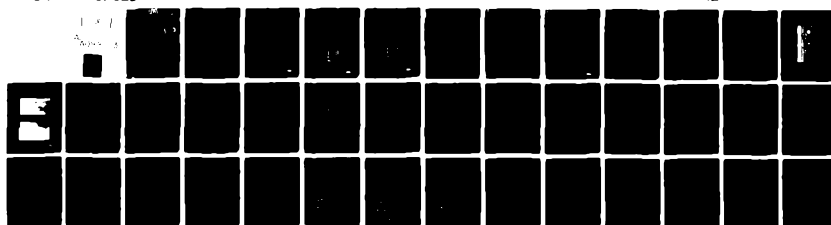


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XM746 PRACTICE FUZE.(U)
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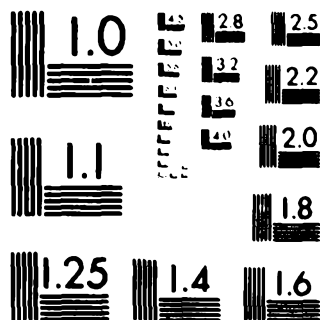
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DM746 PRACTICE FUZE

Progress Report

1 December 1979 through 31 January 1980

Progress Report No. 3

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Contract No. DAAK10-79-C-0040

9 Progress Report 1 Dec 79-31 Jan 80.
(see 5)

11 31 Jan 80

Prepared for:

Department of the Army
U. S. Army Armament Research and
Development Command

442 400

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Prepared by:

MBAssociates
Bollinger Canyon Road
San Ramon, California
94583

222400 80 3 21 047 alt

1.0 INTRODUCTION

This progress report covers the period December 1, 1979 through January 31, 1980 under Contract DAAK10-79-C-0040. This program is for the design and development of the XM746 Practice Fuze Spotting Charge.

In the month of December, (18th and 19th), ballistic testing of the Practice Fuze Spotting Charge was conducted at Ft. Lewis, Washington.

1.1 Object of Test

The primary objective of the testing was to determine which of the three spotting charge candidates, MOD "E", ORI or MBA would reliably produce the best visible smoke cloud in a muddy target area.

1.2 Hardware

All spotting charges were loaded into XM747E2 fuzes and assembled to the four port 155mm, XM804 projectile, (see Figure 1).

The SW522 (MOD "E") and ORI composition was contained within the fuze, as shown in Figure 2. The MBA configuration was assembled, as shown in Figure 3, (see Table 1 for fuze configuration and Tables 2 and 4 for composition).

The weapon used was a 155mm Howitzer with M4A2/5 charge.

1.3 Testing Matrix

The first phase was to eliminate either the MOD "E" or ORI spotting charge based on their performance; the best performance (MOD "E") was carried forward to Phase II testing along with the MBA spotting charge. The Phase II testing yielded a final candidate for further evaluation in Phase III testing, see Table 3.

1.4 Test Set-Up

To observe and score the spotting charges, F.O. (forward observers) were stationed at 2000 and 4000 meters for Phase I and 1800

to p. 5

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Justification/		
By <i>John L. Smith</i>		
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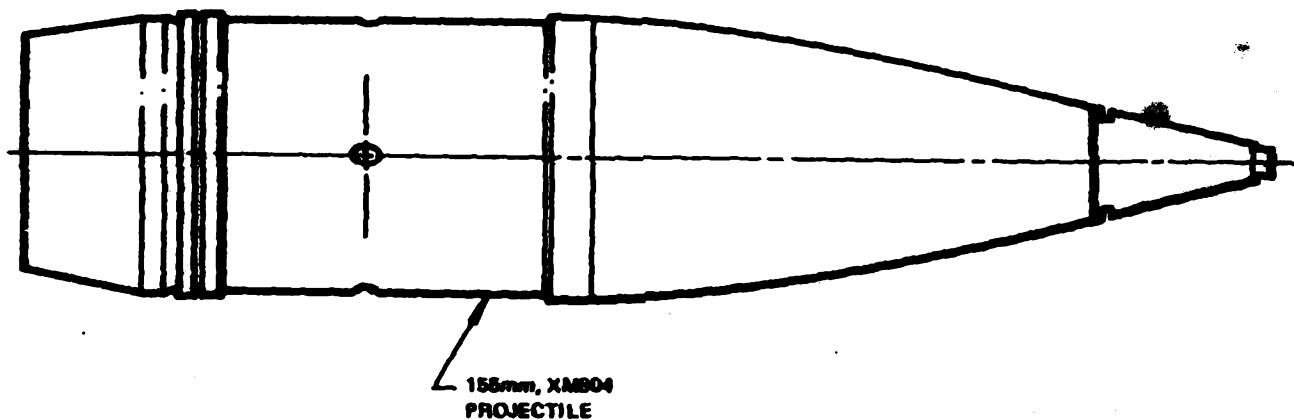


FIGURE 1
PROJECTILE ASSEMBLY

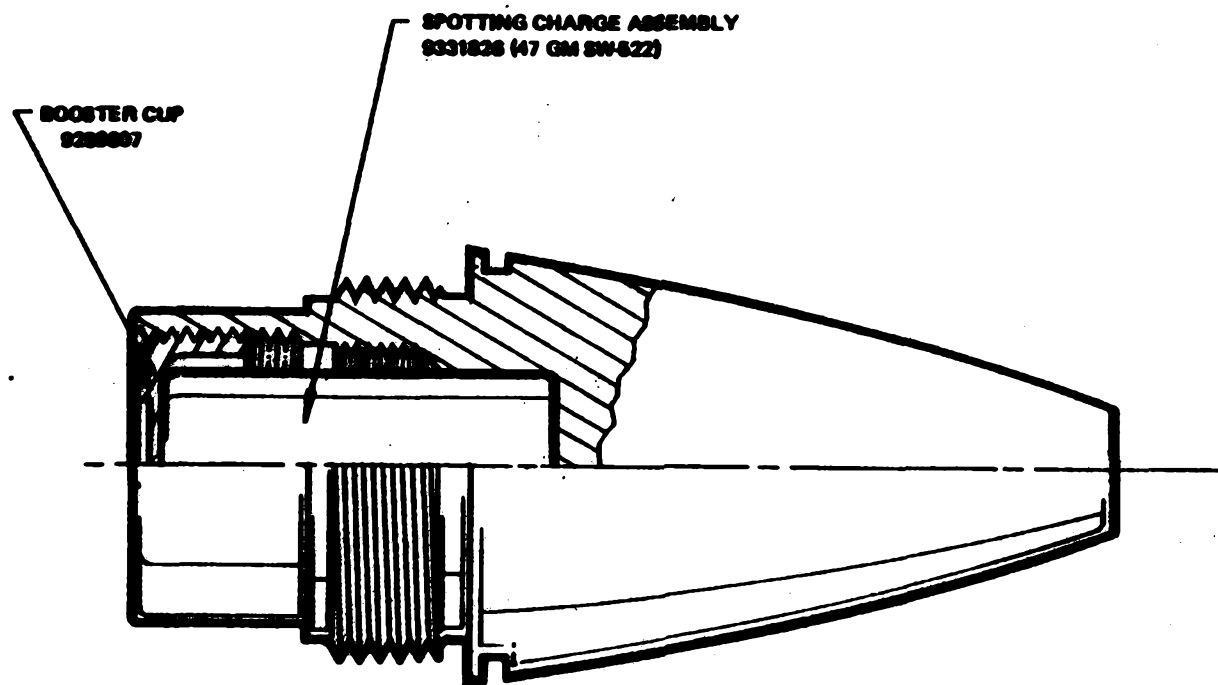


FIGURE 2
MOD "E" AND ORI CONFIGURATION

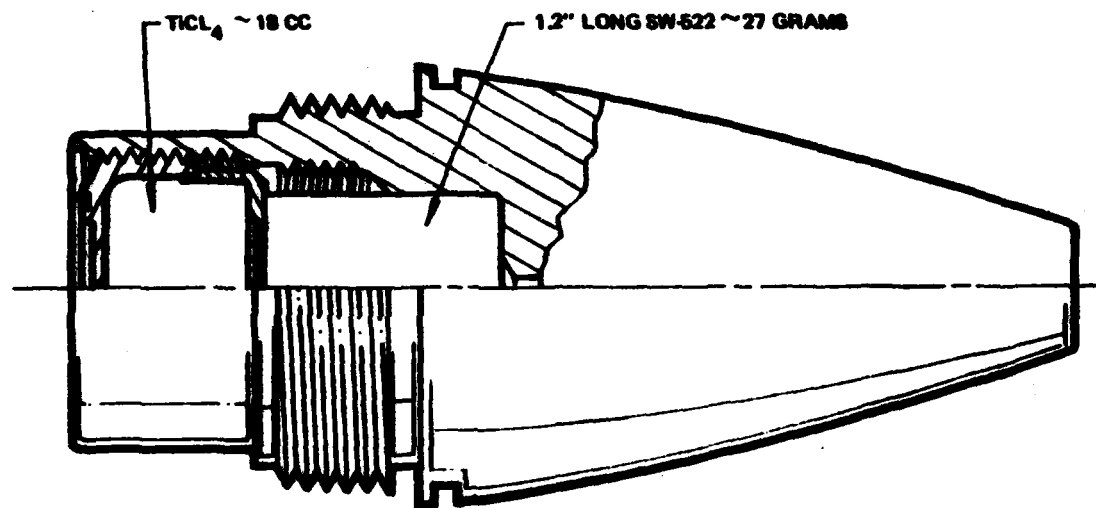


FIGURE 3
TiCl₄/MOD "E" CONFIGURATION

3020-10000

MBA

TABLE 1

XM747

FUZE CONFIGURATIONS
(FOR FT. LEWIS TESTING)

M739 MOD

Description

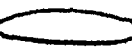
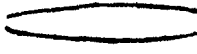
- cont* → MOD E is a  Standard M739 Fuze with cap, cross bar holder assembly, M1 Delay Plunger, safe/army assembly and explosive booster removed, loaded with 47 grams ARRADCOM pyro mix SW522. See Table 2 for composition.
- ORI is the  Same fuze as MOD E except SW-522 smoke composition replaced with a red phosphorous composition. See Table 2 for composition.
- MBA is  Similar to MOD E except smoke charge consists of titanium tetrachloride (TiCl₄) a cold smoke composition which is expelled from the fuze body by an ARRADCOM MOD E smoke ejection charge. See Table 4 for composition.
- 

TABLE 2

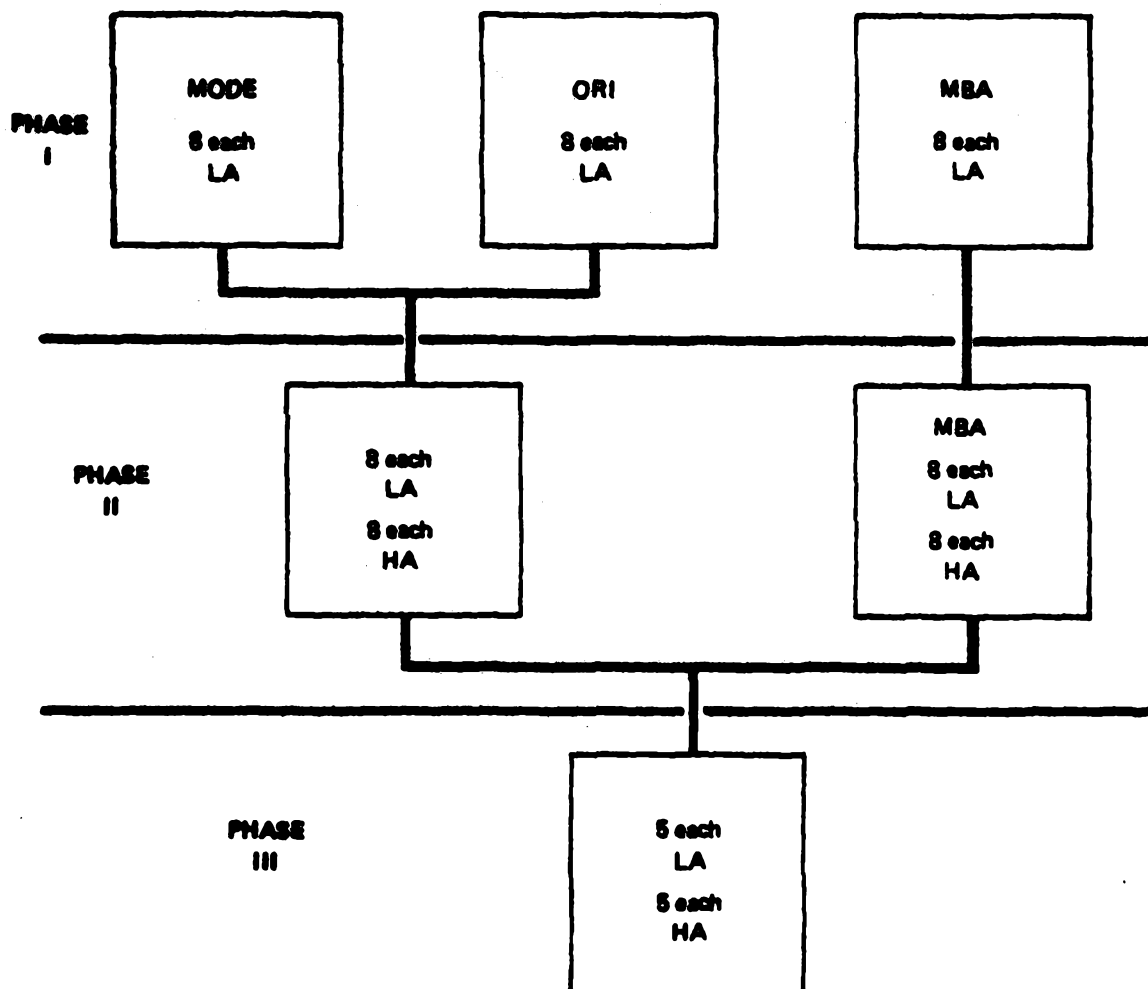
DESCRIPTION OF
PYROTECHNIC SMOKE COMPOSITIONS

