J. Van Vliet (extra)

GPU Nuclear

TMI-1 OTSG

Repair Process Update and Return to Service Overview

October 18/19, 1982

A10

NRC OTSG Update

10/18/82

I. Qualification Program Update	D. Slear
II. Final Eddy Current Test Results	N. Kazanas
III. Return to Service Safety Evaluation Overview	P. Walsh
IV. Interpretation of ECT Results	D. Slear

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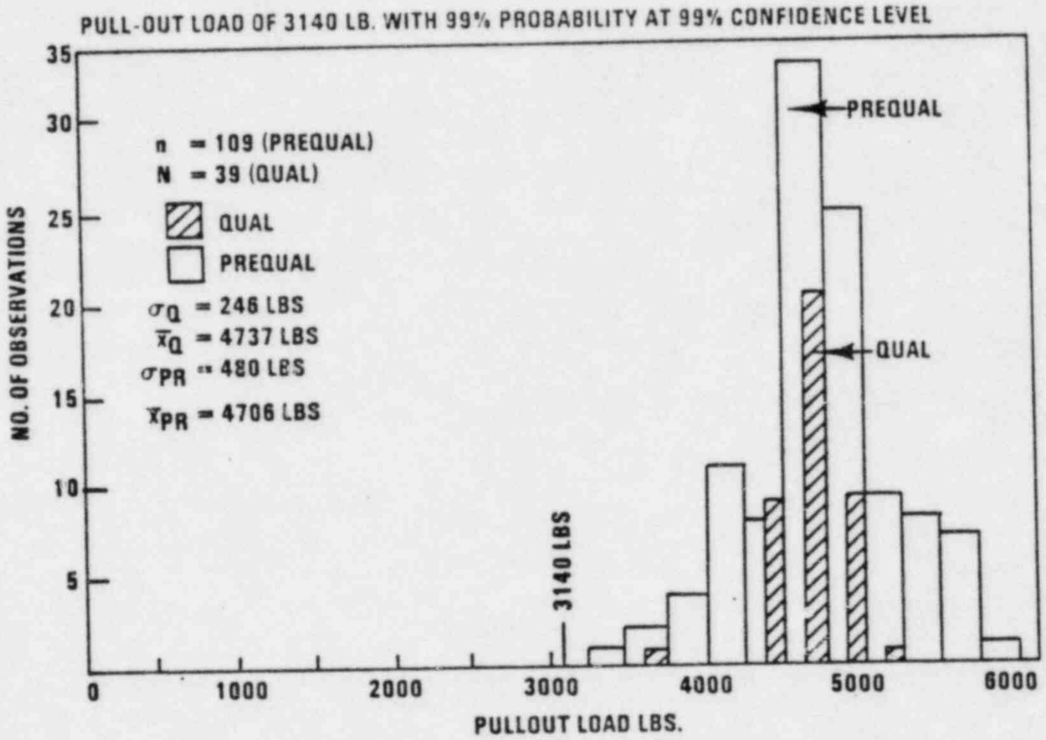
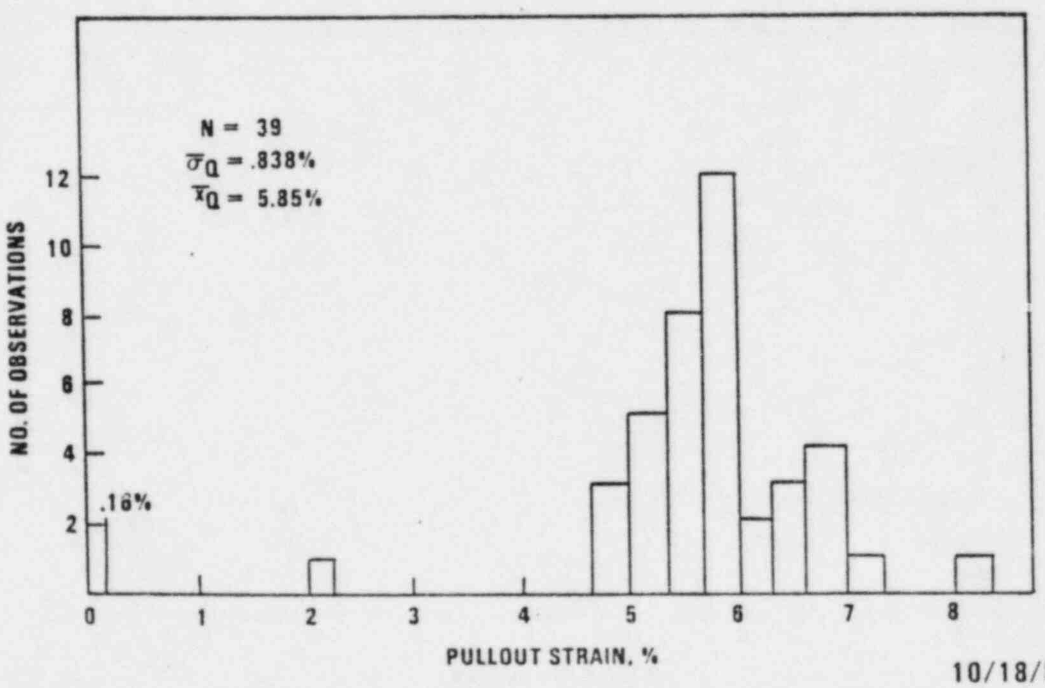
IV. Plant Performance Analysis with Plugging	N. Trikorous
VI. Sulfur Removal Test Program Status	W. Greenaway
VII. Corrosion Test Program	S. Giacobbe
VIII. Steam Generator Post Repair Test Program	P. Walsh

PULLOUT LOAD QUALIFICATION & PREQUALIFICATION DATA



PULLOUT STRAIN QUALIFICATION DATA



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Qualification Program Test Blocks

TEST PROGRAM / BLOCK	THERMAL CYCLING	AFTER HITS	AXIAL LOAD	LEAKAGE (S-P 1275 psi)	LEAKAGE (P-S 1275 psi)	LEAKAGE (S-P 125 psi N_2)	LEAKAGE (P-S 2500 psi)	PULLOUT (70°F)	PULLOUT (300-400 °F)	LEAKAGE (300-400°F)
A	✓	✓			✓			✓		
B								✓		
C	✓				✓			✓		
D	✓				✓			✓		✓
E	✓				✓			✓		
G	✓				✓				✓	
H	✓				✓		✓	✓		
SP-1	✓		✓	✓	✓	✓		✓		

Plugging ~1100 tubes

Expanding all tubes

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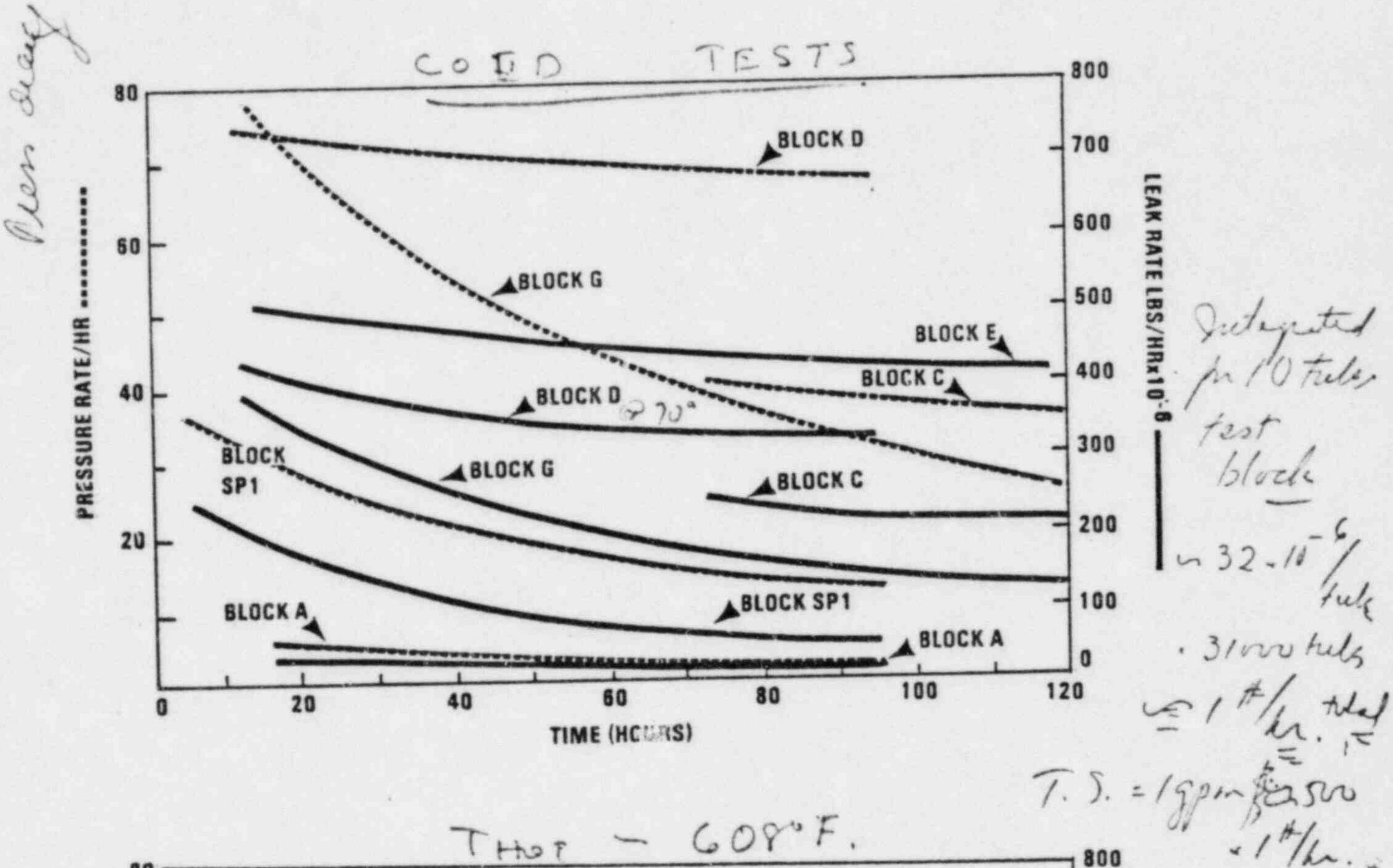
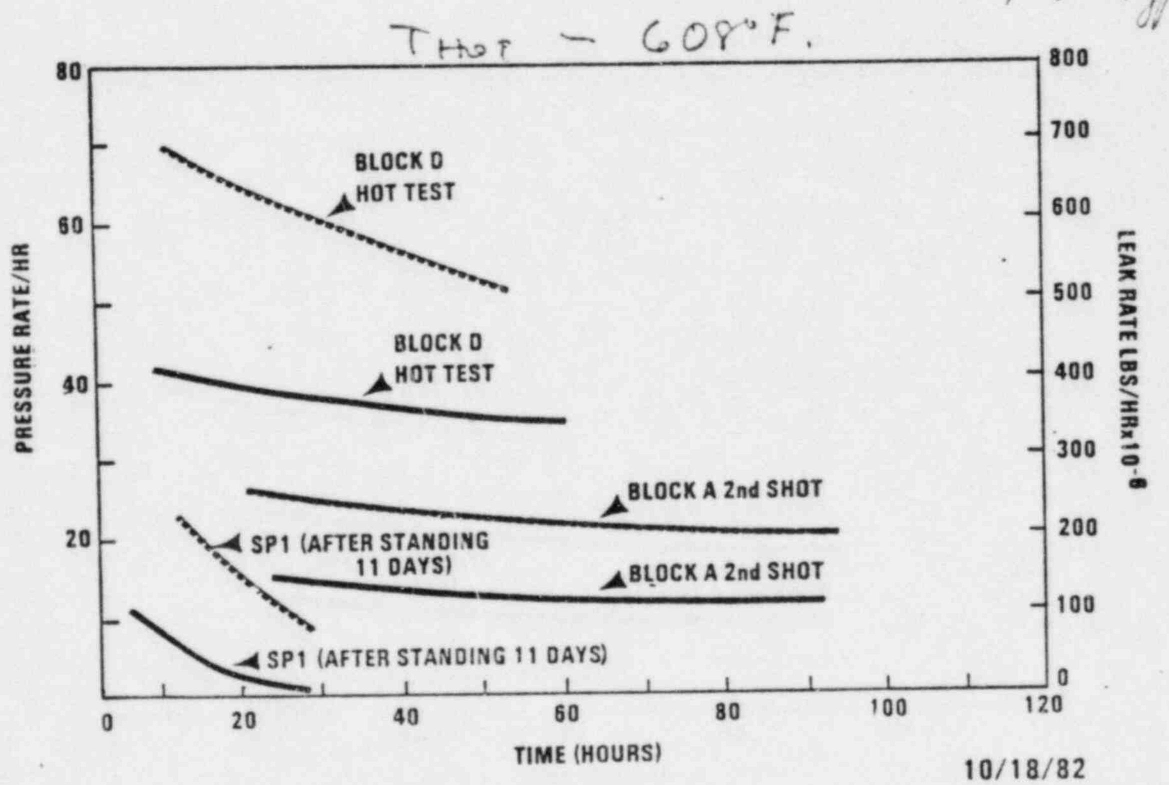
LEAK RATE DATA

QUALIFICATION PROGRAM 10 TUBE TEST BLOCKS





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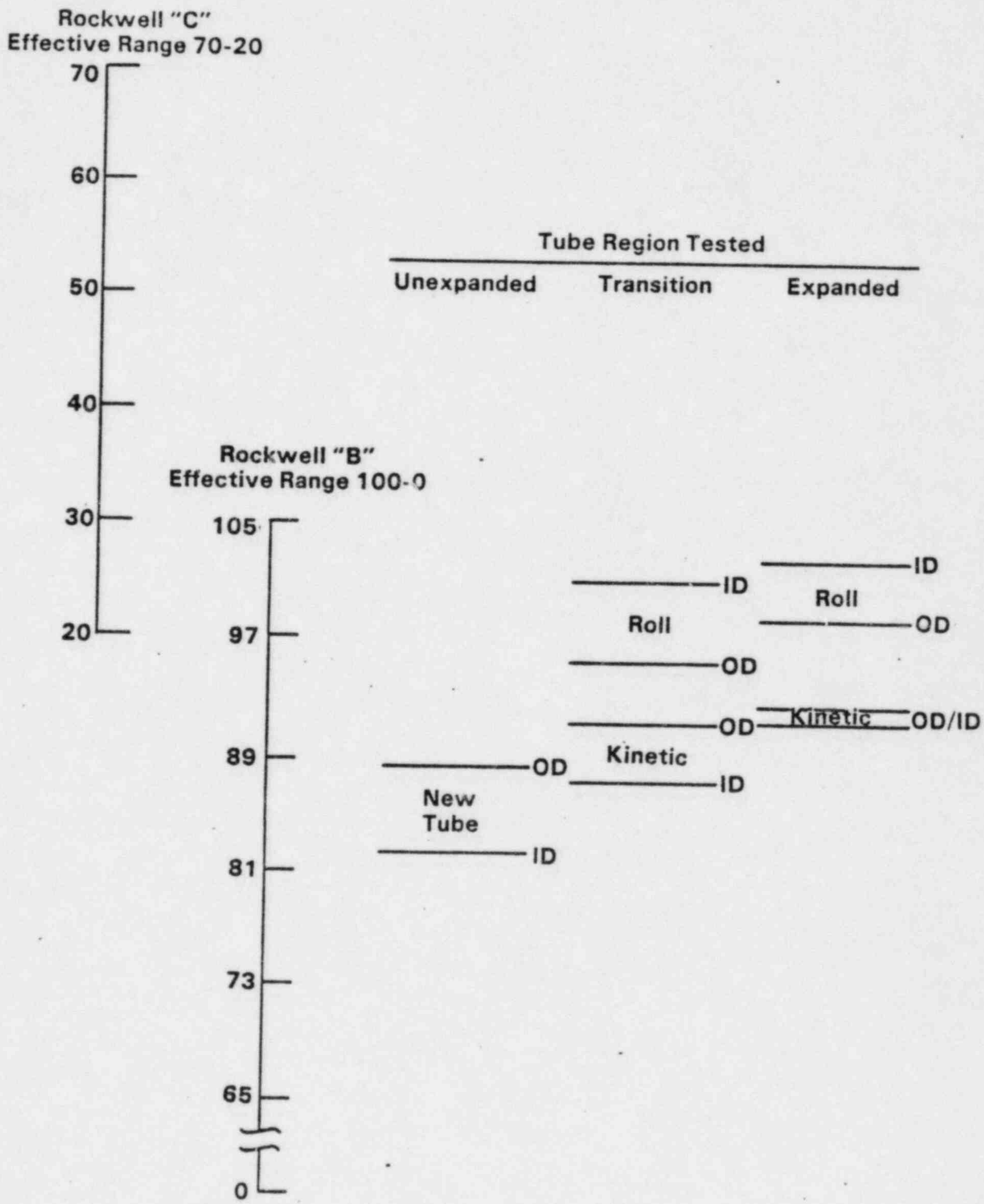
Comparison of Rockwell Hardness



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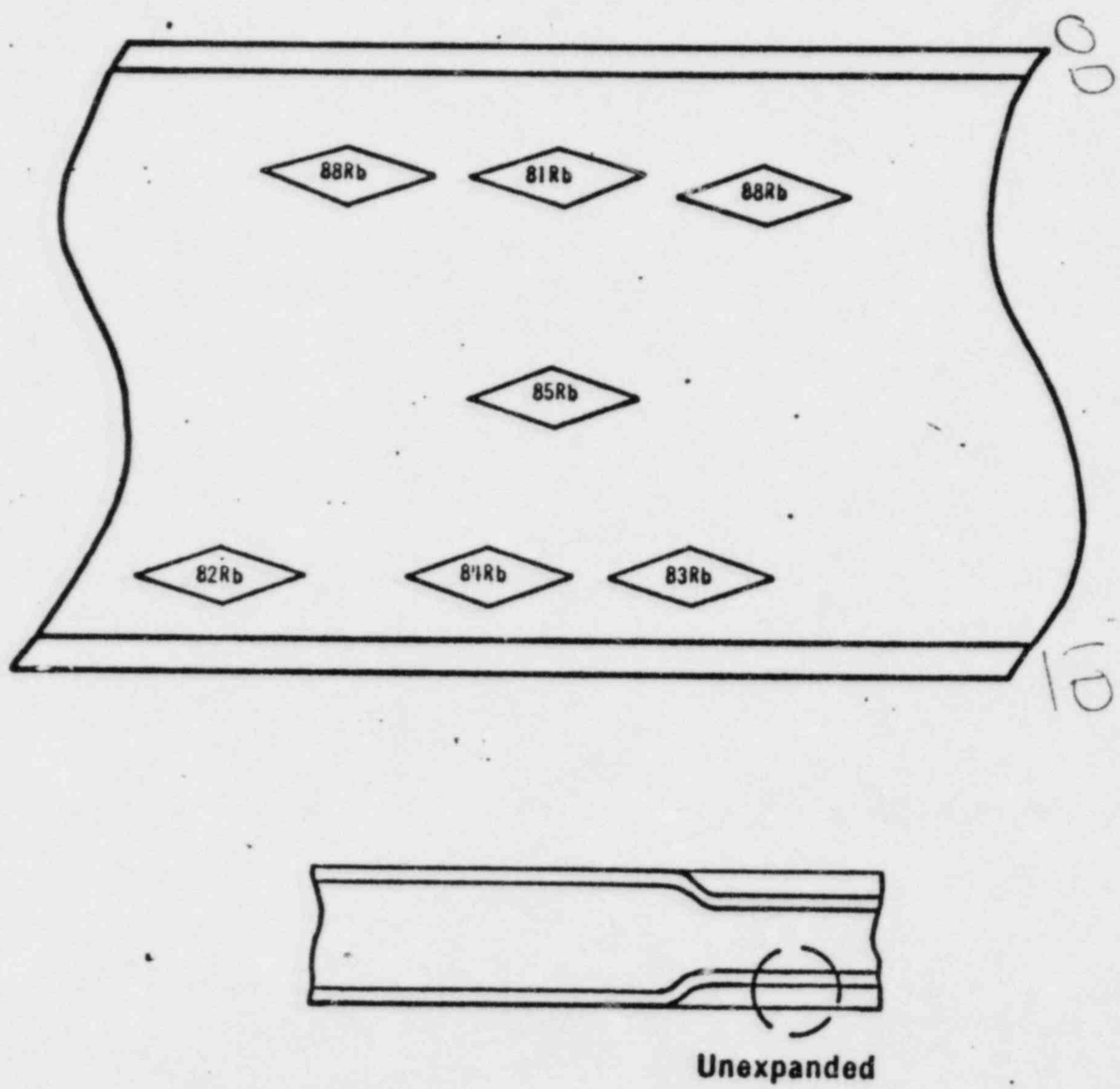
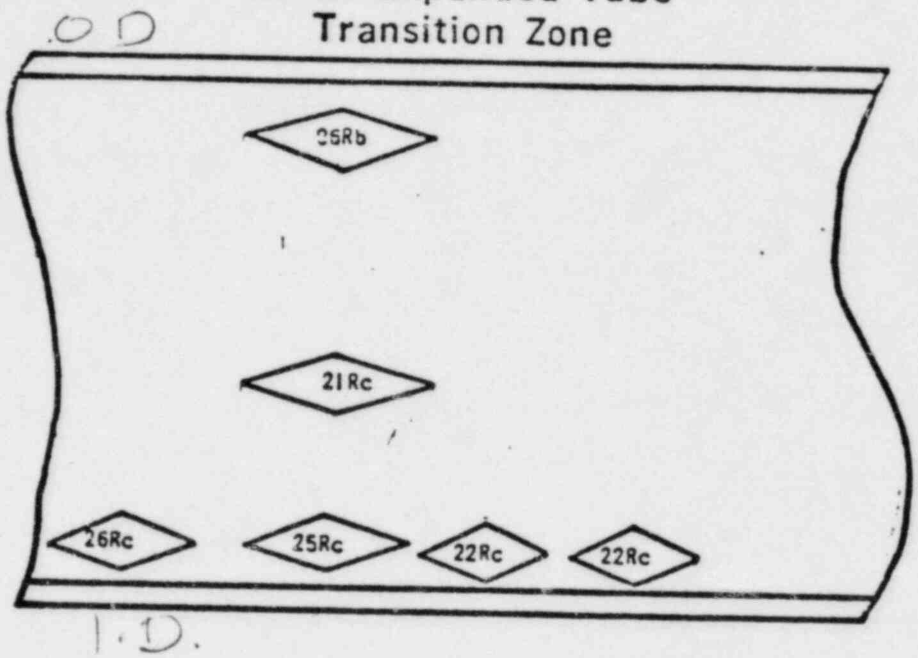
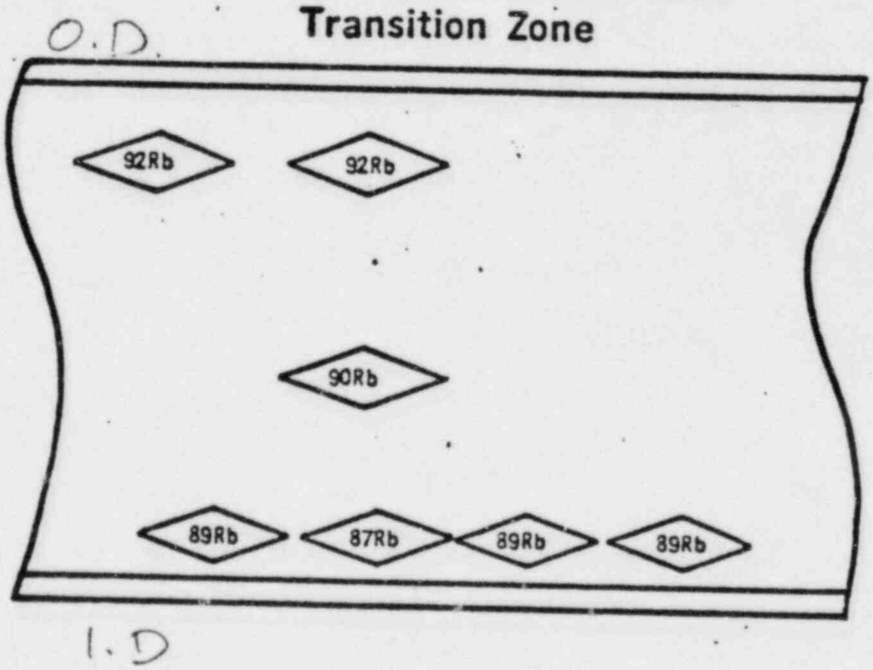
Unexpanded Portion Of Tubes

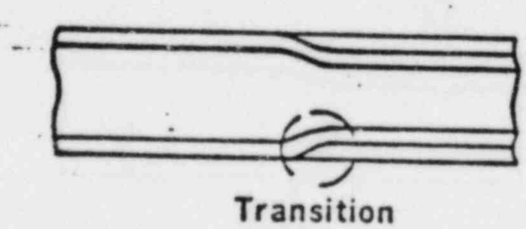


Roller Expanded Tube
Transition Zone

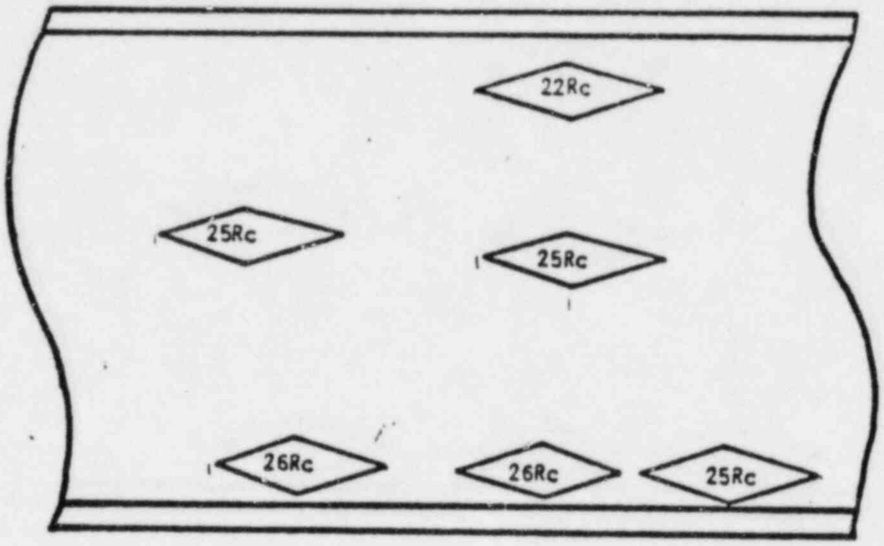


Kinetically Expanded Tube
Transition Zone

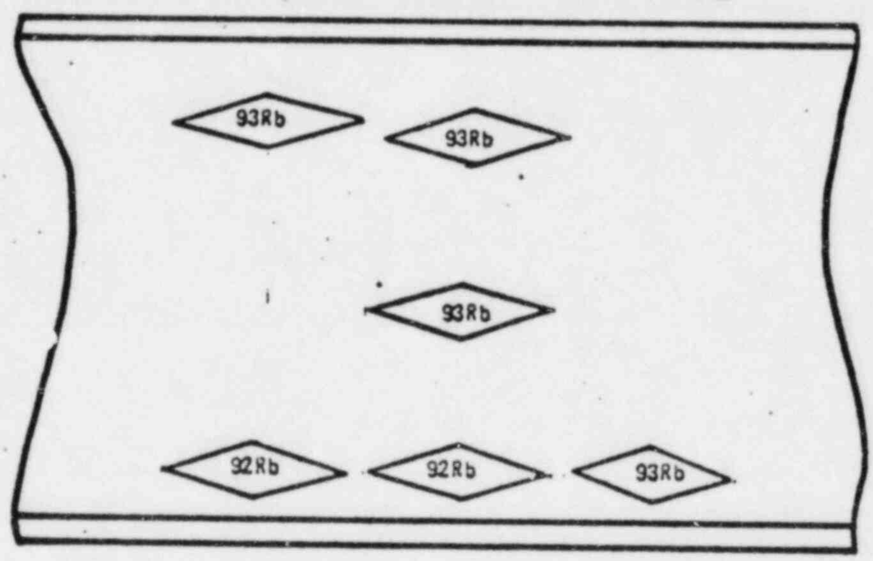


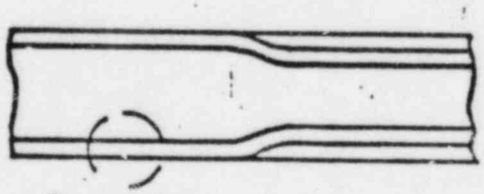


Roller Expanded Tube
Away From Transition Area



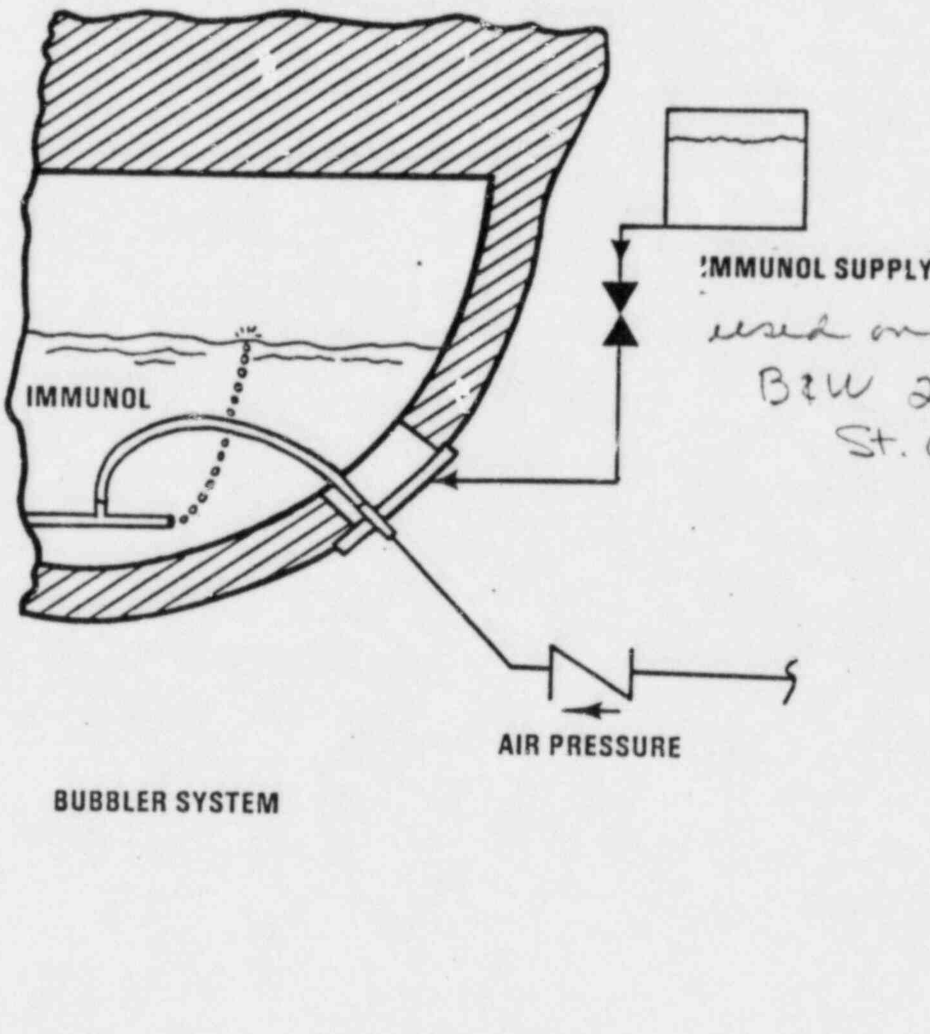
Kinetically Expanded Tube
Away From Transition Area





Expanded

IMMUNOL APPLICATION



used on mfg. of
B&W 205
St. Gen.

