NORTHEAST UTILITIES

THE CONNECTICUT LIGHT AND POWER COMPANY
WESTERN MASSACHUSETTS ELECTRIC COMPANY
HOLYOKE WATER POWER COMPANY
NORTHEAST UTILITIES SERVICE COMPANY
NORTHEAST NUCLEAR ENERGY COMPANY

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July 19, 1985

Docket No. 50-336
B11615

Director of Nuclear Reactor Regulation
Attn: Mr. Edward J. Butcher, Acting Chief
Operating Reactors Branch #3
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Reference: (1) J. F. Opeka letter to E. J. Butcher, dated June 12, 1985

Gentlemen:

Millstone Nuclear Power Station, Unit No. 2
Steam Generator Chemical Cleaning

In Reference (1) Northeast Nuclear Energy Company (NNECO) provided the NRC Staff an updated summary of pertinent information presented to the Staff on May 1, 1985 and updated copies of handouts used during the May 1, 1985 meeting. As a result of subsequent discussions with the Staff, NNECO hereby provides additional information in support of the Reference (1) submittal.

Attachment (1) provides data compilations used in support of the Reference (1) submittal. Additionally, Attachment (2) provides the entire qualification report concerning probe selection and copper elimination tests for the examination of pitting at Millstone Unit No. 2. This report was prepared for Millstone Unit No. 2 by Combustion Engineering, Inc.

We trust you will find this information satisfactory.

Very truly yours,

NORTHEAST NUCLEAR ENERGY COMPANY

J. F. Opeka

J. F. Opeka
Senior Vice President

A001
1/40

ATTACHMENT 1

MILLSTONE [illegible] 2-1985

PIT DETECTABILITY 400 KHZ
(CONSTANT DEPTH) A600 HF PROBE

DIMENSIONS					DETECT? COPPER 600/250 mix			
TYPE	DEPTH	DIAM	VOLx10^{-4}	DETECT? NO COPPER	SHIM 4 mil	PLATE 4 mil	PLATE 12 mil	TUBE
ASME	100%	.052	1	Y	Y	-	-	3/4"
CORR.	100	.090x.070	2.4	Y	-	Y	-	7/8"
CORR.	100	.088	2.8	Y	Y	-	-	3/4"
CORR.	94%	.030x.080	1	Y	-	Y	-	7/8"
ASME	80%	.078	1.8	Y	Y	-	-	3/4"
CORR.	82%	.080	1.9	Y	-	Y	Y	7/8"
"	82%	.080	1.9	Y	-	Y	-	7/8"
"	76%	.090	2.3	Y	-	Y	Y	7/8"
"	79%	.080	1.9	Y	-	Y	-	3/4"
CORR.	69%	.071	1.2	Y	Y	-	-	3/4"
"	70%	.080	1.7	Y	-	Y	Y	7/8"
"	68%	.050	.64	Y		Y	Y	7/8"
"	65%	.068	1.5	Y	Y	-	-	3/4"
"	65%	.090	1.9	Y	Y	-	-	7/4"
ASME	60%	.109	2.7	Y	Y	-	-	3/4"
CORR.	63%	.068	1.1	Y	-	Y	-	3/4"
"	62%	.030	.21	Y	-	Y	Y	7/8"
CORR.	54	.14	3.9	Y	-	Y	-	3/4"
"	50	.13	3.2	Y	Y	-	-	3/4"
F.B. MACH	50	.075	1.0	Y	Y	-	-	3/4"
"	46	.030	.16	Y	N	-	-	3/4"

DIMENSIONS				DETECT? COPPER 600/250 mix			
DEPTH	DIAM	VOLx10^{-4}	DETECT? NO COPPER	SHIM 4 mil	PLATE 4 mil	12 mil	TUBE
TYPE							
" 54	.040	.3	Y	Y	-	-	3/4"
" 46	.050	.4	Y	Y	-	-	3/4"
" 46	.040	.28	Y	N	-	-	3/4"

MILLSTONE POINT 2-1985

PIT DETECTABILITY A600 HF PROBE
(CONSTANT DEPTH)

TYPE	DIMENSIONS DEPTH	DIAM	VOLx10^{-4}	400 KHZ DETECT? NO COPPER	DETECT? COPPER 600/250 mix SHIM 4 mil	PLATE 4 mil	12 mil	TUBE
ASME	40%	.188	5.3	Y	Y	-	-	3/4"
CORR.	40	.059	.54	Y	N	-	-	3/4"
"	40	.081	.65	Y	Y	-	-	3/4"
F.B. MACH	40	.075	.8	Y	Y	-	-	3/4"
	42	.100	1.6	Y	Y	-	-	3/4"
	35	.100	1.3	Y	Y	-	-	3/4"
	40	.030	.13	Y	N	-	-	3/4"
	35	.040	.21	Y	N	-	-	3/4"
	35	.050	.32	Y	Y	-	-	3/4"
	35	.13	2.2	Y	-	Y	-	3/4"
F.B. MACH	31	.075	.6	Y	Y	-	-	3/4"
	29	.100	1.1	Y	N	-	-	3/4"
	27	.030	.09	Y	N	-	-	3/4"
	29	.050	.014	Y	N	-	-	3/4"
CORR.	27	.055	2.9	Y	N	-	-	3/4"
	25	.041	.15	N	N	-	-	3/4"
ASME	20	.188	9.5	Y	Y	-	-	3/4"
F.B. MACH	21	.050	.4	Y	N	-	-	3/4"
	19	.040	.7	Y	N	-	-	3/4"
	19	.030	.06	N	N	-	-	3/4"
	21	.050	.1	Y	N	-	-	3/4"

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ATTACHMENT 2

POWER SYSTEMS

Qualification Report:

Probe Selection and Copper Elimination Tests for the Examination of Pitting at Millstone Point II.

With

C-E Appendix to the Millstone Point II Eddy Current Procedure: Calibration for the Elimination of Effects from Copper on Tube O.D.

Submitted by:

Inspection Applications Development,
Inservice Inspection Department
May 1983

Prepared by: R. D. Stamm

Approved by: L. J. Edwards ASNT Level III E.T.

Approved by: J. P. Lareau Supervisor ISI

Probe Selection and Copper Elimination Tests for the Examination of Pitting at Millstone Point II

ABSTRACT

This report describes the development of new high frequency/narrow focus probes and a procedure which will detect pit type defects in the presence of copper. The development included selection of the probes for the best pit detection, experimentation to find an optimal testing procedure and a determination of the axial resolution of close spaced pits. Other tests determined that the standard 83' probe wand length should be retained. The A600LC/HF/WF bobbin probes with .060" spacing and .030" coil width is the best probe overall in signal strength, resolution, phase spread and signal to noise ratio. Two spring flex probes had similar signal resolution and strength in the presence of copper, however, the phase spread and quality of the high frequency spring flex probe (.030" coil and .060" spacing) make it a better probe than the conventional A560 bobbin probe. The 600/250 KHz copper elimination frequency mix is the best of the tested frequency setups. The use of a 180° copper ring as the copper sample during the copper elimination frequency mixing rather than a 360° ring allows larger amplifier gains to be used without causing signal saturation. Pits separated axially by .060" can be resolved into separate eddy current signals using the high frequency/narrow focus probes and the 600/250 KHz copper elimination frequency mix. This improves resolution by a factor a 2 over conventional probes. The absolute mode was no better than the differential mode of operation. The results and conclusions of this report should be implemented using the procedure that is attached to the end of the report. This procedure was used in examining an electro-chemically induced pit standard with 2-4 mils of copper plating. The accuracy and error band of the high frequency/narrow focus probe is a substantial improvement over the conventional probe.

INTRODUCTION

During the 1981/82 refueling at Millstone Point No. 2, Combustion Engineering performed special eddy current tests (ECT), with a high frequency/narrow focus bobbin probe, on a limited sample of steam generator tubes (SGT). These tests were run to confirm the existence of small OD pit type defects and to eliminate copper signal interference. Subsequent to those examinations, CE developed ECT probes and procedures which were used in 7/8" steam generator tubes in the field to detect OD pits in the presence of copper. The success and accuracy of those tests led to the current development effort for a high frequency/narrow focus ECT probe and procedures for 3/4" SGT of the type found at Millstone Point No. 2. In addition, tests were also run to determine the ability of the probe to detect axially close spaced pits and electrochemically induced pits in the presence of plated copper.

METHODS

Mechanical pit samples were prepared with pit dimensions approximating those found in tubes pulled from operating steam generators (Figure 1 and Figure 2). Comparison tests were run on the pit samples with standard and high frequency probes, using a copper signal elimination frequency mix to determine the probes with the best pit detection characteristics. Next, these probes were used to develop an optimal calibration procedure. This involved experimenting with the test frequencies used, the copper sample used to mix out the copper signal and the phase discrimination of the test frequencies. Finally, the best calibration procedure and probes were used to evaluate and develop the ability to resolve closely spaced pits. Both the absolute and differential modes of ECT were investigated during the close proximity pit tests. The effect of probe wand length on probe performance was investigated.

The criteria for comparing the probes pit detection characteristics is based upon signal amplitude, S/N ratio, ASME standard phase spread, and signal quality (See Table 3 for definition of terms). The effect of frequency on pit detection was judged on ASME standard phase spread, the postion of 40% through wall pit signal, signal amplitude and signal quality.

The test described above were run using Zetec MIZ-12 multifrequency ECT equipment. The equipment included (See Figure 3) a MIZ-12 tester module, and MIZ-12 display module, an 8 channel FM tape recorder, a 2 channel strip chart recorder, a remote amplifier power supply, a 100 ft. length of power supply to remote amplifier cable, a remote amplifier, a 10 ft. remote amp to probe wand cable and the probes listed in Table 1.

The effects of changing the set up of the equipment or the cable lengths described above can be significant. Individuals responsible for the field examination were consulted to determine that the set up specifications were suitable for use in the field.

The set of test probes (Table 1) included the conventional A560 spring flex probe which has .060" coil width and .060" spacing between the coils. This probe is compared with both A600 and A560 probes with .030" coil width and .060" spacing and an A600 probe with .030" coil width and .030" spacing. In addition to the dimensional changes in the coils, the number of coil windings are reduced to retain a suitable impedance matching with the eddy current tester at high frequencies.

Changing the coil width and spacing of a fixed diameter probe affects its frequency range, field extent, and signal shape. Two of the five probes have wand lengths of 40' while the other three have wand lengths of 83'. Wand length can have a significant effect on the impedance matching characteristics and performance of the probe as is shown in the results section. The reduced wand lengths were tested in an attempt to reduce the material cost, the waste volume and the time required to change probes in the probe pusher. Throughout the rest of the report, the probes are referred to by the names given in Table 1, where their coil width and spacing along with wand length can be found. If an A600 LC/HF/WF probe is named the spacing of the probe is .060" unless specifically stated otherwise.

Throughout the tests, the effect of copper on the OD of the SGT is modeled by a 1" X 1-¼" X.004" copper sheet while 360° copper ring and 180° ring samples (described in Table 5) are used to mix out copper signals.

After the final probe selections and procedures were determined chemically induced pit standards (Figures 30 & 31), prepared by the Corrosion Group at Windsor, were tested. These qualification standards more closely model the pit like flaws at Millstone than the drilled pit standards.

RESULTS

Pit Standards

The mechanical pit standard dimensions, as fabricated, are included in Figure 1 and 2. When dimensions of the mechanical pit standards are referred to in this report, they come from Figure 1 and Figure 2.

Probe Comparison

The first four of the five probes listed in Table 1 were compared for their ability to detect pits in the presence of copper. The fifth probe, A560LC/HF/WF, was tested in determining wand length effects and found to perform as well as the A560HF/SF probe (having the same coil width, diameter, and spacing) when both probes had 83' wand lengths. The A560 probes' pit detection abilities are lower than those of the A600LC/HF/WF probe; signal strength is approximately 50% and signal resolution 70% of the A600 probe. The probe comparison tests also include a comparison to the standard test set up which is an A560SF probe with a 400/200 support plate mix.

In Figures 4 through 8, a photograph of the ASME standard phase spread is presented along with strip charts for the 100 mil diameter pits with and without copper being present for the five test setups. These five tests are outlined in Table 2. A numerical evaluation of the data from these tests is presented in Table 3. This data indicated that the A600 LC/HF/WF probe with .060" spacing and .030" coil width to be the best probe overall in signal amplitude, S/N ratio, phase spread and quality of signal. The conventional and high frequency A560SF probes compared closely in S/N ratio and signal strength in the presence of copper, however, the phase spread and signal quality of the high frequency spring flex probe (.030 coil and .060 spacing) were rated better than the conventional probe.

Wand Length Effects

Probes with the same coil width, diameter and spacing, but different wand lengths were compared to determine the effect of wand length on probe performance. The tests included an A560HF/SF probe with an 83' wand, an A560LC/HF/WF probe with 40' and 83' lengths and an A600LC/HF/WF probe with a 40' and 83' wand lengths.

Figures 9-13 present the ASME Standard phase spread and a strip chart for the 100 mil diameter pits, with copper centered over the pits for the five tests. Table 4 contains a numerical evaluation of the signal amplitures and ASME standard phase spreads. This table shows that the A560 probes' signal amplitude with a 83' wand is 70% greater than the signal amplitude with a 40' wand. The A600 probes' signal amplitude is shown to be unaffected by the wand length at the specified gains. Both the A560 and A600 probes demonstrate a nominal 10° reduction in phase spread with the 43' wand extension.

Development of Optimal Testing Procedure

Based on this selection process, further experimentation was done on the A600LC/HF/WF and the A560HF/SF (pictured in Figure 14) probe to optimize the results obtainable with each probe.

Two copper rings were used to mix out the copper signal; one 360° copper ring and one 180° copper ring (dimensions given in Table 5). A brief numerical comparison of the effects of these two mixes is presented in Table 6. In general, the advantage of the 180° over the 360° copper sample is to allow higher gains to be used without causing signal saturation. In practice, the simulation must be representative of the actual tubing.

Using the 180° copper ring sample, various frequency mixes were investigated with both the A600LC/HF/WF and the A560HF/SF probe. This investigation involved changing the lower frequency used in the mix and examining the effects. Figures 15-18 show the ASME standard phase spread and .100" dia. X 42% pit signals for the A600 probe with the different frequency mixes. Figures 19 through 21 show the ASME standard phase spread and .100" X 42% pit signals for the A560 probes with the different frequency mixes. For both the A560 and A600 probes, the pit signal from the 600 KHz test frequency above is masked totally by the presence of copper while the pit signal from the multi-frequency mix to eliminate copper is suitable for a phase determination. The frequency tests are compared numerically in Tables 7 and 8 for the A600 and A560 probes, respectively. The overall phase spread generated with the ASME standard did not change significantly for all of the frequency mixes used for both probes. Signal quality was also independent of frequency mix. Based on the remaining characteristics, signal amplitude and position of the 42% through wall pit signal with and without copper present, the 600/250 KHz mix is the best of the four tested. With this mix, the 42% signal is brought approximately vertical and signal strength approaches its maximum.

Both the effects of changing the upper frequency and rotating the phase of the lower frequency were explored briefly. These changes made it extremely difficult to mix out the copper signal.

Close Pit Descrimination

The ability of theA600LC/HF/WF, the A560HF/SF, the A560 LC/HF/WF and the A560SF probes to resolve closely spaced pits was investigated. In these examinations, the paired pit standard (Figure 2) was run with and without copper centered over the pit pairs. Data analysis was then performed on the ET signals on the strip chart and magnetic tape recordings (Figures 22-26). The results of the analysis are tabulated in Tables 9 and 10. All three HF probes resolved pits separated by .060" or more in the presence of copper. The A560SF probe could separate pits in the presence of copper spaced at .126" apart.

Attempts to improve resolution of paired pits by use of the HF probes in absolute mode were alos made. These attempts were unseccessful; the signal amplitude in the absolute mode was small and pit resolution was poor.

Phase Analysis Diagrams

Phase analysis diagrams are presented as Figures 27-29 for the selected probes and frequency mix, comparing the phase spread with and without copper strips present over the flaws. The shift of the curve to the left in the presence of copper strips has been noted in other laboratory tests. While these tests show the detectability of the flaws in the presence of copper, the phase angles should not be considered for predictive purposes.

Electro-Chemically Induced Pit Samples

The A600LC/HF/WF, A560 HF/SF and A560LC/HF/WF and A560SF probes were tested for their ability to locate and size electro-chemically induced pits in a copper plated tube (the tube is pictured in Figure 30 and its dimensions are given in Table 11). A 600/250 KHz copper elimination frequency mix (using a 180° copper ring) was used to minimize the effects of copper on the OD of the tube. Figures 32,34 and 38 show photographs of an ASME standard run and a run of the pit standard for each of the four probes. Figures 35,37 and 39 are phase analysis diagrams for all four probes that include the eddy current readings for the chemically induced pits. The results are tabulated below:

E.T. OF COPPER PLATED SGT

	MEASURED PIT DEPTH (% THROUGHWALL)	E.T. MEASURED DEPTH A600 HF/LC	A560 HF/LC	A560 HF/SF	A560 SF
	79%	81%	81%	82%	63%
	63%	55	61	58	53
	54%	54	55	55	63
	35%	33	30	37	N.D. 1/
AVE	57.8	55.8	56.8	58.0	59.7
RANGE	--	+2 -8	+2 -5	+3 -5	+9 -16

1/ N.D. , NOT DETECTED

Finally, two additional electrochemically pitted tubes (tubes 2&3) were tested with the A600LC/HF/WF probe (tubes pictured in Figure 31 and dimensions given in Tables 12&13). The two tubes were examined with a 600/250 KHz copper elimination mix with and without copper sheets centered over the flaws. Figure 40 presents the ASME standard run for these tests while Figures 41&42 present runs of the tubes (with and without copper) for tubes 2 and 3 respectively. Figure 43 is a phase analysis diagram for the above tests that include the eddy current readings for the chemically induced pits, in tubes 2 and 3, with and without copper over the pits.

DISCUSSION

The selection of the A600 and A560 probes for these tests was done to bracket the extremes in probe diameters which would be used in actual field tests. As the data has shown, probes which are smaller than A560 should not be expected to give reliable results since the A560 probe responds with decreased sensitivity. With the A560 probe having slightly higher gain settings than the A600 probe (A560 - G:51/42,A600-G:50/37) the signal generated by the A600 and A560 probes in response to the .100" diameter X 42% through wall pit were 2 volts and 1 volt, respectively, in the presence of copper.

A 600/250 KHz copper signal elimination mix was selected as the best of the four mixes tested. The 600/200 KHz copper mix compares closely to the 600/250 mix but the selected mix eliminates copper signals more completely and has optimal phase positioning of the 40% through wall pits. With this phase positioning the 40% signal is brought as close to vertical as possible.

While experimenting with wand lengths it was found that changing the wand length from 40' to 83' increases signal amplitude of the A560 probes by 70% but decreases the overall phase spread by approximately 10°. This loss of phase spread is not considered significant in contrast with the large signal amplitude gain that is achieved so the 83' wand length is preferred.

The phase analysis diagrams in Figures 27-29 compare the phase spread of the ASME standard with and without copper present over the flaws. At present, it is not expected that the shift in the phase diagram in the presence of copper will cause a significant bias in the data in the field.

The phase analysis diagrams in Figures 35-37 and Figure 39 compare the ASME standard phase spread to the eddy current readings of electro-chemically induced pits of known depths for various probes. By taking the greatest deviation from the ASME standard as a gage of probe accuracy, it is seen that the HF/Narrow Focus probes are more accurate than the standard probe (± 8% thru wall vs. ± 16% thru wall accuracy). The HF/Narrow Focus coils are also shown to have less average error than the standard A560SF probe (1 ± 3.4% overall error vs. 6 ± 12.9% overall error).

CONCLUSIONS

1. Probe/Wand Selection:

   Based upon the tests conducted, E.T. probes can be ranked on declining performance as follows: A600HF - A560HF - A560. The A560HF (spring flex or long cone) represents a considerable improvement over the conventional A560 probe. While the A600HF represents the "state-of-the-art", mechanical constraints may limit its usefulness in the field. Detection reliability is presumed to improve with the larger diameter probe. However, if full inspection from one side of the steam generator is desired, the A560HF/SF probe should be used. With all of these probes, the standard 83' wand length should be used.

2. Mix/Copper Sample Selection:

   Experimentation with the mix used to eliminate copper signals has shown that a 600/250 KHz mix, utilizing a .756" ID 180° copper ring (.75" long with a 44 mil wall) will perform optimally. A 600/200 KHz mix is not recommended.

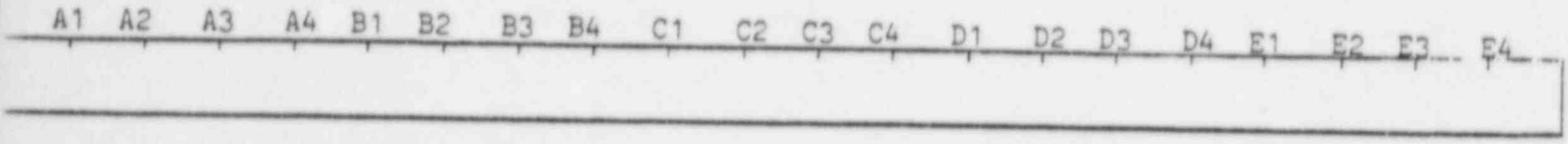
3. Pit Resolution:

The selected probes and mix are all capable of resolving paired pits that are separated axially by as little as .060".

4. Procedure:

The above conclusions were used to develop a procedure to detect pits while eliminating the effects of copper on the tube OD. This procedure is included in the report as Appendix A.

POSITION OF THE PITS



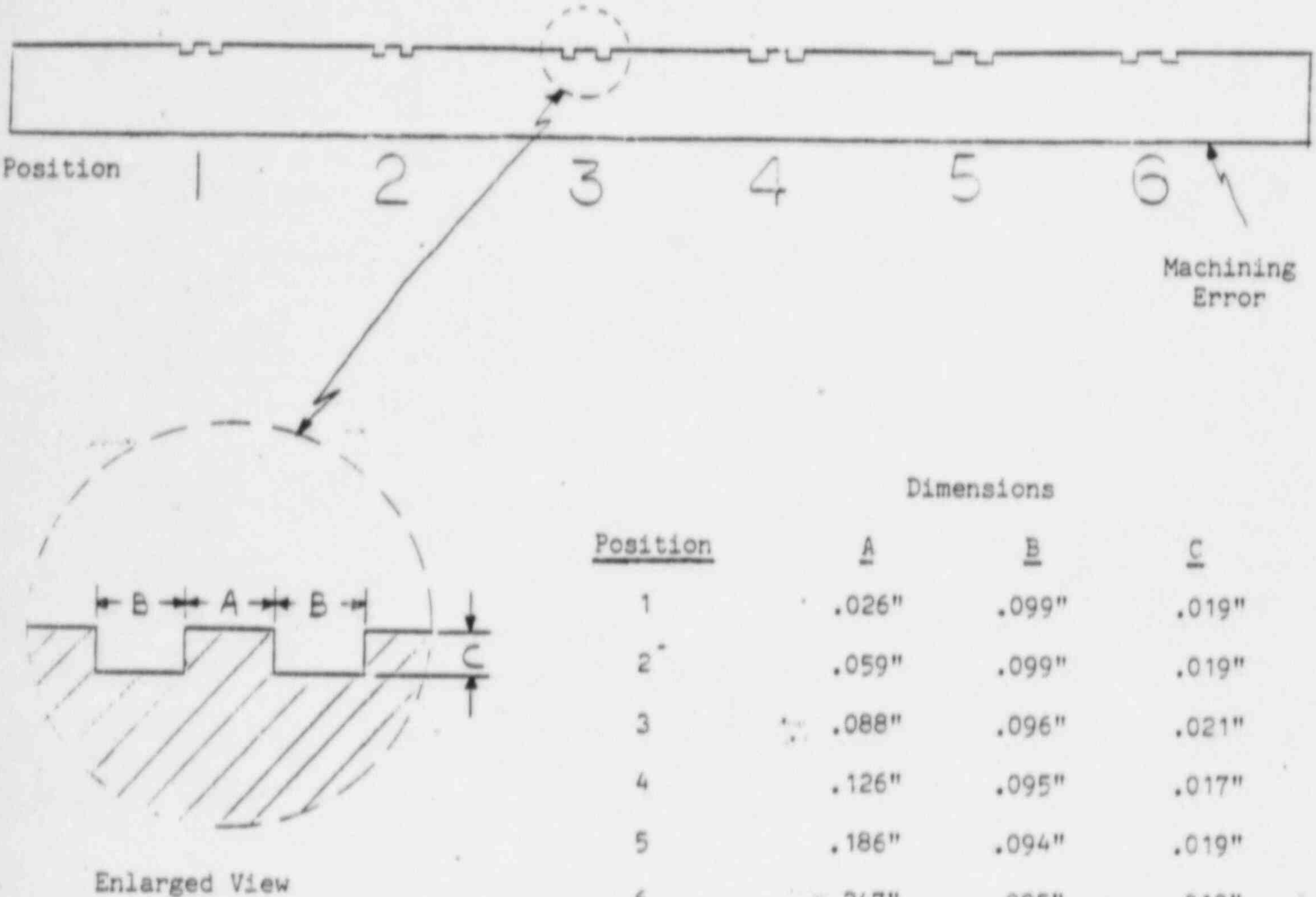
Overall Length: 42"

Material: .750" OD X .048" Wall Inconel 600 Tubing

FABRICATED DIMENSIONS OF PITS IN STANDARD

POSITION	DIAMETER	DEPTH	PERCENT THRU WALL
A1	.050	.022	46
A2	.050	.017	35
A3	.050	.014	29
A4	.050	.010	21
B1	.040	.026	54
B2	.040	.022	46
B3	.040	.017	35
B4	.040	.011	25
C1	.030	.022	46
C2	.030	.019	40
C3	.030	.013	27
C4	.030	.009	19
D1	.100	.020	42
D2	.100	.017	35
D3	.100	.014	29
D4	.100	.009	19
E1	.075	.024	50
E2	.075	.019	40
E3	.075	.015	31
E4	.075	.010	21

Figure 1 Drilled Pit Standard.