SW-522:

<u>Ingredient</u>	<u>% by Wt.</u>	<u>Specification</u>
Zinc Dust	40 $\pm$ 1	JAN-Z-365
Potassium Perchlorate	20 $\pm$ 0.5	MIL-P-217A, GrA, C14
Potassium Nitrate	20 $\pm$ 0.5	MIL-P-15613 C1 2
Aluminum (Atomized)	20 $\pm$ 0.5	MIL-P-14067A Type II

ORI

Magnesium	17	MIL-P-14067 Type I
Sodium Nitrate	17	MIL-S-322B, GrB
Phosphorous, Red	63	MIL-P-211A, C1 2
Zinc Oxide	3	MIL-Z-291C GrA C1 1



LA - OE: 522 mls
HA - OE: 1054 mls

**TABLE 3
TEST MATRIX**

TABLE 4

TITANIUM TETRACHLORIDE - TiCl_4 PHYSICAL PROPERTIES

Chemical Formula	TiCl_4
Molecular Weight	189.7
Color, Form	clear liquid
Melting Point	-30°C
Boiling Point	136.4°C
Specific Gravity (20°C)	1.726
Density (lbs./gal.)	14.4
Stability	decomposes in the presence of moist air

SPECIFICATIONS (Weston, Michigan Plant)

Titanium, wt. %	25.0 minimum		
Chlorine, wt. %	74.0 minimum		
Color	50 maximum		
Metal Analysis, ppm			
Tin (Sn)	10 max.	Chromium (Cr)	5 max.
Aluminum (Al)	10 max.	Antimony (Sb)	5 max.
Iron (Fe)	15 max.	Arsenic (As)	10 max.
Vanadium (V)	10 max.	Lead (Pb)	1 max.
Silicon (Si)	10 max.	Nickel (Ni)	5 max.
Copper (Cu)	5 max.		

SAFETY AND HANDLING

Titanium tetrachloride must be maintained under inert atmosphere. Nitrogen containing less than 10 ppm oxygen is recommended. Exposure to moisture in the air generates hydrochloric acid and titanium dioxide. Refer to the titanium tetrachloride "Product Safety Information" sheet for safety information, and to the Stauffer brochure "A Guide to Cylinder Unloading."

THE ABOVE INFORMATION REPRODUCED FROM STAUFFER CHEMICALS PRODUCT DATA SHEET

and 2000 meters for Phase II and III testing. The F.O. were a mix of ARRADCOM, Ft. Sill, Ft. Lewis, Chamberlin, MBA and Yuma Proving Ground personnel, see attachment A.

The scoring system for Phase I was complex. Two F.O.'s used a number system and 5 F.O.'s used an alphabetical rating system which related as follows: 1 & U = unobserved, 6 & E = excellent. For the balance of the testing, F.O.'s used a numbering system 1 through 5 where 1 = unobserved and 5 = excellent. The spotting charges were fired in an alternate order, MOD "E", ORI, MBA.

The tests were recorded on video tape and 16mm camera as follows: Phase I, 16mm camera and video at 2000 meters and video at 4000 meters. Phases II and III, video at 1800 and 2000 meters and 16mm camera at 1800 for the first part of Phase II.

1.5

Weather

Rain was quite persistent for the two days of testing. The weather conditions listed below were submitted by Ft. Lewis.

		Temperature	Humidity	Wind Direction from (True)	Wind Speed
18th.	1100	51°	89%	-	Calm
	1200	52°	89%	-	Calm
	1300	51°	92%	-	Calm
	1400	52°	82%	-	Calm
	1500	51°	86%	120°	4 Knots
19th.	1100	53°	77%	200°	8 knots
	1200	53°	80%	180°	10 knots
	1300	53°	83%	200°	10 knots
	1400	53°	80%	210°	10 knots
	1500	51°	85%	200°	8 knots
	1600	50°	89%	190°	4 knots
	1700	49°	89%	190°	4 knots

1.6

Ballistic Testing

The Phase I testing went as planned on December 8, 1979, with eight each of MOD "E", ORI and MBA spotting charges fired at a low QE of 522 mils. There were 4 F.O.'s at 2000 meters and 3 at 4000 meters.

Based on the scoring of the 7 F.O's (MOD "E" 174, MBA 143 and ORI 122, summarized in Attachment A), the ORI spotting charge was dropped from further testing. The smoke clouds for MOD "E" and MBA, when observed, appeared similar in intensity and duration (see Figure 3). The flashes observed were judged poor to none for both configurations. Low priority was placed on the flash due to the fact that it is a night training requirement.

For the Phase II testing, the F.O's at 4000 meters were moved to 1800 meters due to the poor visibility and difficulty in spotting the smoke cloud at the extended range. In total there were 4 F.O's at 1800 meters and 7 F.O's at 2000 meters. No Phase II and III testing was conducted on December 9th.

In the first part of Phase II testing, 8 each MOD "E" and MBA fuzes were fired at a low QE of 522 mils. The MBA spotting charge, with the exception of one round, displayed a smoke cloud which was judged to be good to excellent in both cloud size and persistence. The MOD "E" performed much better than the Phase I testing but was scored significantly lower than the MBA spotting charge. See Figure 5 for a photographic comparison of the typical cloud size.

In the high QE (1054 mils) portion of Phase II testing, the MOD "E" and MBA spotting charges performed pretty much the same with many unobserved and relatively poor smoke clouds. The poor performance was not totally unexpected. Static testing at MBA in September 1979 showed the function time of the MOD "E" spotting charge to be an average of 2 ms and MBA to be 2.5 ms, from ignition to display of smoke from the projectile smoke ports. Analysis suggests that on soft ground at high QE's these times are equivalent to, to slightly longer than, projectile burial time.

Figure 6 presents ARRADCOM's estimate of the worst case, most rapid burial condition for the 155mm projectile in question. This condition exists in deeply saturated light sand soils. The ARRADCOM model predicts coverage of the smoke ports located 19 inches back on the projectile, 1.8 milliseconds after impact.

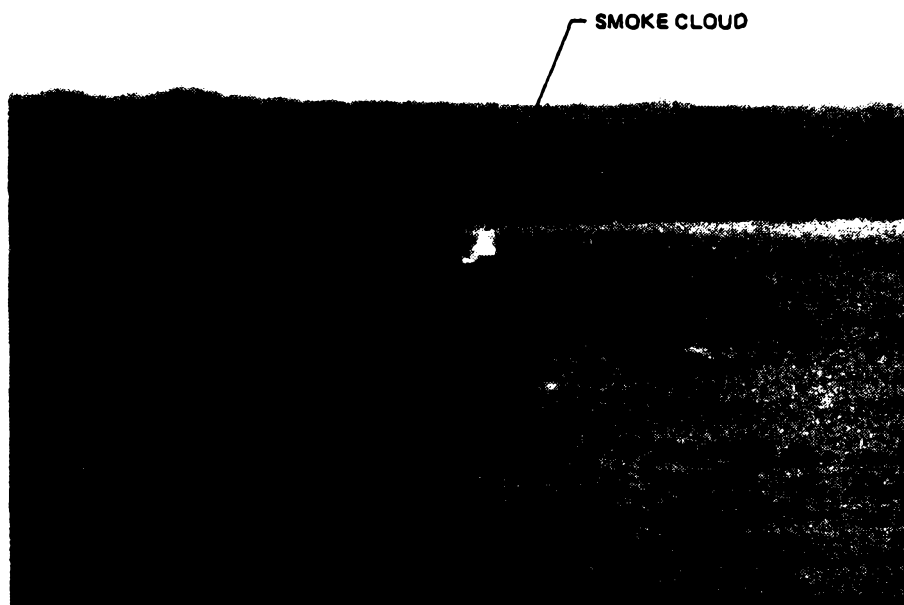
SMOKE CLOUD



FIGURE 4
PHASE I TESTING
TYPICAL SMOKE CLOUD

11

0710-16984
MBA



SMOKE CLOUD

MOD "E"



MBA TiCl_4

FIGURE 5
SMOKE CLOUD COMPARISON

MBA

0710-16985

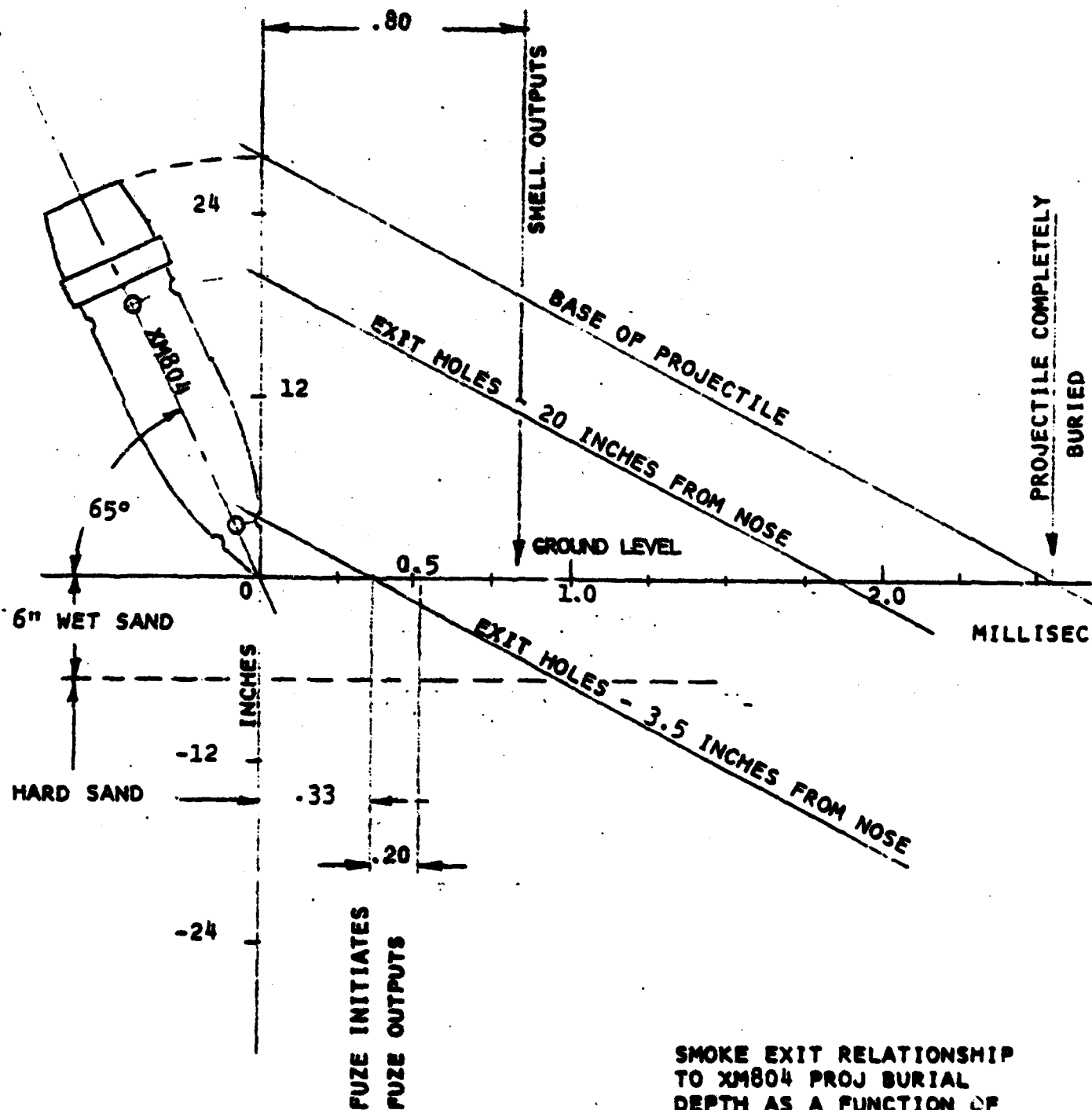


FIGURE 6

L. POST
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Based on the total scoring of the Phase II testing, the MBA spotting charge was selected for the Phase III testing. Due to the poor performance at the high QE firing, it was decided the Phase III firing would be conducted at a low QE of 522 mils.

