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

August 19, 1982

E. Young
~~AR 5037~~
A. Gray

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 AUGUST 9, 1982 CONCERNING GPUN'S STEAM GENERATOR EDDY CURRENT TESTING PROGRAM

Background

As a part of their program to recover the steam generators from intergranular stress corrosion cracking of the tubes, GPUN has been conducting an extensive eddy current testing (ECT) program to ensure that all defective tubes are identified. The purpose of the August 9, 1982 meeting was to brief the staff on GPUN's plans for conducting their ECT inspection program and status of inspection results to date. A copy of GPUN's presentation is attached.

Note: Two Copies

Discussion

GPUN has decided to conduct a 100%, full length ECT program on the steam generators and have been conducting this inspection since early July. They have experimented with various ECT probes and have concluded that a modified standard differential probe (.540") incorporating a higher fill factor and increased gain settings is able to detect circumferential intergranular cracks in the TMI-1 tubing, and hence is being used as the production probe. The .540" probe has proved itself far superior for this application than the standard .510" probe commonly used in steam generator ECT. GPUN has performed correlation studies comparing the results of a 4 x 1 absolute probe with the .540" probe as well as the results of metallurigical examination of approximately 18 feet of TMI-1 tubing. The results of the correlation studies have shown immediate correlation on 99.4% of the indications using the 4 x 1 absolute and .540" probes. The remaining .6% of the non correlating indications (17) were under evaluation; at the time of the meeting, 14 had been reevaluated and had shown correlation, with the remaining 3 not yet evaluated. Hence, there is essentially 100% correlation.[1] Additionally, no defects have been found by metallography below the very top of the tube which were not first identified by ECT.

[1] It should be noted that the correlation study was done on tube defects below the roll transition area.

8506140145 850125
PDR FOIA
DETJEN84-897 PDR

56

Preliminary results of the ongoing full ECT have identified additional indications in the tubes, below 16" from the top of tubes (tubes with defects above 16" can be repaired by the explosive expansion technique). It is presently unknown how many additional tubes will be affected and what the disposition of these indications will be.

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

Enclosure:
GPU Presentation

cc w/enclosure:
See next page

ORB#4:DL

MEETING SUMMARY DISTRIBUTION

Licensee:

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

Docket File
NRC PDR
L PDR
ORB#4 Rdg
GLainas
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:
CMcCracken
LFrank
SReynolds
FYoung

AUGUST 9, 1982

TMI - 1

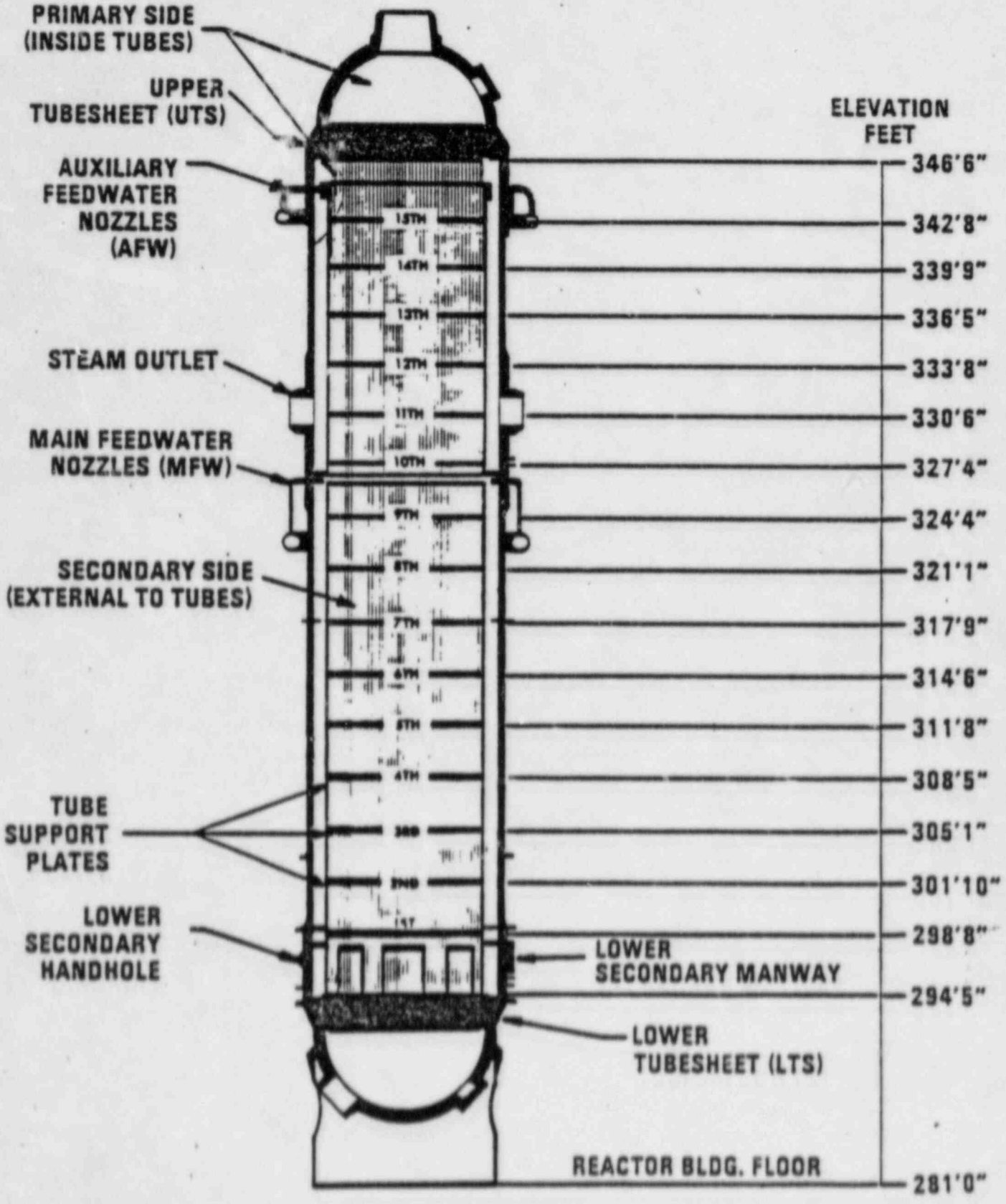
OTSG TASK 4

EDDY CURRENT PRESENTATION

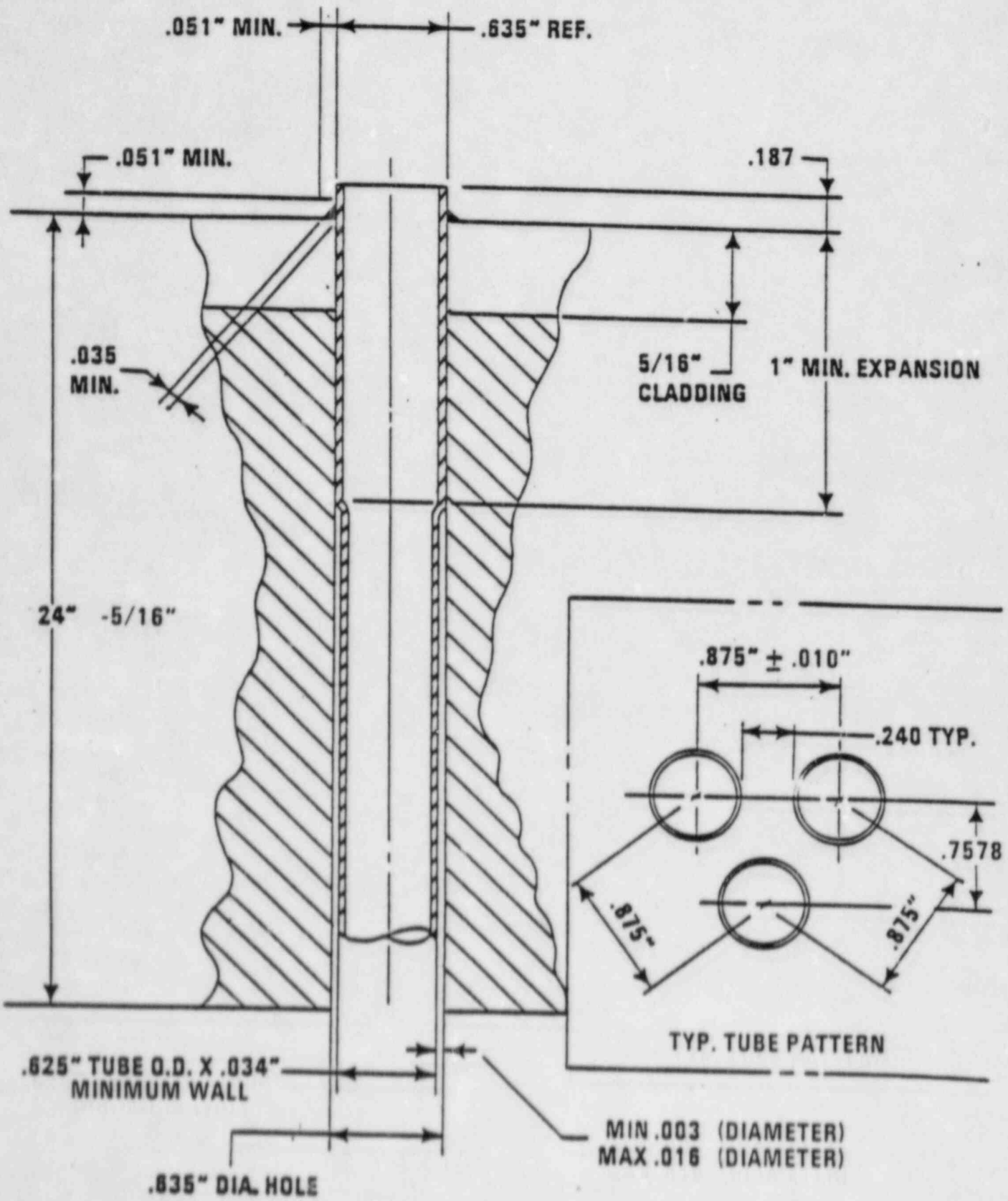
TO THE

N R C

OTSG Longitudinal Section Elevations (Typ.)



TMI-1 OTSG Upper Tubesheet Detail (Typ.)

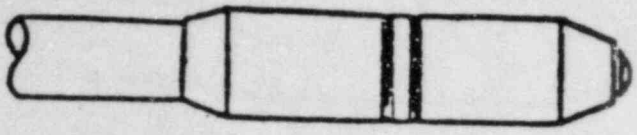


1. E/C Techniques

a) Standard Differential -
Two interacting coils mounted circumferential; resultant signal response is produced by measuring the differential from the area of discontinuity to clean tubing area.

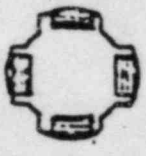
b) Absolute Technique -
Single coil wound in a pancake shape normal to SD coil; two sets of four separate (isolation) coils that are assembled in tandem to provide an effective eight coil coverage; optimum detection of circumferential oriented discontinuities.
Disadvantage -
Not conducive to broad scale production programs because it is extremely fragile and wears rapidly; additionally presents numerous electronic recording and analyst problems associated with having to maintain and read B channel recordings.

TMI-1 Eddy Current Probes
Utilized for OTSG Tubing Examinations



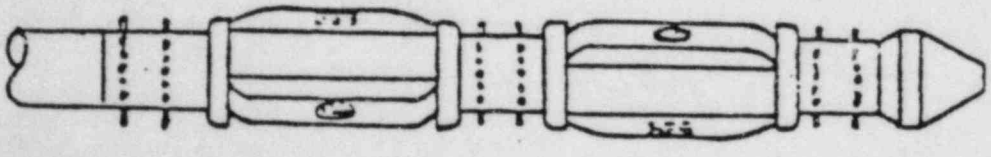
400 KHZ FULL GAIN
MIX 200 KHZ
400 KHZ REDUCED GAIN
MIX 800 KHZ

Differential



400 KHZ

4X



400 KHZ FULL GAIN
MIX 200 KHZ
400 KHZ REDUCED GAIN
MIX 800 KHZ

3 x 3

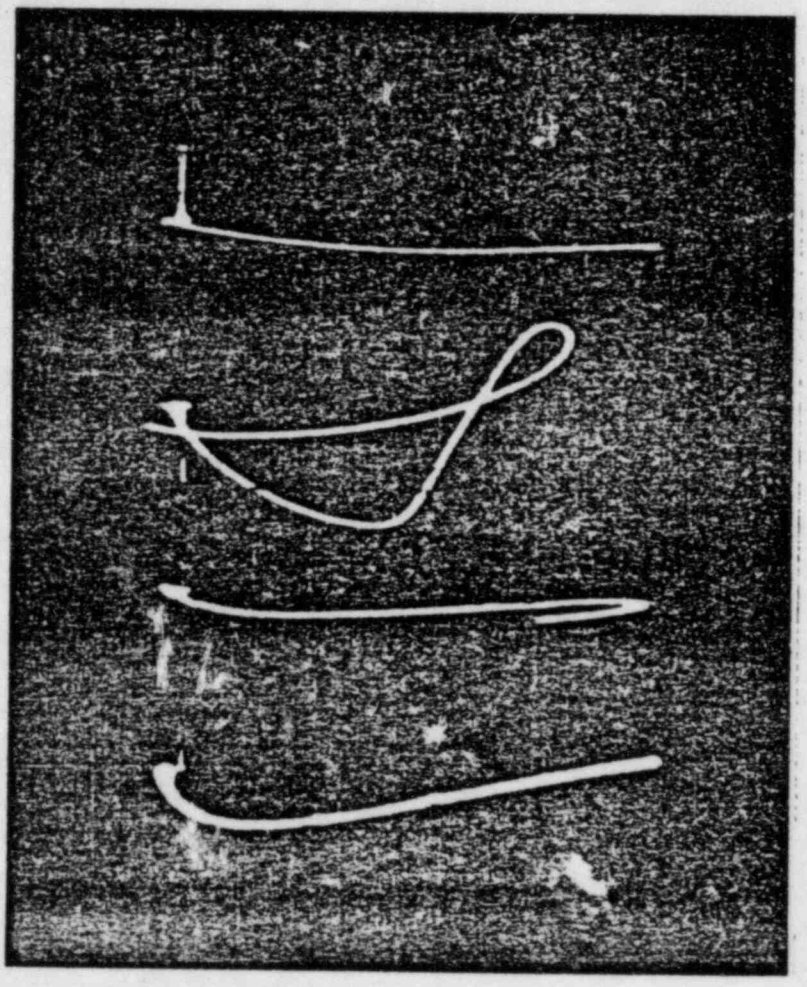
1. E/C Techniques Continued

Multifrequency -
Utilized for all SD examinations; applied 2 base frequencies (400 KHz and 200 KHz) and used an "ID" mix to enhance detection of ID defects and minimize affect of chatter and tube noise.

Saturated Probes -
Improves noise.

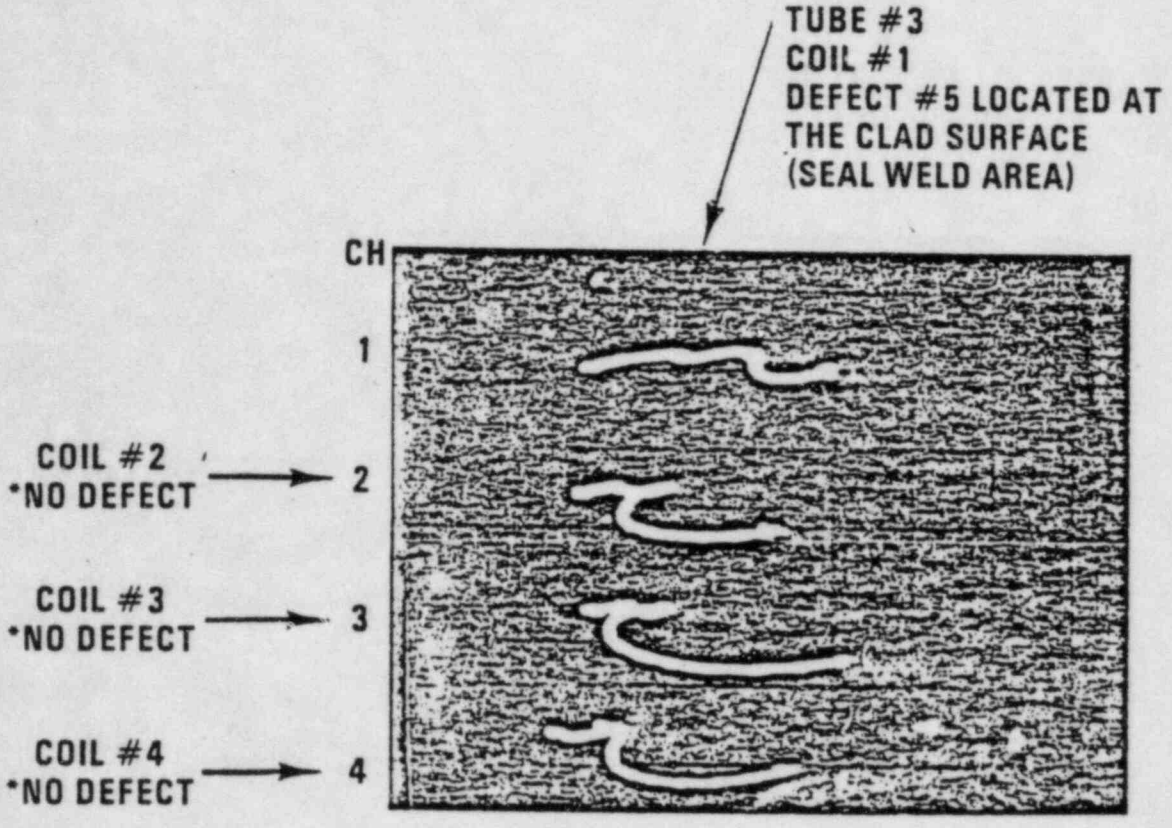
ID mix

Eddy Current Signals
Roll Transition Mockup
Differential Probe



NDD	No Defect
Defect	100% Thru Wall 180°
NDD or NDD-1	40% Thru Wall 90°
NDD-1	40% Thru Wall 3/16 Inch Hole

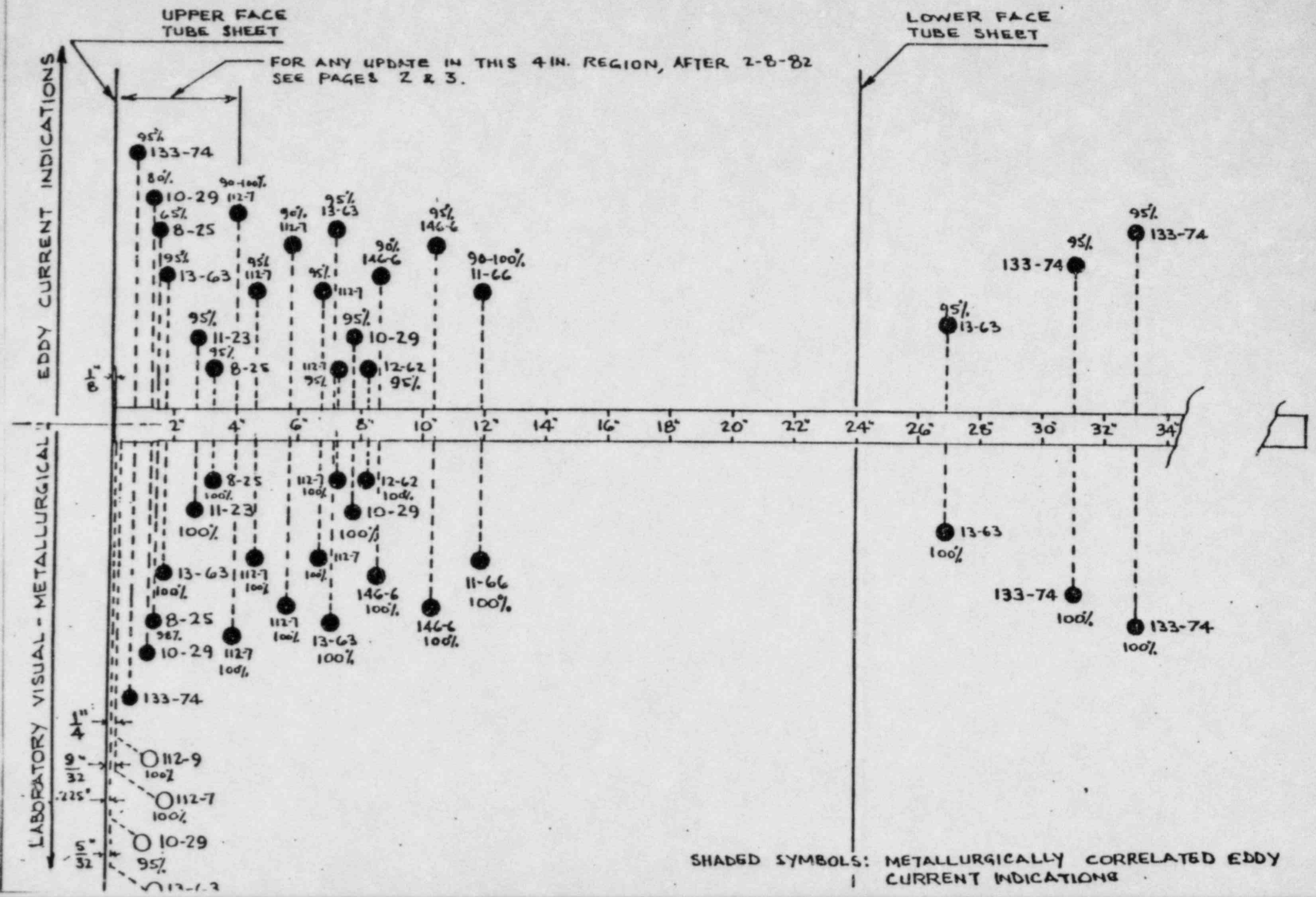
4x1 Absolute E/C Probe Qualification Data



* SIGNAL RESPONSE IS NORMAL DEFECT FREE RESPONSE AT TUBESHEET/TUBE EXIT

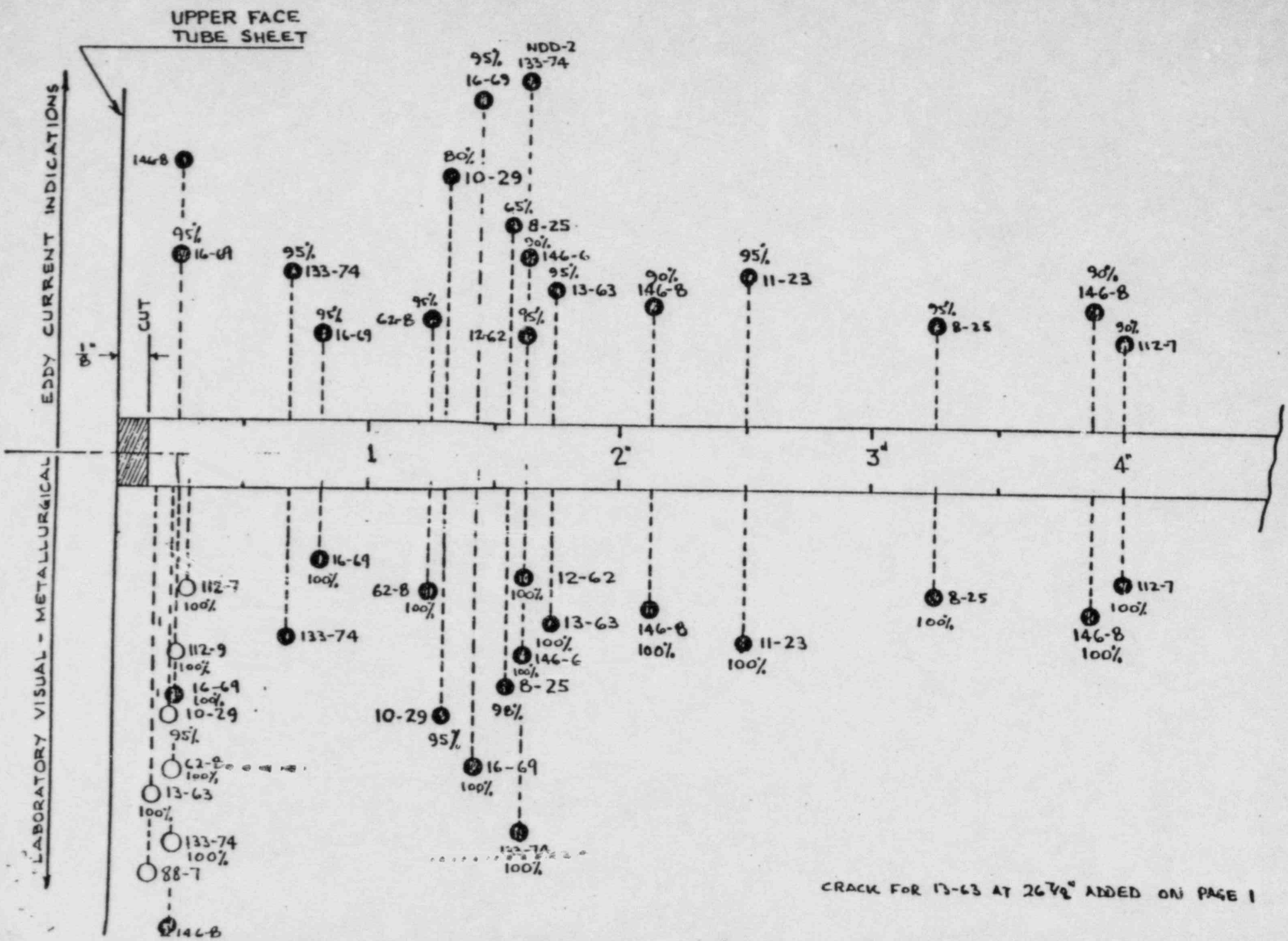
4X1 EDDY CURRENT PROBE RESPONSE TO A 40% ID TUBE WALL DEFECT LOCATED AT THE CLAD SURFACE OF TUBE #3 IN THE SIX (6) TUBE OTSG TUBESHEET MOCKUP

CORRELATION SUMMARY OF DESTRUCT TESTS AND EDDY CURRENT INDICATIONS



SHADED SYMBOLS: METALLURGICALLY CORRELATED EDDY CURRENT INDICATIONS

CORRELATION SUMMARY OF DESTRUCT TESTS AND EDDY CURRENT INDICATIONS



CRACK FOR 13-63 AT 26 7/8" ADDED ON PAGE 1

SHADED SYMBOLS: METALLURGICALLY CORRELATED

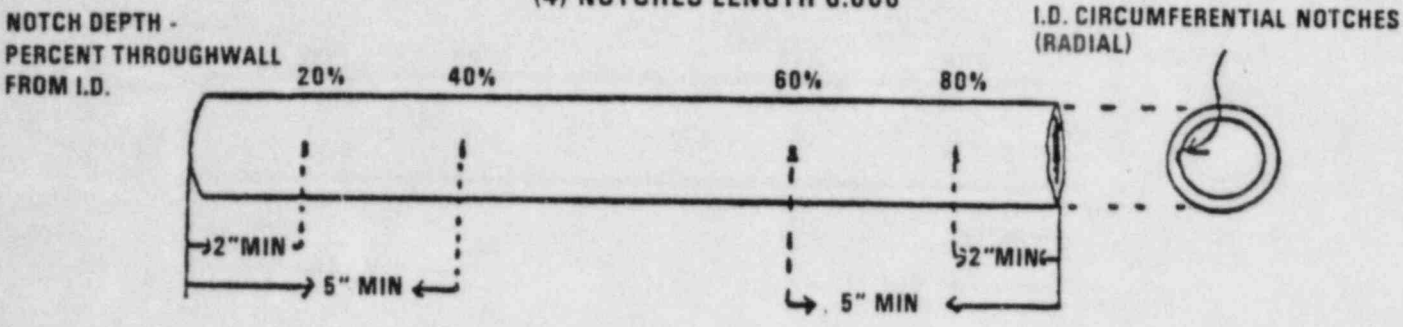
FACTORS AFFECTING ECT RESPONSE

STANDARD DIFFERENTIAL TO BE USED FOR PRODUCTION RUN INVESTIGATION.

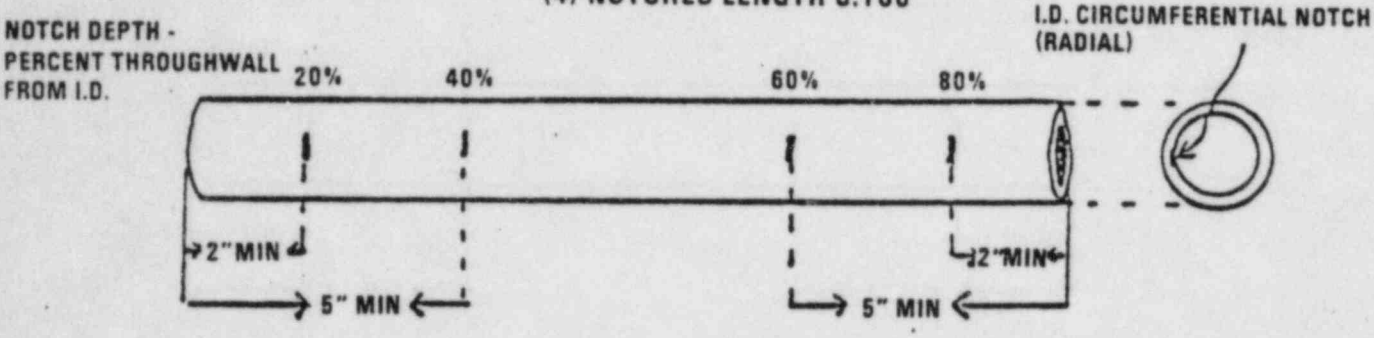
1. CRACK GEOMETRY
   - A) SMALLER ASPECT RATIO (A/L) YIELDS A LOWER AMPLITUDE RESPONSE.
   - B) DETECTION OF CIRCUMFERENTIAL CRACK IS DEPENDENT UPON CRACK WIDTH, AXIAL BRANCHING AND SPIRALING.
2. PROBE DESIGN/CONFIRGUATION
   - A) HIGHER THE FILL FACTOR GREATER THE SENSITIVITY AND REPRODUCEABILITY.
   - B) 360° COVERAGE.
   - C) REDUCE PROBE WOBBLE WITH INCREASING FILL FACTOR.
3. LIMITATION OF INTERPRETATION
   - A) INDICATIONS YIELD LOWER AMPLITUDE RESPONSE.
   - B) GREATLY AFFECTED BY TUBE TRANSITION AREAS.
4. OPERATING PARAMETERS TO BE OPTIMIZED
   - A) FILL FACTOR.
   - B) FREQUENCY.
   - C) GAIN.
   - D) CHART SPEED.
   - E) ID MIXING.
5. CONSIDERATION FOR PRODUCTION
   - A) NOISE AND CHATTER.
   - B) ANALYST PRECISION AND ACCURACY OF COILS.
   - C) DATA HANDLING.