BUBBLER SYSTEM

10/13/82

SUMMARY OTSG ECT PROGRAM

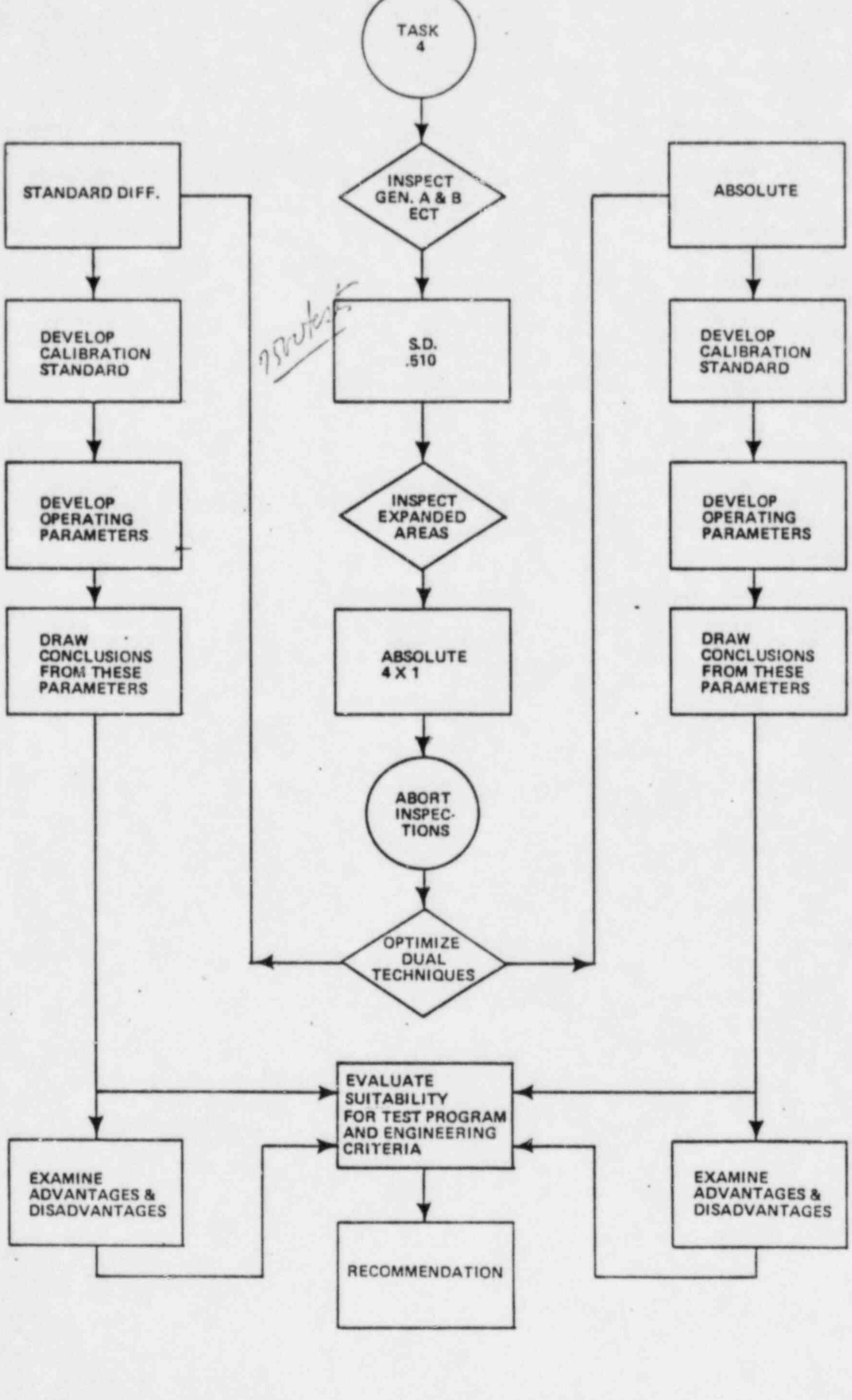
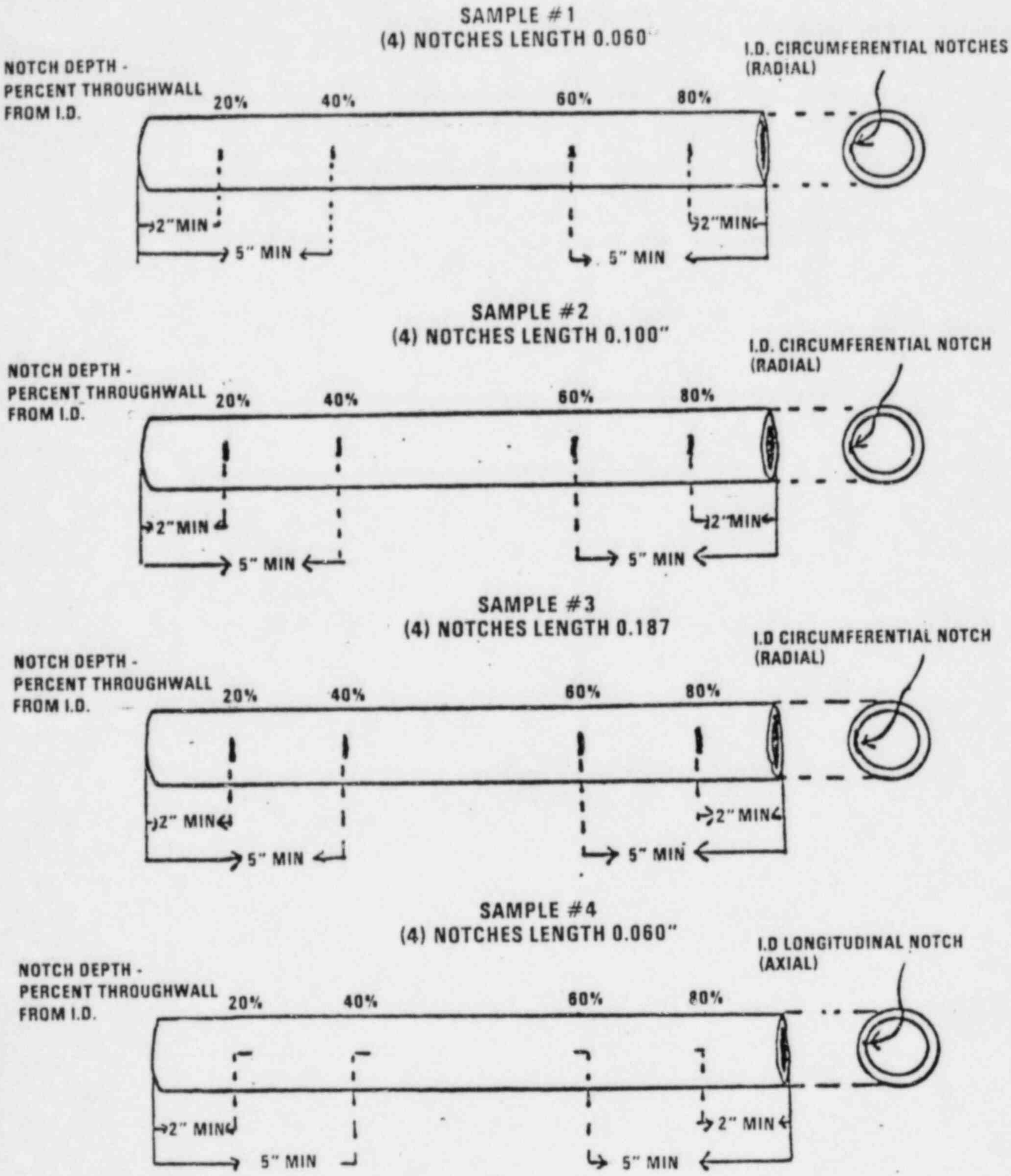
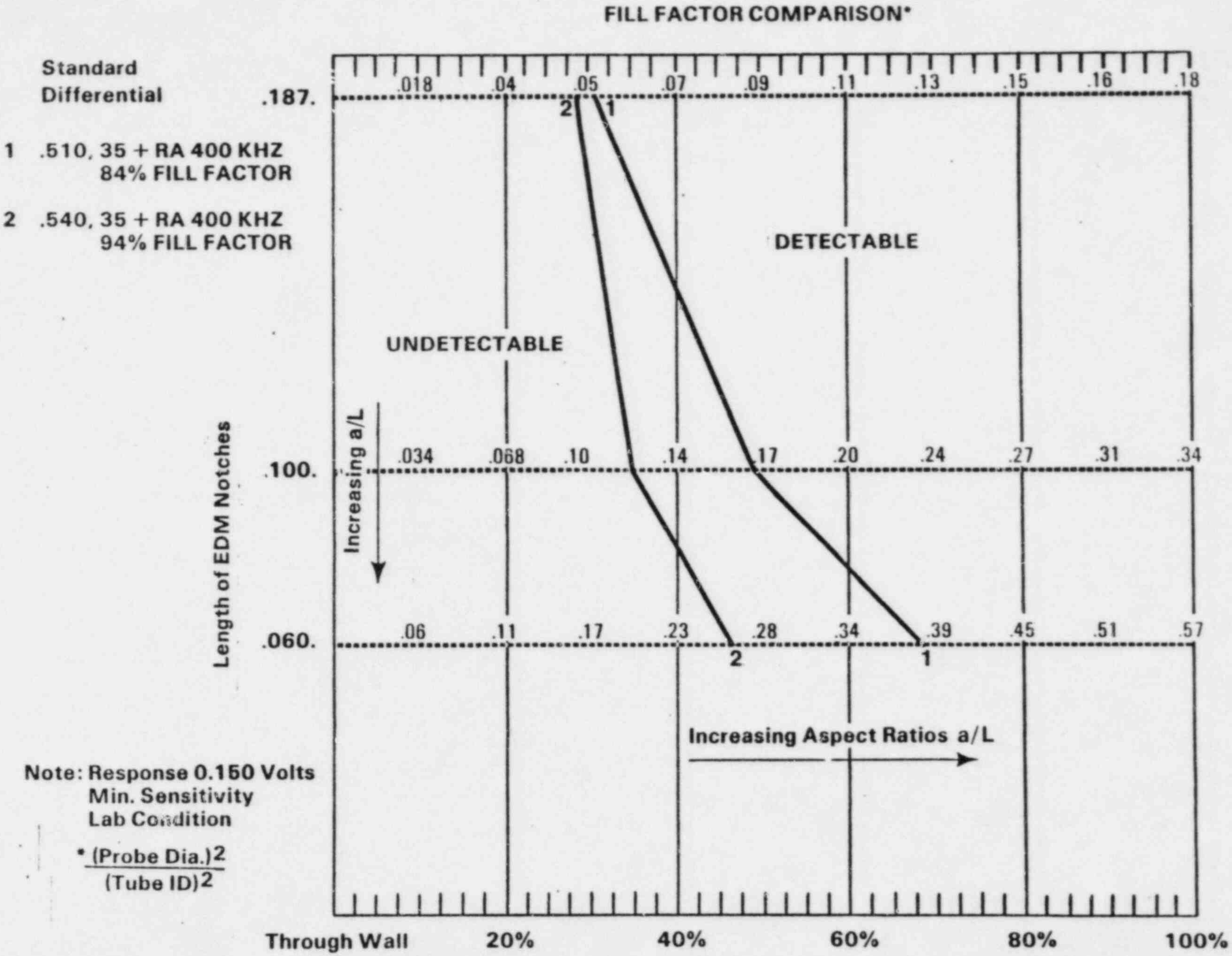


Figure V-2

OTSG TUBING DEFECT MOCKUPS





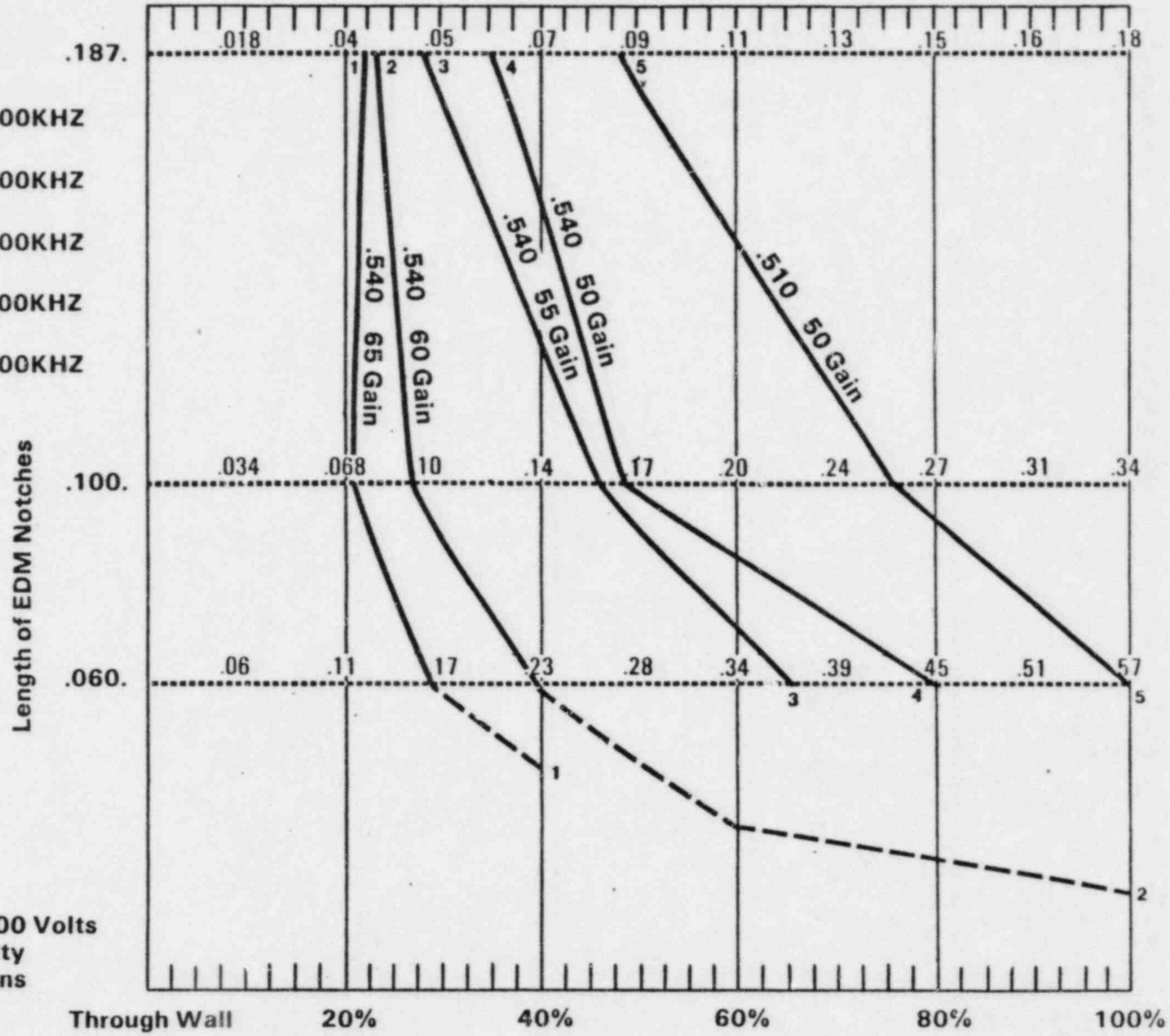
FILL FACTOR COMPARISON*
Standard
Differential
1 .510, 35 + RA 400 KHZ
84% FILL FACTOR
2 .540, 35 + RA 400 KHZ
94% FILL FACTOR
.187.
.018 .04 .05 .07 .09 .11 .13 .15 .16 .18
2 1
DETECTABLE
UNDETECTABLE
Increasing a/L
Length of EDM Notches
.100.
.034 .068 .10 .14 .17 .20 .24 .27 .31 .34
.060.
.06 .11 .17 .23 .28 .34 .39 .45 .51 .57
2 1
Increasing Aspect Ratios a/L
Note: Response 0.150 Volts
Min. Sensitivity
Lab Condition
* (Probe Dia.)2 / (Tube ID)2
Through Wall 20% 40% 60% 80% 100%

Figure V-3

GAIN COMPARISON FOR DETECTION PROBABILITY

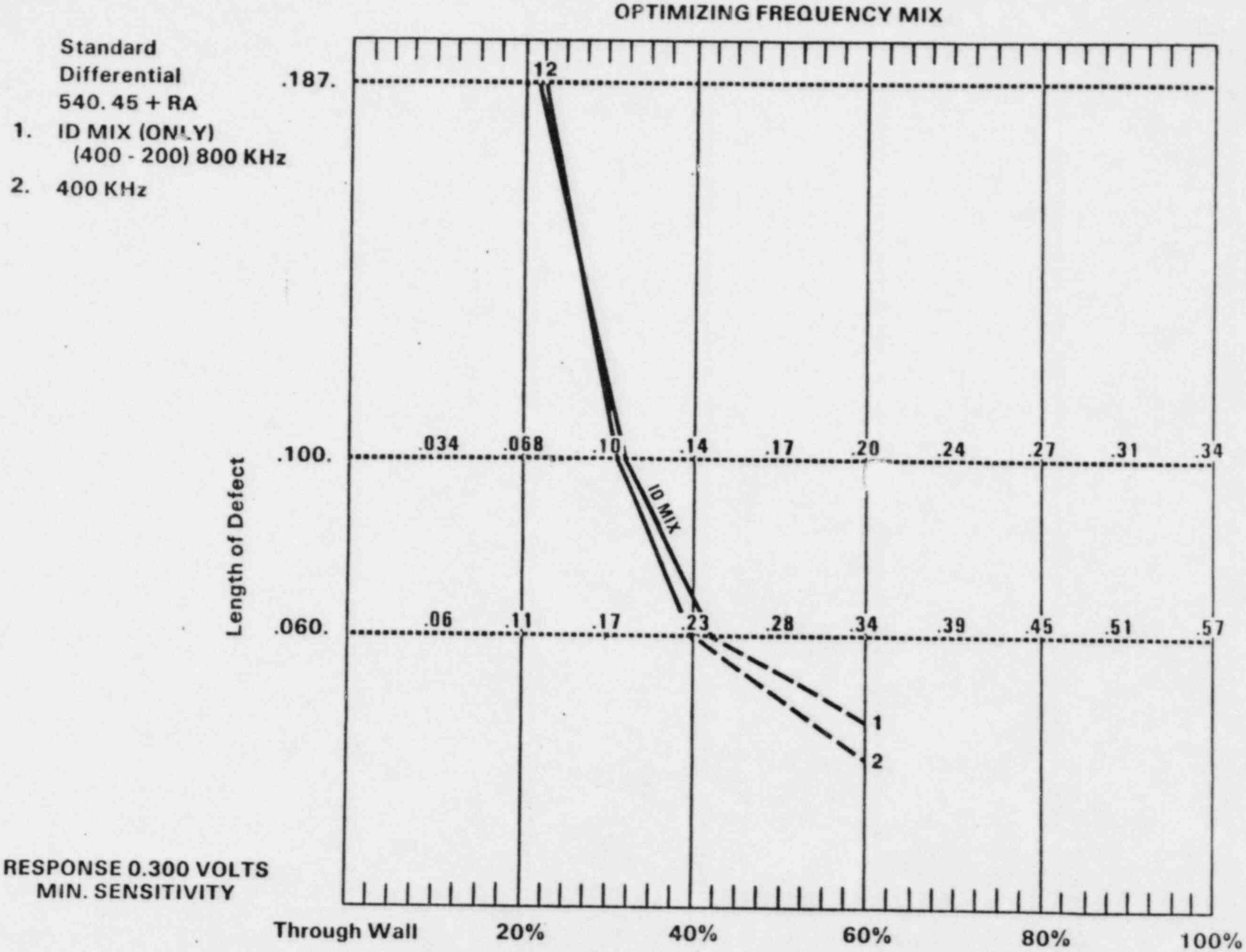
Standard
Differential
100 MV/Div.

1. .540, 50+RA, 400KHZ
2. .540, 45+RA, 400KHZ
3. .540, 40+RA, 400KHZ
4. .540, 35+RA, 400KHZ
5. .510, 35+RA, 400KHZ



Note: Response 0.300 Volts
Min. Sensitivity
Field Conditions

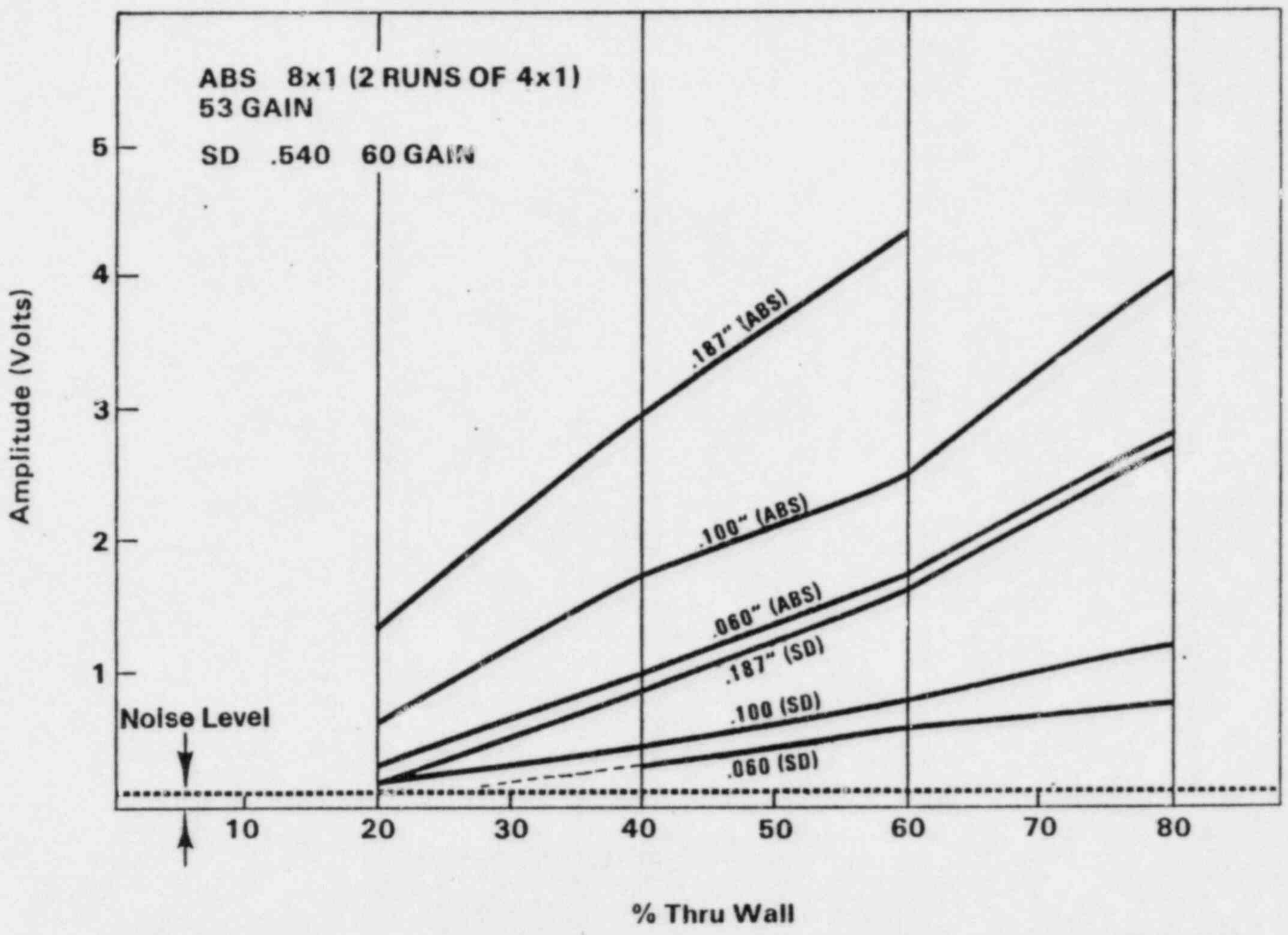
Figure V-7



OPTIMIZING FREQUENCY MIX
Standard
Differential
540. 45 + RA
1. ID MIX (ONLY)
(400 - 200) 800 KHz
2. 400 KHz
.187.
12
.100.
.034
.068
.10
.14
.17
.20
.24
.27
.31
.34
ID MIX
Length of Defect
.060.
.06
.11
.17
.23
.28
.34
.39
.45
.51
.57
1
2
RESPONSE 0.300 VOLTS
MIN. SENSITIVITY
Through Wall
20%
40%
60%
80%
100%

Figure V-9

AMPLITUDE RESPONSE
STANDARD DIFFERENTIAL VS 8x1 ABSOLUTE
SIMULATED DEFECTS 0.005" WIDE



RESULT CONCLUSIONS

STANDARD DIFFERENTIAL

	FILL FACTOR	GAIN	FREQUENCY	MAGNETIC SATURATION	CHART SENSITIVITY
OPTIMIZED PARAMETERS	.540 PROBE	60 - 65	400 KHZ BASE	PERMANENT MAGNET AFFIXED	100 MV/DIV
BENEFITS		INCREASED SENSITIVITY	ID MIX FOR TSP	REDUCED PERMEABILITY SIGNALS	INCREASED ANALYST'S ABILITY FOR INTERPRETATION FROM S.C.R.
	REDUCED PROBE CHATTER (NOISE)	SMALLER DEFECTS DETECTED (40% THRU WALL 0.060" CIRCUMFERENCE)	ID MIX TO REDUCE NOISE 200 } 400 } COMBINED 800 MIX		
	INCREASED RELIABILITY IN REPEATED RESULTS				

ABSOLUTE

	COIL COVERAGE	GAIN	FREQUENCY	MAGNETIC SATURATION	CHART SENSITIVITY
OPTIMIZED PARAMETERS	8 COILS	40 - 53	380 - 420	NOT ADAPTABLE FOR PERMANENT MAGNET	100 MV/DIV
BENEFITS	INCREASED TO 360° COVERAGE	HIGH RESPONSE SIGNAL WELL ABOVE NOISE	MINIMIZED RESONANCE AND CROSS TALK BETWEEN COILS		INCREASE ANALYST ABILITY FOR INTERPRETATION FROM S.C.R.

Recognized Characteristics

S.D.		Absolute	
Advantages	Disadvantages	Advantages	Disadvantages
• Durability	• Poor in expanded areas	• Expanded areas	• Poor durability
• Reliable percentage thru-wall calls	• Overly sensitive to some surface anomalies	• High response signals	• Coil to coil variation for response amplitude
• 360° Coverage	• Low voltage response	• Not overly sensitive to surface	• Unreliable percentage thru-wall calls
• Maintenance and analysis of data well established		• Signal distoration minimal (probe design)	• Maintenance of data analysis

Recommendation for Production Examination

I. S.D. 540 hi-gain most suitable for full production testing.

A) Why?