Dimensions

Position	A	B	C
1	.026"	.099"	.019"
2	.059"	.099"	.019"
3	.088"	.096"	.021"
4	.126"	.095"	.017"
5	.186"	.094"	.019"
6	.247"	.095"	.019"

Figure 2 Standard for the Eddy Current Resolution of Close Spaced Pits

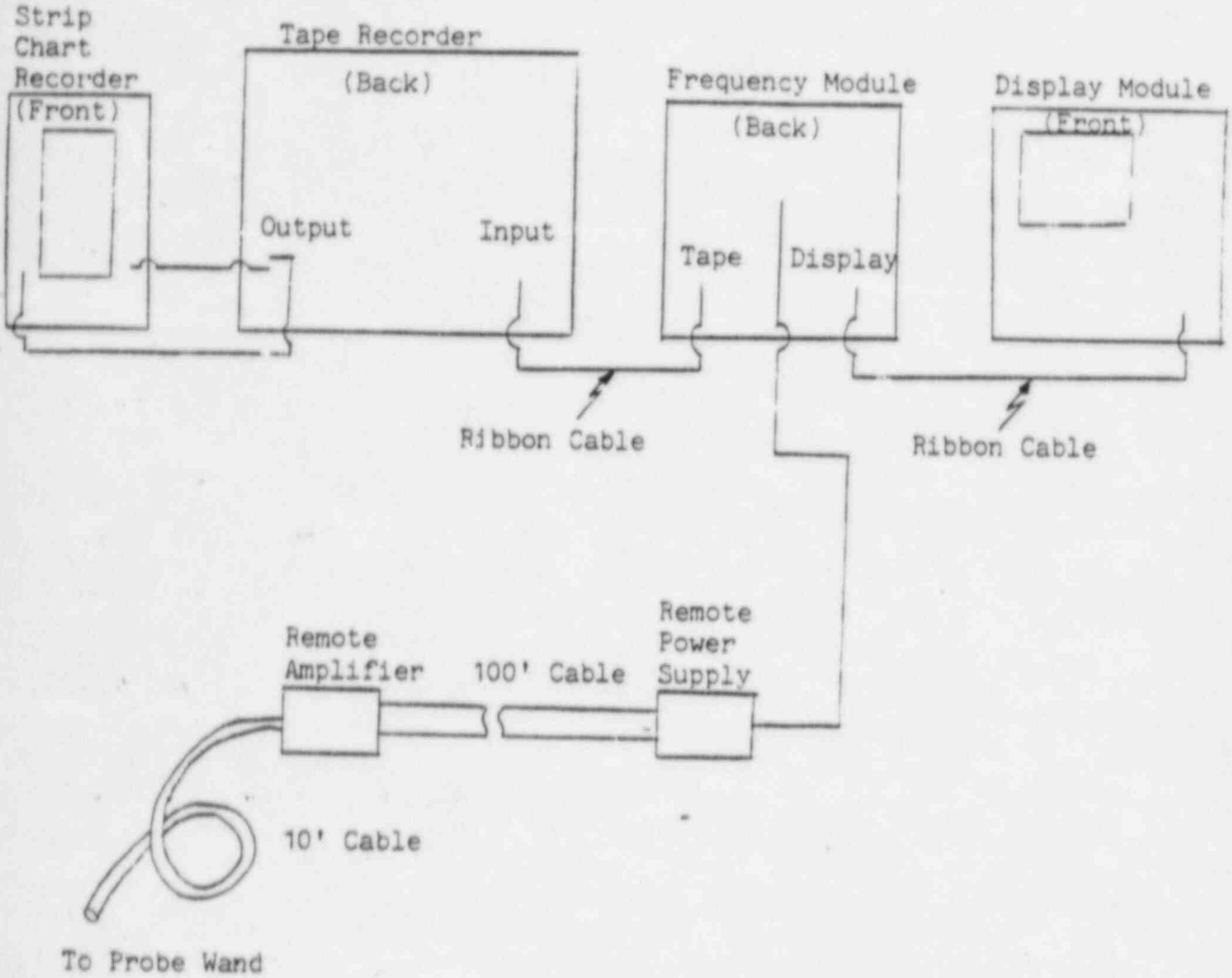


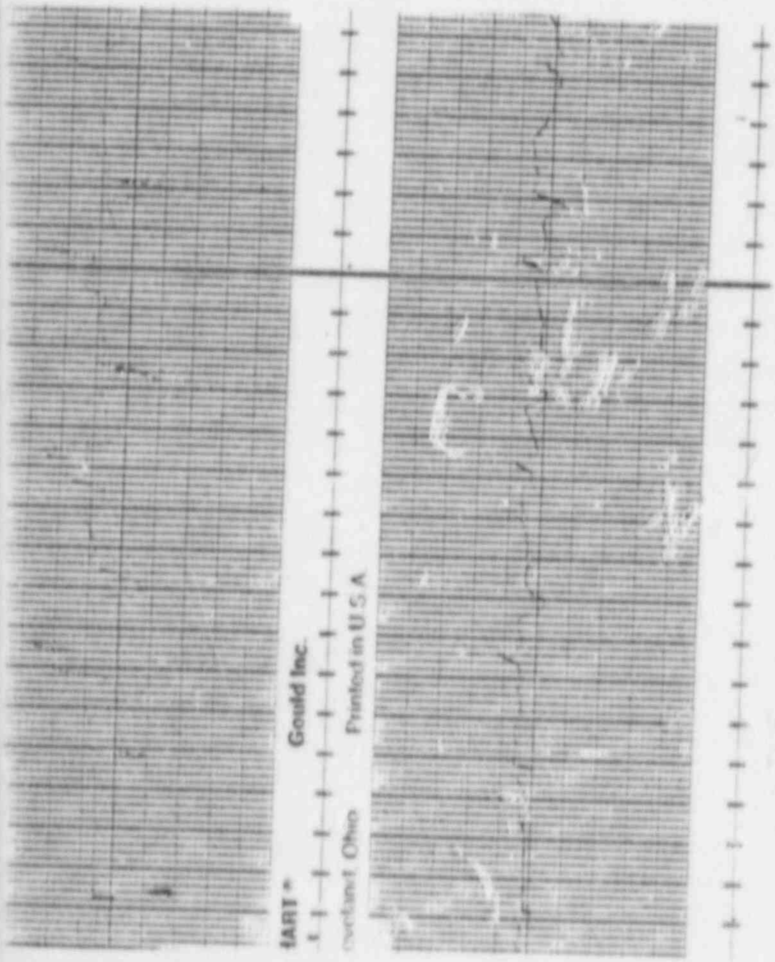
Figure 3 Eddy Current Equipment and Cables Required for Testing for Pits in the Presence of Copper With High Frequency Probes

M.F. Response to
ASME Cal. Standard
Signals

2V/Div

M.F. Response to Pit Standard 2/

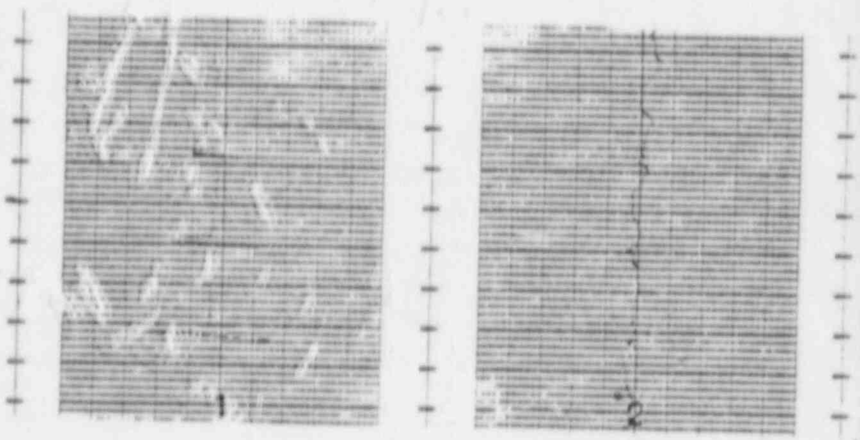
.100" Dia. Pits (Copper) 1/



V.
100mv/Div

H.
200mv/Div

.100" Dia. Pits (No Copper)



V.
100mv/Div

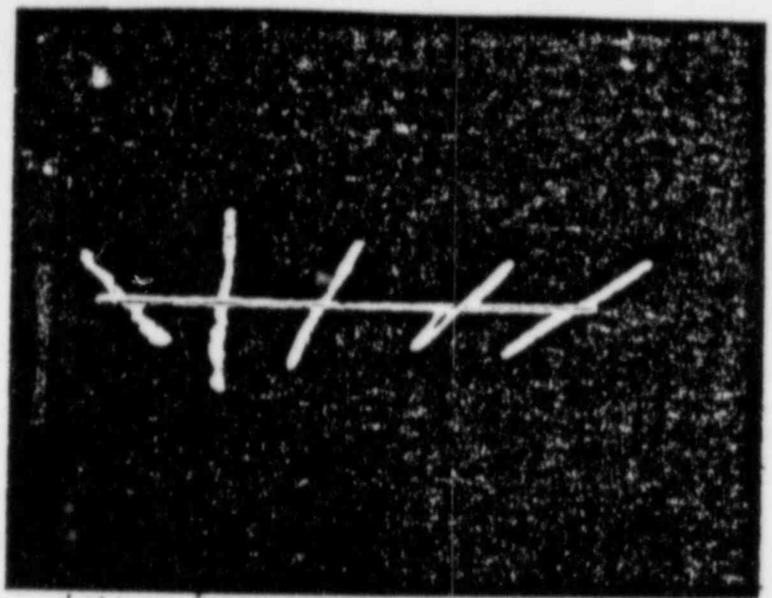
H.
200mv/Div

1/ Copper Foil (1"x1.25"x.004")
centered over the pit

2/ See Figure 1 For Pit Depths.

Figure 4 Multi-Frequency
Probe Comparison Test Probe - A560SF; Mix - 400/200 KHz Support;
Gains - 46/23

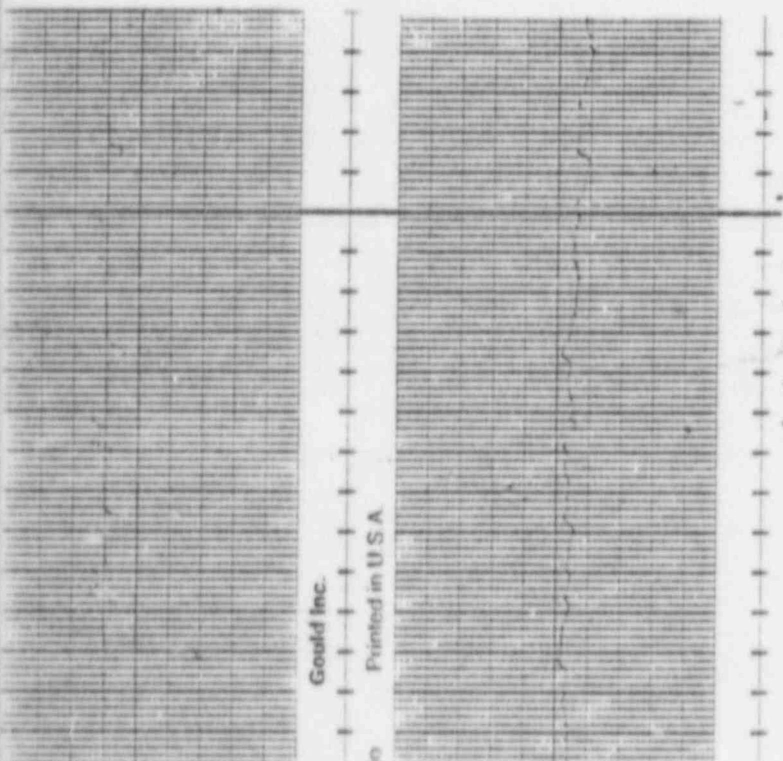
M.F. Response to
ASME Cal. Standard
Signals



1V/Div

M.F. Response to Pit Standard 2/

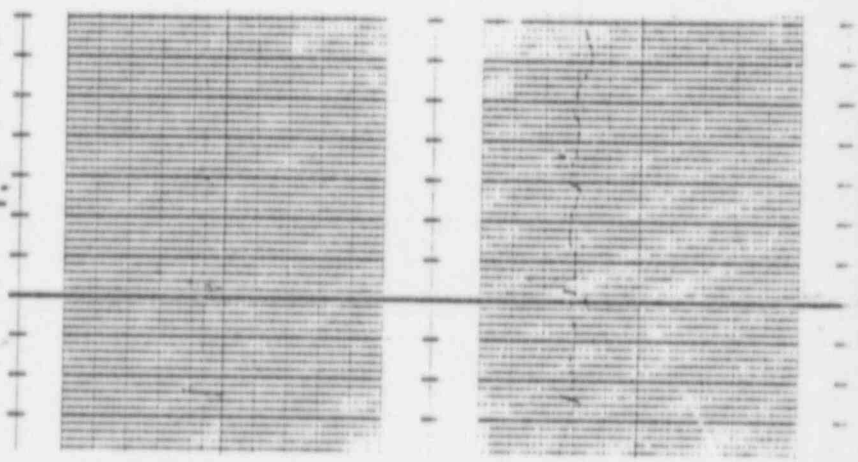
.100" Dia. Pits (Copper) 1/



V.
100mv/Div

H.
200mv/Div

.100" Dia. Pits (No Copper)



V.
100mv/Div

H.
200mv/Div

1/ Copper Foil (1"x1.25"x.004") centered over the pit

2/ See Figure 1 for pit depths

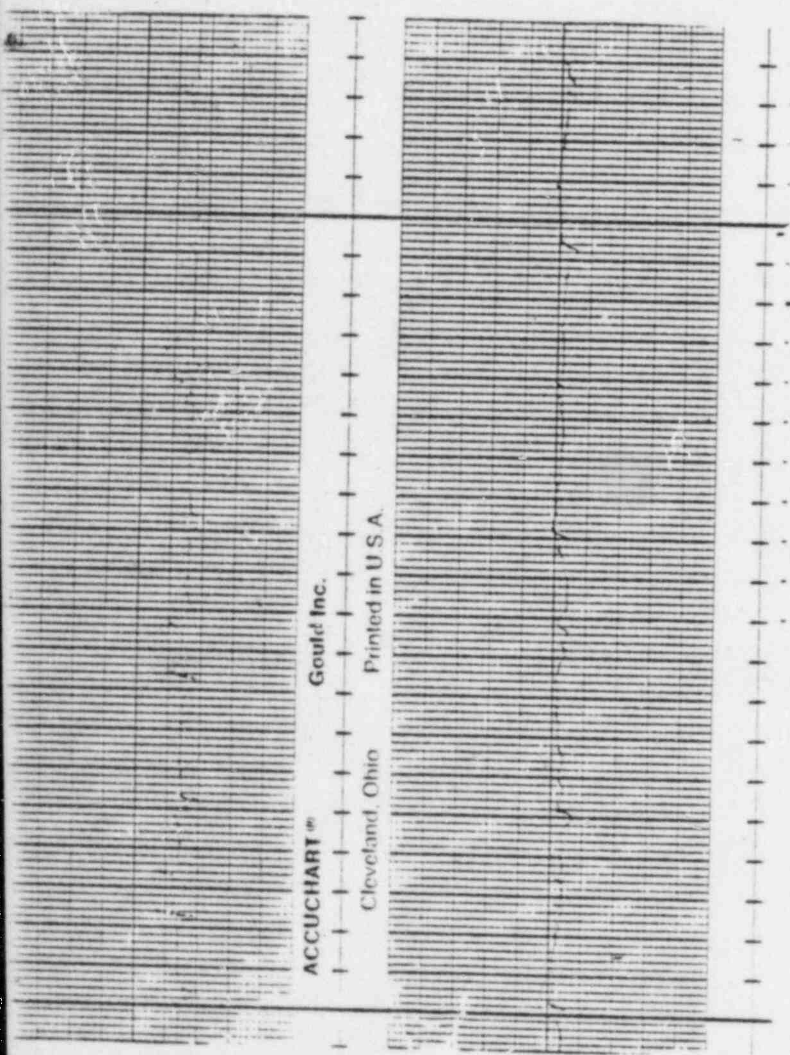
Figure 5 Multi-Frequency
Probe Comparison Test. Probe - A560SF; mix - 600/200 kHz copper; gains - 46/15

M.F. Response to
ASME Cal. Standard
Signals

2v/Div.

M.F. Response to Pit Standard 2/

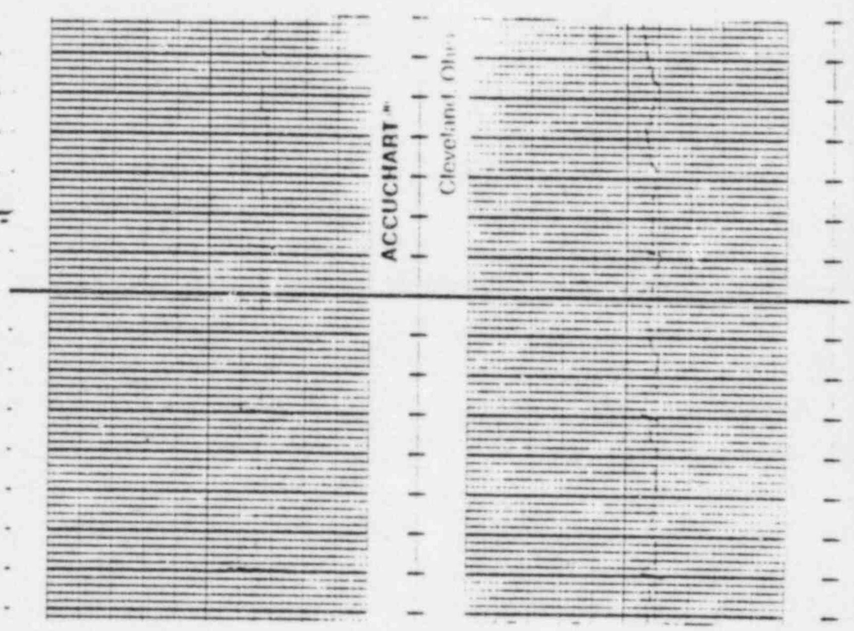
.100" Dia. Pits (Copper) 1/



V.
100mv/Div

H.
100mv/Div

.100" Dia. Pits (No Copper)



V.
100mv/Div

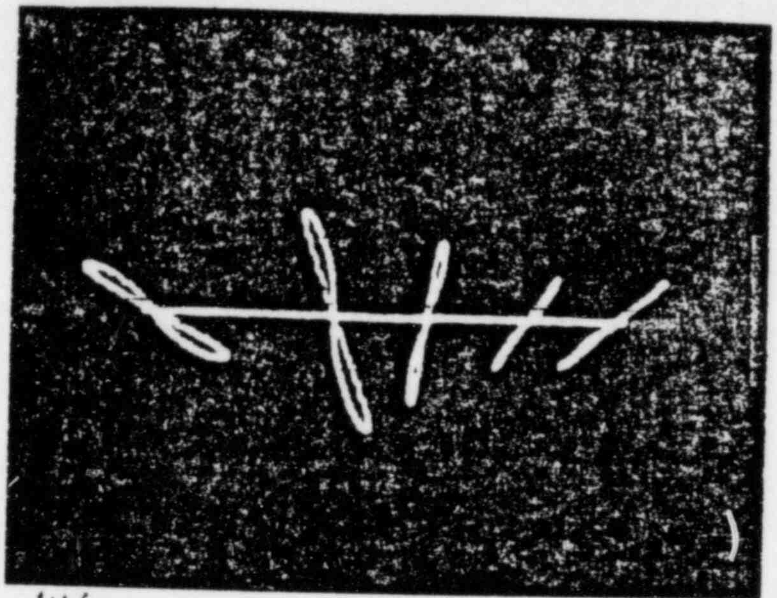
H.
200mv/Div

1/ Copper Foil (1"x1.25"x.004")
centered over the pit

2/ See Figure 1 for Pit Depths.

