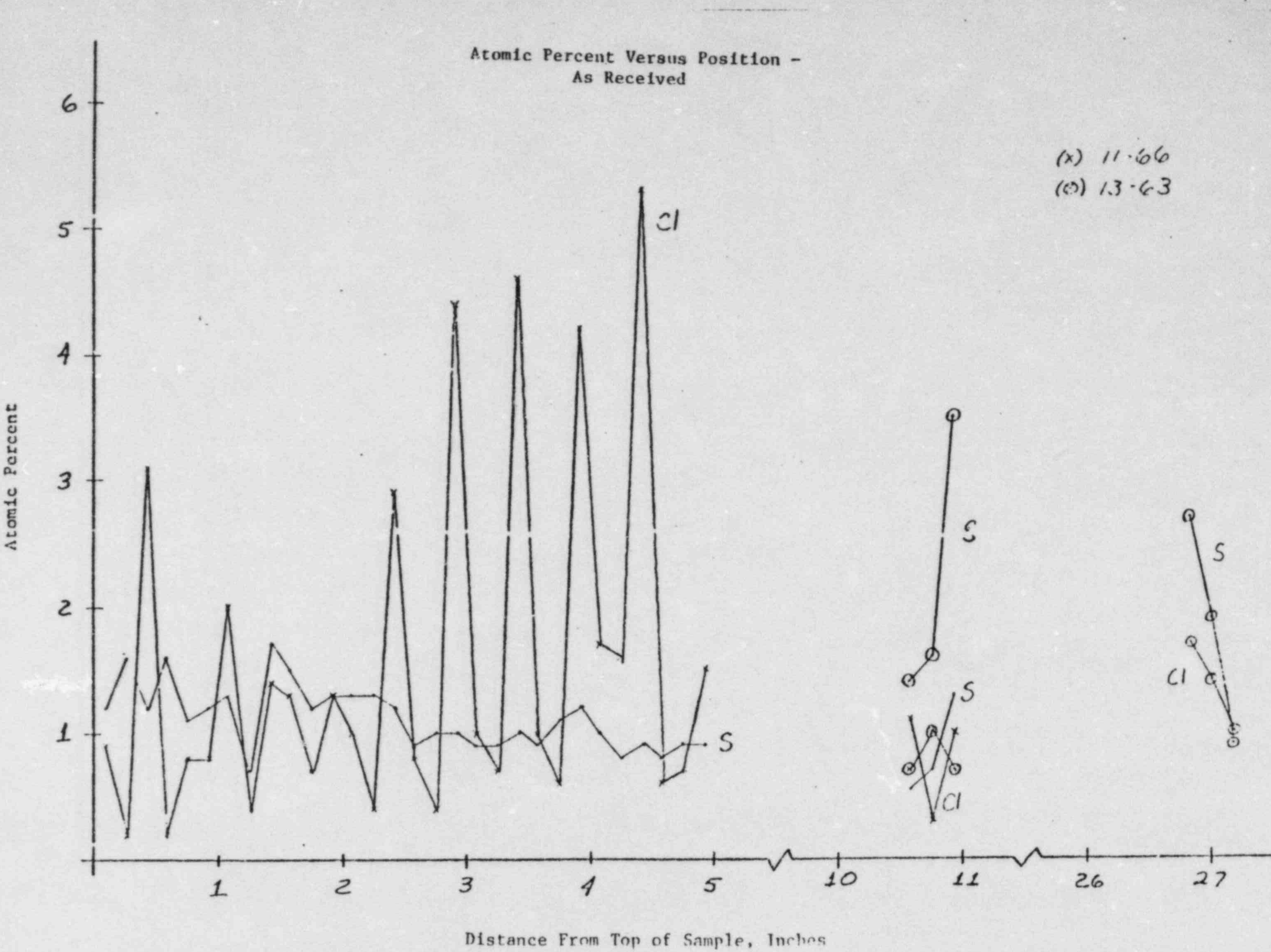

Atomic Percent Versus Position -
As Received
Atomic Percent
6
5
4
3
2
1
Cl
S
(x) 11·66
(⊙) 13·63
1
2
3
4
5
10
11
26
27
Distance From Top of Sample, Inches

TABLE 18. ESCA BINDING ENERGIES AND STATES OF ELEMENTS ON SPECIMEN C FROM TUBE A71-126

Depth Sputtered, Å	Ni	Fe	Cr	C	S	Ratio $S^{-2}/SO_4^{=}$
None	856.0 $Ni(OH)_2$	711.0 FeOOH	577.0 Cr_2O_3	285.0 C	169.0 SO_4^{-2}	0
30	856.0 $Ni(OH)_2$	711.0 FeOOH	577.0 Cr_2O_3	285.0 C	169.0 SO_4^{-2} 162.0 S^{-2}	1.0
630	852.0 Ni	710.0 FeO	577.0 Cr_2O_3	285.0 C	169.0 SO_4^{-2} 162.0 S^{-2}	2.0
1230	852.0 Ni	710.0 FeO	577.0 Cr_2O_3		169.0 SO_4^{-2} 162.0 S^{-2}	2.0
2430	852.0 Ni 855.0 NiO	710.0 FeO	577.0 Cr_2O_3		162.0 S^{-2}	> 10
3630	852.0 Ni 855.0 NiO	710.0 FeO	577.0 Cr_2O_3			> 10

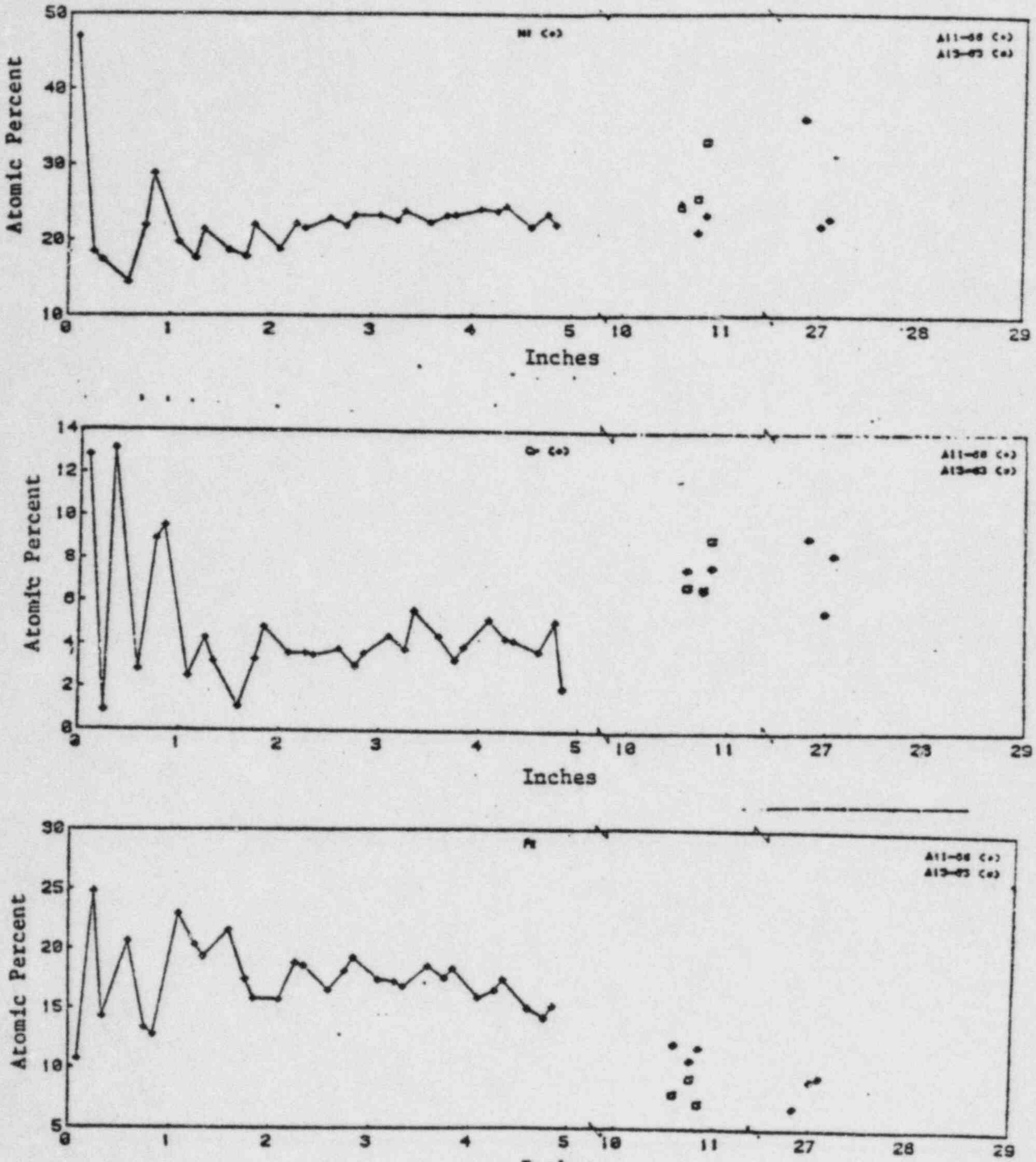


Figure 2.8.1 Concentrations of Nickel, Chromium, and Iron as a Function of Distance From the Top

O. D. OBSERVATIONS

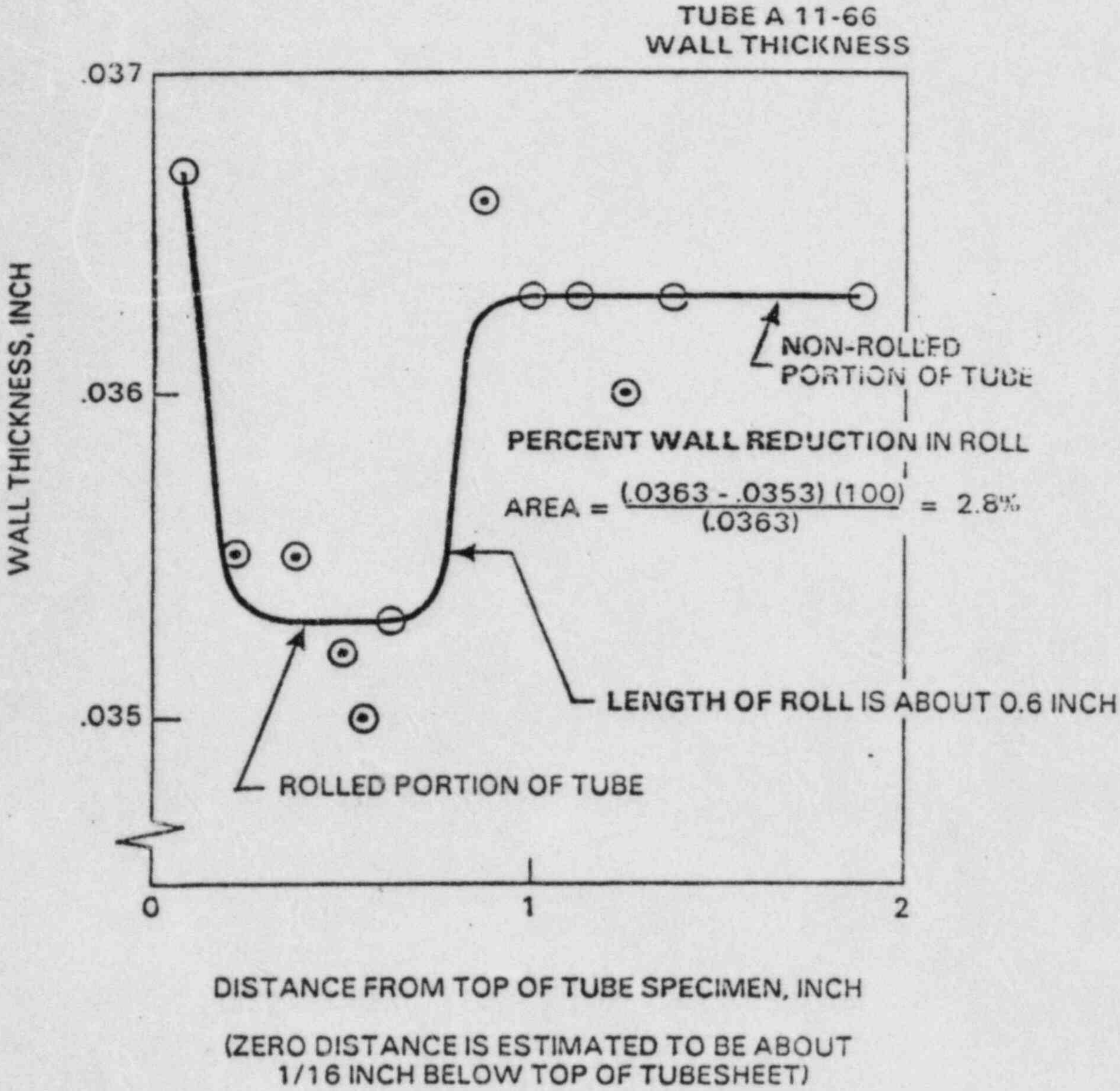
- O. D. DEPOSITS DO NOT COVER THE ENTIRE TUBE SURFACE AND ARE OF COLORS THAT MAY BE NICKEL-SULFUR COMPOUNDS.
- NO INTERGRANULAR CRACKS HAVE BEEN FOUND ON THE O. D. SURFACE
- SMALL AREAS OF INTERGRANULAR ATTACK A FEW GRAINS DEEP HAVE BEEN FOUND ONLY IN SCATTERED LOCATIONS.

STEM Analysis

Tube No.	Heat No.	% C	Axial Location, In[1]	Condition	Basis for Measurement	Results: % Cr Near Grain Boundary	Results: Evaluation
B-33-30	M2867	0.031	8.5	As-Removed	After Service		Severely
B-33-30	M2867	.031	34.5	"	"		Sensitized
A-133-74	M2408	.035	6.5	"	"		-- Carbides
A-133-74	M2408	.035	0.1	"	"		Nearly
B-11-23	M2320	.055	7.0	"	"		Continuous
Archive Tube	M2320	.044-.055		Mill Annealed	As-Received	13-15%	Not Sensitized
"	"	.044-.055		M. A. & Stress Relieved 1150° F, 18 hrs	As-Fabricated	9%	Severely Sensitized
B-111-62	M2560	.045-.047	289	As-Removed	After Service		Specimens not
A-78-32	M2348	.029	12.5	"	"		yet cut from tube

Notes: 1 - Axial location from upper tubesheet face

FIGURE VIII- 2



MECHANICAL TESTING RESULTS

TUBE NO.	A-71-126	B-33-30	A-13-63[1]	SPECIFIED (ASTM B-163)
HEAT NO.	M1617	M2867	M2408	
AXIAL LOCATION	60 7/16 - 68 11/16"	33 1/4 - 41 3/4"	2 5/16 - 10 7/16"	
T. S.	101,000 PSI	101,000 PSI	59,300 PSI[2]	80,000 PSI
Y. S.	53,000 PSI	55,000 PSI	50,700 PSI[2]	35,000 PSI
ELONGATION		33%		30%
TENSILE LOAD		6989 LB.	3077 LB.	
YIELD LOAD		3306 LB.	2630 LB.	