1. Excellent durability
2. Reliable percentage thru-wall calls
3. Maintenance and analysis of data well understood
4. Expanded area of tubes was not a factor

B) Recognized limitations can be resolved by second method

1. Over sensitivity to surface anomalies can be resolved by absolute
2. Low amplitude signals can be interrogated by absolute

II. Absolute as a dispositioning instrument.

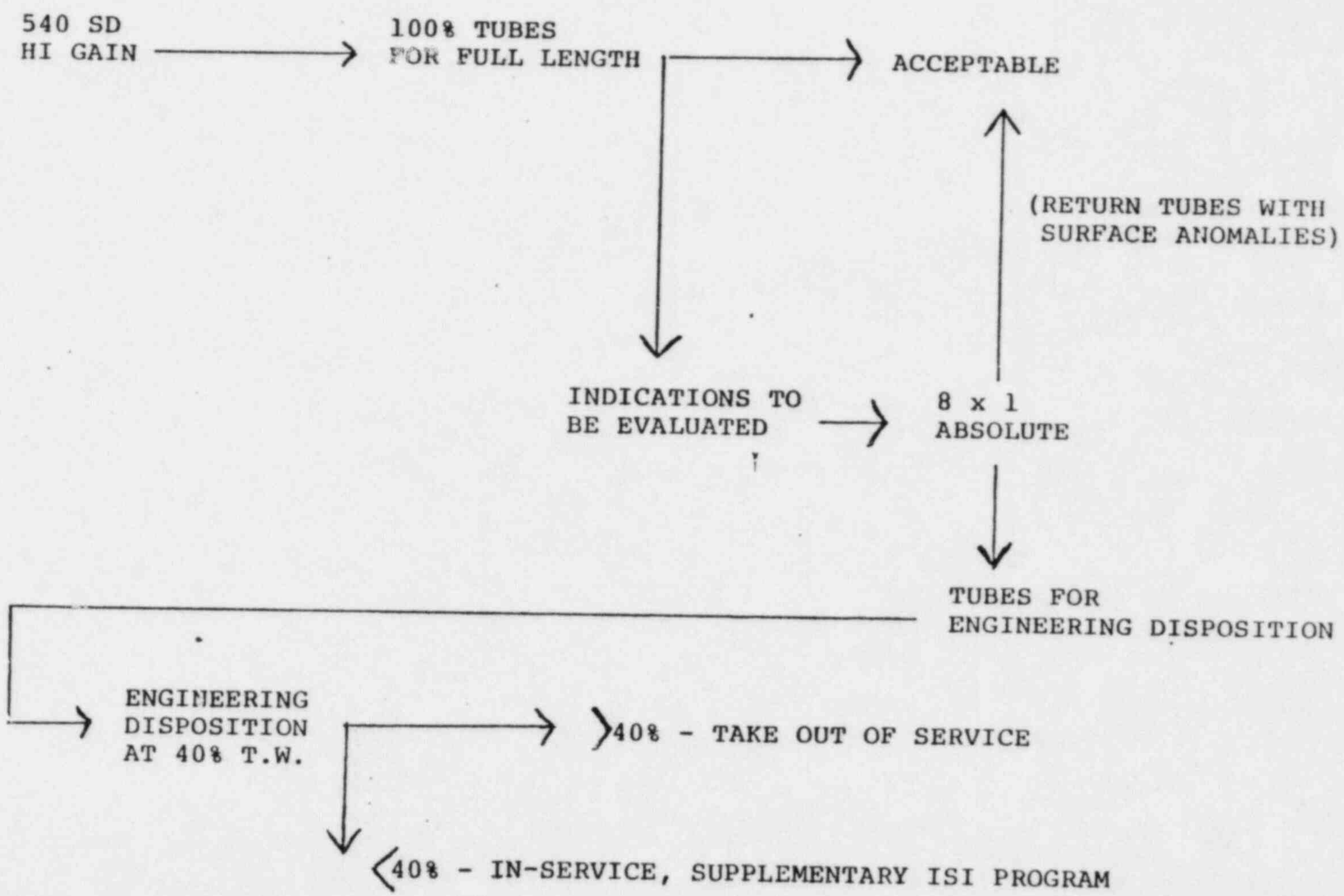
A) Why not for production?

1. Poor durability (0 to 100 tube coverage)
2. Unreliable percentage thru-wall calls

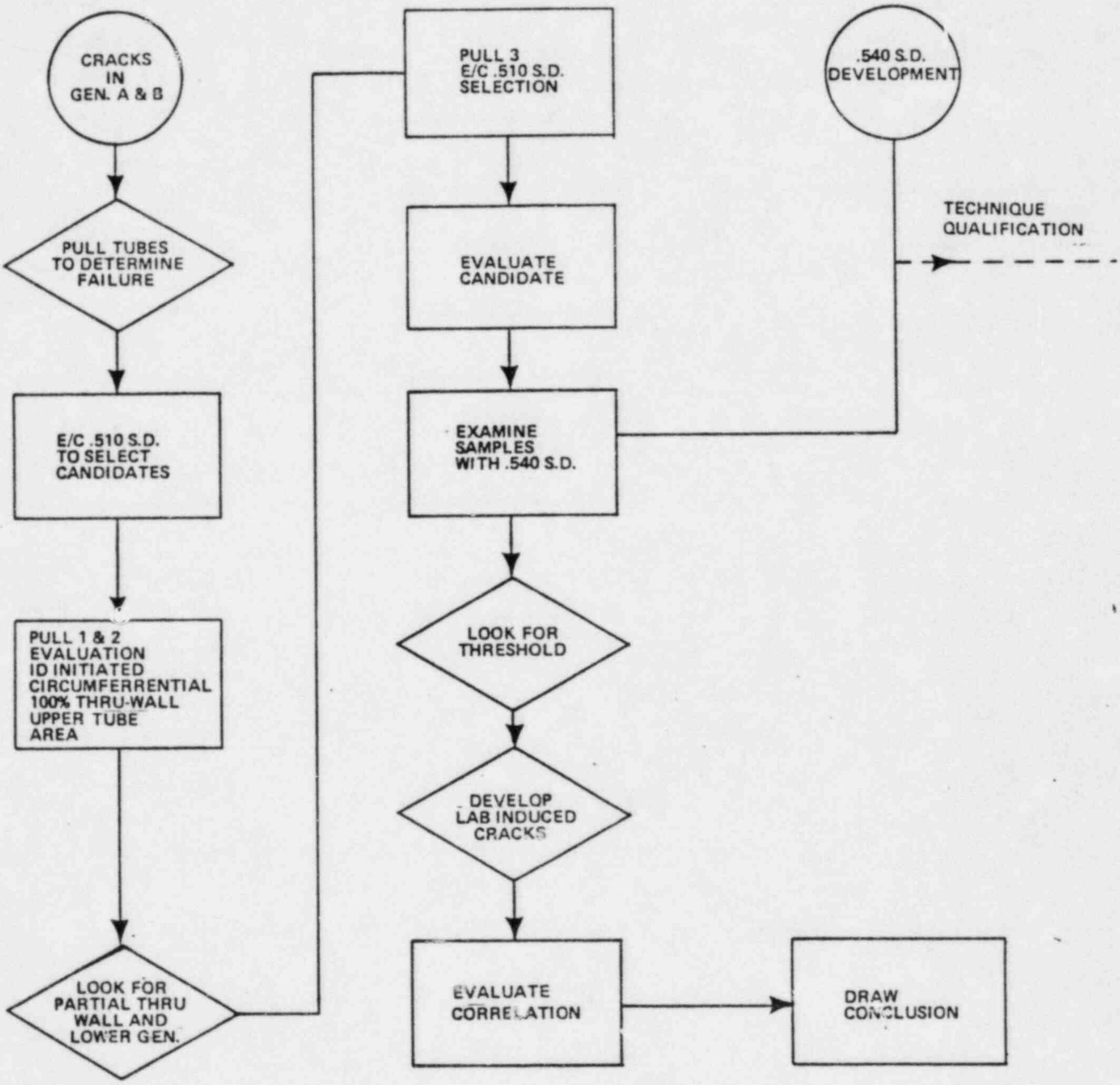
B) Why as a support technique?

1. Excellent support to S.D. limitations
   a. Surface anomalies
   b. Low amplitude
2. Signal distortion is minimal

FLOW CHART ON GPUN ECT PROGRAM
FOR DISPOSITIONING OTSG TUBES



EDDY CURRENT METALLOGRAPHY SUMMARY



S.D. BELOW ROLL TRANSITION

METALLURGICAL CORRELATION

GEN.	TUBES IN SAMPLE	NO. INDICATION REPORTED BY E/C	CONFIRMED INDICATIONS BY E/C	MISCALLS	OVERCALLS
A	12	23	23	0	0
B	3	5	5	0	0
	15	28	28	0	1?

metallograph exam shows no problem

NO. INDICATIONS REPORTED BY E/C 28

OVERCALL - 0

28

CONFIRMED INDICATION BY METALLOGRAPHY 28

MISCALLS 0

28

15 TUBE SAMPLE

100% AGREEMENT S.D.

ABSOLUTE METALLURGICAL CORRELATION

Below .25" From Top of Tube

GEN.	TUBES IN SAMPLE	NO. INDICATIONS REPORTED BY E/C	CONFIRMED INDICATIONS BY METALLOGRAPHY	MISCALL BY E/C	OVERCALLS BY E/C
A	16	25	22*	2	3
B	2	2	2	0	0
	18	27	24	2	3

NO INDICATIONS REPORTED BY E/C	27
OVERCALLS	- 3
	24

CONFIRMED INDICATIONS BY METALLOGRAPHY	24
MISCALLS	+ 2
	26

18 TUBE SAMPLE (INCLUDING ROLL TRANSITION) — 92% AGREEMENT ABSOLUTE

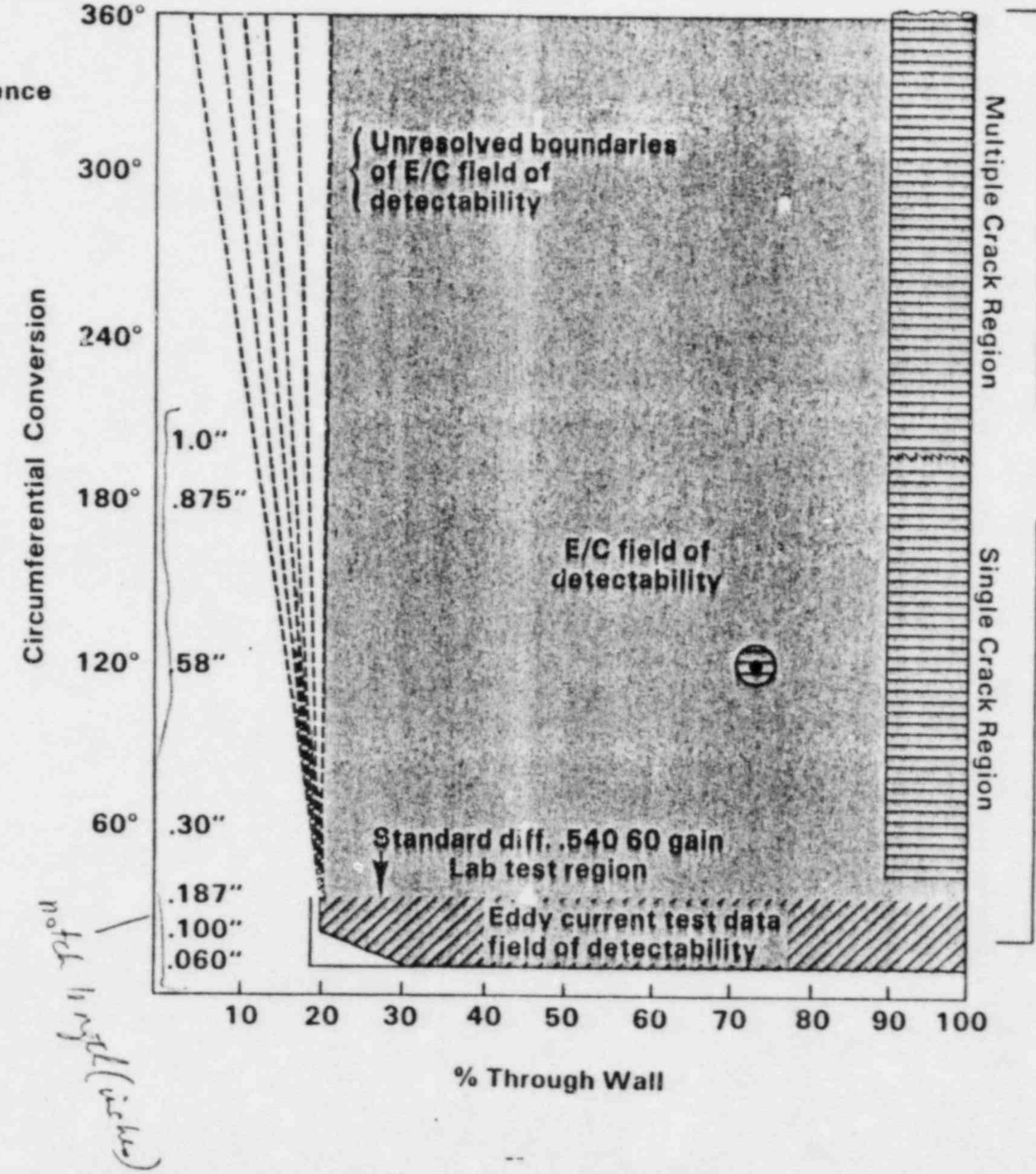
18 TUBE SAMPLE (EXCLUDING ROLL TRANSITION) — 100% AGREEMENT

* - Work performed with 4x1

ASPECT RATIO COMPARISON

METALLOGRAPHY ACTUAL CIRCUMFERENTIAL DEFECTS
E/C SYNTHETIC DEFECTS ORIENTED IN WORST GEOMETRY

Note: (1) 1.75" max.
ID circumference



Summary of metallurgical analysis tubes pulled from generators A & B

LAB INDUCED CRACKS

o 8 SAMPLES TESTED

o HIGH GAIN SD TECHNIQUE

- REPORTED INDICATIONS 7*

  * 5 SAMPLES WERE WITH 540 HIGH GAIN

- CONFIRMED BY METALLOGRAPHY 5

o ABSOLUTE TECHNIQUE

- REPORTED INDICATIONS 5

- CONFIRMED BY METALLOGRAPHY 5

o USING GPUN RECOMMENDED ECT PROGRAM

8 SAMPLES TESTED

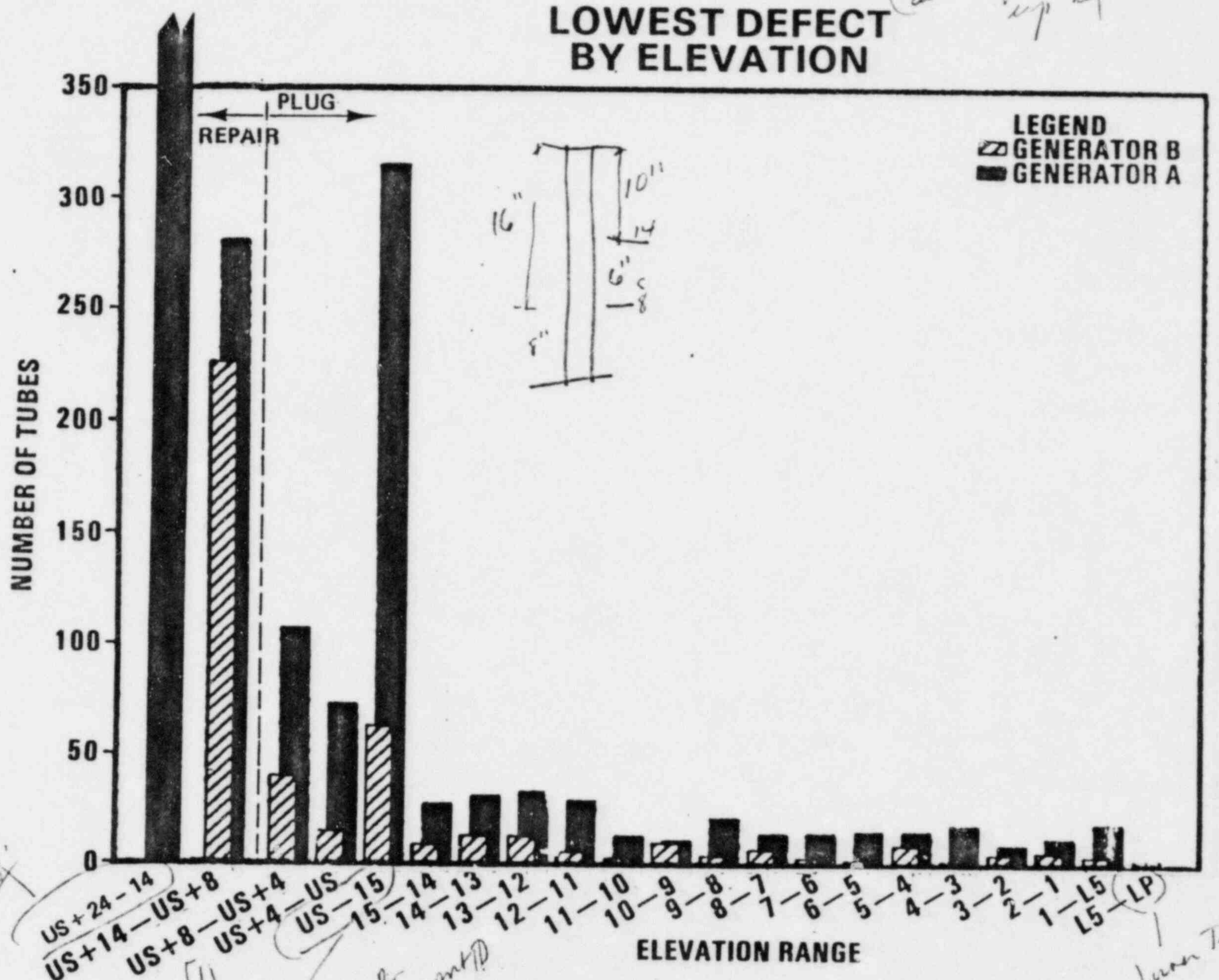
- NO. DISPOSITIONED AS ACCEPTABLE 4

  METALLOGRAPHY CONFIRMATION 100%
  (includes two samples with <40% thru wall)

- NO. DISPOSITIONED REJECT 4

  METALLOGRAPHY CONFIRMATION 100%

LOWEST DEFECT BY ELEVATION



PLANT RETURN TO SERVICE SAFETY EVALUATION OVERVIEW

PLANT SAFE TO OPERATE

- **FAILURE MECHANISM UNDERSTOOD**
  - METALLURGICAL TESTS
  - CORROSION TESTS
- **MEASURES TAKEN TO PREVENT RECURRENCE**
  - OXIDIZE AND/OR REMOVE SULFUR
  - REMOVE THIOSULFATE
  - PREVENT FUTURE CONTAMINATION
  - IMPROVE CHEMISTRY CONTROLS
- **RCS AND SUPPORTING SAFETY SYS. UNDAMAGED**
  - RCS INSPECTION
  - SUPPORTING SYSTEMS INSPECTION
- **STEAM GENERATORS OPERABLE**
  - REPAIR QUALIFICATION EXPANSION PLUGS
  - UNREPAIRED TUBE SECTIONS OPERABLE
  - TESTING PROGRAM
- **NO ADVERSE ENVIRON. IMPACT**
  - APPENDIX I CALCULATIONS

FAILURE MECHANISM ADEQUATELY UNDERSTOOD

- METALLURGICAL TEST RESULTS
  - STRESS ASSISTED INTERGRANULAR CORROSION
  - INITIATED FROM TUBE INSIDE SURFACE
  - SULFUR PRESENT ON FRACTURE SURFACES
  - SENSITIZED TUBING MATERIAL

- CORROSION TEST RESULTS
  - THIOSULFATE CAN PRODUCE SIMILAR CRACKING
  - AN OXIDIZING POTENTIAL IS REQUIRED
  - TUBING MATERIAL PROPERTIES HAVE STRONG EFFECT ON CRACKING SUSCEPTIBILITY
  - CRACK GROWTH RATES ARE RAPID

PREVENT RECURRENCE

- PROGRAM UNDER DEVELOPMENT TO OXIDIZE AND/OR REMOVE SULFUR

- THIOSULFATE REMOVED FROM PLANT

- PREVENT INTRODUCTION OF CONTAMINANTS

- INCREASE SAMPLING FREQUENCY ON SOME ANALYSIS

- NEW SPECIFICATIONS ON:
    - LITHIUM
    - CHLORIDES
    - SULFATE
    - SODIUM
    - PH
    - CONDUCTIVITY
    - SILICA
    - CALCIUM
    - MAGNESIUM

RCS INSPECTION

- LARGE NUMBER OF COMPONENTS INSPECTED
- WIDE RANGE OF MATERIALS REPRESENTED
- WET, DRY AND INTERFACE AREAS INSPECTED
- UT, PT, ECT, VISUAL AND DESTRUCTIVE EXAMINATIONS USED

NO EVIDENCE OF ANY INTERGRANULAR CRACKING

SUPPORTING SYSTEMS INSPECTION

- SYSTEMS INSPECTED IN 1982 AS PART OF THREE YEAR SUPPLEMENTARY ISI PROGRAM WHICH WAS INITIATED DUE TO IGSCC IN SPENT FUEL SYSTEM IN 1979
  - SPENT FUEL
  - DECAY HEAT
  - BULDING SPRAY
- VISUAL AND UT METHODS USED
- NO DISCREPANCIES NOTED IN THESE SYSTEMS
- OTHER SYSTEM INSPECTIONS IN PROGRESS

STEAM GENERATOR REPAIR

- KINETIC EXPANSION
  - JOINT MEETS DESIGN BASIS
- PLUGGED TUBES
  - THREE TYPES OF PLUGS

    WELDED TAPERED PLUG WITH STABILIZER

    EXPLOSIVE PLUG

    ROLLED PLUG
  - ALL TYPES PREVIOUSLY QUALIFIED AT OTHER UNITS
  - ROLLED PLUG QUAL. PROGRAM FOR TMI-1 COMPLETED IN FEBURARY 1982
  - INTERACTION BETWEEN WELDED AND EXPLOSIVE PLUGS AND EXPANSION ANALYZED - NO IMPACT
  - INTERACTION BETWEEN ROLLED PLUG AND EXPANSION - TEST PROGRAM IN PROGRESS
  - OPERATION WITH PLUGGED TUBES ANALYZED - NO IMPACT ON OPERATIONAL OR SAFETY LIMITS

UNREPAIRED TUBE SECTIONS ARE OPERABLE

- DAMAGE MECHANISM ARRESTED
  - CORROSION TESTS - SHORT AND LONG TERM
  - FLAW GROWTH PROGRAM

- DEFECTS THAT COULD PROPAGATE BY MECHANICAL LOADS ARE DETECTABLE AND REMOVED FROM SERVICE
  - ECT CALIBRATION PROGRAM
  - CALCULATIONS OF THRESHOLD FOR PROPAGATION

- UNDETECTABLE DEFECTS ARE ACCEPTABLE
  - SMALL CRACKS WILL NOT PROPAGATE MECHANICALLY
  - LOCAL IGA IS ACCEPTABLE

- A SMALL NUMBER OF "MISSED" DETECTABLE DEFECTS IS ACCEPTABLE
  - SMALL PROBABILITY WITH 100% INSPECTION
  - WILL LEAK DETECTABLY BEFORE FAILURE

- TEST PROGRAM
  - LEAK TESTS
  - COOLDOWN TRANSIENT TESTS
  - "SOAK" TIME TO DETECT LEAKS AND ANY CRACKS THAT PROPAGATE.

ENVIRONMENTAL IMPACT

- ASSUMPTIONS
  - 6 GPH LEAKRATE
    (50 TIMES REPAIR LEAKRATE GOAL)
  - .03% FAILED FUEL
    (MAXIMUM EXPERIENCED AT TMI-1)
  - BASED ON EXISTING PROCESSING CAPABILITY

- RESULTS
  - MAXIMUM HYPOTHETICAL OFF-SITE DOSES:

SOURCE	CALCULATED DOSE	APP. I LIMIT FOR TMI 1
IODINE & PARTICULATES	1.5 MREM/YR	15 MREM/YR
NOBLE GASES		
GAMMA	4.2 MRAD/YR	10 MRAD/YR
BETA	3.4 MRAD/YR	20 MRAD/YR
LIQUID EFFLUENT		
WHOLE BODY	3×10^{-4} MREM/YR	3 MREM/YR
LIVER	5×10^{-4} MREM/YR	10 MREM/YR

STEAM GENERATOR

POST REPAIR TEST PROGRAM

LEAK TESTS

- COLD:

  DRIP TEST

  SECONDARY SIDE FLOODED AT 150 PSIG

  PRIMARY SIDE DRY

  BUBBLE TEST

  SECONDARY SIDE PRESSURIZED WITH NITROGEN AT 150 PSIG

  PRIMARY FLOODED ABOVE UTS

- HOT:

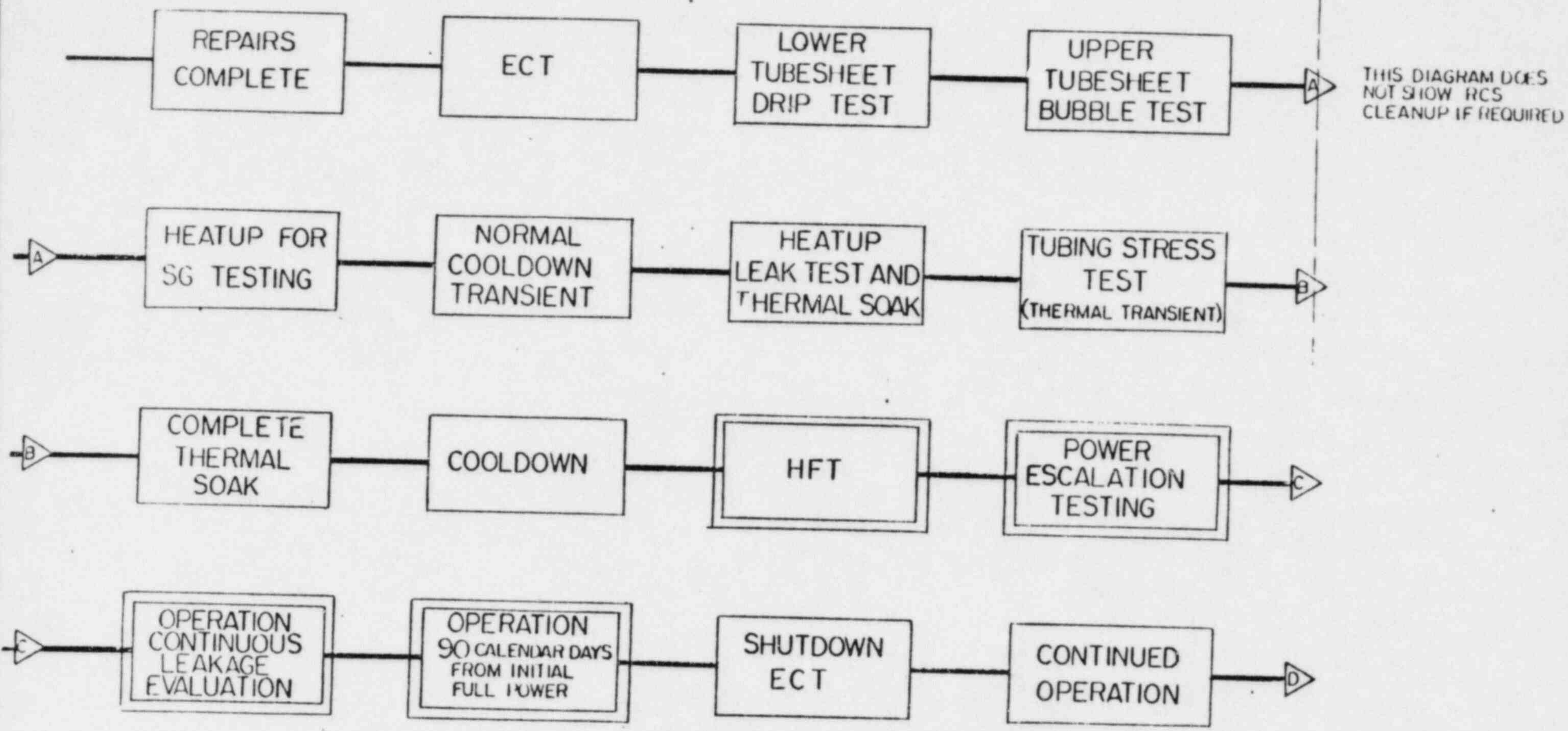
  OPERATIONAL LEAK TEST (1500 PSI DELTA P)