Figure 6 Multi-Frequency
Probe Comparison Test, Probe - A600LC/HF/WF (.030"s); Mix -600/200 kHz copper; Gains - 46/23

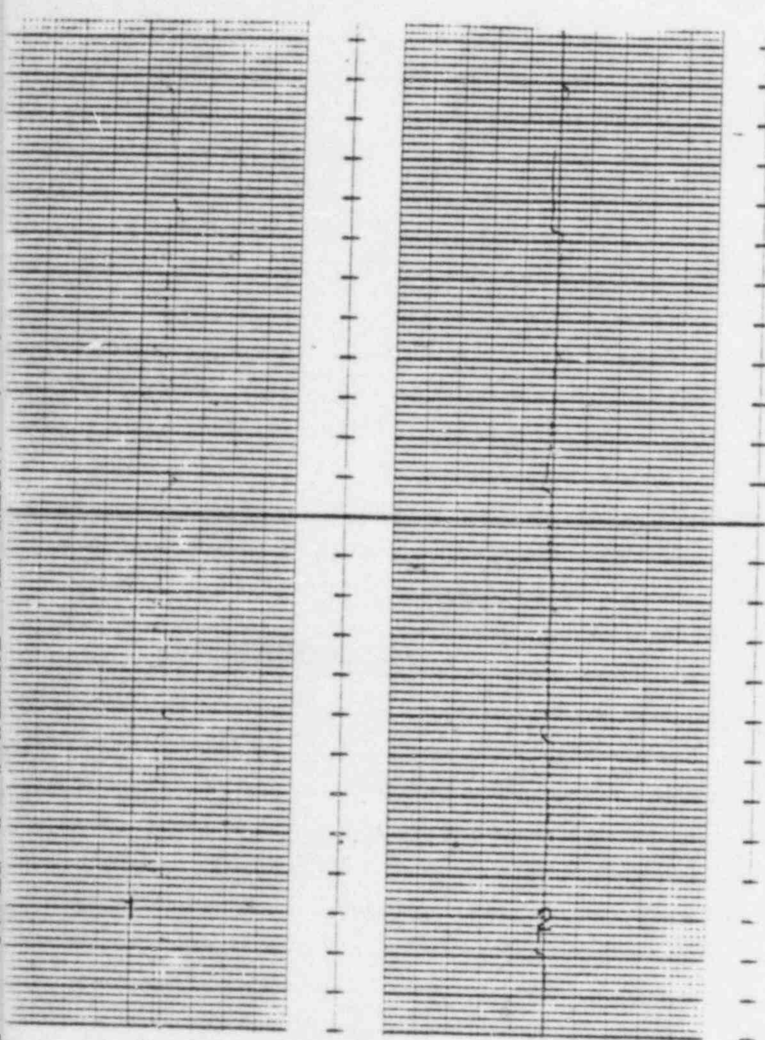
M.F. Response to
ASME Cal. Standard
Signals



1V/Div

M.F. Response to Pit Standard 2/

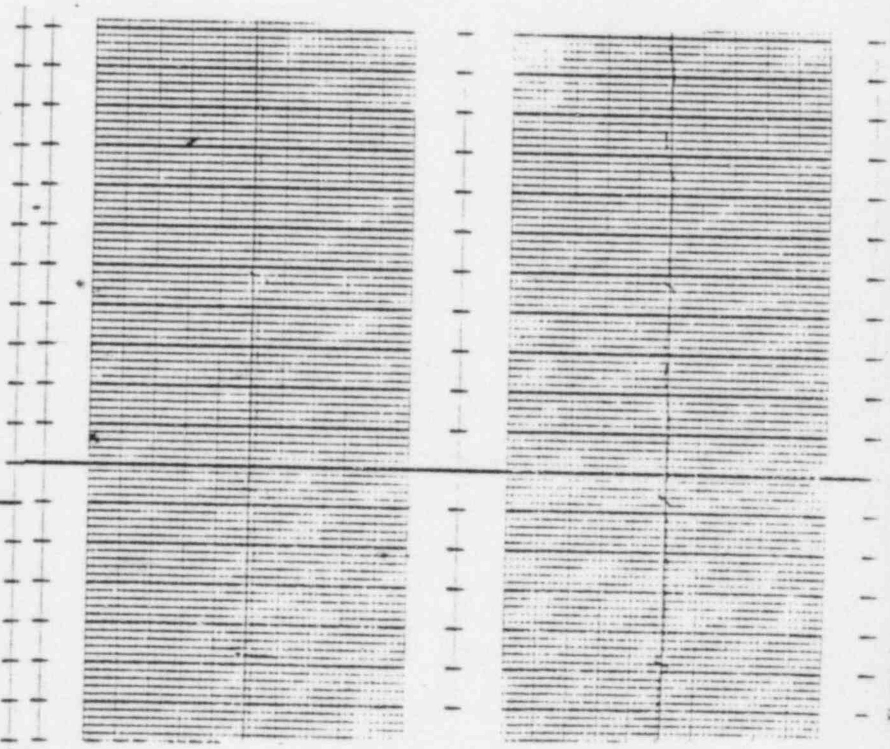
.100" Dia. Pits (Copper) 1/



V
100mv/Div

H
200mv/Div

.100" Dia. Pits (No Copper)



V
100mv/Div

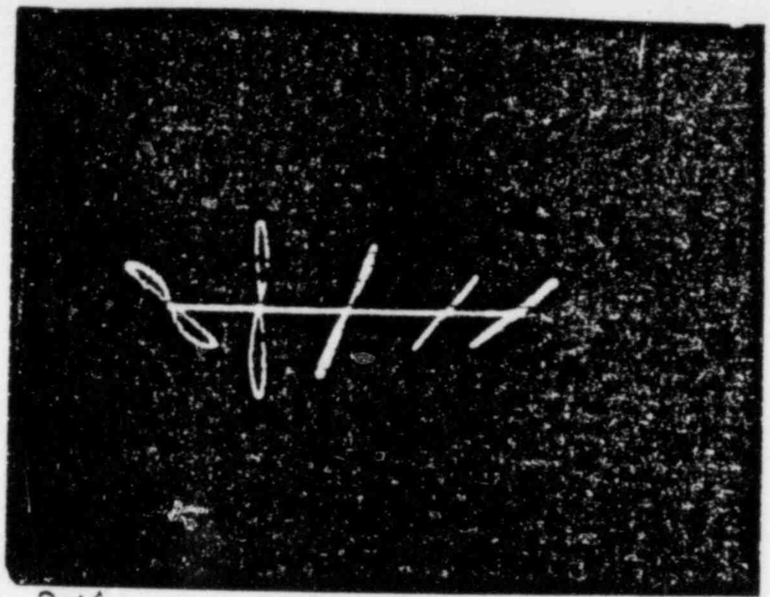
H
200mv/Div

1/ Copper Foil (1"x1.25"x.004")
centered over the pit

2/ See Figure 1 for Pit Depths

Figure 7 Multi-Frequency
Probe Comparison Test, Probe - A560HF/SF; Mix - 600/200 kHz Copper;
Gains - 40/27

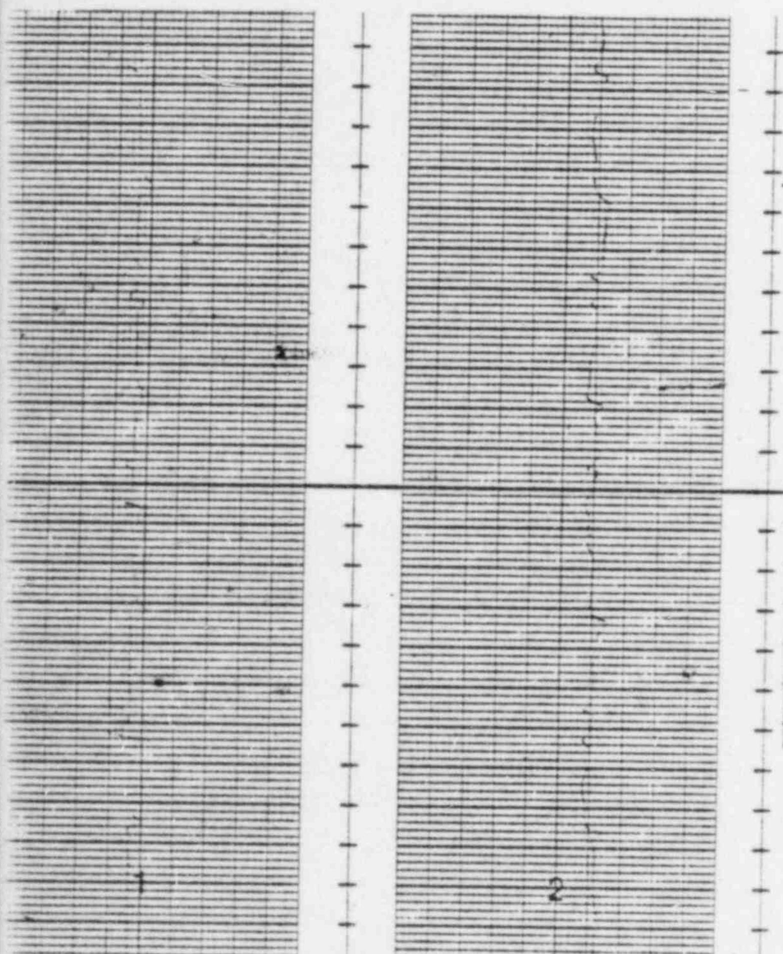
M.F. Response to
ASME Cal. Standard
Signals



2V/Div

M.F. Response to Pit Standard 2/

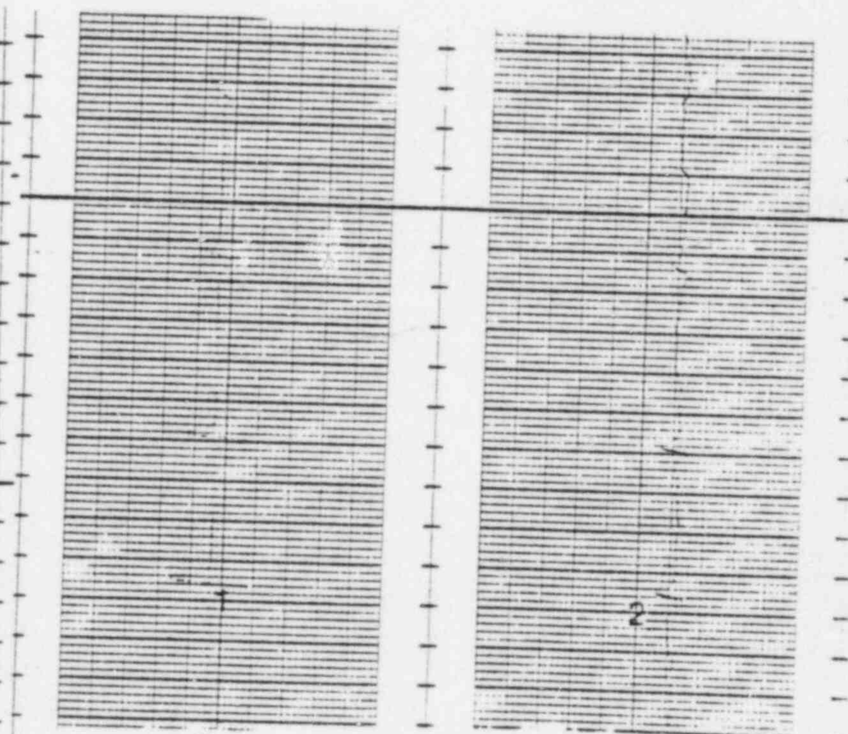
.100" Dia. Pits (Copper) 1/



V.
100mv/Div

H.
200mv/Div

.100" Dia. Pits (No Copper)



V.
100mv/Div

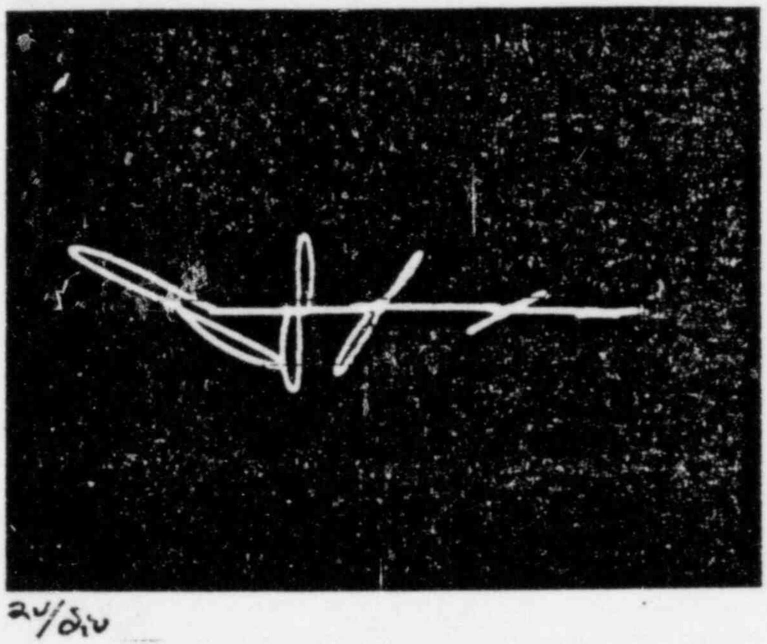
H.
200mv/Div

1/ Copper Foil (1"x1.25"x.004")
centered over the pit

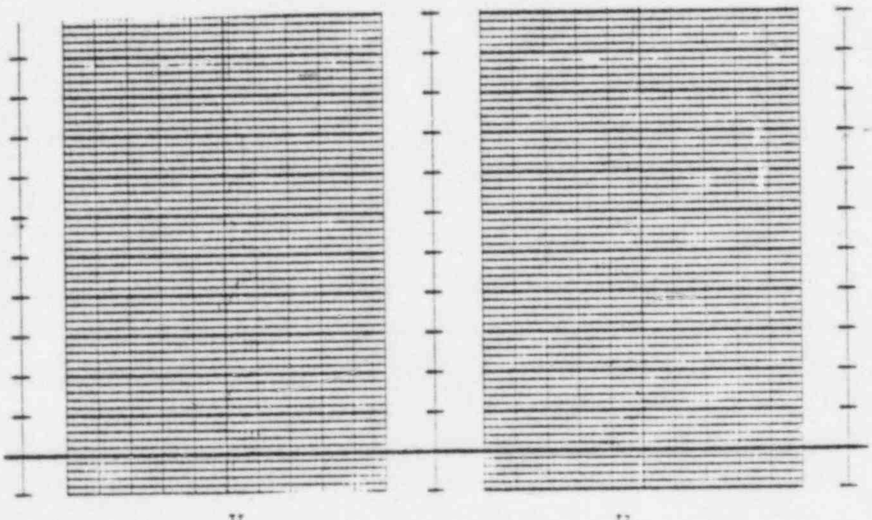
2/ See Figure 1 for Pit Depth

Figure 8 Multi-Frequency
Probe Comparison Test. Probe - A600 LC/HF/WF (.060"); Mix - 600/200 kHz Copper; Gains - 40/25

ASME Standard



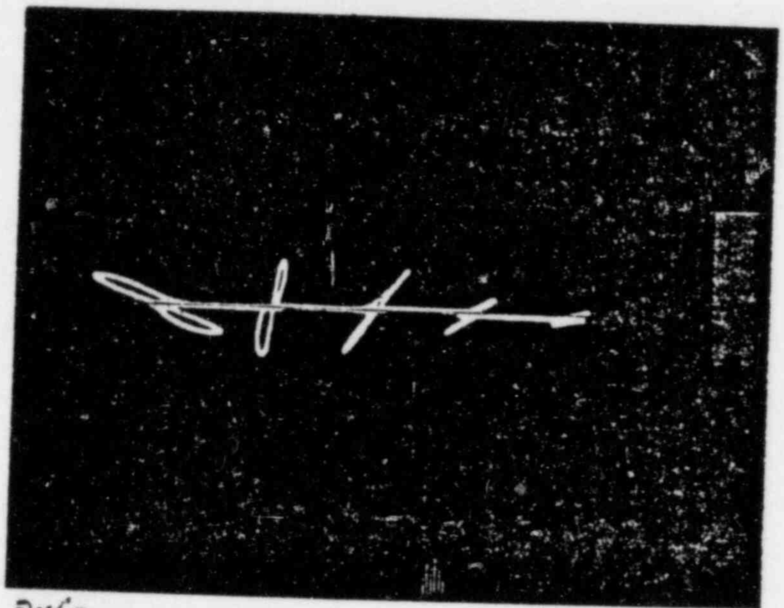
Strip Chart of .100" Dia Pits in the Presence of Copper 1/



1/ Copper Foil (1" X 1.25" X-004") Centered Over the Pit.

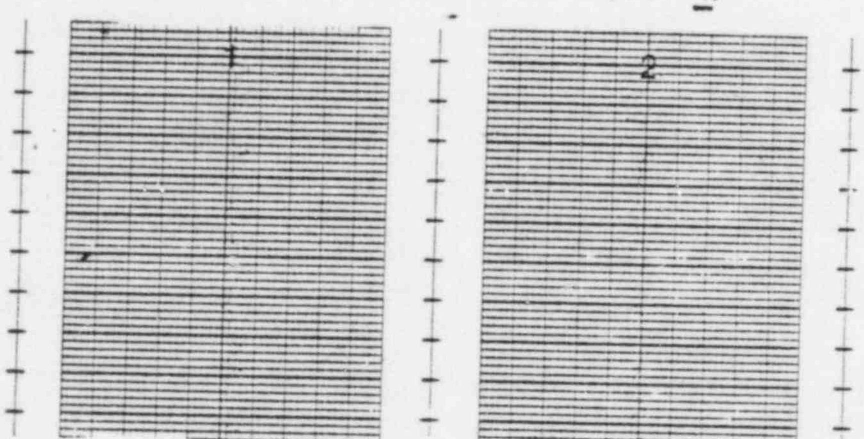
Figure 9 Wand Length Effect Test. Probe - A560HF/SF; Wand Length - 83': Mix - 600/250 KHz Copper Rind (180°); Gains - 51/41

ASME Standard



2v/Div

Strip Chart of .100" DIA
Pits in the Presence of Copper 1/



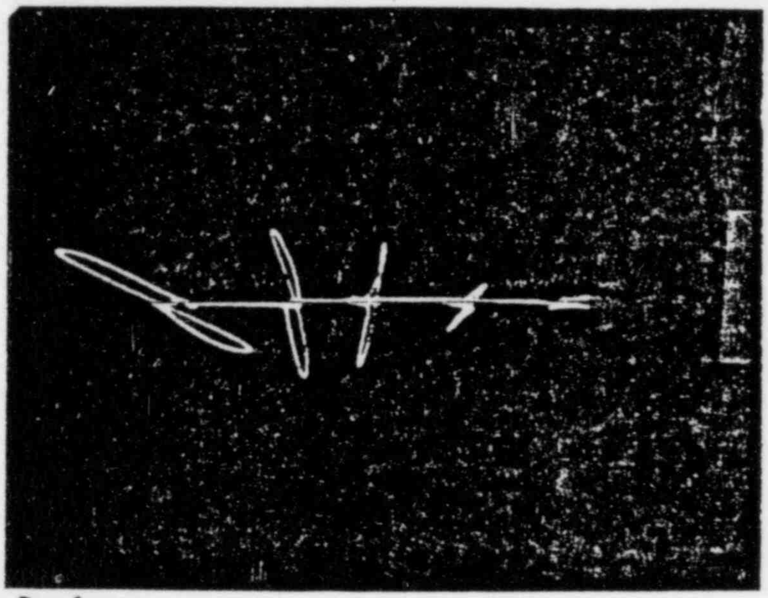
V.
100mv/Div

H.
100 mv/Div

1/ Copper Foil (1"X1.25"X.004") Centered Over the Pit

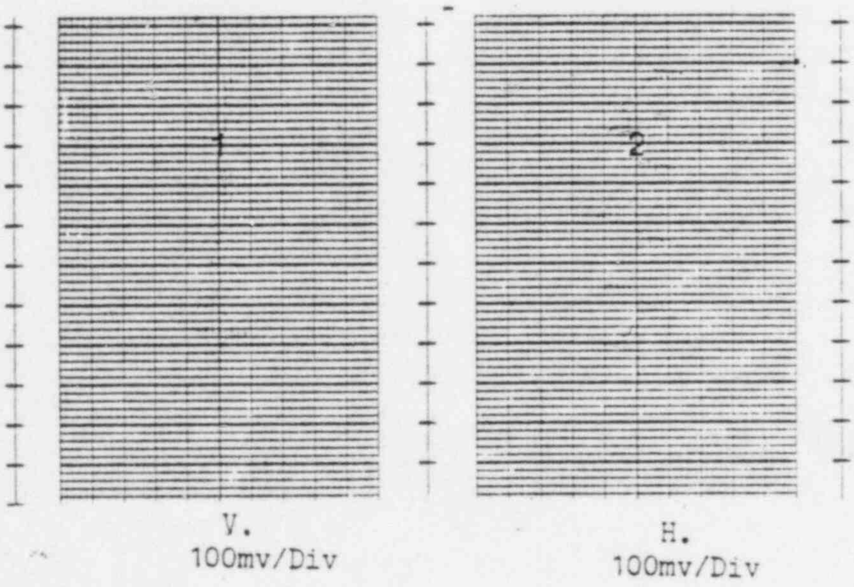
Figure 10 Wand Length Effect Test. Probe - A560LC/HF/WF: Wand Length - 40': Mix - 600/250 KHz Copper Ring (180°): Gains 48/40

ASME Standard



2v/Div

Strip Chart of .100" DIA
Pits in the Presence of Copper 1/



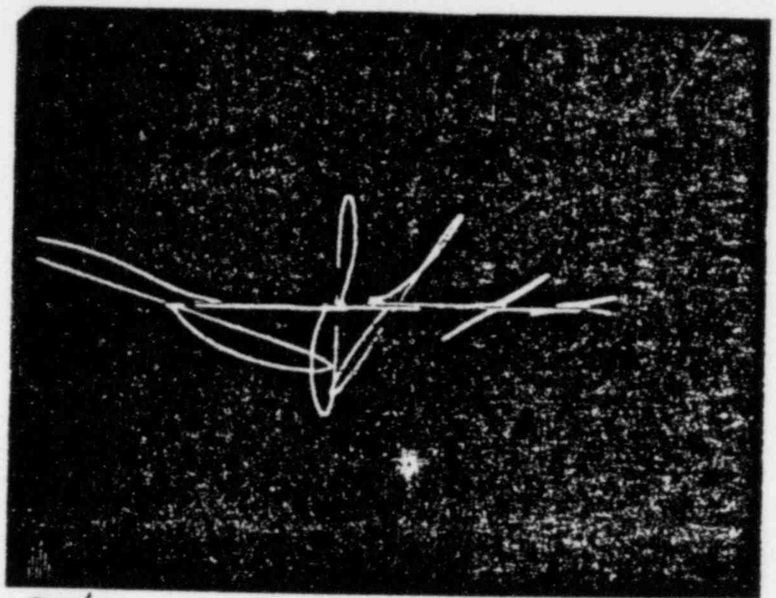
V.
100mv/Div

H.
100mv/Div

1/ Copper Foil (1"X1.25"X.004") Centered Over the Pit.