The Phase III testings were mixed. Three out of the nine firings resulted in smoke clouds judged good to excellent. The remaining six rounds yielded mixed results reported by the observers, per Attachment A, they ranged from fair to no visible smoke cloud.

Rounds 1, 2 & 3 of this test series were assembled to projectiles with 90° ports.

1.7 Conclusions

The smoke clouds produced by the MBA spotting charge, particularly in the low QE Phase II testing, were judged to develop the superior cloud. However, due to the inconsistent performance of both the MOD E and $TiCl_4$ spotting charges, further improvement is needed. Design requirements to achieve function time repeatability need to be better understood. Quality control and manufacturing methods need to be reviewed in detail and upgraded, or otherwise changed, if it is determined they are causing inconsistent spotting charge performance. Environmental testing should be undertaken to establish the effects, if any, on fuze performance after T&H, transportation, vibration, etc.

1.8 Data Reduction

Figures 7 through 17 show the 90% confidence envelopes for each of the fuze tests with the composite of MOD "E" and $TiCl_4$ fuzes shown in Figures 8 and 9. All data has been normalized by averaging the evaluation with the number of observers, adjusting the evaluation to a common scale, and using zero for a non-visible cloud. The cloud observations are scaled from 0 to 4.

A standard procedure, see Attachment B, was used to determine the statistical quantities for 90% confidence. The curves can be interpreted as follows: The cumulative distribution shows the