  PRIMARY 2285 PSIG - SECONDARY 785 PSIG

PRECRITICAL OPERATIONAL TESTS

- HEATUP
- SOAK TO MONITOR LEAKAGE
- COOLDOWN AT 70-100°F/HR FOR 1-2 HRS. (500-1100 LB. TENSION)
- HEATUP
- SOAK TO MONITOR LEAKAGE
- ACCELERATED COOLDOWN AT A RATE AND FOR A PERIOD TO OBTAIN ~ 110% OF NORMAL COOLDOWN LOADS
- HEAT UP
- SOAK TO MONITOR LEAKAGE
- COOLDOWN AT 70-100°F/HR TO COLD SHUTDOWN CONDITIONS (1100 LB. TENSION)

STEAM GENERATOR POST REPAIR TESTING SEQUENCE



NOTE:

DOUBLE LINE BOXES INDICATE NORMAL PLANT TESTING OR OPERATIONS

Flow Induced Vibration
Analysis Overview

Objective

Calculate the threshold between stable and and unstable crack growth based only on mechanical loading in a PWR environment

Compare this threshold to the ECT detectability and demonstrate that ECT has located cracks which would be unstable (ie: fail by fatigue crack propagation within 40 years)

Basis

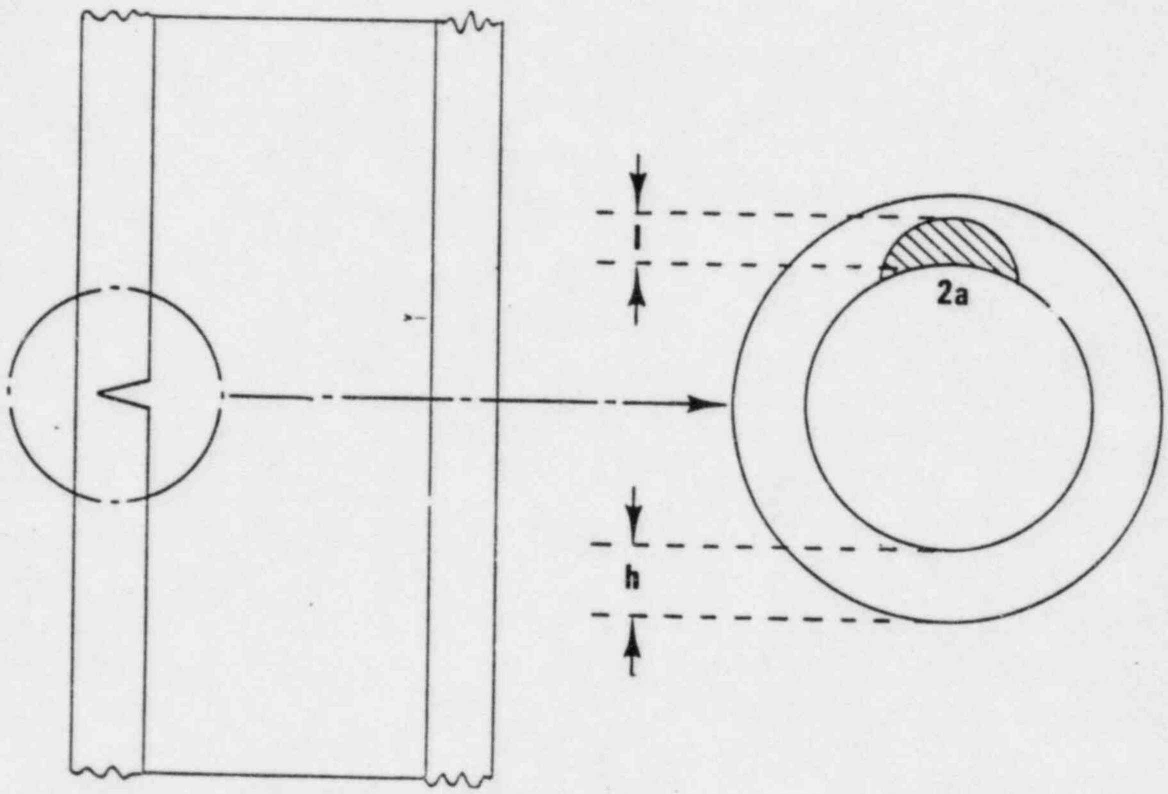
Precritical hot functional testing will confirm that a rapidly progressing corrosion process will not cause tube leaks once critical

Prior to criticality we require assurance that FIV will not cause rapid failure of OTSG tubes

FLOW INDUCED VIBRATION

A) FRACTURE MECHANICS MODEL

OTSG TUBE



GEOMETRY

- PART THROUGH-WALL CIRCUMFERENTIAL FLAWS IN TUBES
- ASPECT RATIO VARIED

$\frac{l}{h}$	.2	.4	.6	.8
$\frac{a}{h}$	1	2	4	8

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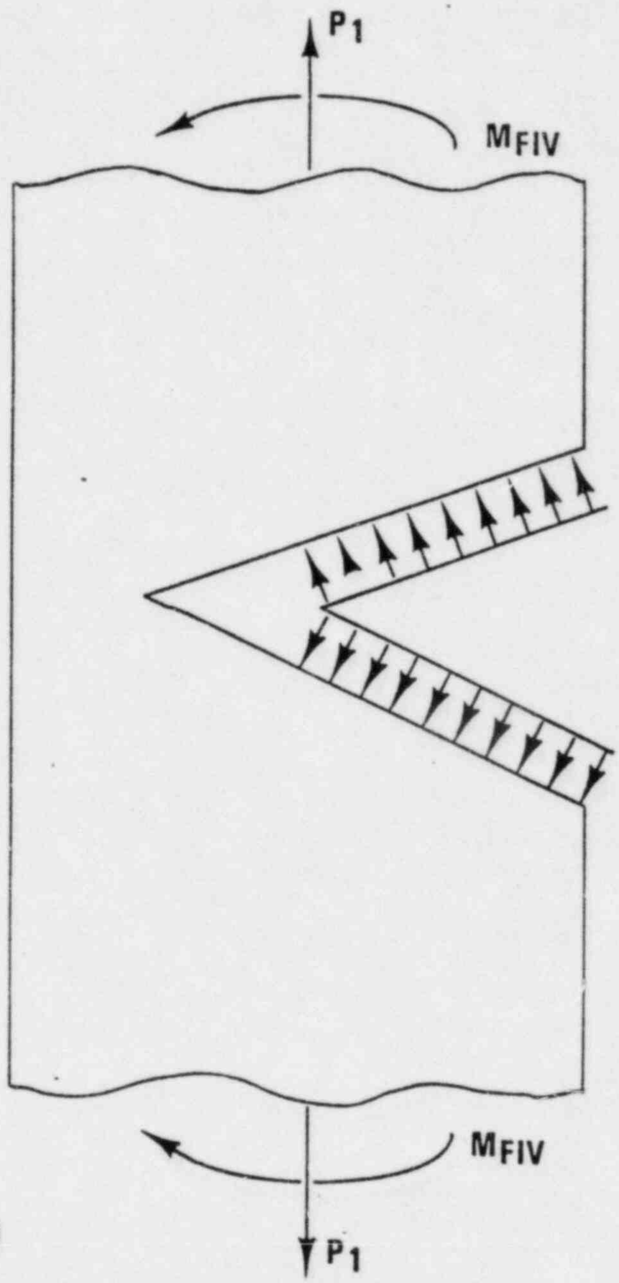
FLOW INDUCED VIBRATION

B) FRACTURE MECHANICS MODEL LOADING



1) P_1 AXIAL LOAD

2) BENDING STRESS DUE TO FLOW INDUCED VIBRATION (M_{FIV})

3) INTERNAL PRESSURE ACTING ON PARTING FACES OF CRACK

4) SOLUTION OF STRESS INTENSITY PROBLEM BY PROF. F. ERDOGAN, LEHIGH UNIV., BETHLEHEM, PA.

10/18/82

Flow Induced Vibration

C) Axial Tube Load Reflects

1. Stretch of steam generator due to pressure in heads on primary side

2. Elastic deformation of tubesheet at center-line (opposing stretch)

3. Tube longindinal stress from internal pressure (poisson's effect)

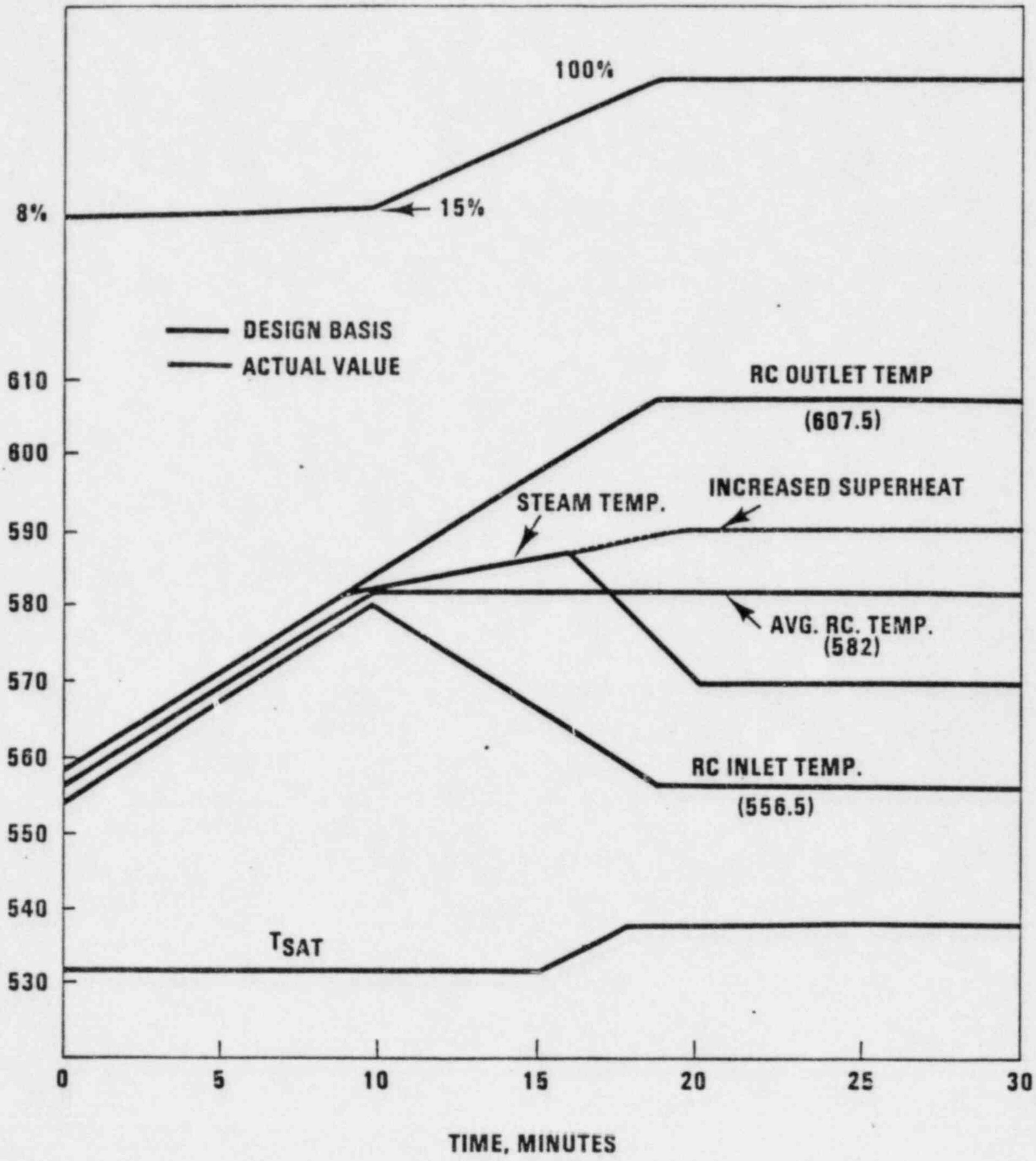
4. Residual axial load from fabrication

5. Shell-to-tube temperature difference, including higher than design basis superheat

   - used + 500 lb_f axial tensile load
   - TMI-2 instrumentation showed 0 to +500 lb_f at > 40% power

10/18/82

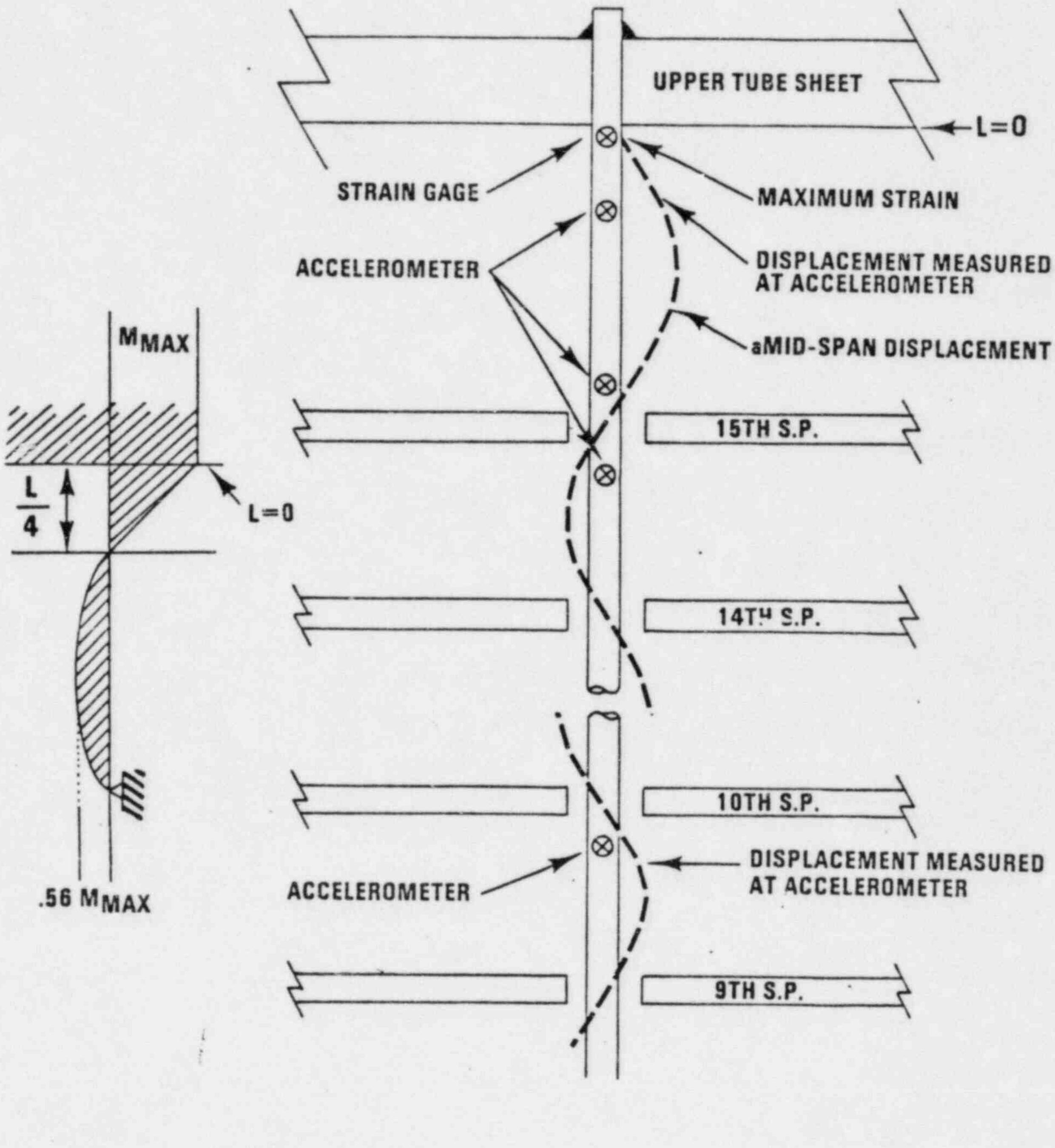
TMI-1 SUPERHEAT - DESIGN BASIS VS ACTUAL



10/18/82

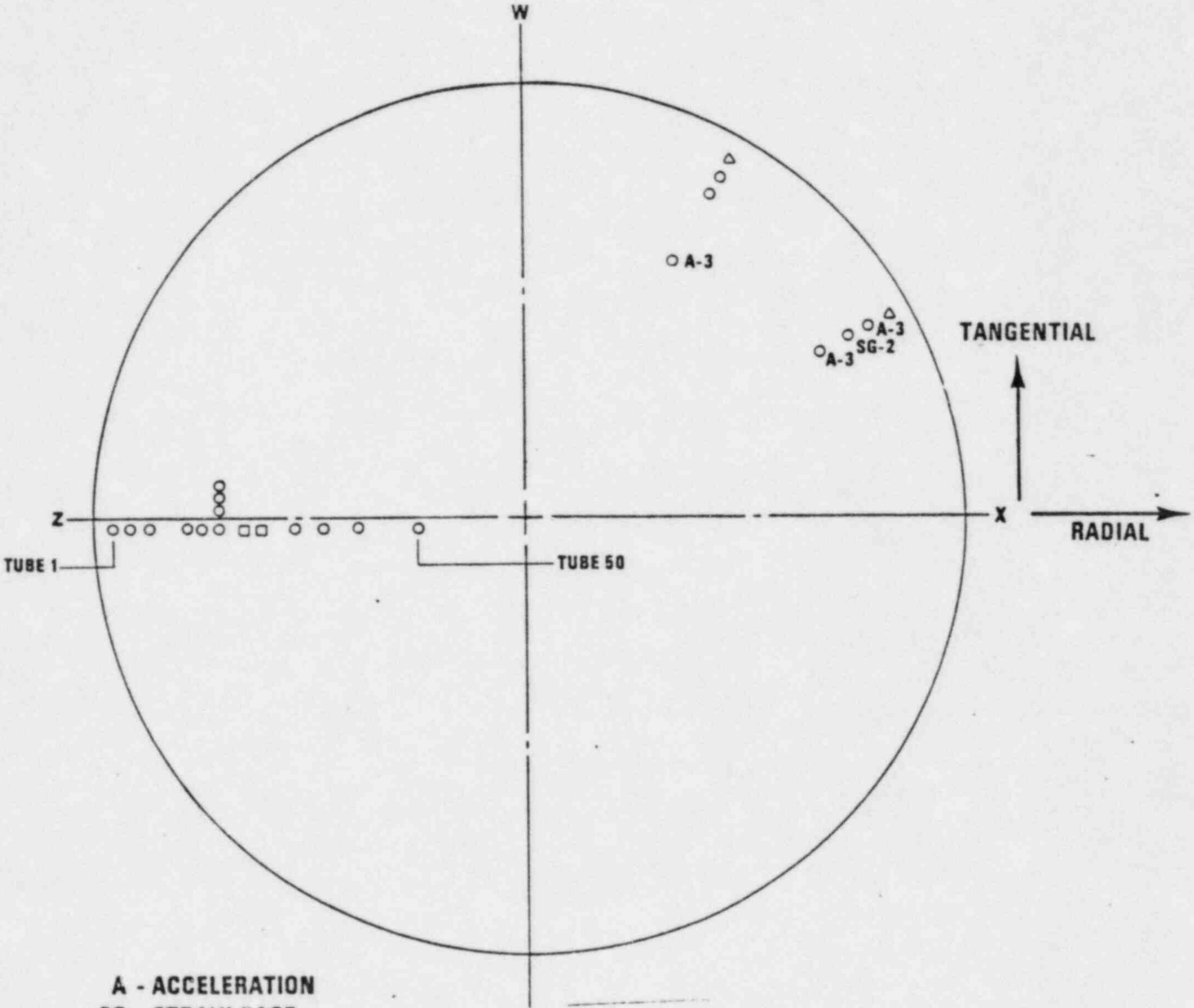
FLOW INDUCED VIBRATION

D) FIV BENDING STRESS - TMI-2 INSTRUMENTATION



- DEFECT CONSIDERED TO BE AT L=0 - LOCATION OF MAXIMUM BENDING STRESS
- TMI-2 FIV RESULTS FROM EPRI NP-1876

TMI-2 FIV INSTRUMENTATION LOCATION



A - ACCELERATION
SG - STRAIN GAGE
□ - SLEEVED TUBE
Δ - ACCELEROMETER LOCATED BETWEEN 9 AND 10 SUPPORT PLATE

- INSTRUMENTATION BOTH ON TUBE LANE AND IN QUADRANT WITH MAIN STEAM OUTLET
- LANE TUBES EXHIBITED HIGHEST FIV RESPONSE
- HIGHEST RESPONSE VALUES USED IN GPUN'S ANALYSIS

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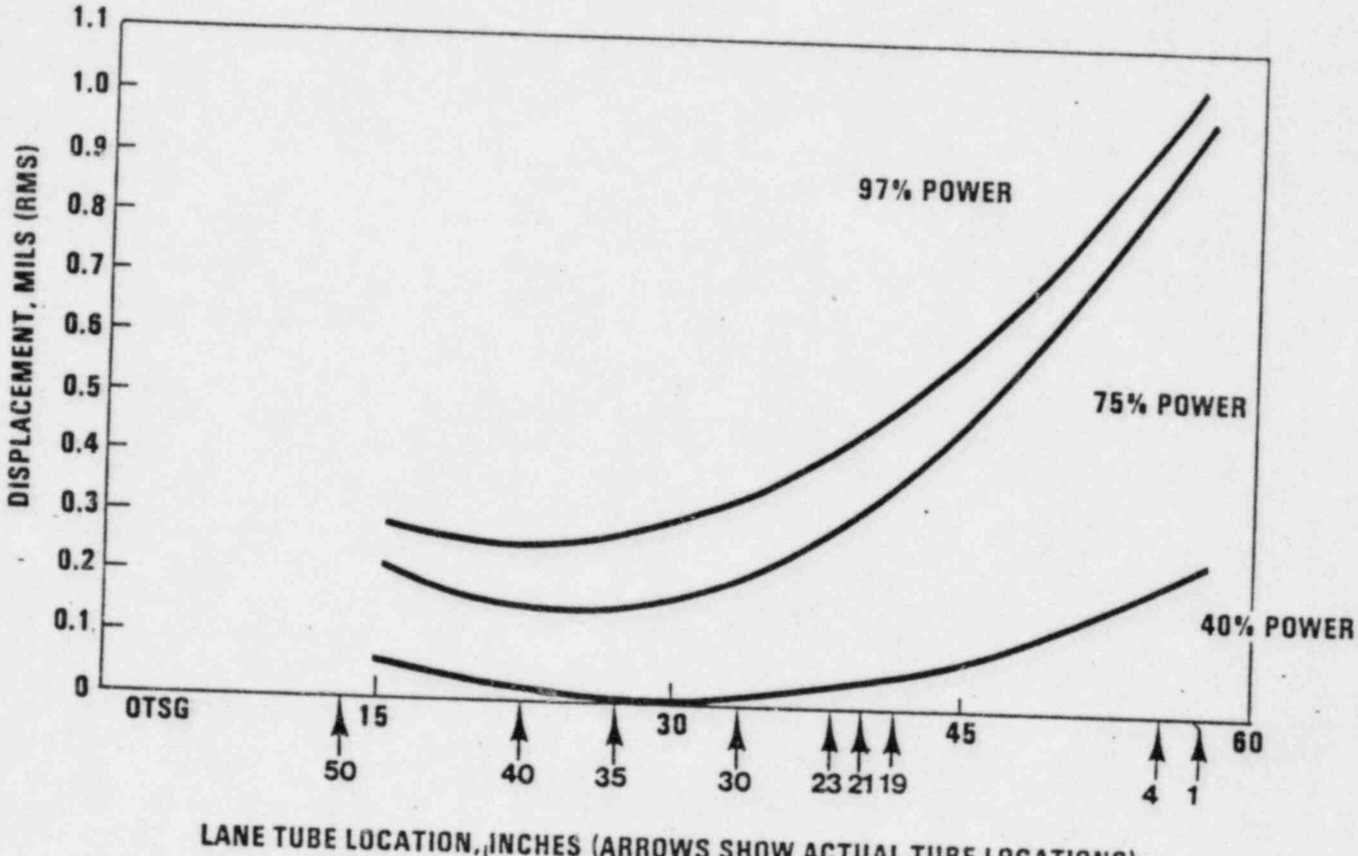
TMI-2 FIV INSTRUMENTATION RESULTS - STEADY STATE TANGENTIAL DISPLACEMENT



- STEADY STATE DEFLECTION FOR FRACTURE MECHANICS ANALYSIS = 3 x MAX RMS VALUE = 3 MILS.
- ONE CAN SAY WITH A CONFIDENCE LEVEL OF 98% THAT FOR A GAUSSIAN DISTRIBUTION THE MAXIMUM AMPLITUDE WILL NOT EXCEED THREE TIMES THE RMS.

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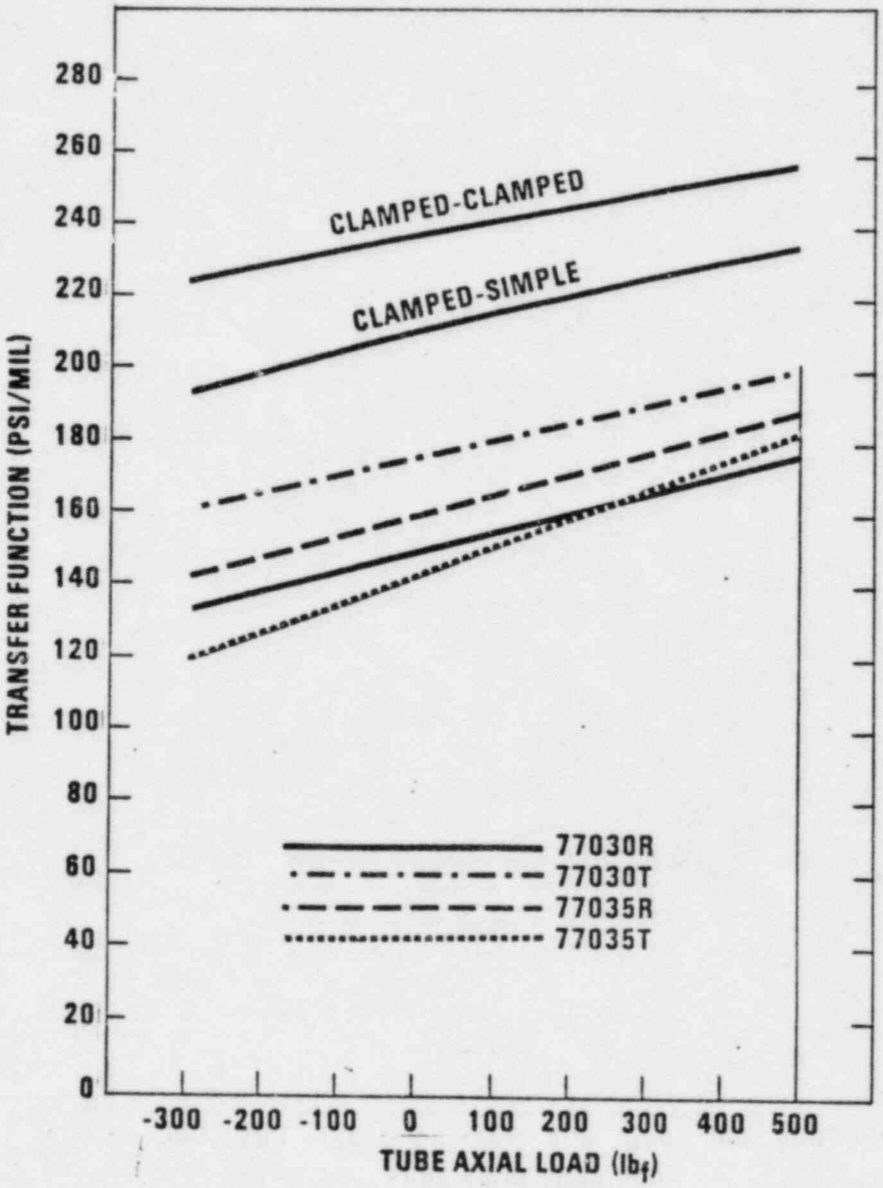
TMI-2 FIV Instrumentation Results - Transients

PEAK HALF-AMPLITUDE DISPLACEMENTS, MILS	75% POWER, PUMP A1 TRIP	3 RC PUMP UNBAL. OTSG OPERATION(a)	90% POWER, REACTOR/ TURBINE	97% POWER, TURBINE TRIP
TUBE 77001 (LANE)	3.7	3.0	3.8	3.4
77050 (LANE)	1.5	1.9	14.9	5.4
40113 (BUNDLE)	2.4	2.4	3.3	9.1
12068 (10TH SPAN)	0.6	1.0	0.8	1.7