OTSG TUBING DEFECT MOCKUPS

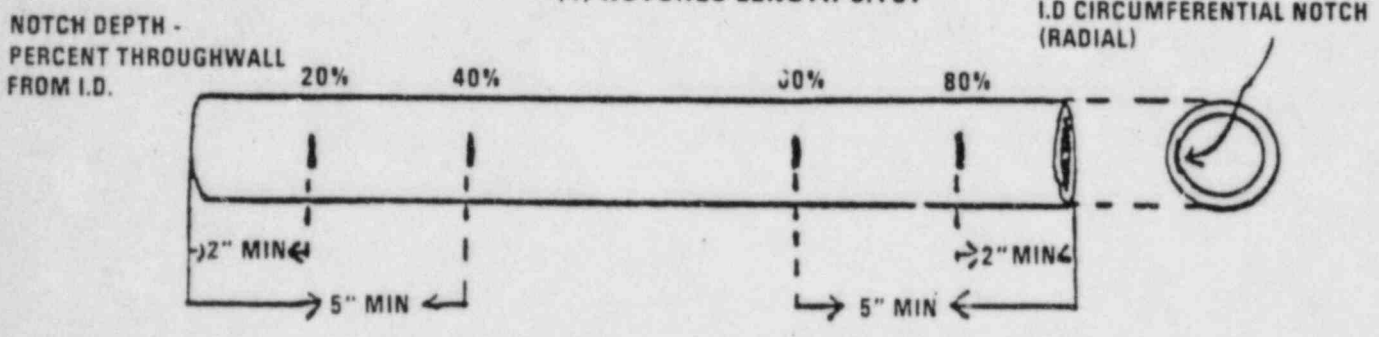
SAMPLE #1
(4) NOTCHES LENGTH 0.060"



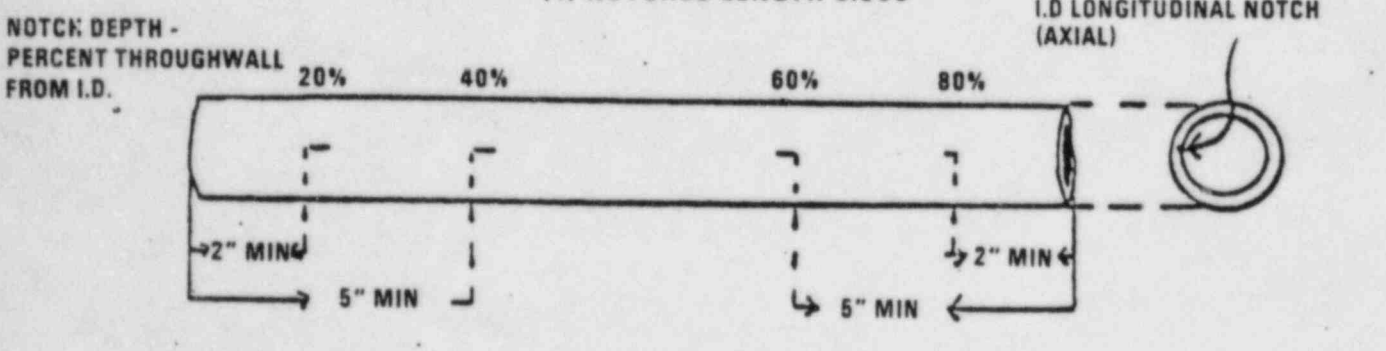
SAMPLE #2
(4) NOTCHES LENGTH 0.100"

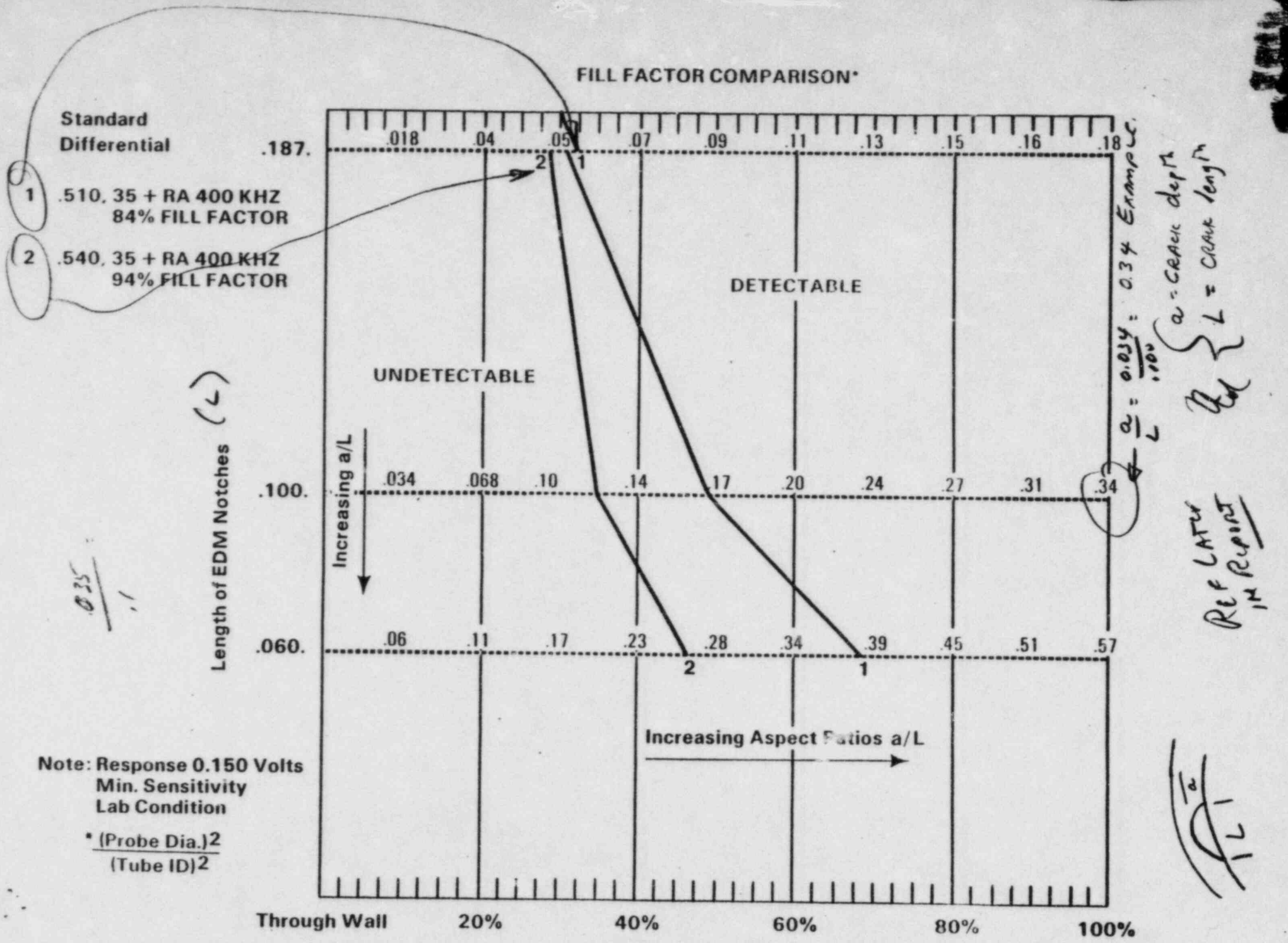


SAMPLE #3
(4) NOTCHES LENGTH 0.187

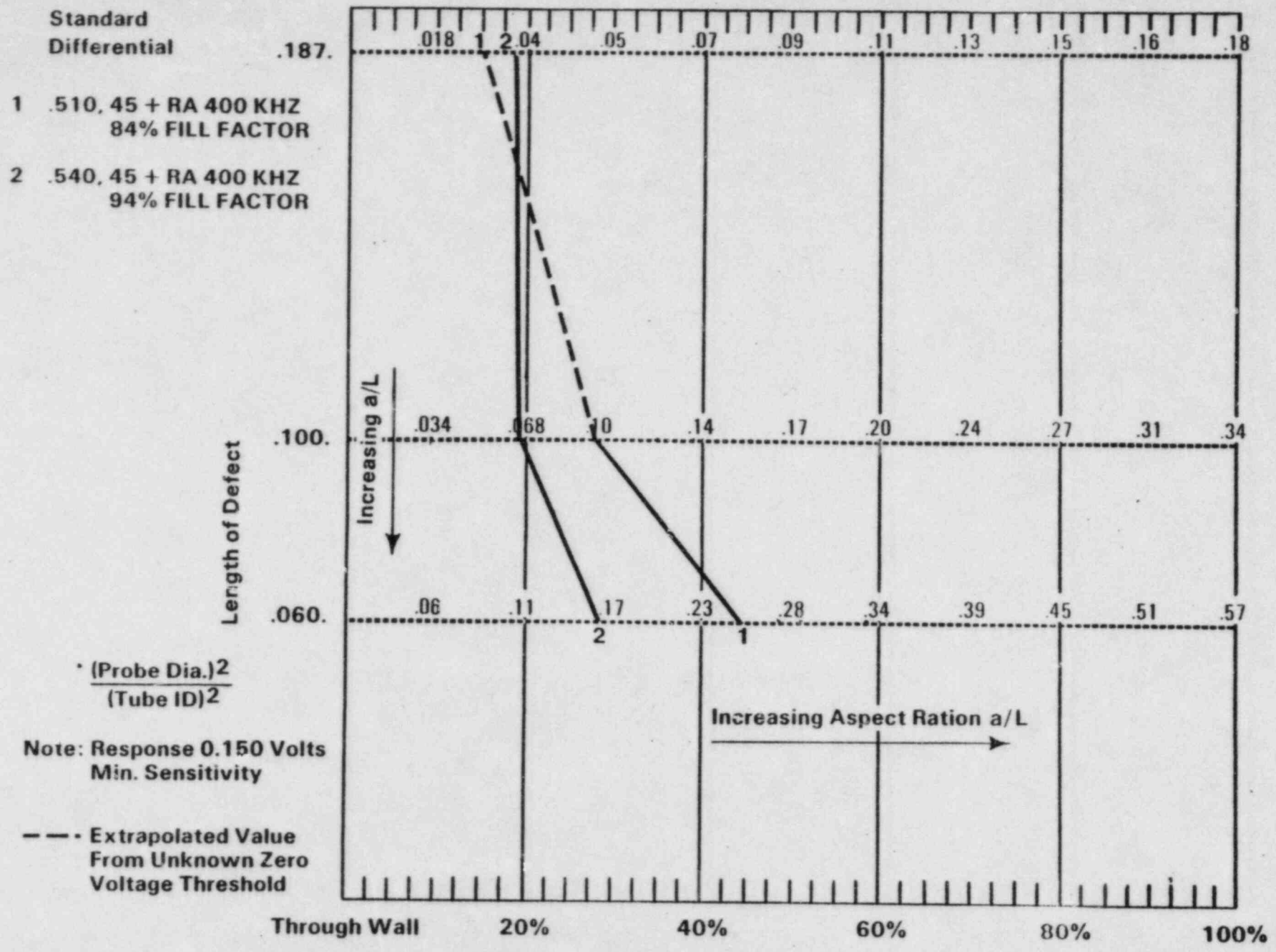


SAMPLE #4
(4) NOTCHES LENGTH 0.060"

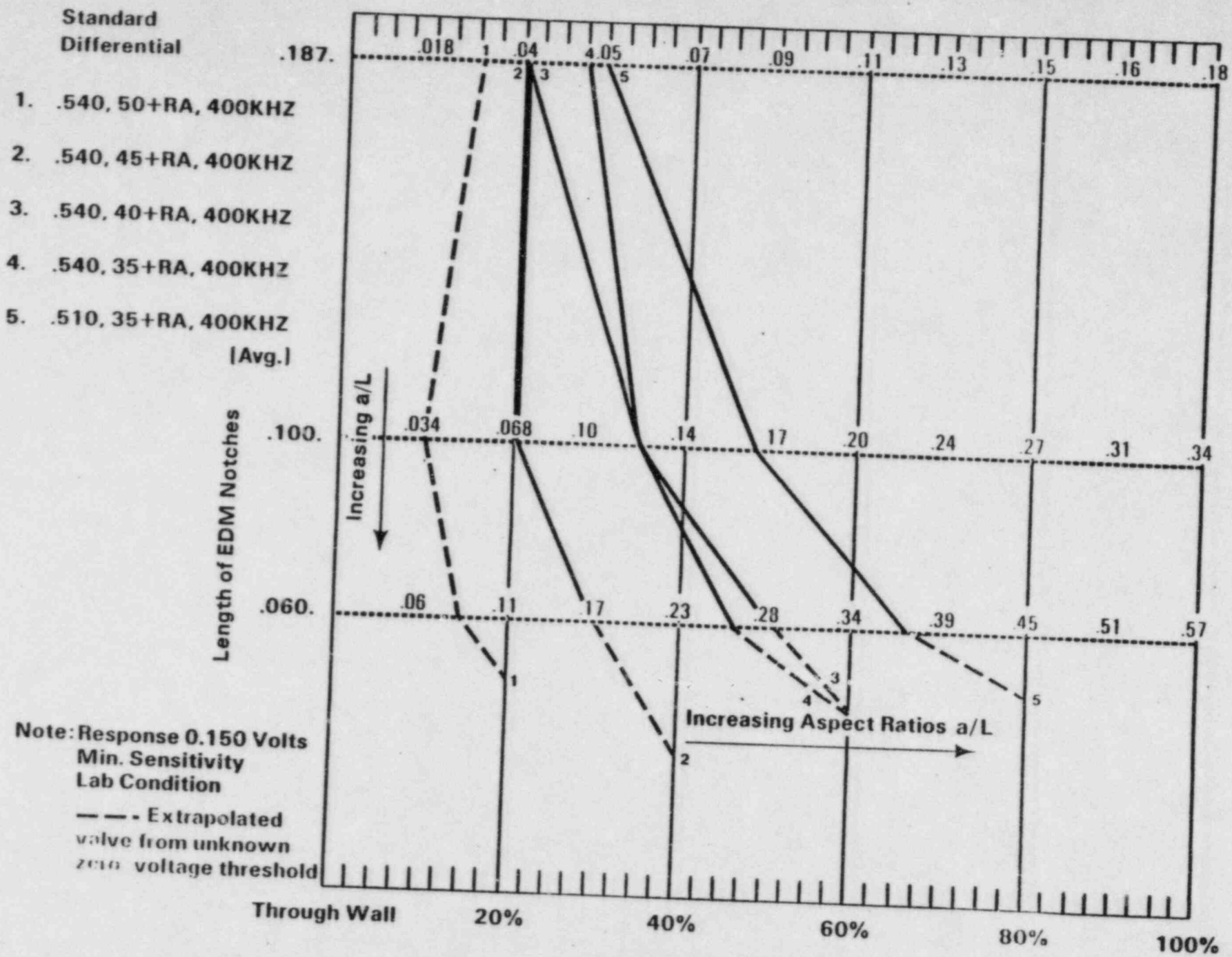



FILL FACTOR COMPARISON*
Standard Differential
1 .510, 35 + RA 400 KHZ 84% FILL FACTOR
2 .540, 35 + RA 400 KHZ 94% FILL FACTOR
.187.
.100.
.060.
.018 .04 .05 .07 .09 .11 .13 .15 .16 .18
.034 .068 .10 .14 .17 .20 .24 .27 .31 .34
.06 .11 .17 .23 .28 .34 .39 .45 .51 .57
DETECTABLE
UNDETECTABLE
Increasing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

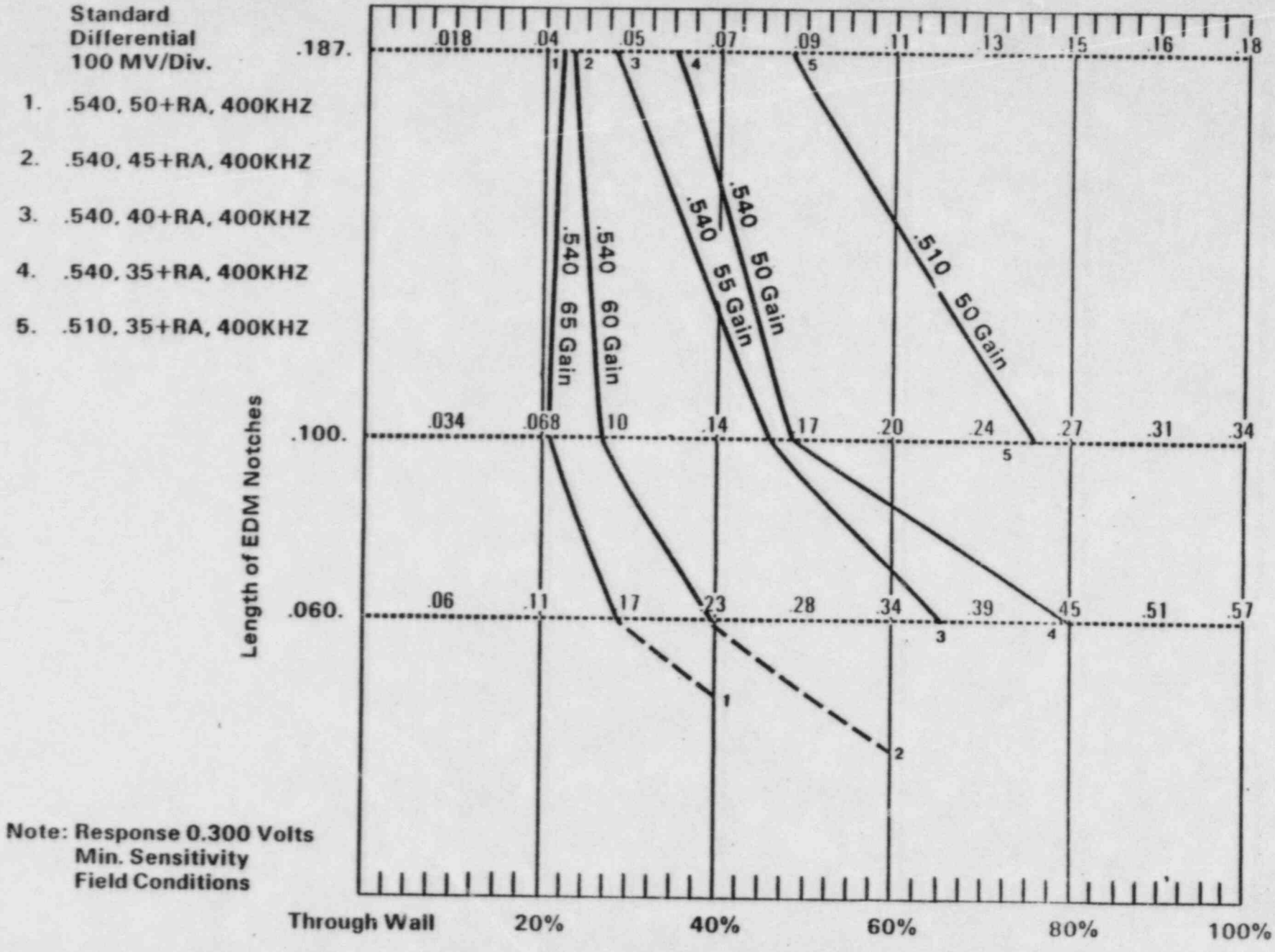
FILL FACTOR COMPARISON*



GAIN COMPARISON FOR DETECTION PROBABILITY

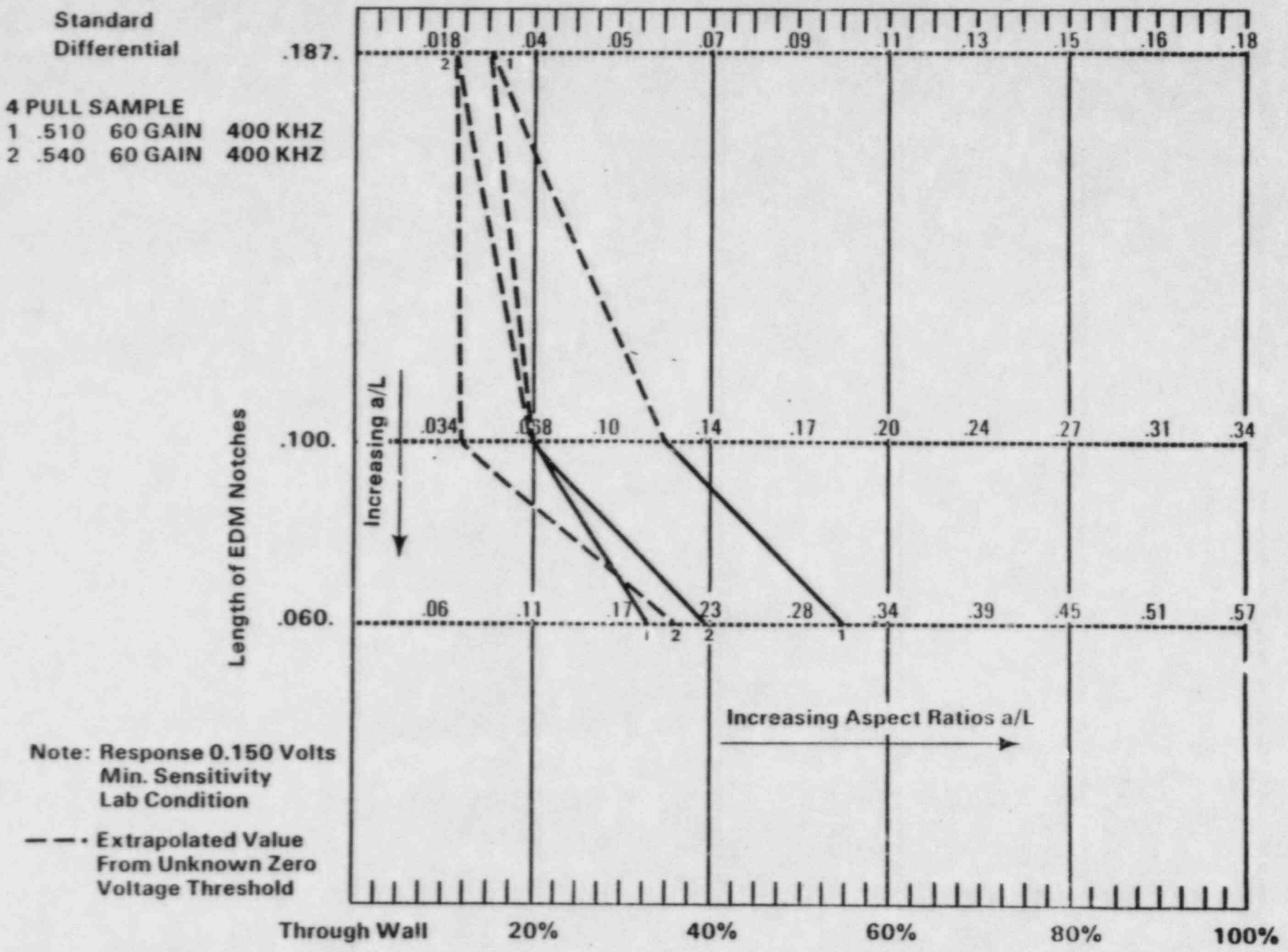


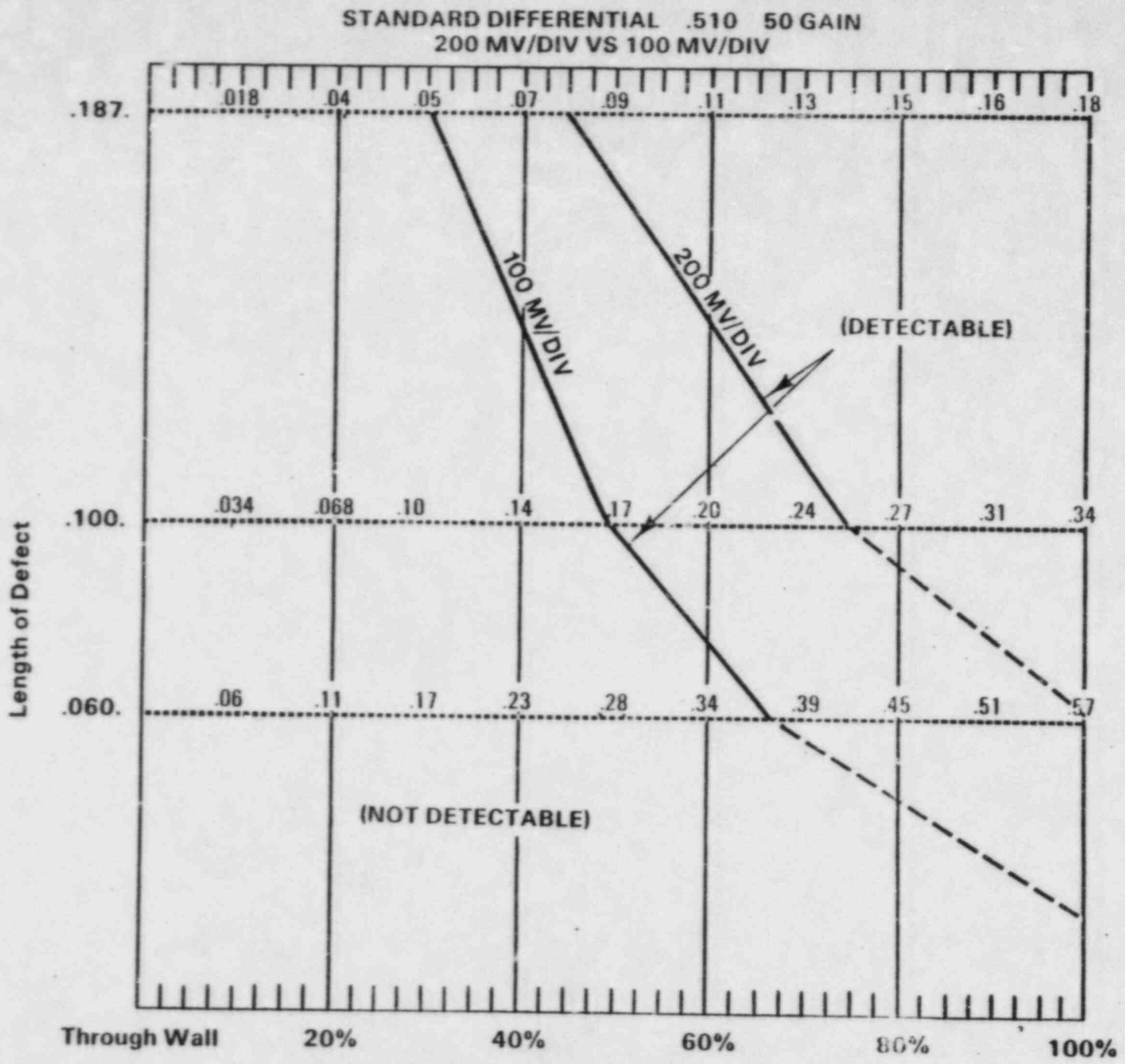
GAIN COMPARISON FOR DETECTION PROBABILITY

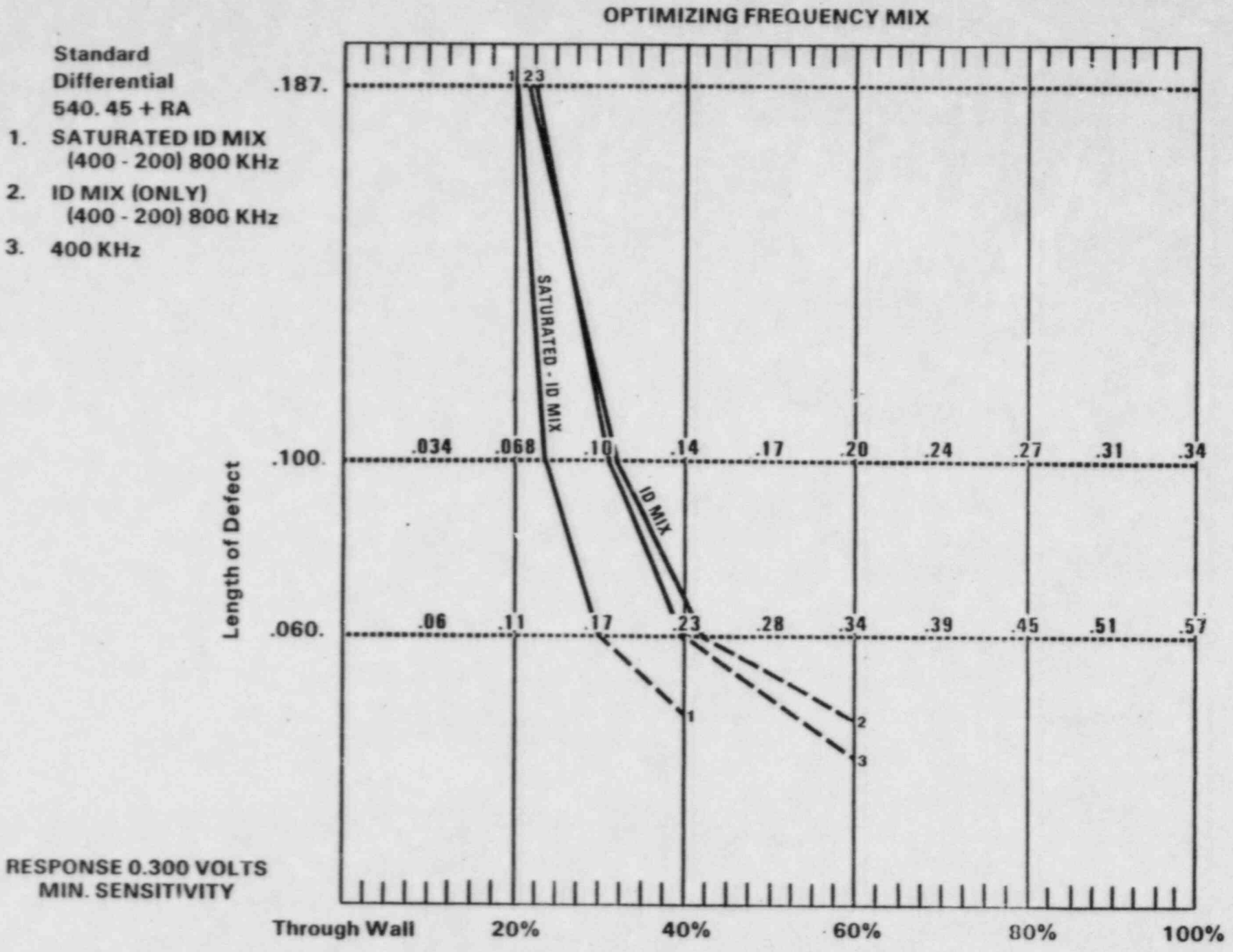


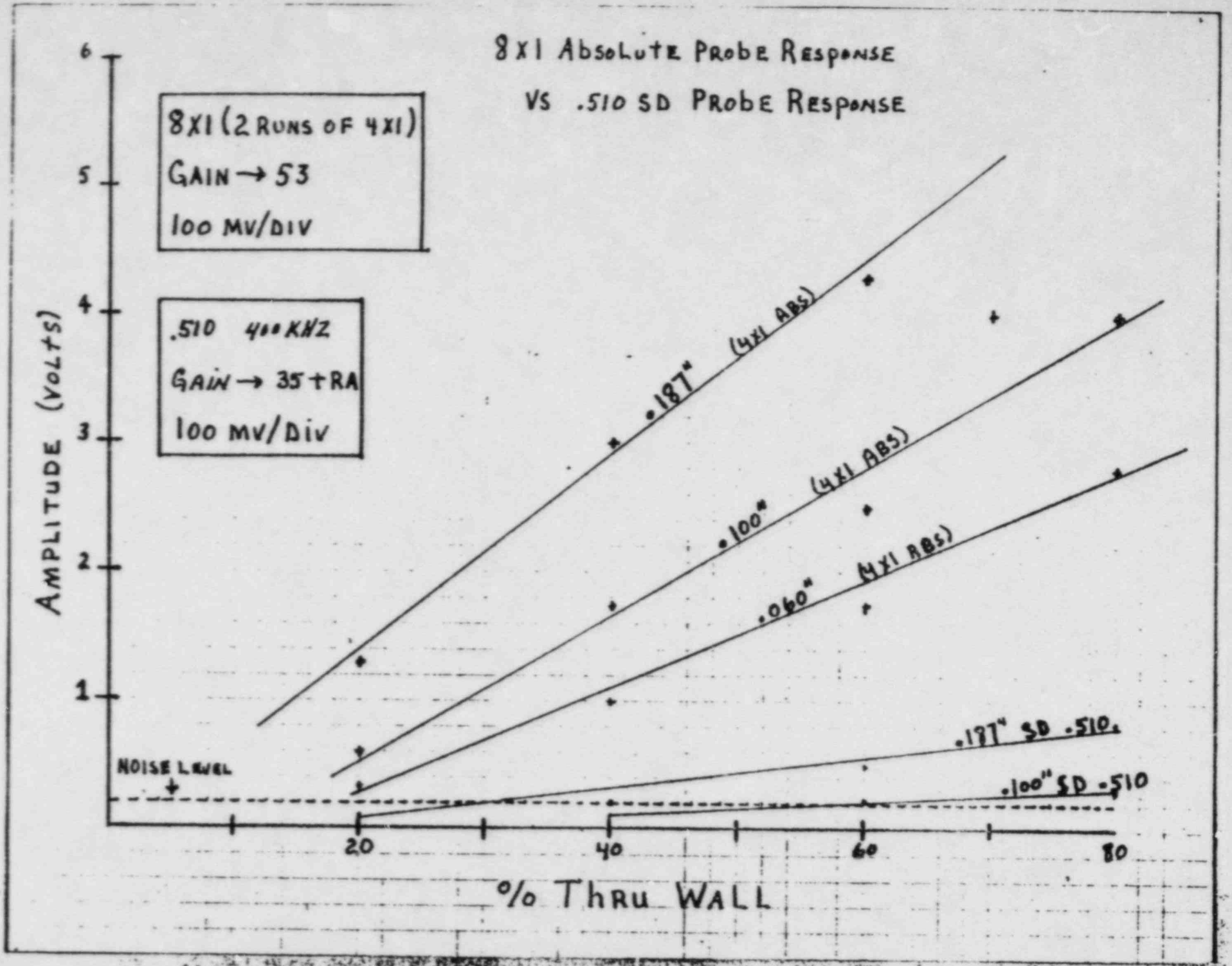
Note: Response 0.300 Volts
Min. Sensitivity
Field Conditions