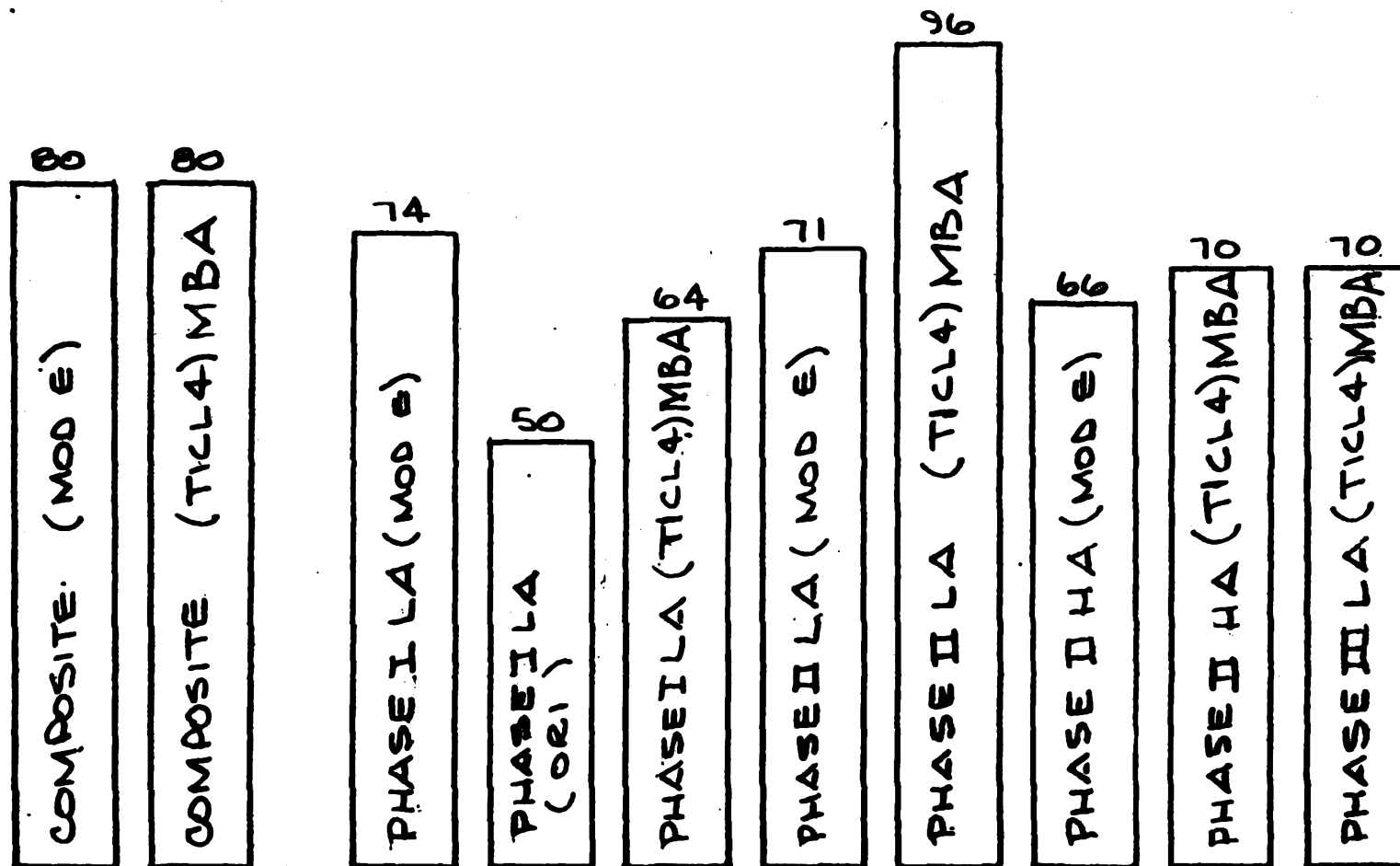


Figure 7 - Comparison of Visible Flares Out of 100 at 90% Confidence

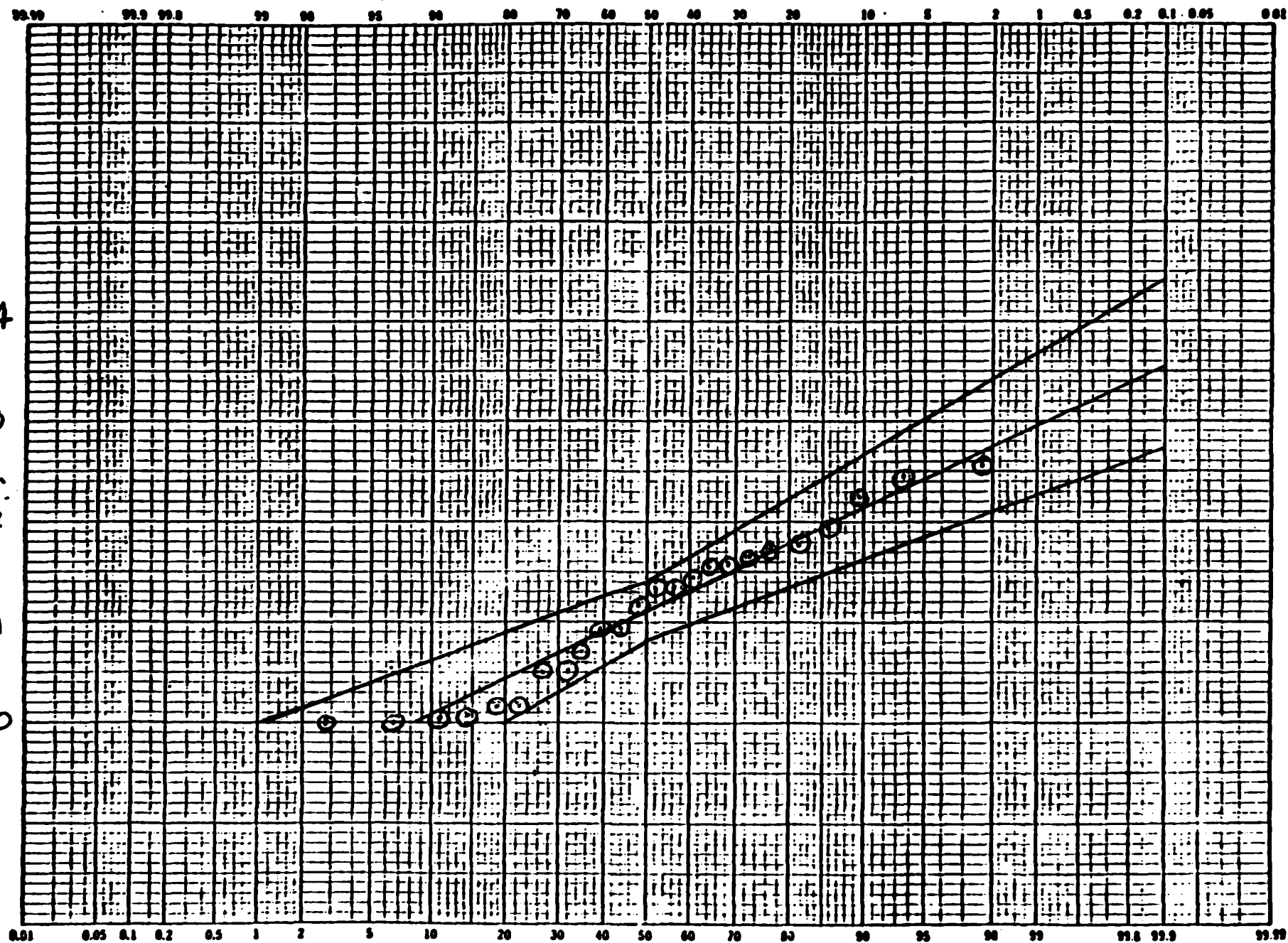


Figure 8 - MOD "E" Composite

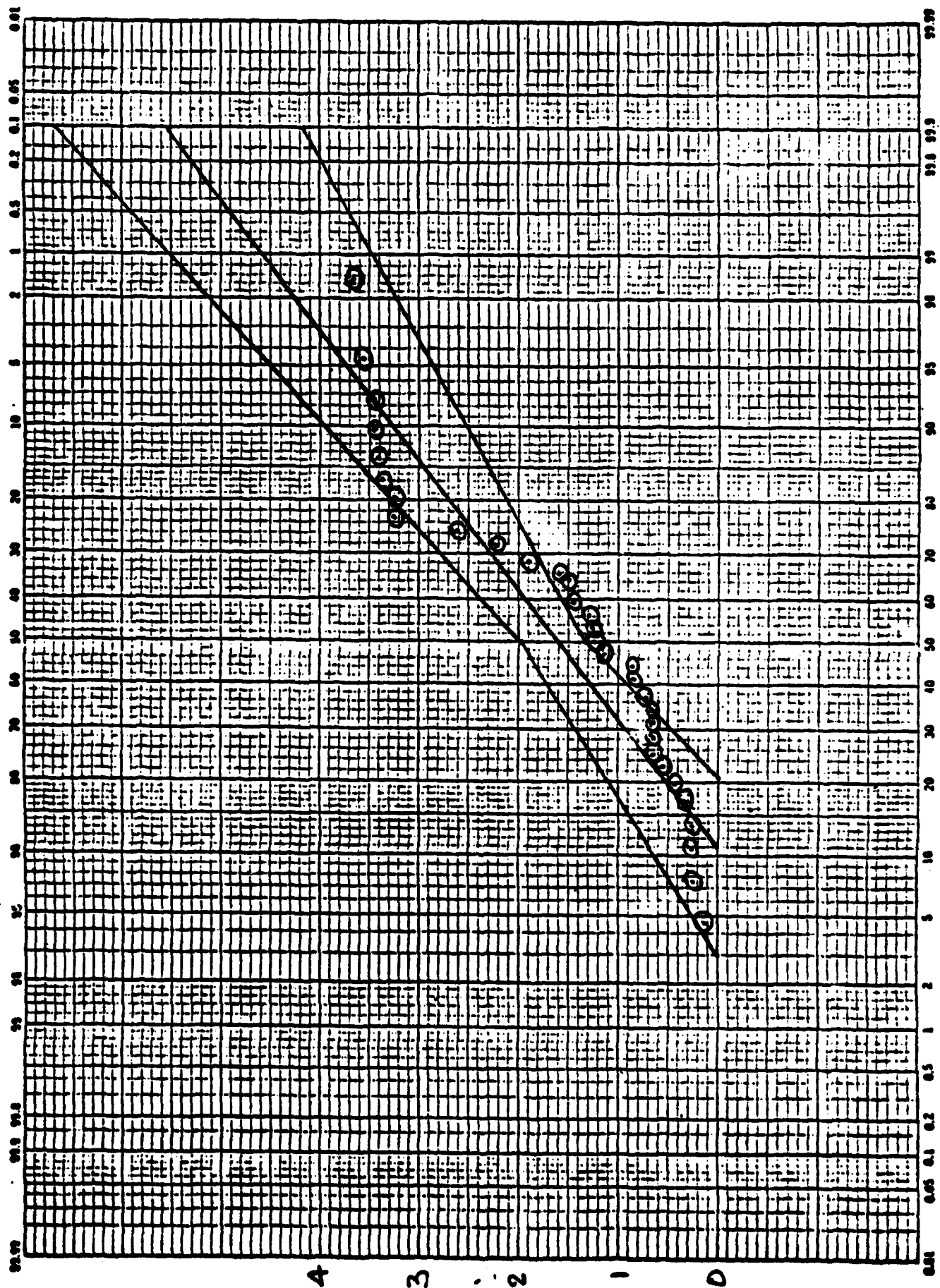


Figure 9 - MRA Composite

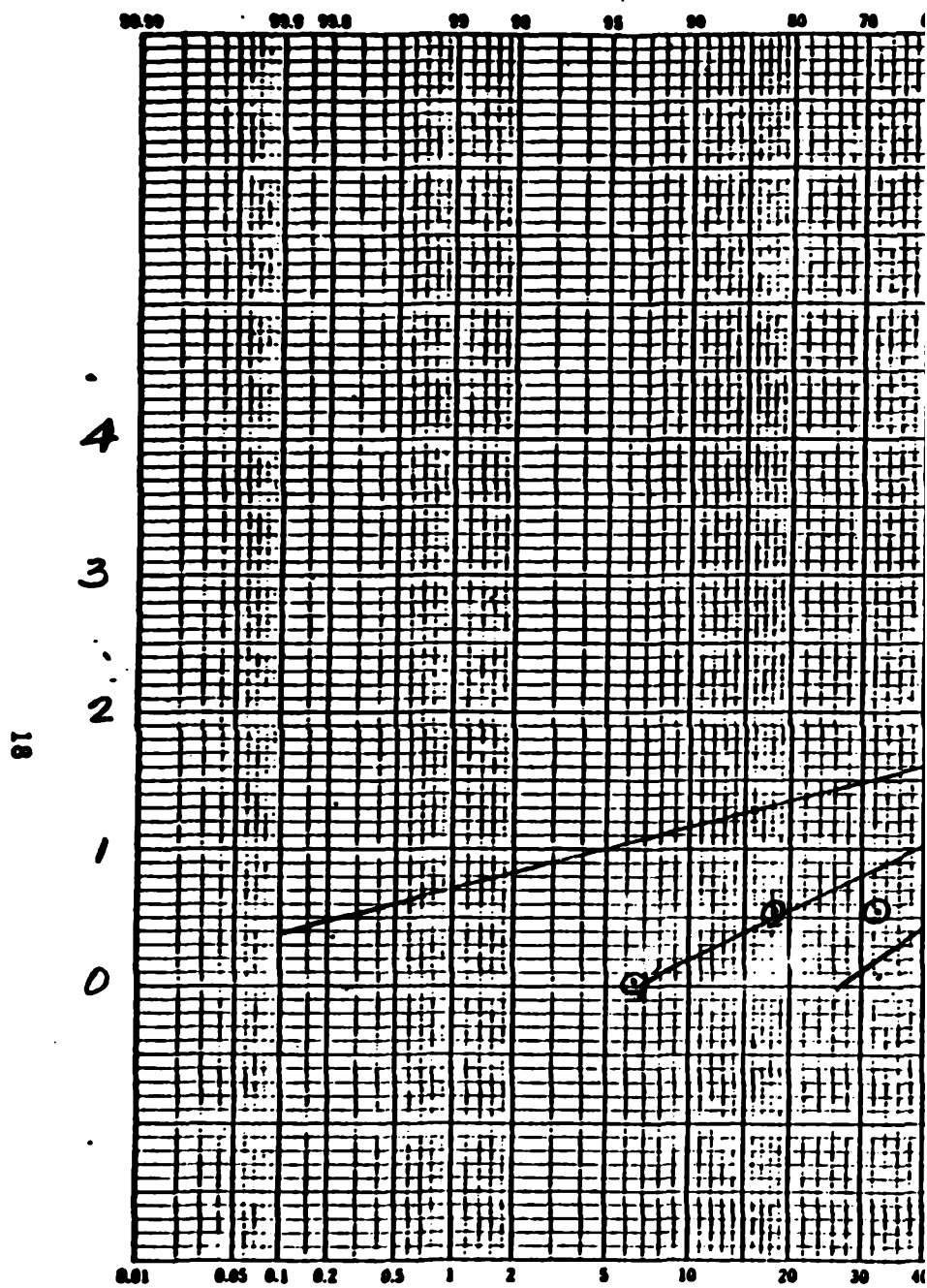
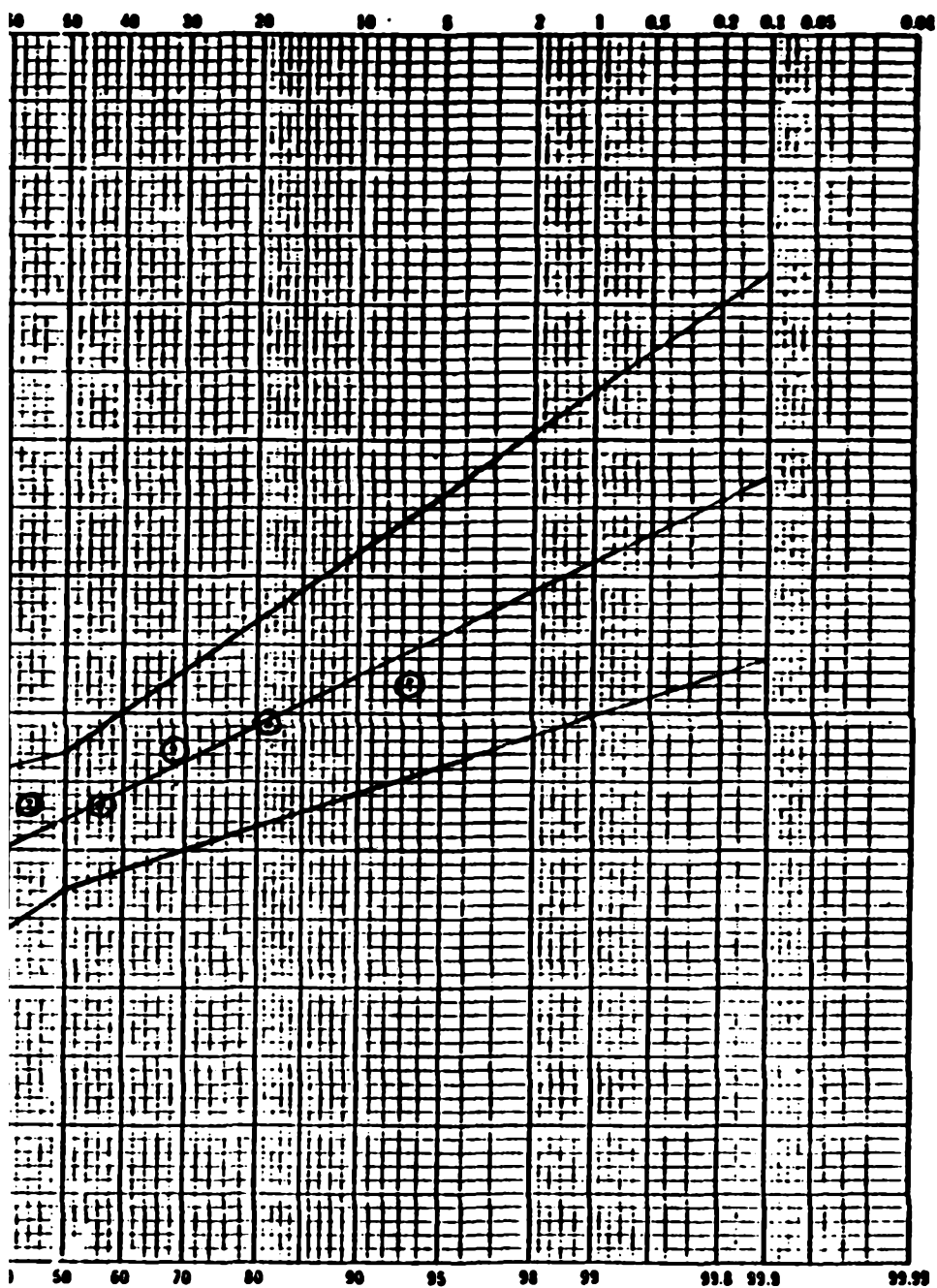


Figure 10 - MOD "