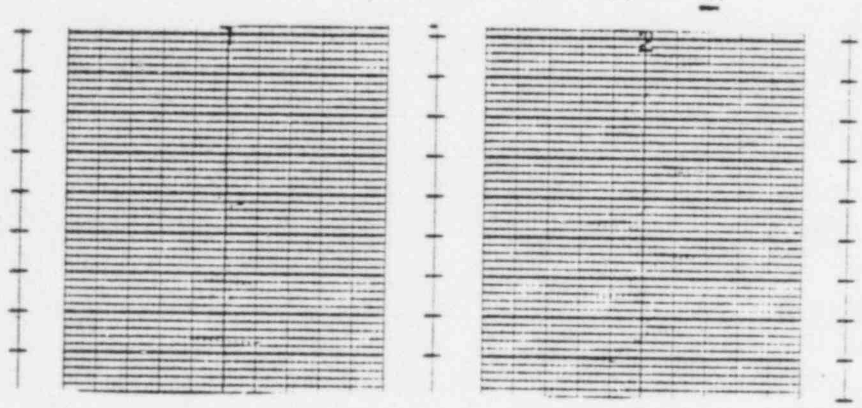
Figure 11 Wand Length Effect Test. Probe - A560LC/HF/WF; Wand Length - 83'; Mix - 600/250 KHz Copper Ring (180°): Gains 48/40

ASME Standard



2v/Div

Strip Chart of .100" DIA
Pits in the Presence of Copper 1/



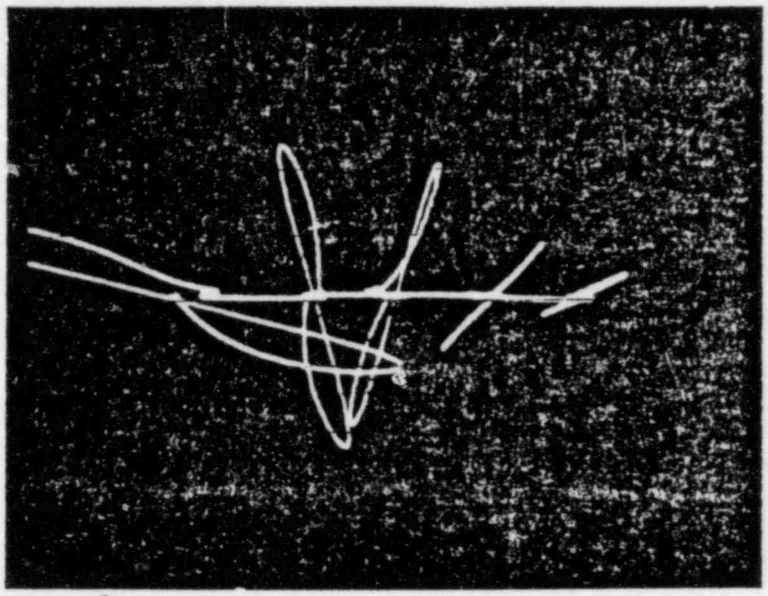
V.
100mv/Div

H.
100mv/Div

1/ Copper Foil (1"X1.25"X.004") Centered Over the Pit

Figure 12 Wand Length Effect Test. Probe - A600LC/HF/WF (.060); Wand Length - 40'; Mix - 600/250 KHz Copper Ring (180°): Gains 49/40

ASME Standard



2v/Div

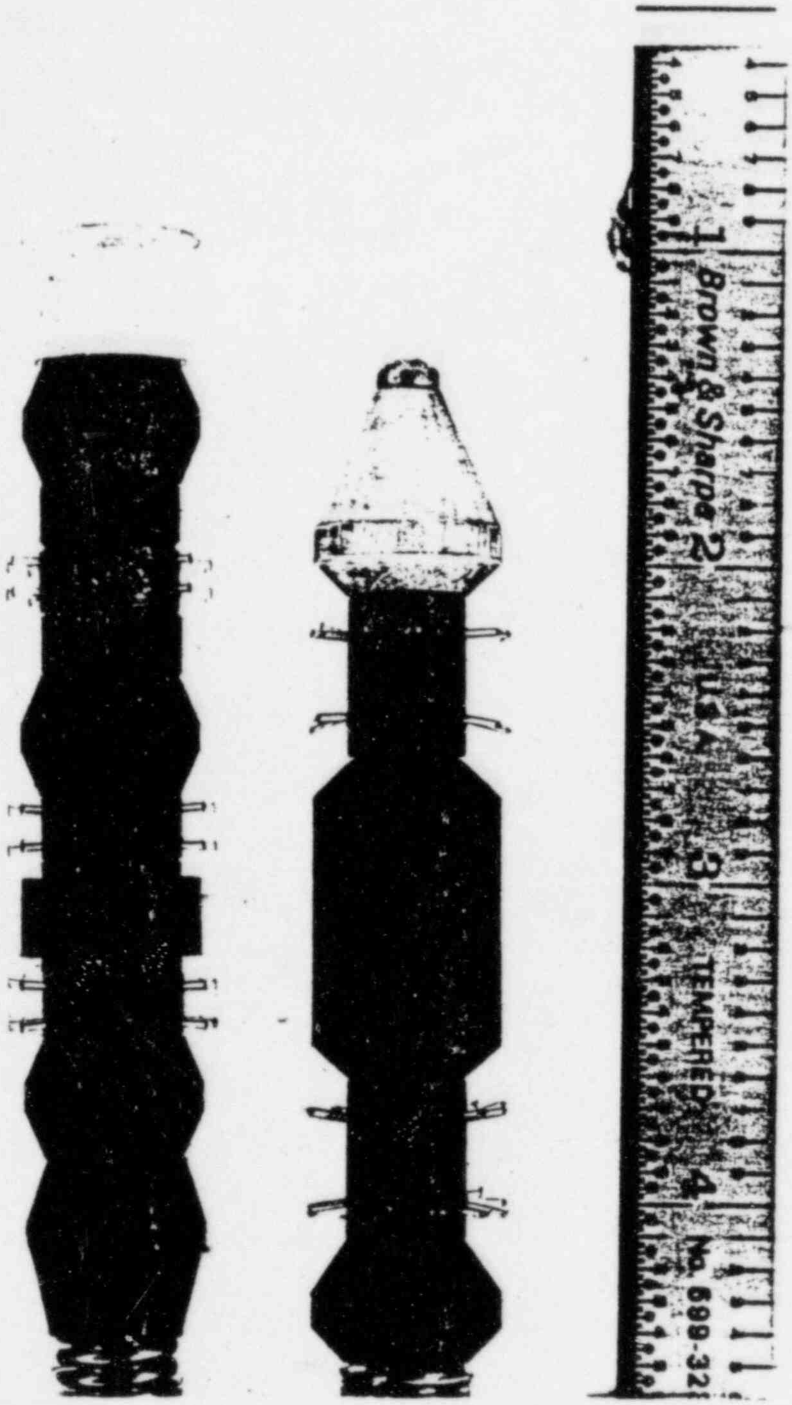
Strip Chart of .100" DIA
Pits in the Presence of Copper 1/

V.
100mv/Div

H.
200mv/Div

1/ Copper Foil (1"X1.25"X.004") Centered Over the Pit

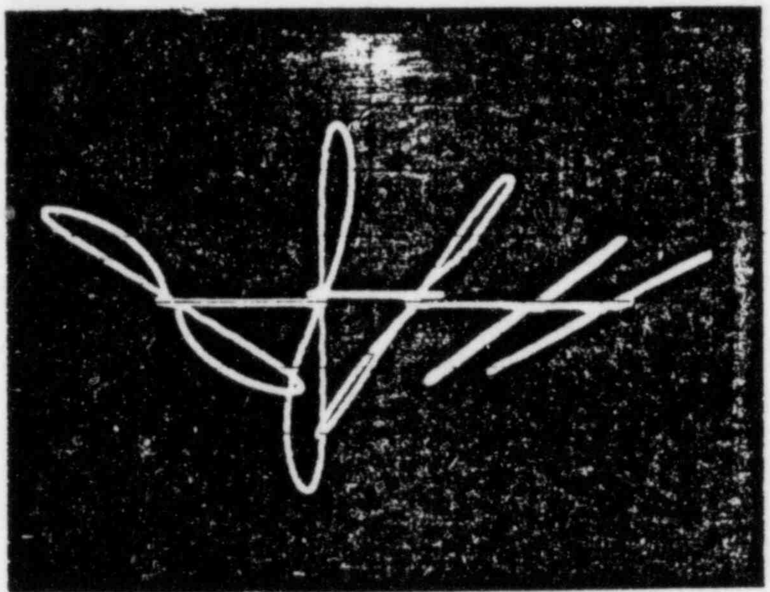
Figure 13 Wand Length Effect Test. Probe - A600LC/HF/WF; Wand Length - 83'; Mix - 600/250 KHz Copper Ring (180°): Gains 49/40



A560   A600

IGURE 14 Side by side photograph of the A600LC/HF/WF (.060) and A560HF/SF Probes.

ASME Standard Signals

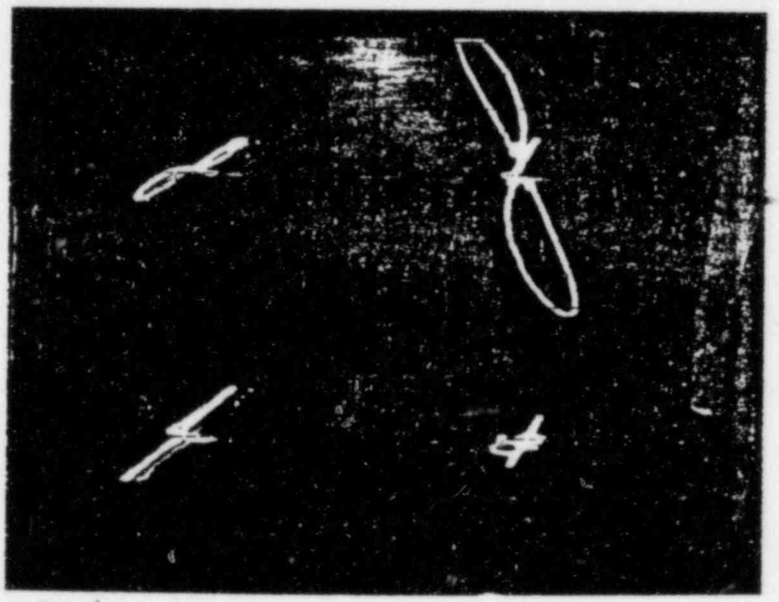


Signals from .100" x 42% pits

No Copper   Copper Over Pit 1/

600 kHz

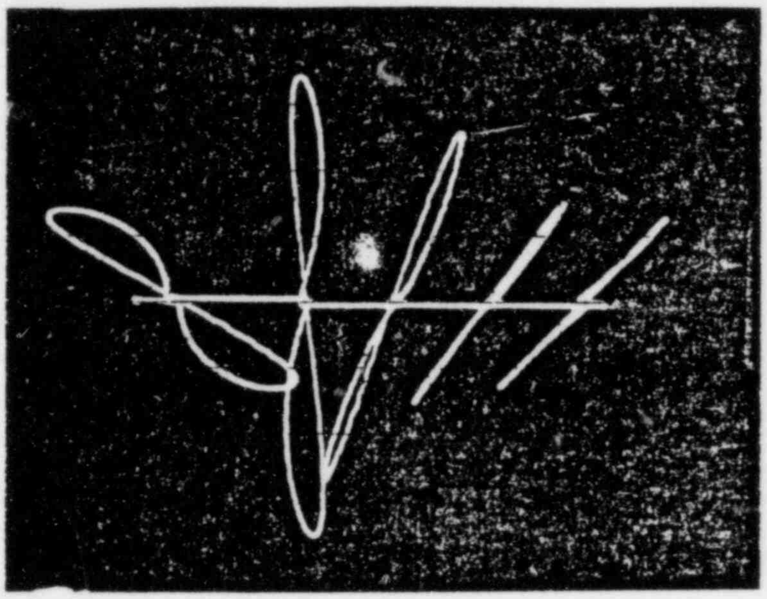
Mix



1/ Copper Foil (1"X1.25"X.004") Centered Over the Pit

Figure 15 Copper Signal Elimination Frequency Mix Comparison Test. Probe - A600 LC/HF/WF (.060"); Mix - 600/150 kHz Copper Ring (180°); Gains - 50/36

ASME Standard Signals



2v/Div

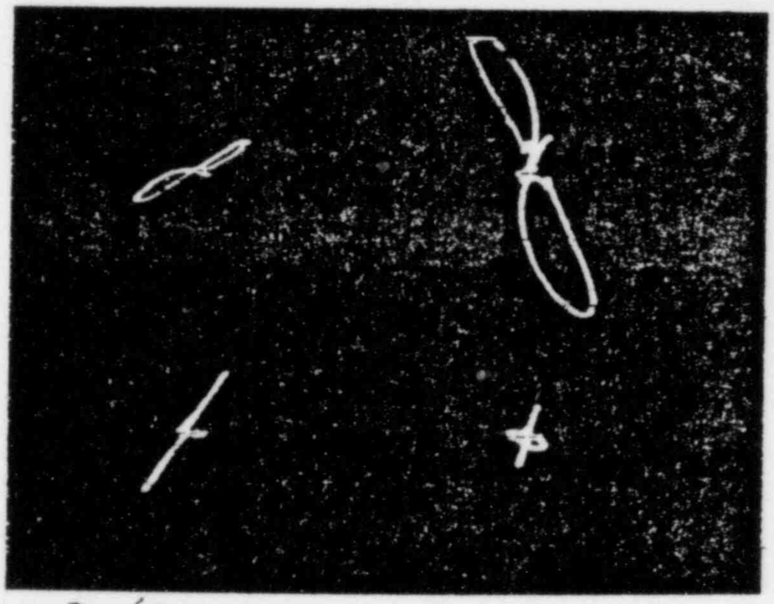
Signals from .100" x 42% Pits

No Copper

Copper Over Pit 1/

600 kHz

Mix

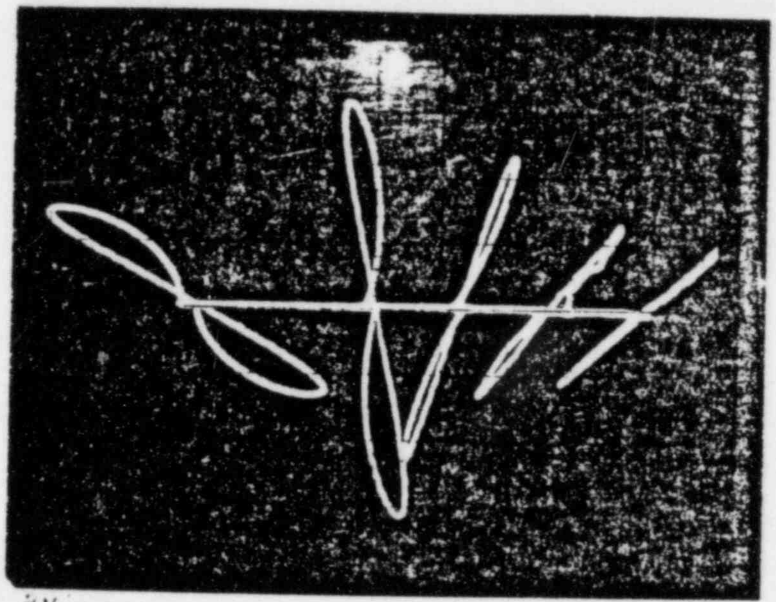


2v/Div

1/ Copper Foil (1"X1.25"X.004") Centered Over the Pit

Figure 16 Copper Signal Elimination Frequency Mix Comparison Test. Probe - A600LC/HF/WF; Mix - 600/200 kHz Copper Ring (180°); Gains - 50/36

ASME Standard Signals

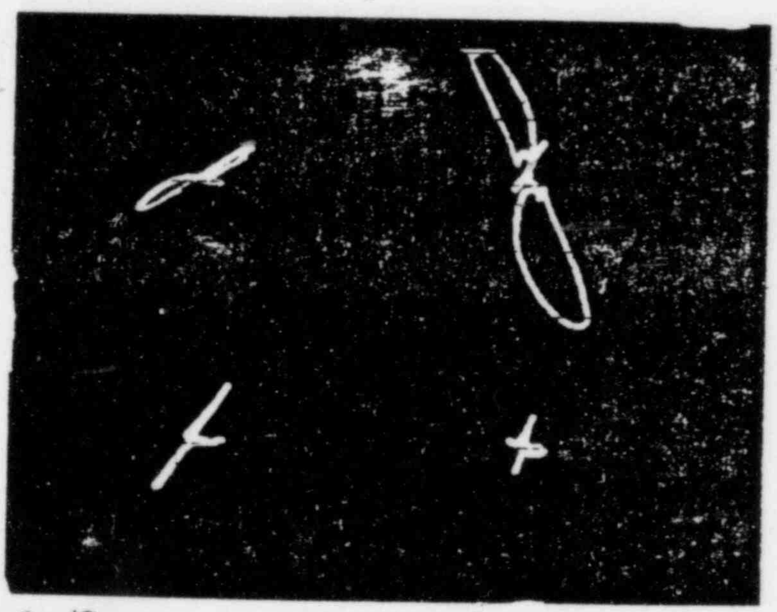


2V/Div

Signals from .100" x 42% Pit

No Copper | Copper Over Pit 1/

600 kHz



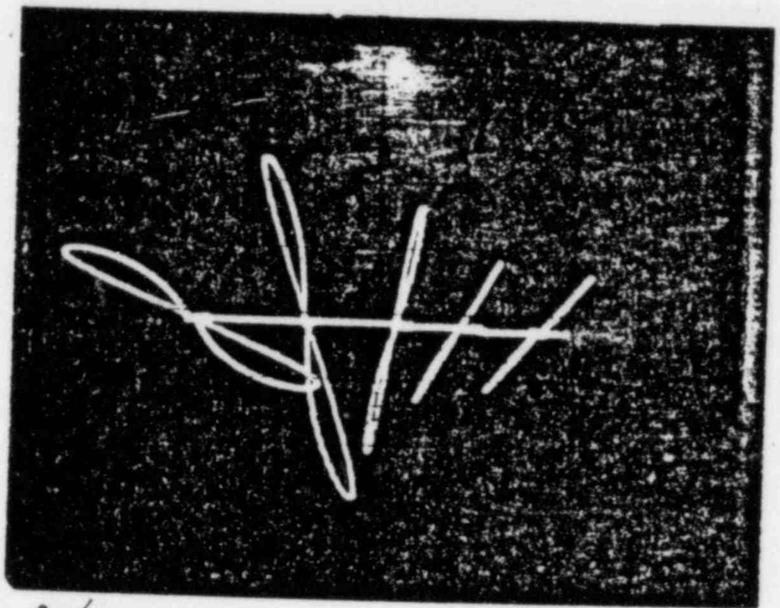
Mix

2V/Div

1/ Copper Foil (1"X1.25"X.004") Centered Over the Pit.

Figure 17 Copper Signal Elimination Frequency Mix Comparison Test. Probe - A600LC/HF/WF (.060"); Mix - 600/250 kHz Copper Ring (180°); Gains - 50/37

ASME Standard Signals



2v/Div

Signals from .100" x 42% pit

No Copper | Copper Over Pit 1/

600 kHz

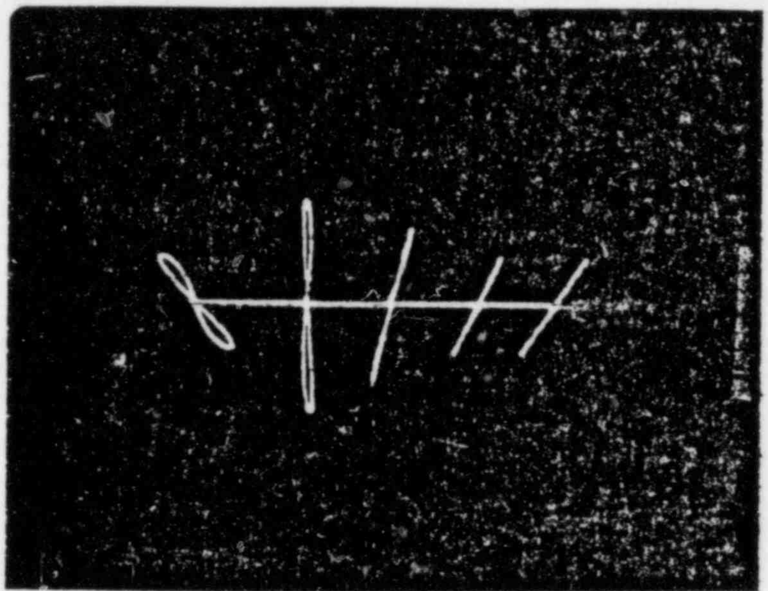
Mix

2v/Div

1/ Copper Foil (1"X1.25"X.004") Centered Over the Pit

Figure 18 Copper Signal Elimination Frequency Mix Comparison Test. Probe - A600 LC/HF/WF (.060); Mix 600/300 Copper Ring (180°); Gains - 50/37

ASME Standard Signals



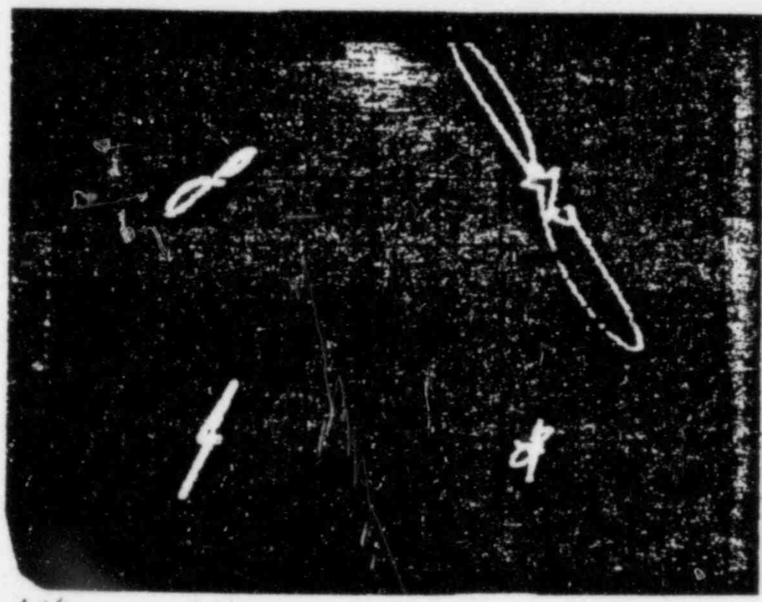
20/Div

Signals from .100" x 42% pits

No Copper | Copper Over Pit 1/

600 kHz

Mix

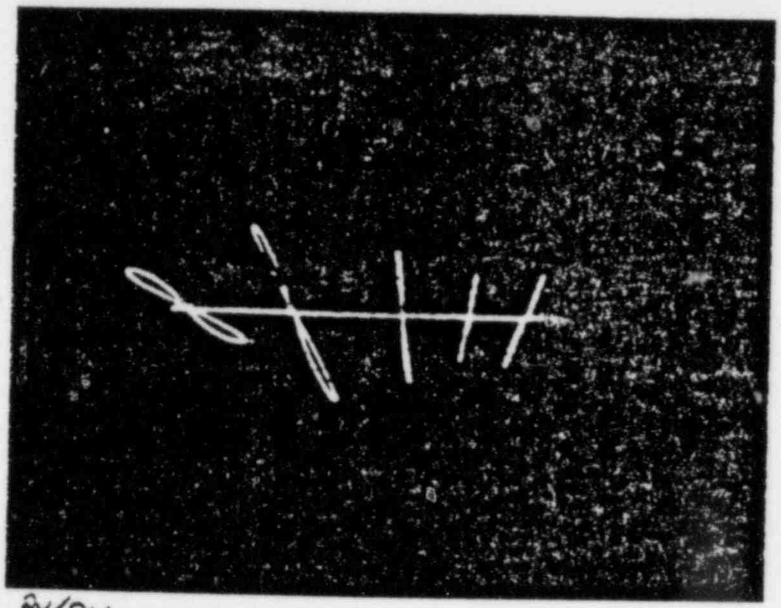


1V/Div

1/ Copper Foil (1"X1.25"X.004") Centered Over the Pit.

Figure 19 Copper Signal Elimination Frequency Mix Comparison Test. Probe - A560HF/SF; Mix 600/200 kHz Copper Ring (180°); Gains - 51/40

ASME Standard Signals



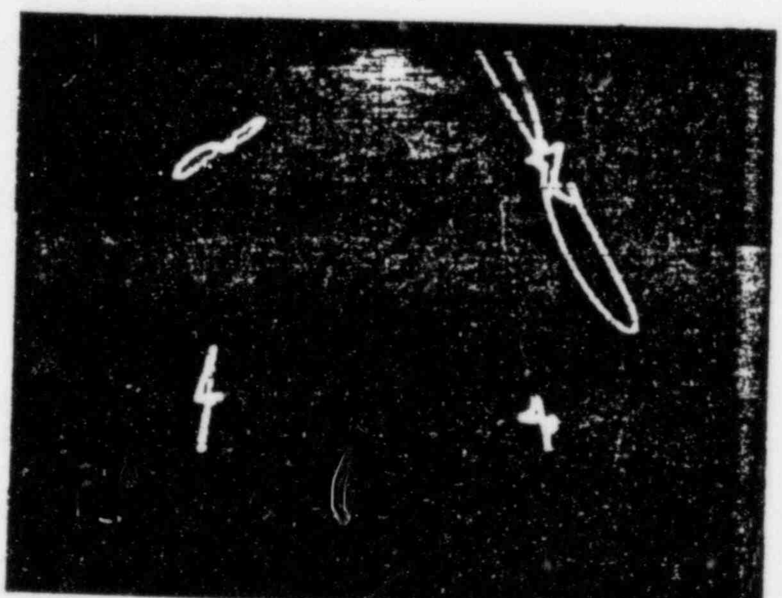
2v/Div

Signals from .100" x 42% pits

No Copper Copper Over Pit 1/

600 kHz

Mix

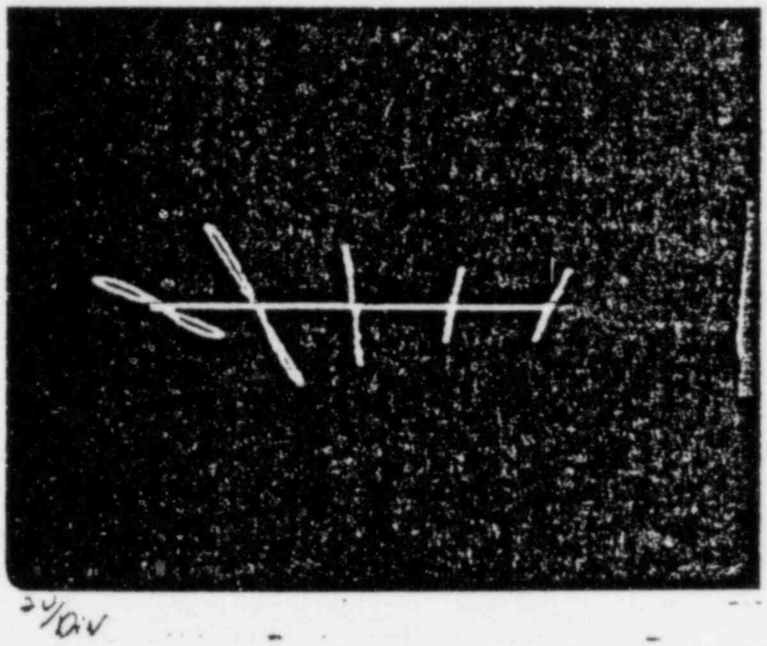


1v/Div.