NOTES: 1 - TUBE CONTAINED 95% 4V DEFECT IN MIDDLE OF AREA

2 - BASED ON 75% OF ORIGINAL CROSS SECTIONAL AREA

EDDY CURRENT CORRELATIONS - ROUND 1 & 2 (CONT.)

Location	Tube	Locations: EC-OTSG D	Locations: EC-OTSG A	Locations: EC-Lab	Bend Test Location
1/4 - RT (1.25-1.50)	A-12-62	1.0 RT	RT	1 3/8	1.50
	A-13-63		1.7	1.25	1.25
	A-62-8	1.0 RT	1.0 RT	1.25	1.25
	A-133-74	1.5	0.6		0.56 1.5
	B-10-29	1.0	NE		1.25
	B-8-25	RT, 1.5	NE	1.25, 1.5	1.25
	B-11-23	1, 1.75	NE	.75, 1.0	1.25
	A-25-93	RT	RT		ND
	A-88-11	RT	RT	1.25	1.25
	A-112-5	RT	RT	1.25	1.25
	A-71-126	RT	RT		ND
	A-16-69	RT	0.8 RT		.69 1.31
Total Category	12	15	11	9	12

Notes: NE - Not Examined

ND - Not Detected

EDDY CURRENT CORRELATIONS - ROUND 1 & 2 (CONT.)

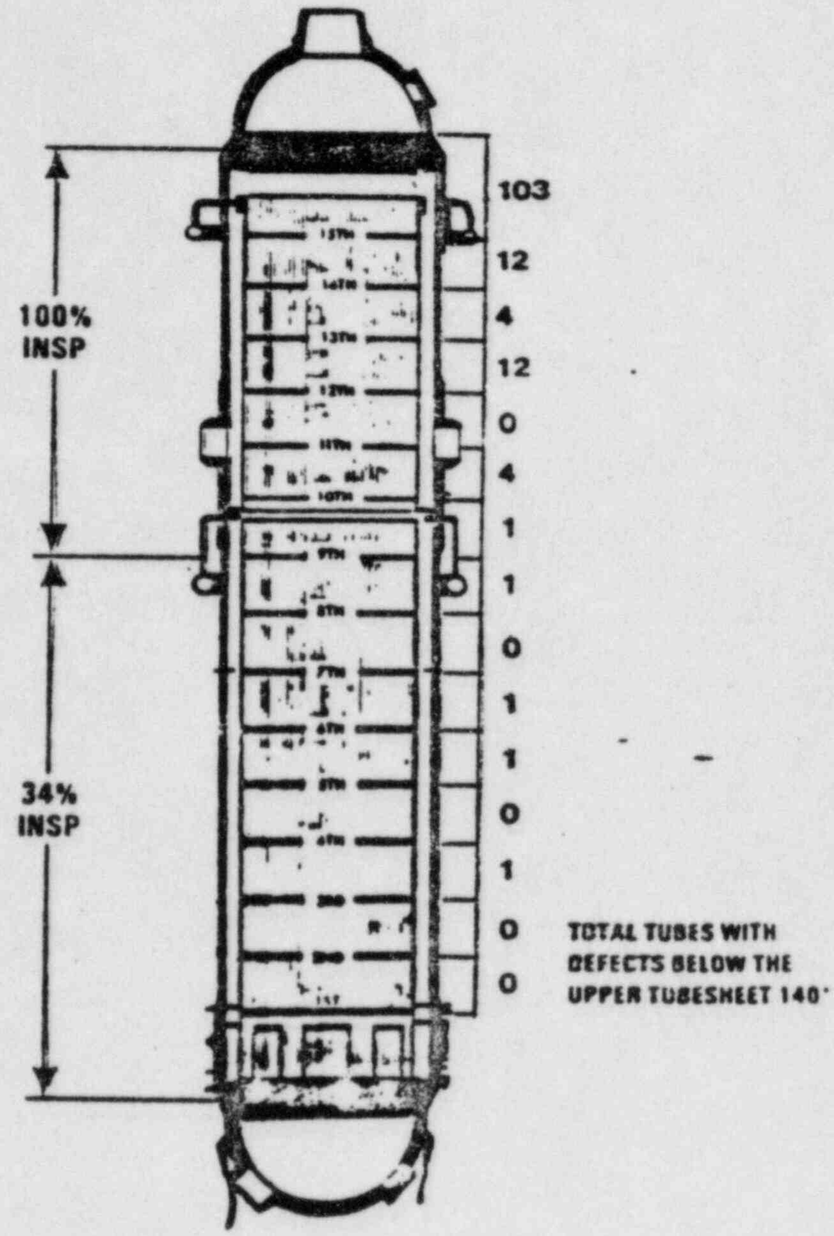
Location	Tube	Locations EC - OTSG D	A	EC-Lab	Bend/Visual Test
10-24	A-11-66	11.75	11.75	11.69	11.6
	B-33-30			23.3	Note 2
	A-146-6	10	10.3	10.25	10.5
Total Category	3	2	2	3	2

Note 2 - 10-30% defect call in laboratory EC - No Crack

Location	Tube	Locations EC- OTSG D	A	EC-Lab	Bend/Visual Test
Below UTS	A-71-126			53	Note 3
to	A-13-63	27	27	26.8	26.8
15th TSP	A-133-74	31	31	32	32
		32	32	33	33
Total Category	3	3	3	4	3

Note 3 - No crack - mechanical damage

OTSG-A Tubes
With Eddy-Current Defect Indications
Located Below Upper Tubesheet



*Most tubes contain more than one (1) defect indication. Lowest defect in tube exhibited, only.

6/7/82

SUMMARY - EDDY CURRENT vs. DEFECT CORRELATIONS

- In - OTSG eddy current reliability was low in the tube end and roll transition area (Since these tubes were removed, specific techniques to inspect this area have been developed).
- Below the roll transition, the in-field eddy current techniques detect actual defects with 100% reliability.
- No undetected defects have been found below the roll transition area during the laboratory investigation.
- Laboratory eddy current techniques tend to detect indications which are not revealed as defects on bending. This is in large measure due to a lack of I.D. defect calibration standards in the laboratory.
- Laboratory eddy current detects damage from the tube pulling operation.

TABLE VIII-1

Tube Residual Tensile Stress

Location	Axial	Circumferential
Weld HAZ	22,000	-22,000
Roll (center)	-10,000	-22,000
Roll Transition	22,000	22,000
Below Roll Transition	0 to 22,000(1)	0 to 22,000(1)

(1) Tube stresses below the roll transition are primarily due to the tube straightening manufacturing process and may vary considerably depending on the location within the tube.

TABLE VIII-2

Maximum Applied Load Tube Stresses (psi)

Location	Axial		Circumferential
	Center Tube	Outer Tube	
Weld HAZ (1)	0	0	10,000
Roll (center)(1)	3,000	6,000	0
Roll Transition	6,000	12,000	10,000
Below Roll Transition	6,000	12,000	10,000

(1) Roll joint axial load capability assumed to be at least 800 lb per B&W tests, which indicate a load capability in excess of this value.

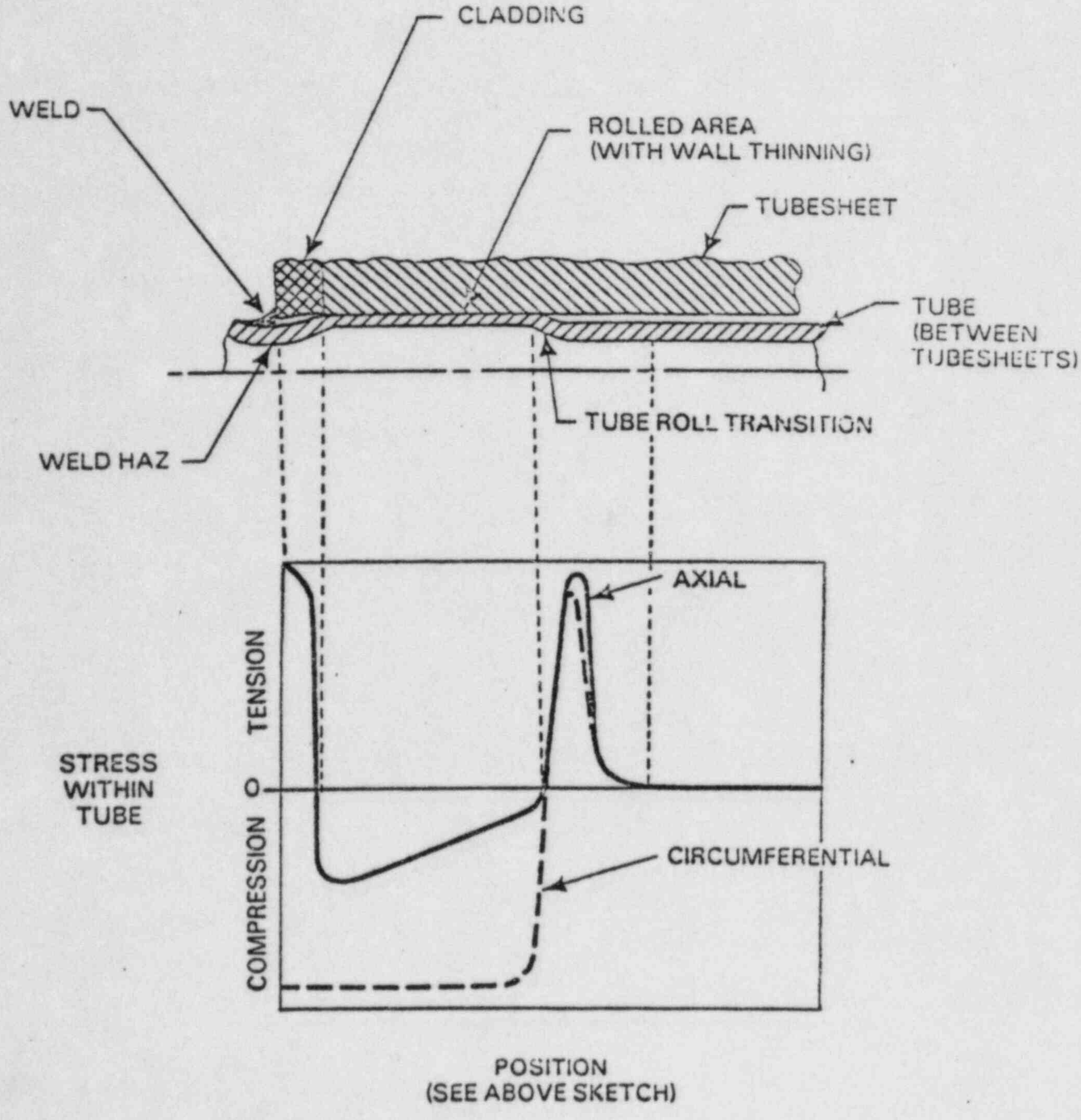
(2) These values are estimated; accurate values can be calculated if the detailed configuration of the joint can be determined.

TABLE VIII-3

Summary of Stresses Maximum Applied and Residual, (psi)

Location	Axial		Circumferential (2)
	Center Tube	Outer Tube	
Weld HAZ	22,000	22,000	-12,000
Roll (center)	-7,000	-4,000	-22,000
Roll Transition	28,000	34,000	32,000
Below Transition	6,000 to 28,000	12,000 to 34,000	10,000 to 32,000

FIGURE VIII-1



TUBE/TUBESHEET ROLLED/WELDED JOINT
ESTIMATED DISTRIBUTION OF TUBE RESIDUAL STRESSES

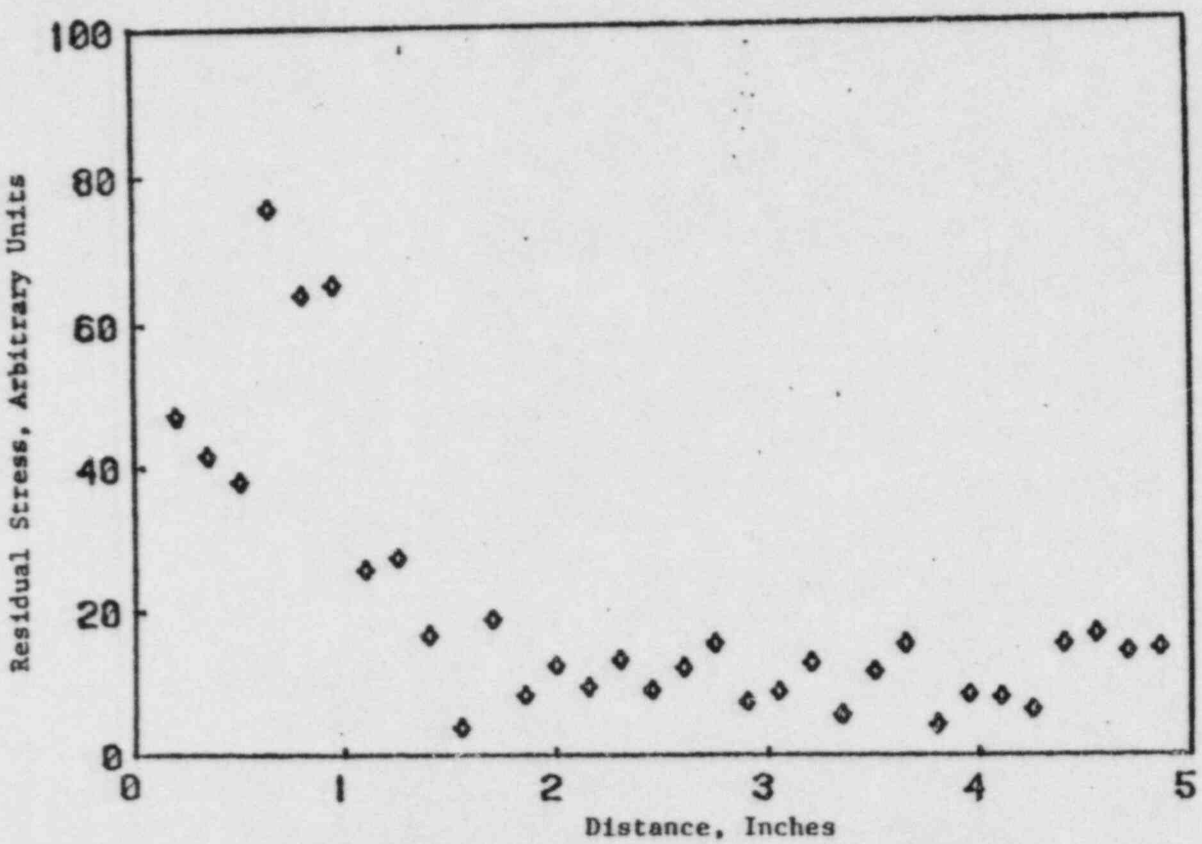


Figure 2.15.1 "Residual Stress" as a Function of Distance from the Top of A11-66

INTENDED INVESTIGATION OF 3RD ROUND TUBE SAMPLES

1) CHECK SULFUR REMOVAL EFFICIENCY BY CHEMICAL CLEANING.
2) CHECK FOR GENERAL IGA ON INSIDE SURFACE.
3) CHECK FOR IGA ON OUTSIDE SURFACE.
4) ANALYZE I.D. DEPOSIT BY WET CHEMISTRY METHODS.
5) VERIFY EDDY CURRENT RESULTS BY EXTENSIVE CUTTING AND BENDING.