REPRODUCEABILITY OF RESULTS

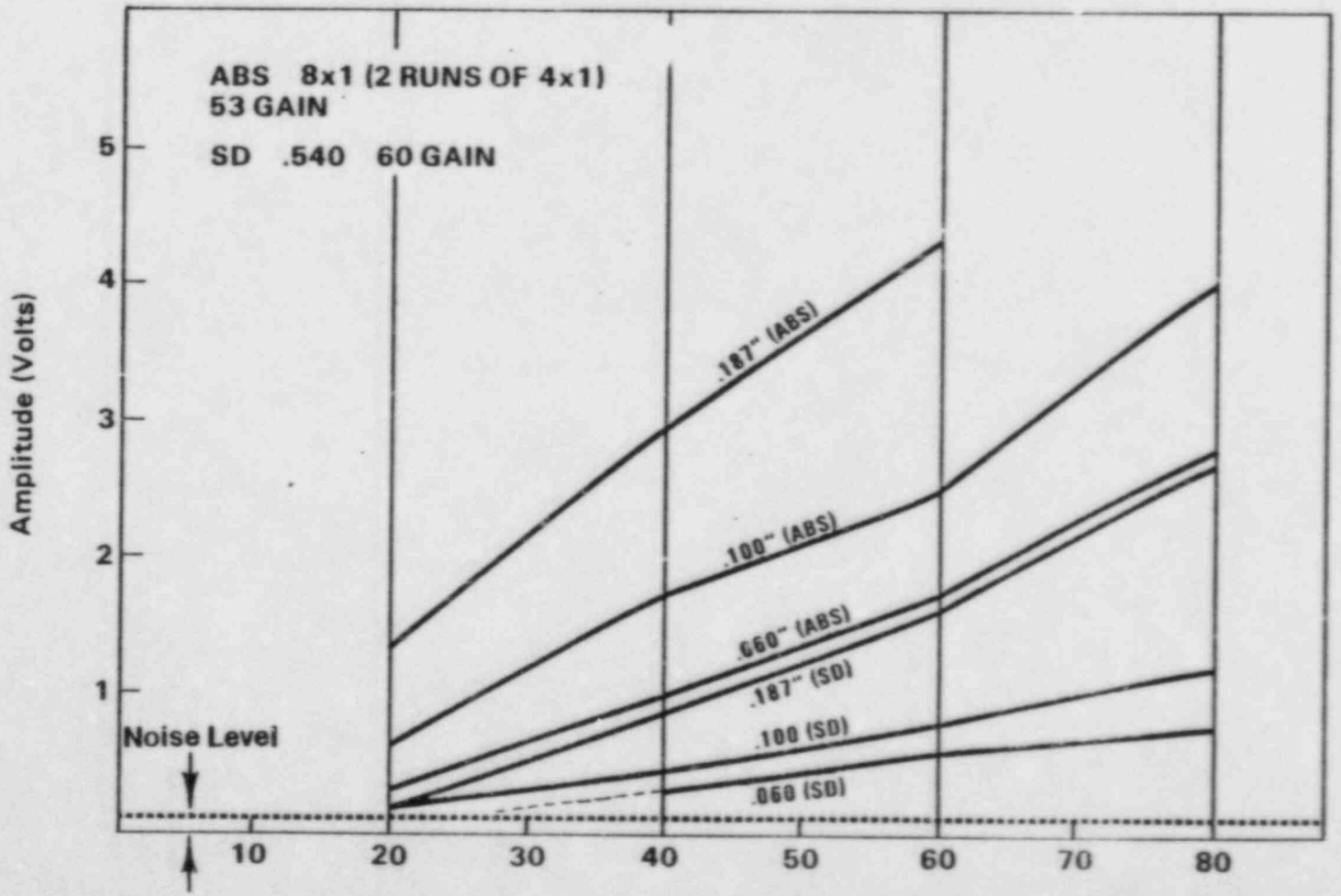



STANDARD DIFFERENTIAL .510 50 GAIN
200 MV/DIV VS 100 MV/DIV
.187.
.100.
.060.
Length of Defect
.018
.04
.05
.07
.09
.11
.13
.15
.16
.18
.034
.068
.10
.14
.17
.20
.24
.27
.31
.34
.06
.11
.17
.23
.28
.34
.39
.45
.51
.57
100 MV/DIV
200 MV/DIV
(DETECTABLE)
(NOT DETECTABLE)
Through Wall
20%
40%
60%
80%
100%


OPTIMIZING FREQUENCY MIX
Standard
Differential
540. 45 + RA
1. SATURATED ID MIX
(400 - 200) 800 KHz
2. ID MIX (ONLY)
(400 - 200) 800 KHz
3. 400 KHz
.187.
.100.
.060.
Length of Defect
1 2 3
SATURATED - ID MIX
ID MIX
.034 .068 .10 .14 .17 .20 .24 .27 .31 .34
.06 .11 .17 .23 .28 .34 .39 .45 .51 .57
1
2
3
RESPONSE 0.300 VOLTS
MIN. SENSITIVITY
Through Wall
20%
40%
60%
80%
100%


8X1 Absolute Probe Response
VS .510 SD Probe Response
8X1 (2 Runs of 4X1)
Gain → 53
100 mV/Div
.510 400 KHz
Gain → 35 + RA
100 mV/Div
Amplitude (Volts)
6
5
4
3
2
1
.187" (4X1 ABS)
.100" (4X1 ABS)
.060" (4X1 ABS)
.187" SD .510
.100" SD .510
Noise Level
20
40
60
80
% Thru Wall

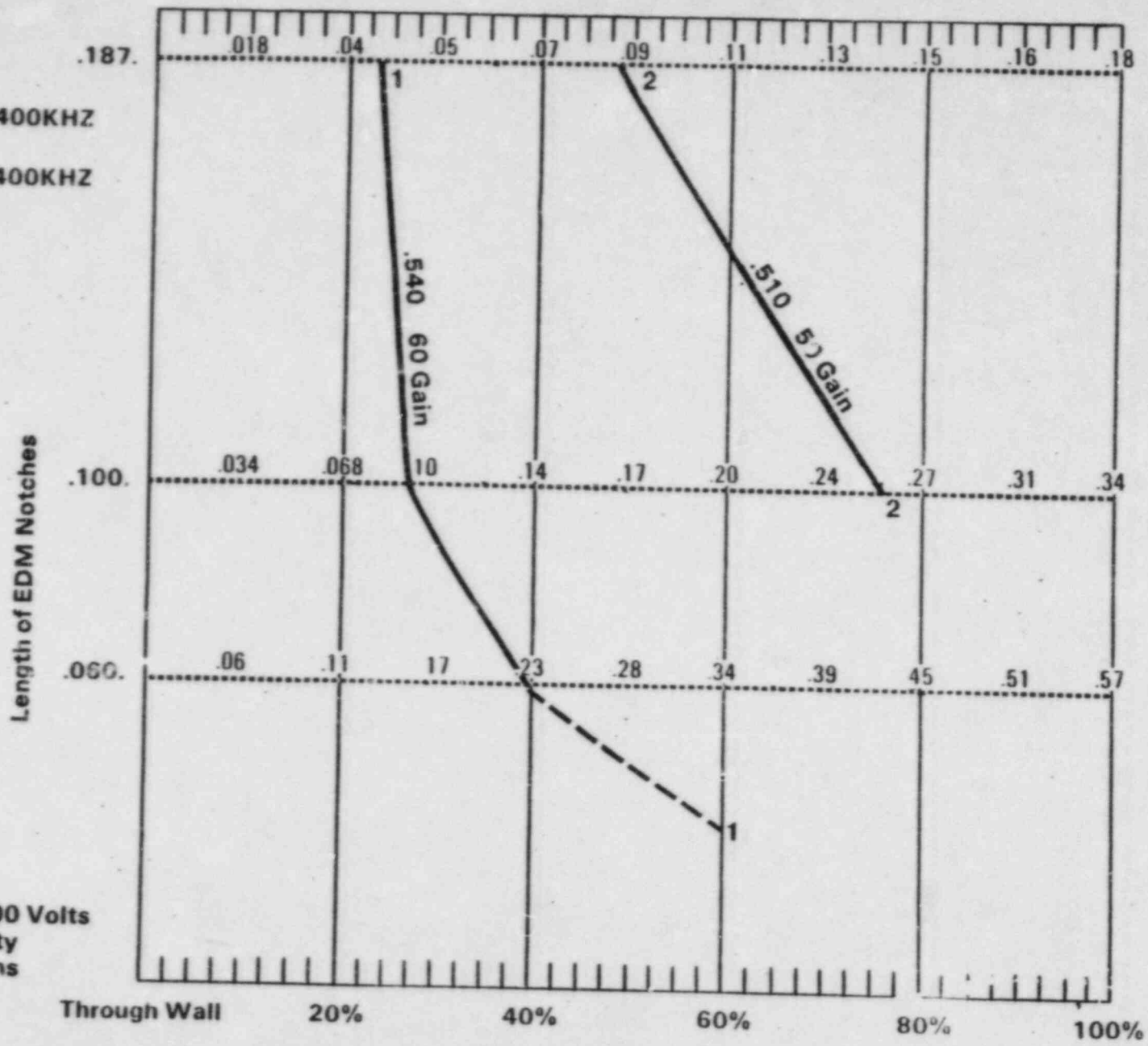
AMPLITUDE RESPONSE
STANDARD DIFFERENTIAL VS 8x1 ABSOLUTE
SIMULATED DEFECTS 0.005" WIDE



GAIN COMPARISON FOR DETECTION PROBABILITY

Standard
Differential
100 MV/Div.

1. .540, 45+RA, 400KHZ
2. .510, 35+RA, 400KHZ



Note: Response 0.300 Volts
Min. Sensitivity
Field Conditions

FACTORS AFFECTING ECT RESPONSE

[redacted]

TO BE USED FOR DISPOSITIONING PURPOSES ONLY"

1. CRACK GEOMETRY
   A) SMALLER ASPECT RATION (A/L) YEILDS LOWER AMPLITUDE RESPONSE

2. PROBE DESIGN/CONFIGURATION
   A) COIL TO COIL VARIANCES
   B) AMPLITUDE OF RESPONSE IS INFLUENCED BY DEFECT TO COIL ORIENTATION
   C) LIMITED FIELD COVERAGE/COIL
   D) SPRING LOADED - LESS SENSITIVE TO MOTION

[redacted]

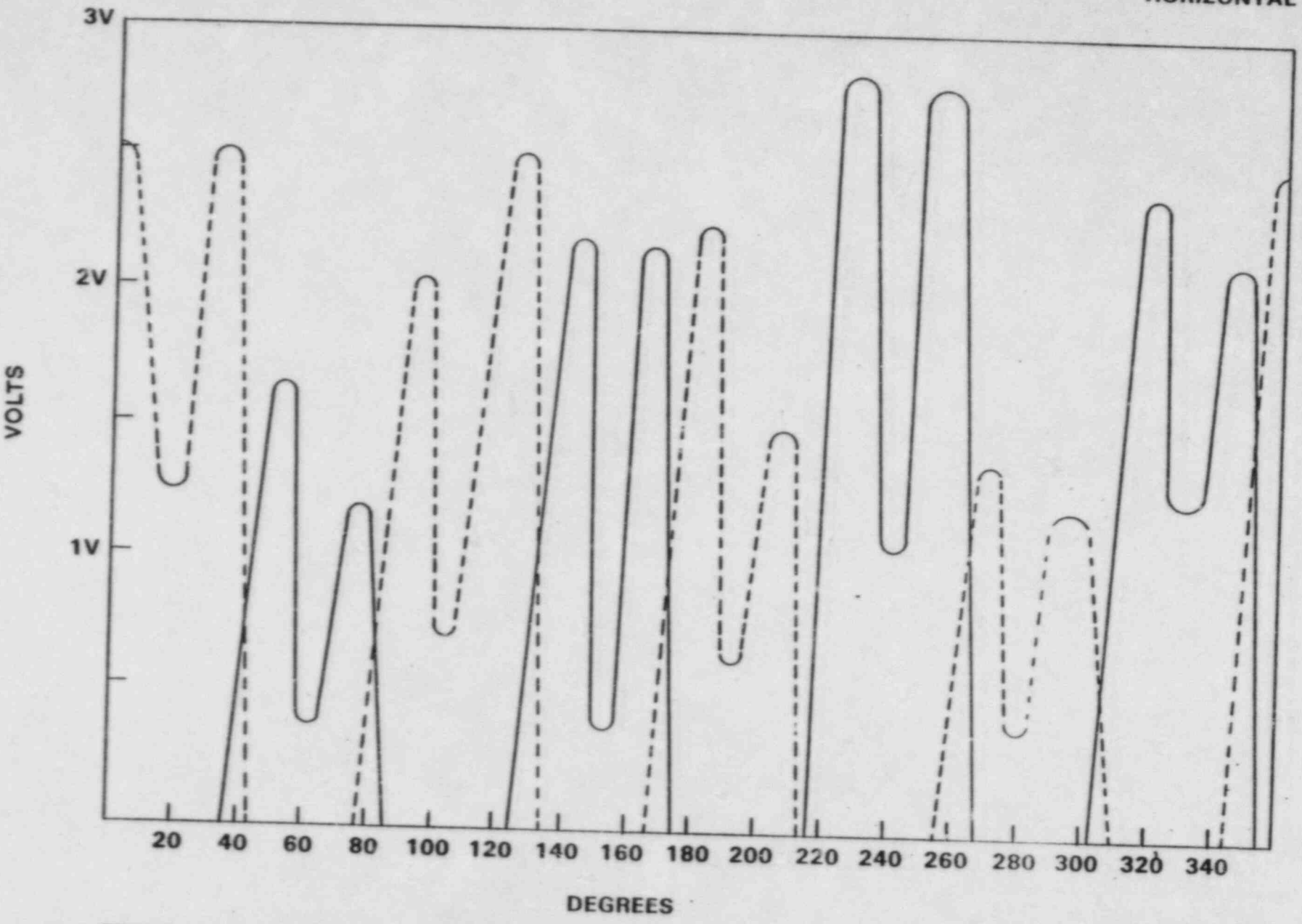
   A) [redacted]
   B) AMPLITUDE OF RESPONSE IS NOT RELATED TO SEVERITY OR EXTENT OF DEFECT

4. OPERATING PARAMETERS TO BE OPTIMIZED
   A) FREQUENCY
   B) GAIN
   C) NO. OF COILS

5. CONSIDERATIONS FOR PRODUCTION
   A) NOISE AND CHATTER - MINIMIZED
   B) ANALYST ACCURACY AND PRECISION OF CALLS
   C) DATA HANDLING
   D) DURABILITY OF PROBE - NOT SUITED FOR PRODUCTION TECHNIQUE
   E) DIFFICULTY OF MAINTENANCE AND ANALYZING 8 TAPE RESPONSES

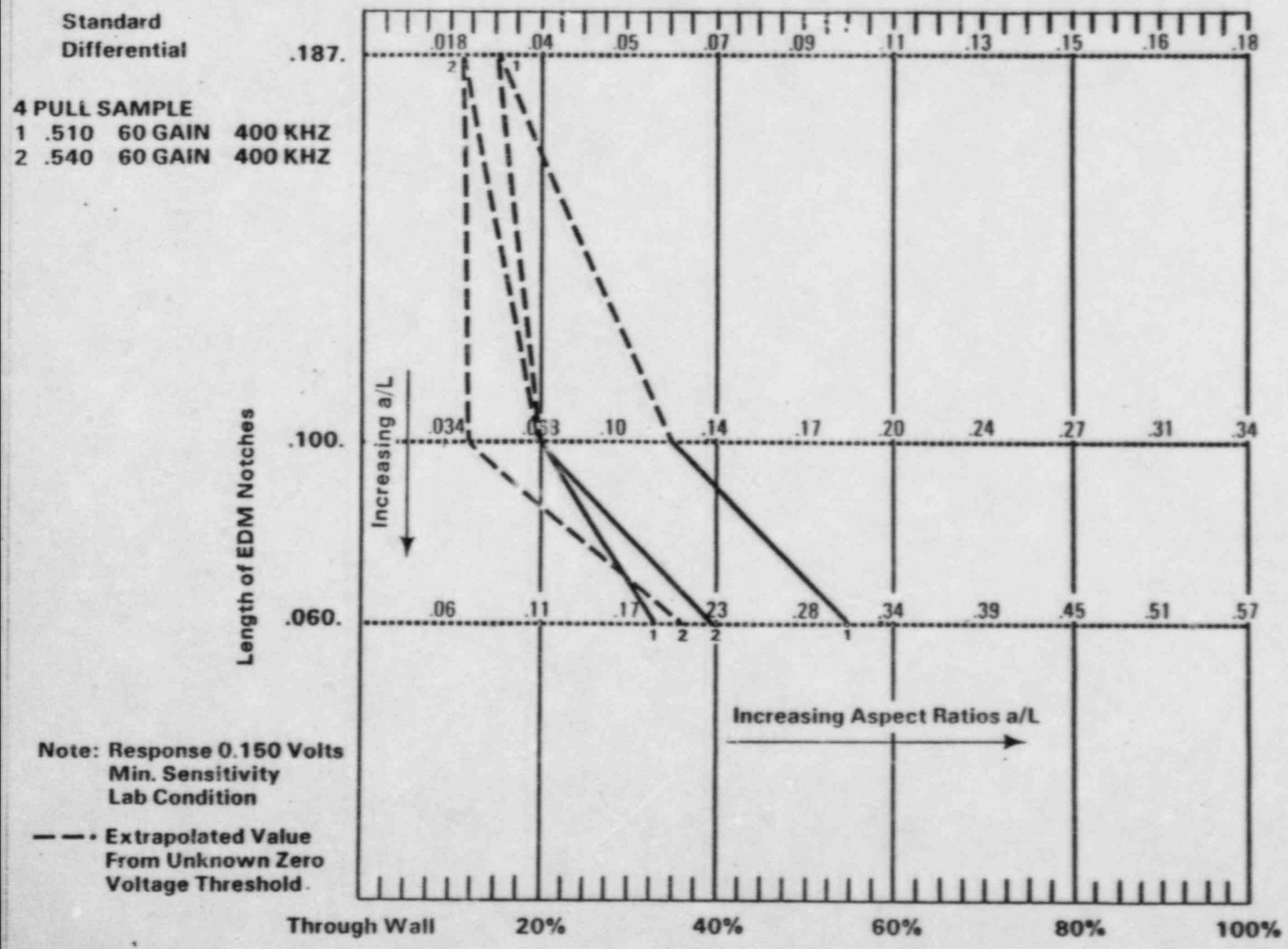
.060" NOTCH X 80%
BACK
FRONT

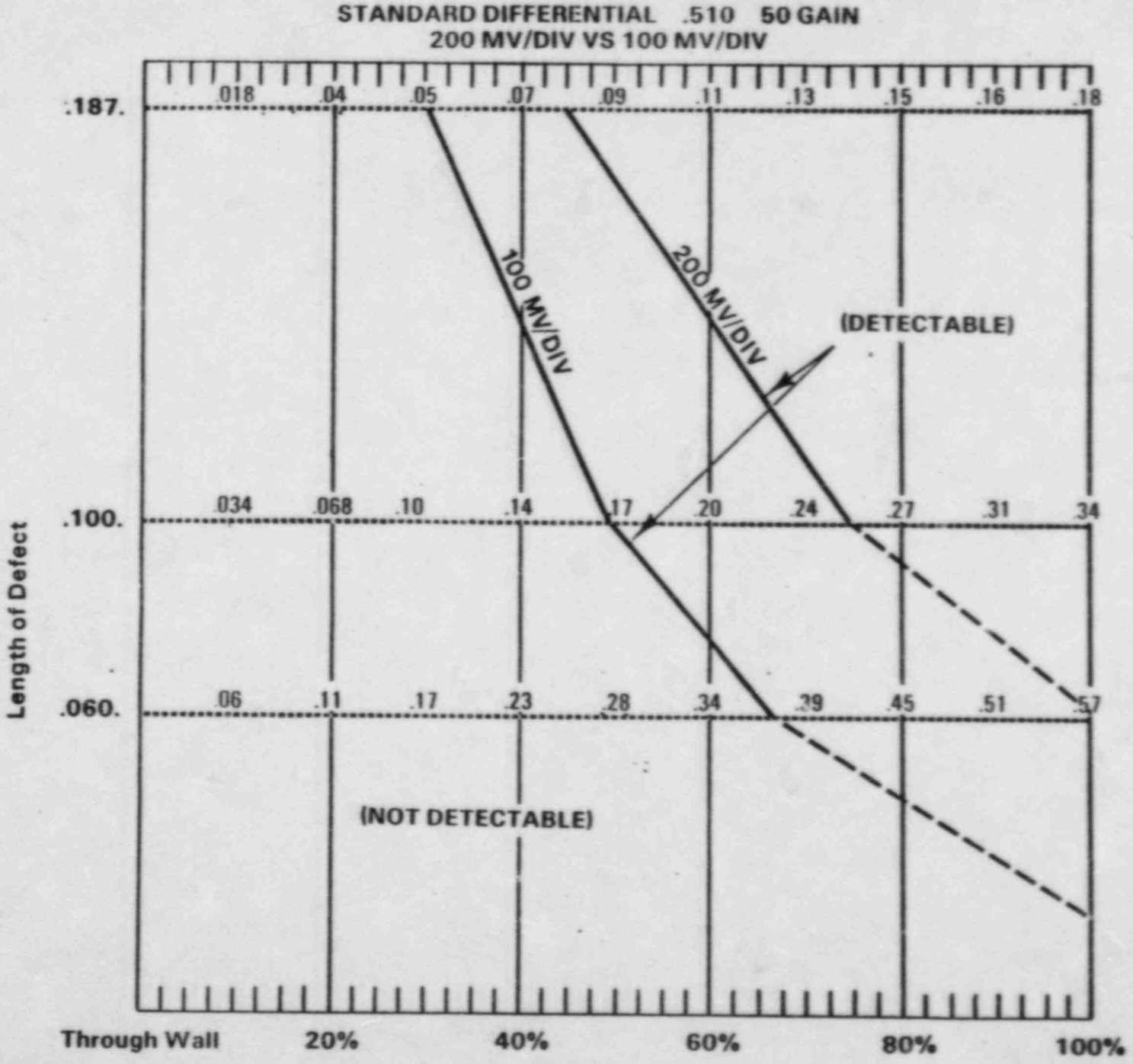
4 x 4 UNIT
400 KHz
$\phi = 300$
GAIN 53
HORIZONTAL



FRONT --- BACK ——

REPRODUCEABILITY OF RESULTS




STANDARD DIFFERENTIAL .510 50 GAIN
200 MV/DIV VS 100 MV/DIV
.187.
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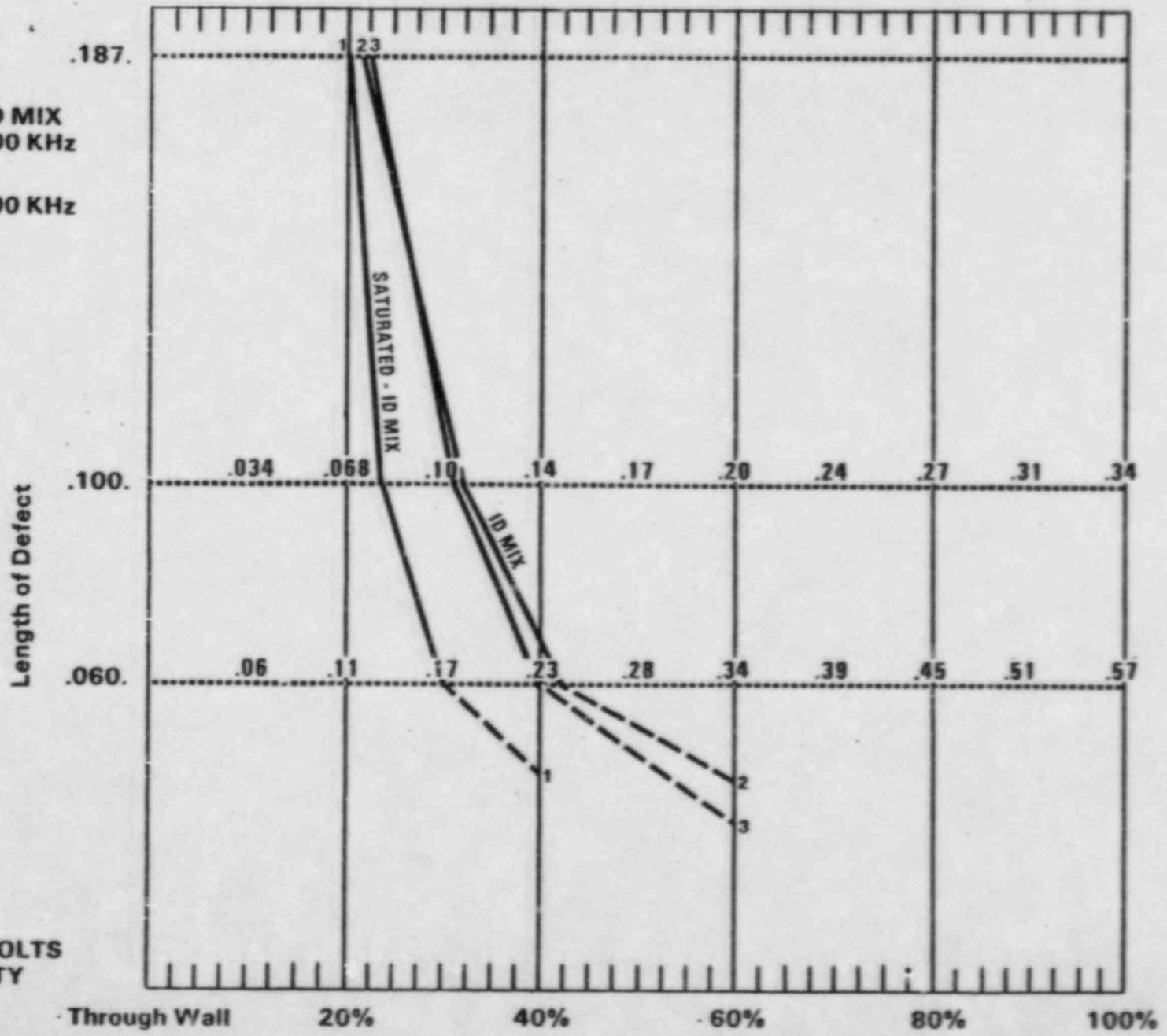
100 MV/DIV
200 MV/DIV
(DETECTABLE)
(NOT DETECTABLE)
Length of Defect
Through Wall
20%
40%
60%
80%
100%

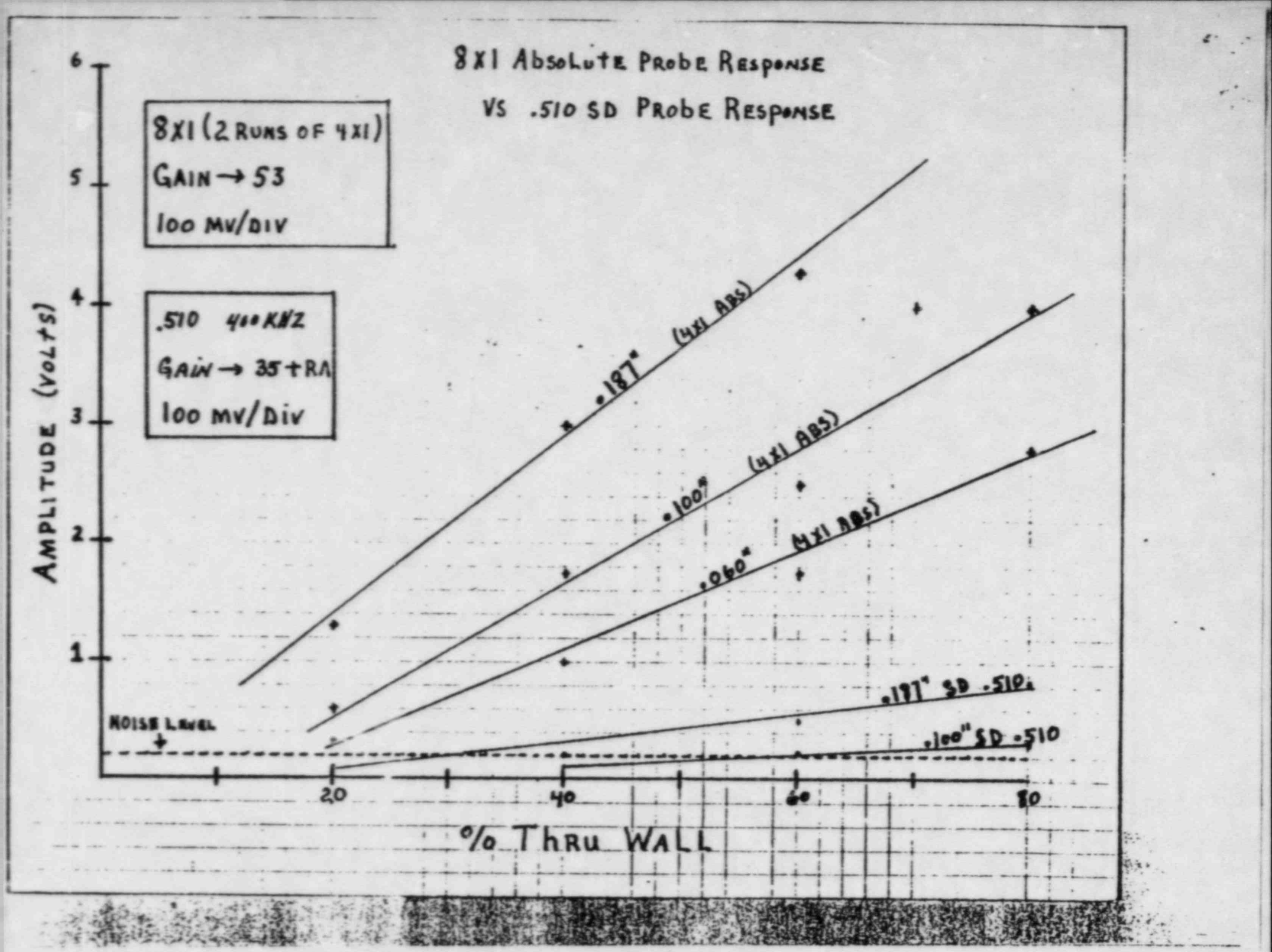
OPTIMIZING FREQUENCY MIX

Standard
Differential
540. 45 + RA

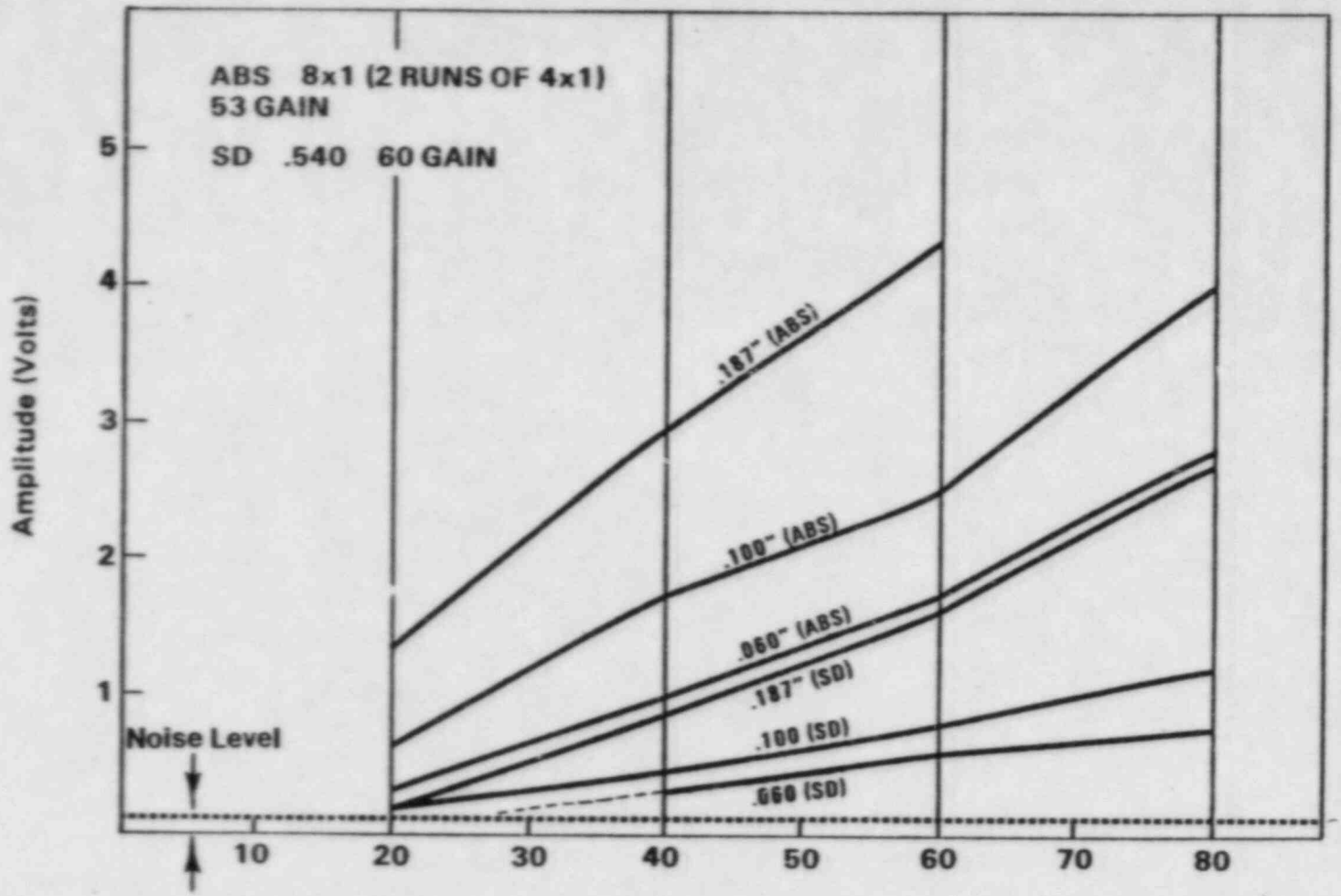
1. SATURATED ID MIX (400 - 200) 800 KHz
2. ID MIX (ONLY) (400 - 200) 800 KHz
3. 400 KHz