TMI-2 FIV INSTRUMENTATION

BENDING STRESS TRANSFER FUNCTION VS ESTIMATED AXIAL LOAD



- RELATION TO OBTAIN BENDING STRESS AT TUBESHEET (L=0) BASED ON TUBE DEFLECTION IN ORDER TO OBTAIN BENDING MOMENT

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Flow Induced Vibration

E) OTSG Tube Fracture Mechanics Evaluation

- Loads

  Axial tension, $F_{ax} = 500\ lb_f$

  Bending Moment = 23.73 in - lb
  (FIV) @ 75 Hz

  Pressure acting on parting faces
  $\Delta p = 1245\ lb/in^2$

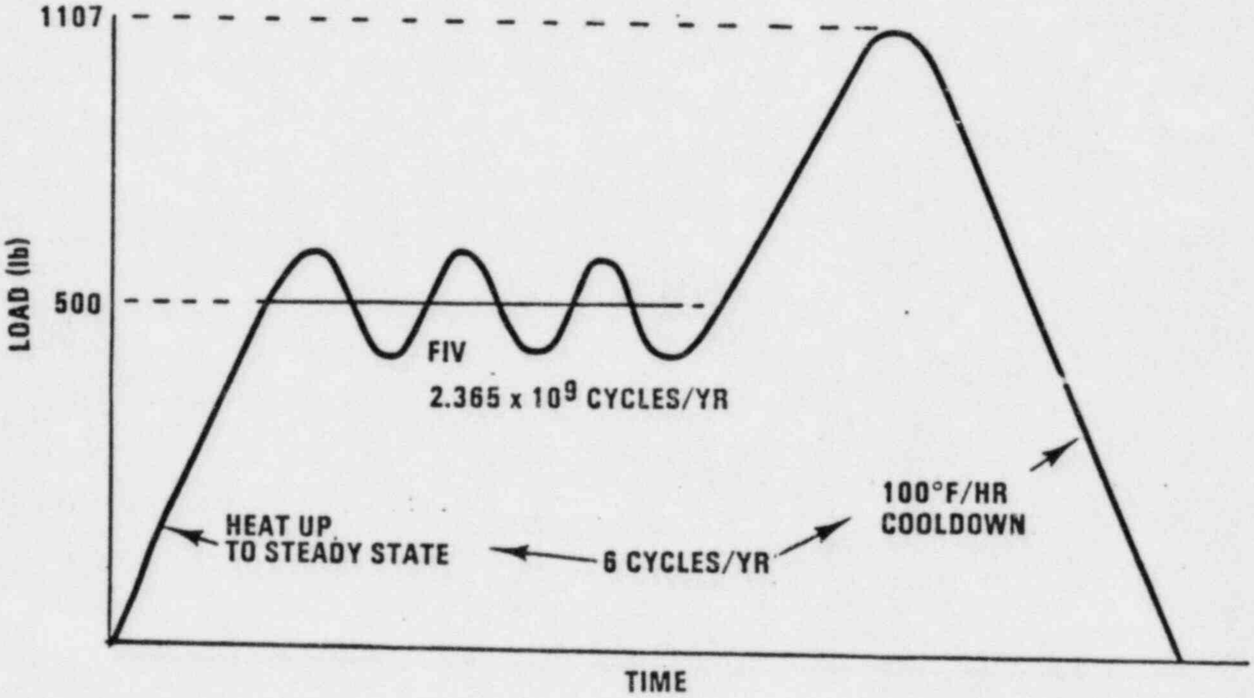
- Propagation threshold, ΔK_{Th}

  The threshold ΔK implies a stress intensity factor range below which an initiated crack will not propagate

FLOW INDUCED VIBRATION

F) LOAD CYCLE APPLIED

- FOR F_{AX}=500 lb, ALTERNATING LOAD IS FIV ONLY
- 40 YEARS OF LOAD CYCLING



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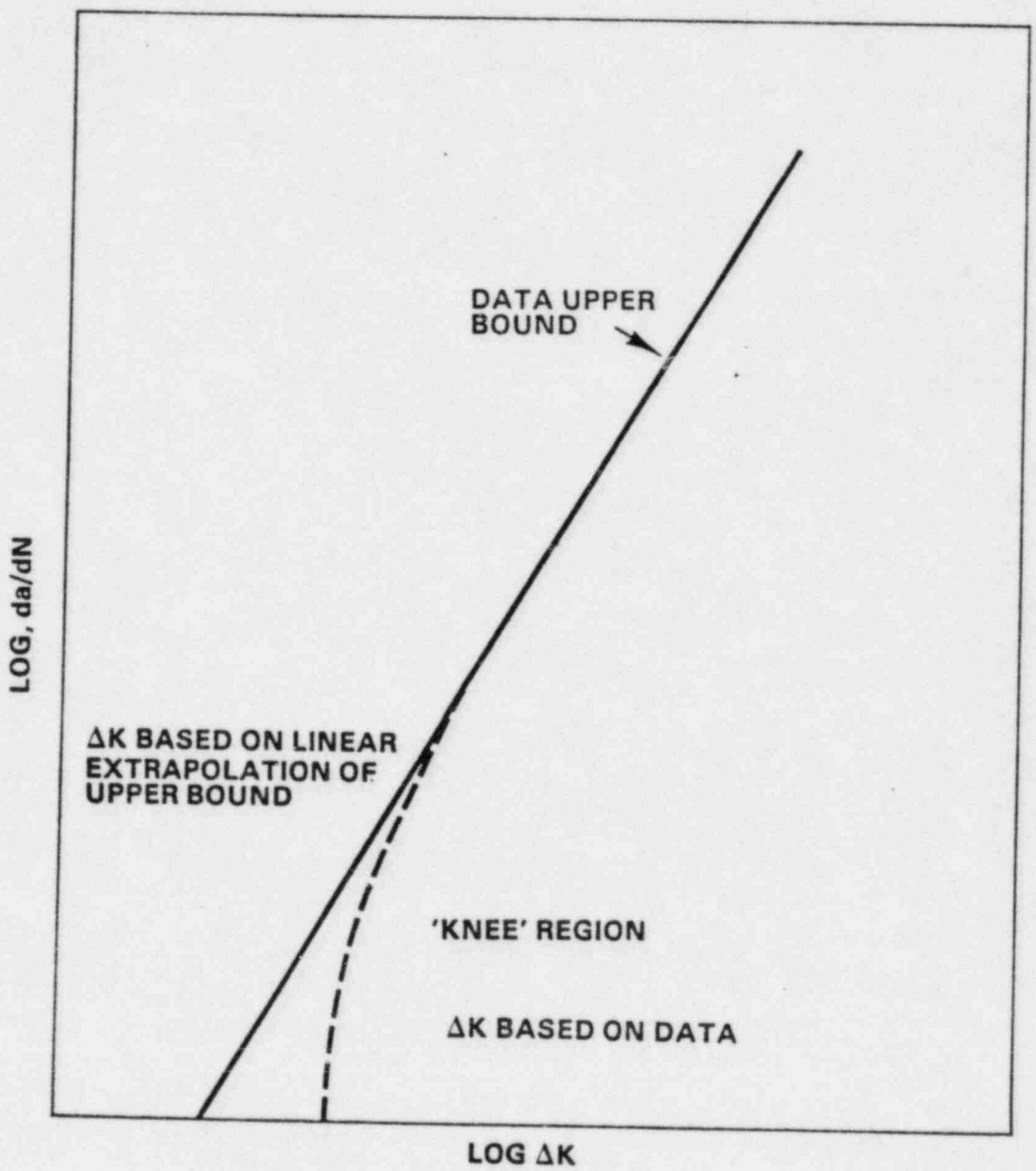
GENERIC THRESHOLD STRESS INTENSITY



- NUREG/CR 1319 DTD JAN. 1980
- SCHEMATIC REPRESENTATION OF THE LINEAR EXTRAPOLATION OF THE UPPER BOUND LINE TO APPROXIMATE THE THRESHOLD ΔK

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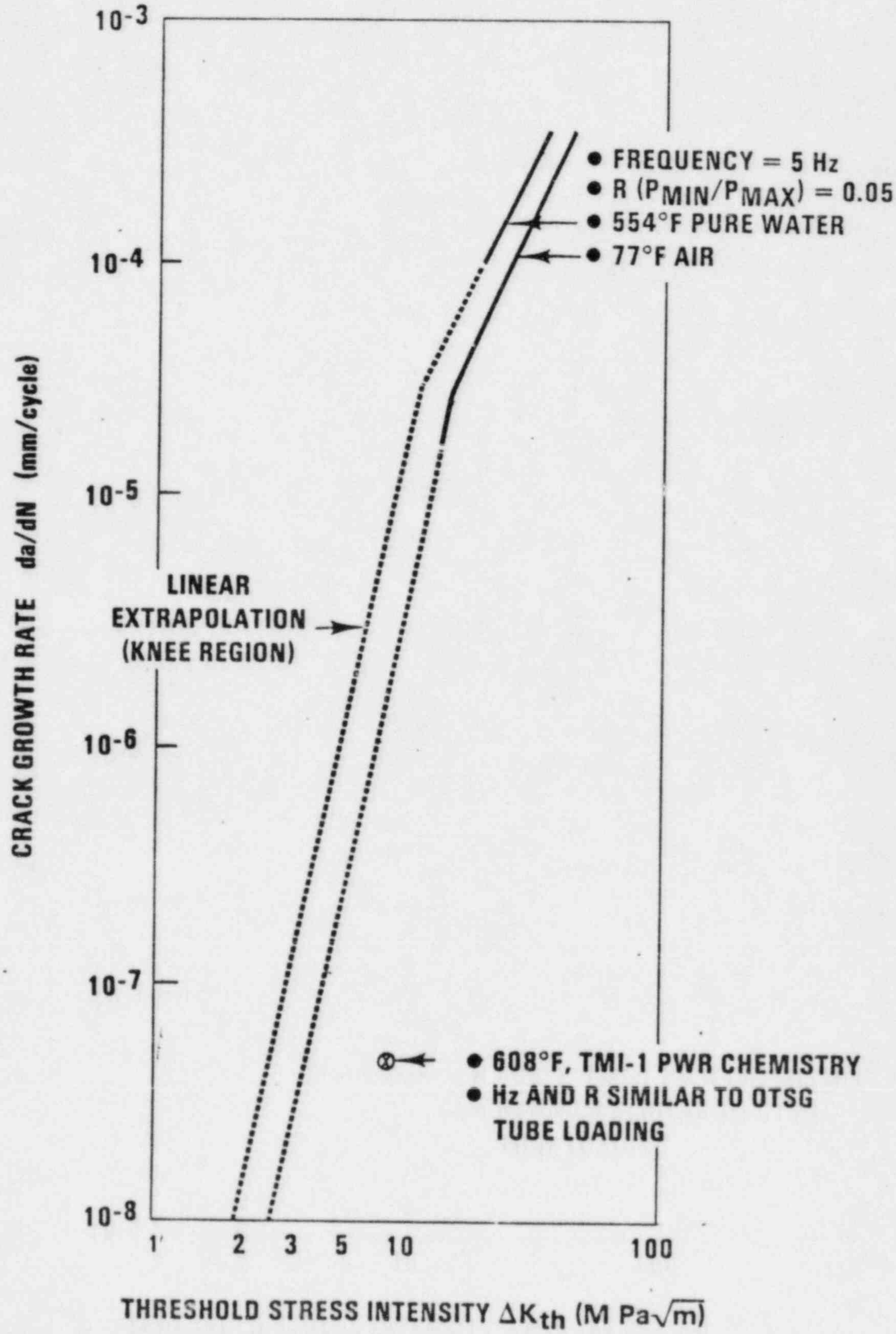
Inconel 600 Threshold Stress Intensity (MIT Corrosion Laboratory Data)



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Stress Intensity Calculation

G) Execution of Stress Intensity Solution

- The L.E.F.M. computational code, "BIGIF", developed for EPRI, was used to integrate over a range of stress intensities following a modified 'PARIS' equation:

$$\frac{da}{dN} 7.4 \times 10^{-10} \Delta K^{3.5}$$

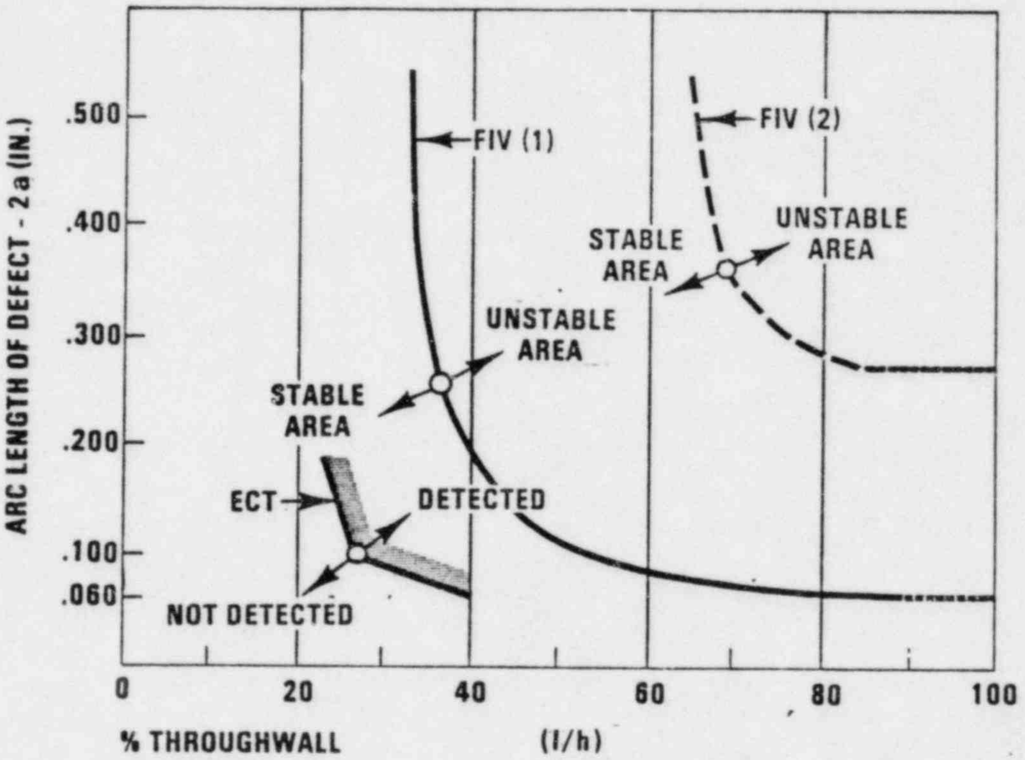
- The modification was that of applying a test for $(\Delta K)_{Th}$

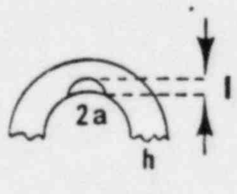
- Different R values were used when calculating crack propagation due to high or low cycle loading to capture the effect of mean stress

ECT DETECTABILITY

VS.

FLOW INDUCED VIBRATION





FIV (1): $\Delta K_{th} = 2.2\ MPa\sqrt{m}$

DEFLECTION = 14 MILS

FIV (2): $\Delta K_{th} = 1.1\ MPa\sqrt{m}$

DEFLECTION = 3 MILS

ECT: DEFECT - 4 MIL WIDE NOTCH
PROBE - DIFFERENTIAL
.540 IN DIA.

GAIN - 40 + RA

SENSITIVITY - 300 MV IN
LAB EQUIVALENT
TO FIELD

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Flow Induced Vibration Conclusion

- The .540 inch diameter high gain standard differential probe used at TMI-1 has detected those defects which would propagate unstably from only the mechanical loads anticipated over a 40 year service life

- Once the threshold stress intensity is exceeded and crack growth commences the crack progresses through wall in about 60 hours

Leak Before Break Analysis Overview

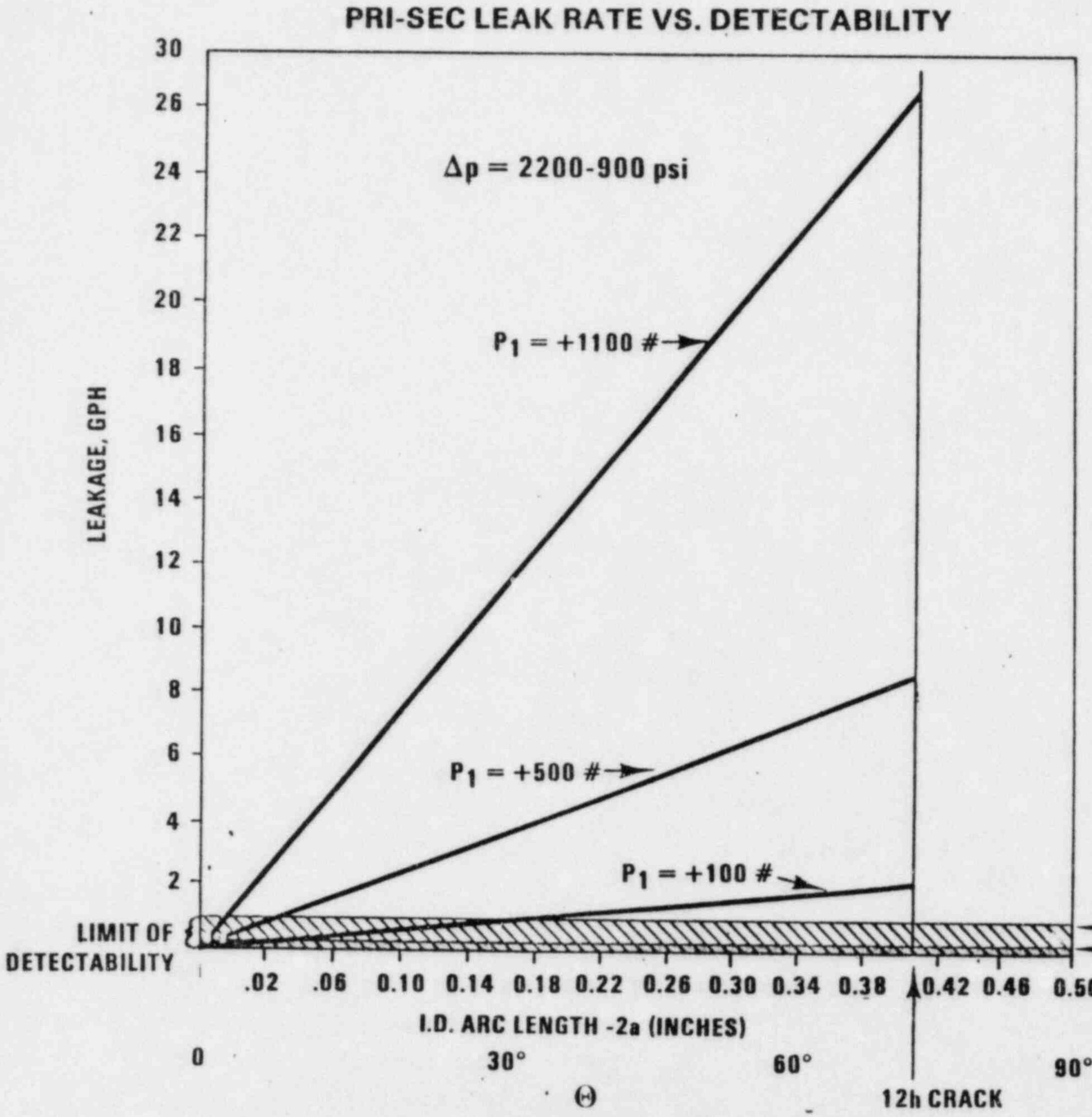
Objective

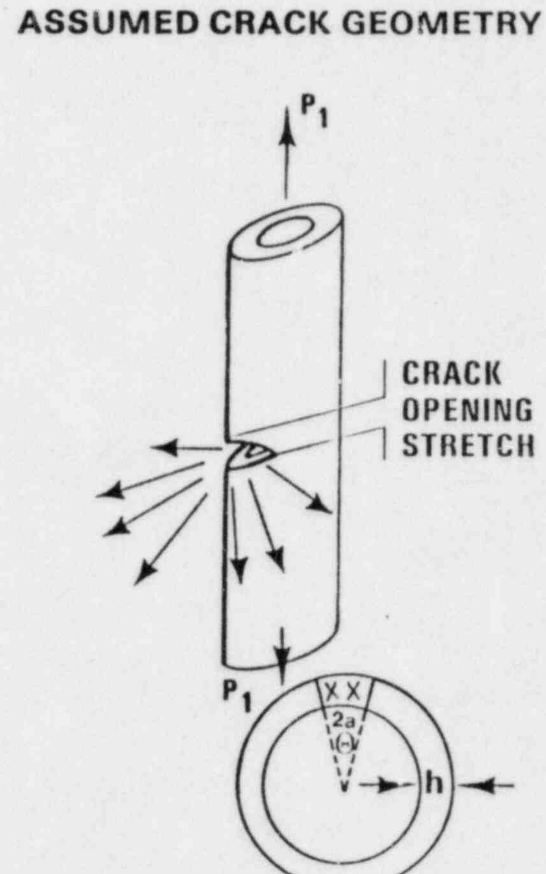
Calculate leakage rate from circumferential cracks to establish leakage as a function of crack geometry

Compare calculated leakage to the detectability limits for leakage, to conclude that leaking tubes can be detected and taken out of service prior to the crack becoming unstable due to plastic tearing or ligament necking during the cooldown following leak detection

Basis

Ensure that tubes can be taken out of service before they are degraded to the point that a double ended rupture will occur during cooldown


PRI-SEC LEAK RATE VS. DETECTABILITY
Δp = 2200-900 psi
P1 = +1100 #
P1 = +500 #
P1 = +100 #
LEAKAGE, GPH
30
26
24
22
20
18
16
14
12
10
8
6
4
2
LIMIT OF DETECTABILITY
.46 GPH OPERATING @ .03% FF
.1 GPH 150 psi N2 BUBBLE TEST
.02 .06 0.10 0.14 0.18 0.22 0.26 0.30 0.34 0.38 0.42 0.46 0.50
I.D. ARC LENGTH -2a (INCHES)
0
30°
60°
90°
Θ
12h CRACK


ASSUMED CRACK GEOMETRY
P1
CRACK
OPENING
STRETCH
P1
2a
h

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Small ECT ID Indications

Objective

To leave in service a limited number of small cracks to provide inspectability for crack growth rate studies

ECT Results

Cracks identified with < 40% through wall

Identified cracks are acceptable:

- Cracks will not propogate by FIV
- Cracks are too small to initiate ductile tearing
- Small number (~76)

Conclusion

ECT identified cracks < 40% through wall will not be plugged

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Steam Generator Tube Plugging Plan

- Tubes with defects in high cross flow areas will be plugged and stablilized
- Tubes requiring plugging, but with no defects in high cross flow areas will be plugged but not stabilized
- Plugging plans

	Crack Location	Number	Area of Stabilization
Stabilized:	UTS + 4″ → 15th TSP	551±	UTS + 24″ → 14th TSP
Being evaluated:	LTS → 1st TSP	6±	LTS → 1st TSP
Not Stabilized:	UTS + 4 → UTS + 8	246±	
	15th TSP → 1st TSP	343±	
Total Plugged Tubes		1146±	

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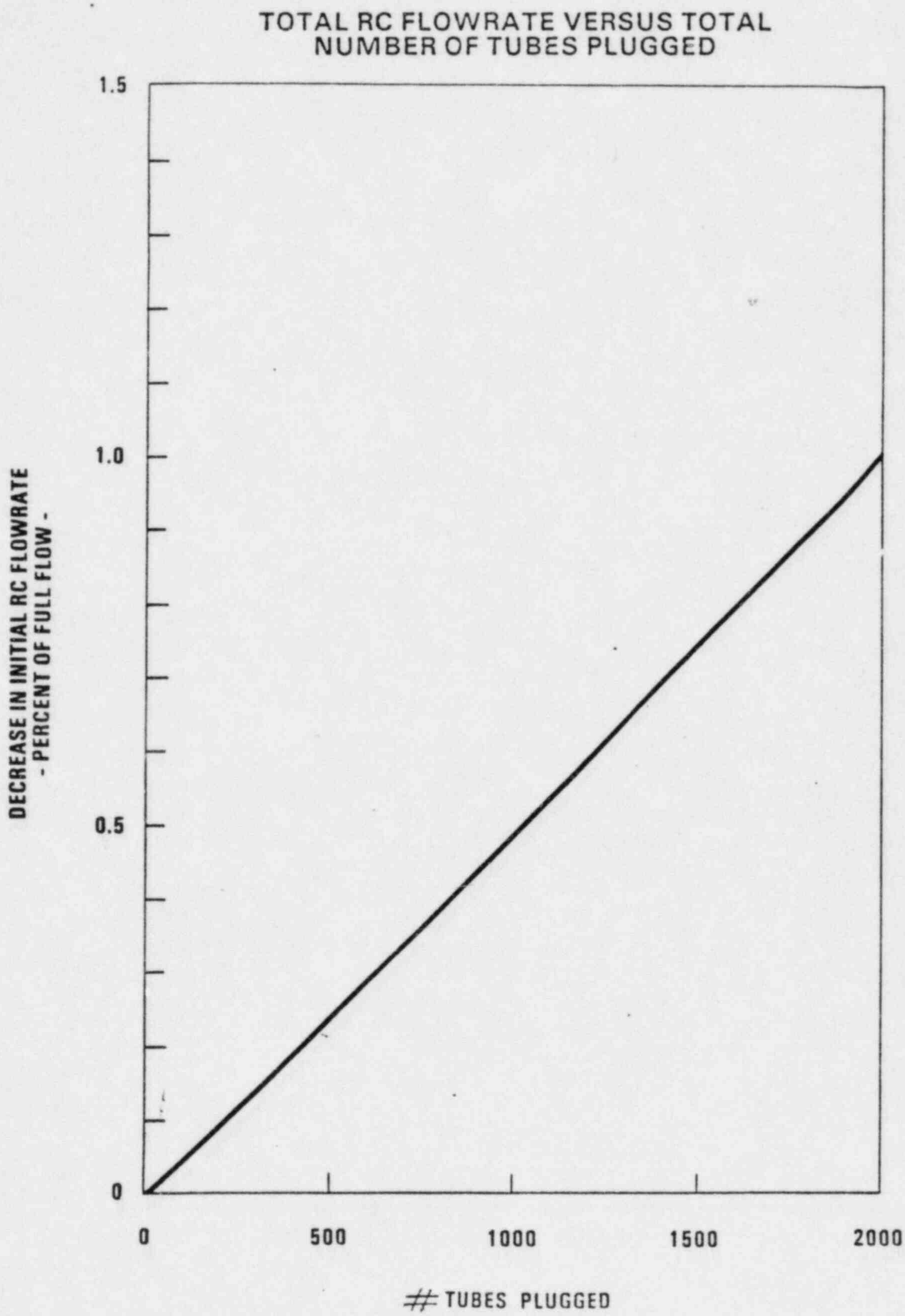
DESIGN BASIS ANALYSIS CONSIDERATIONS

OF TMI-1 SG TUBE PLUGGING

- PLANT PERFORMANCE PARAMETERS
  - REACTOR COOLANT SYSTEM FLOW RATE
  - REACTOR COOLANT PUMP FLOW COASTDOWN RATE
- LOCA ANALYSIS CONSIDERATIONS
  - SMALL BREAK LOCA
  - LARGE BREAK LOCA
- FSAR TRANSIENTS

RCS FLOW RATE

- MINIMUM CALCULATED RCS FLOW RATE AT TMI-1 = 109.5% OF DESIGN FLOW
- MAXIMUM ERROR ON CALCULATION = 1.5%
- MINIMUM AVAILABLE FLOW RATE = 108% DESIGN
- FLOW REQUIRED IN TMI-1 TRANSIENT ANALYSIS = 106.5% DESIGN
- FLOW MARGIN = 1.5%
- FLOW REDUCTION FROM 1500 PLUGGED TUBES = 0.8%


TOTAL RC FLOWRATE VERSUS TOTAL NUMBER OF TUBES PLUGGED
DECREASE IN INITIAL RC FLOWRATE - PERCENT OF FULL FLOW -
1.5
1.0
0.5
0
0
500
1000
1500
2000
TUBES PLUGGED

RC PUMP FLOW COASTDOWN RATE

- ANALYSIS PERFORMED WITH B & W "PUMP" CODE
  - HYBRID DIGITAL AND ANALOG CODE
- CASES ANALYZED
  - CASE 1: 1 PUMP TRIP WITH ZERO PLUGGED TUBES
  - CASE 2: CASE 1 WITH 1500 PLUGGED TUBES
  - CASE 3: TRIP ALL RC PUMPS WITH ZERO PLUGGED TUBES
  - CASE 4: CASE 3 WITH 1500 PLUGGED TUBES
- RESULTS
  - 1500 PLUGGED TUBES HAS NEGLIGIBLE EFFECT ON SINGLE PUMP TRIP AND TRIP OF ALL RC PUMPS

FLOW COASTDOWN

FOR ONE PUMP TRIP

TIME (SECONDS)	CORE FLOW (%) (ZERO PLUGGED TUBES)	CORE FLOW (%) (1500 PLUGGED TUBES)
0	99.73	99.74
1	98.87	98.92
2	97.42	97.55
3	95.61	95.75
5	91.88	91.94
7	87.88	87.93
9	84.63	84.87

FLOW COASTDOWN FOR

FOUR PUMP TRIP

TIME (SECONDS)	CORE FLOW (%) (ZERO PLUGGED TUBES)	CORE FLOW (%) (1500 PLUGGED TUBES)
0	99.92	99.83
1	98.24	97.82
2	94.0	93.24
3	87.67	86.74
5.5	71.8	71.09
7.5	62.4	61.6
9.5	54.6	54.34

SMALL BREAK LOCA

- CONCERNS

  A. STEAM GENERATOR HEAT REMOVAL IN BOILER - CONDENSER MODE

  B. EMERGENCY FEEDWATER SPRAY HEAT REMOVAL

  C. EFFECTS OF REDUCED RCS LIQUID INVENTORY ON CORE UNCOVERY TIME

STEAM GENERATOR HEAT REMOVAL

IN BOILER-CONDENSER MODE

- GENERIC LOCA ANALYSIS POWER LEVEL WAS 2772 MW_T
- 1500 PLUGGED TUBES APPROXIMATELY EQUAL TO 5% SG AREA REDUCTION
- HEAT REMOVAL CAPABILITY OF SG WILL BE DEGRADED BY APPROXIMATELY 5%
- HEAT REMOVAL CAPABILITY REDUCTION CAN BE OFFSET BY POWER REDUCTION
  - 5% POWER REDUCTION FROM GENERIC VALUE REQUIRED
- MAXIMUM ALLOWABLE GENERIC POWER LEVEL OF 2633 MW_T
- TMI-1 LICENSED POWER LEVEL OF 2535 MW_T PROVIDES ADDITIONAL 4% MARGIN
- GENERIC SMALL BREAK LOCA ANALYSIS IS APPLICABLE TO TMI-1 WITH PLUGGED TUBES

SMALL BREAK LOCA

EMERGENCY FEEDWATER HEAT REMOVAL

- SMALL BREAK LARGE ENOUGH TO DEPRESSURIZE SYSTEM (WORST CASE SB LOCA)

  - PRIMARY AND SECONDARY TEMPERATURES EQUAL AT ABOUT 300 SECONDS (SG HEAT REMOVAL CEASES)
  - CORE UNCOVERY BEGINS AT 1350 SECONDS
  - PEAK CLADDING TEMPERATURE OCCURS BETWEEN 1600 AND 1700 SECONDS
  - CORE RECOVERED AT ABOUT 1750 SECONDS
  - EFFECT OF SG COOLING ON THIS ACCIDENT IS NEGLIGIBLE (SG ACTS AS HEAT SOURCE FOR MOST OF THE TIME DURING THIS EVENT)
  - EFFECTS OF REDUCED EFW HEAT REMOVAL ARE NEGLIGIBLE

- SMALL BREAK WHICH REQUIRES SG HEAT REMOVAL TO DEPRESSURIZE SYSTEM

  - THESE BREAK SIZES DO NOT RESULT IN CORE UNCOVERY
  - REDUCED SG COOLING WILL RESULT IN ADDED PRIMARY SYSTEM INVENTORY BOIL OFF
  - INVENTORY REMAINING IS SUFFICIENT TO PREVENT CORE UNCOVERY
  - PEAK CLADDING TEMPERATURE REMAINS AT SYSTEM SATURATION TEMPERATURE (500 - 650°F)
  - REDUCED EFW COOLING NOT EXPECTED TO RESULT IN CORE UNCOVERY

SMALL BREAK LOCA

RCS LIQUID INVENTORY

- FOR WORST CASE SB LOCA

  - ANALYSIS PERFORMED AT 2772 MW_T
  - CORE UNCOVERY OCCURED AT APPROXIMATELY 1350 SEC
  - WITH 1500 PLUGGED TUBES:

    1. CORE UNCOVERY WILL OCCUR APPROXIMATELY 3 SECONDS EARLIER
    2. PEAK CLADDING TEMPERATURE WILL INCREASE BY ABOUT 10°F
    3. PEAK CLADDING TEMPERATURE WILL REMAIN AT APPROXIMATELY 1100°F

- CONCLUSION

  - GENERIC SMALL BREAK LOCA ANALYSIS APPLICABLE FOR TMI-1 WITH PLUGGED TUBES

LARGE BREAK LOCA

- CONCERN

  - ALTERATION OF LOOP AND CORE FLOW PATTERNS DURING EARLY PHASE OF LB LOCA

- EVALUATION

  - FLOW REDUCTION OF 0.8% FROM 1500 PLUGGED TUBES

  - FLOW RATE USED IN GENERIC LOCA ANALYSIS WAS 137.9 x 10^6 LBS/HR

  - TMI-1 DESIGN BASIS FLOW RATE IS 106.5% OF CYCLE 1 DESIGN FLOW OR 139.8 x 10^6 LBS/HR. REDUCED FLOW = 138.7 x 10^6 LBS/HR.