ITEMS TO BE RESOLVED

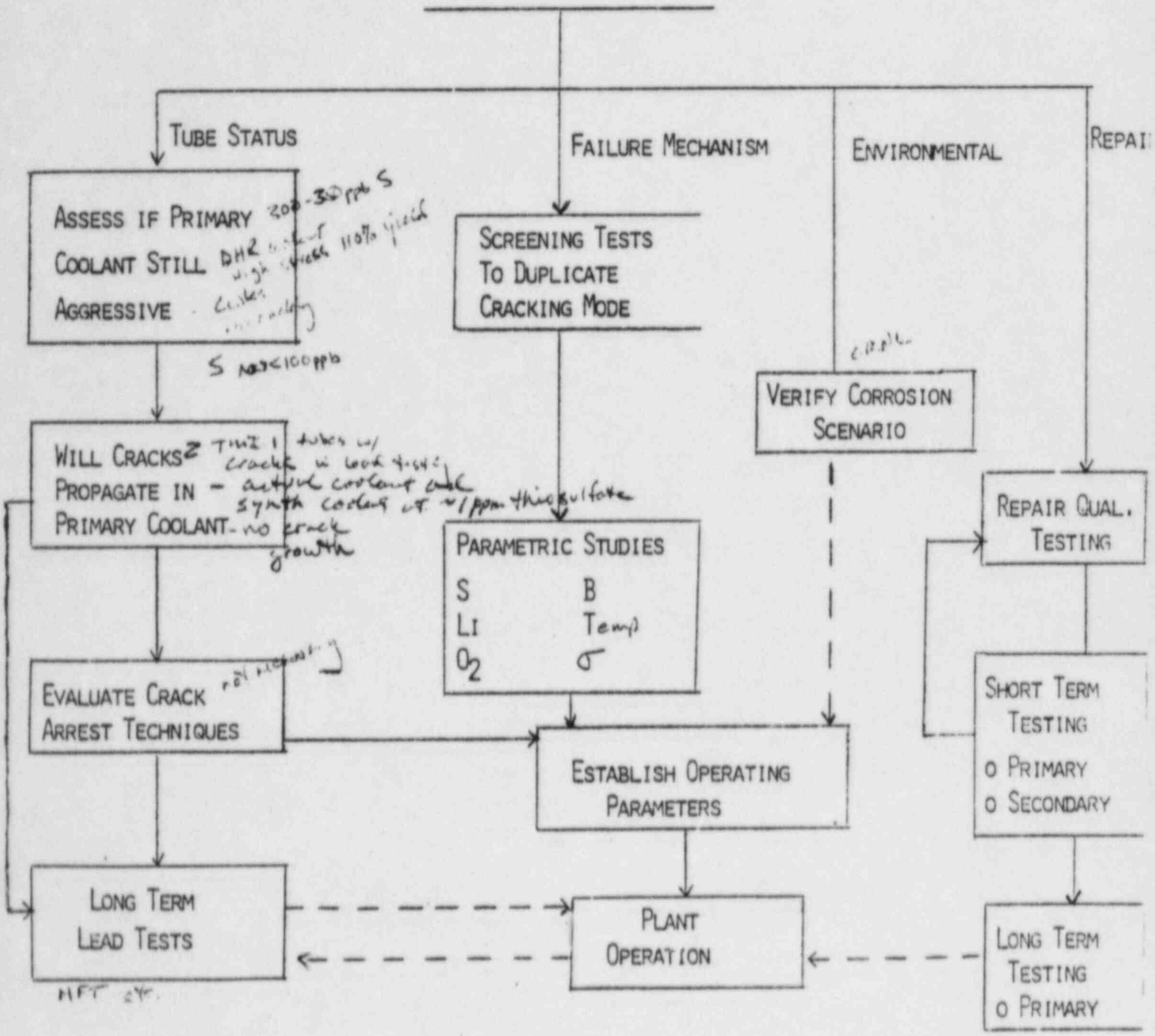
1) PRESENCE OF IGA ON O.D. OF TUBES
2) PRESENCE AND EXTENT OF O.D. "DRY-OUT" DEPOSITS.
3) FORM OF CARBON IN THE SURFACE FILMS.
4) FORM OF NICKEL AND SULFUR AND THE NATURE OF THEIR ASSOCIATION IN THE SURFACE FILMS.
5) CORRELATION OF STANDARD DIFFERENTIAL AND 4 X 1 ABSOLUTE EDDY CURRENT TECHNIQUES.

THIRD ROUND TUBE REMOVAL

Tube No.	Reason	Pull to TSP
A-24-94	MULTIPLE DEFECTS	15
A-78-32	BAD TUBE/GOOD AREA	15
A-111-13	VERIFY EDDY CURRENT	10
A-37-29	LOW LEVEL DEFECTS	9
B-16-22	LIP CRACK, GOOD TUBE/BAD AREA	15
B-27-47	GOOD TUBE/BAD AREA	15
B-34-19	INCOMPLETE EXIT SIGNAL	15
B-94-27	LOW LEVEL DEFECTS	10
B-111-62	GOOD TUBE/GOOD AREA	9
B-113-62	BAD TUBE/GOOD AREA	15

CORROSION TEST PROGRAM

OTSG RECOVERY



TUBE EXPANSION QUALIFICATION

CORROSION TESTING - SHORT TERM

- ELECTROCHEMICAL CORROSION TEST TO ASSESS EFFECT OF RESIDUAL STRESS FROM EXPLOSIVE EXPANSION

A. - INCONEL TUBE/INCONEL TUBESHEET SINGLE TUBE MOCKUP
- 10% NAOH SOLUTION
- 550° F TEMPERATURE
- POLARIZE AT CRACKING POTENTIAL
- TEST UNTIL CRACKING IS OBSERVED OR 5 DAYS MAXIMUM

B. - INCONEL TUBE/INCONEL TUBESHEET SINGLE TUBE MOCKUP
- 1 PPM THIOSULFATE SOLUTION
- 170° & 550° F TEMPERATURES
- TEST UNTIL CRACKING IS OBSERVED OR 5 DAYS MAXIMUM

LONG TERM CORROSION TEST PROGRAM

LEAD TEST

OBJECTIVE:	DUPLICATE HFT SEQUENCE AND TYPICAL REACTOR OPERATION IN THE LABORATORY TO ASSESS ENVIRONMENTAL EFFECTS ON TUBE PERFORMANCE. THIS TEST WILL LEAD ACTUAL OTSG OPERATION AND ATTEMPT TO DUPLICATE PLANNED OPERATIONAL SEQUENCES.	
TEST DURATION:	APPROXIMATELY 12 MONTHS	
TEST SPECIMENS:	C-RINGS FULL SECTION TUBES	} ACTUAL TMI TUBING
TEST PARAMETERS:	CHEMISTRY -	TYPICAL PRIMARY WATER CHEMISTRY WITH CONTAMINANTS AT MAXIMUM SPECIFICATION LEVELS
	TEMPERATURE -	AMBIENT TO 600° F WITH TEMPERATURE CYCLING
	LOAD -	C-RINGS STRESSED AT 90% Y.S. FULL SECTION TUBES LOADED 200-1100 LBS. CYCLED DURING COOLDOWN

CORROSION TEST PROGRAM

CORROSION SCENARIO

TEST PARAMETERS

TEMPERATURE: HFT THERMAL CYCLE - 14 DAYS

MATERIAL: HT. M1671 - ACTUAL TMI TUBE

SPECIMENS: C-RINGS

STRESS LEVEL: YIELD POINT

TEST SOLUTION: BORON - 2350 PPM
LITHIUM - .6 PPM
HYDRAZINE - 12 PPM

CONTAMINANTS: 1) THIOSULFATE - 1 PPM
2) SULFATE - 30 PPM (pH =5)

RESULTS:
- NO VISIBLE CRACKS ON SIX SPECIMENS TESTED IN EACH TEST.
- NO IGA ON TWO SPECIMENS DESTRUCTIVELY EXAMINED IN EACH TEST.

CORROSION TEST PROGRAM

INTERIM RESULTS

TEST PARAMETERS

TEMPERATURE: 130° F

BORON: 2350 PPM

LITHIUM: .6 PPM

ATMOSPHERE: AIR - OPEN CIRCUIT

STRESS LEVEL: YIELD POINT

TEST SPECIMEN	S_2O_3 (PPM)	TIME TO FAILURE
M2867 - TMI	200	13.5 HRS
M2320 -ARCHIVE	200	14.5 HRS
M2320 -MODEL BOILER	10	24.5 HRS
M2320 - MODEL BOILER	1	65.0 HRS
M2867 - TMI	1	22.0 HRS
M2867 - TMI	0	425.0 HRS - NO FAILURE

CORROSION TESTING STATUS

APRIL 30, 1982

TEST NO.	SPECIMEN	B	LI	S_2O_3	TEST TYPE	COVER GAS	RESULTS
1	M2320 ARCHIVE	2350	.6	100	A.P.	H_2	SEVERE CRACKING
2	M2320 ARCHIVE	2350	.6	10	A.P.	H_2	CRACKED
3	M2320 ARCHIVE	2350	.6	5	A.P.	H_2	CRACKED
4	M2320 ARCHIVE	2350	.6	1	A.P.	H_2	PITTING
5	M2320 ARCHIVE	2350	.6	10	O.C.	AIR	NO CRACKS (190 HRS.)
6	M5442 ARCHIVE	2350	.6	10	A.P.	H_2	NO CRACKS
7	ACTUAL TUBE	2350	.6	10	O.C.	AIR	CRACKED (68 HRS.)
8	ACTUAL TUBE	2350	.6	10	O.C.	H_2	NO CRACKS (200 HRS.)
9	MODEL BOILER	2350	.6	10	O.C.	AIR	CRACKED (24 HRS.)
10	MODEL BOILER	2350	.6	1	O.C.	AIR	CRACKED (65 HRS.)

NOTE: A.P. = ANODIC POLARIZATION

O.C. = OPEN CIRCUIT

REACTOR COOLANT SYSTEM (RCS) REVIEW

RECERTIFY RCS COMPONENTS FOR CONTINUED SAFE OPERATION

BY:

- SELECTIVE EXAMINATION CONSIDERING MATERIAL CONDITION, ENVIRONMENT AND STRESS
- APPROPRIATE BUT DIVERSIFIED EXAMINATION TECHNIQUES

6/7/82

RCS MATERIAL EVALUATION

MATERIAL	SUSCEPTIBLE TO SULFUR ATTACK: BASE MATERIAL	SUSCEPTIBLE TO SULFUR ATTACK: SENSITIZED, STRESSED	INCLUDED IN INSPECTION/TEST PLAN: BASE MATERIAL	INCLUDED IN INSPECTION/TEST PLAN: SENSITIZED, STRESSED
INCONEL 600	POSSIBLE	YES	YES	YES
INCONEL 718	POSSIBLE	YES	YES	YES
INCONEL X750	POSSIBLE	YES	YES	YES
ALLOY A286	POSSIBLE	NONE	YES	NONE
SS 304	UNLIKELY	YES	YES	YES
SS 316	UNLIKELY	PROBABLE	YES	YES
SS 304L	UNLIKELY	UNLIKELY	YES	YES
SS 316L	UNLIKELY	UNLIKELY		(HEATERS ONLY)
SS 403, 410, 43L	POSSIBLE	NA	YES	NA
17-4PH	POSSIBLE	NA		NA
15-5PH	POSSIBLE	NA	YES	NA
STELLITE NO. 6, NO. 12	UNKNOWN	NA		NA
BRAZE MATERIAL	UNKNOWN	NA	YES	NA
ZIRCALOY-4	NO	NA	YES	NA

6/7/82

RCS TEST PLAN SUMMARY (CONTINUED)

EXAM TYPE	MATERIAL	MAJOR COMPONENTS
DYE PENETRANT	INCONEL 600	CLADDING
	308 STAINLESS STEEL	CLADDING
FUNCTIONAL TESTS	INCONEL 600/AUSTENITIC STAINLESS STEEL	INCORE DETECTORS
	AUSTENITIC S.S. AND VARIOUS	VENT VALVES
DESTRUCTIVE METALLURGICAL EXAM	INCONEL 718	RV "O" RING
	304 S.S.	CRDM END FITTING, RNS HOUSING
	INCONEL X750	RNS SPRING

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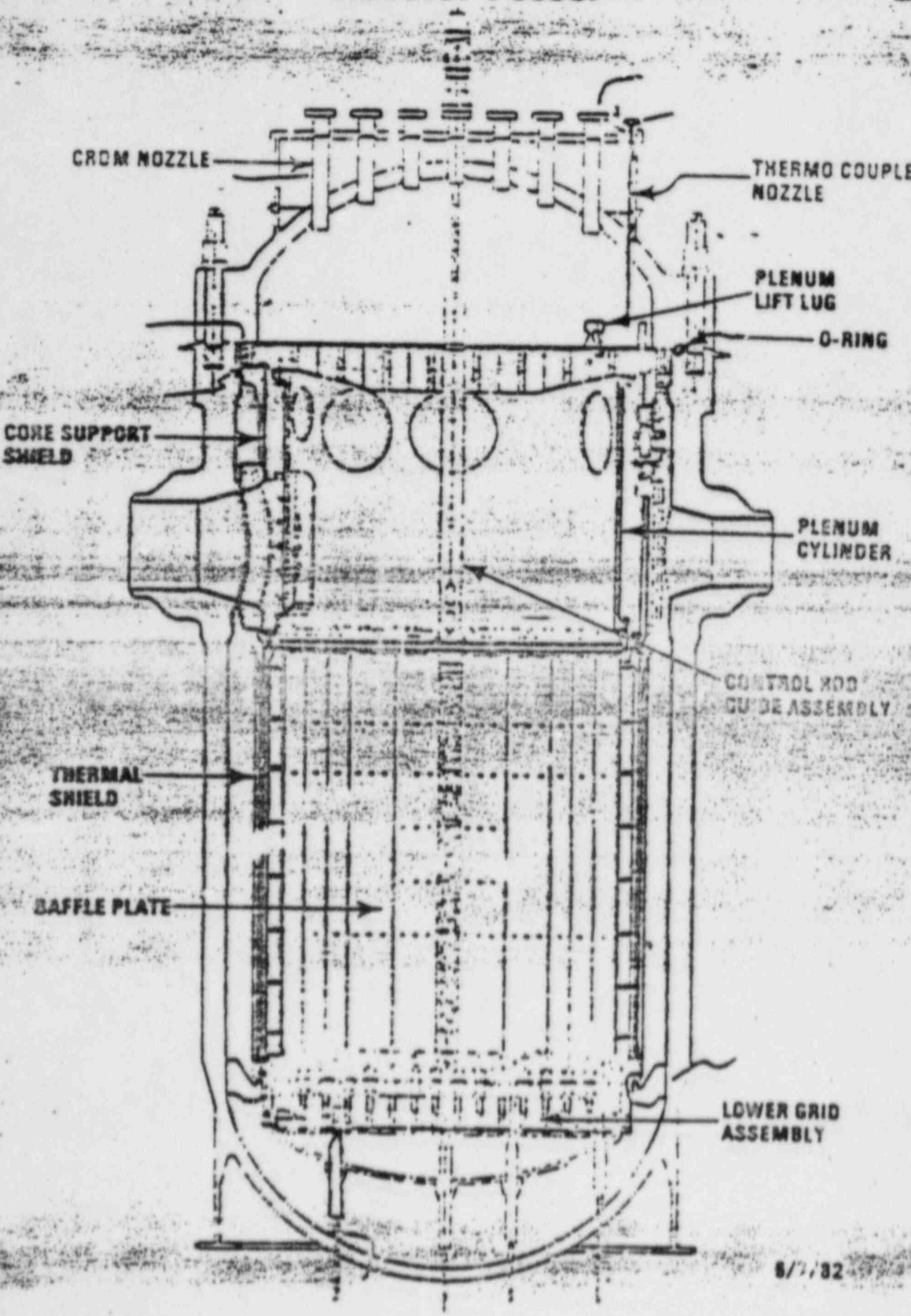
Reactor Vessel