RESPONSE 0.300 VOLTS
MIN. SENSITIVITY


8X1 Absolute Probe Response
Vs .510 SD Probe Response
8X1 (2 Runs of 4X1)
Gain → 53
100 mv/div
.510 400 KHz
Gain → 35+RA
100 mv/Div
Amplitude (Volts)
6
5
4
3
2
1
.187" (4X1 ABS)
.100" (4X1 ABS)
.060" (4X1 ABS)
.187" SD .510
.100" SD .510
Noise Level
20
40
60
80
% Thru Wall

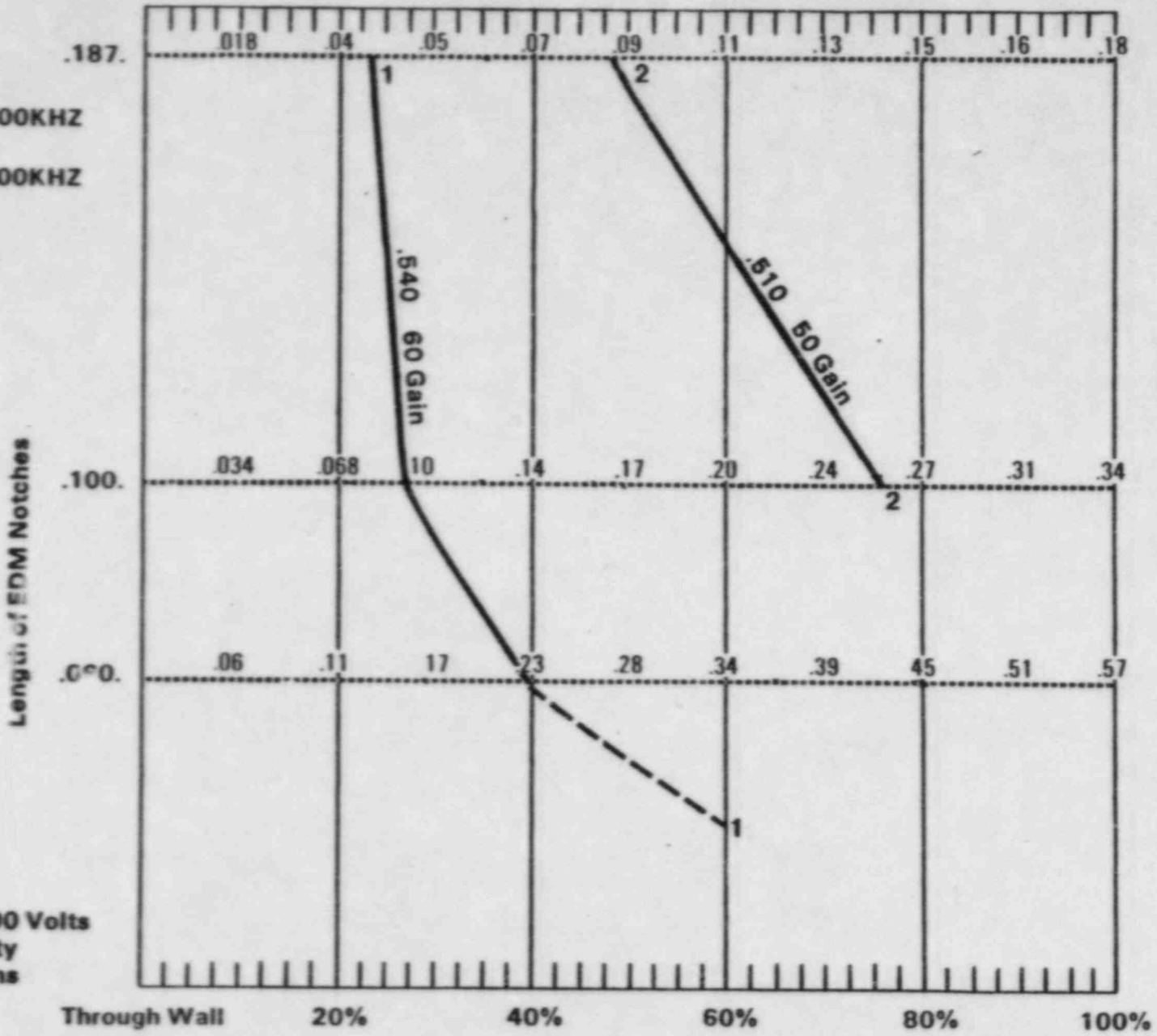
AMPLITUDE RESPONSE
STANDARD DIFFERENTIAL VS 8x1 ABSOLUTE
SIMULATED DEFECTS 0.005" WIDE



GAIN COMPARISON FOR DETECTION PROBABILITY

Standard
Differential
100 MV/Div.

1. .540, 45+RA, 400KHZ
2. .510, 35+RA, 400KHZ



Note: Response 0.300 Volts
Min. Sensitivity
Field Conditions

FACTORS AFFECTING ECT RESPONSE

ABSOLUTE -

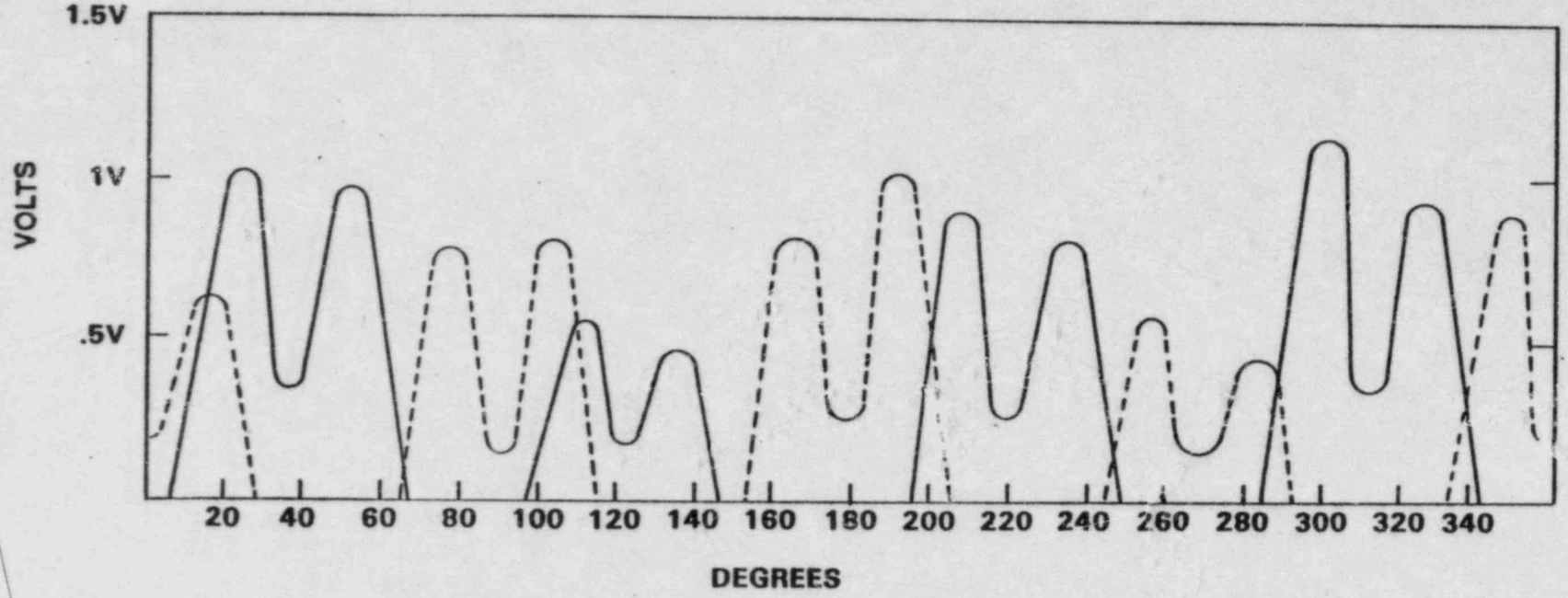
"TO BE USED FOR DISPOSITIONING PURPOSES ONLY"

1. CRACK GEOMETRY
   A) SMALLER ASPECT RATION (A/L) YEILDS LOWER AMPLITUDE RESPONSE
2. PROBE DESIGN/CONFIGURATION
   A) COIL TO COIL VARIANCES
   B) AMPLITUDE OF RESPONSE IS INFLUENCED BY DEFECT TO COIL ORIENTATION
   C) LIMITED FIELD COVERAGE/COIL
   D) SPRING LOADED - LESS SENSITIVE TO MOTION
3. LIMITATIONS OF INTERPRETATION
   A) PERCENT THRU WALL DETERMINATIONS ARE NOT RELIABLE
   B) AMPLITUDE OF RESPONSE IS NOT RELATED TO SEVERITY OR EXTENT OF DEFECT
4. OPERATING PARAMETERS TO BE OPTIMIZED
   A) FREQUENCY
   B) GAIN
   C) NO. OF COILS
5. CONSIDERATIONS FOR PRODUCTION
   A) NOISE AND CHATTER - MINIMIZED
   B) ANALYST ACCURACY AND PRECISION OF CALLS
   C) DATA HANDLING
   D) DURABILITY OF PROBE - NOT SUITED FOR PRODUCTION TECHNIQUE
   E) DIFFICULTY OF MAINTENANCE AND ANALYZING 8 TAPE RESPONSES

(EXTRA (SET))

4 x 4
400 KHz
PHASE = 003
GAIN = 40
VERTICAL

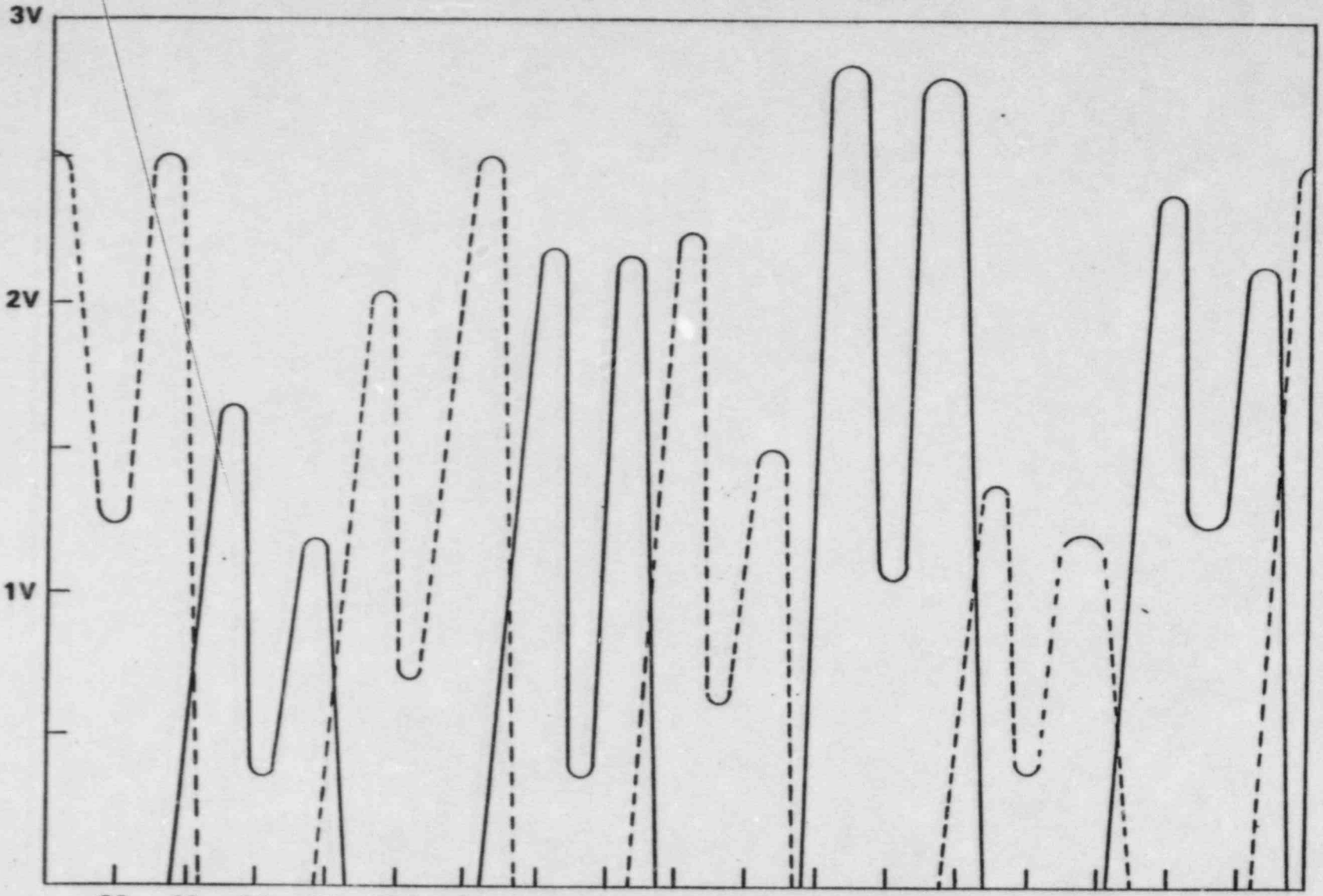
.060" NOTCH X 80%



FRONT ----
BACK ——

.060" NOTCH X 80%
BACK
FRONT

4 x 4 UNIT
400 KHz
ϕ = 300
GAIN 53
HORIZONTAL



Extra Copy

FRONT --- BACK ——

.060" NOTCH X 80%

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PHASE = 003
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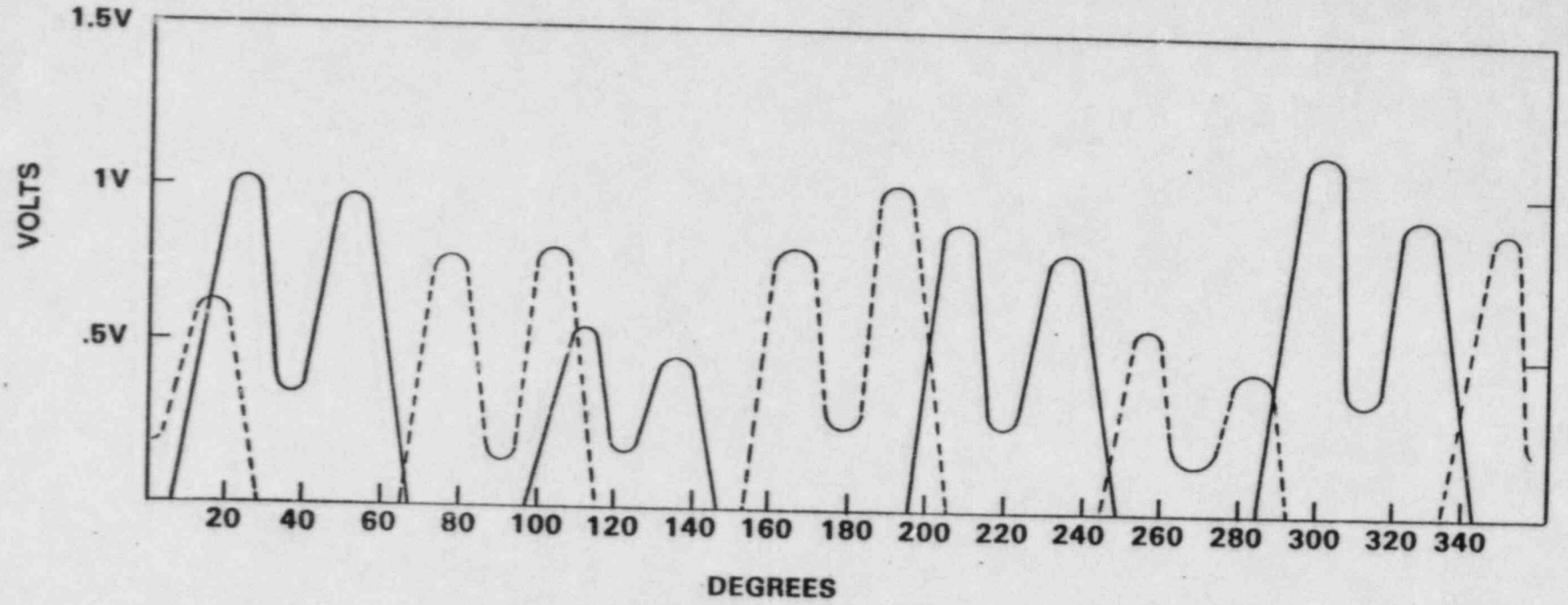

FRONT ----
BACK ——

Field Studies

Flaw growth study
Analyst correlation
Processing data study
Characterization of absolute vrs. 510
Characterization of absolute vrs. 540
Characterization of 540 vrs. 510

[redacted]

Plan -

Check 100 tubes in each generator at different points in time to establish if new defects appear or if existing defects increase

a) 102 tube sample from "A"

b) 104 tube sample from "B"

c) All tubes selected from different areas of generator

d) Test employed .510 probe (35 Gain & RA)

Original Retest	"A" Generator 12/11/81	"B" Generator 12/17/81
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3 -	1/26/82	1/31/82
4 -	2/2/82	4/4/82
5 -	3/5/82	4/30/82
6 -	7/3/82	7/5/82

[redacted]

No substantial increase in number of defects or extent over time period shown

f) Effect of using .540 probe (high gain) versus .510 above

	A Generator Subtotal	B Generator Subtotal	Grand Total	%
Agreement	95	93	188	94
No agreement	5	8	13	6
- Below US + 13	0	2	2	1
- Above US + 13	5	6	11	5

PROJECT: DETERMINE THE PROBABILITY OF ERROR IN THE ANALYSIS OF EDDY CURRENT RESULTS.

PLAN: RE-EVALUATE PRODUCTION RESULTS OF SAMPLE OF 500 TUBES PROCESSED BY 3 CONAM ANALYSTS USING 3 OTHER VENDOR ANALYSTS.

RESULTS:

A.	INITIAL AGREEMENT	446 SAMPLES	89.2%
B.	AFTER RESOLUTION	492 SAMPLES	98.4%
	1. OVERCALLS	4 SAMPLES	0.8
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[redacted]

A. USE A SECOND ANALYST TO OVERCHECK STRIP CHART READINGS BY FIRST ANALYST.

B. SCAN REVIEW MAGNETIC-TAPE DISPLAY FOR ENTIRE LENGTH PROBE AND INTERROGATE (EVALUATE) ALL AREAS AS INDICATED BY STRIP CHART.

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RESULTS: (DATA FOR OTSG 'B' ONLY)

A.	AGREEMENT	≈15000 SAMPLES	≈99.7 %
B.	UNDER CALLS	21 SAMPLES	≈ 0.14%
C.	OVERCALLS	5 SAMPLES	≈ 0.03%
D.	MISSCALLS	21 SAMPLES	≈ 0.14%
	DIFFERENCE OF 1 INCH + IN LOCATION REPORTED		
E.	TOTAL	47 SAMPLES	≈ 0.3%

RECOMMENDATION:

1. DURING 540 PROBE WITH HIGH GAIN WORK WE WILL REVIEW DATA SHEETS AND COMPARE TO COMPUTER HISTORY FILE FOR ALL TUBES WITH INDICATIONS BELOW FIRST REPAIR PLUS 6"

2. MAKE CORRECTIONS NOTED

3. DO NOT MAKE ANY ADDITIONAL CHANGES AFFECTING QC CONTROLS ON INPUT

PLAN: CHARACTERIZE INDICATIONS SEEN BY 4x1 ABSOLUTE BUT NOT SEEN BY 510

TEST POPULATION	3233	
NO. OF TUBES WITH CORRELATION	3153	(97.5%)
NO. OF TUBES WITHOUT CORRELATION	80	
NO. OF INDICATIONS WITHIN 80 SAMPLE	99	

A. CIRCUMFERENTIAL EXTENT - 99 DEFECTS

# COILS	#INDICATIONS	CUMULATIVE %
1	90	90
2	7	98
3	2	100
4	0	100

b. % THRUWALL CALL BY ANALYST

%THRUWALL	#INDICATIONS	CUMULATIVE %
90-100	23	24
80-90	14	38
70-80	8	45
60-70	5	51
50-60	8	59
40-50	20	79
30-40	13	92
20-30	8	100

will use .540 data

PLAN: CHARACTERIZE INDICATIONS SEEN BY ABSOLUTE BUT NOT SEEN BY 540 (HIGH GAIN)

TEST POPULATION	3233	
NO. OF TUBES WITH CORRELATION	3216	99.4%
NO. OF TUBES WITHOUT CORRELATION	17	
NO. OF INDICATIONS WITHIN DATA SET*	17	

A. CIRCUMFERENTIAL EXTENT
100% OF 17 DEFECTS WERE ONE COIL.

B. AFTER ID MIXING (TO REMOVE CHATTER) THE NUMBER OF TUBES WITH CORRELATION IMPROVED TO 3229.

C. 14 OF 17 DEFECTS ARE RESOLVED AT THIS TIME.
% THRUWALL CHARACTERIZATION

% THRUWALL	# INDICATIONS	CUMULATIVE %
90-100	12	85.7
80-90	0	
70-80	0	
60-70	0	
50-60	1	92.8
40-50	0	
30-40	0	
20-30	0	
NO DESIGNATION	1	

C.1 THREE TUBES UNRESOLVED
ONE TUBE PLUGGED.
TWO TUBES HAVE NOT BEEN EXAMINED WITH SAT. PROBE & ID MIXING.

PLAN: CHARACTERIZE INDICATIONS SEEN BY 540 BUT NOT SEEN BY 510

TEST POPULATION	2771	
NO. OF TUBES WITH CORRELATION	2589	(93)%
NO. OF TUBES WITHOUT CORRELATION*	182	(7)%
NO. OF INDICATIONS FOR *	288	

A. AMPLITUDE OF INDICATION

70%	1 VOLT AND LESS
90%	2 VOLTS AND LESS
96%	3 VOLTS AND LESS
98.9%	4 VOLTS AND LESS
100%	5 VOLTS AND LESS

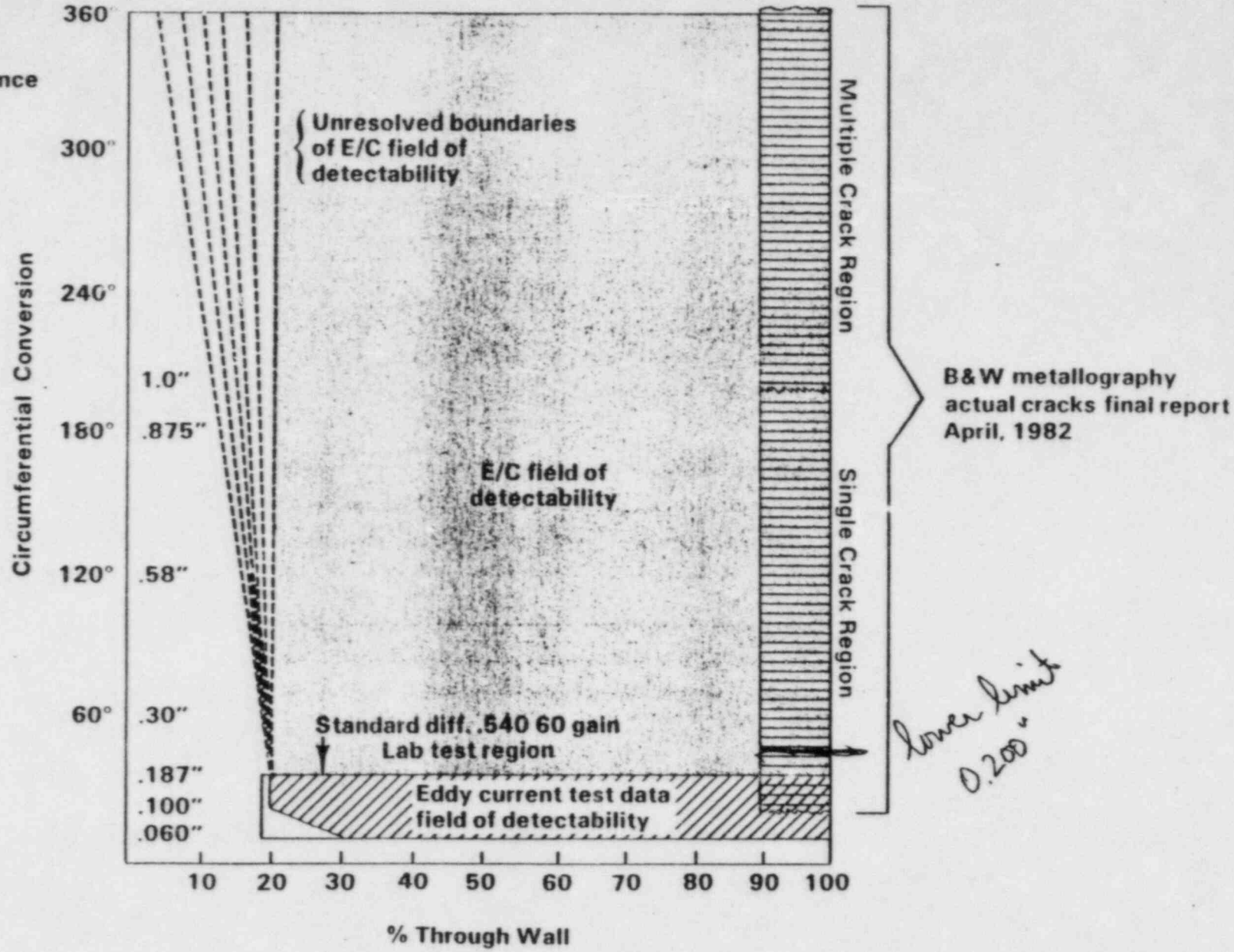
B. % THRUWALL CHARACTERIZATION

THRUWALL %	FREQUENCY	CUMULATIVE %	REMARKS
90-100	82	28	68% 1V or less
80-90	23	36	65% 1V or less
70-80	25	45	80% 1V or less
60-70	42	59	76% 1V or less
50-60	46	75.7	65% 1V or less
40-50	36	88	86% 1V or less
30-40	15	93	60% 1V or less
20-30	19		47% 1V or less
10-20	0		

ASPECT RATIO COMPARISON

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

Note: (1) 1.75" max.
ID circumference



LABORATORY WORK TO BE COMPLETED

1. NATURAL IGSCC CRACKS ARE TO BE GROWN (BEST ATTEMPTS) TO FULL PENETRATION AND SMALLEST "L"S POSSIBLE

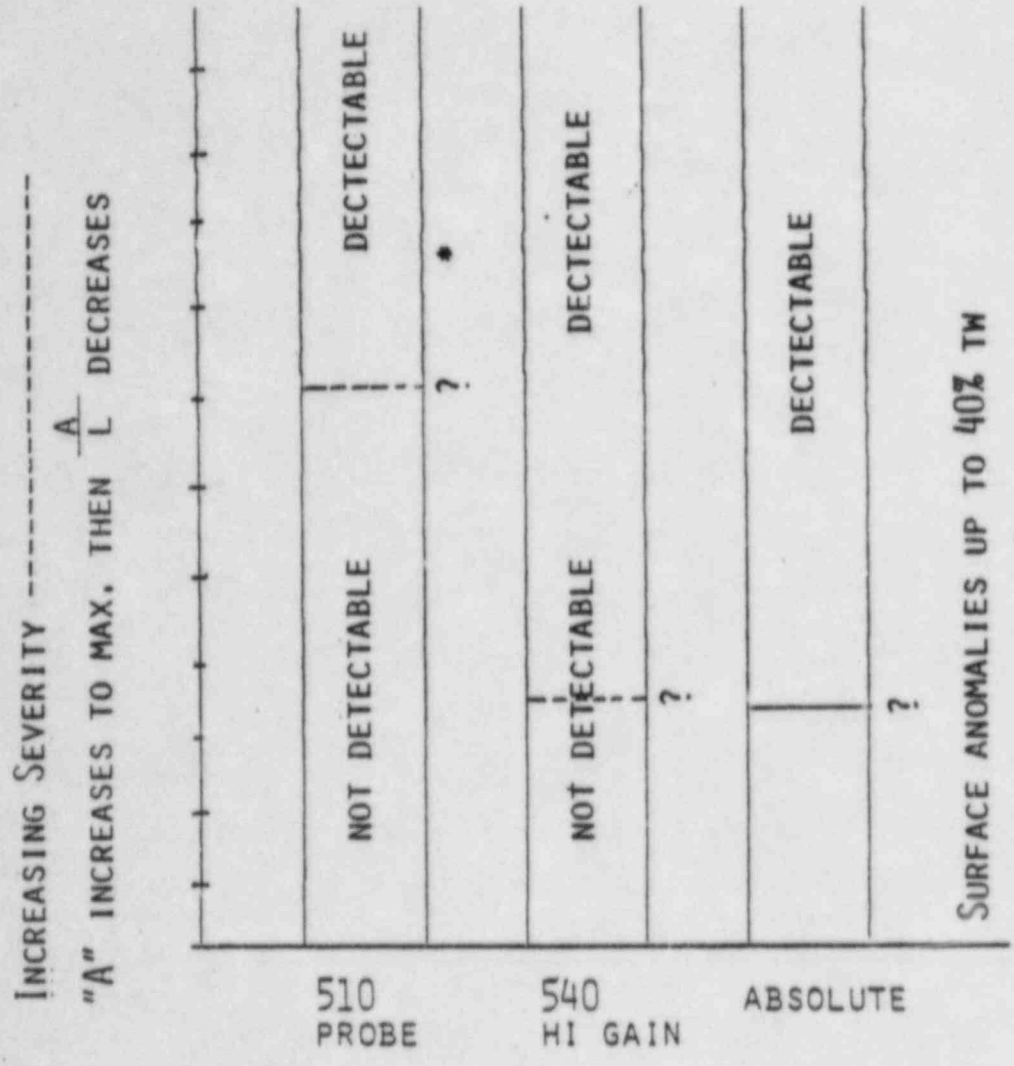
2. BACK OFF FROM TIME ELEMENT AND GROW ADDITIONAL CRACKS AT SMALLER "L" AND THEN SMALLER THRU WALL "A"

3. ESTABLISH THRESHOLD OF DETECTABILITY FOR 510, 540 SD, AND ABSOLUTE

4. METALLURGICALLY EVALUATE TO CONFIRM "A" AND "L" MEASUREMENTS

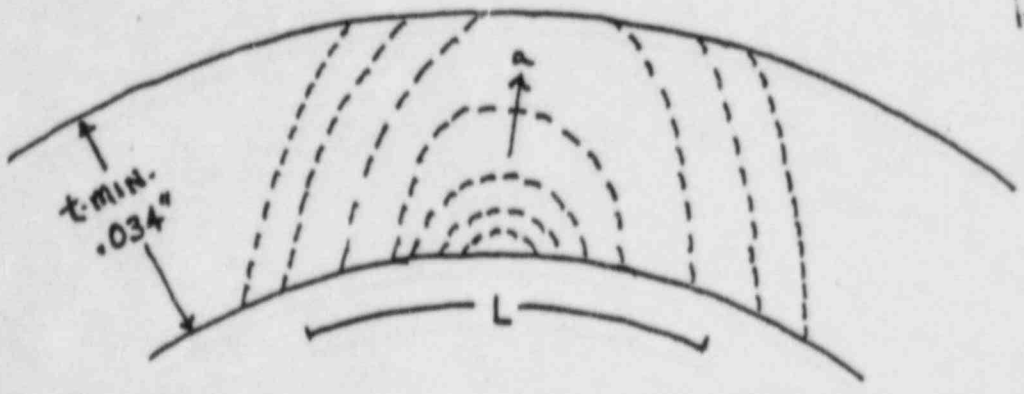
CORRELATION TO BE ESTABLISHED

THRESHOLD OF DETECTABILITY



*SMALLEST DEFECT 100% THRU WALL LENGTH.