E'' Phase I Low Angle

0 - 1 - 2 - 3 - 4

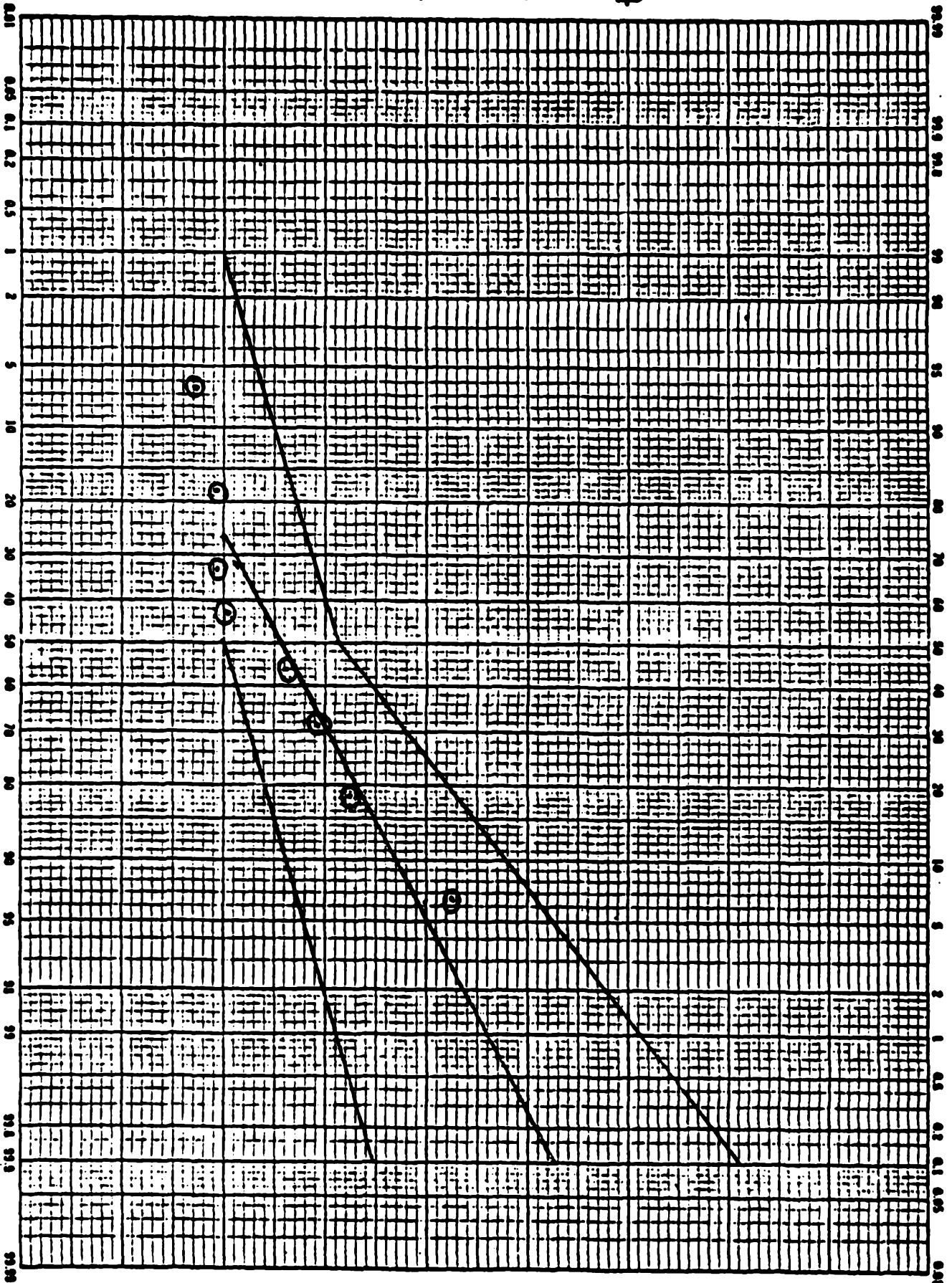


Figure 11 - ORI Phase I Low Angle

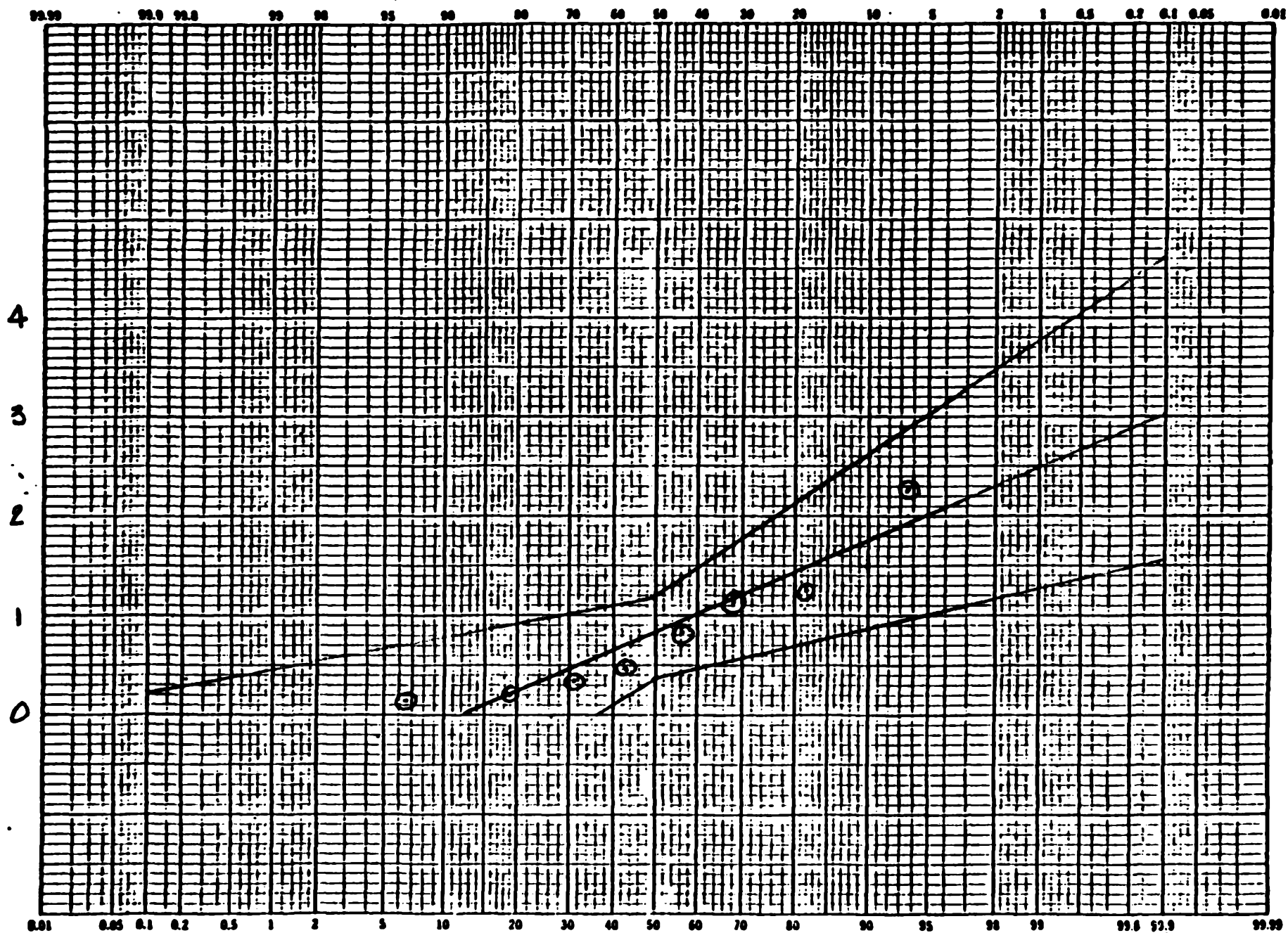


Figure 12- MBA Phase I Low Angle

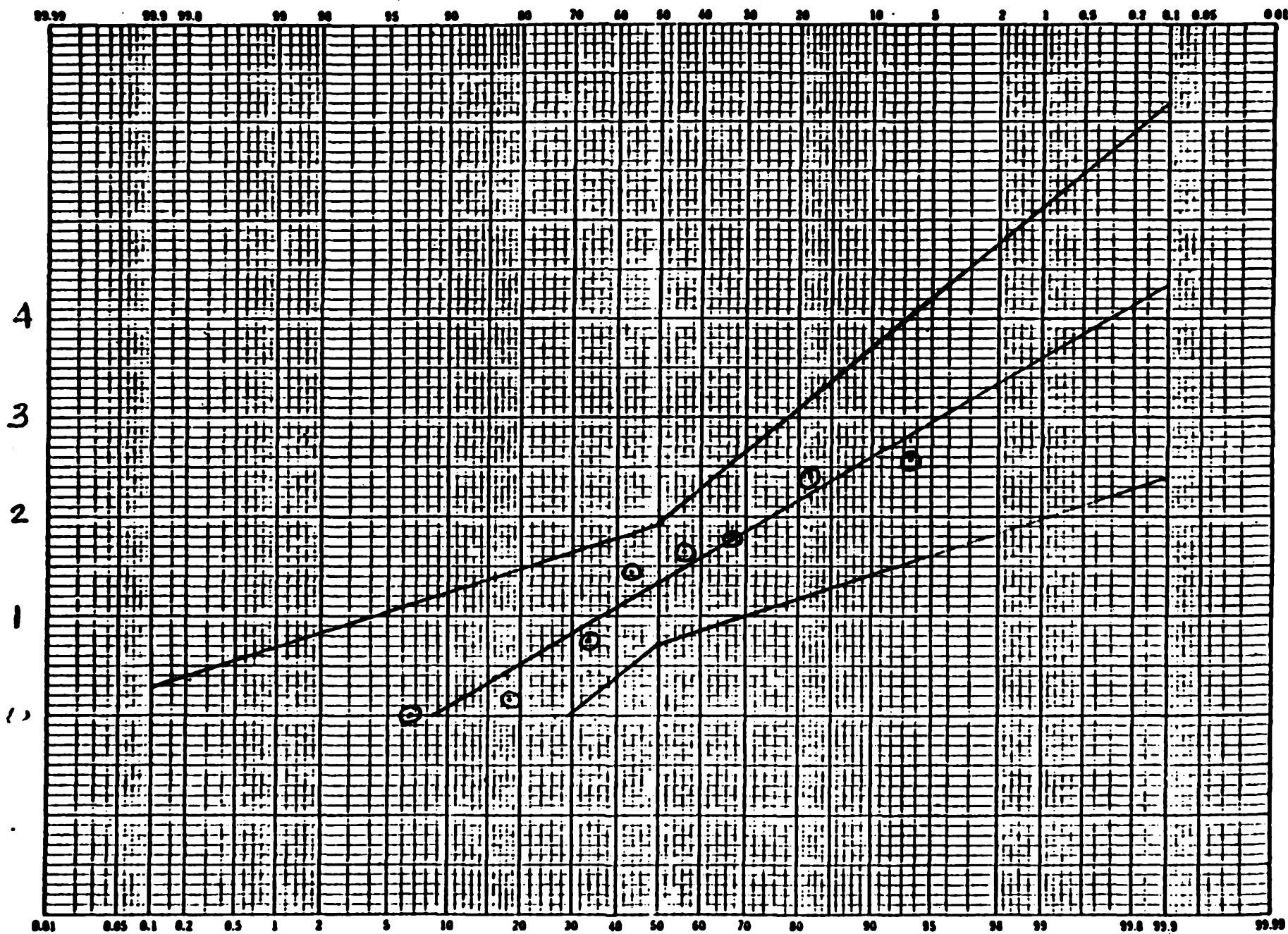


Figure 13 - MOD "E" Phase II Low Angle

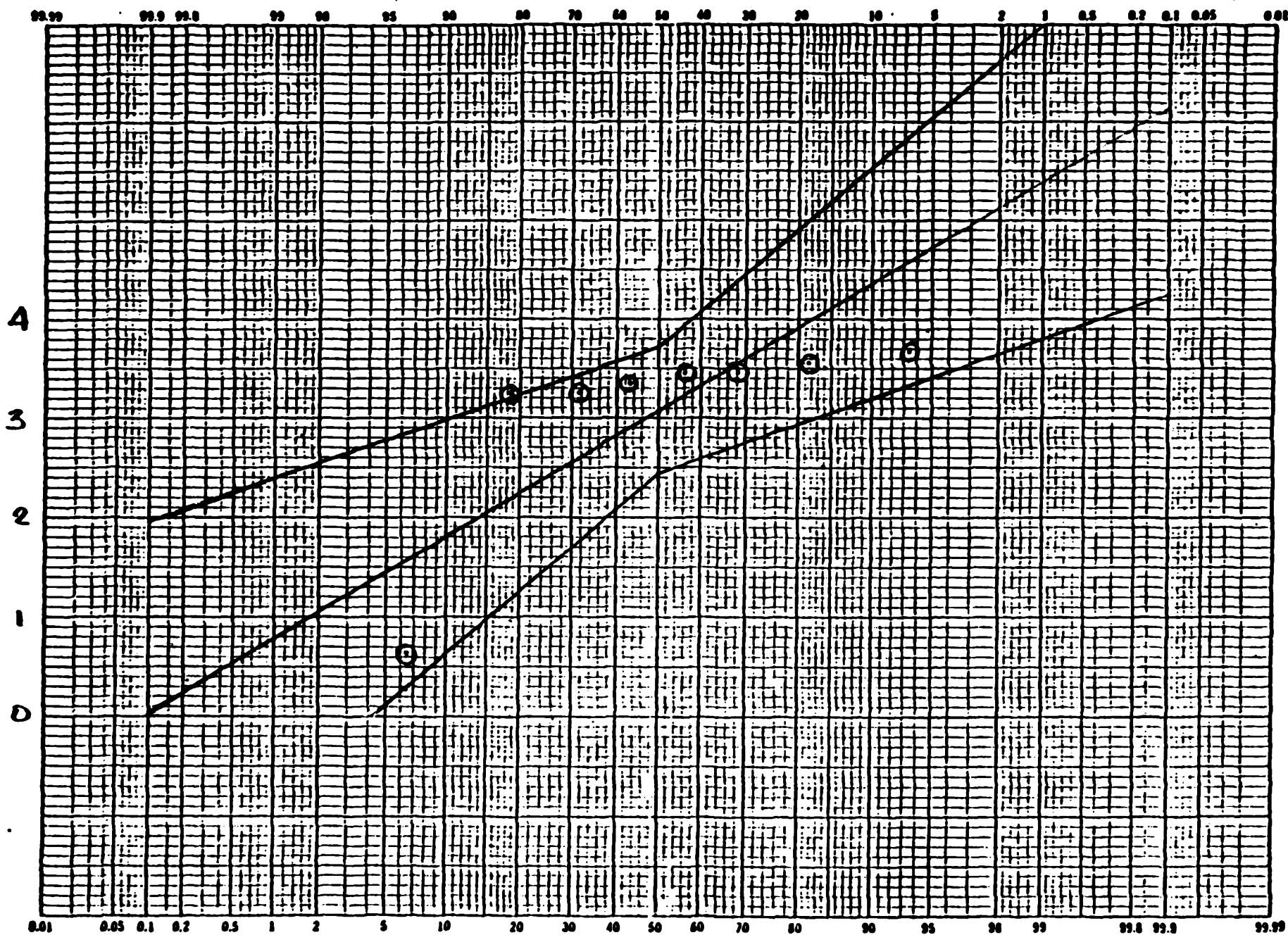