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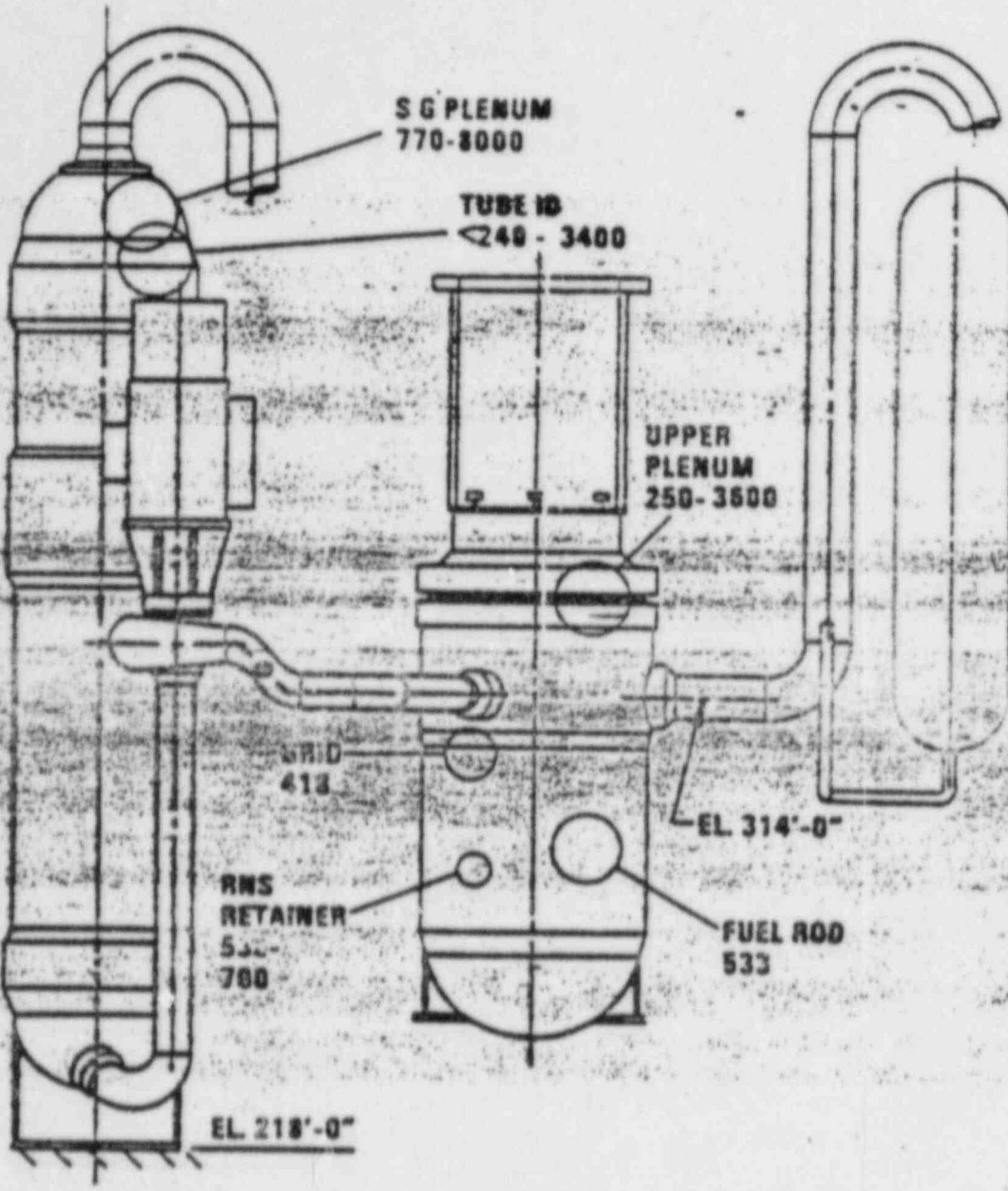
RCS Inspection Results - Sulfur Levels ($\mu g/ft^2$)



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RCS EXAMINATION CONCLUSION

NO CRACKING OR DEFECTS ATTRIBUTABLE TO

SULFUR ASSISTED STRESS CORROSION CRACKING

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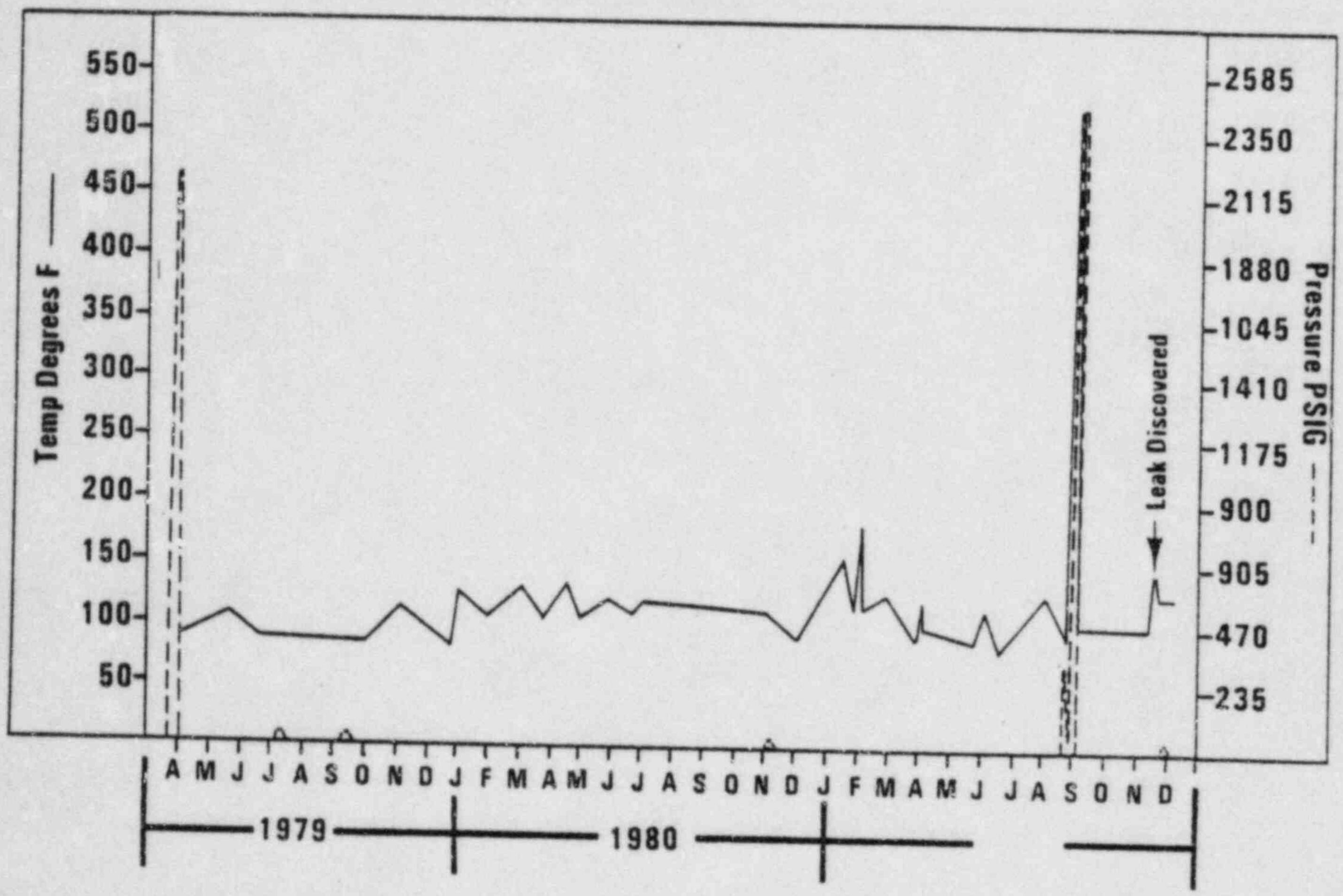
GPU Nuclear

TMI-1 OTSG Status and Repair Process Description

June 29, 1982

Reactor Coolant System



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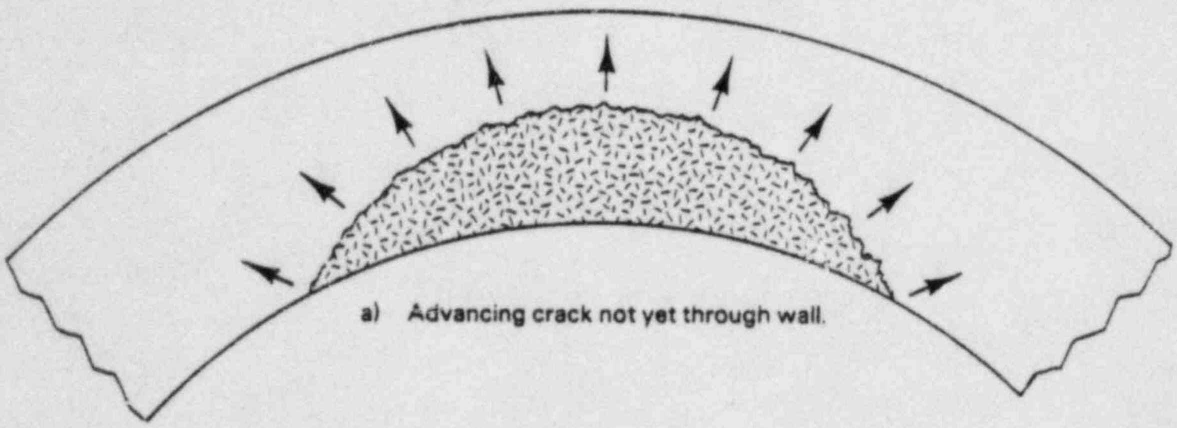
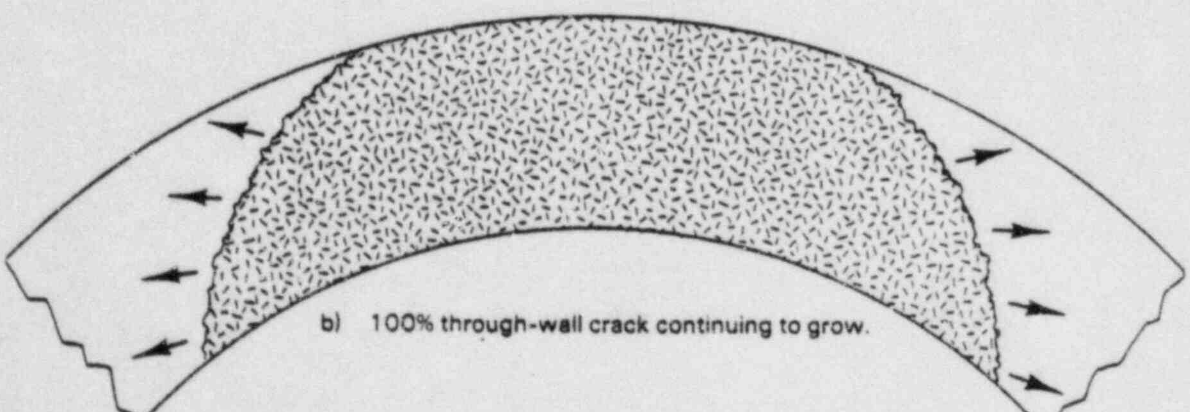
SKETCH OF TYPICAL CRACK SHAPES



a) Advancing crack not yet through wall.



b) 100% through-wall crack continuing to grow.

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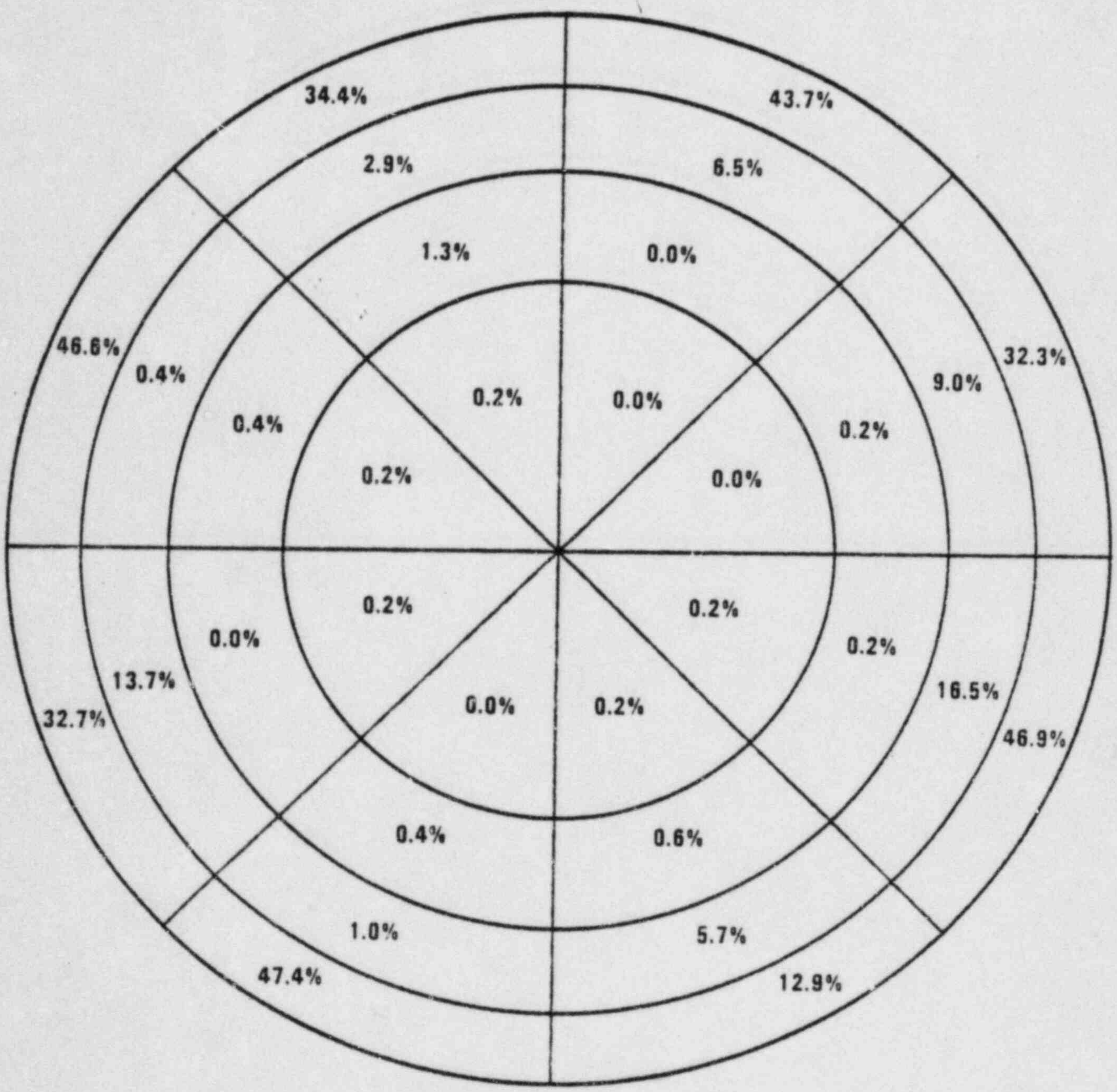
Three Mile Island Nuclear Generating Station Unit 1 Steam Generator A