? = DIVISION OF UNCERTAINTY



WORK TO BE COMPLETED

1. COMPLETE THE 540 HIGH GAIN PRODUCTION WORK AND RECORD ALL INDICATIONS KNOWING WE ARE PROBABLY RECORDING SURFACE ANOMALIES AND OD SIGNALS

2. COMPLETE LAB ANALYSIS FOR ESTABLISHING THRESHOLDS

3. DISPOSITION THE RESULTS SO AS TO ACCEPT SURFACE ANOMALIES AND SMALL OD SIGNALS PROVIDING WE DON'T ACCEPT IGSCC (>40%)

4. ESTABLISH AS SUPPLEMENTARY ISI PROGRAM TO SPECIALLY TREAT ITEMS ACCEPTED IN "D"

SUMMARY

1. ECT QUALIFICATION IS NEARING COMPLETION.

2. USING SYNTHETIC DEFECTS WAS ABLE TO ESTABLISH A HIGH GAIN 540 TECHNIQUE THAT IS SENSITIVE ENOUGH TO ASSURE THAT ALL NATURAL (IGSCC) INDICATIONS ARE REPORTED.

3. NEED TO ESTABLISH AN ENGINEERED BASIS FOR ACCEPTING TUBES WITH NON-RELEVANT INDICATIONS.

4. DISPOSITION GENERATOR AND COMPLETE REPAIR.

5. SAFETY ANALYSIS AND REPORTING.

AUGUST 9, 1982

TMI - 1

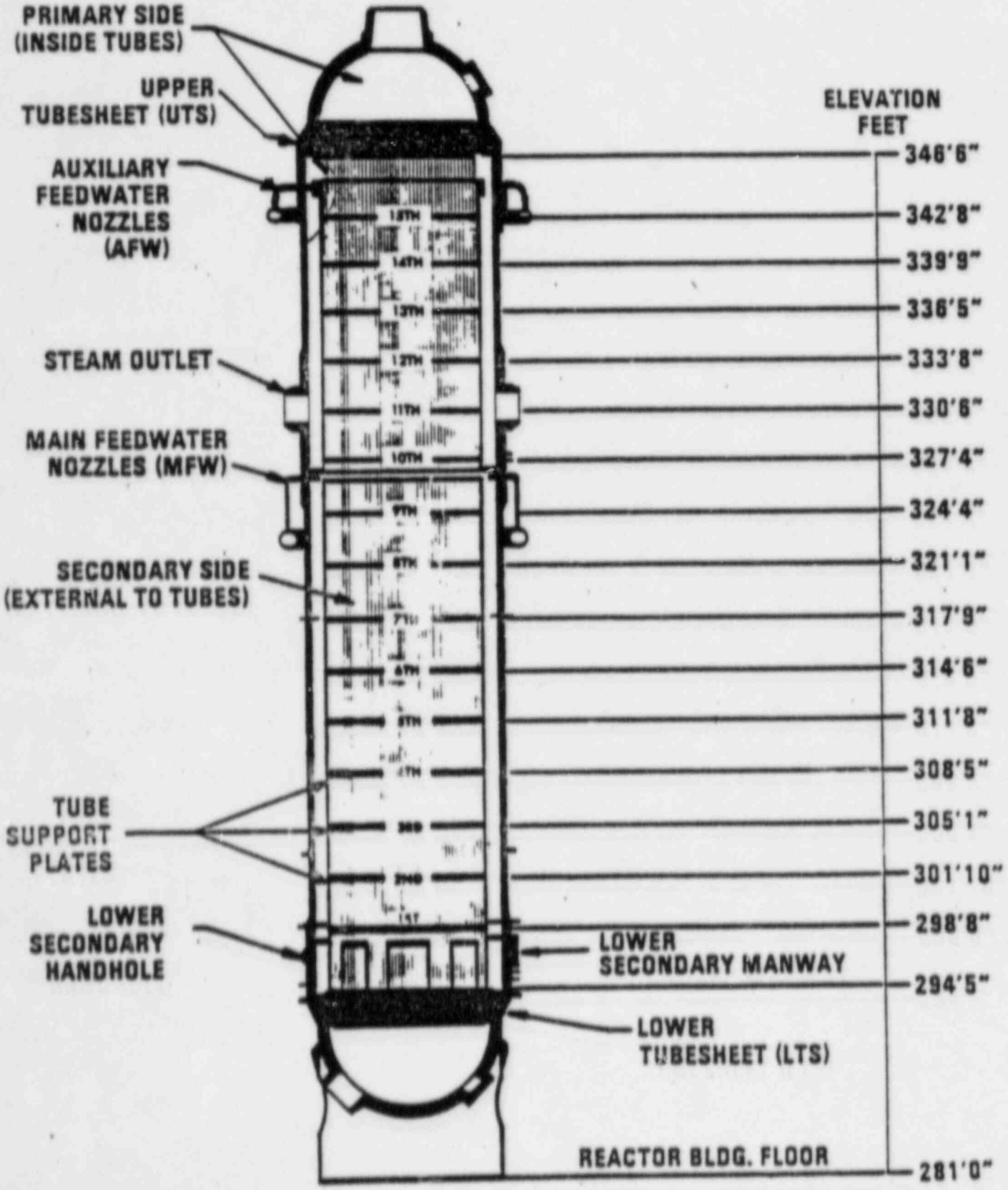
OTSG TASK 4

EDDY CURRENT PRESENTATION

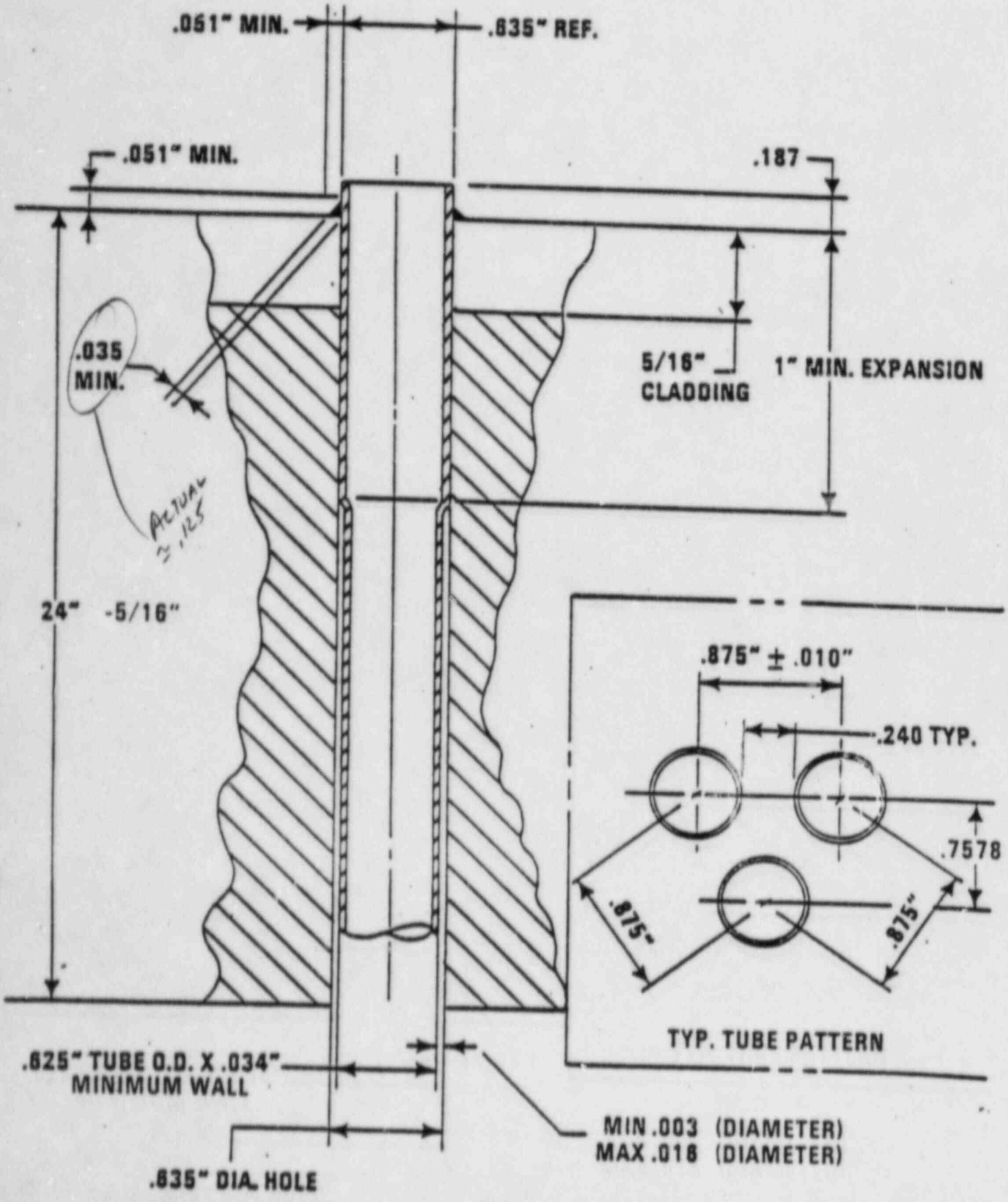
TO THE

N R C

OTSG Longitudinal Section Elevations (Typ.)



TMI-1 OTSG Upper Tubesheet Detail (Typ.)

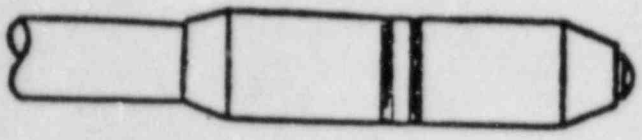


1. E/C Techniques

a) Standard Differential -
Two interacting coils mounted circumferential; resultant signal response is produced by measuring the differential from the area of discontinuity to clean tubing area.

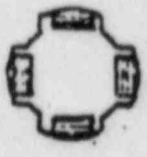
b) Absolute Technique -
Single coil wound in a pancake shape normal to SD coil; two sets of four separate (isolation) coils that are assembled in tandem to provide an effective eight coil coverage; optimum detection of circumferential oriented discontinuities.
Disadvantage -
Not conducive to broad scale production programs because it is extremely fragile and wears rapidly; additionally presents numerous electronic recording and analyst problems associated with having to maintain and read 8 channel recordings.

TMI-1 Eddy Current Probes
Utilized for OTSG Tubing Examinations



400 KHZ FULL GAIN
MIX 200 KHZ
400 KHZ REDUCED GAIN
MIX 800 KHZ

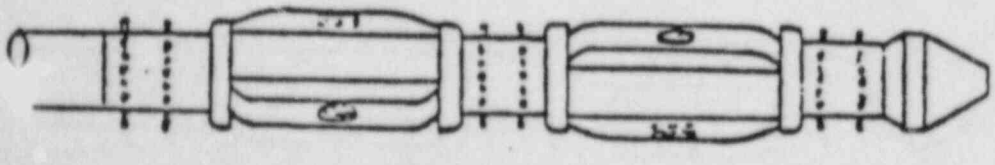
Differential



4X

400 KHZ

8x in the P



400 KHZ FULL GAIN
MIX 200 KHZ
400 KHZ REDUCED GAIN
MIX 800 KHZ

3 x 3

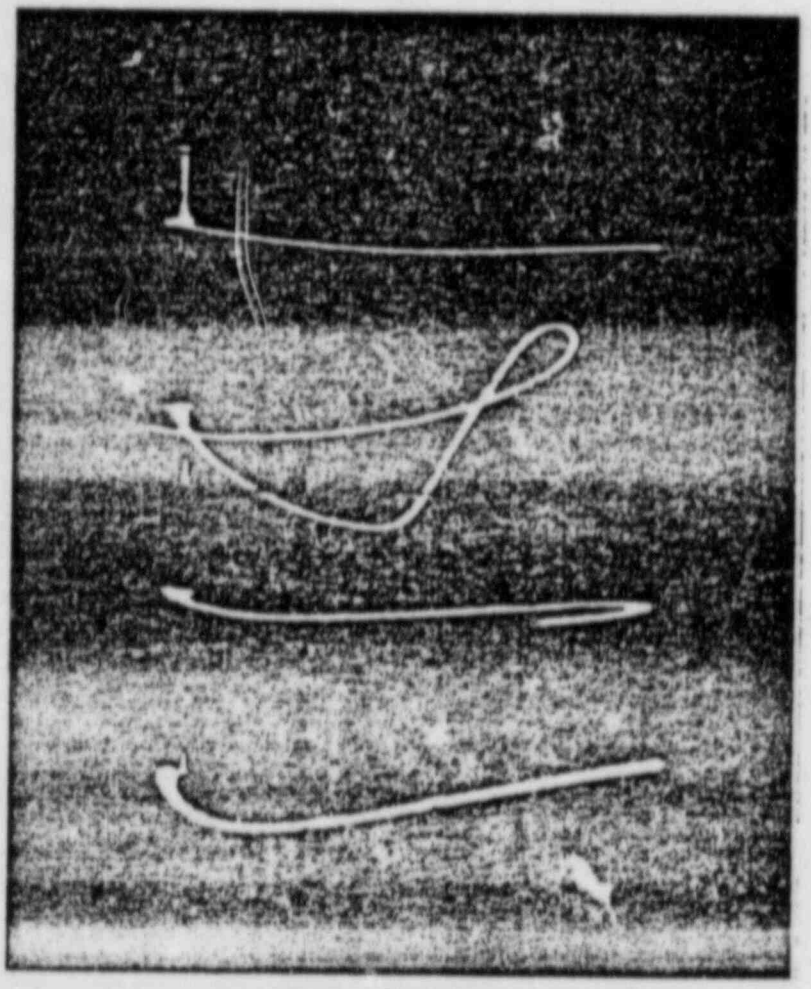
1. E/C Techniques Continued

Multifrequency -
Utilized for all SD examinations; applied 2 base frequencies (400 KHz and 200 KHz) and used an "ID" mix to enhance detection of ID defects and minimize affect of chatter and tube noise.

Saturated Probes -
Improves noise.

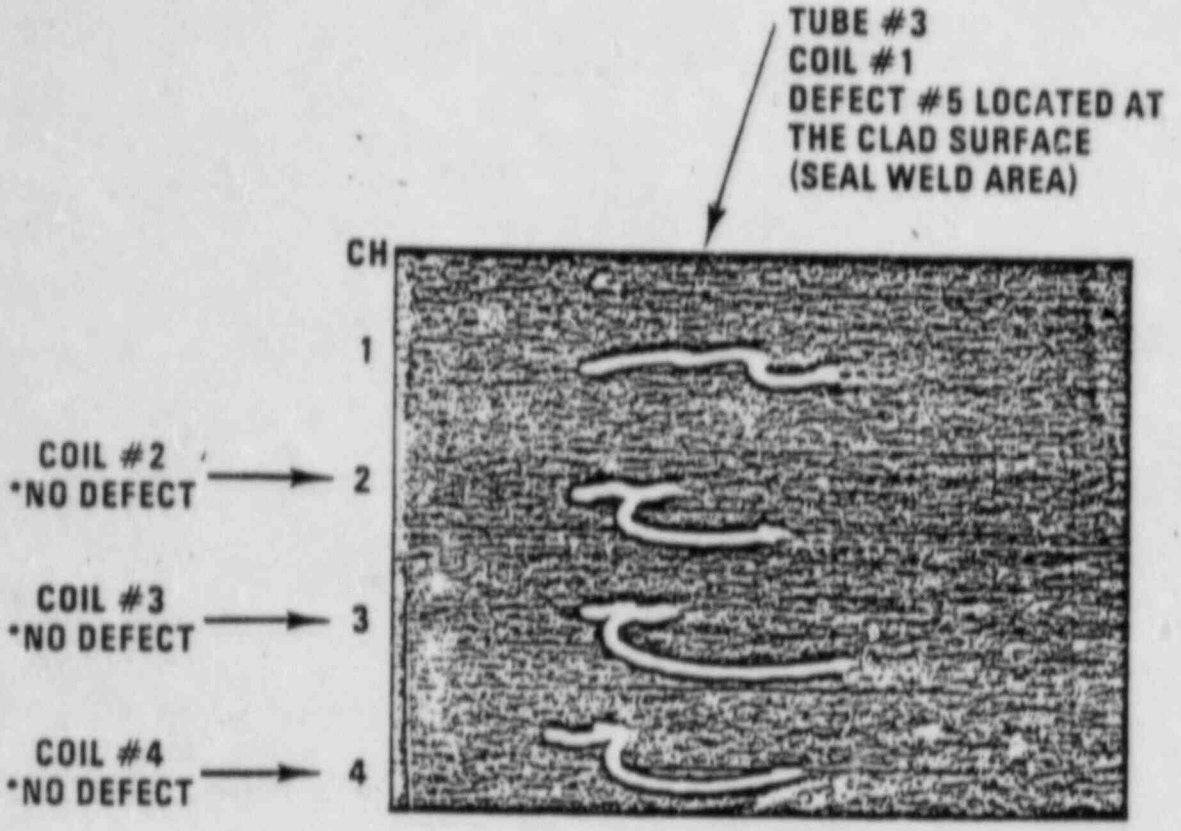
ID mix

Eddy Current Signals
Roll Transition Mockup
Differential Probe



NDD	No Defect
Defect	100% Thru Wall 180°
NDD or NDD-1	40% Thru Wall 90°
NDD-1	40% Thru Wall 3/16 Inch Hole

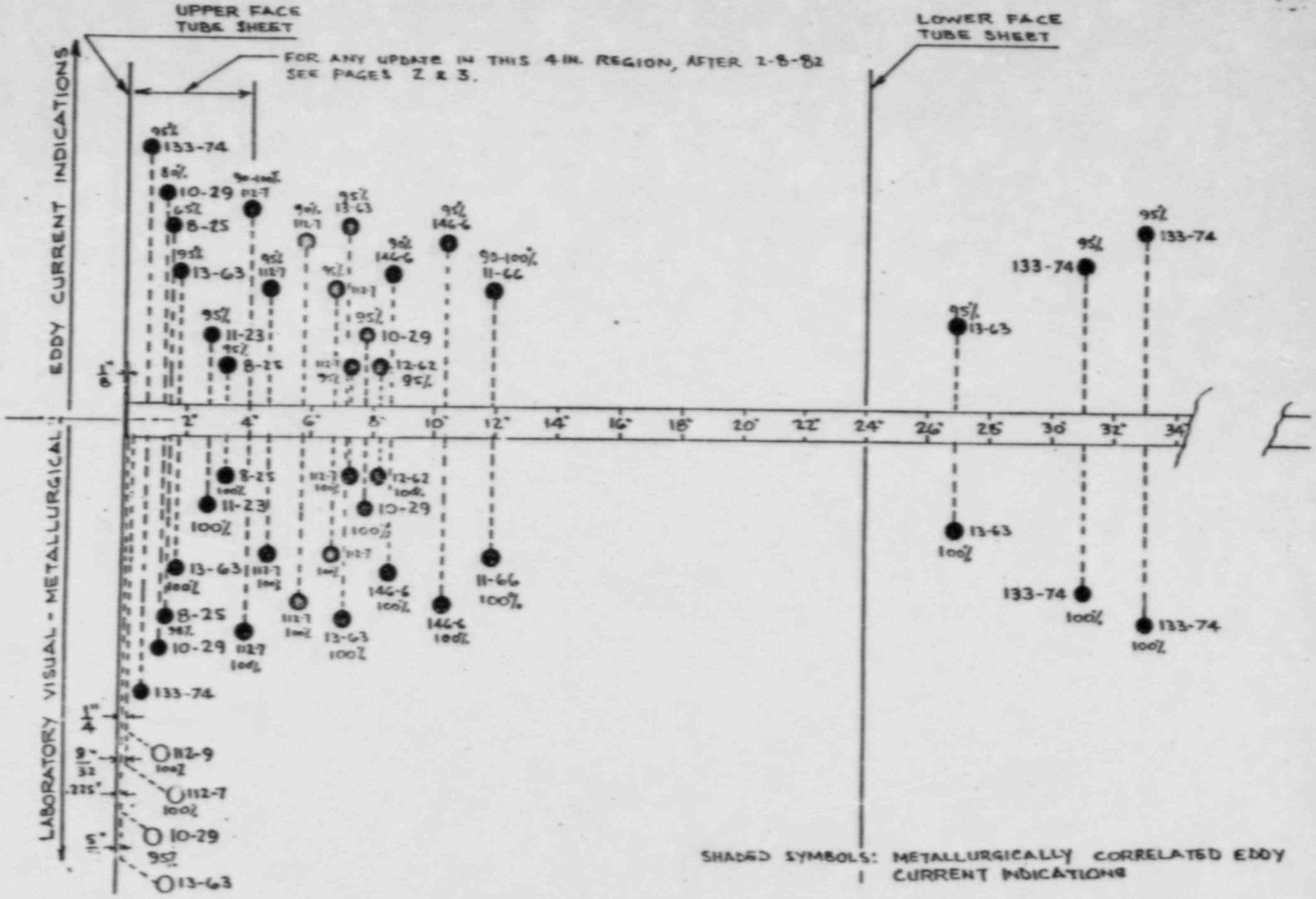
4x1 Absolute E/C Probe Qualification Data



* SIGNAL RESPONSE IS NORMAL DEFECT FREE RESPONSE AT TUBESHEET/TUBE EXIT

4X1 EDDY CURRENT PROBE RESPONSE TO A 40% ID TUBE WALL DEFECT LOCATED AT THE CLAD SURFACE OF TUBE #3 IN THE SIX (6) TUBE OTSG TUBESHEET MOCKUP

CORRELATION SUMMARY OF DESTRUCT TESTS AND EDDY CURRENT INDICATIONS



SHADED SYMBOLS: METALLURGICALLY CORRELATED EDDY CURRENT INDICATIONS

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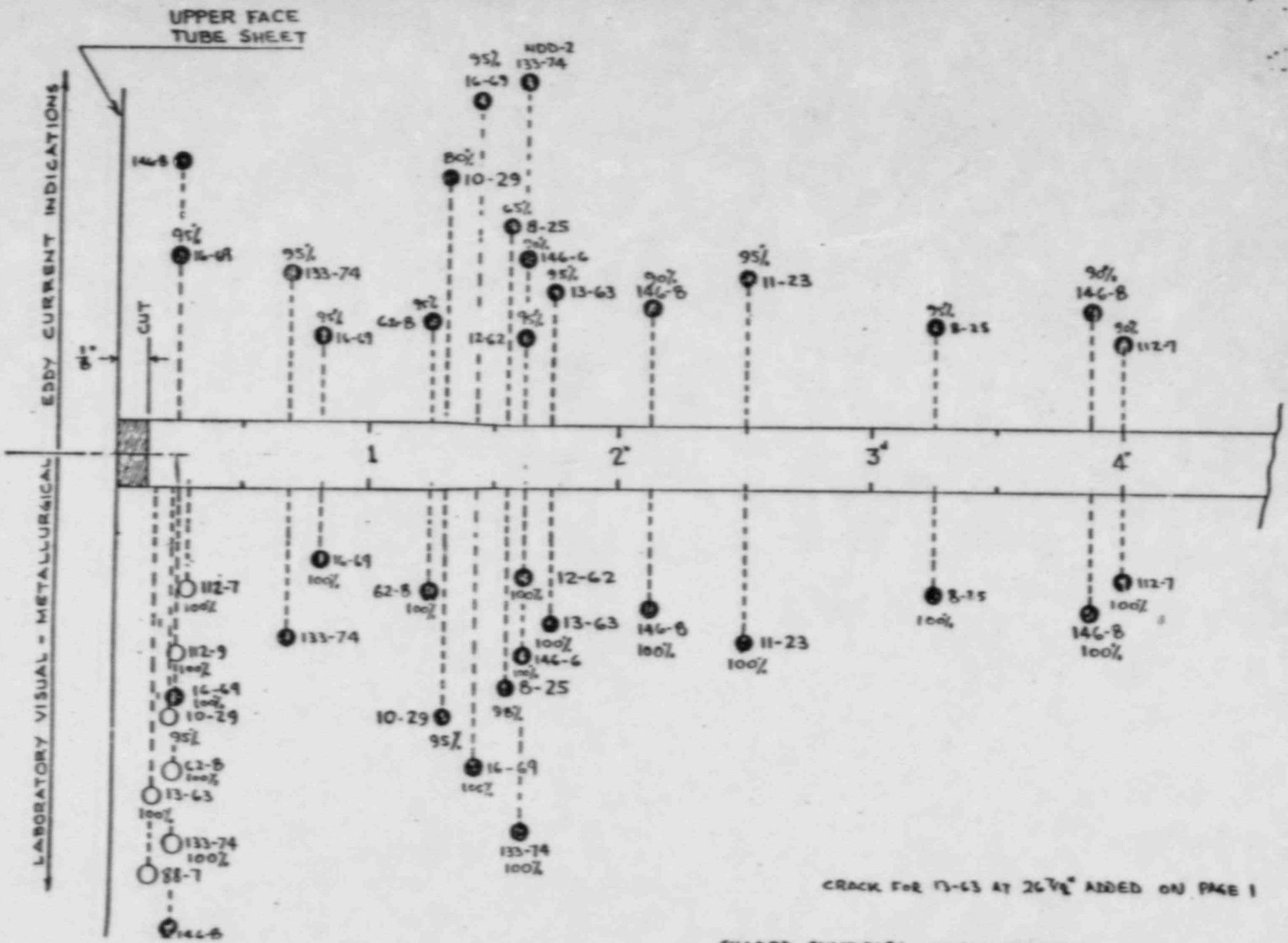


CRACK FOR 13-63 AT 26 7/8" ADDED ON PAGE 1

SHADED SYMBOLS: METALLURGICALLY CORRELATED EDDY CURRENT INDICATIONS

FACTORS AFFECTING ECT RESPONSE

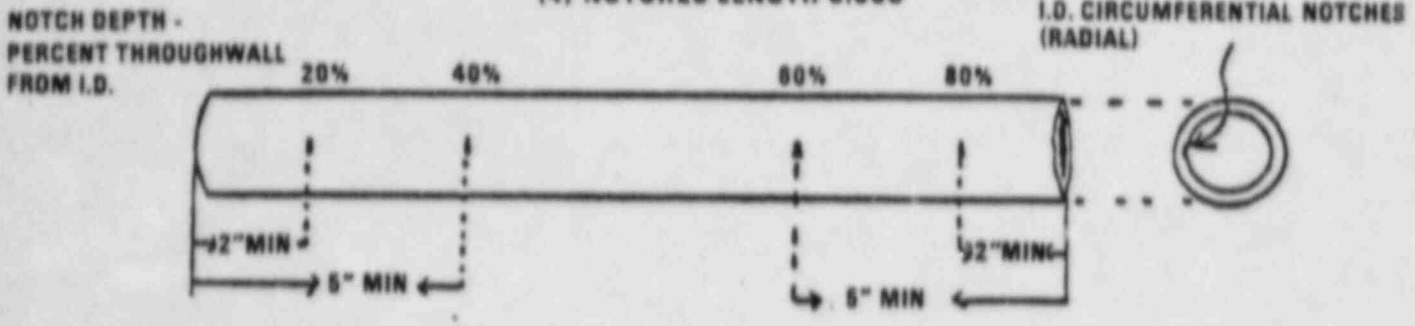
STANDARD DIFFERENTIAL TO BE USED FOR PRODUCTION RUN INVESTIGATION.

1. CRACK GEOMETRY
   A) SMALLER ASPECT RATIO (A/L) - depth of penetration / circumferential length YIELDS A LOWER AMPLITUDE RESPONSE.
   B) DETECTION OF CIRCUMFERENTIAL CRACK IS DEPENDENT UPON CRACK WIDTH, AXIAL BRANCHING AND SPIRALING.
2. PROBE DESIGN/CONFIRGUATION
   A) HIGHER THE FILL FACTOR GREATER THE SENSITIVITY AND REPRODUCEABILITY.
   B) 360^{0} COVERAGE.
   C) REDUCE PROBE WOBBLE WITH INCREASING FILL FACTOR.
3. LIMITATION OF INTERPRETATION
   A) INDICATIONS YIELD LOWER AMPLITUDE RESPONSE.
   B) GREATLY AFFECTED BY TUBE TRANSITION AREAS.
4. OPERATING PARAMETERS TO BE OPTIMIZED
   A) FILL FACTOR.
   B) FREQUENCY.
   C) GAIN.
   D) CHART SPEED.
   E) ID MIXING.
5. CONSIDERATION FOR PRODUCTION
   A) NOISE AND CHATTER.
   B) ANALYST PRECISION AND ACCURACY OF ~~COILS~~ coil's.
   C) DATA HANDLING.