Figure 14 - MBA Phase II Low Angle

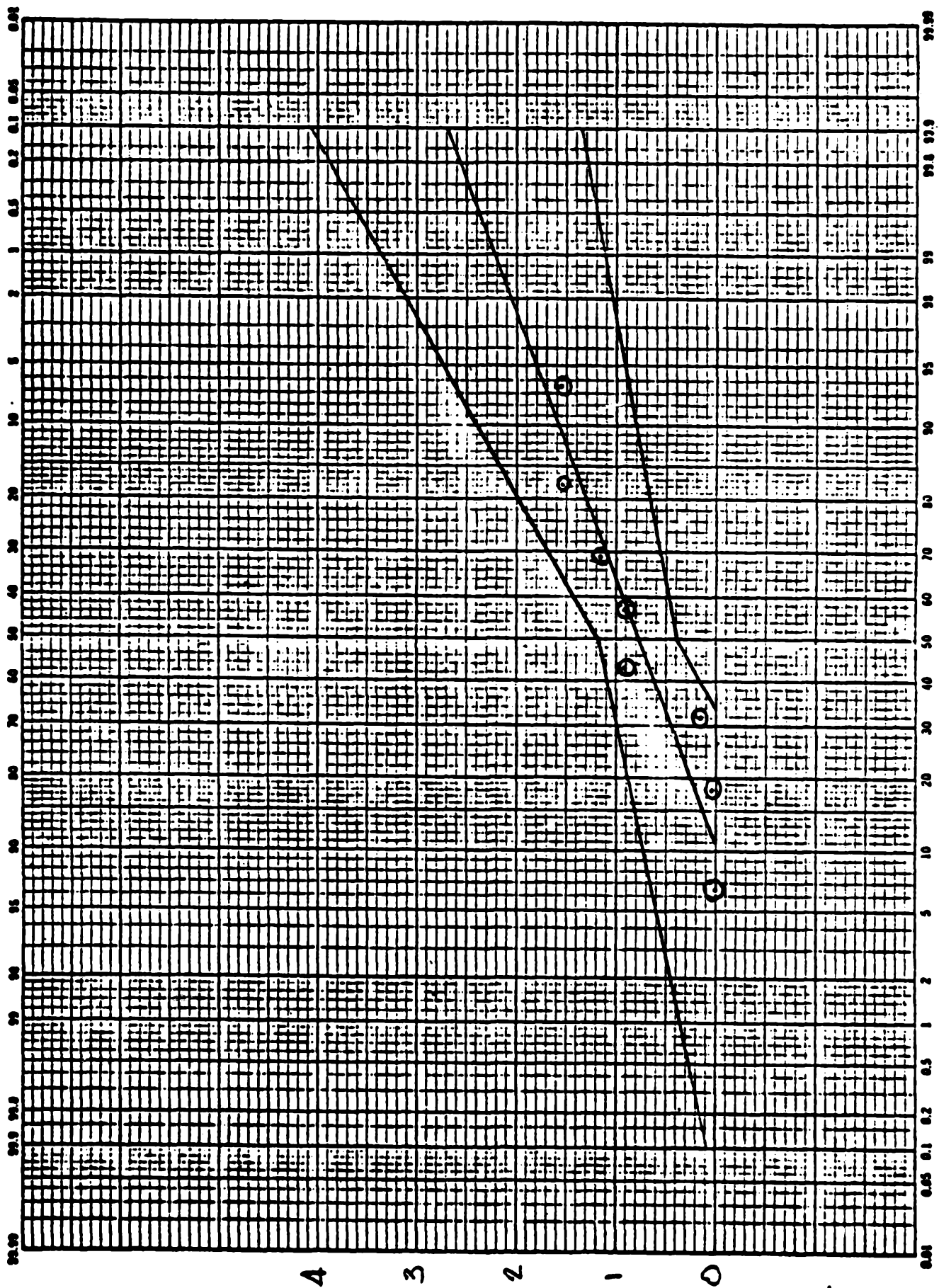


Figure 15 - MOD "g" Phase II Low Angle

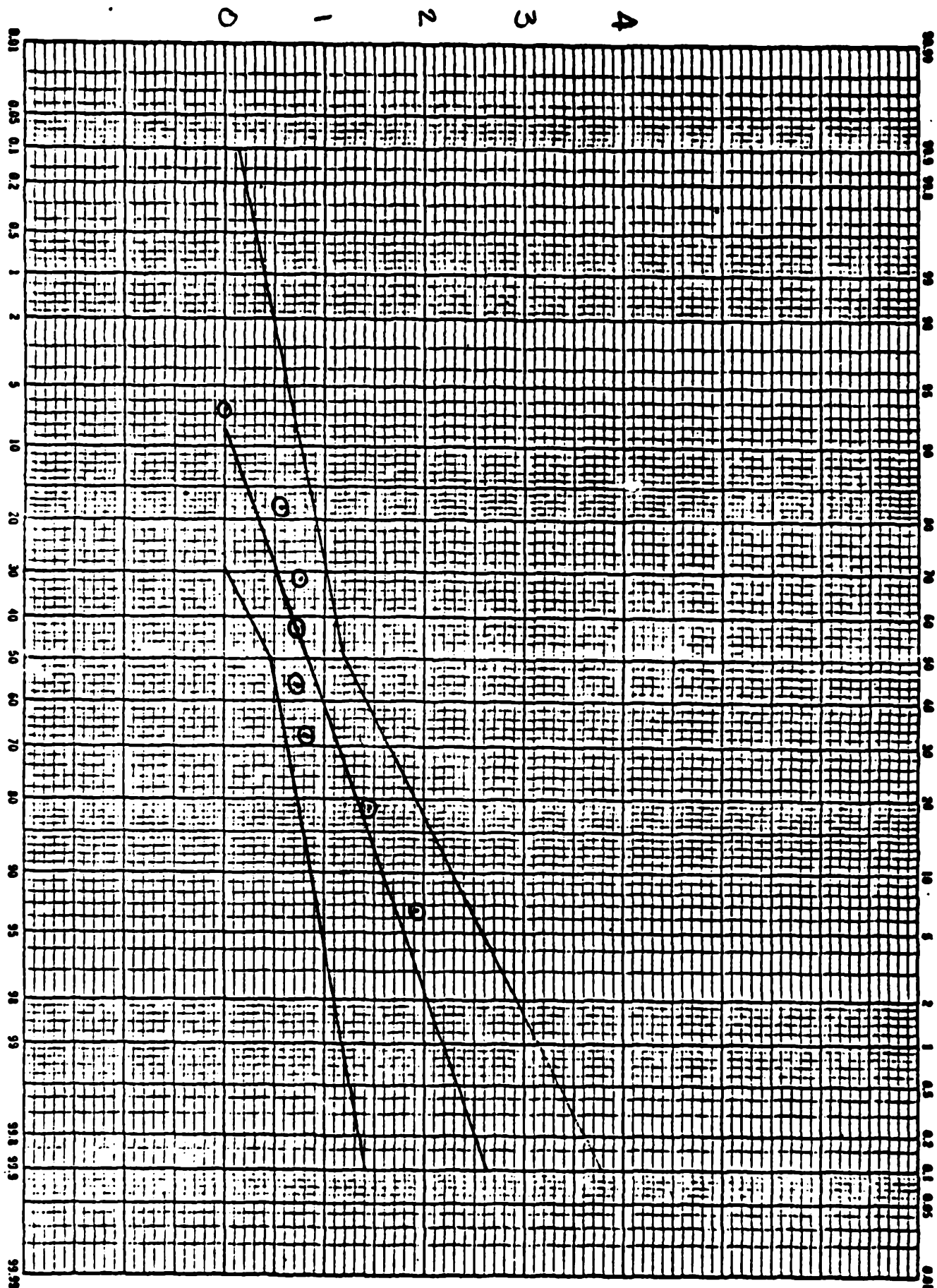


Figure 16 - MBA Phase II Low Angle

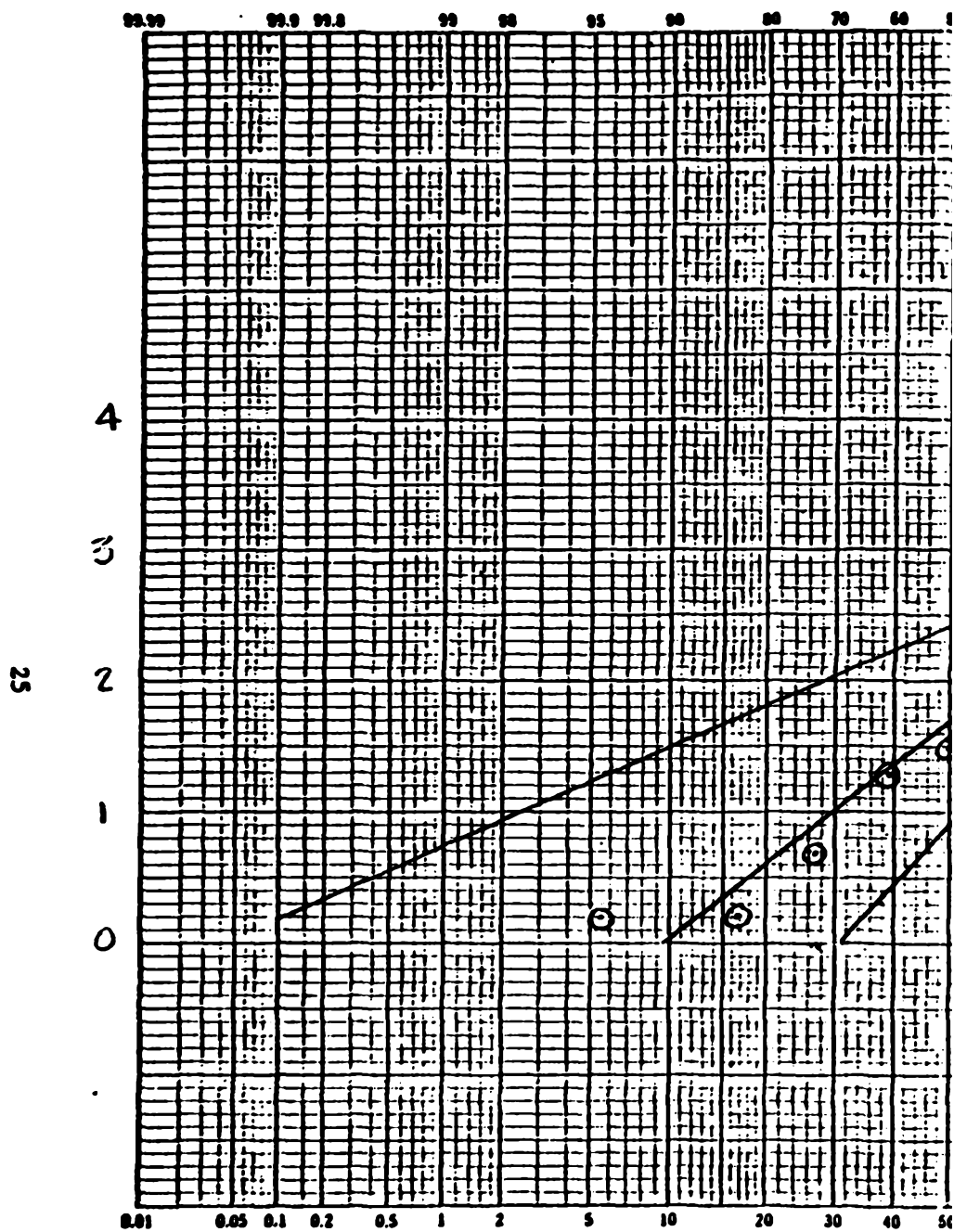
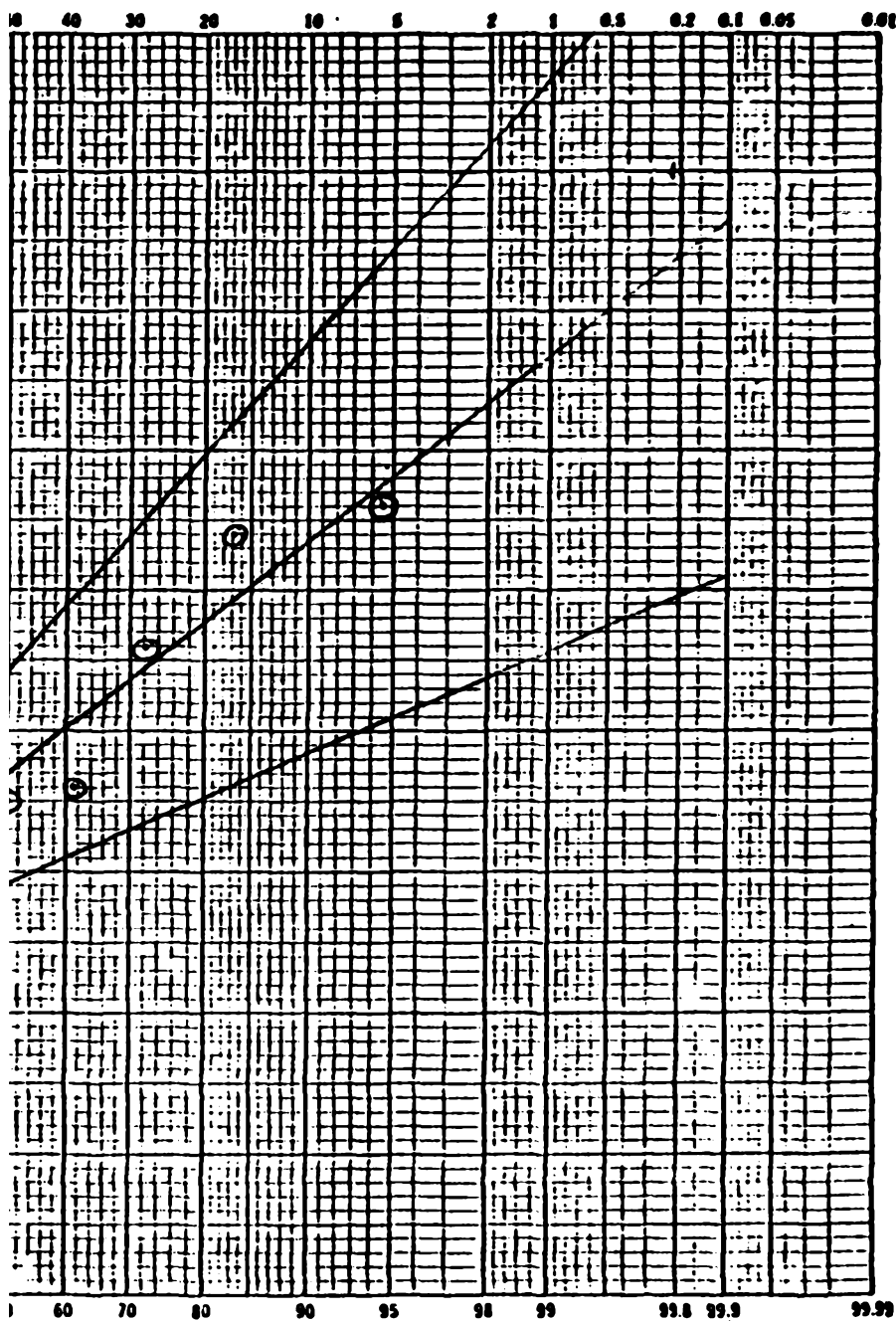