1/ Copper Foil (1" X 1.25" X .004") Centered Over the Pit.

Figure 20 Copper Signal Elimination Frequency Mix Comparison Test. Probe - A560HF/SF; Mix 600/250 kHz Copper Ring (180°); Gains - 51/42

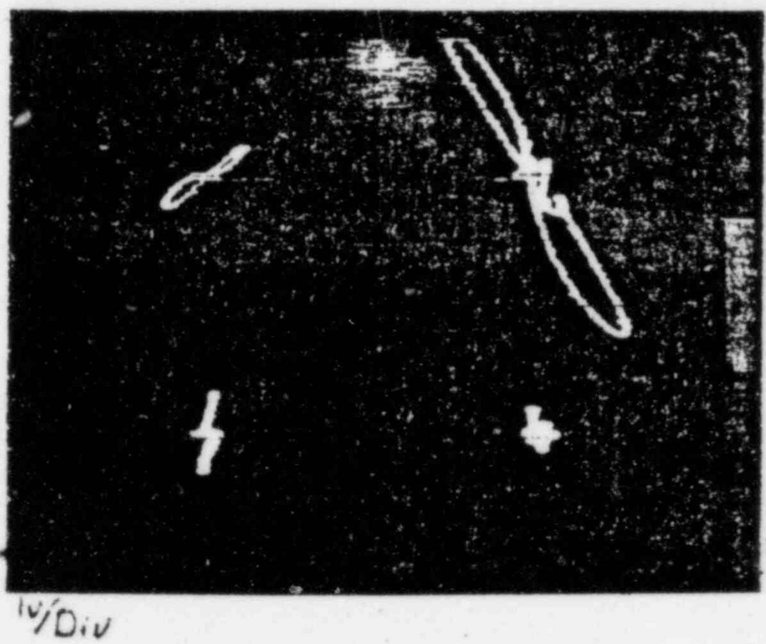
ASME Standard Signals



Signals from .100" x 42% pits

No Copper Copper Over Pit 1/

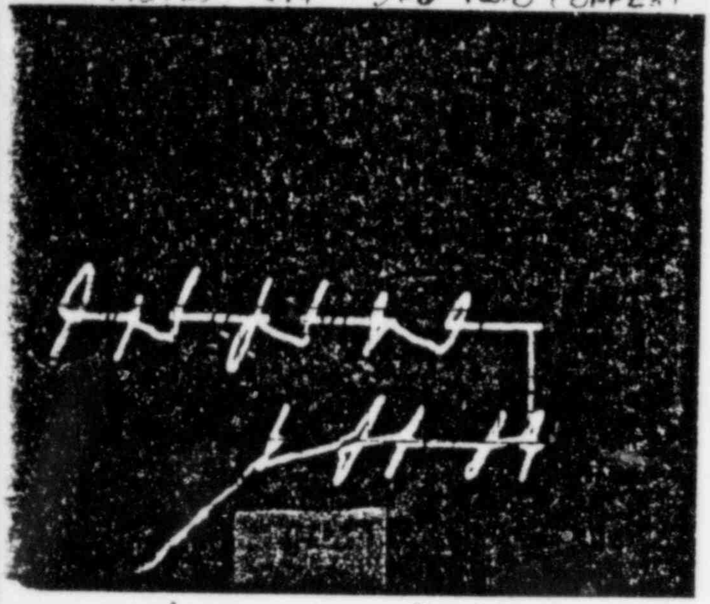
600 kHz



Mix

1/ Copper Foil (1"X1.25"X.004") Centered Over the Pit.

Figure 21 Copper Signal Elimination Frequency Mix Comparison Test. Probe - A560HF/SF; Mix 600/300 kHz Copper Ring (180°); Gains - 51/44



Pit Signals

Strip Chart of tests with copper (top) and without copper centered over the pits

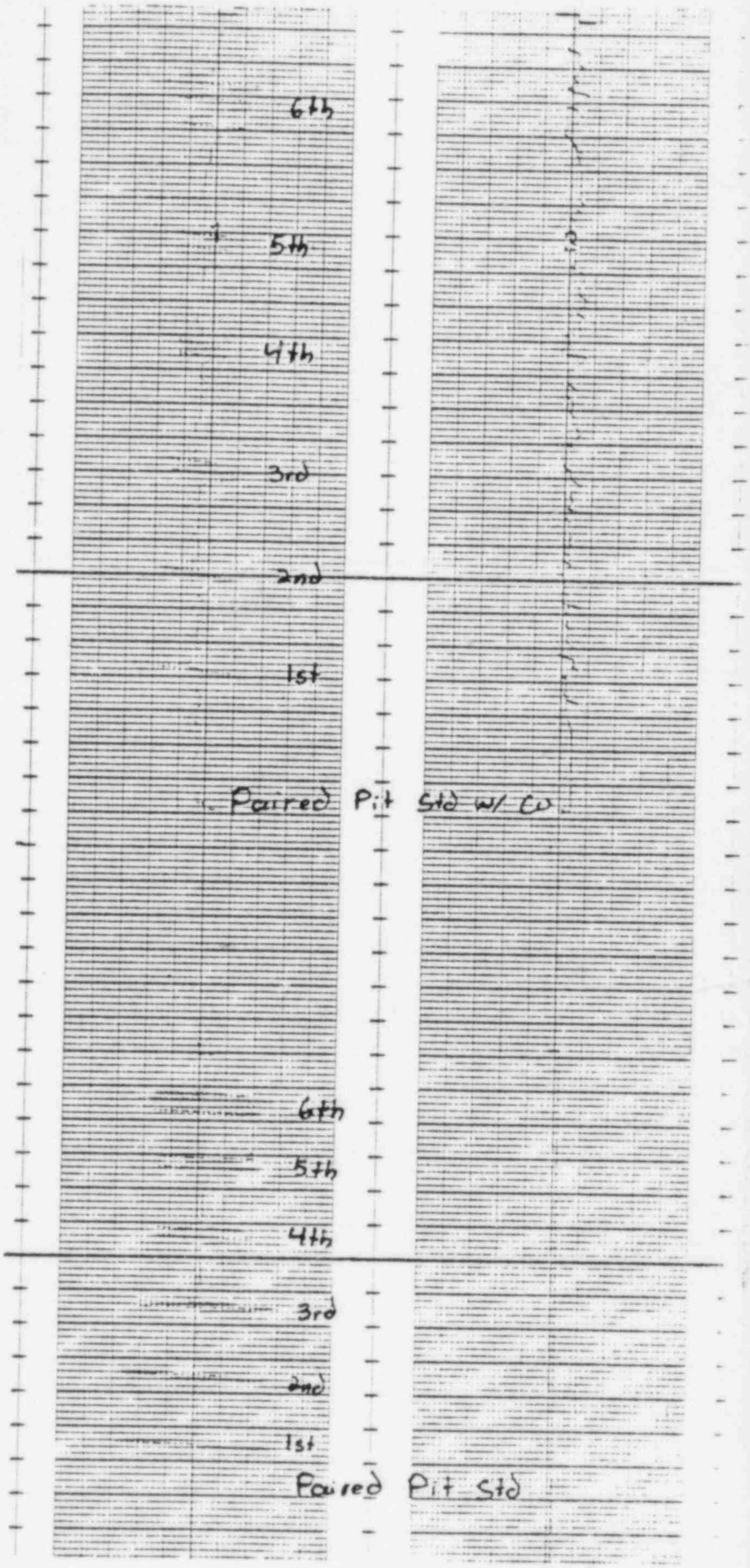
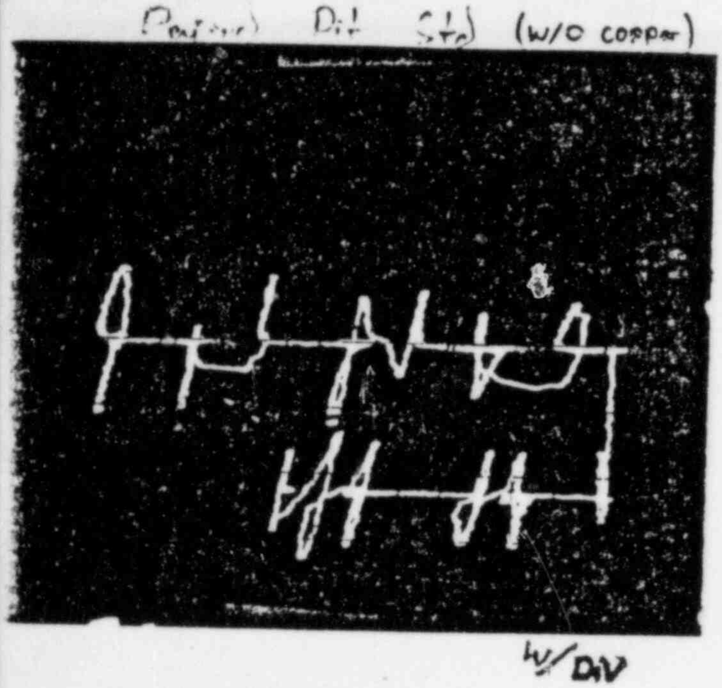
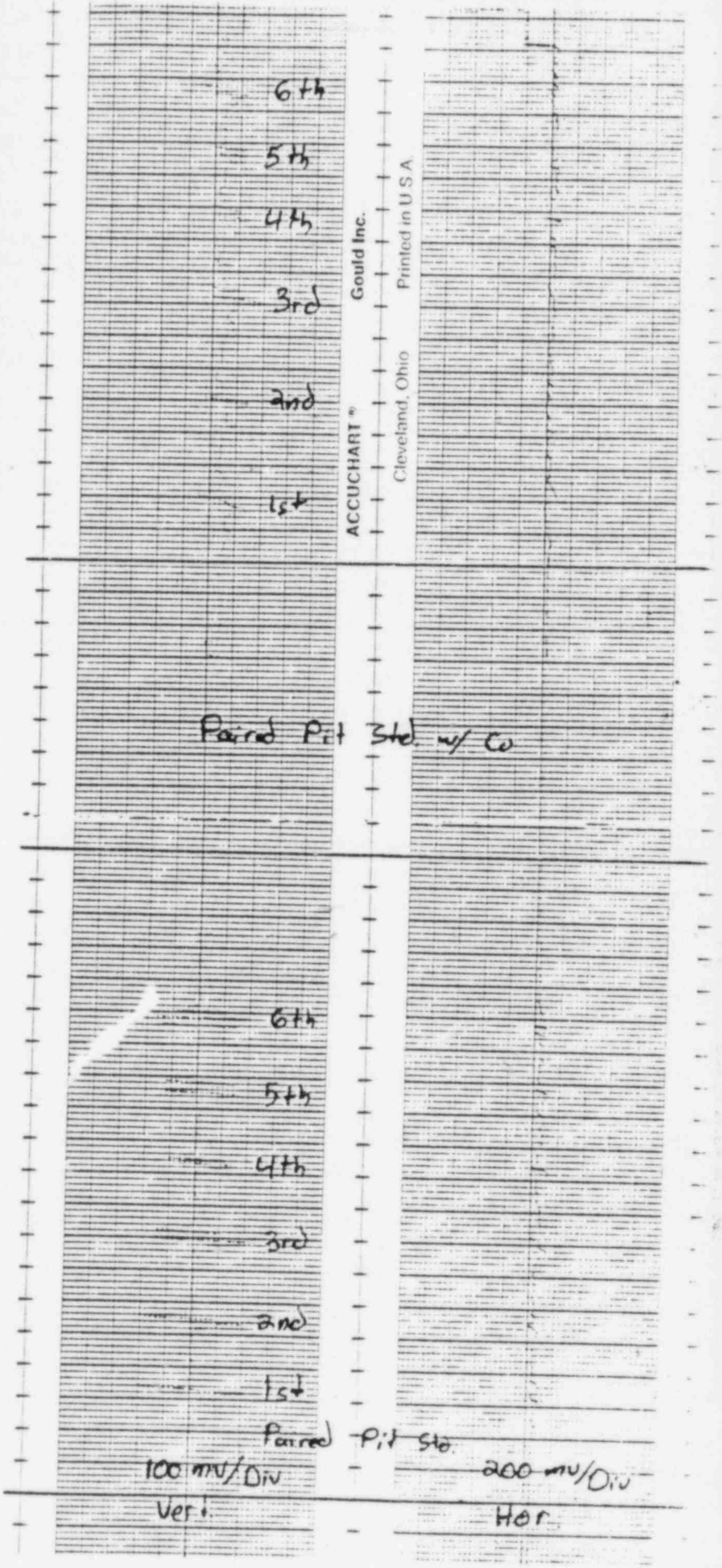


Figure 22 Pit Resolution Test
Probe - A600LC/HF/WF (.060); Mix 600/250 kHz copper ring (180°); Gain 50/39

NOTE: Dimensions of pit pairs can be found in Figure 2.



Pit Signals

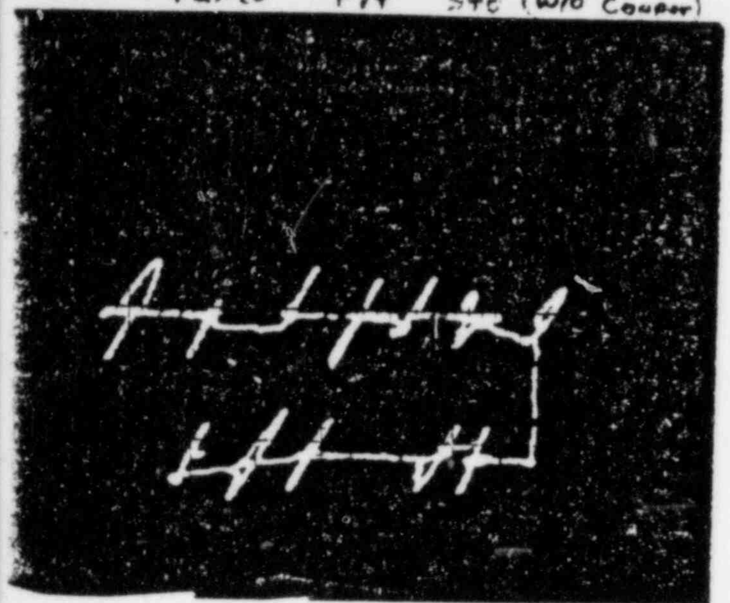


Strip Chart of tests with copper (top) and without copper centered over the pits

Figure 23 Pit Resolution Test
Probe - A560HF/SF; Mix 600/250 kHz copper ring (180°);
Gains - 50/39

NOTE: Dimensions of pit pairs can be found in Figure 2.

Paired Pit Std (w/o Copper)



1v/div

Pit Signals

Strip Chart of Tests with copper (top) and without copper centered over the pits

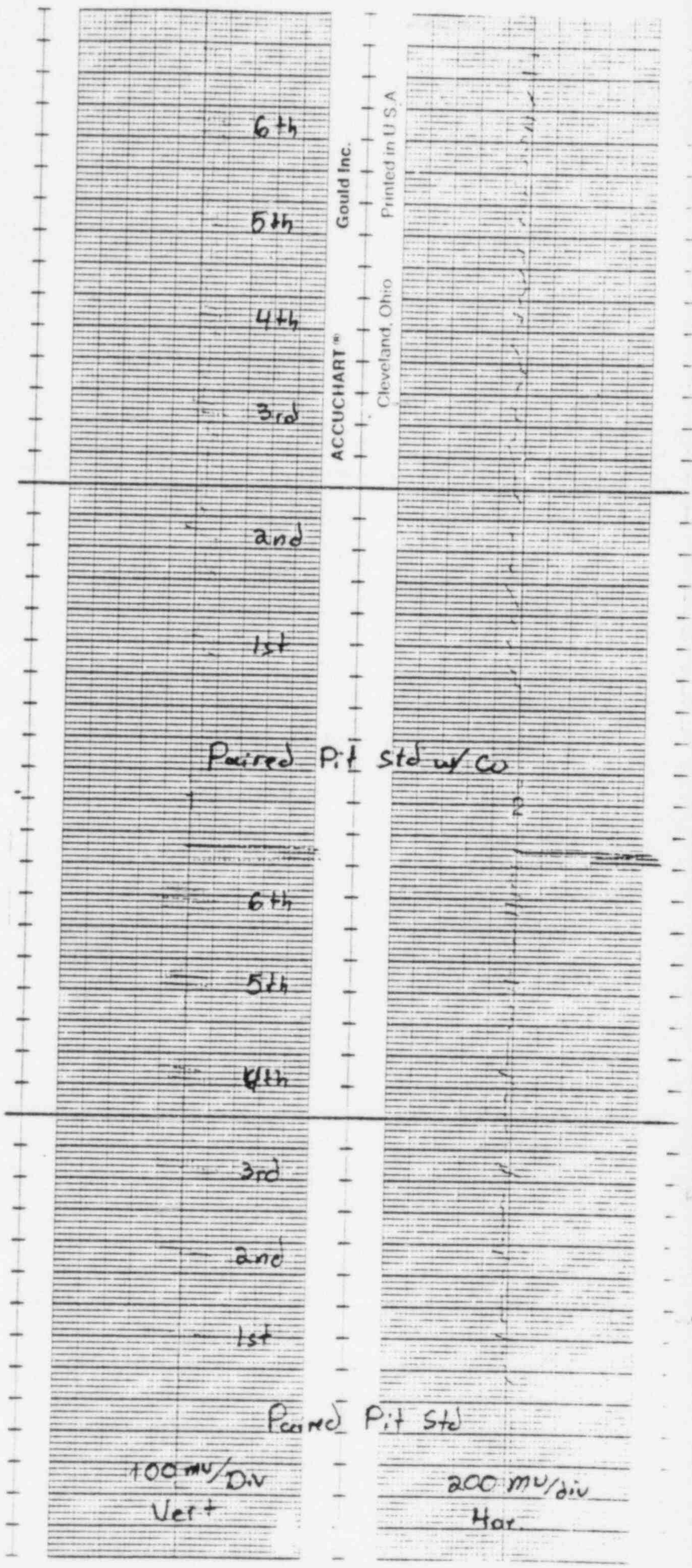
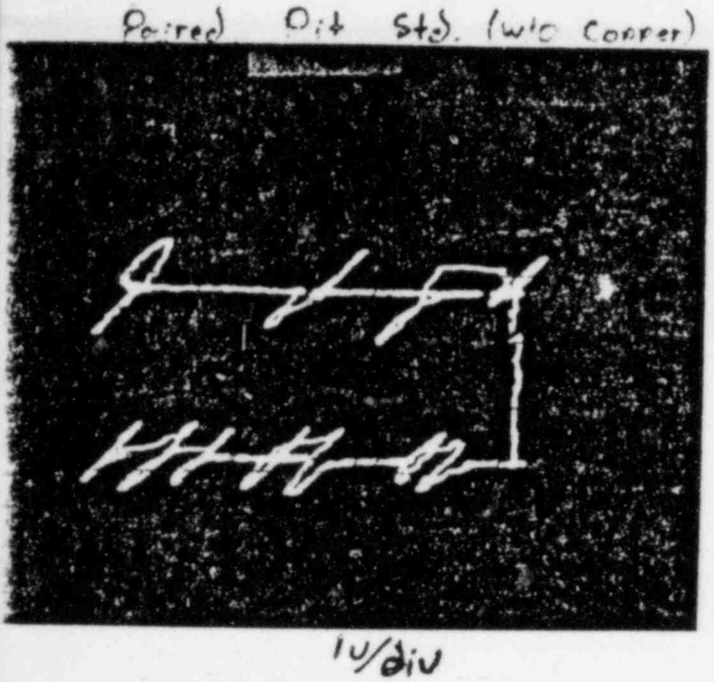
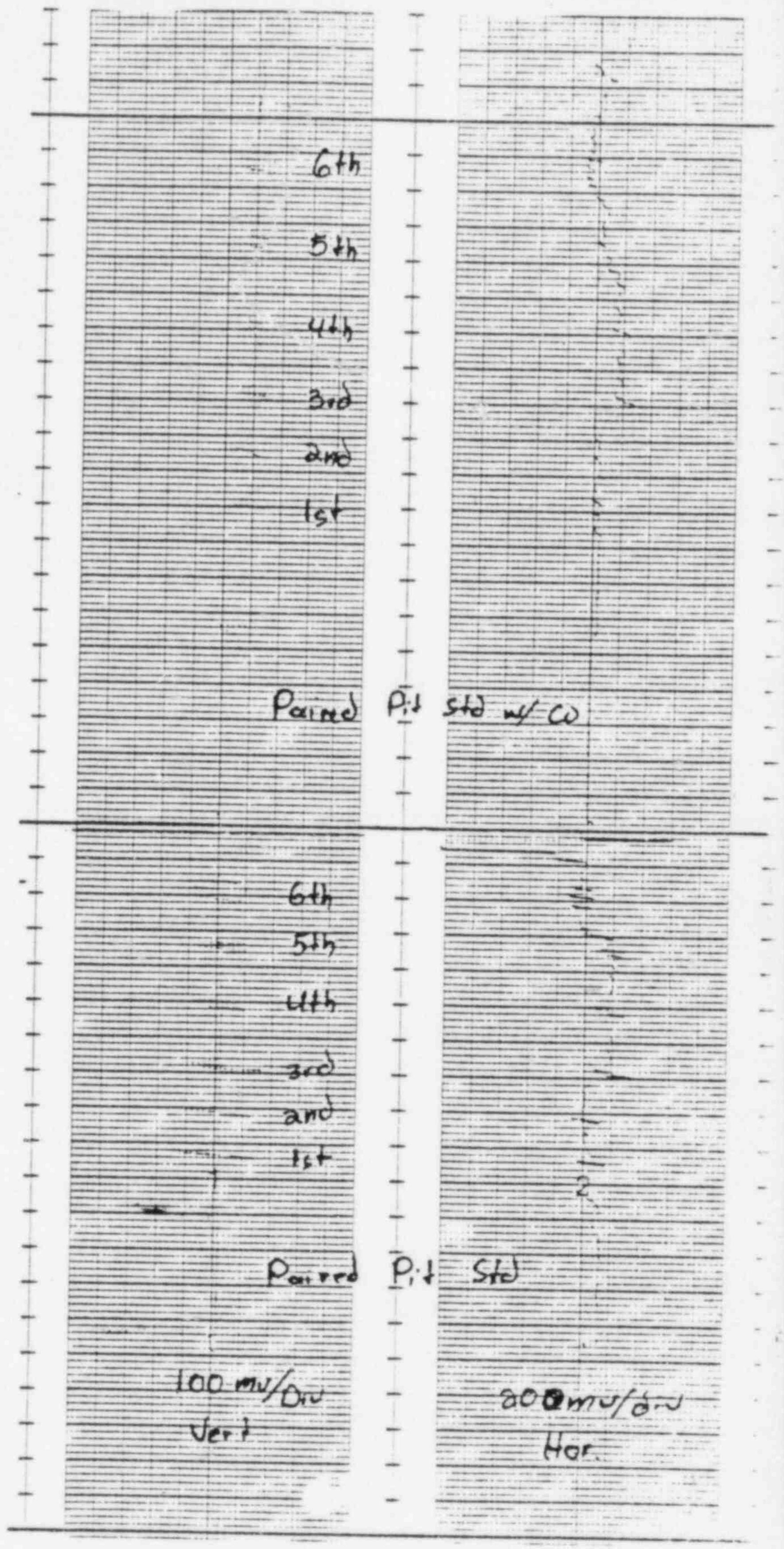


Figure 24 Pit Resolution Test Probe - A560LC/HF/WF; Mix - 600/250 kHz copper ring (180°); Gains - 50/36

NOTE: Dimensions of pit pairs can be found in Figure 2.