Standard Differential
Eddy Current Results
Percent of Tubes with Defects

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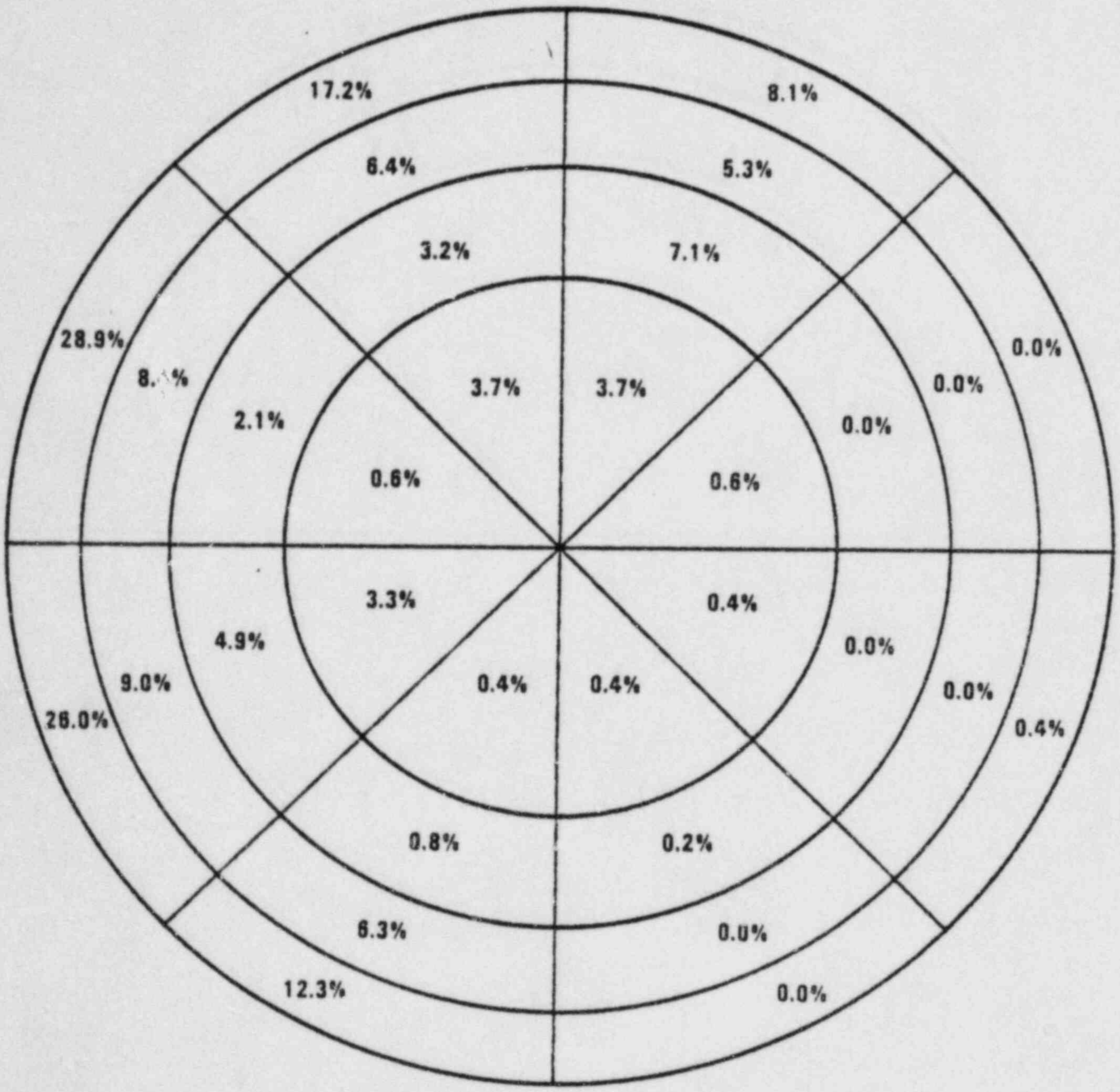
Three Mile Island Nuclear Generating Station Unit 1 Steam Generator B



Standard Differential
Eddy Current Results
Percent of Tubes with Defects

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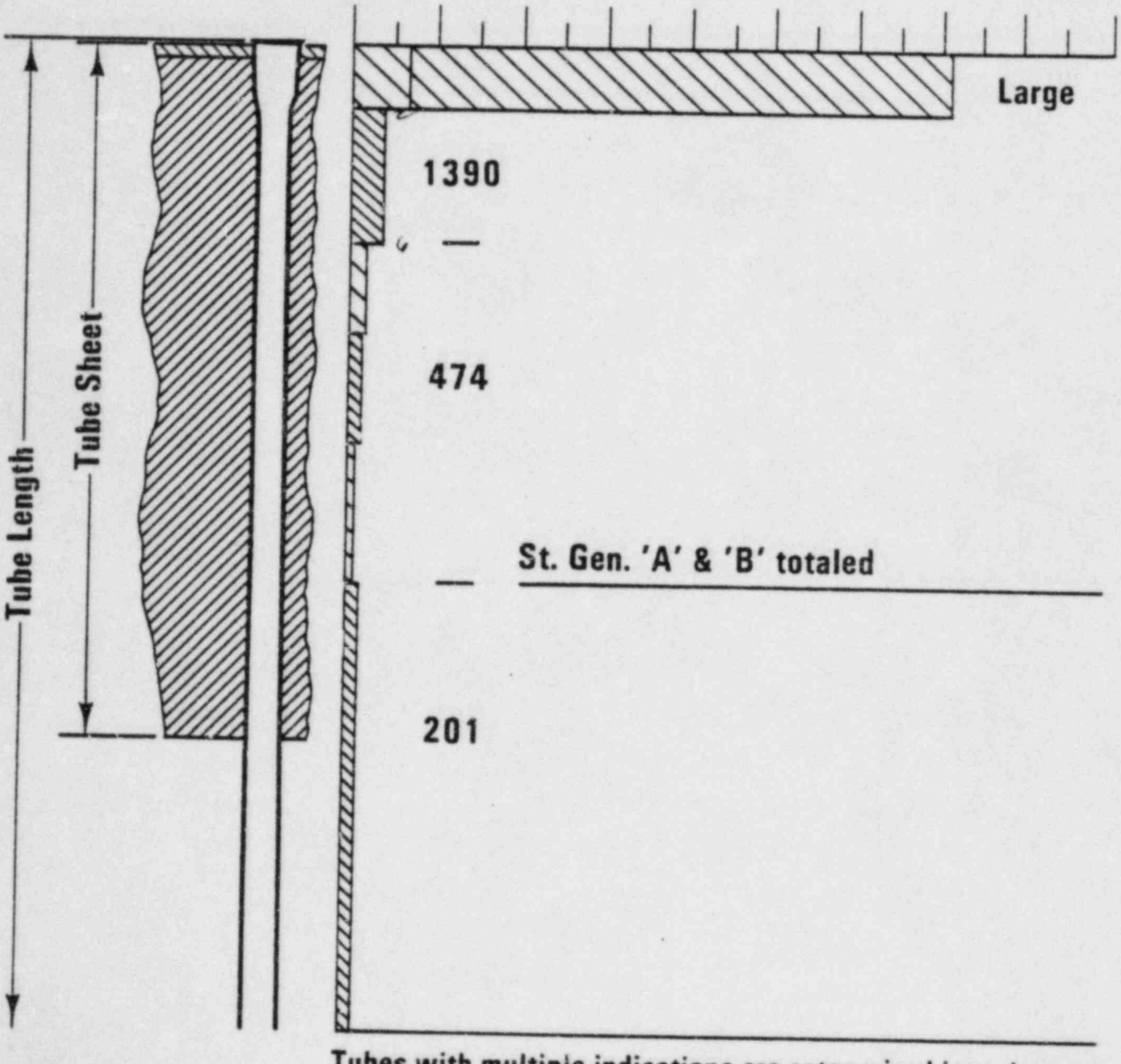
TMI OTSG Tube Defect Distribution

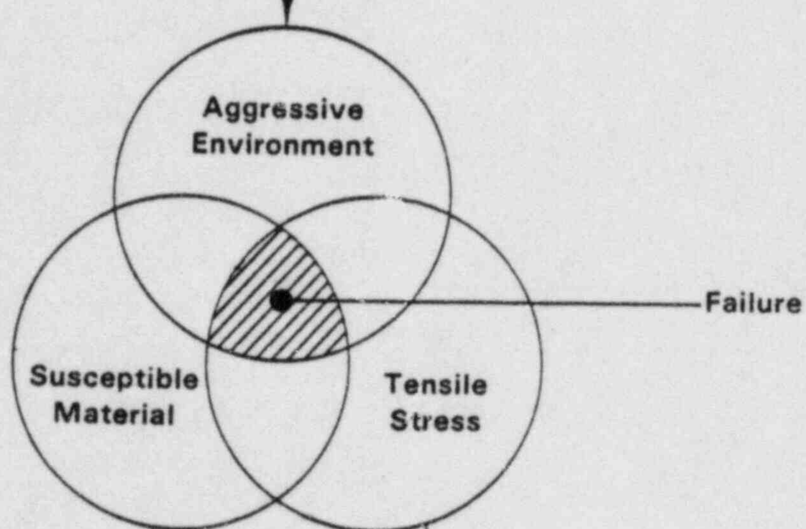


Tubes with multiple indications are categorized into the zone farthest from the tube sheet face

6/29/82

Intergrannular Stress Corrosion Cracking

- Sulfur in the primary coolant as high as several ppm.
- Solution hydrogenated and heated
- Solution cooled and oxygenated
- Agressive reduced sulfur species

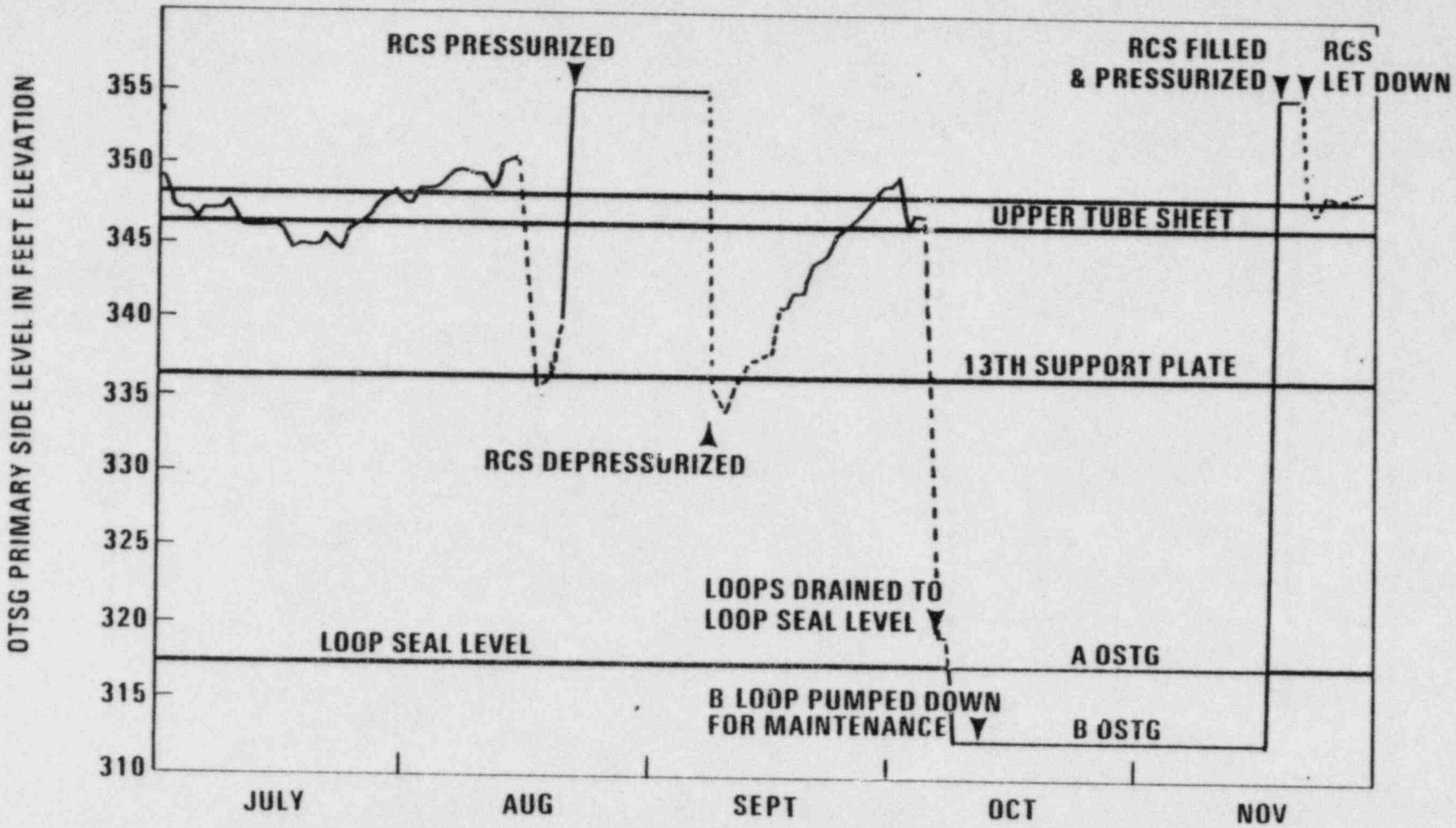


- Inconel 600
- Mill annealed at ~1900°F/stress relieved at ~1150°F
- Grain boundary chromium less than 10%

- Cracks oriented circumferentially
- Calculated residual axial stresses high in the seal weld heat affected zone and vicinity of the roll transition
- Applied axial tensile stress during cooldown and at cold shutdown