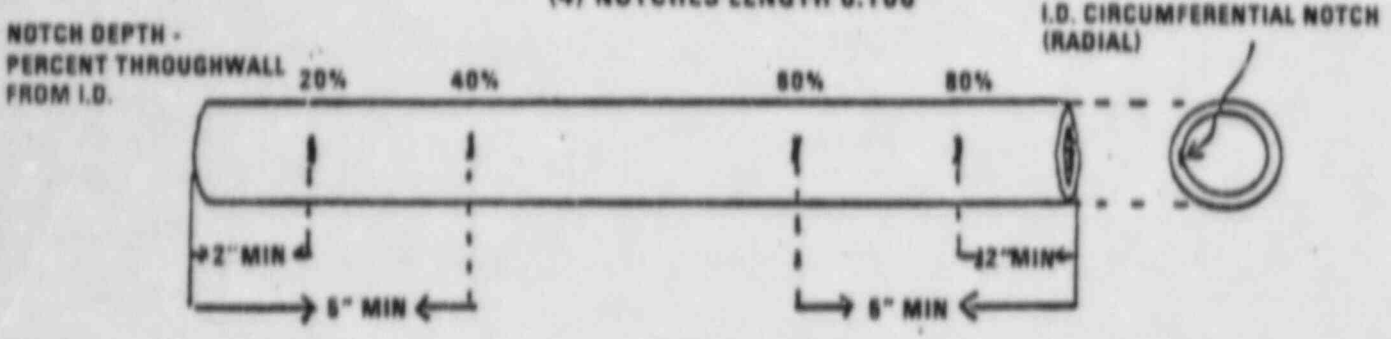
OTSG TUBING DEFECT MOCKUPS

(.)..46 .004 .005"

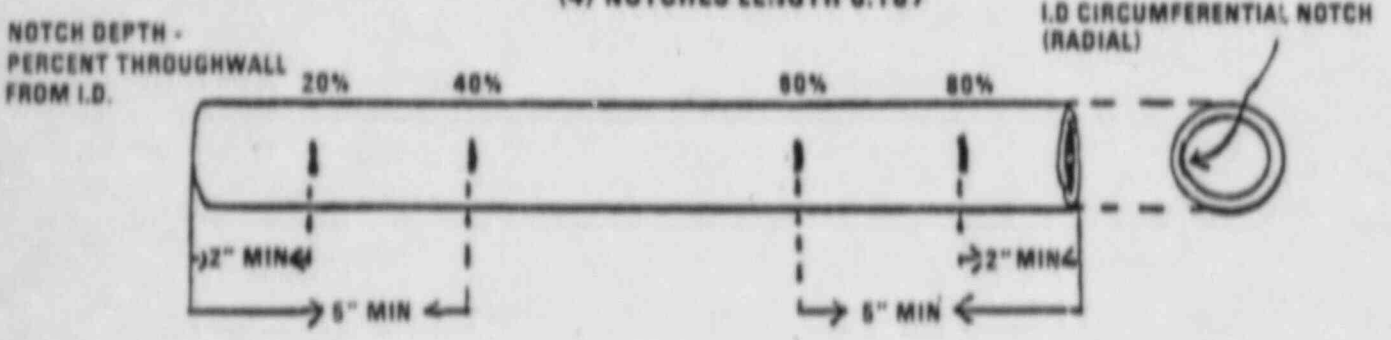
SAMPLE #1
(4) NOTCHES LENGTH 0.060"



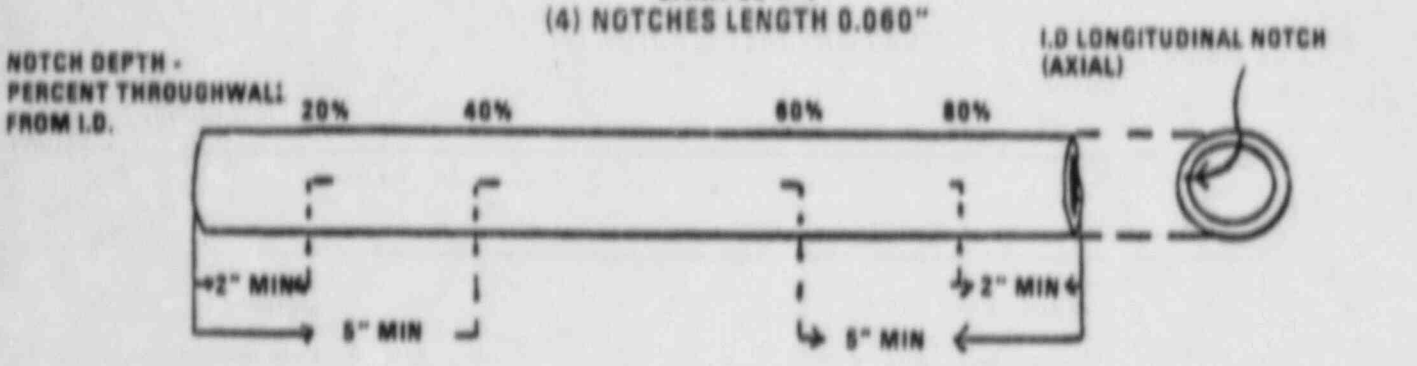
SAMPLE #2
(4) NOTCHES LENGTH 0.100"



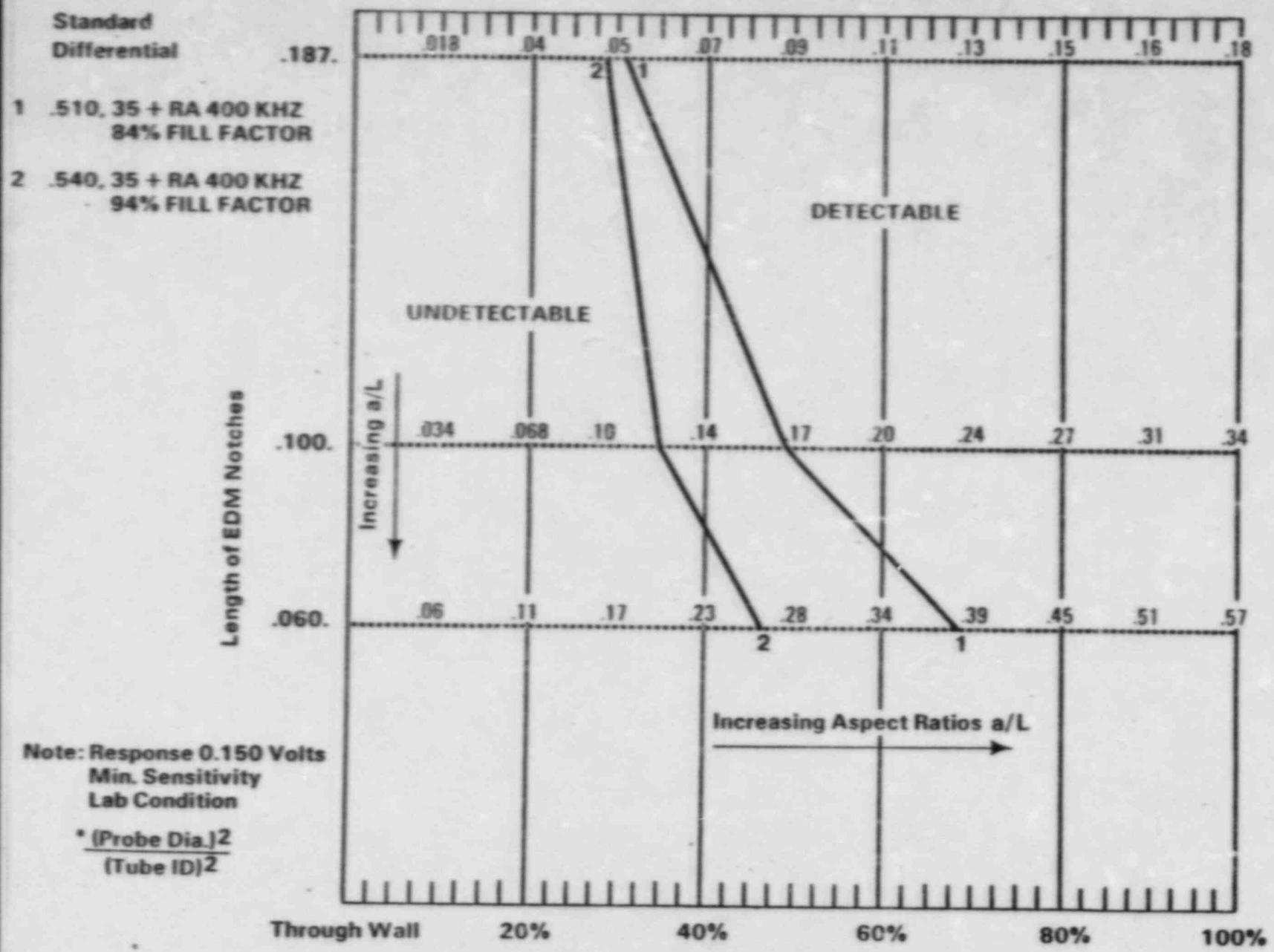
SAMPLE #3
(4) NOTCHES LENGTH 0.187



SAMPLE #4
(4) NOTCHES LENGTH 0.060"



FILL FACTOR COMPARISON*



Note: Response 0.150 Volts
Min. Sensitivity
Lab Condition

$$* \frac{(\text{Probe Dia.})^2}{(\text{Tube ID})^2}$$

Field Studies

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Analyst correlation
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Characterization of absolute vrs. 540
Characterization of 540 vrs. 510

Flaw Growth Study

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e) Conclusion -

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1. DURING 540 PROBE WITH HIGH GAIN WORK WE WILL REVIEW DATA SHEETS AND COMPARE TO COMPUTER HISTORY FILE FOR ALL TUBES WITH INDICATIONS BELOW FIRST REPAIR PLUS 6"

2. MAKE CORRECTIONS NOTED

3. DO NOT MAKE ANY ADDITIONAL CHANGES AFFECTING QC CONTROLS ON INPUT

PLAN: CHARACTERIZE INDICATIONS SEEN BY 4x1 ABSOLUTE BUT NOT SEEN BY 510

TEST POPULATION	3233	
NO. OF TUBES WITH CORRELATION	3153	(97.5%)
NO. OF TUBES WITHOUT CORRELATION	80	
NO. OF INDICATIONS WITHIN 80 SAMPLE	99	

A. CIRCUMFERENTIAL EXTENT - 99 DEFECTS

# COILS	#INDICATIONS	CUMULATIVE %
1	90	90
2	7	98
3	2	100
4	0	100

b. % THRUWALL CALL BY ANALYST - will change because uses 4x1 to call % thru wall not very reliable

%THRUWALL	#INDICATIONS	CUMULATIVE %
90-100	23	24
80-90	14	38
70-80	8	45
60-70	5	51
50-60	8	59
40-50	20	79
30-40	13	92
20-30	8	100

PLAN: CHARACTERIZE INDICATIONS SEEN BY ABSOLUTE BUT NOT SEEN BY 540 (HIGH GAIN)

TEST POPULATION	3233	
NO. OF TUBES WITH CORRELATION	3216	99.4%
NO. OF TUBES WITHOUT CORRELATION	17	
NO. OF INDICATIONS WITHIN DATA SET*	17	

A. CIRCUMFERENTIAL EXTENT
100% OF 17 DEFECTS WERE ONE COIL.

B. AFTER ID MIXING (TO REMOVE CHATTER) THE NUMBER OF TUBES WITH CORRELATION IMPROVED TO 3229.

C. 14 OF 17 DEFECTS ARE RESOLVED AT THIS TIME.
% THRUWALL CHARACTERIZATION

% THRUWALL	# INDICATIONS	CUMULATIVE %
90-100	12	85.7
80-90	0	
70-80	0	
60-70	0	
50-60	1	92.8
40-50	0	
30-40	0	
20-30	0	
NO DESIGNATION	1	

C.1 THREE TUBES UNRESOLVED
ONE TUBE PLUGGED.
TWO TUBES HAVE NOT BEEN EXAMINED WITH SAT. PROBE & ID MIXING.

PLAN: CHARACTERIZE INDICATIONS SEEN BY 540 BUT NOT SEEN BY 510

TEST POPULATION	2771	
NO. OF TUBES WITH CORRELATION	2589	(93)%
NO. OF TUBES WITHOUT CORRELATION*	182	(7)%
NO. OF INDICATIONS FOR *	288	

CHARACTERIZING THE 288 NEW INDICATIONS

A. AMPLITUDE OF INDICATION

70%	1 VOLT AND LESS
90%	2 VOLTS AND LESS
96%	3 VOLTS AND LESS
98.9%	4 VOLTS AND LESS
100%	5 VOLTS AND LESS

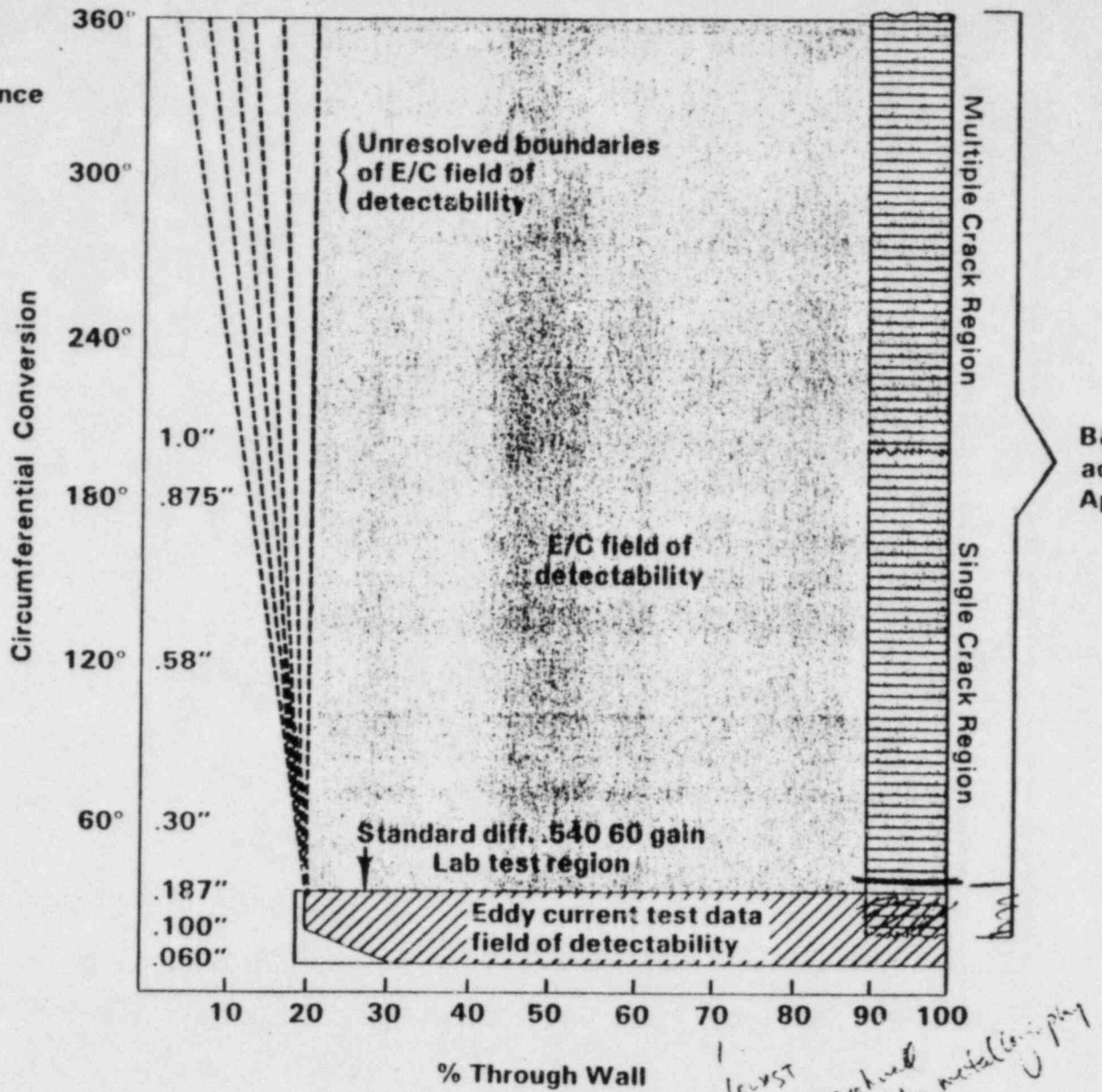
B. % THRUWALL CHARACTERIZATION

THRUWALL %	FREQUENCY	CUMULATIVE %	REMARKS
90-100	82	28	68% ~~IV~~ IV+ or less
80-90	23	36	65% IV or less
70-80	25	45	80% IV or less
60-70	42	59	76% IV or less
50-60	46	75.7	65% IV or less
40-50	36	88	86% IV or less
30-40	15	93	60% IV or less
20-30	19		47% IV or less
10-20	0		

ASPECT RATIO COMPARISON

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

Note: (1) 1.75" max. ID circumference



B&W metallography actual cracks final report April, 1982

least % through wall seen by metallography

LABORATORY WORK TO BE COMPLETED

1. NATURAL IGSCC CRACKS ARE TO BE GROWN (BEST ATTEMPTS) TO FULL PENETRATION AND SMALLEST "L"S POSSIBLE

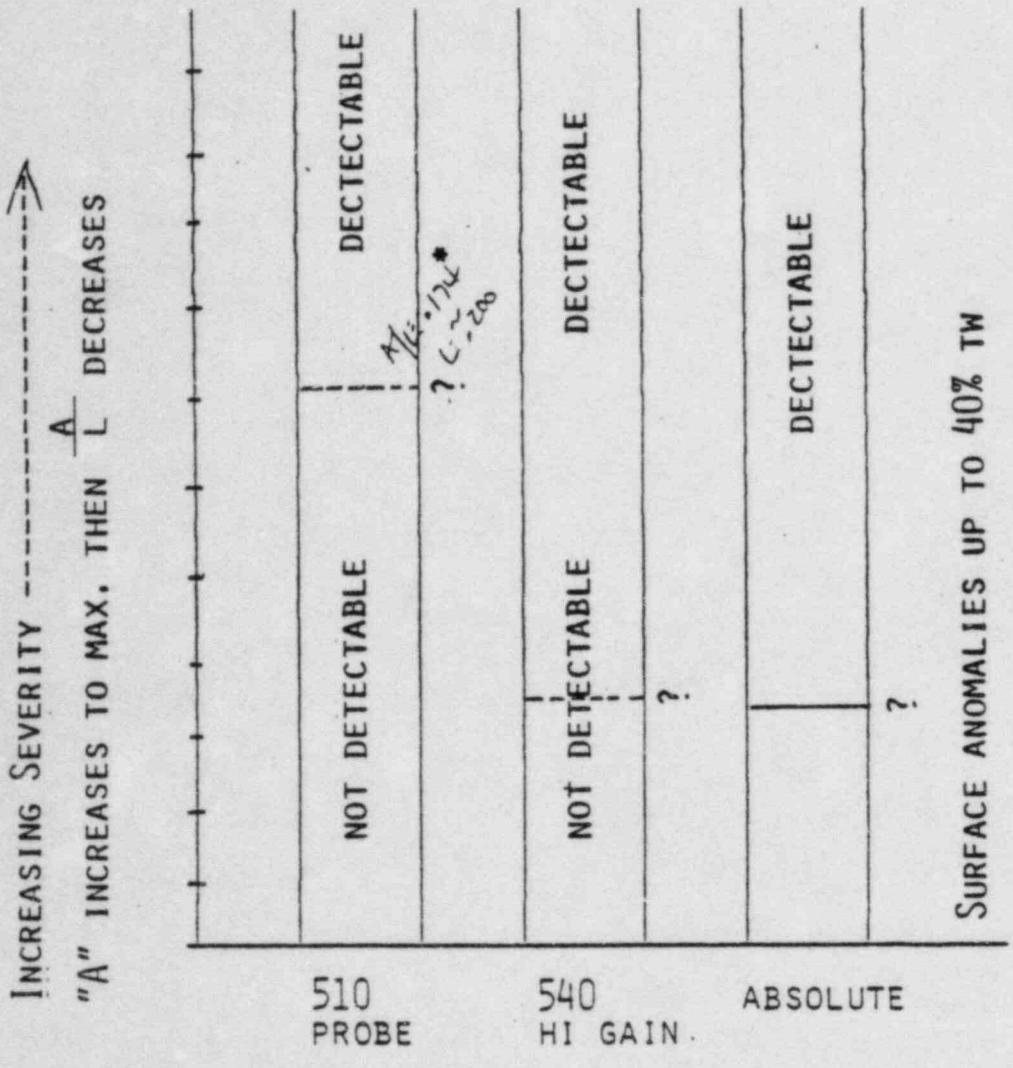
2. BACK OFF FROM TIME ELEMENT AND GROW ADDITIONAL CRACKS AT SMALLER "L" AND THEN SMALLER THRU WALL "A"

3. ESTABLISH THRESHOLD OF DETECTABILITY FOR 510, 540 SD, AND ABSOLUTE

4. METALLURGICALLY EVALUATE TO CONFIRM "A" AND "L" MEASUREMENTS

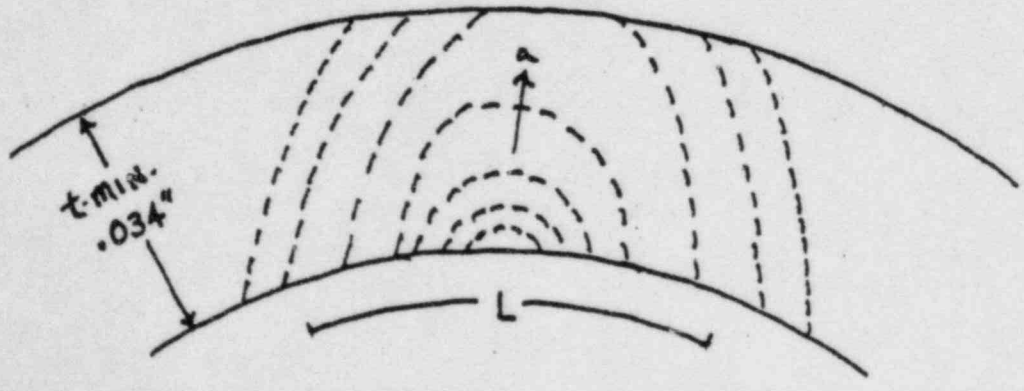
CORRELATION TO BE ESTABLISHED

THRESHOLD OF DETECTABILITY



*SMALLEST DEFECT 100% THRU WALL LENGTH.

? = DIVISION OF UNCERTAINTY



WORK TO BE COMPLETED

1. COMPLETE THE 540 HIGH GAIN PRODUCTION WORK AND RECORD ALL INDICATIONS KNOWING WE ARE PROBABLY RECORDING SURFACE ANOMALIES AND OD SIGNALS - Finish ~ 5/1

2. COMPLETE LAB ANALYSIS FOR ESTABLISHING THRESHOLDS

3. DISPOSITION THE RESULTS SO AS TO ACCEPT SURFACE ANOMALIES AND SMALL OD SIGNALS PROVIDING WE DON'T ACCEPT IGSCC (>40%)

4. ESTABLISH AS SUPPLEMENTARY ISI PROGRAM TO SPECIALLY TREAT ITEMS ACCEPTED IN "B" "3"

SUMMARY

1. ECT QUALIFICATION IS NEARING COMPLETION.

2. USING SYNTHETIC DEFECTS WAS ABLE TO ESTABLISH A HIGH GAIN 540 TECHNIQUE THAT IS SENSITIVE ENOUGH TO ASSURE THAT ALL NATURAL (IGSCC) INDICATIONS ARE REPORTED.

3. NEED TO ESTABLISH AN ENGINEERED BASIS FOR ACCEPTING TUBES WITH NON-RELEVANT INDICATIONS.

4. DISPOSITION GENERATOR AND COMPLETE REPAIR.

5. SAFETY ANALYSIS AND REPORTING.

TYPES OF INTERGRANULAR ATTACK

1 - IGA - ISLANDS

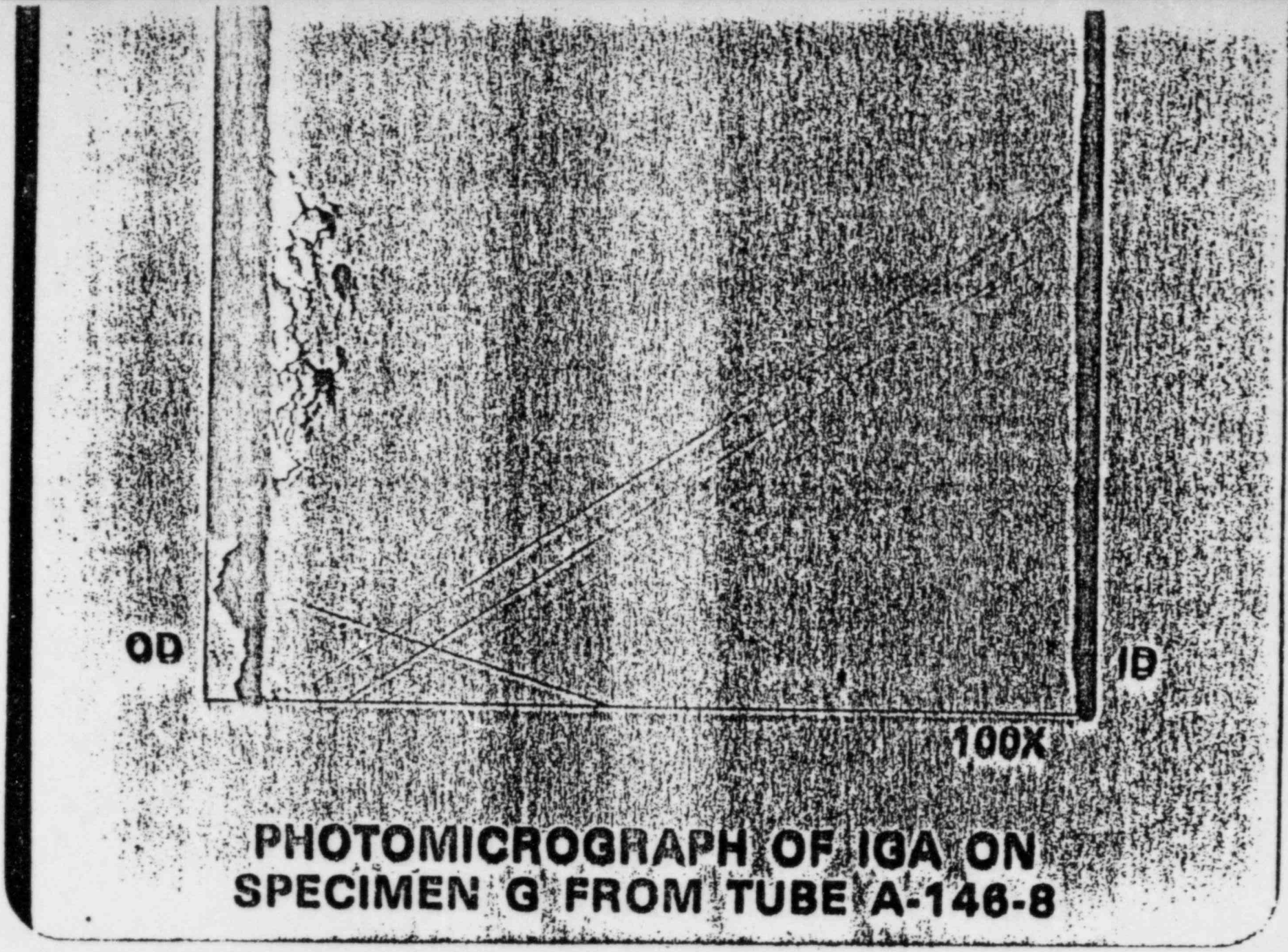
- o < 5 GRAINS DEEP
- o TEND TO OCCUR UNDER DEPOSITS
- o GRAINS REMAIN IN PLACE

2 - IGA - PITS

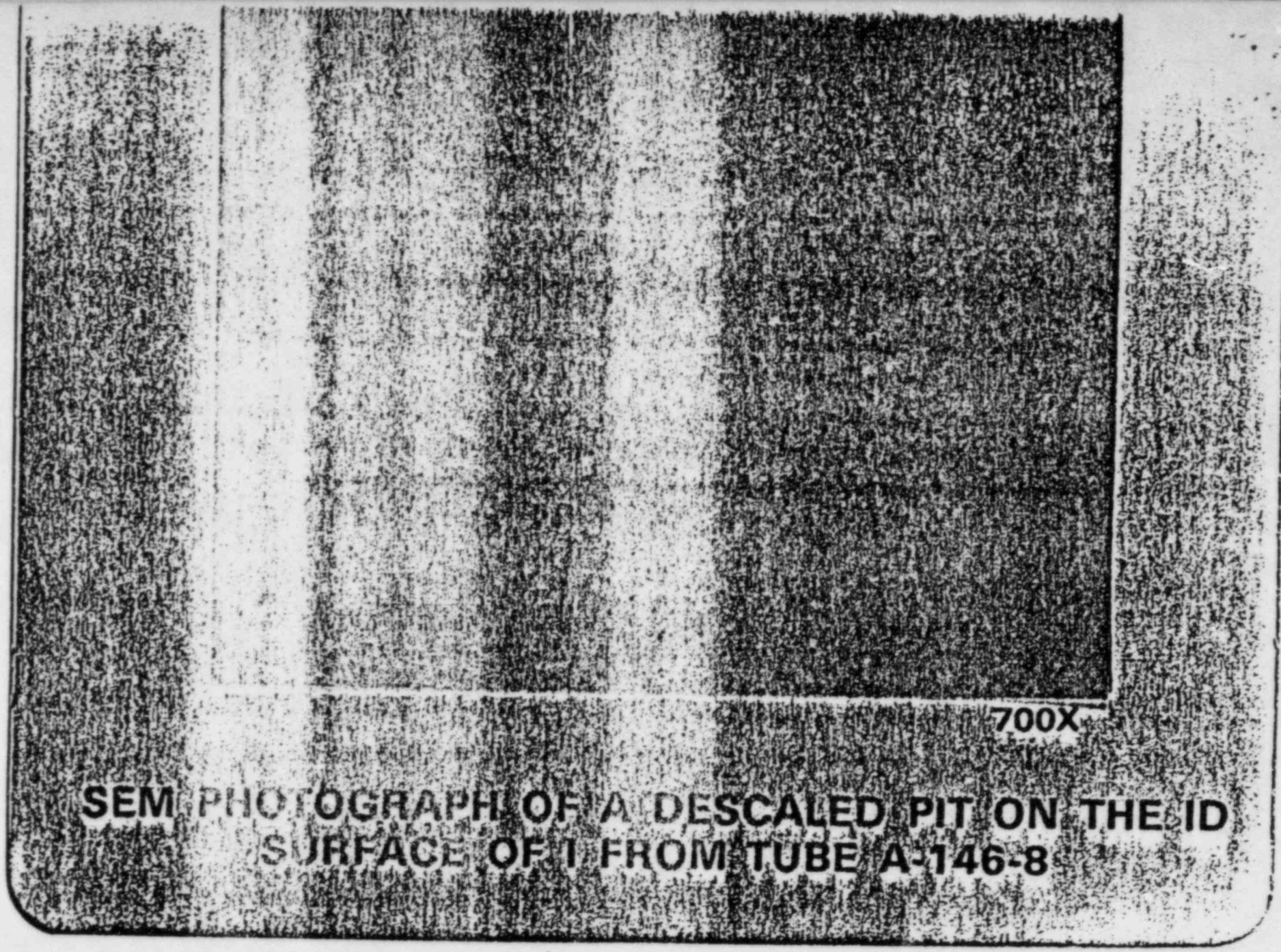
- o RESULT FROM GRAIN DROPPING FROM IGA - ISLANDS
- o FEW GRAINS TO 10 GRAINS DEEP