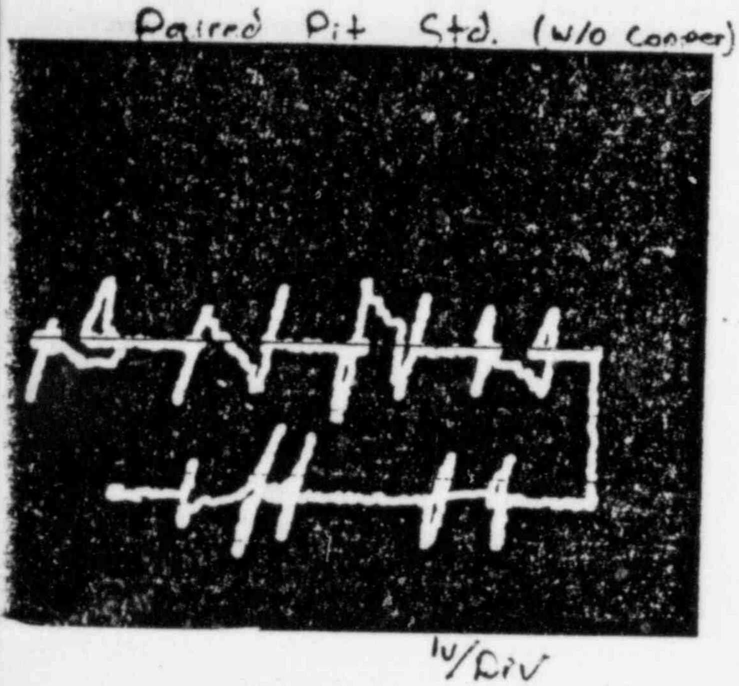
Pit Signals



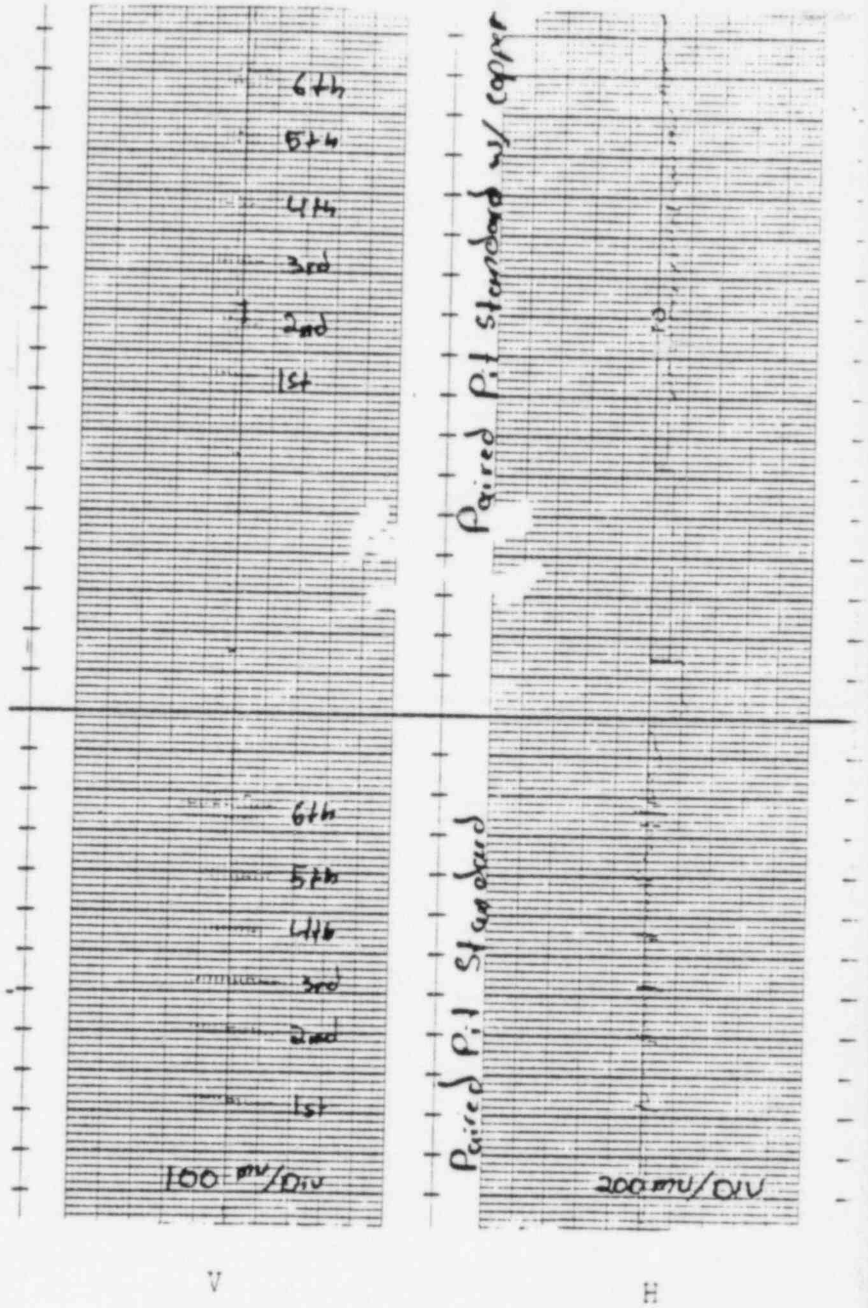
Strip Chart of tests with copper (top) and without copper centered over the pits

Figure 25 Pit Resolution Test
Probe - A560SF; Mix 600/250 kHz copper ring (180°); Gains 55/24

NOTE: Dimensions for pit pairs can be found in Figure 2.



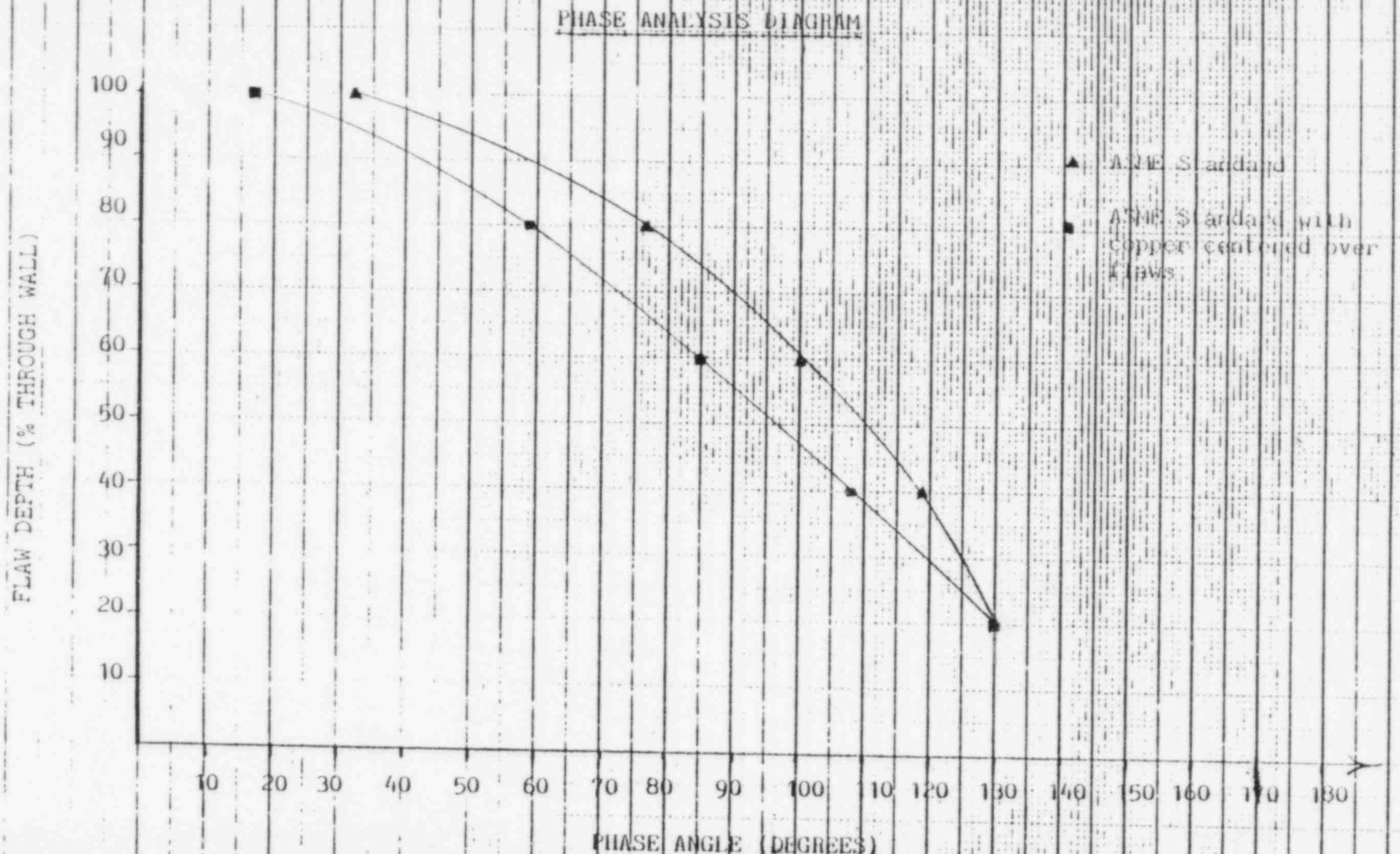
Pit Signals



Strip Chart of tests with copper (top) and without copper centered over the pits

Figure 26 Pit Resolution Test
Probe - A600LC/HF/WF (.030);
Mix 600/250 kHz copper ring (180°); Gains - 57/49

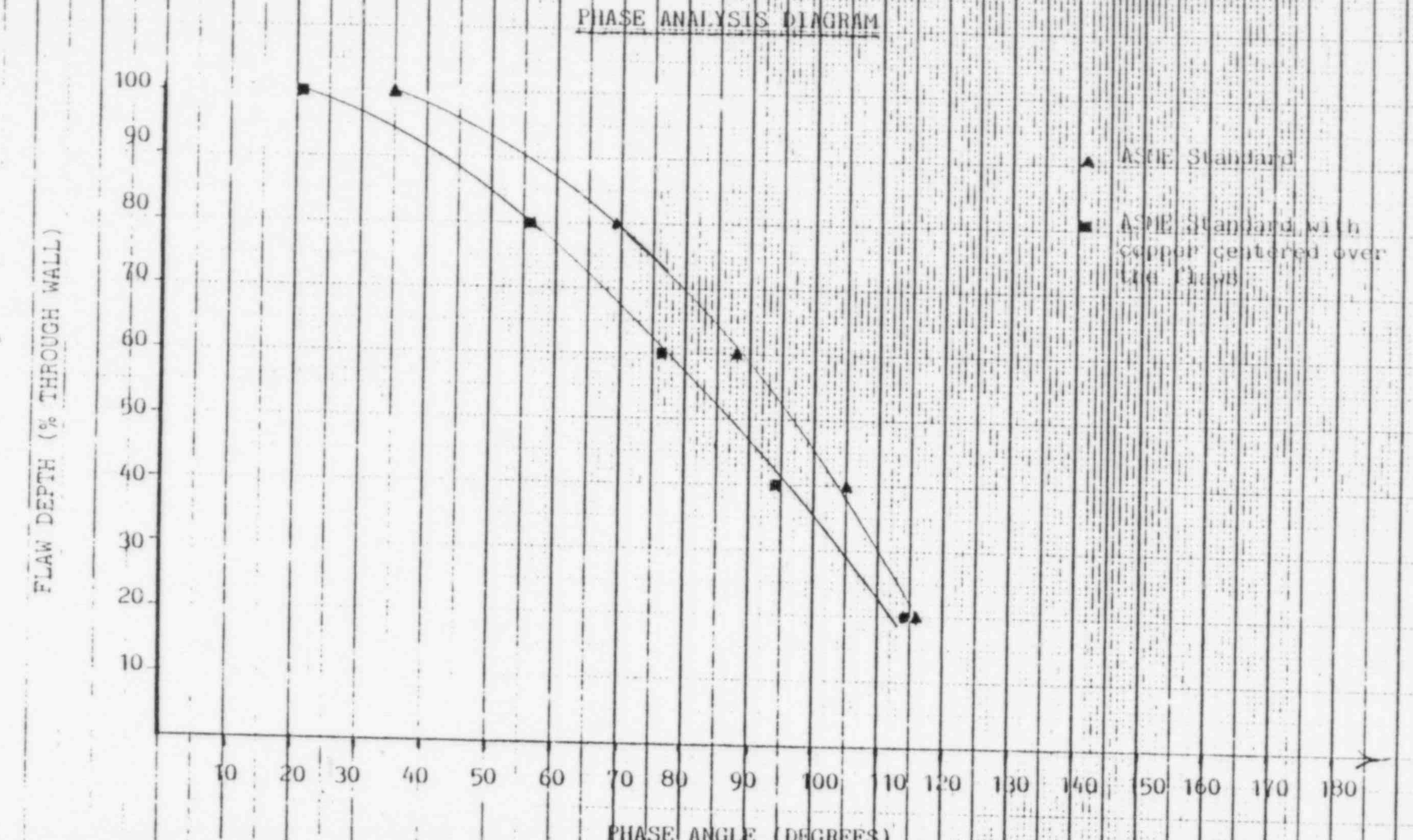
NOTE: Dimensions for pit pairs can be found in Figure 2.



Probe: A600LC/HF/WF
Spacing: .060" Coil: .030"
Freq: 600/250 kHz Mix
Mix: Copper Ring 180°
Gain: CH1: 50 CH2: 39

Comments: Pit detection in the presence of copper showing the shift in the phase analysis curve in the presence of copper.

461510



Probe: A560 HE/SE

Spacing: .060" Coil: .030"

Freq: 600/250 kHz Mix

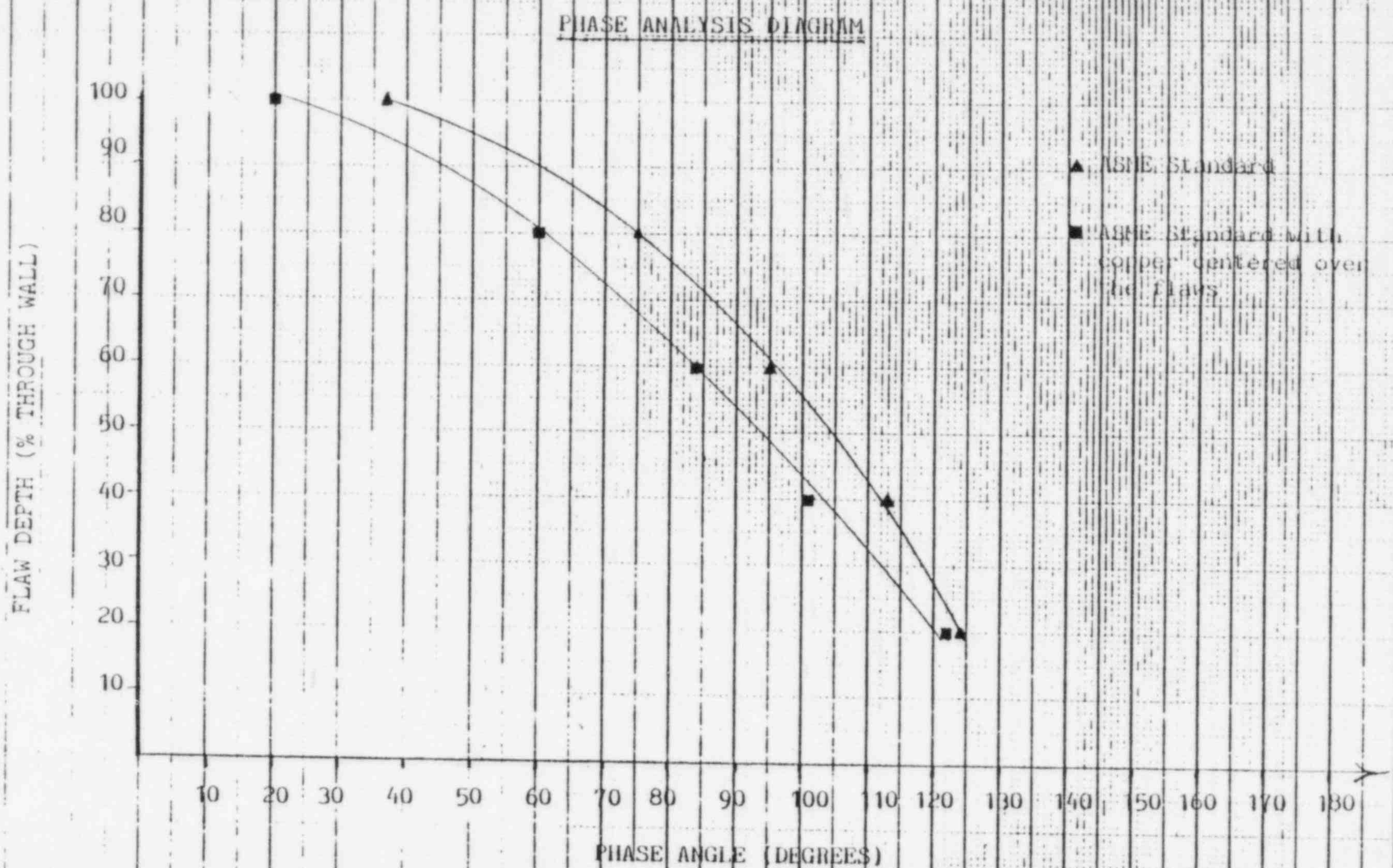
Mix: Copper Ring 180°

Gain: CH1: 51 CH2: 42

Comments: Pit detection in the presence of copper showing the shift in the phase analysis curve in the presence of copper.

Figure 28

461510



Probe: A560 LC/HF-WF
Spacing: .060" Coil: .030"
Freq: 600/250 kHz Mix
Mix: Copper Ring 180°
Gain: CH1: 49 CH2: 36

Comments: Pit detection in the presence of copper showing the shift in the phase analysis curve in the presence of copper

Figure 29

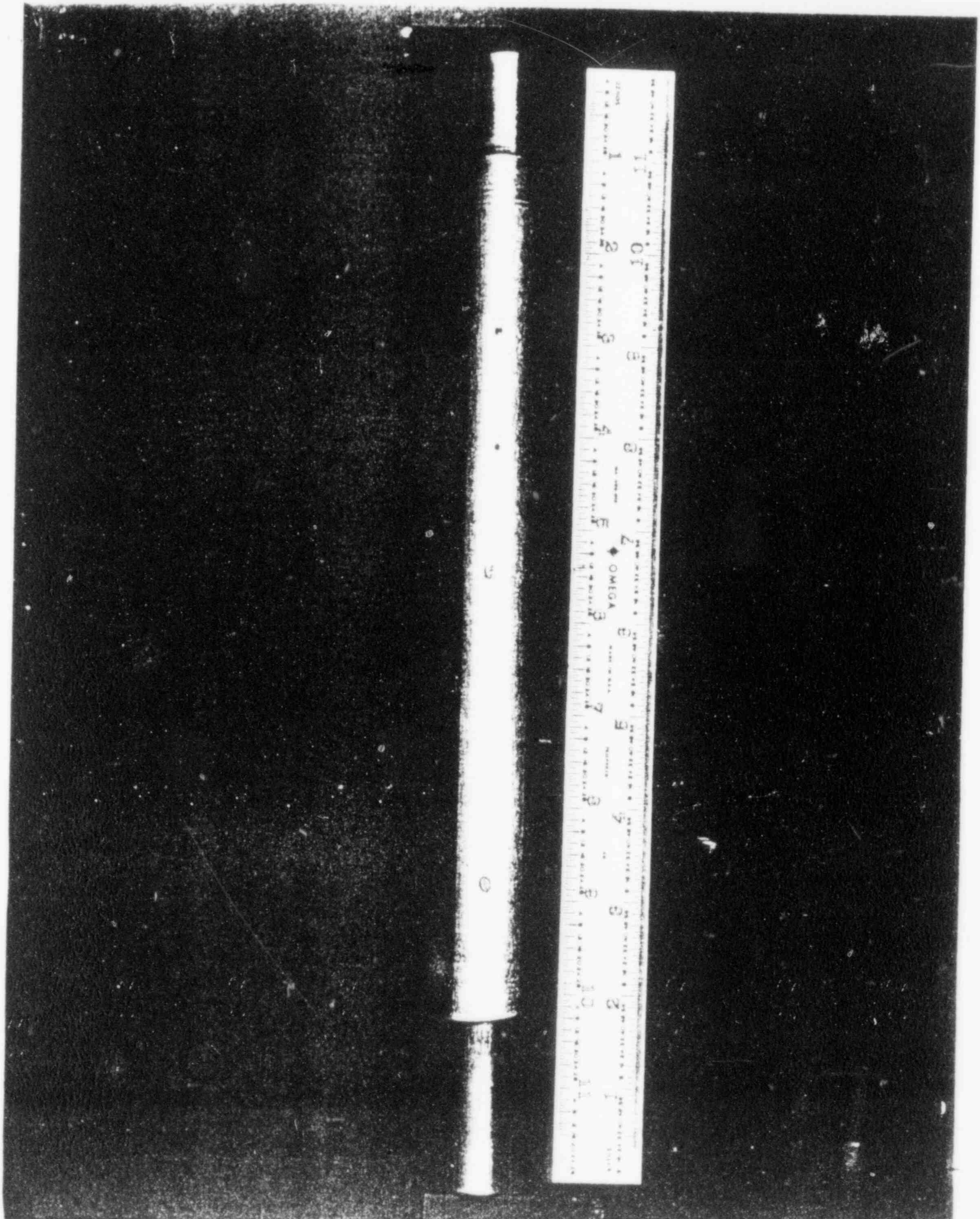


FIGURE 20 Photograph of electro-chemically induced Pb. Sample after [illegible] of copper plating. (Dimensions given in Table [illegible])

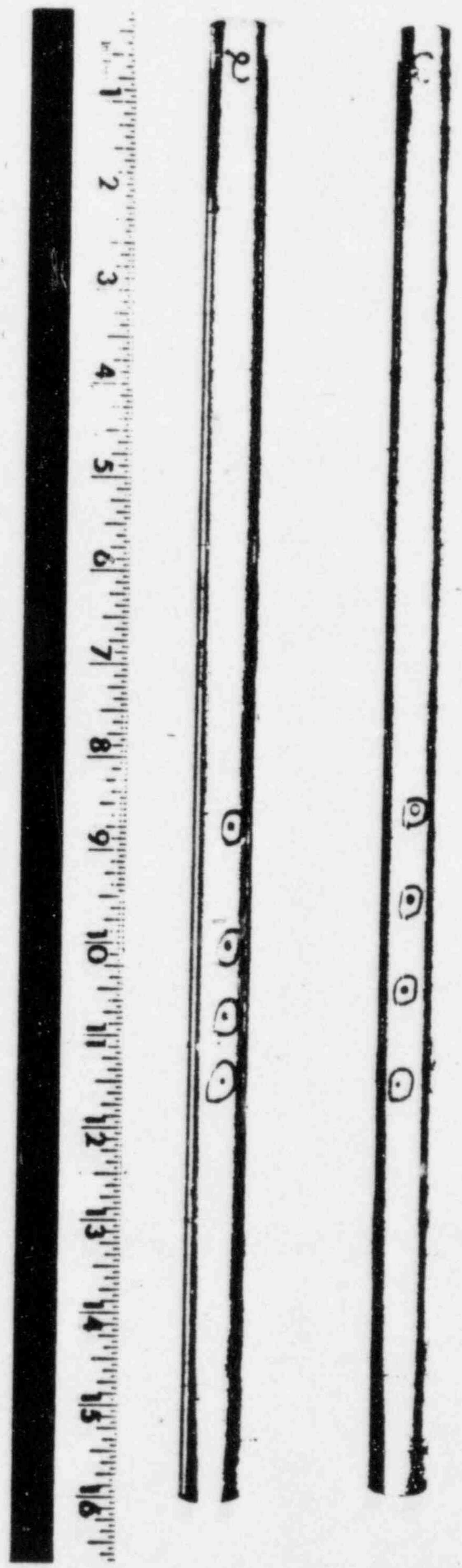
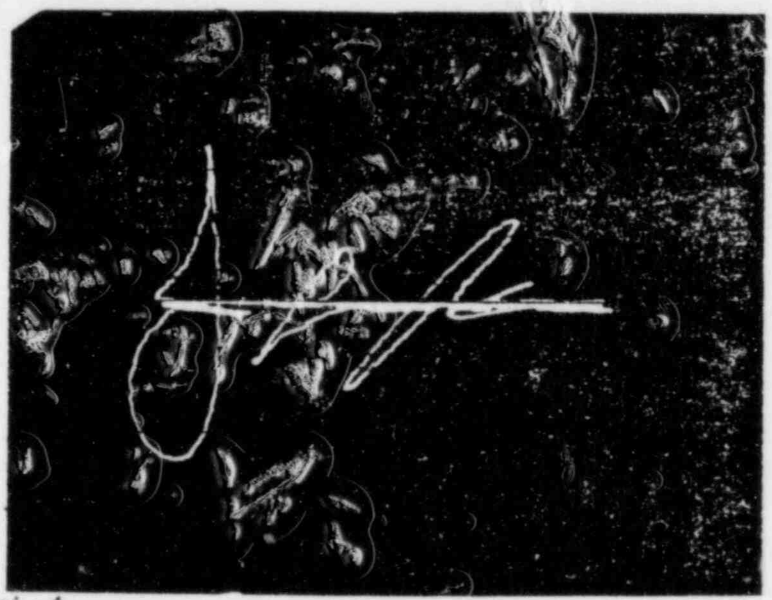


Figure 31 Photograph of Electro-chemically Induced Pit Samples 2 and 3.