  - TMI-1 REDUCED FLOW RATE GREATER THAN LOCA ANALYSIS VALUE

  - B & W SENSITIVITY STUDIES HAVE SHOWN THAT HIGHER INITIAL RCS FLOW RESULTS IN LOWER PEAK CLADDING TEMPERATURES

- CONCLUSION

  - GENERIC LARGE BREAK LOCA ANALYSES ARE APPLICABLE TO TMI-1 WITH PLUGGED TUBES.

FSAR TRANSIENTS

TRANSIENT	EFFECT
1. UNCOMPENSATED OPERATING REACTIVITY CHANGES	REACTIVITY AND RADIATION RELEASE TYPE OF EVENTS ARE UNAFFECTED BY TUBE PLUGGING
2. STARTUP ACCIDENT/CRA WITHDRAWAL AT POWER	
3. MODERATOR DILUTION	
4. COLD WATER ACCIDENT	
5. STUCK/DROPPED ROD	
6. FUEL HANDLING	
7. ROD EJECTION	
8. MAXIMUM HYPOTHETICAL	
9. WASTE GAS TANK RUPTURE	

FSAR TRANSIENTS (CONT'D)

	TRANSIENT	EFFECT
10.	LOSS OF COOLANT FLOW	UNAFFECTED SINCE FLOW COASTDOWN RATE UNCHANGED FROM ZERO PLUGGING CASE. FSAR ANALYSIS ALSO BASED ON MINIMUM RC FLOW.
11.	LOSS OF ELECTRIC POWER	FSAR RESPONSE UNCHANGED.
12.	STEAMLINE FAILURE	FSAR ASSUMPTION OF SG INVENTORY WAS VERY CONSERVATIVE (55,000 LBM). FSAR BOUNDING.
13.	SG TUBE RUPTURE	FSAR ANALYSIS WILL BE UNCHANGED.
14.	LOSS OF FW/FEEDLINE BREAK	NO EFFECT OF TUBE PLUGGING ON PEAK PRESSURE IS EXPECTED. LONG TERM DH REMOVAL CAPABILITY WILL NOT BE EFFECTED.

CONCLUSION: PLUGGING OF 1500 TUBES WILL HAVE NO IMPACT ON FSAR ANALYSES. FSAR REMAINS BOUNDING.

RCS Cleanup

Purpose - Eliminate Possibility of Future Attack

- Convert sulfur to innocuous form (SO_4) as quickly as possible under protective (alkaline) conditions

- Remove as much as the SO_4 from the system as possible

Options

- Steam generators only
- Entire primary system
- Core in or out

Use known, safe technology

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Extent of Sulfur Contamination
(μgm SO_4/ft^2)

Fuel Rod (Clean)	533
Grid	418
RNS Retainer	530-700
RNS Spring	144
Tubes - upper SG plenum	970-3600
Tubes - lower SG plenum	770-930
Tubes - during fabrication	$<$250

(Method sensitivity - 250)

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BMI Ni S Tests

Ni S	17 ppm SO_4 ($r = 5 \times 10^{-3}$ cm)
H_2O_2	200 ppm, O ppm
Temp	25°C, 33°C
Cover gas	air, argon
pH	4.5, 8, 9

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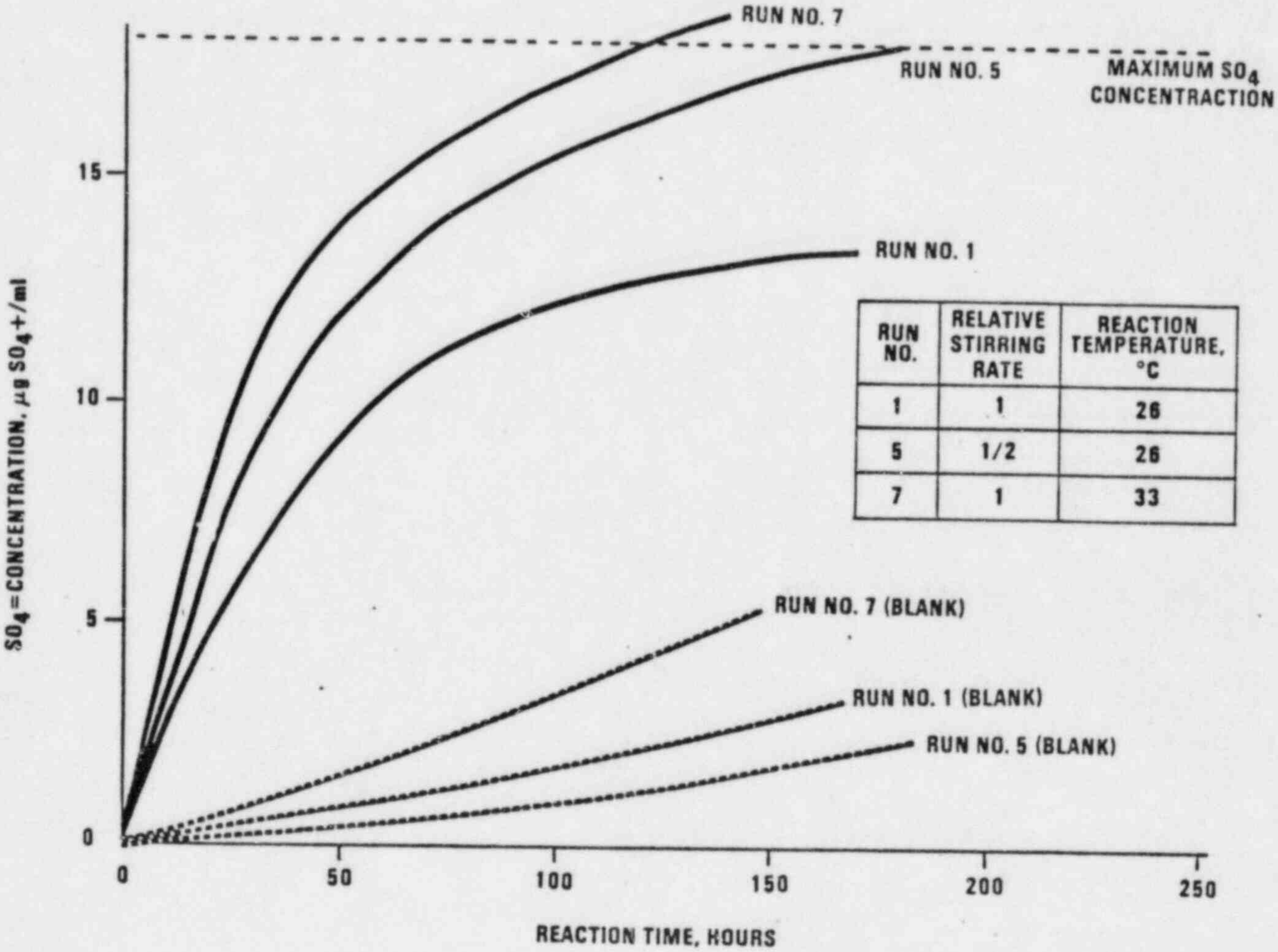
$SO_4^=$ FORMATION RATE MEASUREMENTS FOR REACTION BETWEEN NiS AND H_2O_2 IN AQUEOUS MEDIA AT pH8.



RUN NO.	RELATIVE STIRRING RATE	REACTION TEMPERATURE, °C
1	1	26
5	1/2	26
7	1	33

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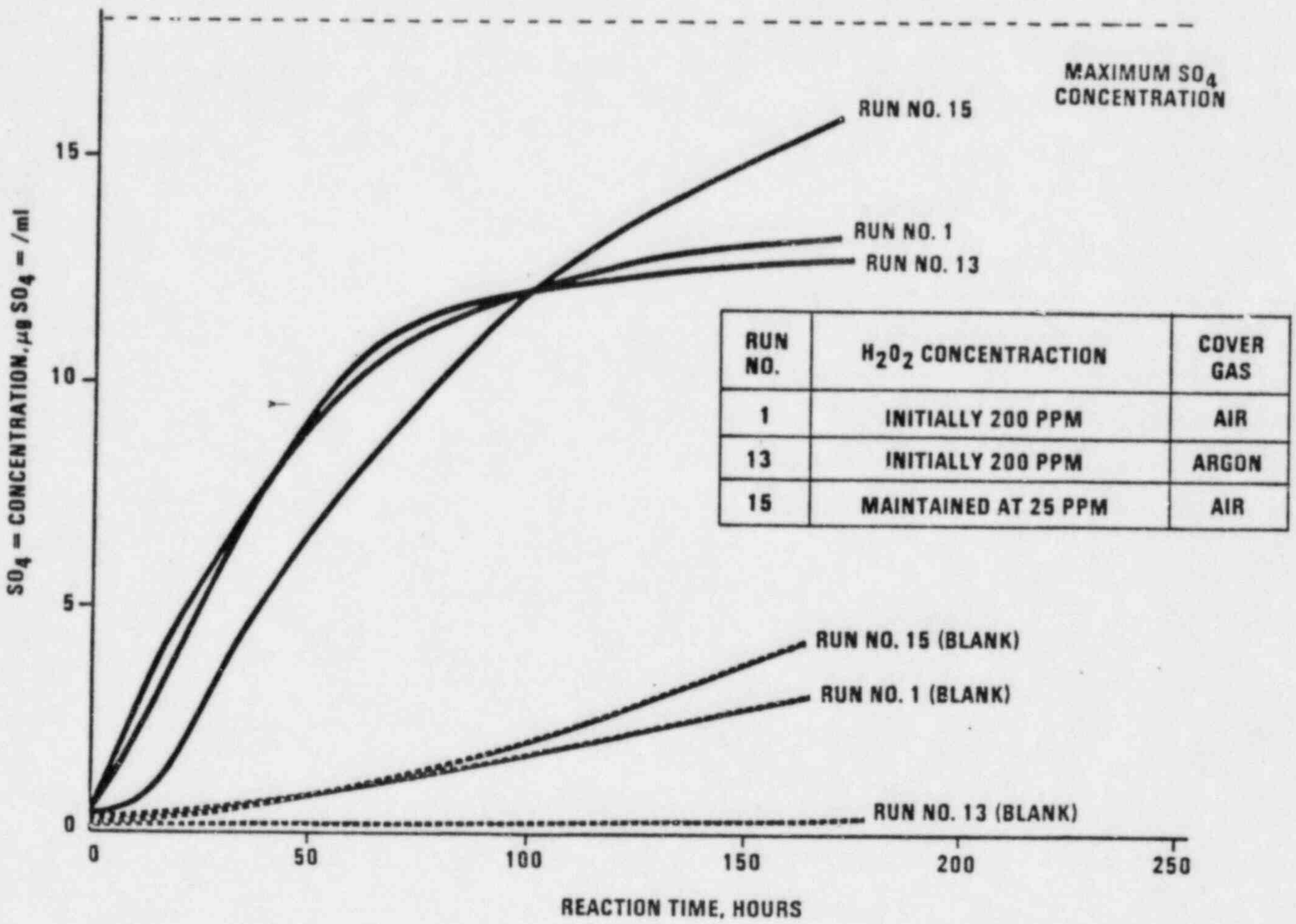
SO_4 = FORMATION RATE MEASUREMENTS FOR REACTION BETWEEN NiS AND H_2O_2 IN AQUEOUS MEDIA AT ROOM TEMPERATURE, pH8, AND RELATIVE STIRRING RATE OF ONE.



RUN NO.	H_2O_2 CONCENTRACTION	COVER GAS
1	INITIALLY 200 PPM	AIR
13	INITIALLY 200 PPM	ARGON
15	MAINTAINED AT 25 PPM	AIR

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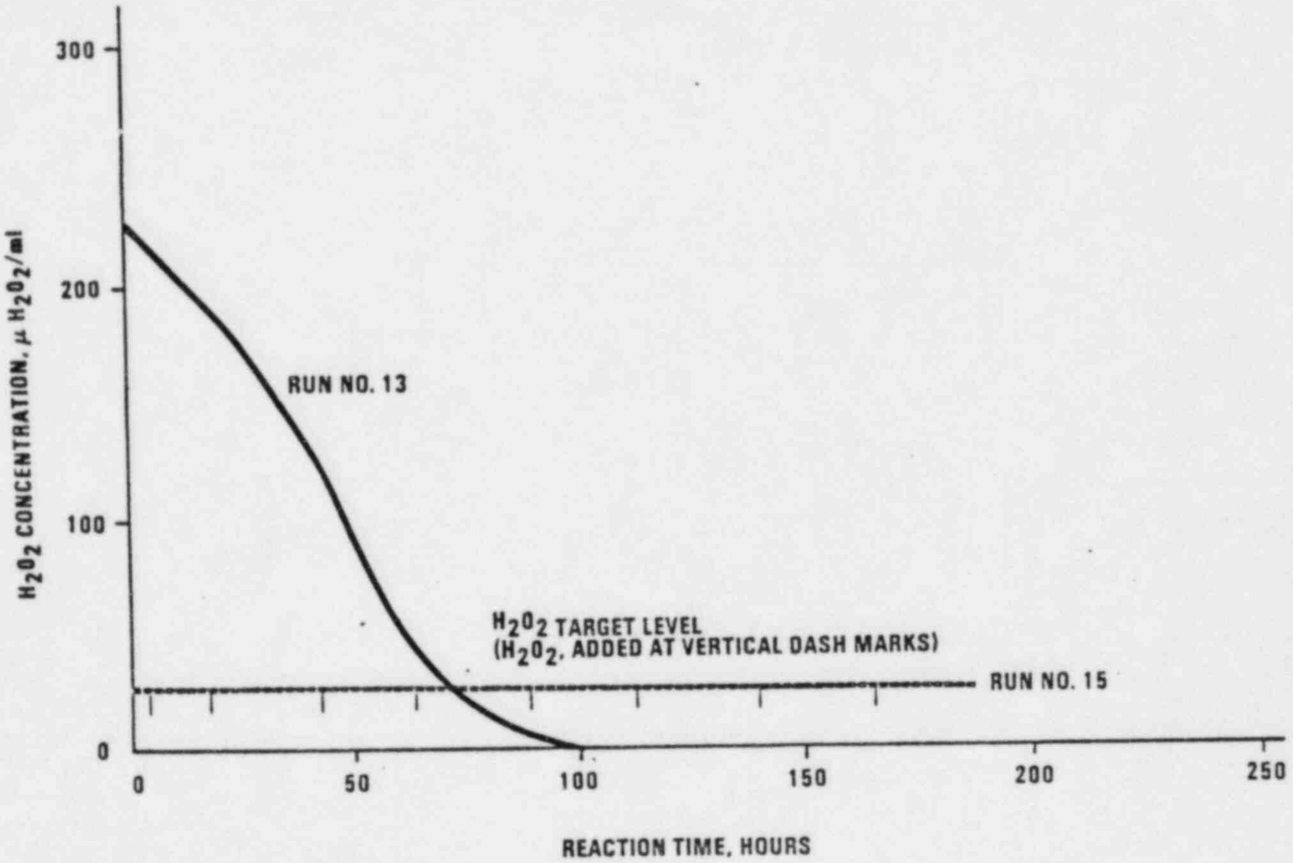
H_2O_2 CONCENTRATION MEASUREMENTS FOR THE REACTION BETWEEN NiS AND H_2O_2 IN AQUEOUS MEDIA AT ROOM TEMPERATURE, pH 8, AND RELATIVE STIRRING RATE OF ONE



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Conclusions from NiS Reaction Rate Measurements

I. With H_2O_2

- Decreasing stirring rate increased SO_4 formation rate
- Increasing temperature increased SO_4 formation rate
- SO_4 formation rate the same at pH 8 and pH 9 but initially about 4 times slower at pH 4.5
- No difference in SO_4 formation rate between air and argon

II. Without H_2O_2

- SO_4 formation rate decreased with decrease in stirring rate
- Increasing temperature increased SO_4 formation rate
- SO_4 formation rate decreased with decreasing pH
- SO_4 formation rate approximately zero in argon.
- Initial and final conversion rates made slower than with H_2O_2

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Consultants
GPUN Workshop - RCS Cleanup
Battelle-Columbus
August 9-10, 1982

Name	Company
Jack H. Hicks	Bablock & Wilcox Company
Yale Solomon	Westinghouse Electric Corp.
Fred Pement	Westinghouse Electric Corp.
Marv Miller	Battelle-Columbus
Arun K. Agrawal	Battelle-Columbus
Henry Leidheiser	Lehigh University
Warren E. Berry	Battelle-Columbus
Merl J. Bell	NWT Corporation
R.H. Barnes	Battelle-Columbus
Paul Cohen	Consultant (EPRI)
Joan Lathouse	Battelle-Columbus
Afaf Wensky	Battelle-Columbus

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PHASE II

Priority	Description	pH	H_2O_2 (ppm)	B (ppm)	S Form	Temperature
1	Zero Run-1	8 (NH_3)	200 (unstablized)	2300	NiS (17 ppm)	Room Temperature
	Zero Run-2	8 (NH_3)	200 (unstablized)	2300	NiS + I-600	Room Temperature
	Zero Run-3	8 (NH_3)	200 (unstablized)	2300	Tetrathionate (20 ppm)	Room Temperature
	Zero Run-4	8 (NH_3)	200 (unstablized)	2300	NiS + I-600	130°F
2	Tubes Run-1	8 (NH_3)	20 (maintained)	2300	Tubes (3"-7")	130°F
	Tubes Run-2	8 (NH_3)	20 (maintained)	2300	Tubes (3"-7")	130°F
	Tubes Run-3	10 (LiOH)	20 (maintained)	0	Tubes (3"-7")	130°F
	Tubes Run-4	10 (LiOH)	20 (maintained)	0	Tubes (3"-7")	130°F
3 deleted	Tubes Run-5	8 (NH_3)	O_2 (cover gas)	2300	Tubes (3"-7")	130°F
	Tubes Run-6	8 (NH_3)	O_2 (cover gas)	2300	Tubes (3"-7")	130°F
	Tubes Run-7	10 (LiOH)	O_2 (cover gas)	0	Tubes (3"-7")	130°F
	Tubes Run-8	10 (LiOH)	O_2 (cover gas)	0	Tubes (3"-7")	130°F
4	Corrosion Run-1	8 (NH_3)	20 (maintained)	2300	U-tubes, C-rings, and tetrathionate (20 ppm)	130°F
	Corrosion Run-2	8 (NH_3)	20 (maintained)	2300		130°F
	Corrosion Run-3	10 (LiOH)	20 (maintained)	0		130°F
	Corrosion Run-4	10 (LiOH)	20 (maintained)	0		130°F
5 deleted	Corrosion Run-5	8 (NH_3)	O_2 (cover gas)	2300	U-tubes, C-rings, and tetrathionate (20 ppm)	130°F
	Corrosion Run-6	8 (NH_3)	O_2 (cover gas)	2300		130°F
	Corrosion Run-7	10 (LiOH)	O_2 (cover gas)	0		130°F
	Corrosion Run-8	10 (LiOH)	O_2 (cover gas)	0		130°F
6[(a)]	Immunol Run-1	8 (NH_3)	20 (maintained)	2300	3-1, 3-2, 3-3	130°F
	Immunol Run-2	8 (NH_3)	20 (maintained)	2300	3-4, 3-5, 3-6	130°F
	Immunol Run-3	8 (NH_3)	20 (maintained)	2300	3-7, 3-8, 3-9	130°F
	Immunol Run-4	8 (NH_3)	20 (maintained)	2300	4-1, 4-2, 4-3	130°F

(a) = All samples (12 pieces) should be rinsed with DI H_2O (pH 9-10 with NH_4OH). Use 100 ml from a squirt bottle for each piece and as much as possible treat them identically.

Corrosion Tests

Conditions - like cleaning except O_2 cover

Specimens - 304SS (Sens.) U-bends, I-600 U-bends (TMI Heat Treat), C-rings from TMI tubing

NaS added as corrodant at same rate as released in first test

Test length twice time of SO_4 release $\simeq$ 140 hrs

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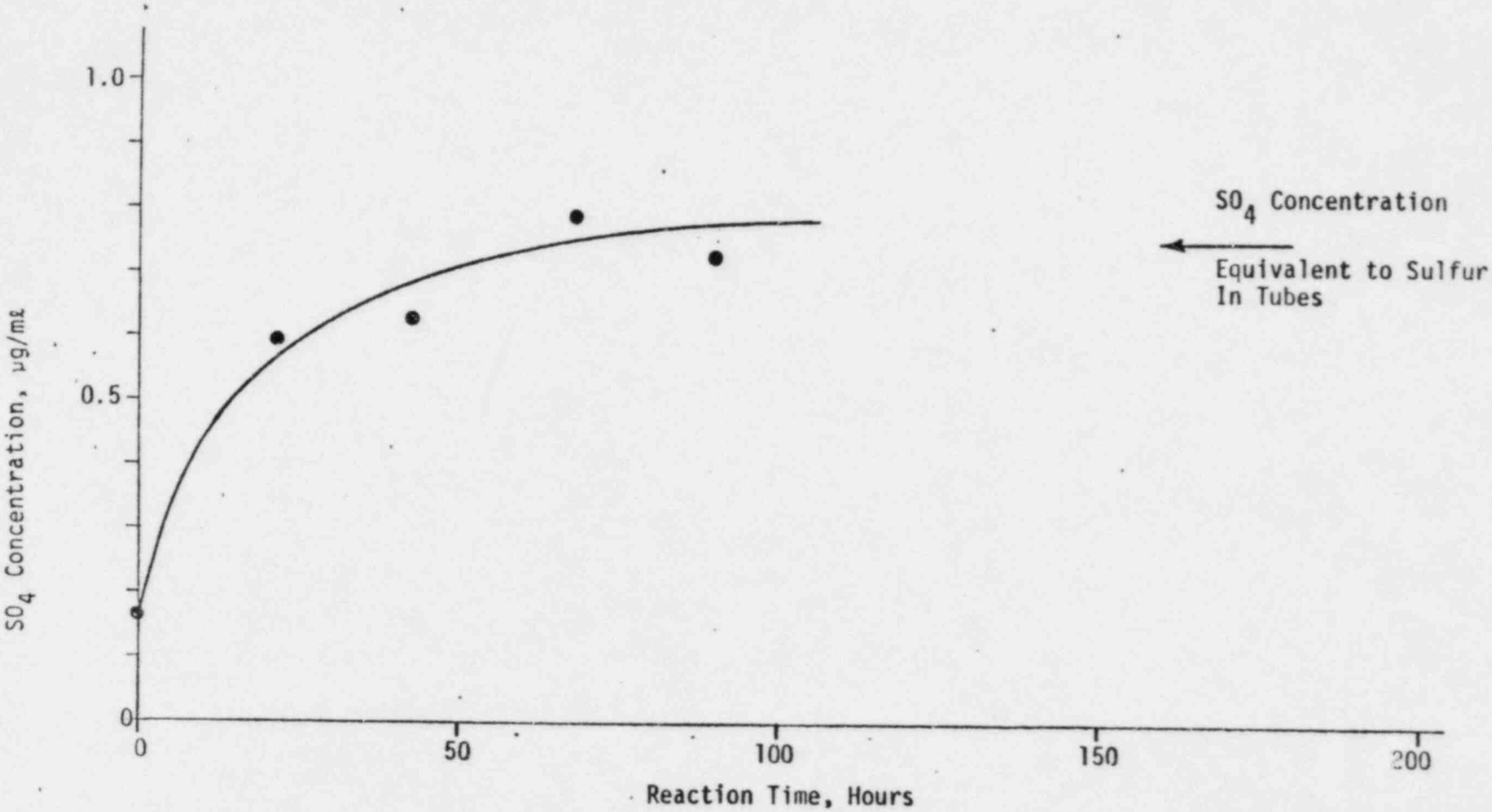
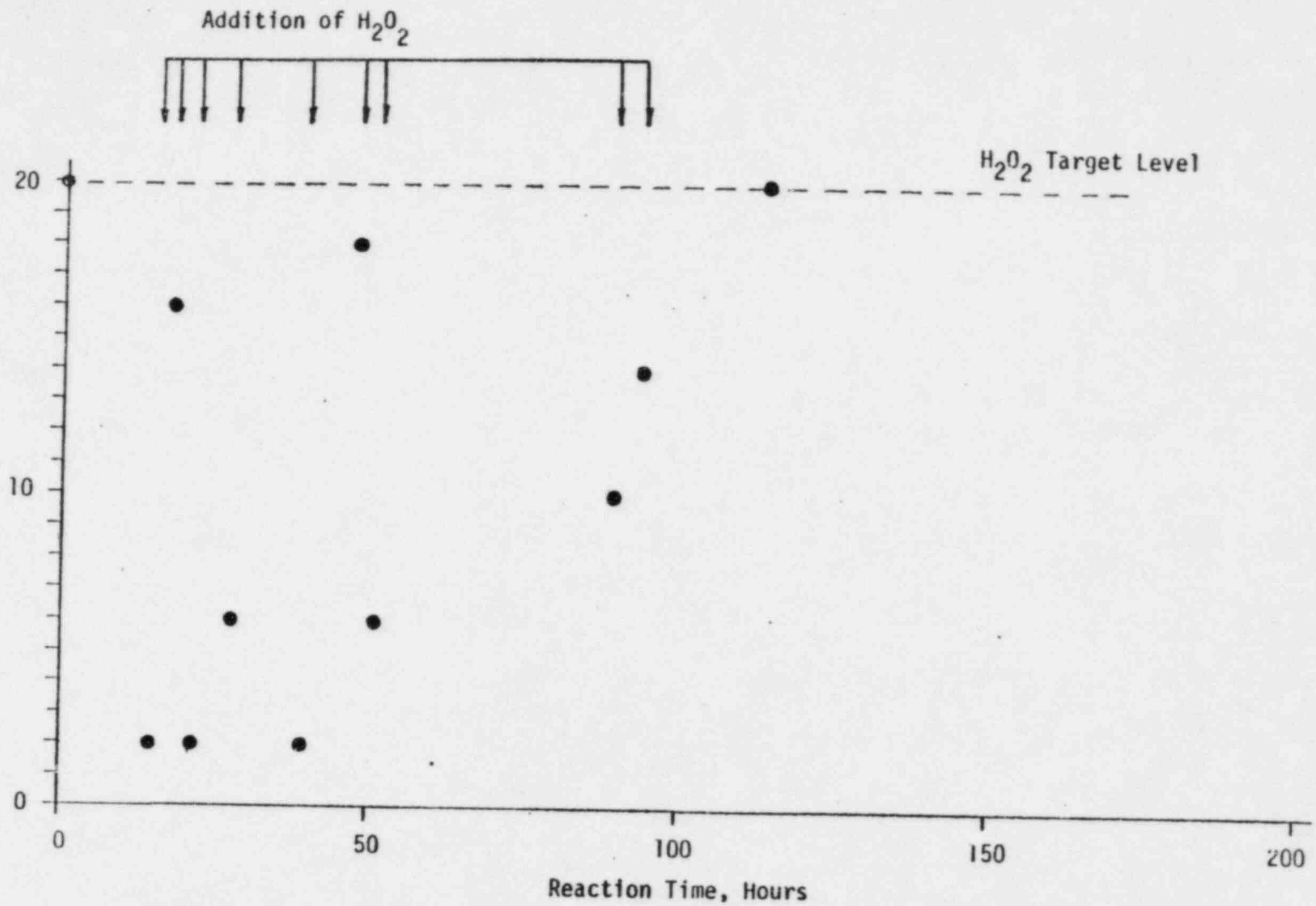
TUBE CLEANING EXPERIMENTS