6/29/82

OTSG Level
July 1981 — November 1981



DOTTED LINE MEANS ESTIMATED LEVEL
VENTING ARRANGEMENT CAUSES UP TO 27" ERROR

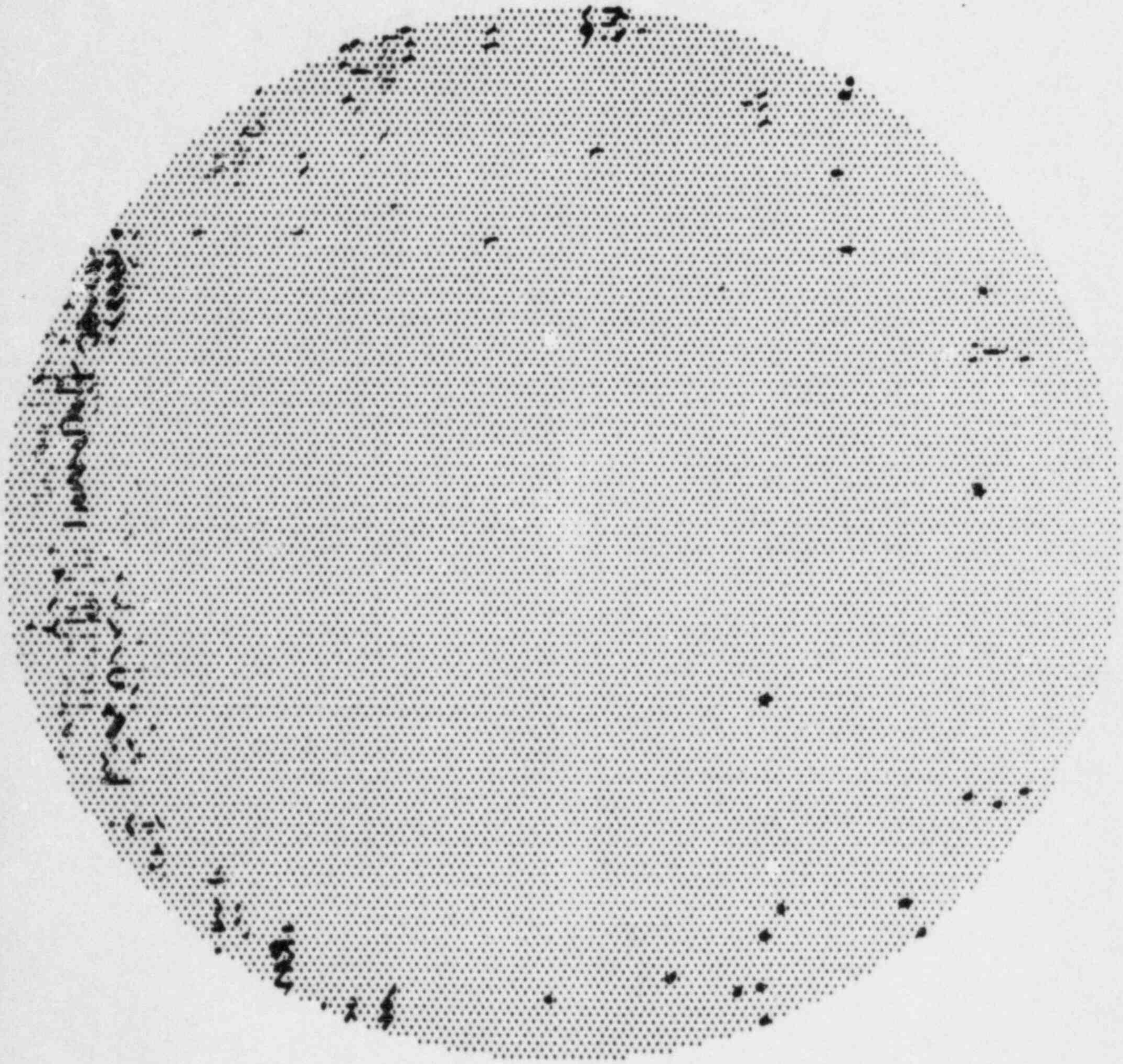
6/29/82

Heat Vs Defect Correlation Summary

- Tube failures are associated with specific locations in the generator not heat relationships
- The defect patterns in the two generators appear to be different and this will need to be explained by a parameter other than heat number
- Heats of material exist which have high defect frequencies in bad areas and the same heats will have low defect frequencies in good areas

6/29/82

TMI-1 Steam Generator A
Defective Tube Locations of Four Tube Heats



6/29/82

Summary of Failure Analysis Continued...

- Residual stress measurements in roll and roll transition region show no stress peaks but rather a uniform distribution
- Chromium levels in the grain boundaries vary from 8 wt.% to 20 wt.%
- The inconel microstructure appears typical for steam generator tubing with discrete chromium carbide particles in the grain boundaries
- Small areas of intergranular corrosion several grains deep have been observed on the ID and OD surfaces at random locations
- No relationship has been established between material heats and defective tubing
- Mechanical testing of uncracked tubes show that the material exceeds minimum specification requirements

Features Covered by Scenario

- Time of cracking
- Mode of cracking
- Axial distribution of cracking
- Radial distribution of cracking (OTSG-A)
- Corrosion test results

6/29/82

Preliminary Corrosion Test Results

- Corrosion tests in actual primary coolant indicate it is currently innocuous
- Reduced sulfur species can reproduce the type of cracking observed in steam generator tubes
- The degree of sensitization (i.e., prior heat treatment) is a key parameter in defining the materials susceptibility to IGSCC
- Crack initiation appears to be the rate controlling parameter
- Crack growth rate is very rapid on the order of 1mm/day
- Cracking appears to be a low temperature occurrence
- Cracking tendency is reduced by raising the pH

6/29/82

Proposed TMI-1 OTSG Repair Process (Steps/Sequence)

1. Flush secondary side tube/tubesheet crevice
2. Heat crevice to drive out moisture
3. Kinetically expand tube for ~14"
4. Cleanup debris
   A. Polyethylene on surfaces
   B. Explosive residue
   C. Pieces of polyethylene candle
5. Leak tests
6. Plug or roll/flush (if required)
7. Pre critical operational testing

6/29/82

Repair Criteria

(2) Repaired tube shall sustain, with adequate margins, the design basis loads

Loads	Generic 177FA	TMI-1
LOCA	+ 2641 lb	+ 2641 lb
MSLB	+ 3140 lb	+ 3140 lb
FWLB	- 620 lb	- 620 lb
Normal cooldown:	+ 1107 lb	+ 1107 lb

\+ = tension

\- = compression

6/29/82

Primary System Cleanup

Sulfur in RCS water has been reduced from 750ppb to 100ppb

If analysis shows it is required, we plan to reduce the amount of sulfur on the surfaces of primary system components and OTSG tubes

Cleanup method identification will consider:

- H_2O_2 concentrations of 0, 10, 100, and 1000ppm
- pH of 7.0, 8.0, and 9.0 with LiOH or NH_4OH additive
- Normal RCS chemistry

6/29/82

FW PRESENTATION TO THE NRC

BOB BALLET PRESIDENT

FW EXPERIENCE

- EXPANDED OVER 5,000,000 TUBES IN HEAT EXCHANGERS OVER THE LAST 20 YEARS.

- HAVE PERFORMED VARIOUS FIELD REPAIR (DETNAFORM™ AND DETNAPLUG™) OF HEAT EXCHANGERS SINCE 1969.

- USED DETNAFORM FOR THE CRBRP INTERMEDIATE HEAT EXCHANGER (17,100 EXPANSIONS) SS304 TUBES, SECTION III, CL 1 AND RDT STANDARDS.

- REPAIRED MSR'S AT SALEM 1 AND 2
  12 UNITS, EACH WITH 735 TUBES. THESE ARE UNITS WHICH WERE ROLLED AND WELDED ORIGINALLY.

6/29/82

SIGNIFICANT RESULTS

- Charge Sizing and Combination
- Length required to assure adequate Pullout Strength.
- Effect of Neighboring (After) Hits.
- Effect of Corrosion on Pullout.
- Leakage Rate Data.
- Interim Recommendations.

6/29/82

Table 15

STATISTICAL SUMMARY FOR 20/14-8" EXPANSIONS

TUBE YIELD	2 - HITS $\bar{X}$; S	ALL HITS $\bar{X}$; S	2 - HITS 99/99 LOWER LIMIT	ALL HITS 99/99 LOWER LIMIT
57.0	5283;214	5200;276	4609	4331
53.6 CORRODED	5340;299	5373;303	4398	4417
46.1	4607;407	4672;395	3325	3427
43.9 CORRODED	4613;208	4613;208	3957	3957
ALL TUBING	4977;448	5001;437	3564	3624

NOTE: 1) ALL DATA FROM DEGREASED OR CORRODED TUBESHEETS.
2) 99/99 LOWER LIMITS EXTRAPOLATED TO SAME BEHAVIOR WITH 48 DATA POINTS, I.E., $\bar{X}$ - 3.15(s)

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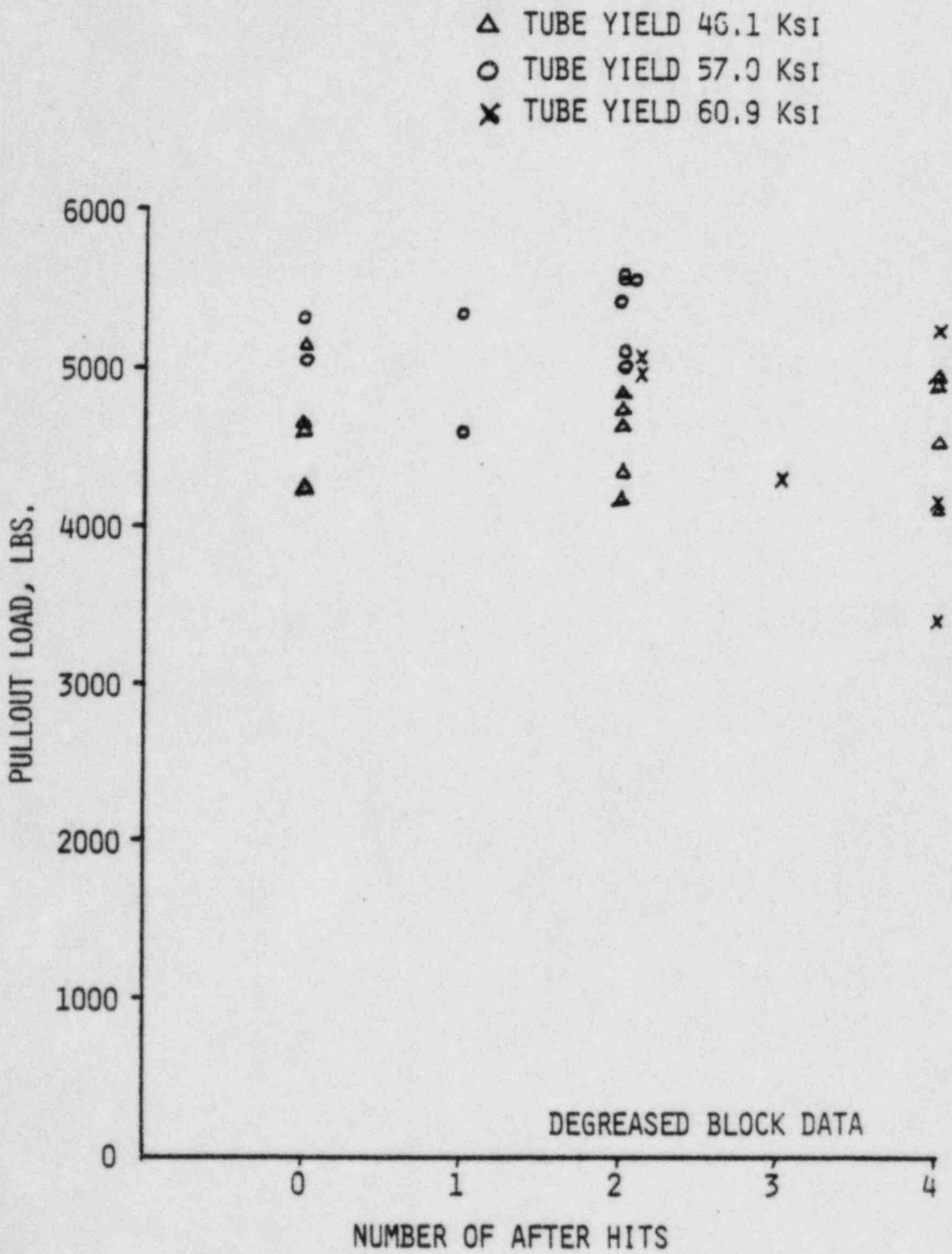
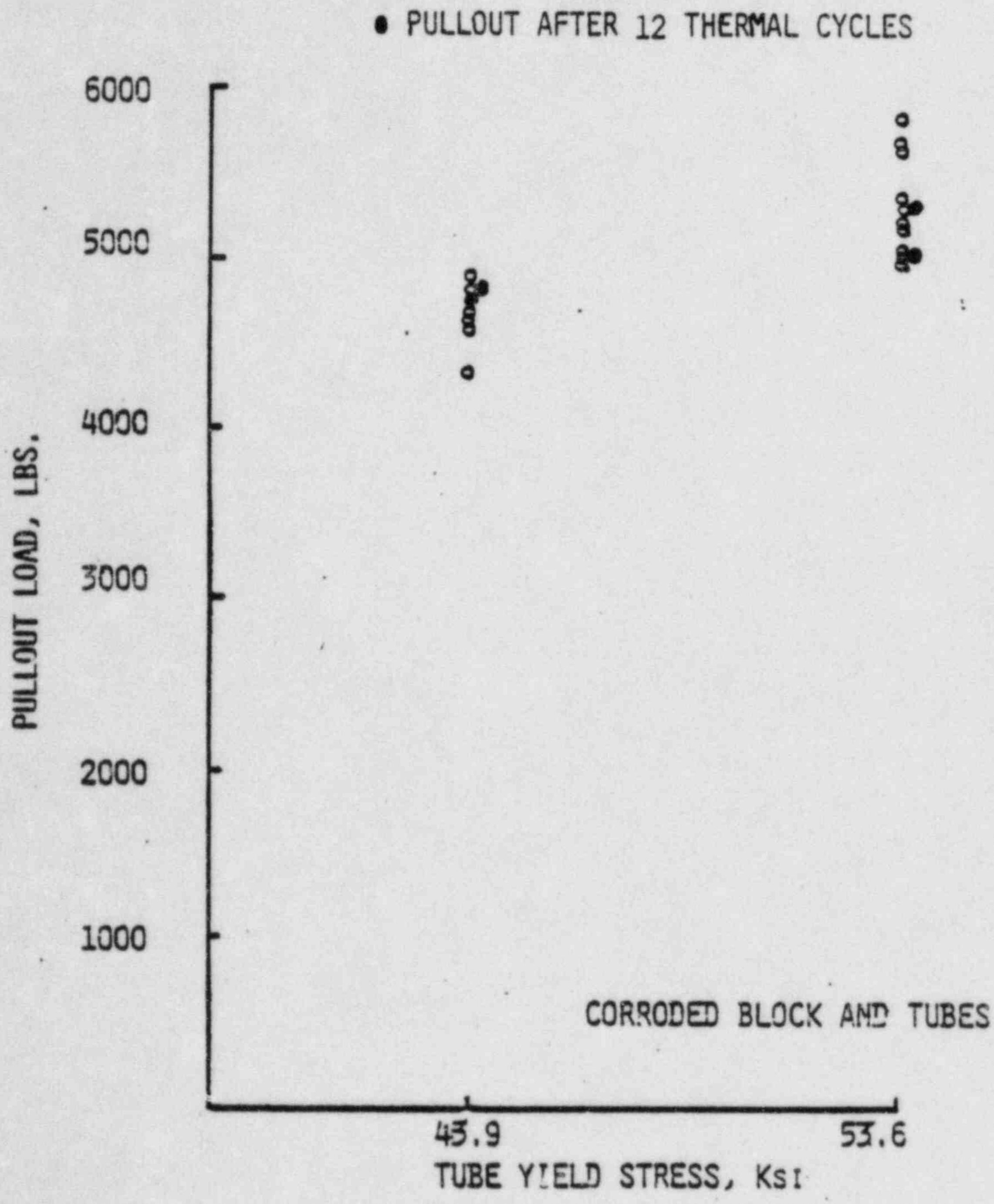