ASME Standard

2V/Div

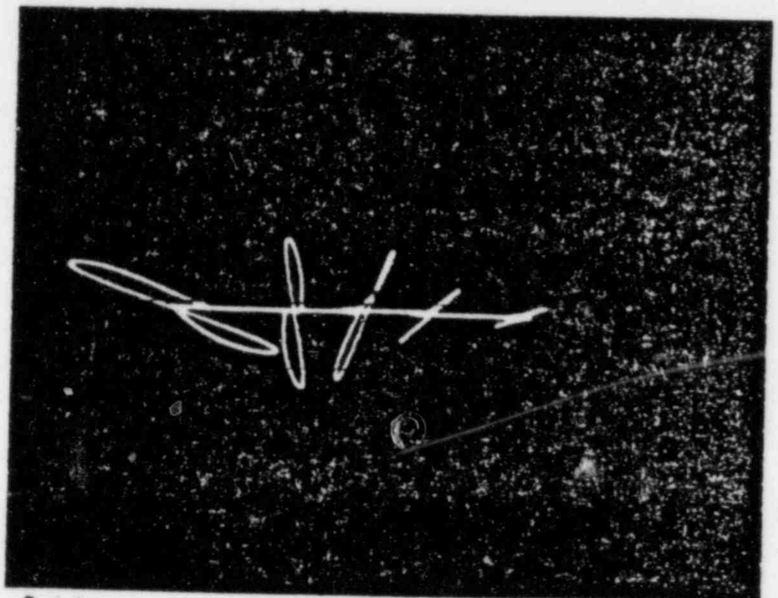
Electrochemically Induced Pit
Sample with Copper Plating



1V/Div

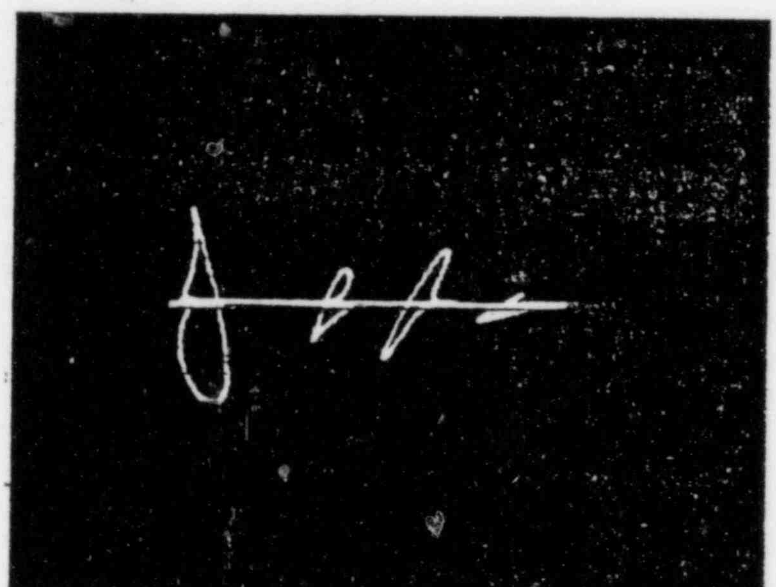
Figure 32 Chemically Pitted Tube Test. Probe - A600LC/HF/WF; Mix - 600/250 KHz
Copper Ring (180°); Gains - 49/40 ; Tube #1

ASME Standard



2V/div

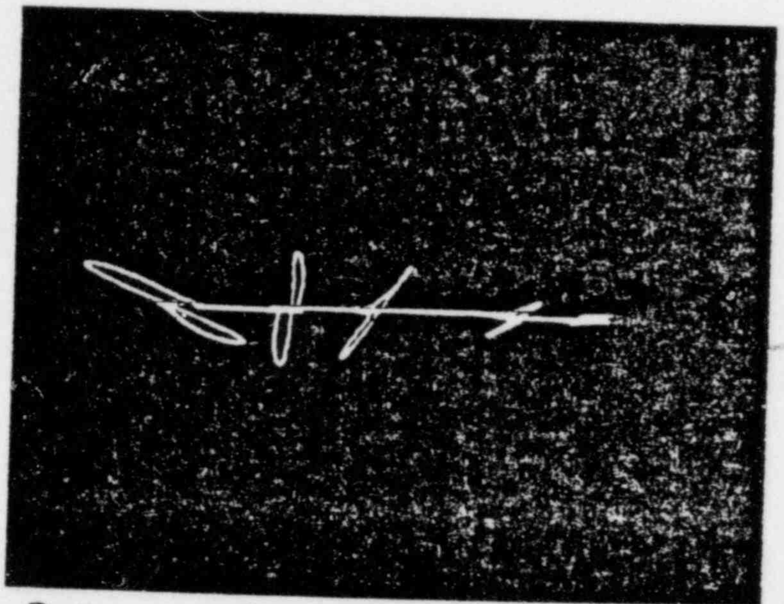
Electro Chemically Induced Pit
Sample with Copper Plating



1V/div

Figure 33 Chemically Pitted Tube Test. Probe - A560HF/SF; Mix - 600/?50 KHz
Copper Ring (180°): Gains - 50/42 ; Tube #1

ASME Standard

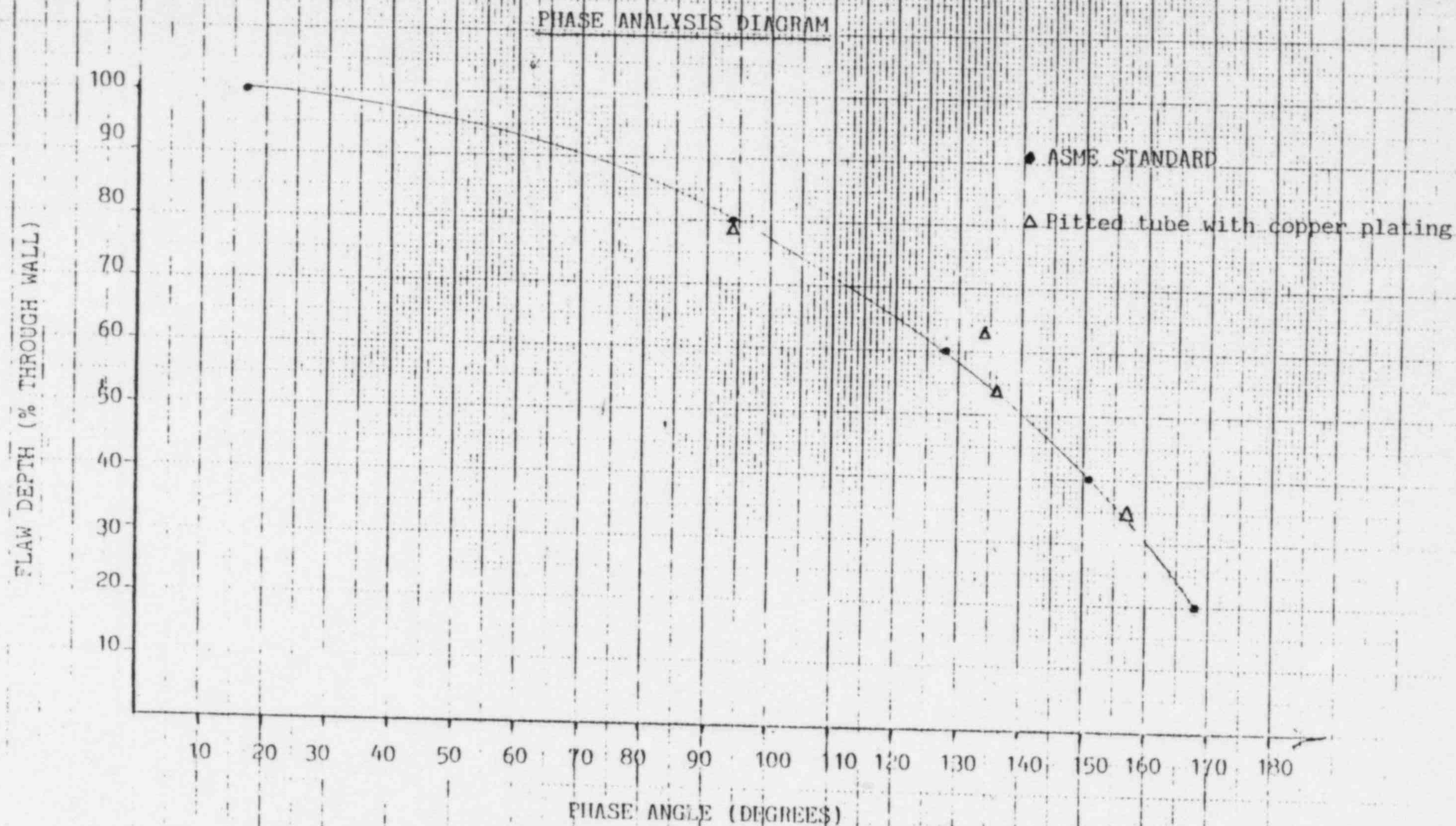


2V/Div

Electrochemically Induced Pit Sample with
Copper Plating

1V/Div

Figure 34 Chemically Pitted Tube Test. Probe - A560LC/HF/WF; Mix - 600/250 KHz
Copper Ring (180°); Gains - 48/39; Tube #1



Probe: A600LC/HF/WF

Spacing: .060" Coil: .030"

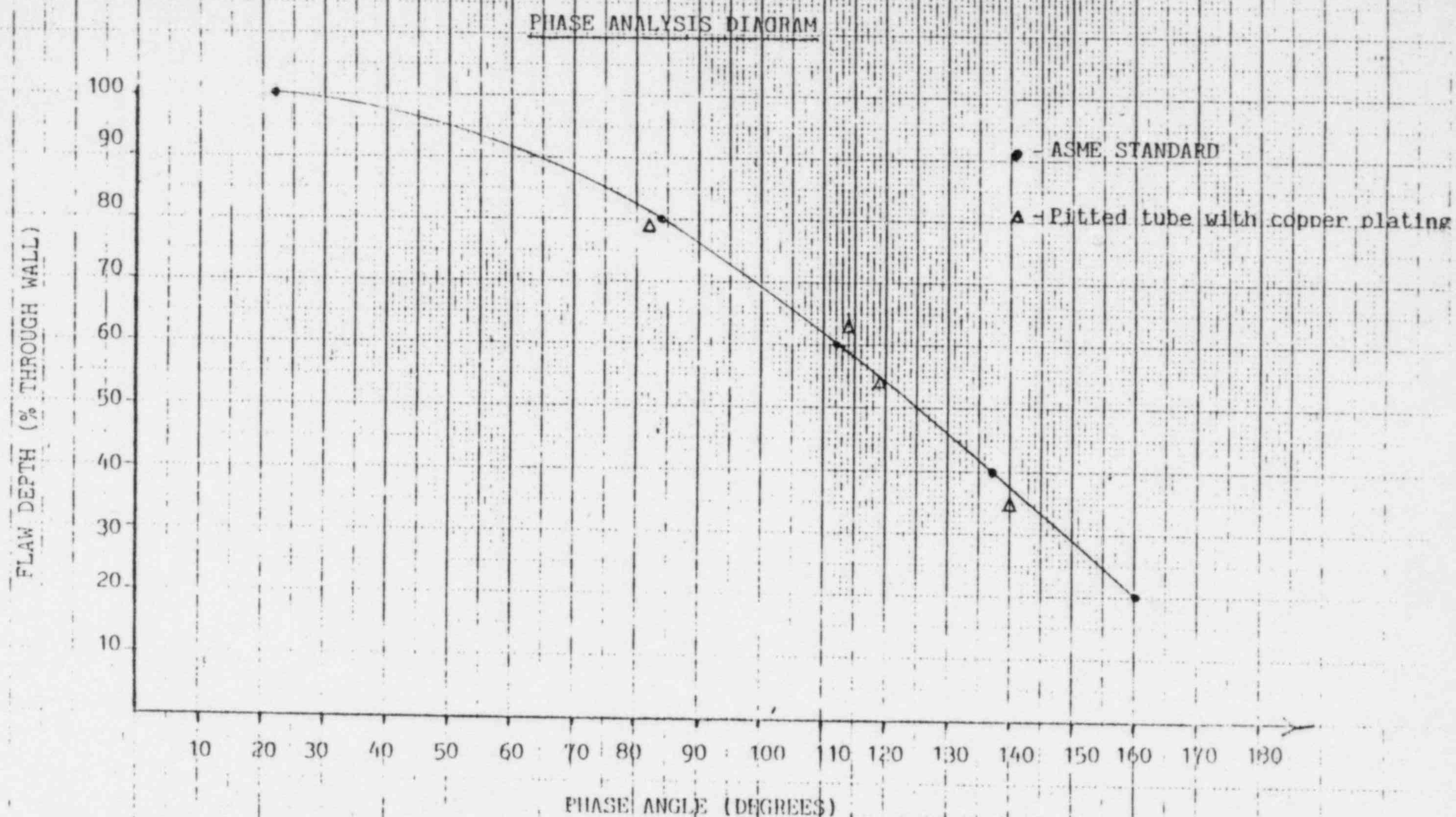
Freq: 600/250 KHz

Mix: 180° Copper

Gain: 49/40

Comments: Eddy Current Test of Chemically Pitted 3/4" SGT with 2-4 mils of copper plating.

Figure 35

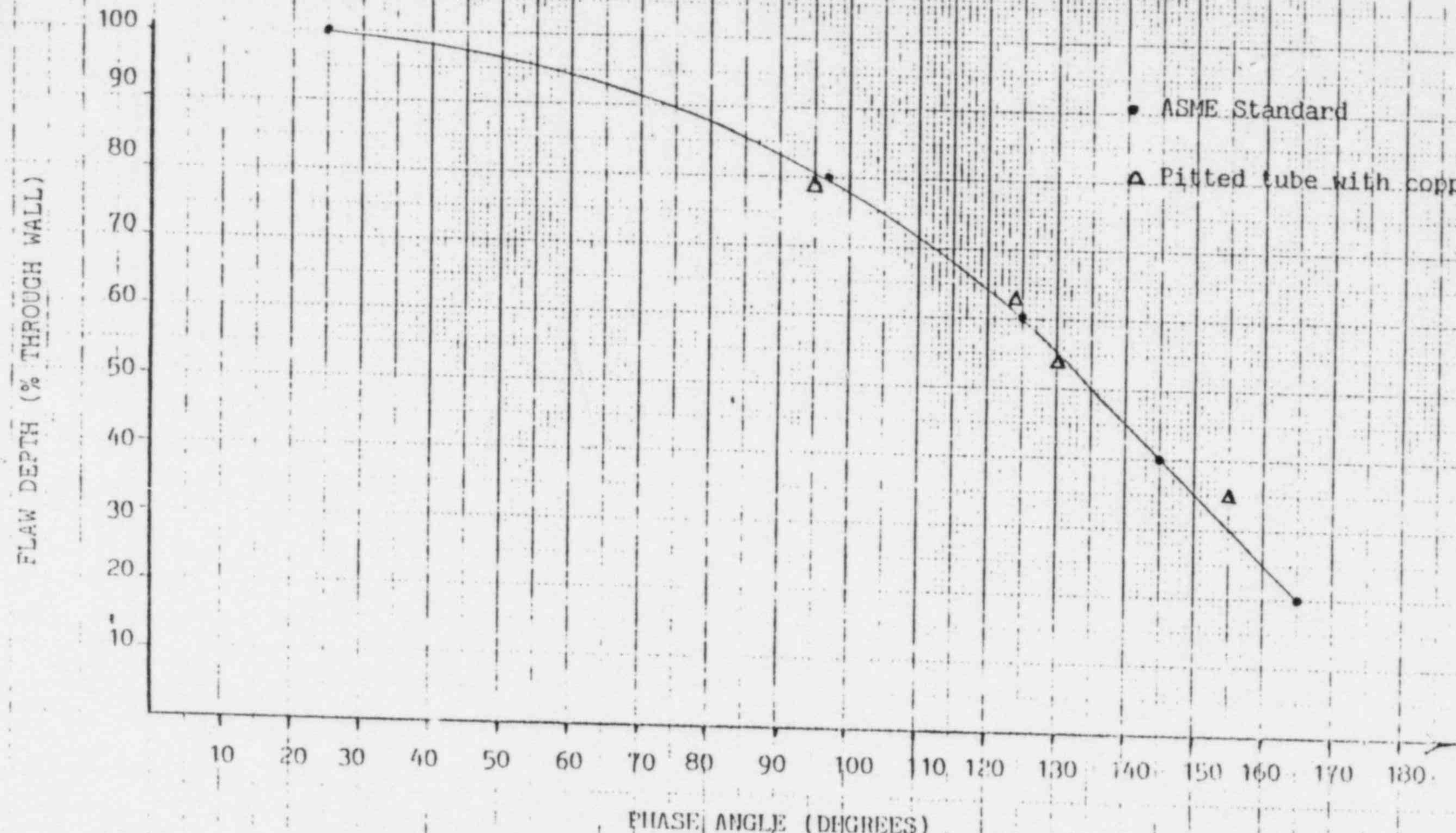


Probe: A560 HF/SF
Spacing: .060" Coil: .030"
Freq: 600/250 KHz
Mix: 180° Copper
Gain: 50/42

Comments: Eddy Current test of Chemically Pitted 3/4" SGT with 2-4 mils of copper plating.

Figure 36

PHASE ANALYSIS DIAGRAM



Probe: A560LC/HF/WF

Spacing: .060" Coil: .030"

Freq: 600/250 KHz

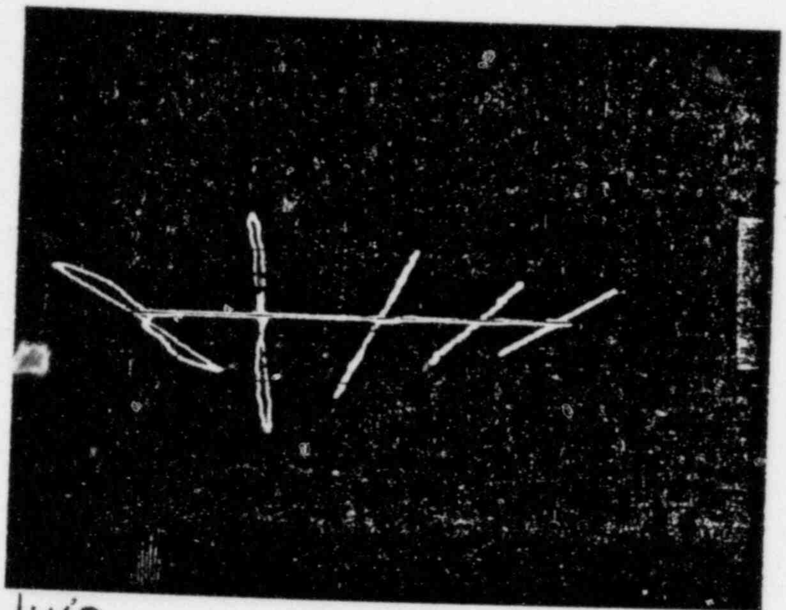
Mix: 180° Copper

Gain: 48/39

Comments: Eddy Current Test of Chemically pitted 3/4" SGT with 2-4 mil copper plating.

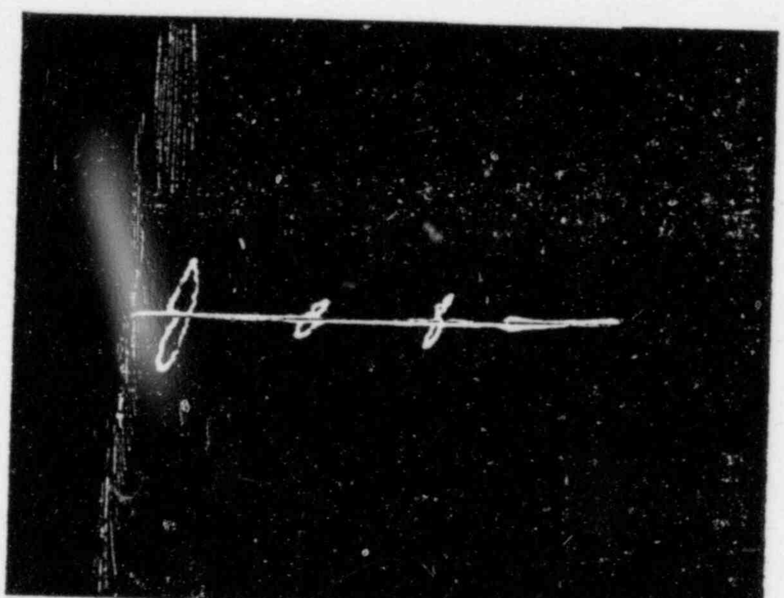
Figure 37

ASME Standard



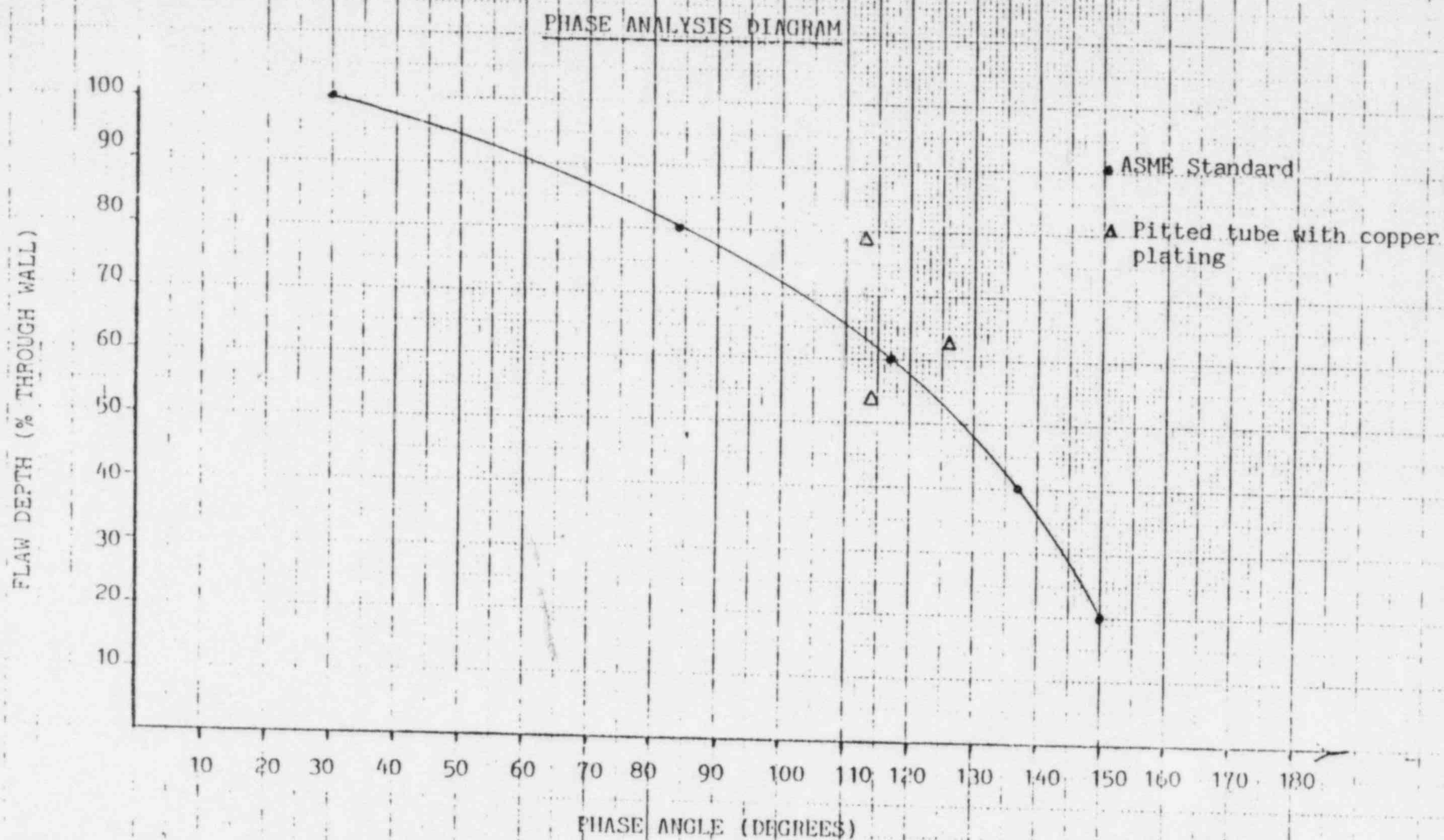
1v/Div

Electro Chemically Induced Pit
Sample with Copper Plating



1v/Div

Figure 38 Chemically Pitted Tube Test. Probe - A560SF; Mix - 600/250 KHz
Copper Ring (180°); Gains - 53/31; Tube #1



Probe: A 560'SF
Spacing: .060" Coil: .060"
Freq: 600/250 KHz
Mix: 180° Copper
Gain: 53/31

Comments: Eddy Current Test of Chemically Pitted 3/4" SGT with 2-4 mil copper plating.