3 - INTERGRANULAR STRESS CORROSION CRACKING

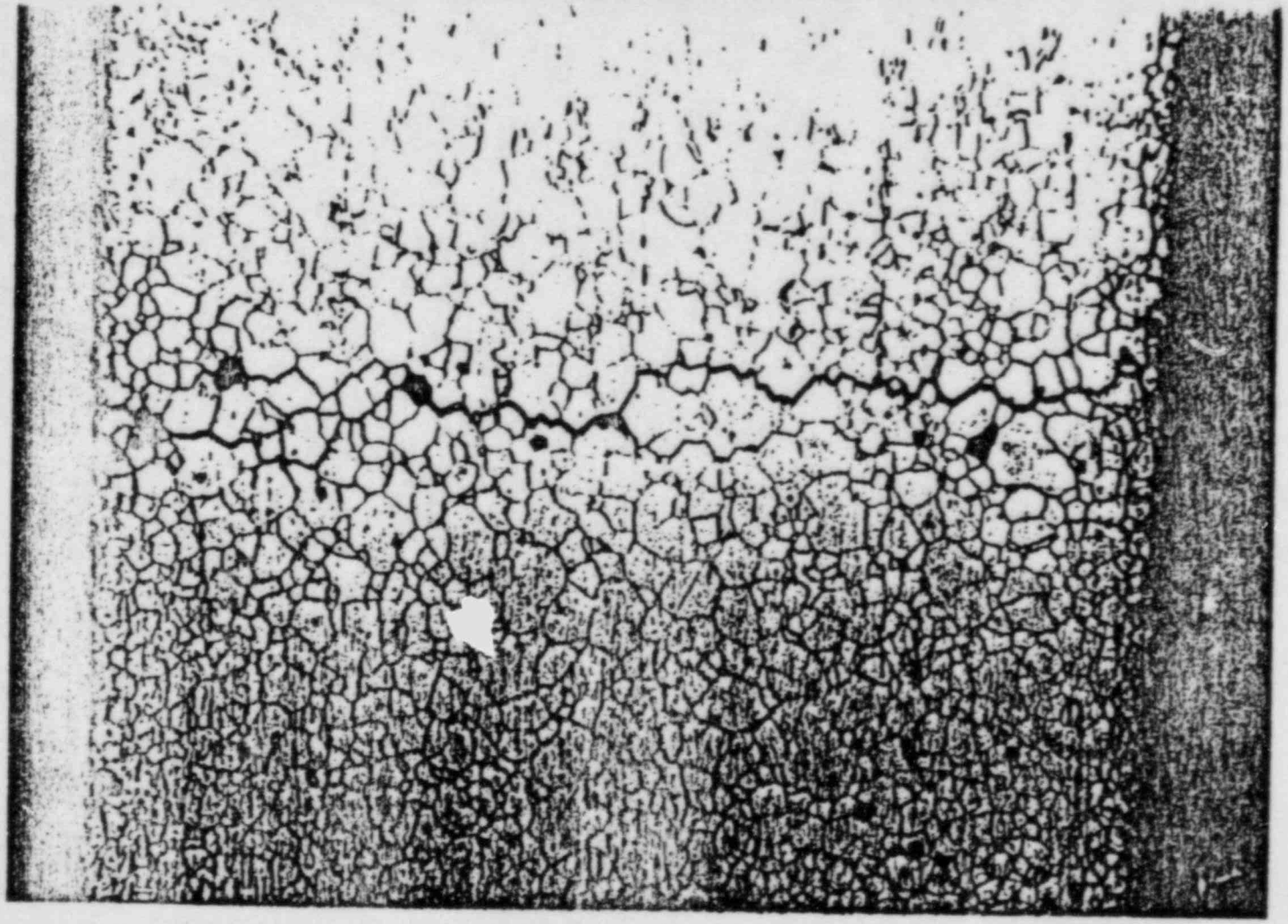
- o RESULT OF IGA IN REGIONS OF HIGH LOCAL STRESS
- o CIRCUMFERENTIAL EXCEPT AT EXTREME TOP END OF TUBE
- o MAY DEVELOP FROM IGA - PITS
- o EXTENT OF IGA VARIES FROM 2-10 GRAINS
- o MAY EXHIBIT BRANCHING



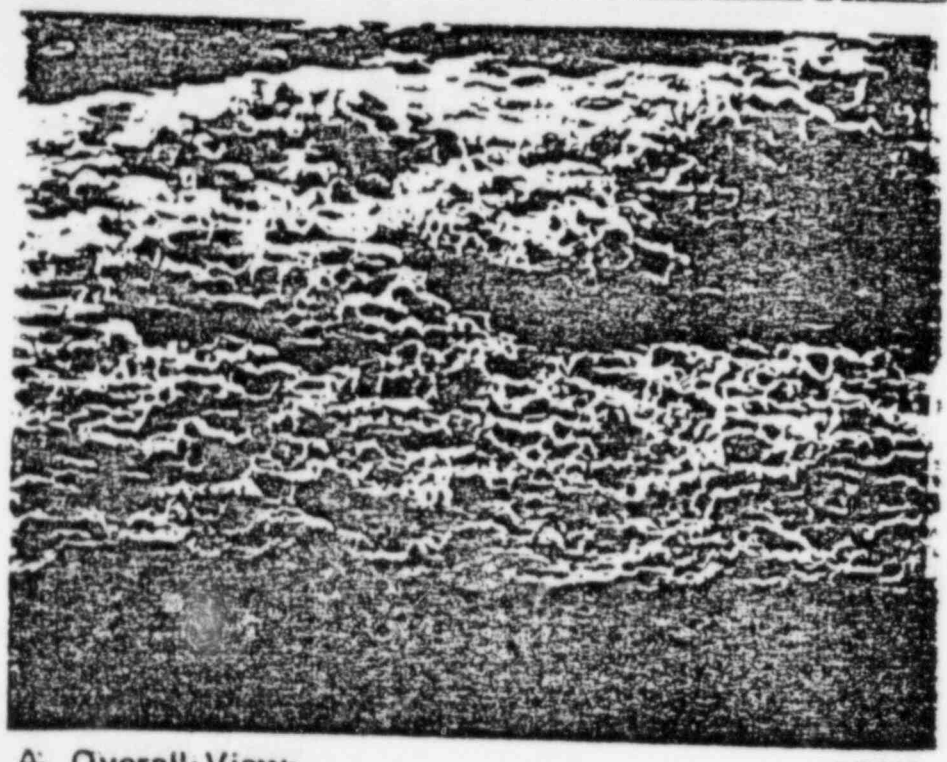
PHOTOMICROGRAPH OF IGA ON SPECIMEN G FROM TUBE A-146-8



SEM PHOTOGRAPH OF A DESCALED PIT ON THE ID SURFACE OF 1 FROM TUBE A-146-8



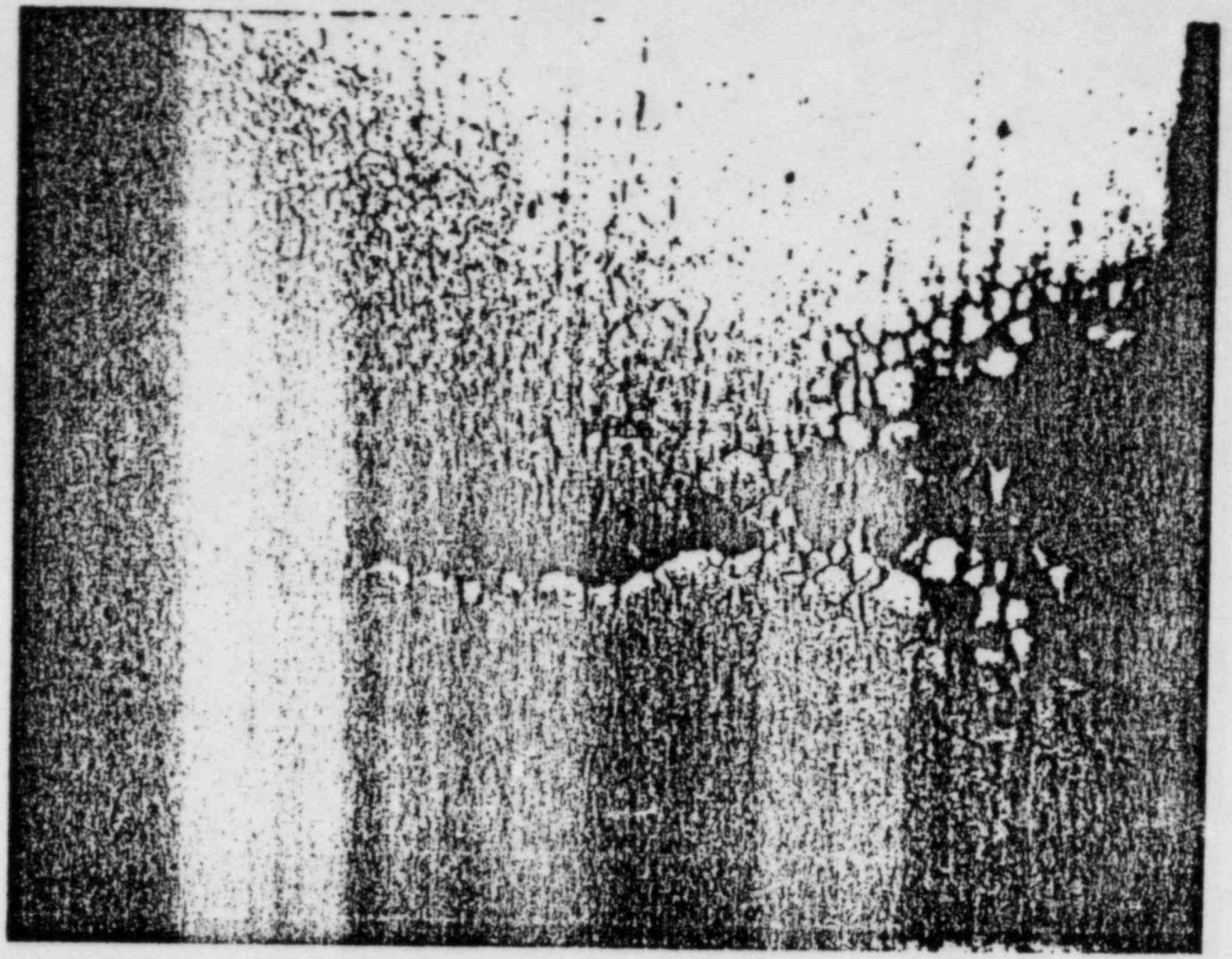
PHOTOMICROGRAPH OF THROUGH WALL IGC IN SPECIMEN C FROM TUBE A-146-6



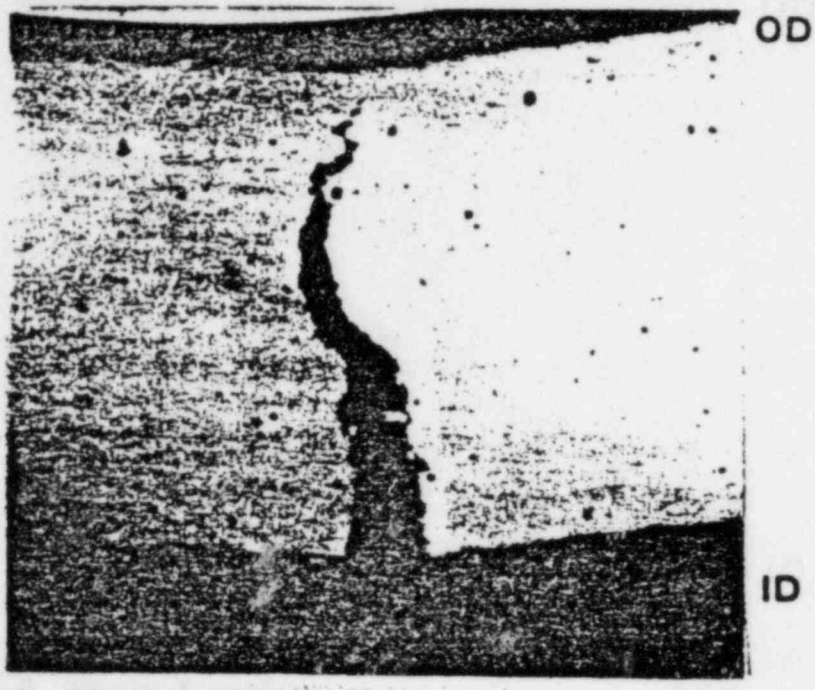
A. Overall View 120X

B. Fluffy Deposit 900X

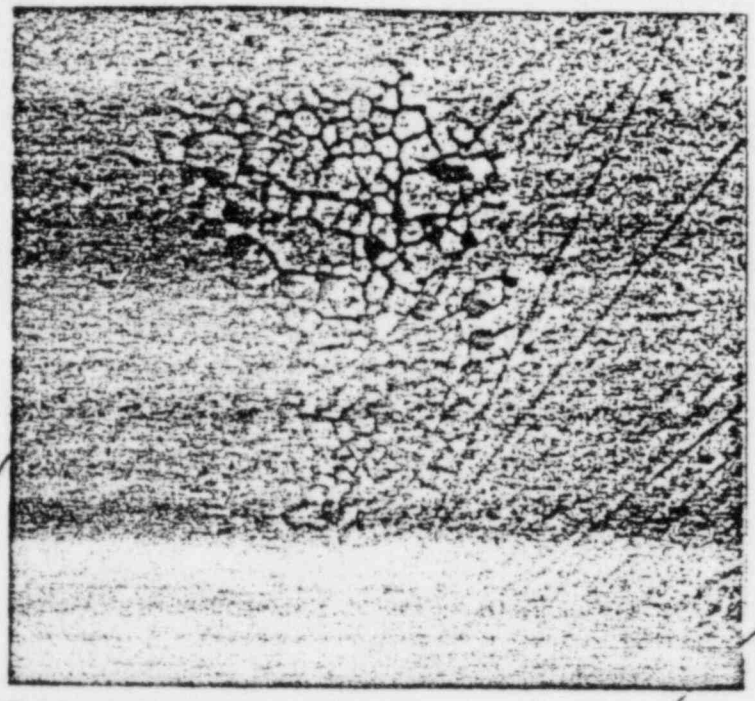
SEM PHOTOGRAPHS OF THE FRACTURE SURFACE OF SPECIMEN A6 FROM TUBE B-8-25



PHOTOMICROGRAPH OF THE CROSS SECTION OF PIT AND CRACK IN SPECIMEN D FROM TUBE A-146-6

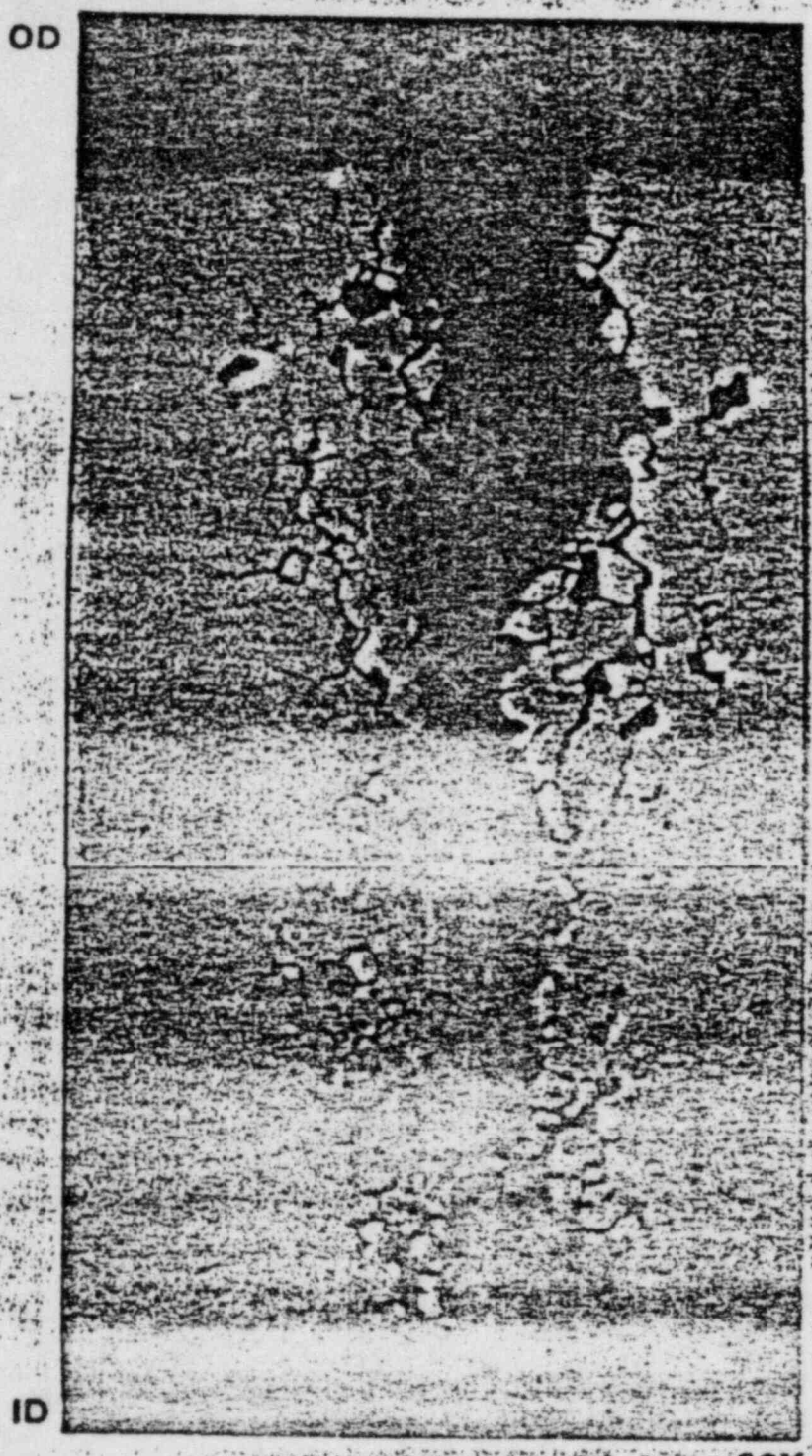


A. Main Crack 60X

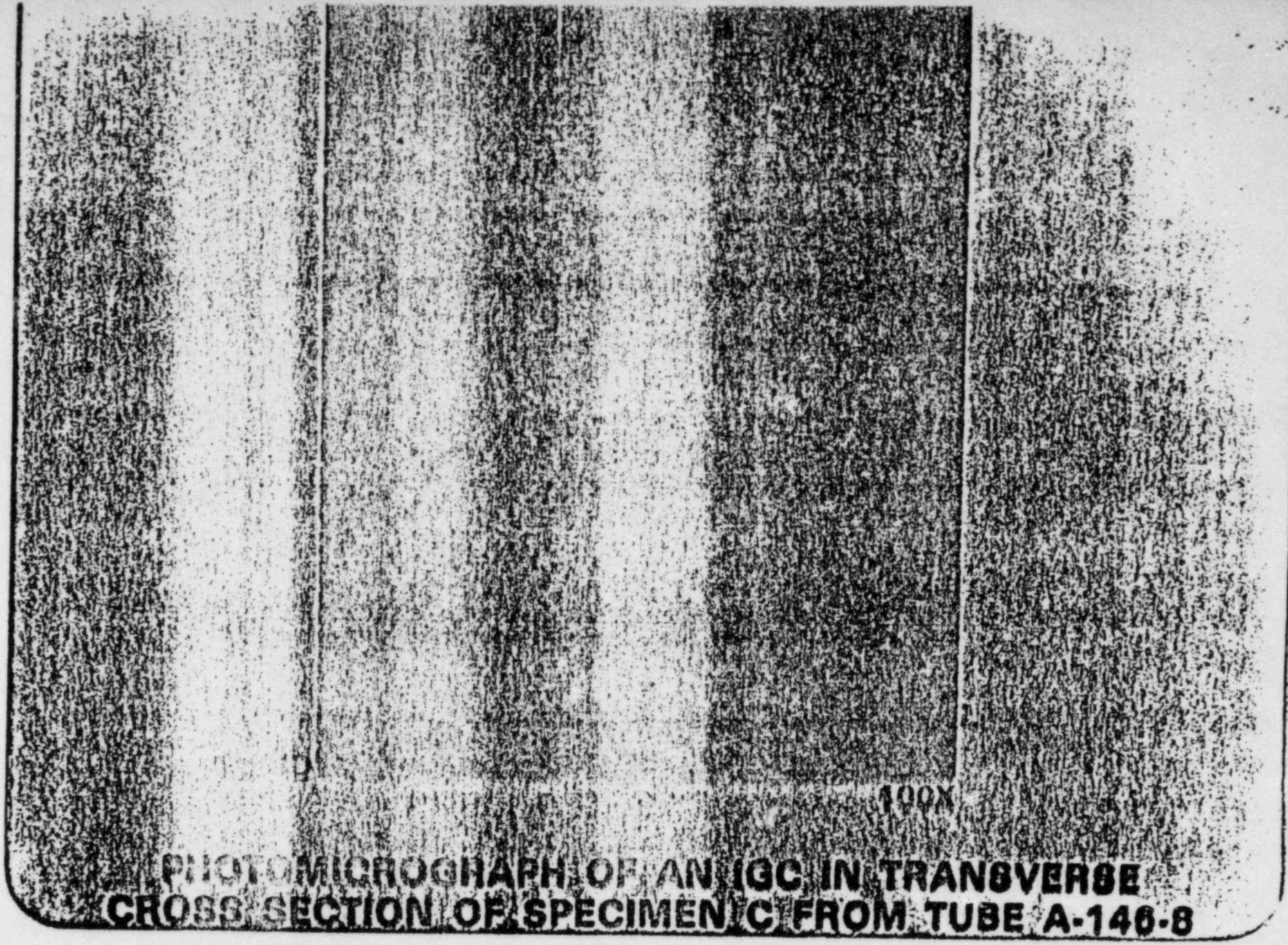


B. Intergranular Attack 120X

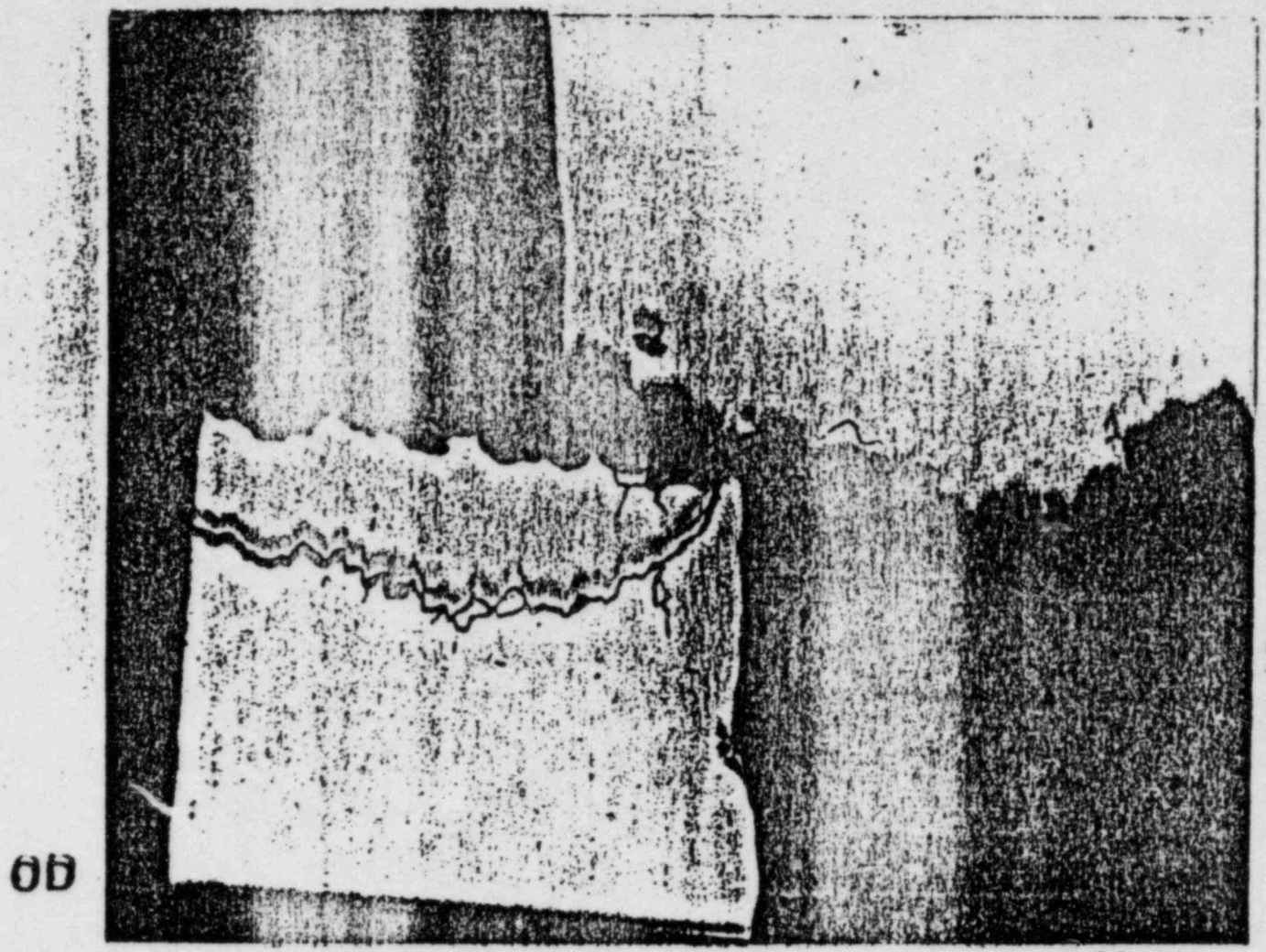
PHOTOMICROGRAPHS OF THE CROSS SECTION OF BENT SPECIMEN A2 FROM TUBE B-8-25



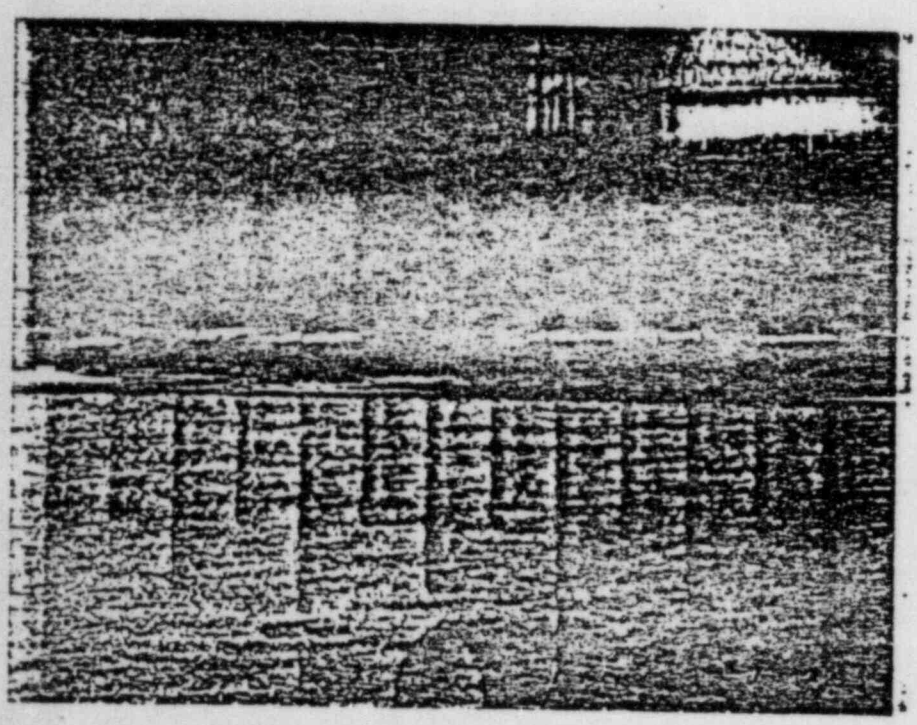
PHOTOMICROGRAPH OF SPECIMEN A FROM TUBE B-11-23 SHOWING IGC AND SEVERE IGA ON EITHER SIDE OF THE CRACK