EFFECT OF AFTER HITS ON PULLOUT LOAD

20/14-8" EXPANSION

6/29/82



EFFECT OF TUBE YIELD ON PULLOUT LOAD

20/14-8" EXPANSION

6/29/82

Application Of Kinetic Expansion Process To TMI-1

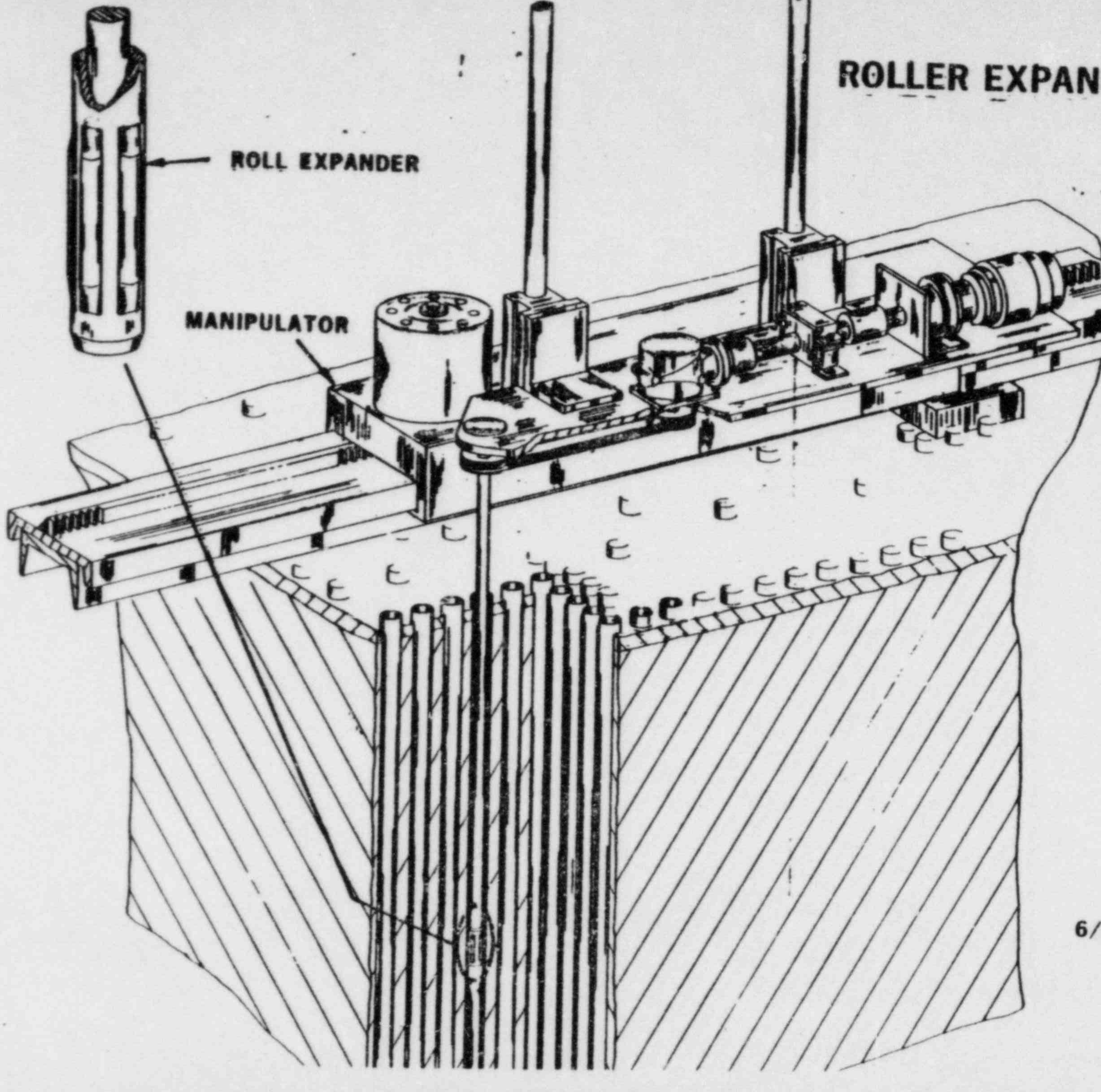
6/29/82

Concept And Relation To Repair Criteria

- Basic concept of essentially leak tight mechanical joint capable of load carrying is unchanged
- Mechanical roll is held as backup to kinetic expansion
- Sleeving capability is retained
- Repair criteria presented 4/7/82 are unchanged and have been implemented by GPUN specification

6/29/82

ROLLER EXPANDER



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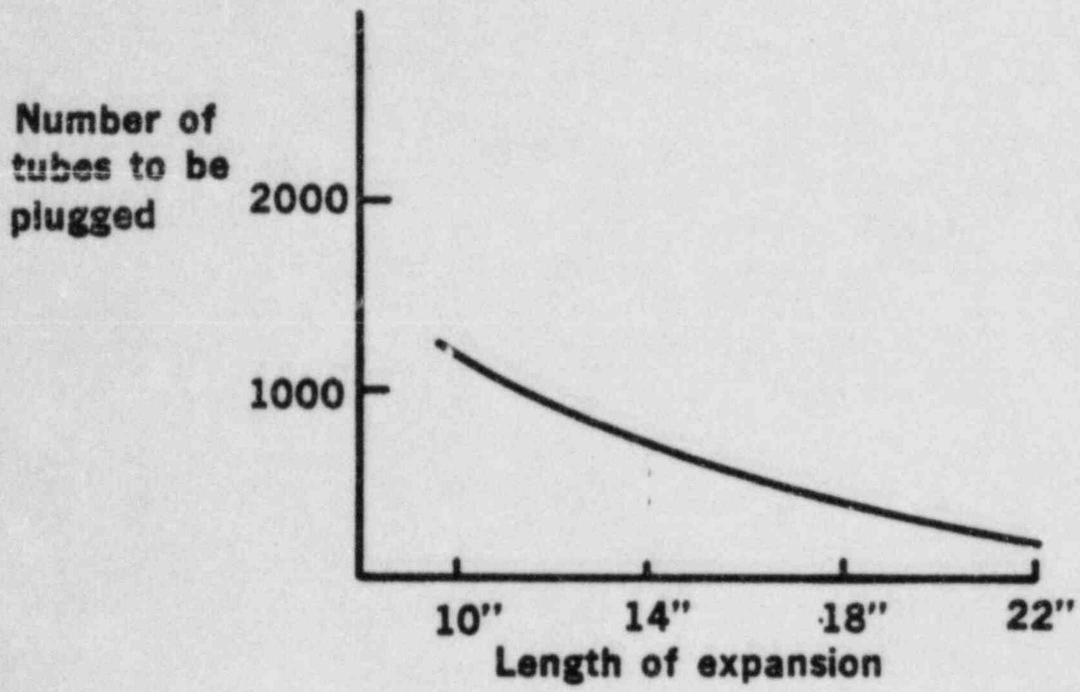
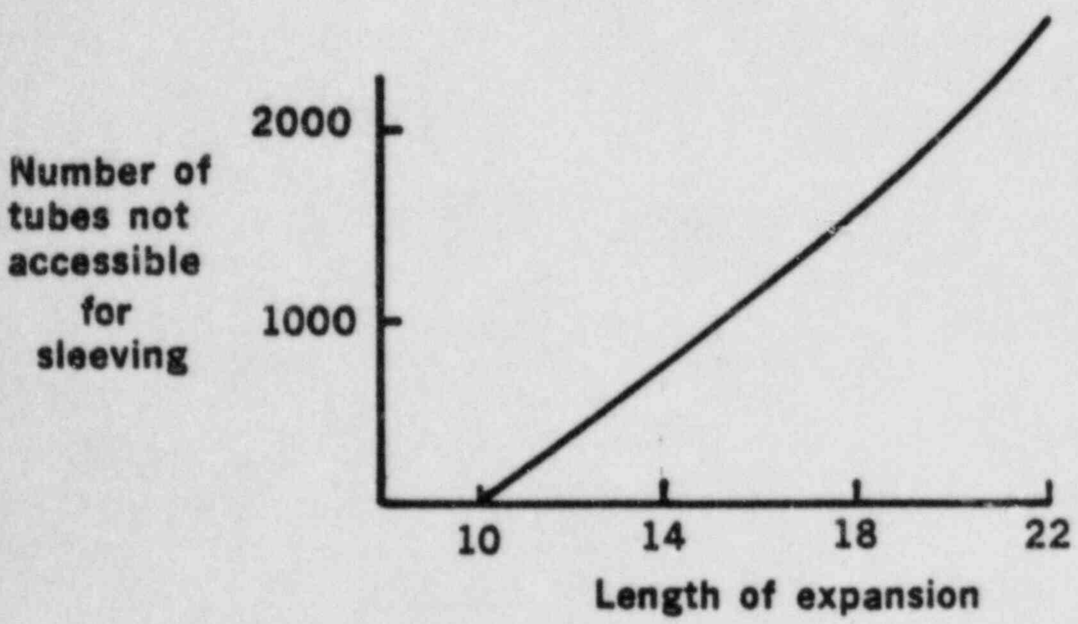
Considerations In Specific Application

- Tube and tubesheet materials and geometry
- Depth of expansion
- Kinetic expansion materials
- Residue
- Cleaning

6/29/82

Approximate
Expansion Length Trade-Offs





<u>Note</u>: Sleeve Length = Expansion Length + 3"

6/29/82

Tentative Cleaning Conclusions

- Tube I.D. pre-expansion cleaning not necessary
- Candle protects expanded I.D. surface
- Tube I.D. post expansion cleaning
  - Felt plugs and/or LP Flush
- Sulfur removal by chemical means if required

6/29/82

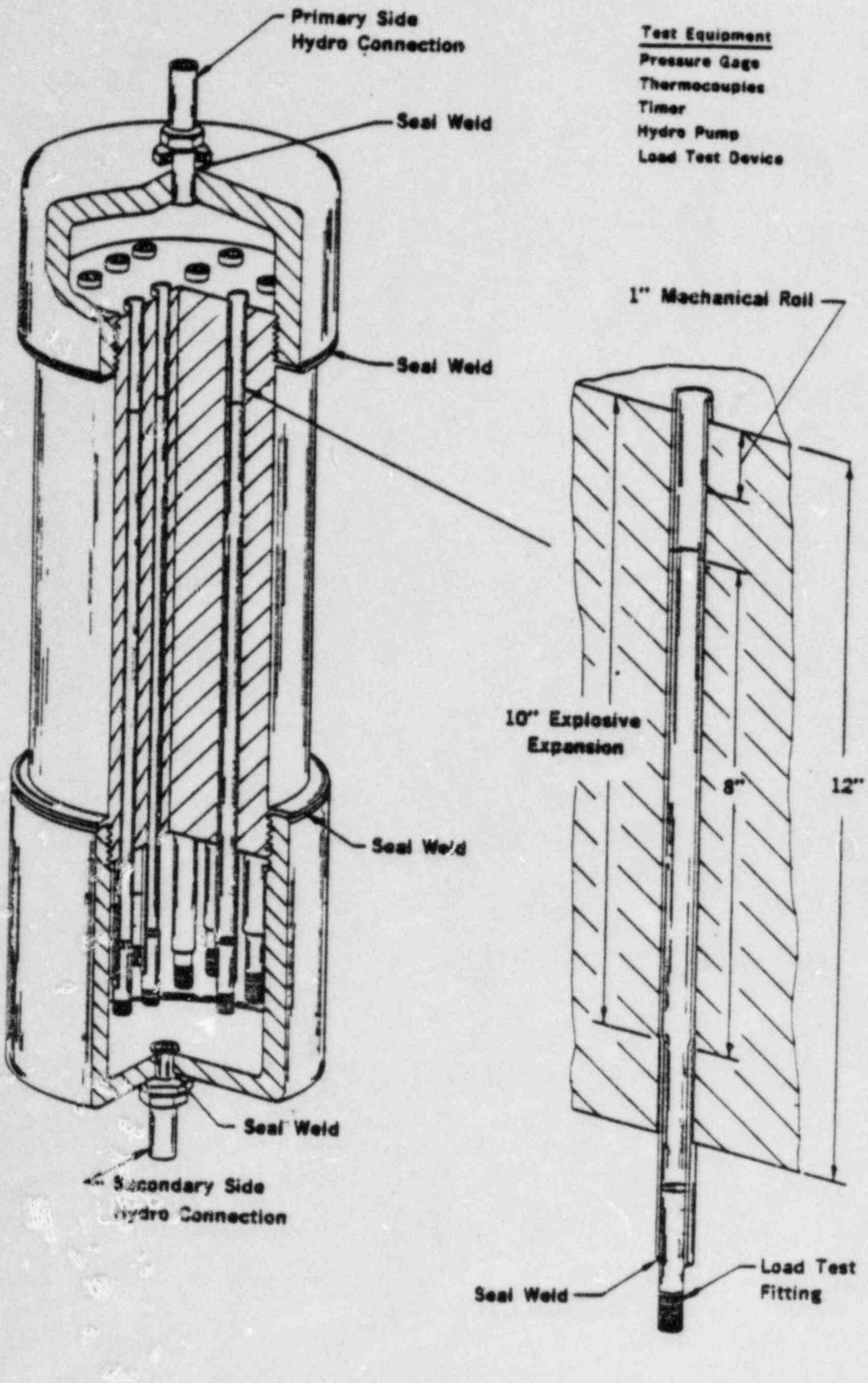
Decisions on Process Qualification Application

- Decide on kinetic expansion
  - One or two expansions
  - With or without vacuum
- Confirm use of ordnance cord
- Select expansion length
- Establish cleaning method

6/29/82

10 Tube
Leak and Load Test Fixture

Test Equipment
- Pressure Gage
- Thermocouples
- Timer
- Hydro Pump
- Load Test Device



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Kinetic Expansion
Leak & Axial Load Tests

Objectives

- Measure leak rate past expansion pri-sec/sec-pri
- Show no movement from expected load
- Measure load which will cause slip
- Confirm no ligament distortion
- Determine the effect on expansions of adjacent expansions
- Correlate rate and water leak rate