Figure 17 - MBA Phase I



II Low Angle

number of fuzes that will either exceed or be less than a certain value. Using Figure 10 as an example, the intersection of the lower curve with zero, (20), shows the cumulative number of events that would not yield visible results or conversely, 100 less the intersection value which will give visible results. Because the curve is the 90% confidence envelope, this condition is stated as follows:

"You can be 90% confident that 80 times out of 100 the observer will see a cloud."

These results for each individual test and the MOD "E" and $TiCl_4$ composites are shown in the bar chart of Figure 4.

The center line between the 90% confidence lines is included on the figures because it represents the average line or 50% confidence curve. The test points are ordered in increasing values and plotted on the figures using the procedures given in the reference. Note that, for the most part, all data points fall within the 90% confidence envelope and that approximately 50% fall on either side of the 50% confidence curve.

The composite 90% confidence performance of the MOD "E" and the $TiCl_4$ configurations are approximately equal. The MOD "E" has a lower average observed intensity, but also a lower dispersion about the average than the $TiCl_4$, which yields good high confidence values. The $TiCl_4$, although some 40% higher than the MOD "E" in average observed intensity, experienced a lower reliability and, therefore, a higher dispersion. It can be expected that with reliability improvements, the $TiCl_4$ configuration will show much better results. For instance, if the $TiCl_4$ reliability is improved to match the MOD "E" configuration, some 92 out of 100 of the $TiCl_4$ clouds would be visible at 90% confidence.

1.8

Contract Add-On

In the month of January 1980, MBA was informed of a contract add-on for \$9,250 for 576 XM747E Practice Fuzes, for additional testing at Ft. Sill and ARADCOM.

1.9

Plans for Next Period

Fabricate and assemble XM747E fuse assemblies for shipment on February 29, 1980.

1.10

Expenditures

Expenditures for January 1979 through January 1980, \$89,500.

ATTACHEMENT A

SUMMARY - FT LEWIS TEST RESULTS

FUZE, PRACT XM747E-, PROJ 155MM, XM804
(155MM NOW M114A1 - CHG M4A2/5)

DATE	QMM	MOD	PROJ MOD	QE	RNG OF OBSER (KM)	RESULTS
DEC 79		FUZE/SMOKE				
<u>PHASE I</u>						
18	8	E2/E	4-Hole	LA	1.8	FAIR TO GOOD SMOKE & FLASH
	8	E2/ORI	"	LA	TO	POOR SMOKE & FLASH (ELIMINATE IN PH II)
	8	E2/MBA	"	LA		FAIR SMOKE, NEGLIGIBLE FLASH
	5	M739	M107/T2	LA	4.0	CONTROLS
<u>PHASE II(1)</u>						
19 (AM)	8	E2/E	4-Hole	LA	1.8	POOR TO FAIR SMOKE
	8	E2/MBA	"	HA		GOOD TO EXCELLENT SMOKE (SELECT FOR PHASE III)
	8	E2/E	"	LA	TO	POOR SMOKE
	8	E2/MBA	"	HA		POOR SMOKE
	3	M739	M107/T2	2 LA, 1 HA	2.0	CONTROLS
<u>PHASE III</u>						
19 (PM)	9(2)	E2/MBA	4-Hole	LA	1.8	POOR TO FAIR SMOKE & FLASH
	1	E2/E	"	LA		POOR TO FAIR SMOKE & FLASH
	10	M739	T2	LA	TO	FLASH/SMOKE SMALL - NOT PERSISTENT
	10	M739	H6	LA		BETTER THAN T2 TYPE
	3	E1/E	NONE	LA		VERY POOR
	1	M739	M107/T2	LA	2.0	CONTROLS
TOT	98					

(1) INADVERTENTLY SEVEN XM804 PROJECTILES W/90° HOLES WERE FIRED AMONG PROJECTILES W/45° HOLES WITHOUT ASSOCIATION TO FUZE/ROUND COMBINATION.

(2) FIRST THREE ROUNDS WERE PROJECTILES WITH 90° HOLES. ALL OTHERS HAD 45° HOLES.

PHASE II - OBSERVER ANALYSIS
155MMXM804 TRAINING PROJECTILE
WITH 4 EACH 1/2" DIA PORTS

LOW ANGLE - QE 522 MILS

TEST DATE: DEC. 19, 1979 (A.M.)

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LEGEND
1. UNOBSERVED
2. POOR
3. FAIR
4. GOOD
5. EXCELLENT

OBSERVERS									
W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002
W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002
W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002
W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002
W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002
W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002
W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002
W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002
W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002	W0002

TYPE	TEST	SMOKE											FLASH											RATING
		1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11	
FUSE	SERIES	1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11	SUMMATION
	1	1	1	1	1	2	1	2	1	1	1													13
	2	3	4	4	3	2	2	1	2	1	3	2												27
	3	1	1	1	1	1	1	1	1	1	1	1												11
	4	4	5	5	4	4	3	2	4	1	3	4												39
	5	3	2	2	3	1	1	1	1	3	1	1												19
	6	3	4	3	3	3	2	2	3	1	3	2												29
	7	3	5	5	4	3	3	3	4	1	4	3												38
MOOIE	8	4	3	4	3	3	2	1	2	4	2	2												30
	TOTAL																							205
	1	2	2	3	2	2	2	1	1	1	1	1			X									18
	2	5	5	5	4	4	3	4	4	4	4	5			X									47
	3	5	5	5	4	4	4	3	5	4	4	5												48
	4	5	5	5	4	4	4	4	5	4	4	5												49
	5	5	5	5	4	4	4	4	4	5	4	5												50
	6	4	5	5	4	4	4	4	3	5	4	4	5											47
MBA	7	4	5	5	4	4	4	4	4	5	4	5												49
	8	4	5	5	5	4	4	4	5	4	5	5												51
	TOTAL																							358

NOTE:
INADVERTENTLY SEVEN XM804 PROJECTILES
WITH 90° HOLES WERE FIRED AMONG PROJECTILES
WITH 46° HOLES IN PHASE II WITHOUT ASSOCIATION
TO TYPE OF FUSE/ROUND COMBINATION.

OBSERVERS

MEASUREMENT 100M
 GI-FO 100M
 GI-FO 100M
 APRADCOM 100M
 GI-FO 100M
 GI-FO 100M
 APRADCOM 100M
 Y.P.G. 200M
 CHAMBERLAIN 200M
 APRADCOM 200M
 ET CILL 200M
 200M

PHASE II - OBSERVER ANALYSIS
 155 MMXM804 TRAINING PROJECTILE
 WITH 4 EACH 1/2" DIA PORTS
 HIGH ANGLE-QE 1054 MILS

TEST DATE: DEC. 19, 1979 (AM)

TYPE	TEST	SMOKE											FLASH											RATING
FUSE	SERIES	1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11	SUMMATION
MOD'E	1	3	2	3	3	2	2	2	3	2	3	3												28
	2	2	1	1	1	1	1	1	1	1	1	1												12
	3	1	1	1	1	1	1	1	1	1	1	1												11
	4	3	3	2	3	2	2	1	2	1	1	1												21
	5	1	3	3	3	1	3	3	4	3	2	2												28
	6	3	1	1	1	1	1	1	1	1	1	1												13
	7	2	3	3	3	1	1	1	4	1	2	3												24
	8	2	2	2	3	1	2	2	2	1	2	2												21
	TOTAL																							158
MBA	1	2	2	3	2	2	2	1	1	1	1	1												18
	2	3	3	3	2	2	2	2	4	2	2	2												27
	3	1	1	1	1	1	1	1	1	1	1	1												11
	4	2	3	2	1	1	1	1	3	1	1	2												18
	5	2	2	2	1	2	2	2	2	1	1	1												18
	6	1	3	3	3	2	2	1	2	1	1	1												20
	7	1	2	2	1	2	1	2	2	1	2	1												17
	8	1	4	4	2	2	3	4	3	2	3	3												30
	TOTAL																							161

NOTE:

INADVERTENTLY SEVEN XM804 PROJECTILES
 WITH 90° HOLES WERE FIRED AMONG PROJECTILES
 WITH 45° HOLES IN PHASE II WITHOUT ASSOCIATION
 TO TYPE OF FUSE/ROUND COMBINATION.

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LEGEND

- 1 - UNOBSERVED
- 2 - POOR
- 3 - FAIR
- 4 - GOOD
- 5 - EXCELLENT

MR. ASSOCIATES	1800M
ARCAIDCOM	1800M
ARRADCOM	2000M
ARRADCOM	2000M
CHAMBERLAIN	2000M
FT. GILL	2000M
G1-FO	2000M
G1-FO	2000M
G1-FO	2000M
G1-FO	2000M
	1800M
	2000M

LOW ANGLE-QE 522 MILS

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「HAPPY」

1. UNOBSERVED
2. POOR
3. FAIR
4. GOOD
5. EXCELLENT

ATTACHMENT B

How to Use Probability Paper to Solve Materials Problems

It can help you

1. Set specification limits
2. Check material or process performance over a period of time
3. Check a supplier's claims

by Donald Peckner, Associate Editor, Materials in Design Engineering

Application of statistical quality control principles is simplified when arithmetic probability paper is used. This type of paper has as its abscissa a probability scale, and as its ordinate a linear arithmetic scale on which the variable is plotted.

On a probability plot, a large

amount of data, which may extend over a wide range, is condensed to only two numbers: the arithmetic mean $\bar{X}$, and the estimate of the standard deviation, s . For most engineering purposes, the arithmetic mean and the estimate of standard deviation, together, furnish the information necessary

so that a material can be used.

Since 50% of the total number of observations will be above, and 50% below, the arithmetic mean, the intercept of the ordinate and the 50% abscissa can be read to obtain the mean directly.

To obtain the value of s , another well-known property of the normal distribution is used. On probability paper the area under the curve between the 16% and 84% abscissas is equivalent to the value of $\bar{X} \pm s$. Therefore, determining the intercept of the curve with the 84% abscissa and subtracting $\bar{X}$ will give the value of s directly.