PHOTOMICROGRAPH OF AN IGC IN TRANSVERSE CROSS SECTION OF SPECIMEN C FROM TUBE A-146-8



PHOTOMICROGRAPH OF AN IGC IN LONGITUDINAL CROSS SECTION OF SPECIMEN A FROM TUBE A-146-R

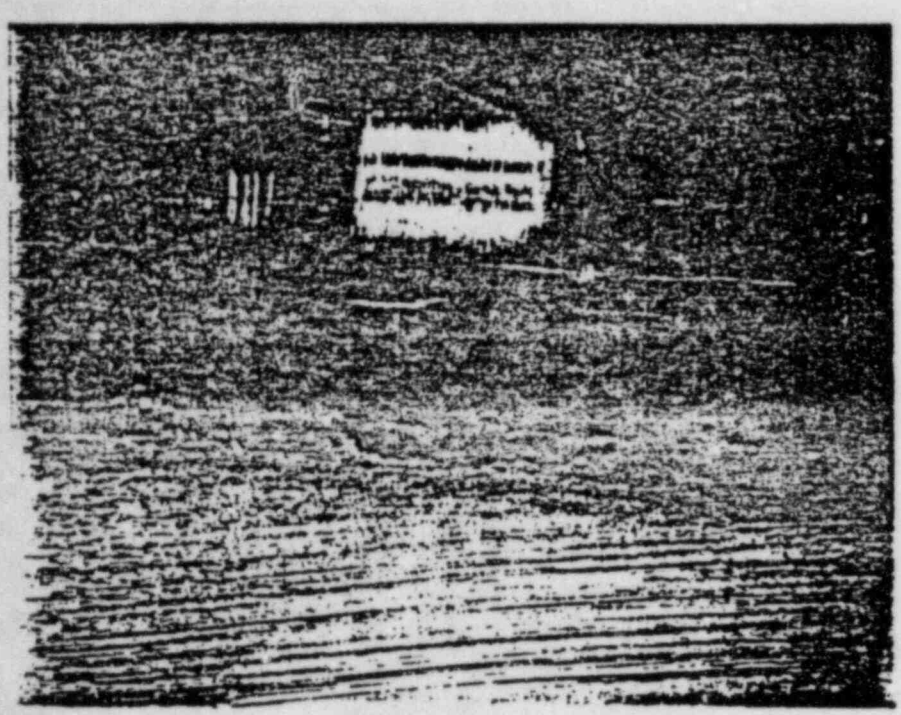


A-24-94-12

180-270

EC 40-70%

Bright Spot is Tube Removal Damage

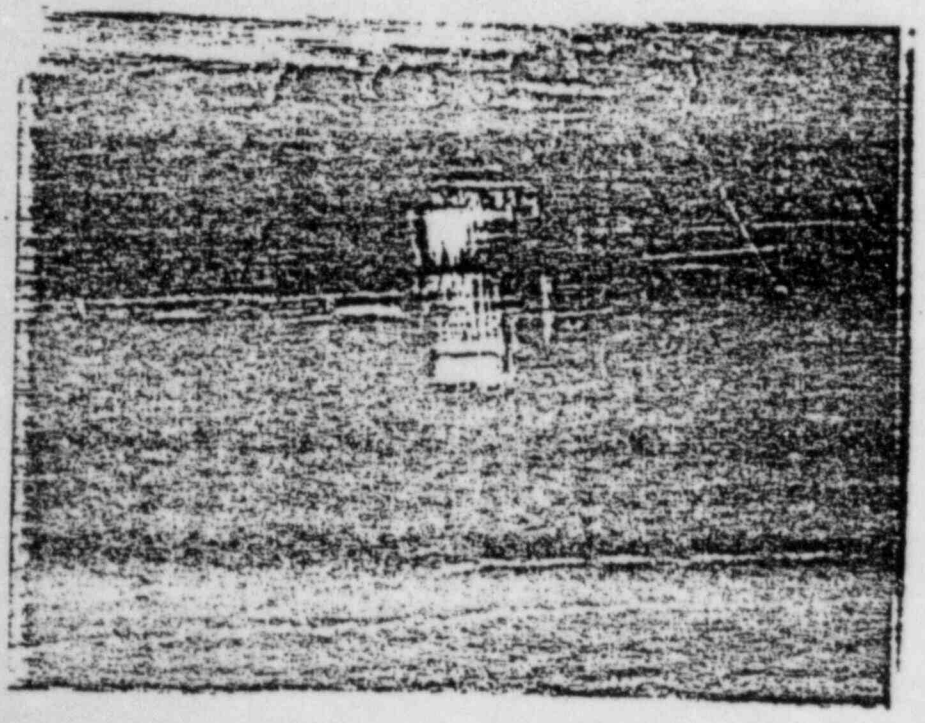


A-24-94-123
180-270

EC 40-70½

other half of piece showing tube removal damage

EC 40-70

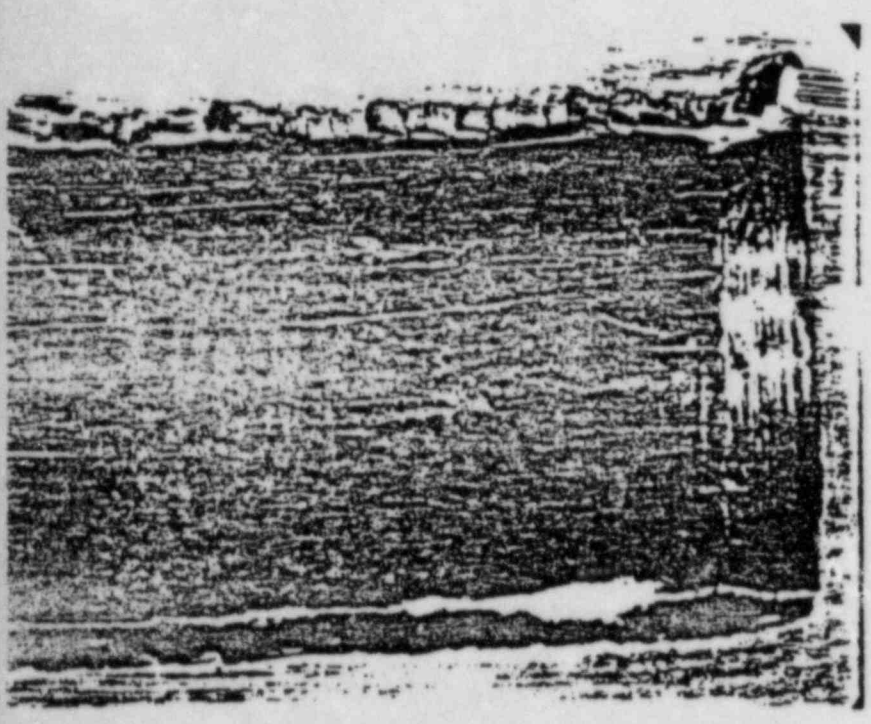


A-24-94-123

270-360

tube removal damage & axial scratch

EC 40-70

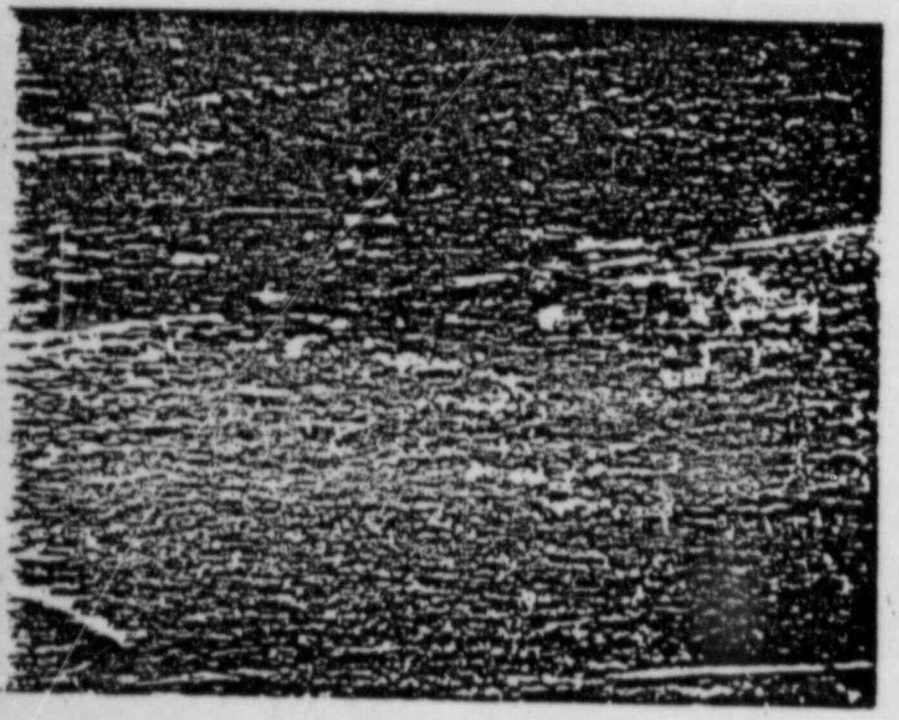


A-24-94-12:
270-360

EC 80-1::

pitted area
@ 13.0

(⅓ from
right to
left)



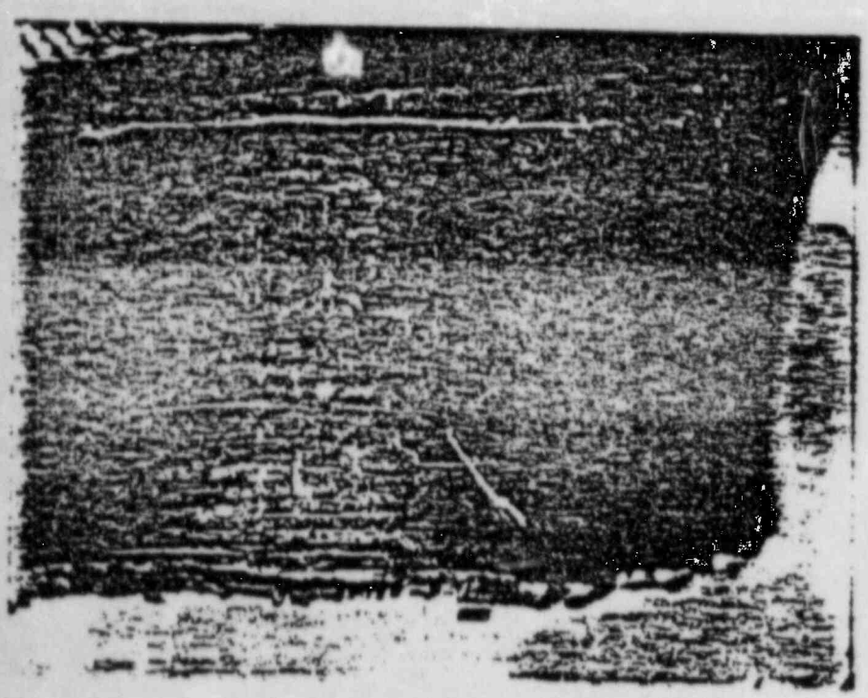
A-24-94-12:

270-360

Closeup of pits at ~13.0

T

3M CATALOG NO. 15 - 1006 - 4
3M CENTER, ST. PAUL, MINN 55101
MADE IN U. S. A.



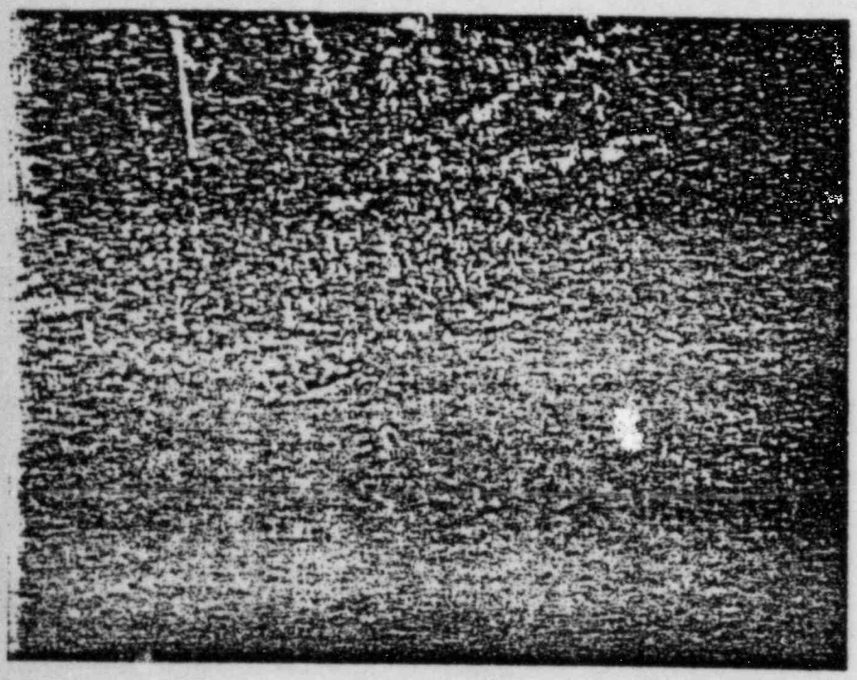
A-24-94-12

270-360

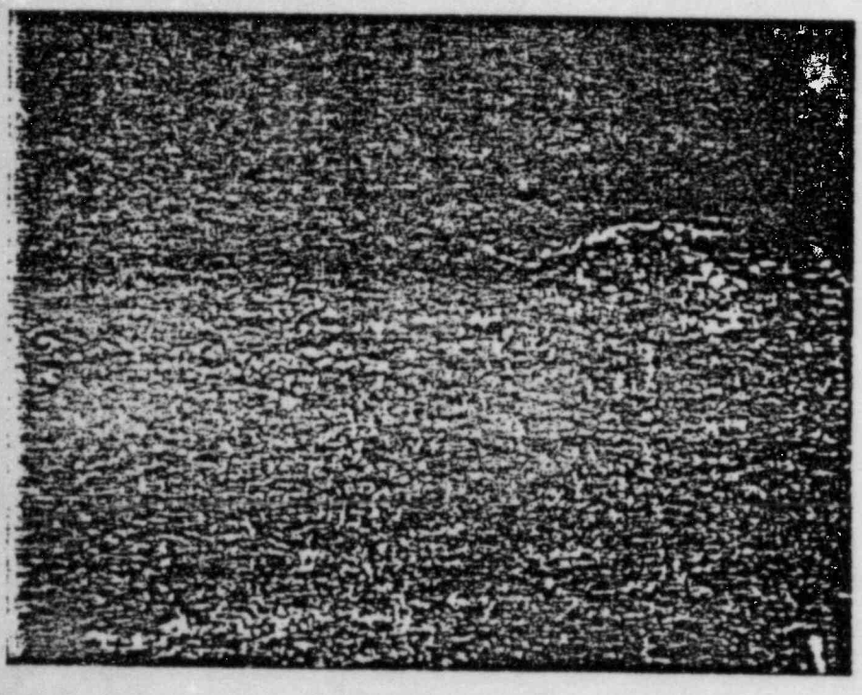
EC 80-100

Crack opened on bendin at 12.8 – not in puts at 1

CATALOG NO. 15 - 1006 - 4
3M CENTER, ST. PAUL, MINN 55101
MADE IN U. S. A.



A-24-94-12.
270-360
45x
overall
view of
crack



A-24-94-12
270-360
65X

multiple
cracking &
branching

EDDY CURRENT CORRELATIONS - ROUND 1 AND 2

LOCATION: 0-1/4"

TUBE	EDDY CURRENT RESULTS: DIFFERENTIAL LOCATION	DIFFERENTIAL % T.W.	ABSOLUTE LOCATION	ABSOLUTE % T.W.	BEND TEST RESULTS: LOCATION[4]	% T.W.	ASPECT RATIO
A-88-7					0.03	100%	.057
A-13-63			0.4	95%	0.125	100%	.049
A-112-7					0.125	100%	.085
A-112-9					0.125	100%	.049
A-133-74					0.125	100%	.049
B-10-29			NE		0.125	100%	.031
A-23-93			0.3	95%	0.25	100%	.174
A-88-11					0.25	100%	NR
A-112-5			0.5	95%	0.25	100%	.043
A-71-126			0.6	95%	0.25	100%	NR
A-146-8					0.25	100%	NR
A-16-69			0.3	95%	0.125	100%	.043

built in .2" inaccuracy because of seal weld removal

NOTES:
1) NE - NOT EXAMINED
2) BLANK SPACE MEANS THAT NO EDDY CURRENT INDICATIONS WERE REPORTED.
3) NR - NOT REPORTED
4) BEND TEST RESULTS REFERENCED TO CUT END OF TUBE - APPROX. 0.2" REMOVED DURING PULLING.

EDDY CURRENT CORRELATIONS - ROUND 1 & 2

LOCATION: 1/4" - ROLL TRANSITION

TUBE	EDDY CURRENT RESULTS				BEND TEST RESULTS		
	DIFFERENTIAL		ABSOLUTE				
	LOCATION	% T.W.	LOCATION	% T.W.	LOCATION	% T.W.	ASPECT RATIO
A-12-62	1.0	75%			ND		
	RT	NDD-2	RT	95%	1.5	100%	.015
A-13-63	RT	POSSIBLE DEFECT	1.7	95%	1.25	100%	.034
A-62-8	1.0	90%	1.0	95%	1.25	100%	.049
	RT	NDD-1	RT	95%	ND		
A-133-74			0.6	95%	0.56	100%	0.136
	1.5	POSSIBLE DEFECT			1.5	NR	NR
B-10-29	1.0	80%	NE		1.25	100%	.034
B-8-25	RT	65%	NE		ND		
	1.5	60%	NE		1.25	100%	.035
B-11-23	1.0	95%	NE		1.25	100%	.043
	1.75	95%	NE		1.50	100%	.174
A-23-93	RT	NDD-1	RT	95%	ND		
A-88-11	RT	NDD-2	RT	DEFECT	1.25	100%	.130
A-112-5	RT	NDD-2	RT	95%	1.25	100%	.074
A-71-12[illegible]	RT	NDD-1	RT	95%	ND		
A-16-69			0.8	95%	.69	100%	.113
	RT	NDD-2	RT	95%	1.31	100%	.057

NOTES: ND - NO DEFECT FOUND ON BEND TEST

RT - IN ROLL TRANSITION AREA

EDDY CURRENT CORRELATIONS - ROUND 1 & 2

LOCATION: ROLL TRANSITION - 10"

TUBE	EDDY CURRENT RESULTS				BEND TEST RESULTS		
	DIFFERENTIAL LOCATION	% T.W.	ABSOLUTE LOCATION	% T.W.	LOCATION	% T.W.	ASPECT RATIO
A-12-62	8.0	75%	8.7	95%	8.19	100%	.056
A-112-7	2	70% MULT.	2-5	95%	NR		
			4	50%	3.9	100%	.149
			4.5	90%	4.5	100%	.115
	6	80%	6	90%	5.6	100%	.073
			6.5	90%	6.5	100%	.005
	7	90%	7	50%	7.125	100%	.085
A-23-93	2.0	80%	1.8	95%	1.75	100%	.093
A-88-11			2	95%	2.25	100%	.073
A-146-6	9	85%	8.4	90%	8.25	100%	.045
A-146-8	3	55%	4	90%	4	70%	.045
B-10-29	7.6	95%	NE		7.6	100%	.147

EDDY CURRENT CORRELATIONS - ROUND 1 AND 2

LOCATION: 10" - 24"

	Eddy Current Results				Bend Test Results		
	Differential		Absolute				
Tube	Location	% T.W.	Location	% T.W.	Location	% T.W.	Aspect Ratio
A-11-66	12	55%	11.7	90%	11.6	100%	.113
A-146-6	10	55%	10.3	95%	10.5	100%	.043

LOCATION: 24" - 15TH TSP

A-13-63	27	90%	26.3	95%	26.8	100%	.043
A-133-74	31	95%	30.7	90%	32	100%	.147
	32	95%	32	90%	33	100%	.147

Summary of Eddy Current Correlations - Round 1 & 2

Location	Number of Tubes w/Bend Tests	Cracks opened on Bend Test	Indications Found by Eddy Current	
			0.510" Differential	4x1 Absolute
0 - 1/4	12	12	0	5
1/4 - RT	12	13	11	8[1]
BELOW RT - 10	7	11	8	10[2]
10 - 24	2	2	2	2
24 - TSP	2	3	3	3

NOTES: 1) 4 TUBES WITH CRACKS IN THIS AREA NOT EXAMINED WITH 4 x 1 ABSOLUTE PROBE.

2) 1 TUBE WITH CRACK IN THIS AREA NOT EXAMINED WITH 4 x 1 ABSOLUTE PROBE.

SUMMARY - EDDY CURRENT vs. DEFECT CORRELATIONS

- o 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.).
- o Below the roll transition, the in-field eddy current techniques detect actual defects with 100% reliability.
- o No undetected defects have been found below the roll transition area during the laboratory investigation.

TYPES OF TUBE SAMPLES - ROUND 3

- o TUBE WITH DEEP DEFECTS (EC QUALIFICATIONS)
- o BAD TUBE/GOOD REGION (DEFECT PATTERNS)
- o GOOD TUBE/BAD REGION (DEFECT PATTERNS)
- o TUBE WITH MULTIPLE DEFECTS (TESTING)
- o GOOD TUBE/DEEP SAMPLE (EC QUALIFICATIONS)
- o TUBES WITH ROLL REGION EC INDICATION (EC QUALIFICATIONS)
- o GOOD TUBE/GOOD AREA

EDDY CURRENT TEST METHOD CORRELATION

- OBJECTIVE - VERIFY REPRODUCIBILITY BETWEEN EXAMINATION METHODS AND CORRELATE RESULTS WITH METALLOGRAPHIC EXAMINATION.

- EDDY CURRENT METHODS USED -
  1) IN-SITU - 0.510" PROBE, STANDARD DIFFERENTIAL
  2) IN-SITU - 4 X 1 ABSOLUTE PROBE (TOP END OF TUBES)
  3) AT B&W - 0.500" STANDARD DIFFERENTIAL PROBE
  4) EPRI - DEVELOPED 0.540" STANDARD DIFFERENTIAL PROBE

- METALLOGRAPHIC EXAMINATION BY SECTIONING AND BENDING OF SELECTED INDICATIONS.

EDDY CURRENT CORRELATIONS - 3RD ROUND TUBES

TUBE	ELEVATION	FIELD DIFFERENTIAL	FIELD ABSOLUTE	B&W LAB	0.540" DIFFERENTIAL	METALLOGRAPHY RESULT	REMARKS
A-24-94	0.2		95				
	1.3		95	80-100	80-100	100% T.W.	
	3.4	95		80-100	80-100	100% T.W.	
	5.2			40-70	40-70	No Crack	Localized small pits
	12.3			40-70	40-70	No Crack	Removal damage
	12.8	95		NDD	NDD	70% T.W.	Within 1/2" of cut edge
	15	95		90-100	90-100	Not tested	Scheduled for repair testing
	34	95		90-100	90-100	" "	" " " "
	41	95		NDD	NDD	" "	No testing scheduled
	53.5	95		NDD	NDD	" "	" " "
A-37-29	112	40		40	40	No crack	Manufacturing artifact
A-111-13	0.2		95			Not tested	No testing scheduled
	3		80			" "	No bend test scheduled
B-16-22	0.2		40			Cracks	4 axial cracks 1/4"
B-94-27	12.5			90-100	90-100	Not tested	Scheduled for Corrosion Test
	13.2			80-100	80-100	" "	" " " "
	14	95 (multiple)		90-100	90-100	" "	" " " "
	238	95		NDD	NDD	No crack	Within 1/4" of cut edge
B-34-19	0.2		Incomplete signal			Cracks	5 axial cracks 1/4"

SUMMARY OF EDDY CURRENT RESULTS

1) EDDY CURRENT CALLS OF > 80% CORRELATE WITH IGSCC.

2) EDDY CURRENT CALLS OF 40-70% REPRESENT SURFACE ANOMALIES OTHER THAN CRACKING.

3) NO CRACKS FOUND WHERE EDDY CURRENT REPORTS NO INDICATIONS.

SUMMARY - METALLURGICAL CORRELATIONS

- BELOW THE ROLL TRANSITION, EDDY CURRENT INDICATIONS CORRELATE WITH TUBE WALL DEFECTS.

- BEND TESTING HAS BEEN DONE ON:

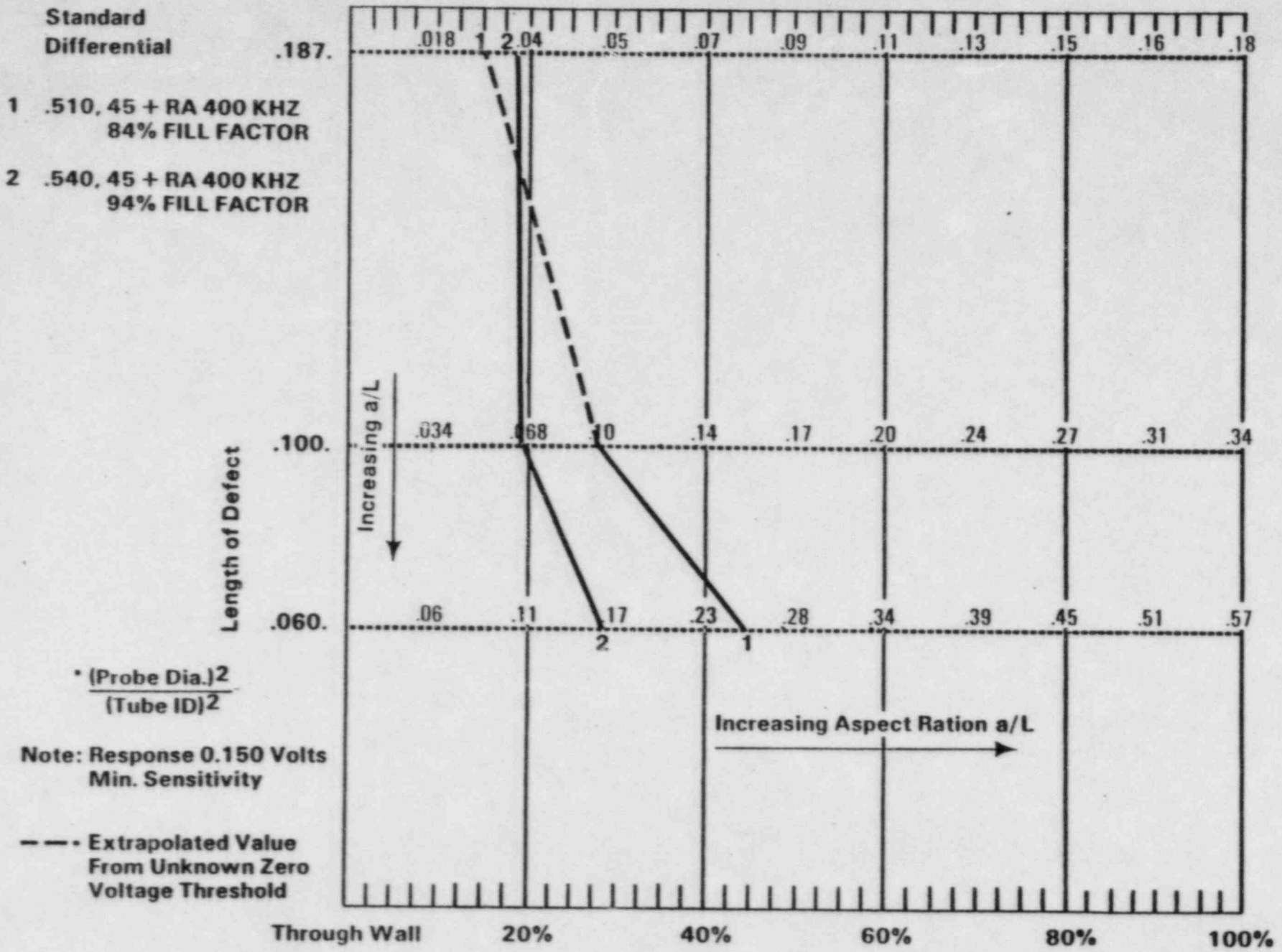
  ROUND 1 & 2 - 14.1 FT. OUT OF 37.8 FT. REMOVED.

  ROUND 3 - 4.5 FT. OUT OF 124 FT. REMOVED.

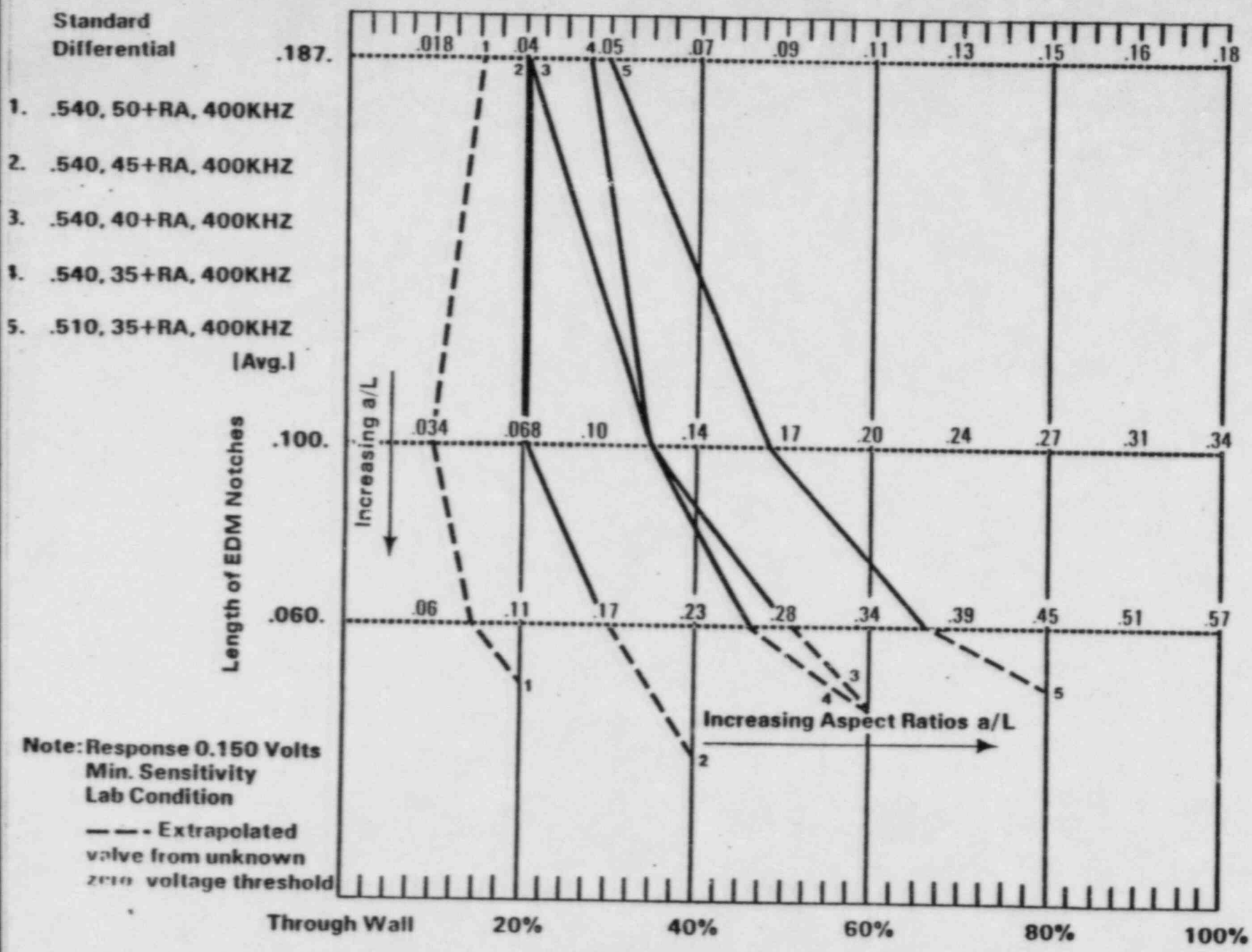
  ADDITIONAL 6 FT. OF ROUND 3 TUBING SCHEDULED.

- NO DEFECTS UNDETECTED BY EDDY CURRENT HAVE BEEN DETECTED BY BEND TESTS.

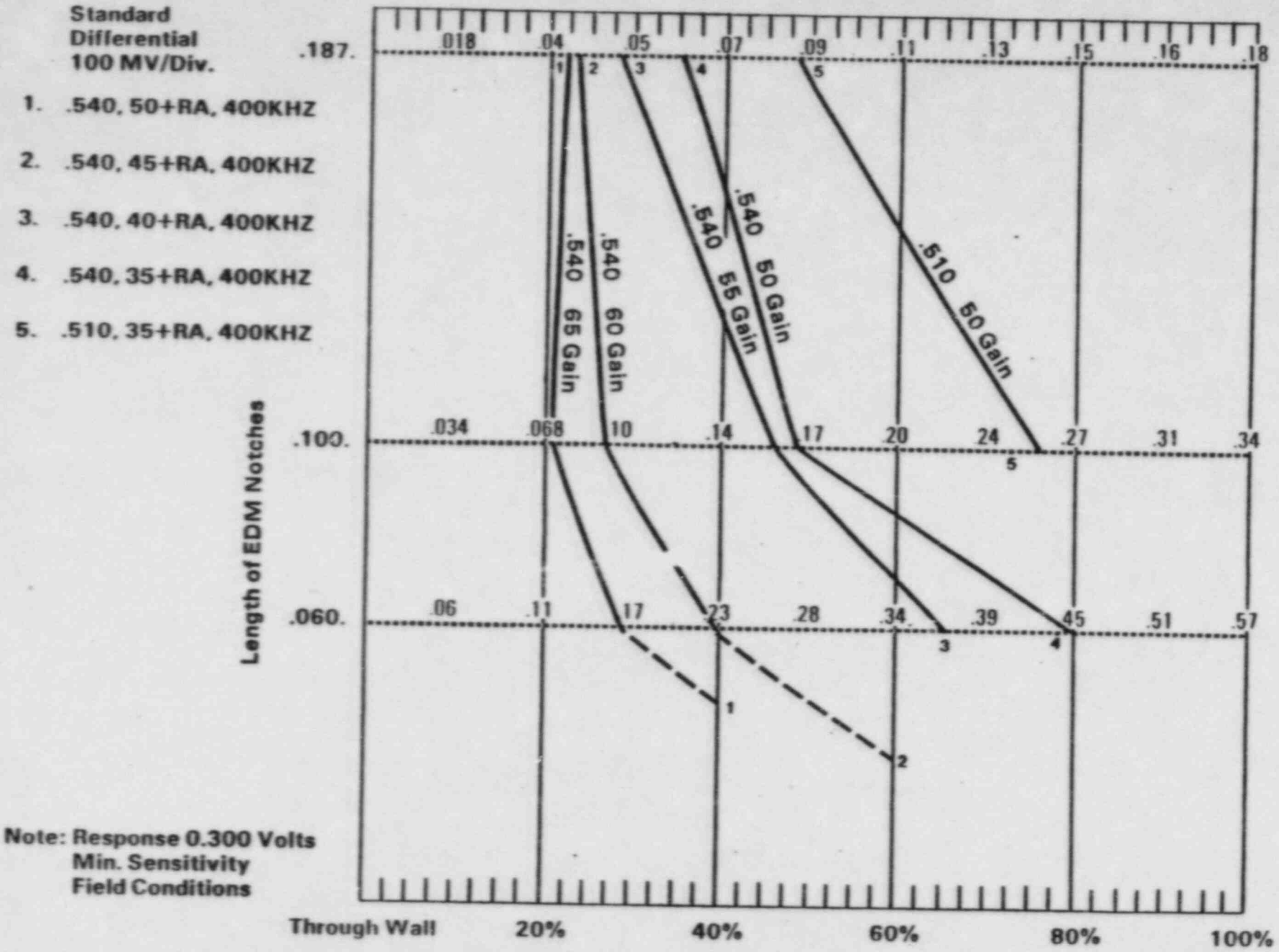
FILL FACTOR COMPARISON*



GAIN COMPARISON FOR DETECTION PROBABILITY



GAIN COMPARISON FOR DETECTION PROBABILITY



Note: Response 0.300 Volts
Min. Sensitivity
Field Conditions