Type of Test	Sample	pH	H_2O_2 Concentration, ppm*	Reaction Temperature, of	Cover Gas
• Sulfur Cleaning	Inconel Tubes	pH 8 (H_3BO_3/NH_4OH)	20, maintained	130	Air
		pH 10 (LiOH)	20, maintained	130	Air
• Corrosion	Inconel C-Rings and U-Bends	pH 8 (H_3BO_3/NH_4OH)	20, maintained	130	O_2
		pH 10 (LiOH)	20, maintained	130	O_2
• Sulfur Cleaning of Immunol treated Tubes	Immunol Treated Inconel tubes 4 feet from expanded region	pH 8 (H_3BO_3/NH_4OH)	20, maintained	130	Air
		pH 10 (LiOH)	20, maintained	130	Air
• Sulfur Cleaning of expanded Immunol treated tubes	Transition region of Immunol treated Inconel tube	pH 8 (H_3BO_3/NH_4OH)	20, maintained	130	Air
	Transition region of untreated expanded Inconel Tube	pH 8 (H_3BO_3/NH_4OH)	20, maintained	130	Air
	Immunol Treated Inconel tube 20 inches from expanded region	pH 8 (H_3BO_3/NH_4OH)	20, maintained	130	Air
	Untreated Inconel Tube 20 inches from expanded region	pH 8 (H_3BO_3/NH_4OH)	20, maintained	130	Air

*Unstabilized H_2O_2



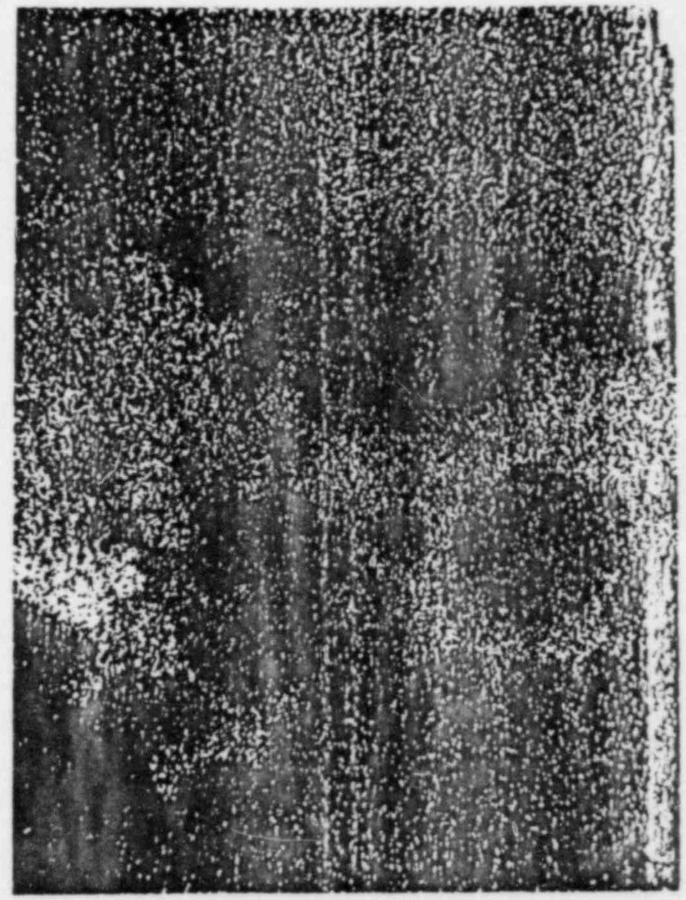
PRODUCTION OF SO_4 DURING CLEANING OF SULFUR CONTAMINATED INCONEL-600 TUBE SAMPLES WITH H_2O_2 MAINTAINED AT 20 ppm (Tube A 78-32-2)



H_2O_2 MEASUREMENTS MADE DURING CLEANING OF SULFUR CONTAMINATED INCONEL-600 TUBE SAMPLES WITH H_2O_2 MAINTAINED AT 20 ppm (Tube A 78-32-2).

36296 500X

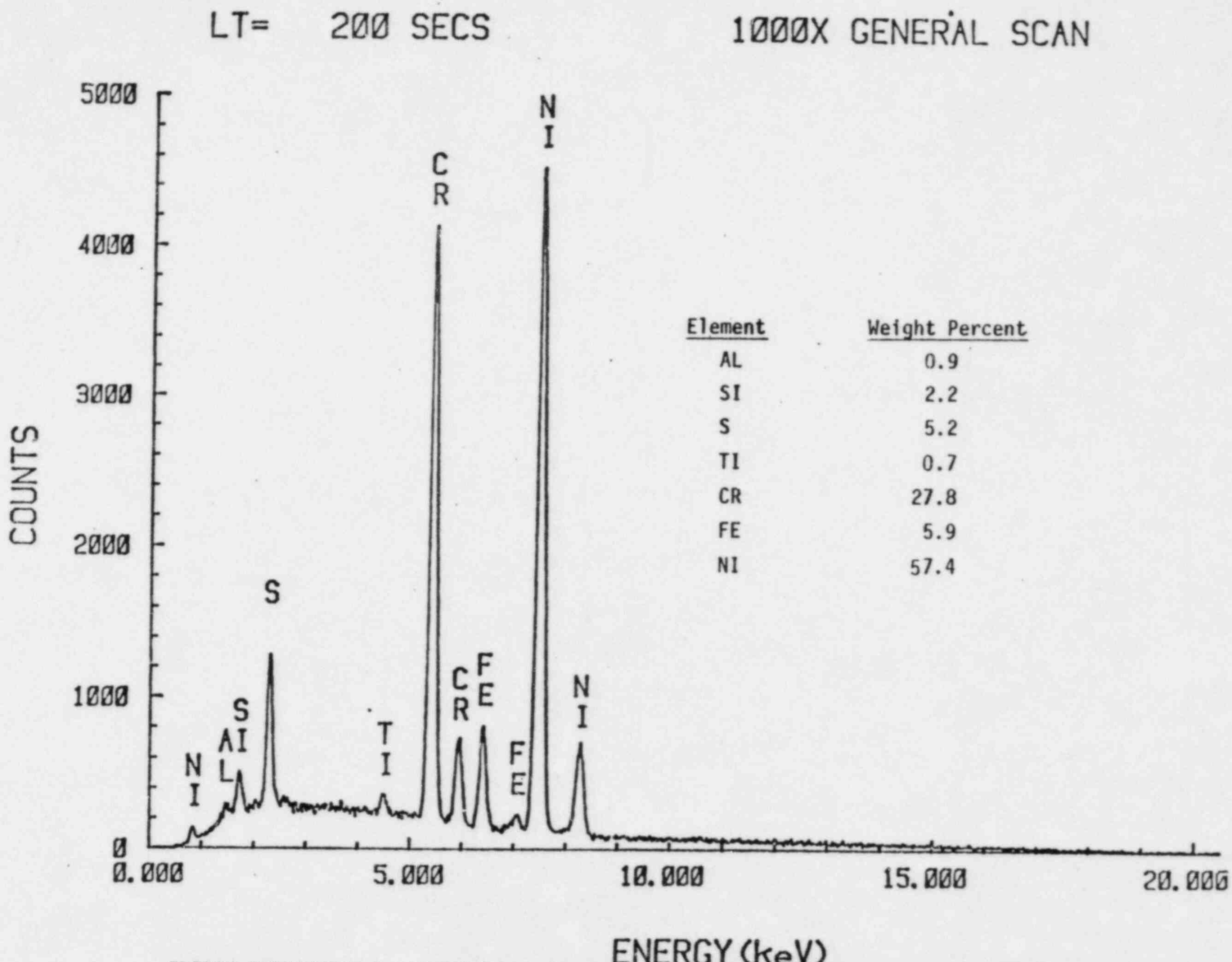
Photomicrograph



36212 500X

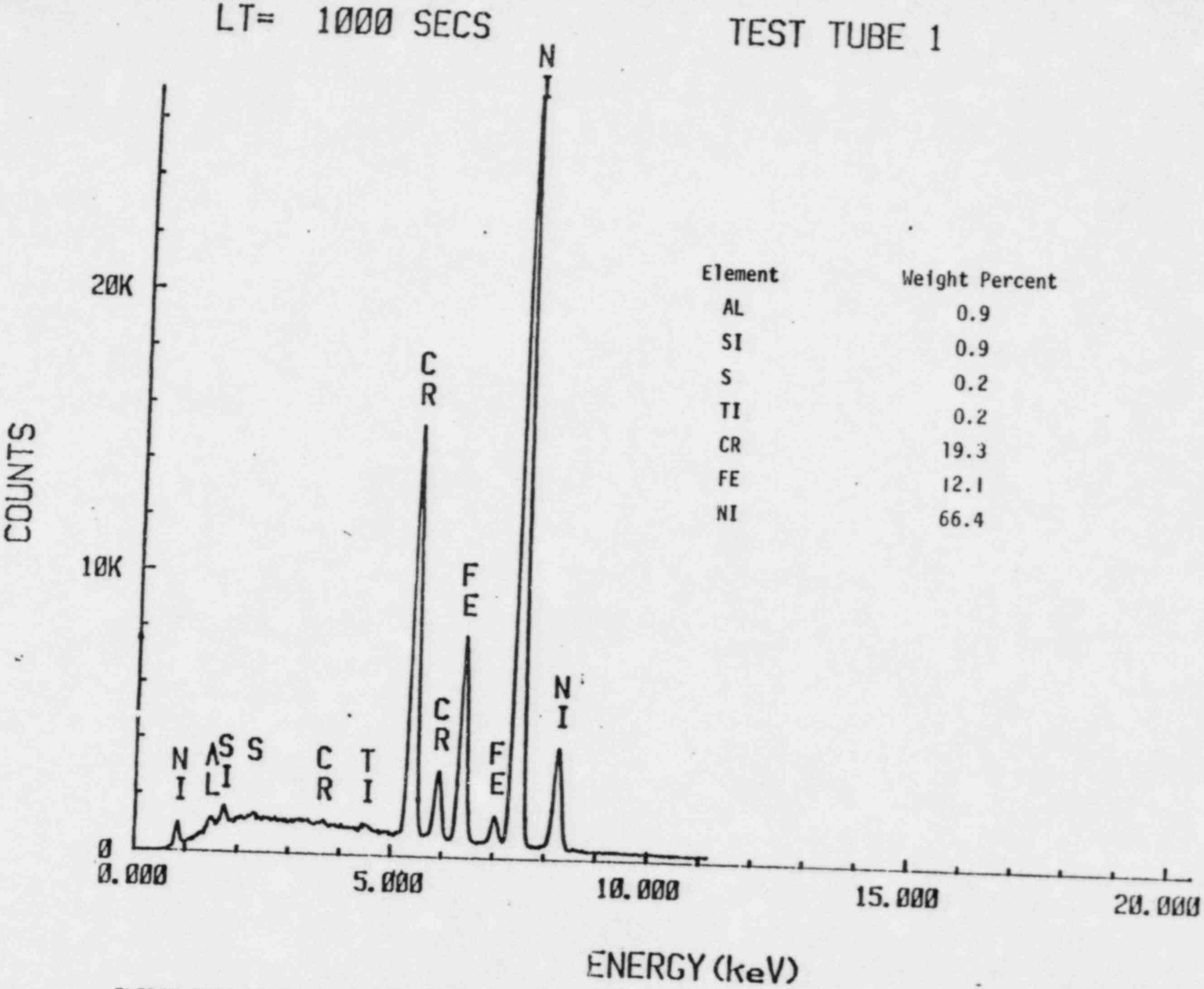
Sulfur X-Ray

SEM PHOTOMICROGRAPH AND X-RAY MAP FOR SULFUR CONTAMINATED AREA IN CROSS SECTION OF AS-RECEIVED INCONEL-600 TUBE SAMPLE.



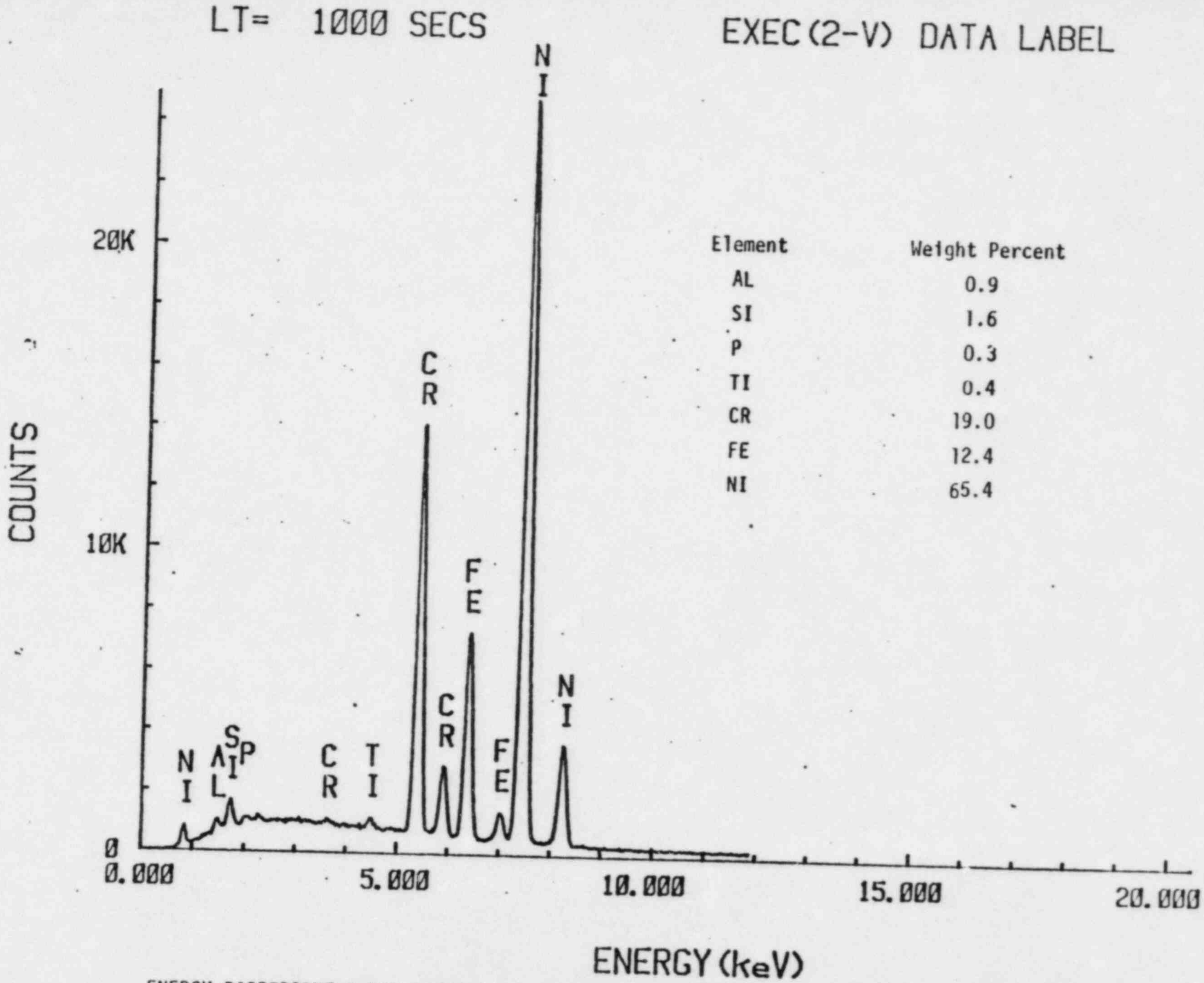
Element	Weight Percent
AL	0.9
SI	2.2
S	5.2
TI	0.7
CR	27.8
FE	5.9
NI	57.4

ENERGY DISPERSIVE X-RAY SPECTRUM FOR SULFUR CONTAMINANT AREA (AREA C) IN CROSS SECTION OF AS-RECEIVED INCONEL-600 TUBE.

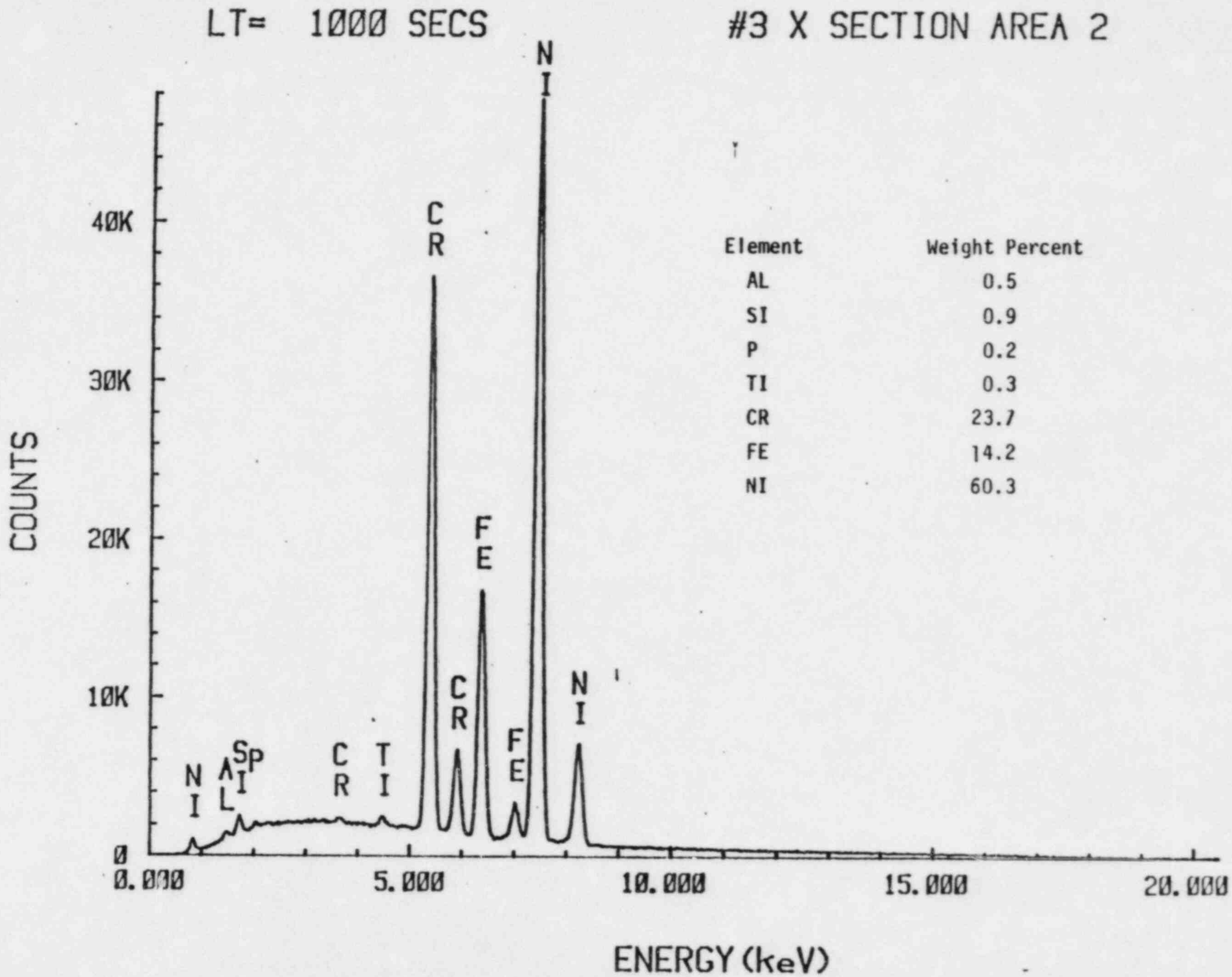


Element	Weight Percent
AL	0.9
SI	0.9
S	0.2
TI	0.2
CR	19.3
FE	12.1
NI	66.4

ENERGY DISPERSIVE X-RAY SPECTRUM FOR ID SURFACE INCONEL-600 TUBE SAMPLE AFTER CLEANING WITH H_2O_2 AT pH8.

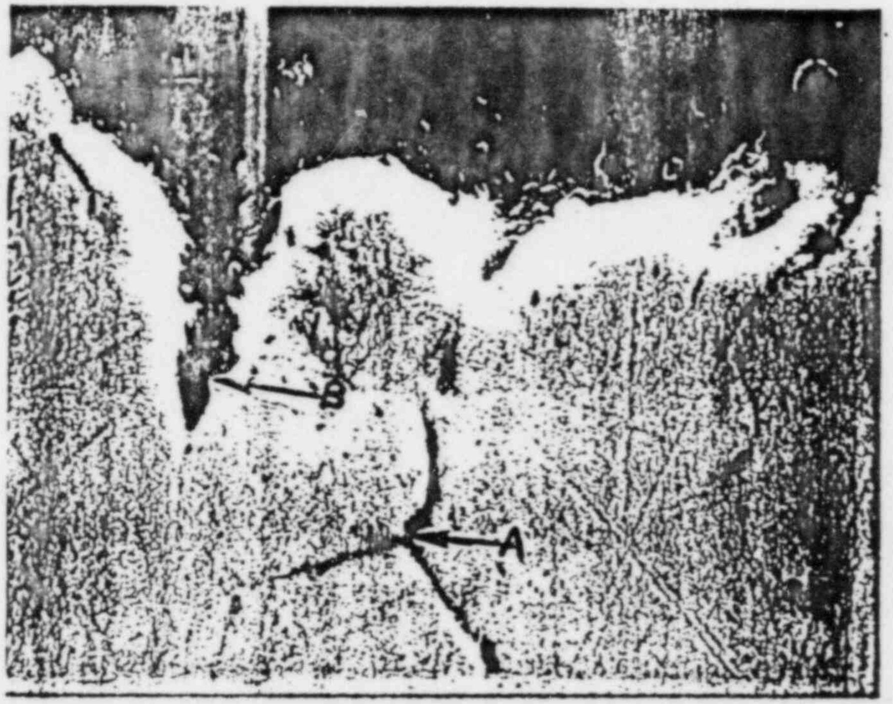


ENERGY DISPERSIVE X-RAY SPECTRUM FOR ID SURFACES INCONEL-600 TUBE SAMPLE AFTER CLEANING WITH H_2O_2 AT pH 10.



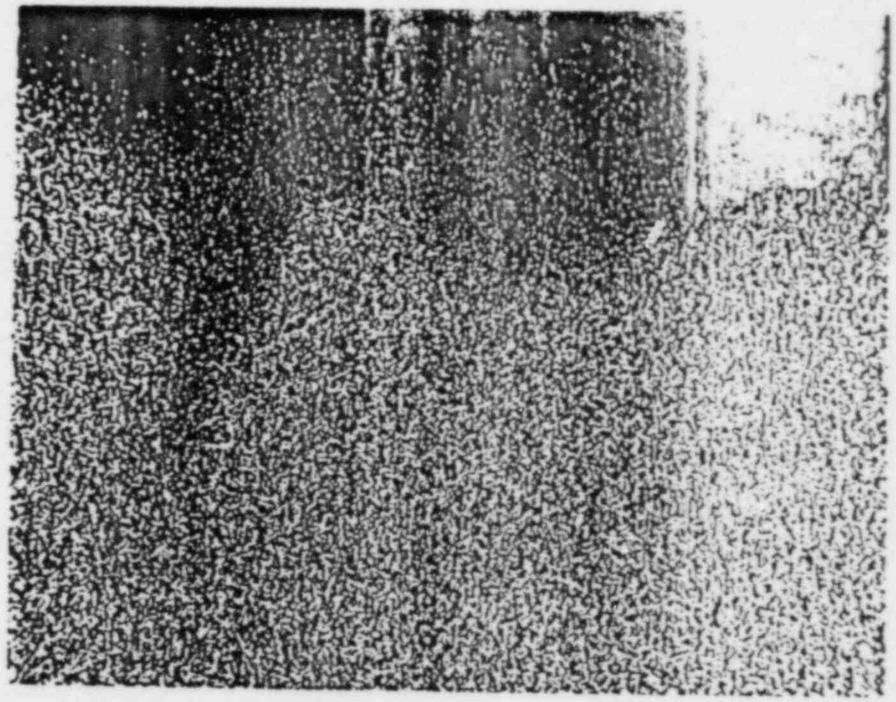
Element	Weight Percent
AL	0.5
SI	0.9
P	0.2
TI	0.3
CR	23.7
FE	14.2
NI	60.3

ENERGY DISPERSIVE X-RAY SPECTRUM FOR SULFUR CONTAMINATED AREA(AREA 2) IN CROSS SECTION OF INCONEL 600 TUBE SAMPLE AFTER CLEANING WITH H_2O_2 AT pH_8



36632 5000X

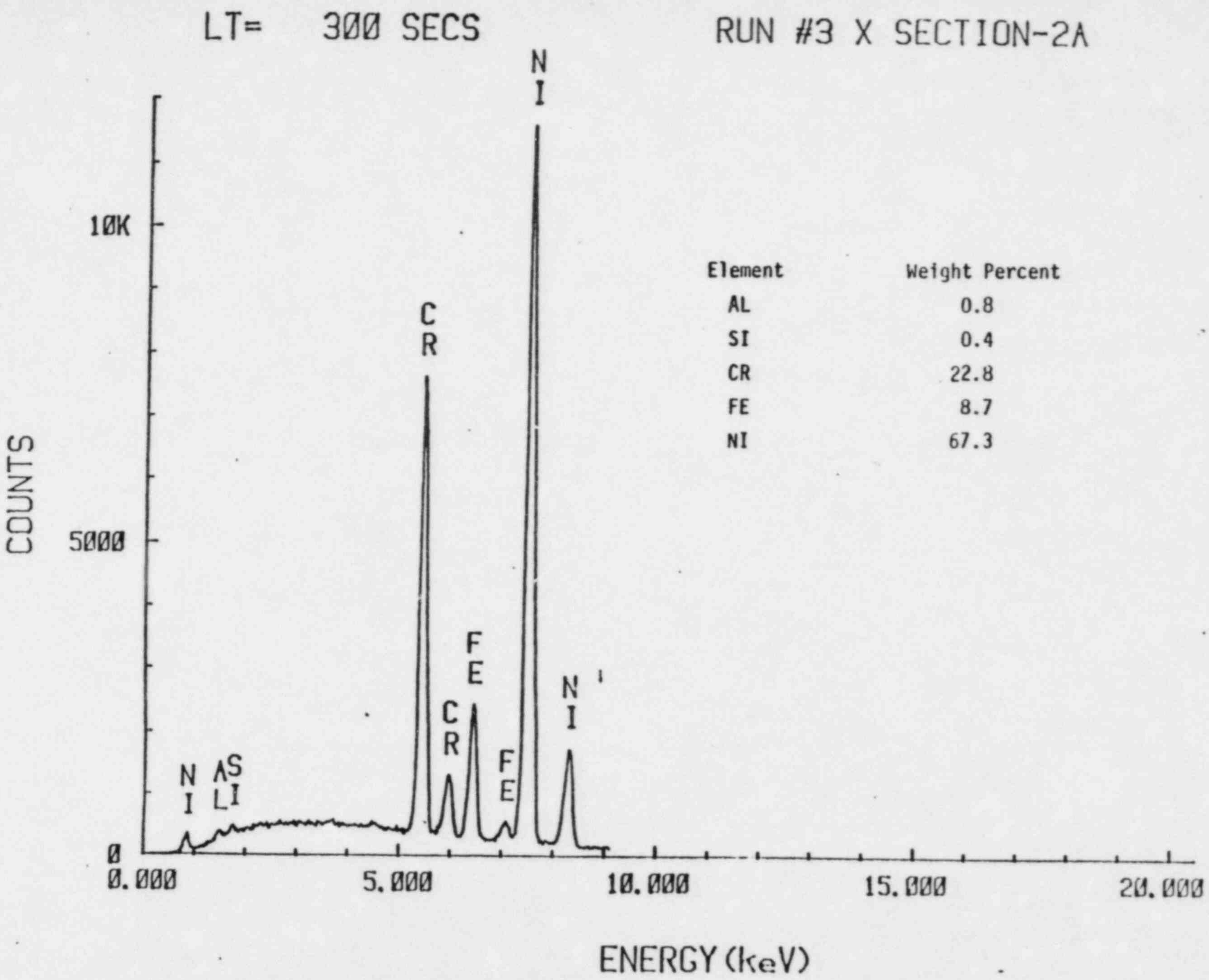
Photomicrograph



36634 5000X

Nickel X-Ray Map

SEM PHOTOMICROGRAPH AND X-RAY MAP OF SULFUR CONTAMINATED AREA IN CROSS SECTION OF IMMUNOL COATED INCONEL-600 TUBE SAMPLE FROM ABOUT FIVE FEET FROM EXPANSION ZONE AFTER REMOVAL OF SULFUR BY H_2O_2 CLEANING AT pH 10 (Area 2).