Figure 39

ASME STANDARD
RUN

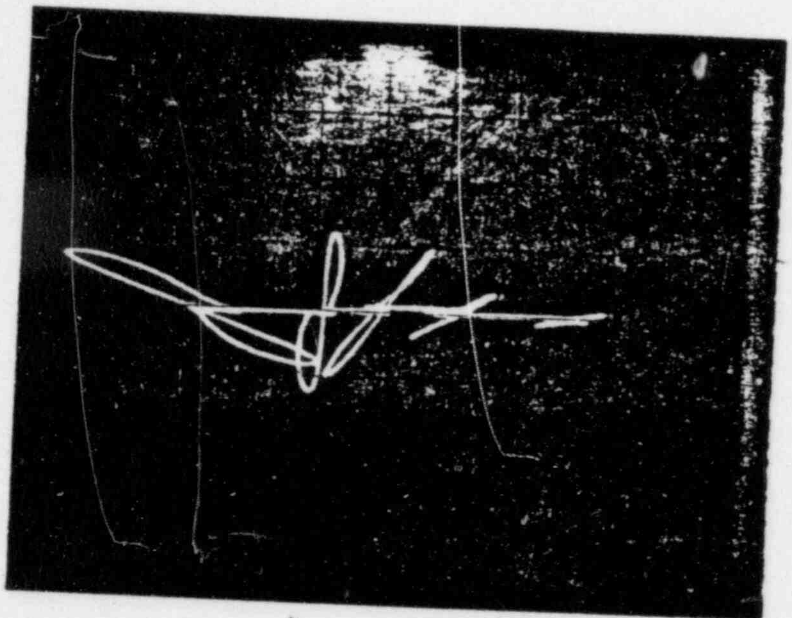
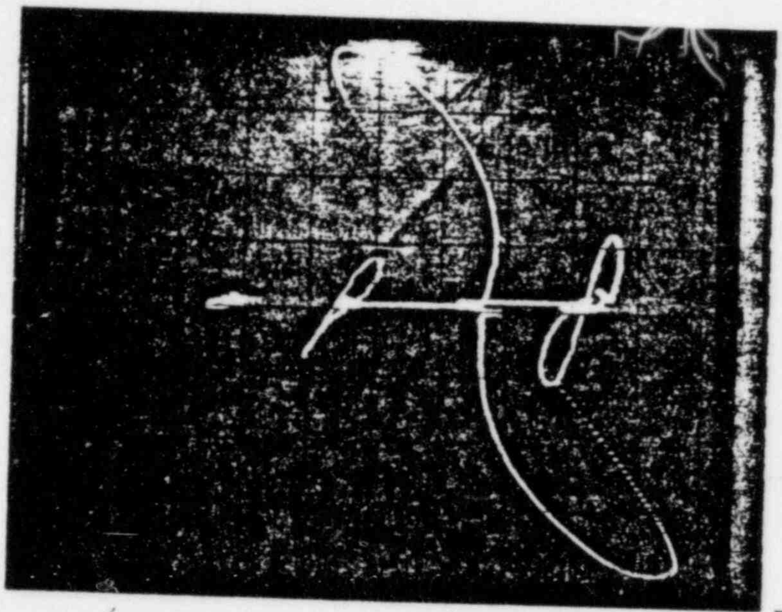
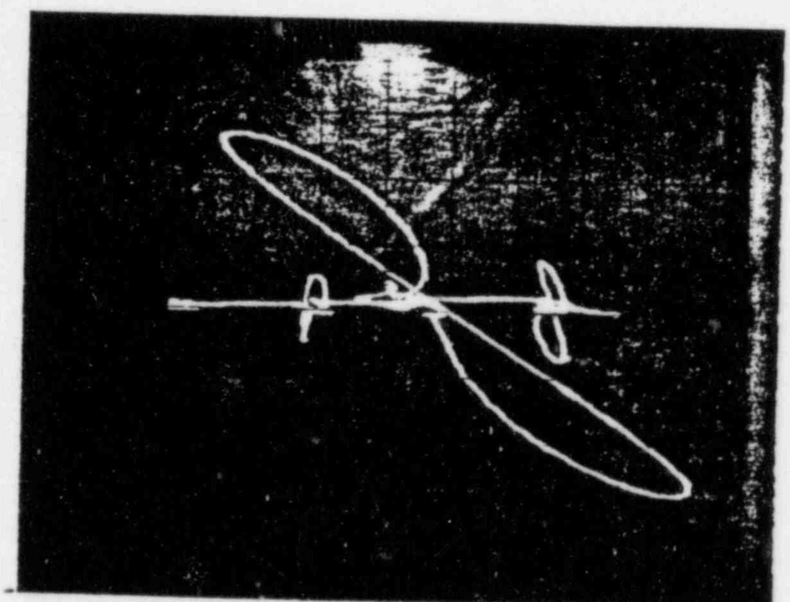


Figure 40 Chemically Pitted Tube Test, Probe - A600LC/HF/WF: Mix - 600/250KH-

RUN OF TUBE #2
WITHOUT COPPER 1/



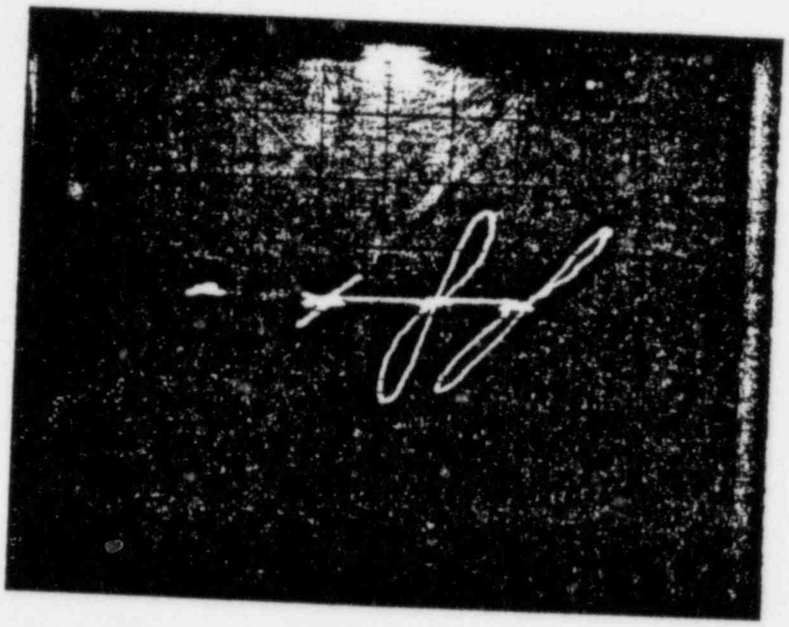
RUN OF TUBE #2
WITH COPPER



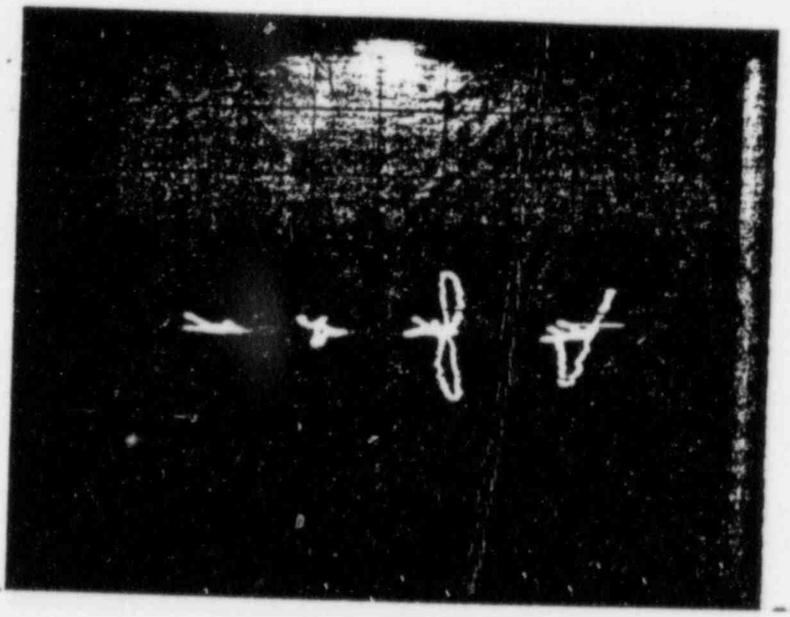
1/ Copper Foil (1"X1.25"X.004)
Centered Over the Pits.

Figure 41 Chemically Pitted Tube Test. Probe - A600LC/HF/WF; Mix - 600/250 KHz; Copper Ring (180°); Gains 48/37.

RUN OF TUBE #3
WITHOUT COPPER 1/



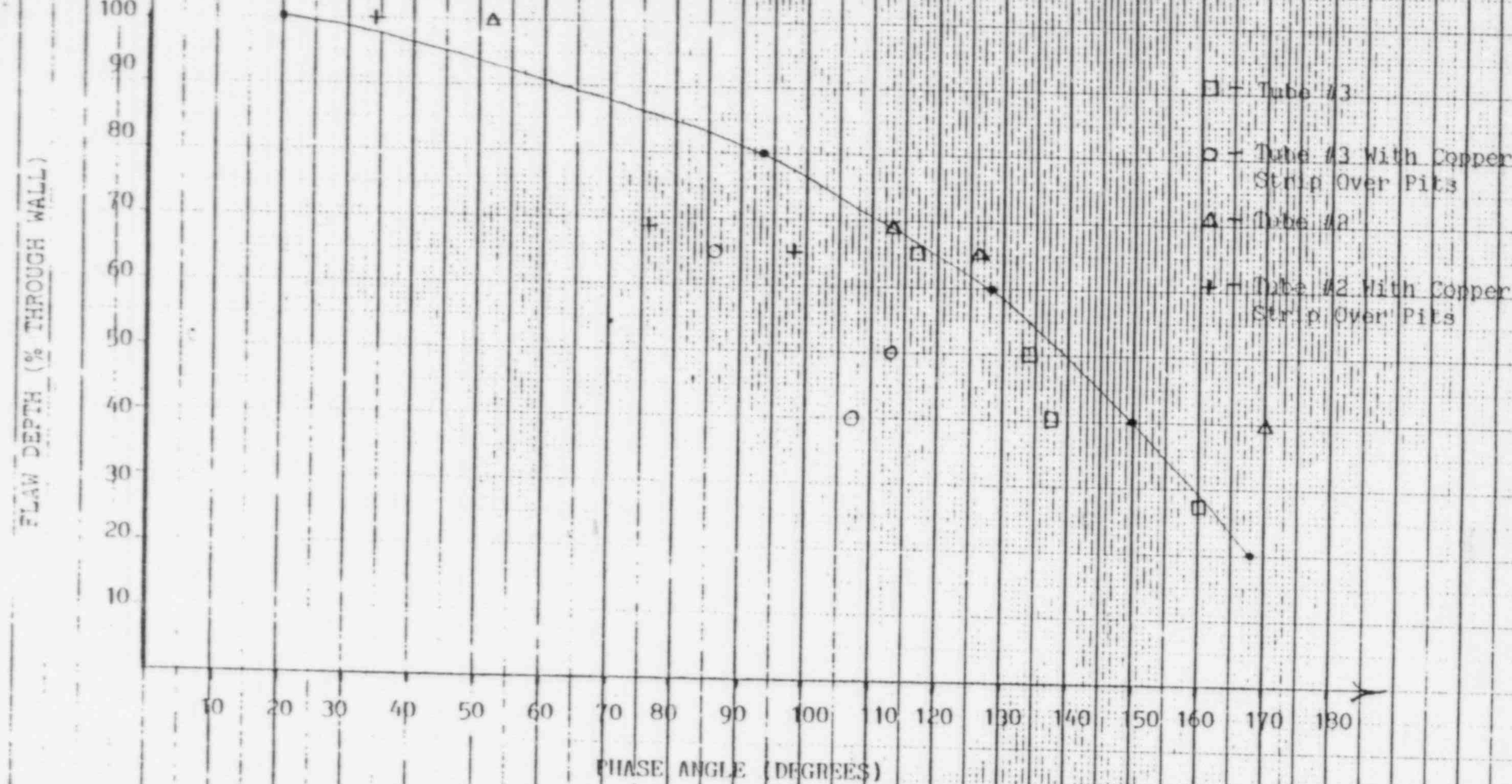
RUN OF TUBE #3
WITH COPPER



1/ Copper Foil (1"x1.25"X.004")
Centered Over the Pits

Figure 42 Chemically Pitted Tube Test. Probe - A600LC/HF/WF; Mix - 600/250 KHz
Copper Ring (180^{o}); Gains 48/37

PHASE ANALYSIS DIAGRAM



Probe:	A600LC/HF/WF
Spacing:	.060" Coil: .030"
Freq:	600/250 KHz
Mix:	180° Copper
Gain:	48/37

Comments: Electro-chemically Pitted Tubes (Pit Depths Based on Dial Depth Gage Measurements)

Figure 43

TABLE 1

EDDY CURRENT PROBES USED IN PIT DETECTION DEVELOPMENT

PROBE	COIL WIDTH	COIL SPACING	WAND LENGTH
A560SF	.060"	.060"	83 ft.
A600LC/HF/WF (.030)	.030"	.030"	83 ft.
A560 HF/SF	.030"	.060"	83 ft.
A600LC/HF/WF (.060)	.030"	.060"	40 ft.
A560LC/HF/WF	.030"	.060"	40 ft.

Abbreviations

LC = Long Cone

SF = Spring Flex

WF = Whisker Feet

HF = High Frequency

A = Bobbin Coil

TABLE 2

PROBE COMPARISON TESTS

PROBE	FREQUENCY MIX
A560SF	400/200 Support
A560SF	600/200 Copper
A600LC/HF/WF (.030)*	600/200 Copper
A560HF/SF	600/200 Copper
A600LC/HF/WF (.060)	600/200 Copper

NOTE: These tests include running the probe through:

1. The ASME Calibration Standard
2. A 3/4" SGT with a copper or support plate ring
3. The pit standard (Table 1)
4. The pit standard with copper foil over the pits

*Used at Millstone Point II in 1982.

TABLE 3

COMPARISON OF THE PROBES' S/N RATIO. PHASE SPREAD, AND SIGNAL QUALITY

PROBE	MIX	S/N RATIO[1] OF 75 MIL	100 MIL	ASME STD. PHASE SPREAD	SIGNAL[2] QUALITY
A560SF	400/200 Support	.46	.7	69°	2
A560SF	600/200 Copper	1.0	1.0	101°	1
A600LC/HF/SF (.030")	600/200 Copper	1.0	1.3	109°	3
A560HF/SF	600/200 Copper	1.25	1.5	109°	3
A600LC/HF/WF (.060")	600/200 Copper	1.60	2.25	100°	3

1. S/N Ratio is the ratio of pit signal/copper signal voltages for the 40% and 35% through pits of 75 mil and 100 mil dia., respectively.

2. Signal quality is a semiquantitative evaluation of the quality of the ASME Standard signals based on the openess and symmetry of EC signals. It is given the following values:

    1. Poor, all flaw signals closed but symmetrical

    2. Fair, deepest flaws slightly open and symmetrical

    3. Good, all but smallest flaws open and symmetrical

TABLE 4

COMPARISON OF WAND LENGTH EFFECTS ON SIGNAL AMPLITUDE AND PHASE SPREADS

Probe	Wand Length	Gain*	Vert. Signal Amplitude From .100" DIA Pits: 42% thru	35% thru	29% thru	ASME Standard Phase Spread
A560HF/SF	83'	51/41	.75v	.50v	.25v	146°
A560LC/HF/WF	40'	48/40	.45v	.30v	.15v	146°
A560LC/HF/WF	83'**	48/40	.80v	.50v	.25v	135°
A600LC/HF/WF	40'	49/40	1.20v	.75v	.40v	149°
A600LC/HF/WF	83'**	49/40	1.20v	.75v	.45v	135°

* The gains used in testing were set according to the attached procedure. The two A560 probes were set up so that their signals were maximized while the A600 probe was set up so the signal from a 180° copper ring was approximately 9 volts peak to peak. At the gain settings listed, the voltage from the 180° copper ring for the A560 and A600 probes were 5-7 volts (P-P) and 9 volts, respectively.

* These wand lengths were created by adding a 43' length of cable (the same cable as is used in the probe wands) to the end of the 40' probe wand.

TABLE 5

COPPER SAMPLE DIMENSIONS

DIMENSION	360°	180°
ID	.788"	.756"
OD	.872"	.844"
Wall Thickness	.042"	.044"
Length	.780"	.772"

TABLE 6

COMPARISON OF RESULTS USING A 180° OR A 360° COPPER RING FOR FREQUENCY MIXING

PROBE	MIX FREQUENCY	180°/360° RING MIX	GAIN CH1/CH2	PIT SIGNAL W/ CU .100" DIA x 42%	SIGNAL QUALITY 1/
A560HF/SF	600/200 Copper	360°	40/27	.45v Vert.	3
A600LC/HF/WF (.060")	600/200 Copper	360°	40/25	.7v Vert.	3
A560HF/SF	600/200 Copper	180°	51/40	1.0v Vert.	3
A600LC/HF/WF (.060")	600/200 Copper	180°	50/36	2.0v Vert.	3+

Signal quality is a semiquantative evaluation of the quality of the ASME Standard signals based on openess and symmetry of the EC signal. It is given the following values:

1. Poor, all flaw signals closed but symmetrical
2. Fair, deepest flaws slightly open and summetrical
3. Good, all but smallest flaws open and symmetrical

TABLE 7

EFFECT OF FREQUENCY ON PIT DETECTION IN THE PRESENCE OF COPPER WITH AN A600LC/HF/WF (.060") PROBE

FREQUENCY MIX (KHZ)	GAIN CH1/CH2	PHASE SPREAD	ANGLE OF 42% THRU WALL PIT W/O CU	W/CU	VOLTS, VERT. FROM .100"x42% PIT	SIGNAL [1] QUALITY
600/150 Copper	50/36	118°	139°	121°	1.6v	3
600/200 Copper	50/36	102°	124°	108°	2.0v	3
600/250 Copper	50/37	110°	124°	105°	1.9v	3
600/300 Copper	50/37	109°	112°	99°	1.5v	3

1. Signal quality is a semiquantitative evaluation of the quality of the ASME standard signals based on openness and symmetry of the EC signals. It is given the following values:

   1. Poor, all flaw signals closed but symmetrical
   2. Fair, deepest flaws slightly open and symmetrical
   3. Good, all but smallest flaws open and symmetrical

TABLE 8

EFFECT OF FREQUENCY ON PIT DETECTION,
IN THE PRESENCE OF COPPER WITH AN A560HF/SF PROBE

FREQUENCY MIX (KHZ)	GAIN CH1/CH2	PHASE SPREAD	ANGLE OF 50% THRU WALL PIT W/O CU	W/CU	VOLTS, VERT. FROM .100"X42% PIT	SIGNAL 1 QUALITY
600/150 Copper	51/40	The copper signal could not be elimianted.				
600/200 Copper	51/40	80°	114°	100°	1.0v	3
600/250 Copper	51/40	85°	95°	79°	.9v	3
600/300 Copper	51/44	97°	96°	75°	.75v	3

Signal quality is a semiquantitative evaluation of the quality of the ASME standard signals based on openness and symmetry of the EC signals. It is given the following values:

1. Poor, all flaw signals closed but symmetrical
2. Fair, deepest flaws slightly open and symmetrical
3. Good, all but smallest flaws open and symmetrical

TABLE 9

PAIRED PIT RESOLUTION, 1/
IN THE ABSENCE OF COPPER USING A
600/250 KHZ COPPER ELIMINATION FREQUENCY MIX

PROBE	SPACING .026"	.059"	.088"	.126"	.186"	.247"
A600LC/HF/WF (.060")	1	2	2	3	3	3
A560HF/SF	1	2	2	2	3	3
A560LC/HF/WF	1	2	2	3	3	3
A560SF	1	1	2	2	3	3
A600LC/HF/WF (.030") 2/	2	2	3	3	3	3

1/ Resolution Key. This analysis is based upon a slow speed playback of the recorded signals on the eddy current display.

1. Poor, pit signals not resolved
2. Good, pit signals resolved but incomplete
3. Excellent, pit signal resolved and complete

2/ Use of this probe significantly reduces the overall quality of the tests being run (See Table 4).

TABLE 10

PAIRED PIT RESOLUTION, 1/
IN THE PRESENCE OF COPPER USING A 600/250 KHZ
COPPER ELIMINATION FREQUENCY MIX

PROBE	PIT SPACING					
	.026"	.059"	.088"	.126"	.186"	.247"
A600LC/HF/WF (.060")	1	2	2	3	3	3
A560HF/SF	1	2	2	2	3	3
A560LC/HF/WF	1	2	2	2	3	3
A560SF	1	1	1	2	3	3
A600LC/HF/WF (.030") 2/	2	2	2	3	3	3

1/ Resolution key. This analysis is based upon a slow speed playback of the recorded signals on the eddy current display.

1. Poor, pit signals not resolved
2. Good, pit signals resolved but incomplete
3. Excellent, pit signal resolved and complete

2/ Use of this probe significantly reduces the overall quality of the tests being run (See Table 4).

TABLE 11

Description of Chemically Induced Pit Sample #1
(With Copper Plating)

Pit (From Deepest Pitted End)	Depth*
1st	79% thru
2nd	63% thru
3rd	54% thru
4th	35% thru

Material: Inconel 600

OD: .750"

ID: .654"

Plating Thickness: .002" - .004"

*Depth measured with a dial depth gage.

TABLE 12

Description of Chemically Induced Pit Sample #2

Pit (From Deepest Pitted End)	Depth*
1st	69% thru
2nd	100% thru
3rd	65% thru
4th	40% thru

Material: Inconel 600

OD : .750"

ID : .654"

*Depth measured with a dial depth gage.

TABLE 13

Description of Chemically Induced Pit Sample #3

Pit (From Deepest Pitted End)	Depth*
1st	50% thru
2nd	65% thru
3rd	40% thru
4th	27% thru

Material: Inconel 600

OD : .750"

ID : .654"

* Depth Measured with a dial depth gage