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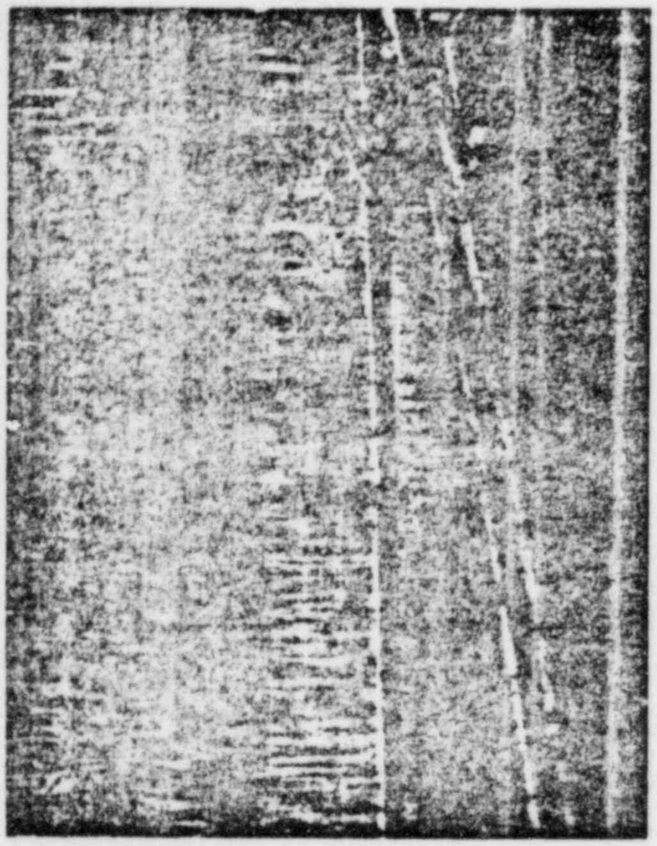
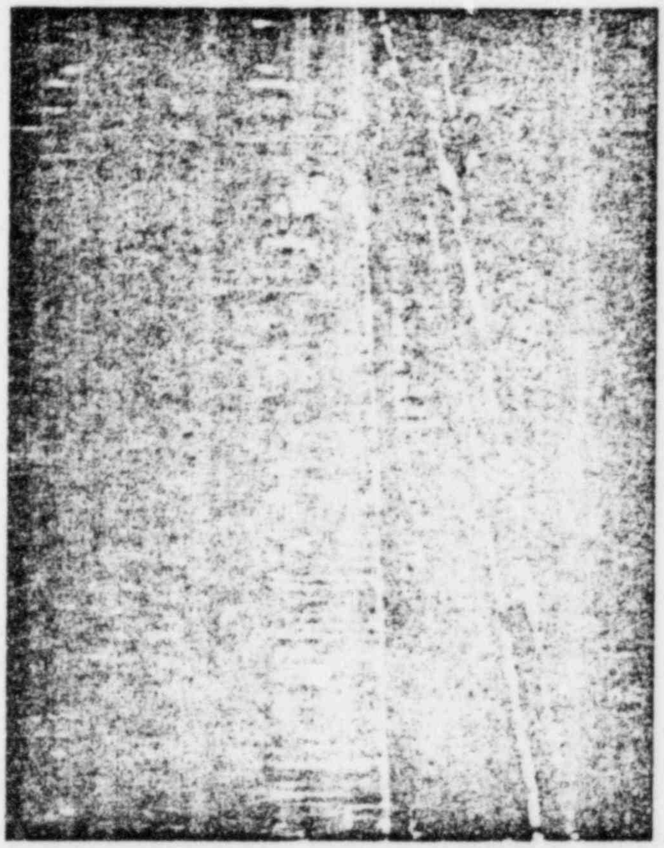
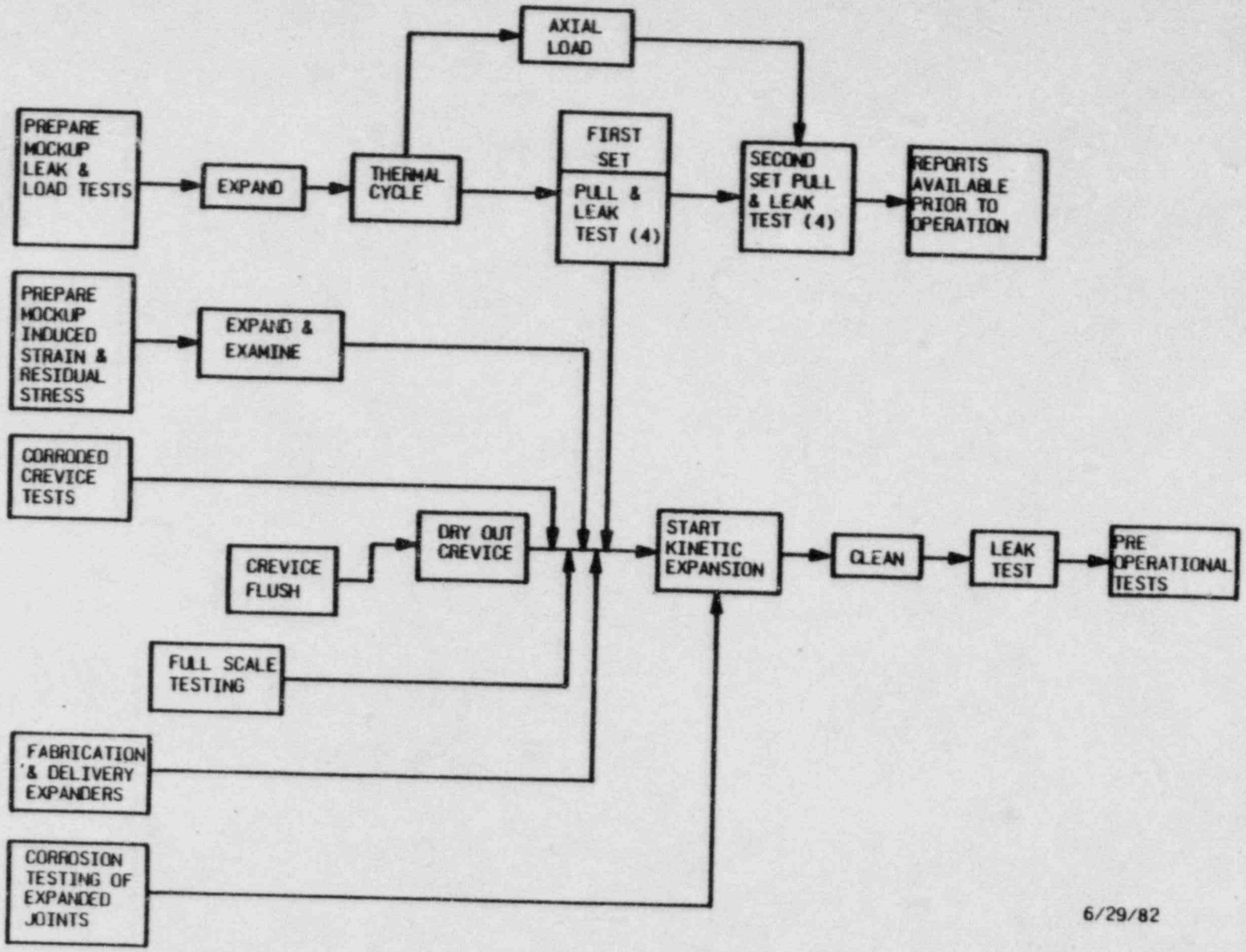




STEREO PAIR

- TMI-1 TUBE #A133-74 (PIECE 2)
  UPPER CRACK - 18.1" FROM TOP OF TUBE
- TUBE EXPLOSIVELY EXPANDED - 25 GRAINS/FT
- MAGNIFICATION - 63 X
- ONLY ABOUT 1/3 OF CRACK SHOWS IN PICTURES

Qualification Program Logic



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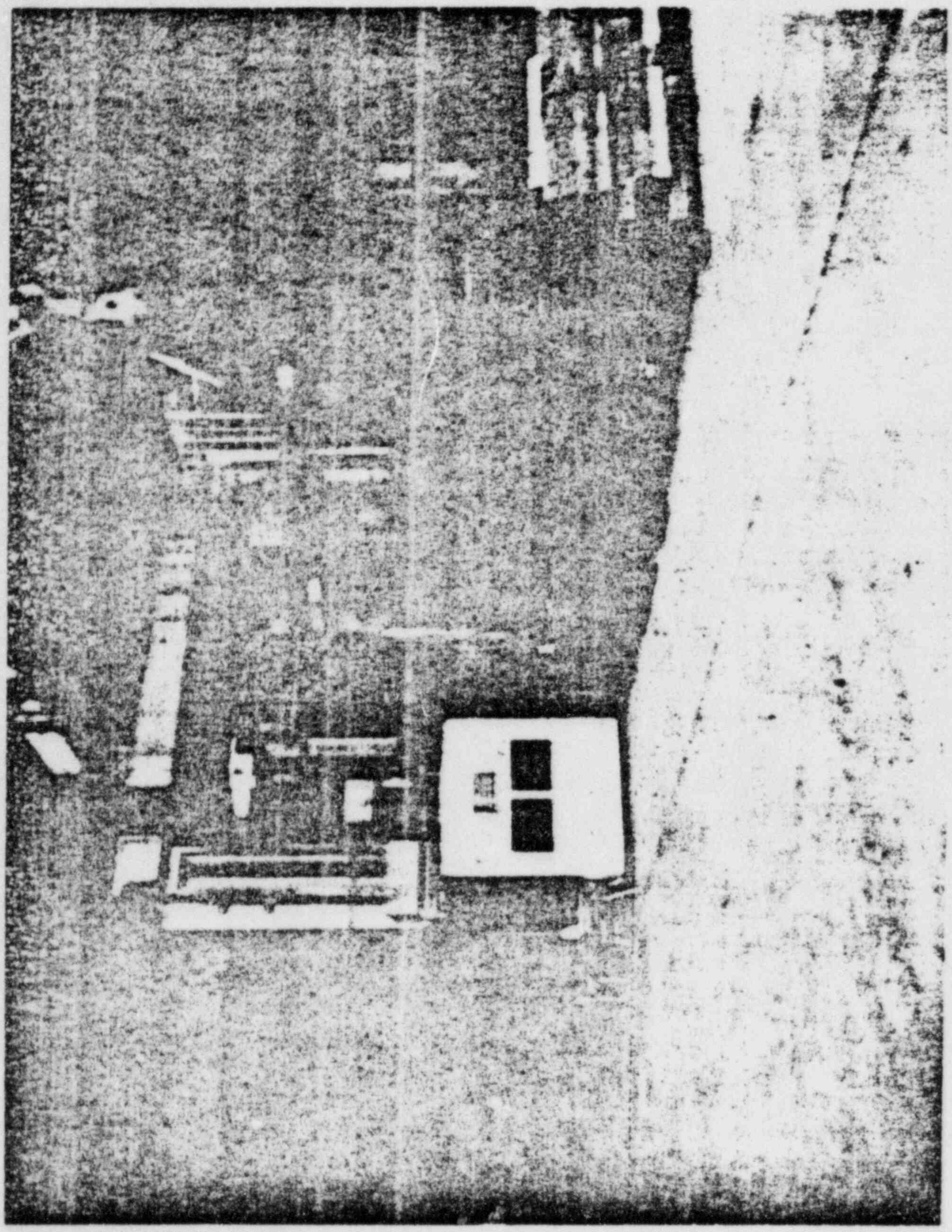
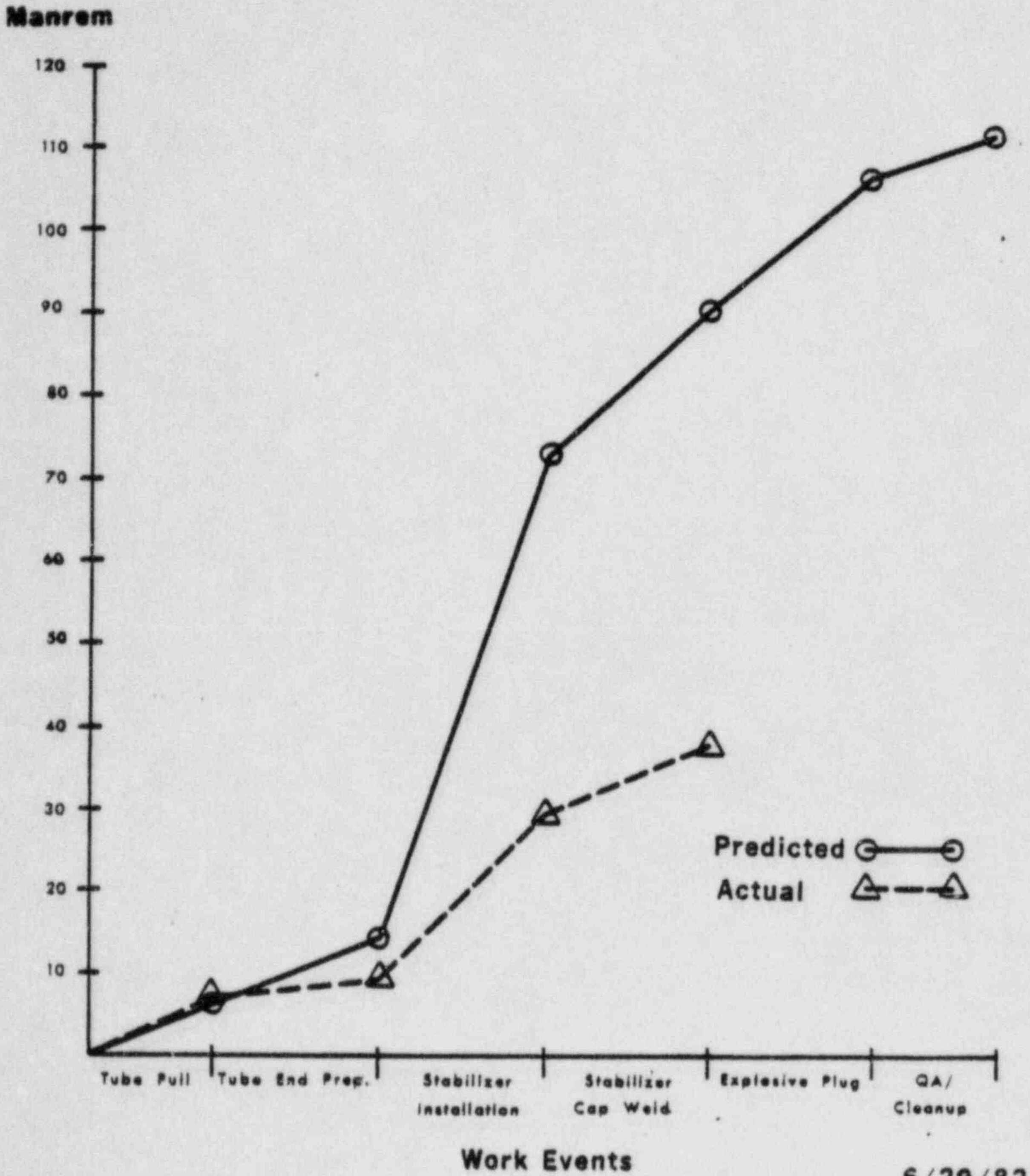
Test Objectives

- Provide personnel familiarization walk-thru training with process
- Evaluate OTSG environmental concerns
  - Pressure wave
  - Noise
  - Ventilation
- Evaluate cleanup requirements for OTSG Internals
- Demonstrate operability of:
  - Video system
  - Ventilation system
  - Others (test, atmosphere analyzers, radiation detectors, etc.)
- Evaluate post kinetic expansion tube condition
- ALARA

6/29/82



Tube Pull/Tube Stabilization
Radiation Exposure Summary



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Summary

- Initial testing and analysis indicates kinetic expansion is practical for application to TMI-1
- Final qualification testing and analysis to confirm process fulfills specification requirements
- Planning, training, rehearsal to implement repair process at TMI-1

6/29/82