ENERGY DISPERSIVE X-RAY SPECTRUM FOR AREA 2, POINT A IN CROSS SECTION OF IMMUNOL COATED INCONEL-600 TUBE SAMPLE FROM ABOUT FIVE FEET FROM EXPANSION ZONE AFTER REMOVAL OF SULFUR BY H_2O_2 CLEANING AT pH 10.

Preliminary Conclusions from TMI Tubing Cleaning & Corrosion Tests

1. The process works about as anticipated
2. Cleaning time appears to be <100 hrs
3. No indication of corrosion has been seen
4. Presence of Immunol does not appear to be detrimental to the process

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Work in Progress

1. Loop tests
2. Preparation of plant procedure
3. Completion of radwaste considerations
4. Confirmation of IX performance
5. Method development on reduced sulfur on swipes

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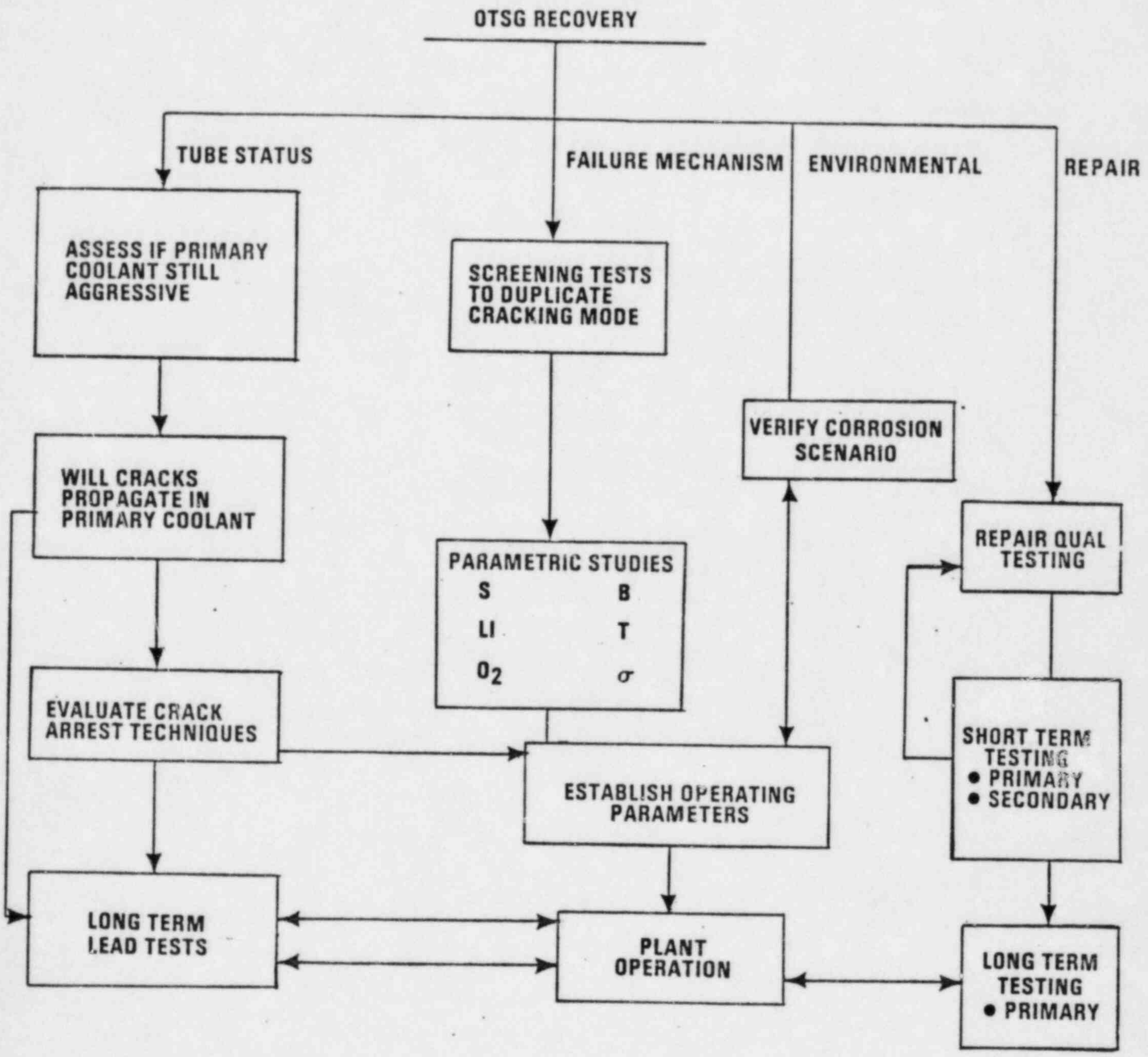
CORROSION TEST PROGRAM



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Long Term Corrosion Test Program

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 17 months

Test Specimens:

Lead Test

Full section tubes	Actual TMI tubing
C-rings	Actual TMI tubing and archive tubing (heat M2320)

Repair Qualification

Single tube/tubesheet mockups using actual TMI tubing

Test Parameters:

Chemistry	- Typical primary water chemistry with contaminents at maximum specification levels
Temperature	- Ambient to 600° F with temperature cycling
Load	- C-rings stressed at 90% Y.S. Full section tubes loaded 500-1100 lbs
Pressure	- Actual primary and secondary operating pressures

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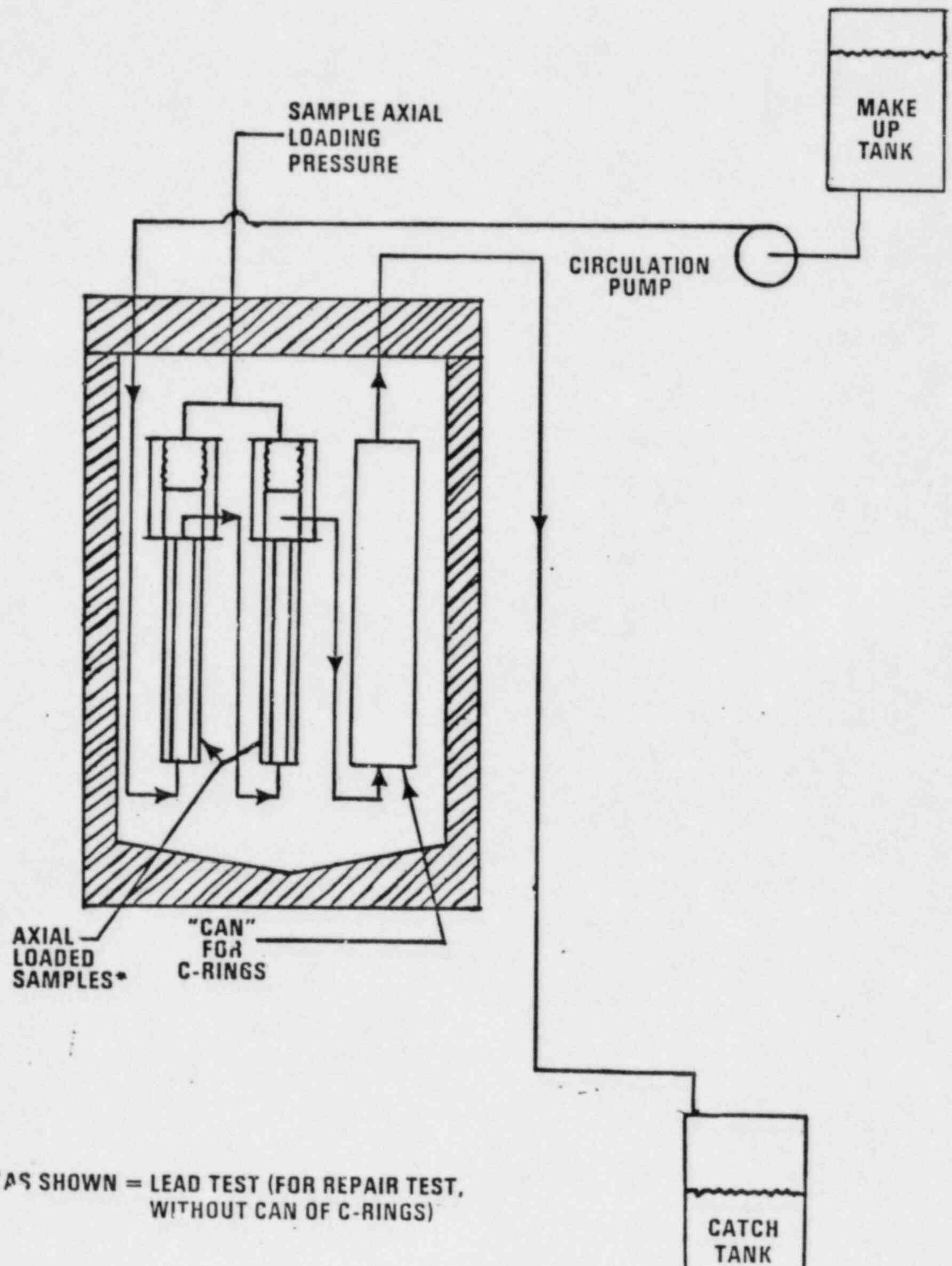
TEST LOOP SCHEMATIC



*AS SHOWN = LEAD TEST (FOR REPAIR TEST, WITHOUT CAN OF C-RINGS)

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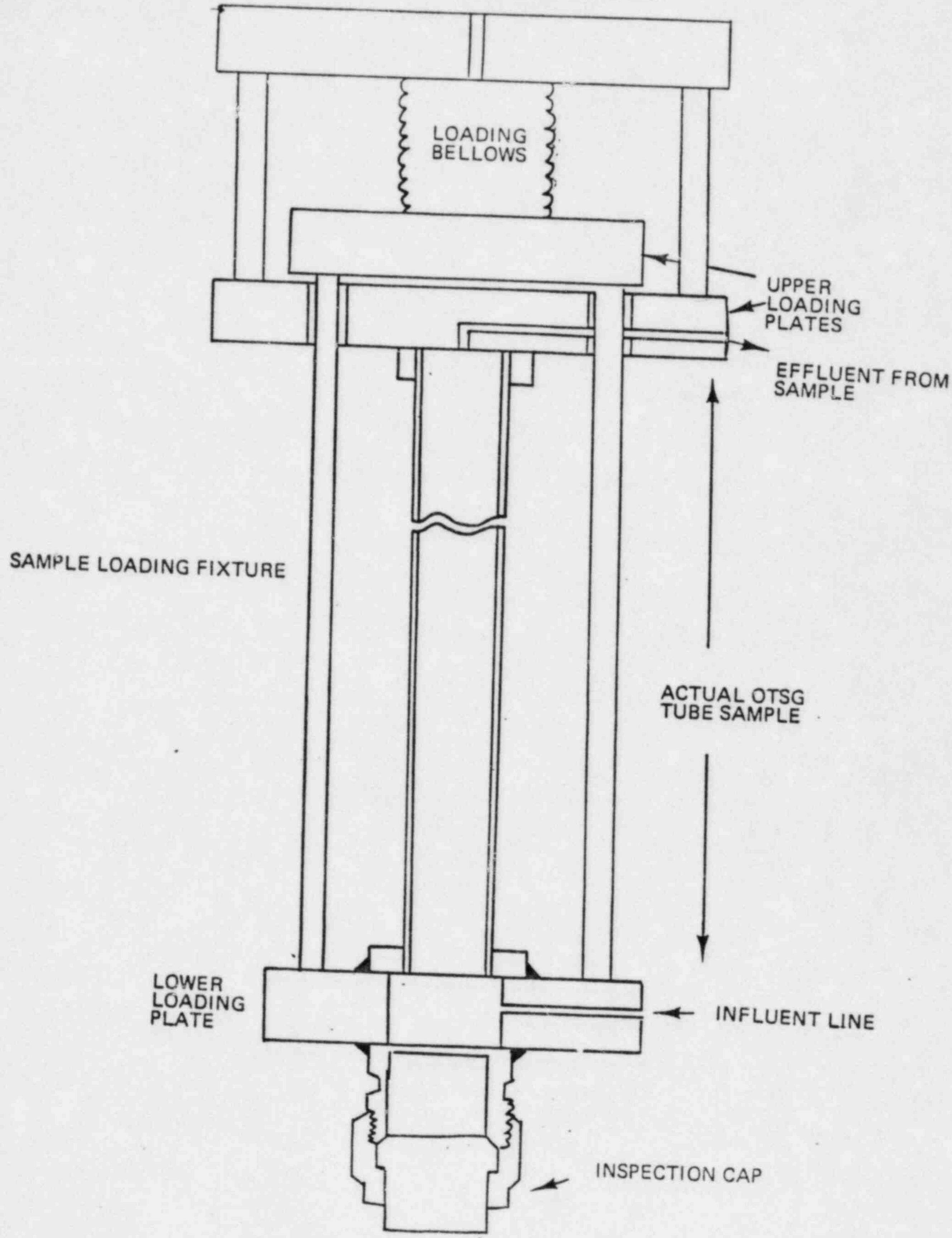
SAMPLE LOADING FIXTURE



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Summary of Specimens-
Long Term Corrosion Testing

Lead Test

	Solution 1 (thiosulfate)	Solution 2 (sulfate)
Full Tube Sections		
w/o indications		
as-removed	1	1
Immunol treated		1
Immunol and H_2O_2 treated		1
w/ indications		
as-removed	1	1
Immunol treated		1
Immunol and H_2O_2 treated		1
ID stressed C-rings		
actual TMI-1 tubing	15	15
archive tubing	4	4

Repair Test

all actual tube sections without defects
- as expanded - 4 loaded, 2 unloaded
- Immunol treated, expanded, H_2O_2 cleaned - 2 loaded, 1 unloaded

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SOLUTION CHEMISTRY

	Lead Test Solution 1	Lead Test Solution 2	Repair Test
Boron, ppm as B	2350-100	2350-100	1200-100
Li, ppm as Li	0.7 - 2.5	0.7 - 2.5	0.7 - 2.5
Chloride, ppm as Cl	.05 - .15	.05 - .15	.05 - .15
Fluoride, ppm as F	.05 - .15	.05 - .15	.05 - .15
Thiosulfate, ppm as SO_4	.05 - .15		
Sulfate, ppm as SO_4		.05 - .15	.05 - .15
Hydrazine, ppm (initial)	2 - 10	2 - 10	2 - 10
O_2 ppb	<10	<10	<10
H_2 cc/kg	15 - 40	15 - 40	15 - 40
H_2O_2			To be defined

Test Loop Operation

1 - Precondition

- No samples in place
- Establish 550-600 F in autoclave
- Flush with demineralized water until conductivity is acceptable
- Run test solution until:

  Outlet SO_4 is $\geq$ 90% of inlet concentration

2 - Insert Specimens

3 - Operate System

- Run simulated cycles - HFT and operationai
- Specimen load - 500 lb during heatup and hold, 1100 lb during cooldown

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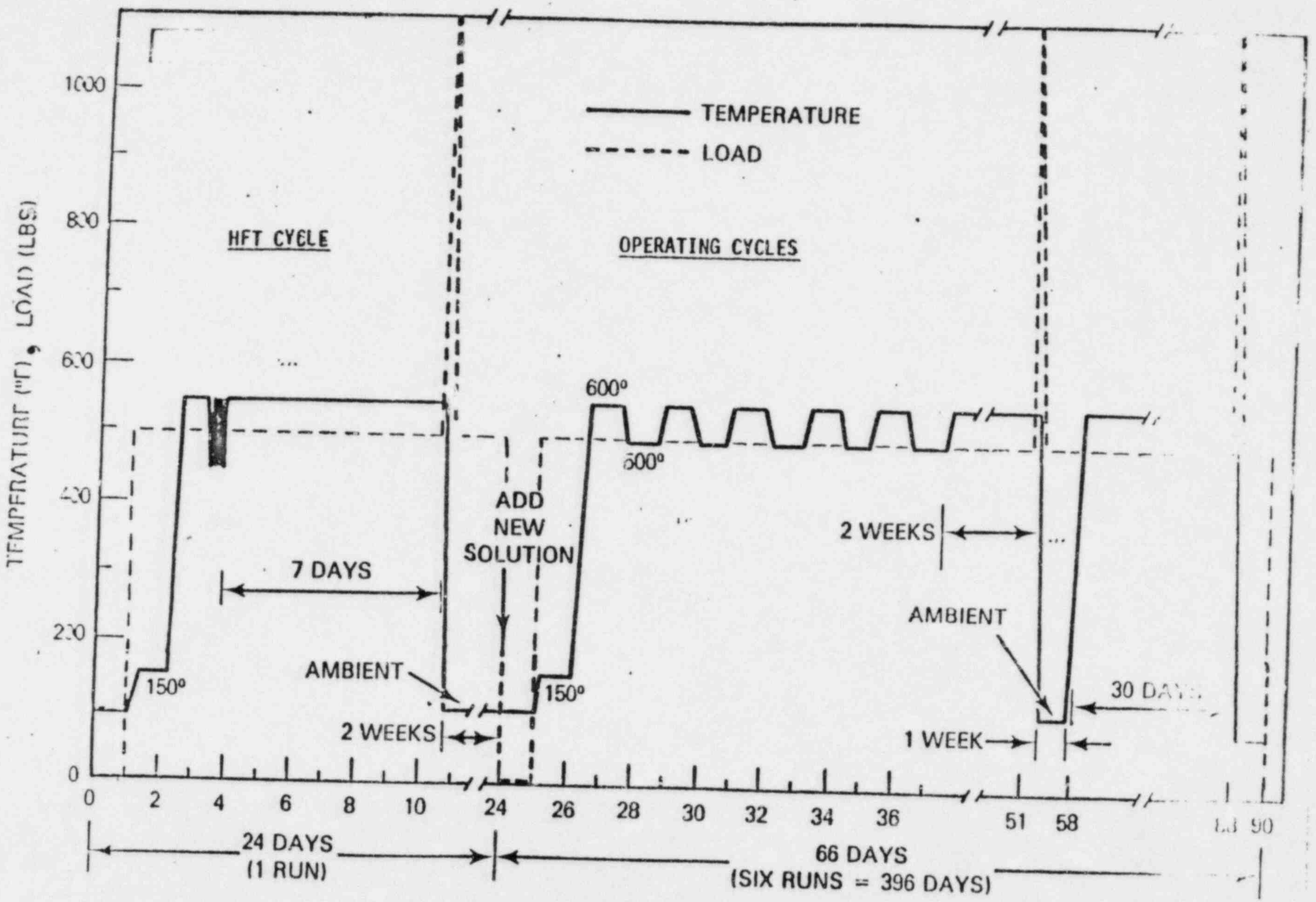
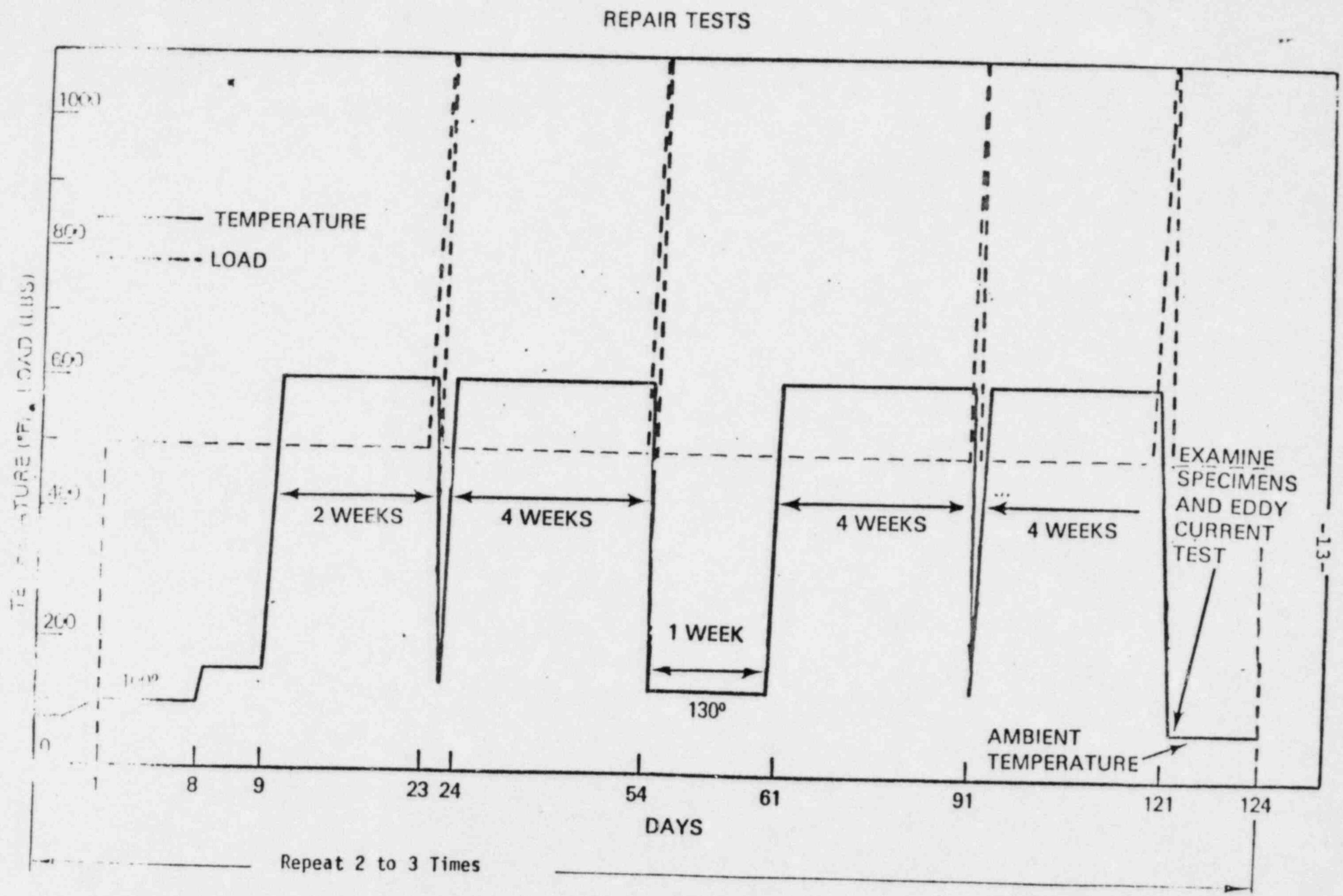
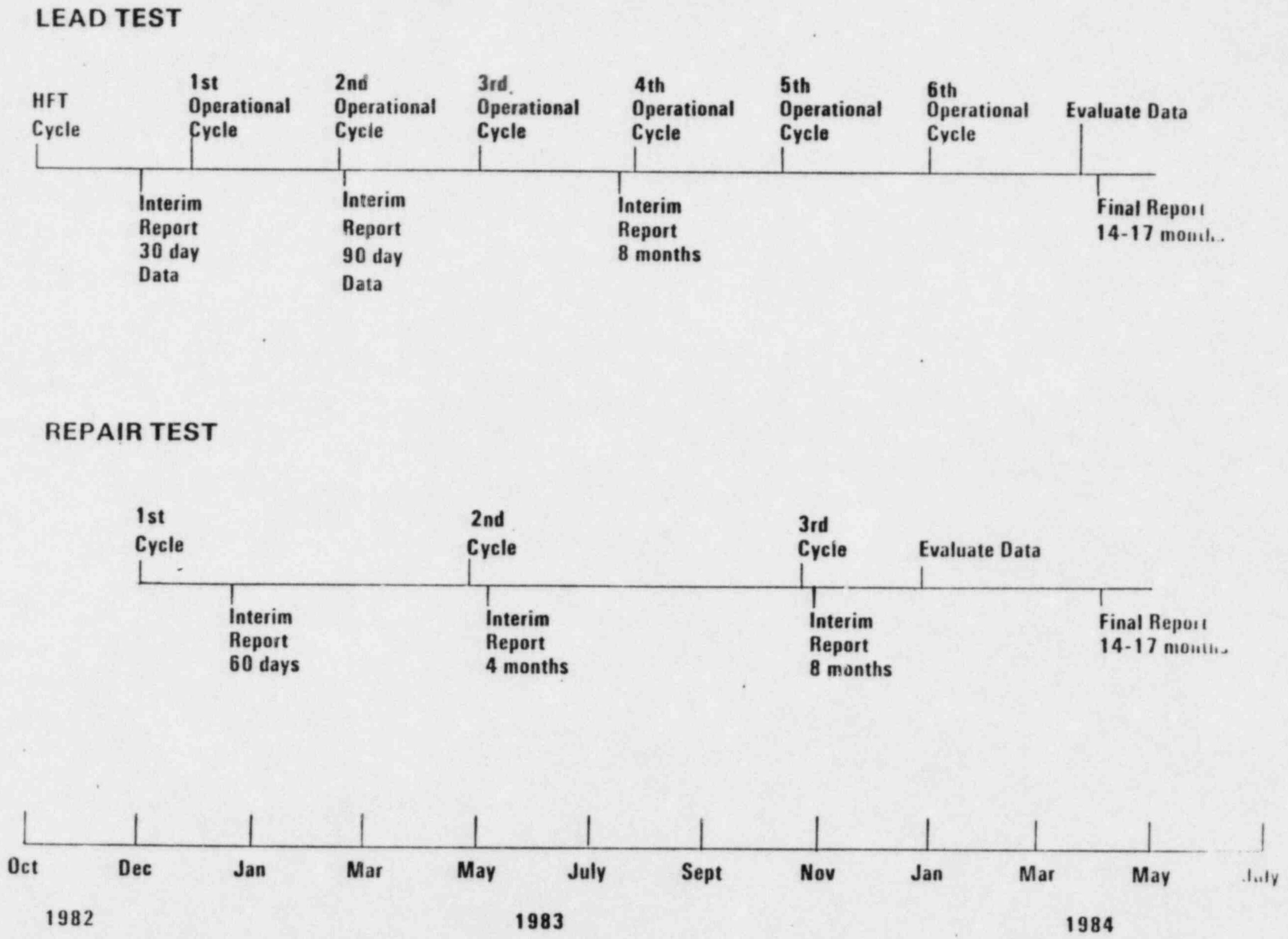
LEAD TESTS



TEMPERATURE
LOAD
HFT CYCLE
OPERATING CYCLES
TEMPERATURE (°F), LOAD (LBS)
1000
800
600
400
200
0
150°
600°
500°
150°
7 DAYS
ADD NEW SOLUTION
AMBIENT
2 WEEKS
2 WEEKS
AMBIENT
1 WEEK
30 DAYS
0
2
4
6
8
10
24
26
28
30
32
34
36
51
58
90
24 DAYS
(1 RUN)
66 DAYS
(SIX RUNS = 396 DAYS)


REPAIR TESTS
1000
800
600
400
200
0
100°
TEMPERATURE
LOAD
2 WEEKS
4 WEEKS
1 WEEK
130°
4 WEEKS
4 WEEKS
EXAMINE SPECIMENS AND EDDY CURRENT TEST
AMBIENT TEMPERATURE
1
8
9
23
24
54
61
91
121
124
DAYS
Repeat 2 to 3 Times

LONG TERM CORROSION TEST SCHEDULE



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Specimen Evaluation

1 - Full Tube Specimens

- Eddy current prior to operation with 0.540" std. differential probe
- Eddy current after each testing cycle
- Metallurgically evaluate at end of program

2 - C-Rings

- After each cycle, visually inspect all specimens
- At end of each cycle, remove one C-ring and metallurgically evaluate
- Metallurgically evaluate all specimens at end of program

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