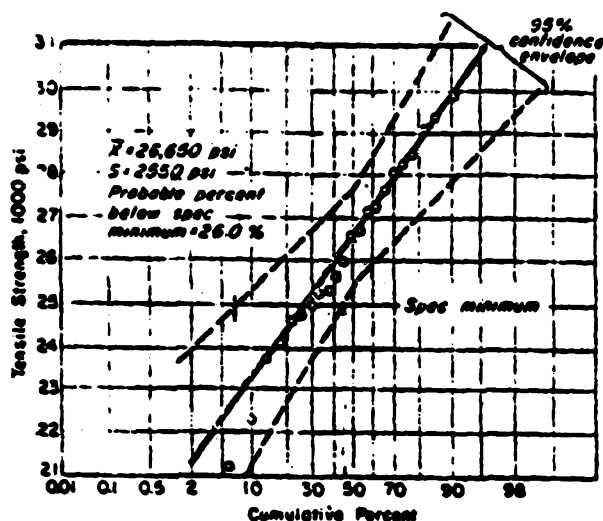
How to plot the data

The next few paragraphs describe how to plot data on prob-

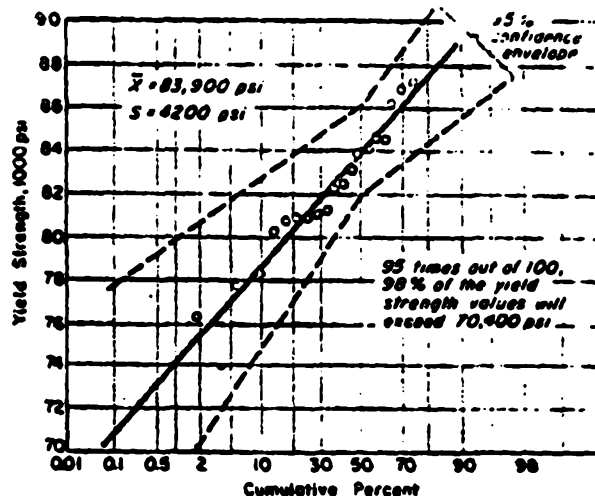
TABLE 1—CUMULATIVE PERCENTS CORRESPONDING TO VARIOUS SAMPLE SIZES

Observation Number	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	5	4.5	4.2	3.9	3.6	3.3	3.1	2.9	2.6	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.9	1.8	1.7	1.7	1.6
2	15	13.6	12.5	11.5	10.7	10.0	9.4	8.8	8.3	7.9	7.5	7.1	6.8	6.5	6.25	6.0	5.8	5.6	5.4	5.2	5.0
3	25	22.7	20.8	19.2	17.8	16.7	15.6	14.7	13.9	13.2	12.5	11.9	11.4	10.9	10.4	10.0	9.6	9.3	8.9	8.6	8.3
4	35	31.8	29.2	26.9	25.0	23.3	21.9	20.6	19.4	18.4	17.5	16.7	15.9	15.2	14.6	14.0	13.5	13.0	12.5	12.1	11.7
5	45	40.9	37.5	34.6	32.1	30.0	28.1	26.4	25.0	23.7	22.5	21.4	20.4	19.6	18.75	18.0	17.3	16.7	16.1	15.5	15.0
6	55	50.0	45.8	42.3	39.2	36.7	34.4	32.3	30.6	29.0	27.5	26.2	25.0	23.9	22.9	22.0	21.2	20.4	19.6	19.0	18.3
7	65	59.1	54.2	50.0	46.4	43.3	40.6	38.2	36.1	34.2	32.5	30.9	29.6	28.3	27.1	26.0	25.0	24.1	23.2	22.4	21.7
8	75	68.2	62.5	57.7	53.5	50.5	46.9	44.1	41.7	39.5	37.5	35.7	34.1	32.6	31.25	30.0	28.9	27.8	26.8	25.9	25.0
9	85	77.3	70.8	65.4	60.7	56.7	53.1	50.0	47.2	44.8	42.5	40.5	38.7	37.0	35.4	34.0	32.7	31.5	30.4	29.3	28.3
10	95	86.4	79.2	73.1	67.8	63.3	59.4	56.0	52.8	50.0	47.5	45.2	43.2	41.3	39.6	38.0	36.6	35.2	33.9	32.8	31.7
11		95.5	87.5	80.8	75.0	70.0	65.6	61.8	58.4	55.3	52.5	50.0	47.7	45.7	43.75	42.0	40.4	38.9	37.5	36.2	35.0
12			96.3	88.5	82.1	76.7	71.9	67.7	63.8	60.5	57.5	54.7	52.2	50.0	47.9	46.0	44.2	42.6	41.1	39.7	38.3
13				96.2	88.2	82.3	78.1	73.6	69.4	66.0	62.8	59.5	56.8	54.4	52.1	50.0	48.1	46.3	44.6	43.1	41.7
14					96.4	88.6	84.4	79.8	75.6	71.3	67.5	64.4	61.4	58.7	56.25	54.0	51.9	50.0	48.2	46.6	45.0
15						96.7	88.8	84.6	80.4	76.4	72.5	68.1	64.8	62.1	60.4	58.0	55.8	53.7	51.8	50.0	48.3
16							96.9	91.2	86.1	81.6	77.5	73.5	70.5	67.4	64.6	62.0	59.6	57.4	55.4	53.7	51.7
17								97.1	91.7	86.9	82.5	78.6	75.0	71.8	68.75	66.0	63.5	61.1	58.9	56.9	55.0
18									97.2	92.2	87.5	83.4	79.6	76.1	72.9	70.0	67.3	64.9	62.5	60.4	58.3
19										97.4	92.6	88.1	84.1	80.5	77.1	74.0	71.2	68.5	66.1	63.8	61.7
20											97.5	93.0	88.6	84.8	81.25	78.0	75.0	72.5	69.8	67.3	65.0
21												97.7	93.2	89.2	85.4	82.0	78.8	75.9	73.2	70.7	68.3
22													97.7	93.5	89.6	86.0	82.7	79.6	76.8	74.2	71.7
23														97.9	94.0	90.0	86.5	83.3	80.4	77.6	75.0
24															97.9	94.0	90.0	87.0	83.9	81.1	78.3
25																98.0	94.2	91.0	87.5	84.5	81.7
26																	98.1	94.4	91.1	88.0	85.0
27																		98.1	94.5	91.4	88.3
28																			98.2	94.6	91.7
29																				98.3	94.8
30																					98.3

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1—Distribution of tensile strength on arithmetic probability paper is accurate check on material performance.



2—Distribution of yield strength forecasts minimum expected values for use in setting specification limits.

ability paper in two situations: 1) when the number of data is small, and 2) when the data are available in large quantities that cannot be conveniently handled without grouping.

After arranging the data so that cumulative percentages can be obtained and plotted, the next step is to determine the scatter of data that might be encountered. This can be done by making use of the confidence envelope which is described in detail in an accompanying box.

When the number of data is small (30 or less)—Arithmetic probability paper, in this case, is used as follows:

1. Arrange the data in order

TABLE 2—ARRANGING DATA FOR USE WITH TABLE 1

Observation	Rearranged, Magnitude Increasing	Cumulative Percent*
477	370	4.2
370	440	12.5
491	463	20.8
463	471	29.2
440	477	37.5
465	478	45.8
506	488	54.2
491	491	62.5
471	483	70.8
488	496	79.2
478	508	87.5
483	509	95.8

*Taken from Table 1.

of increasing magnitude and assign each datum point a cumulative percentage value from Table 1.

2. Choose an appropriate scale on the abscissa and plot the data against the appropriate cumulative percentage value on the ordinate.

Table 2 is an example of random numbers rearranged and assigned a cumulative percentage from Table 1.

When the number of data is large—When more than 30 observations must be plotted, the method just described becomes both lengthy and tedious. The procedure is varied as follows:

1. Tabulate the number of observations that lie in equal-sized intervals. The interval should be at least 10 times the last significant figure to which the values are measured.

2. Calculate the percentage of

observations in each interval and determine the cumulative percentage in and below the interval.

3. Plot the cumulative percent on the probability scale against the top of each interval on the abscissa.

A typical arrangement of data is shown in Table 3.

How probability paper can be used

To check material performance

—Fig 1 demonstrates the use of arithmetic probability paper to check performance of a material. The data represent a permanent mold cast aluminum alloy with a specified minimum tensile strength of 25,000 psi. Data were obtained over a three month period. As seen in Fig 1:

1. Average tensile strength to be expected is 26,650 psi.

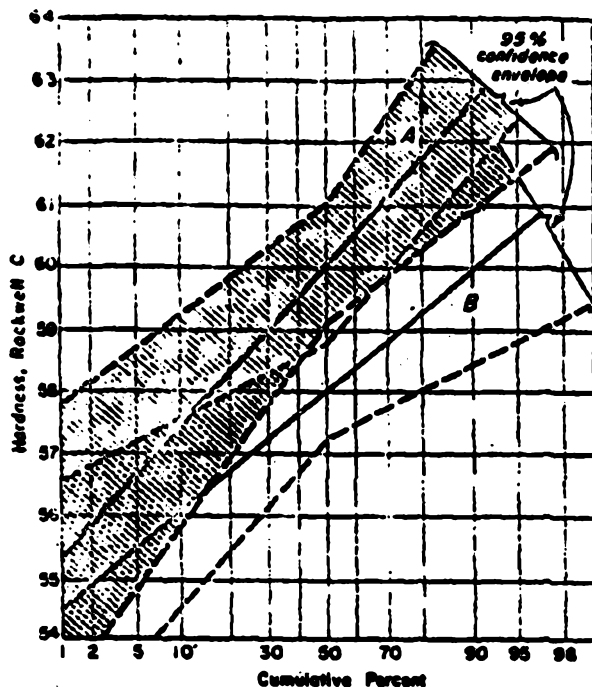
2. By inspection, the intercept of the specification minimum and the curve indicates that 26% of

TABLE 3—ARRANGING LARGE NUMBERS OF OBSERVATIONS

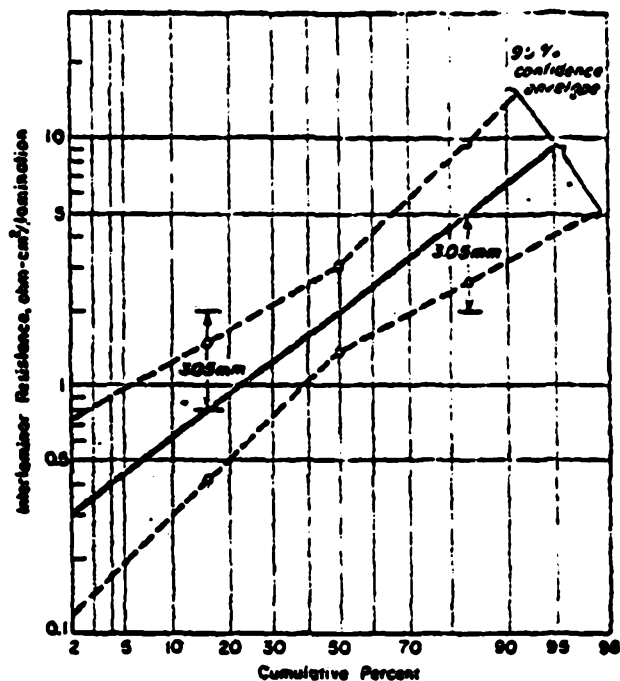
Interval, arbitrary units	Number of Observations in Each Interval	Observations in Each Interval, %	Cumulative Percent
6.01-6.10	1	0.5	0.5
6.11-6.20	9	4.5	5.0
6.21-6.30	36	18.0	23.0
6.31-6.40	68	34.0	57.0
6.41-6.50	57	28.5	85.5
6.51-6.60	24	12.0	97.5
6.61-6.70	4	2.0	99.5
6.71-6.80	1	0.5	100.0

*This number cannot be plotted since, theoretically, it is at infinity on this scale.

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3—Two groups of hardness data are compared. Since confidence envelopes do not overlap at the 50% ordinate, the groups are different and Process A will produce better results than Process B 95% of the time.



4—Confidence envelope for logarithmic probability paper. Estimate of standard deviation (s) is made equivalent to distance between 50% ordinate and either 16% or 84% ordinate.

the material will probably be below the specification minimum.

3. The confidence envelope indicates that 95 times out of 100, as little as 7.5% and as much as 45% of the material can be expected to exhibit a tensile strength below the specification minimum.

Probability paper, then, shows the engineer how well a material is performing and suggests a course of action to follow. In this case, there are two possible courses: either revise the specification properties in accordance with the facts of actual performance, or choose a new alloy for the application.

To set up specification limits—Take a case where a literature survey turned up a promising casting alloy but, as usual, only average mechanical properties were quoted. Since an arithmetic average gives no indication of values at the extremes of a distribution, a more precise estimate of mechanical properties was needed for specification purposes.

By pouring tensile bars from several experimental heats, it is possible to forecast the minimum

expected values of yield strength, tensile strength, elongation, etc., and incorporate them into a specification. In this use the probability plot in Fig 2 indicates that 95% of the time a specified yield strength of 70,000 psi will be obtained 98 times out of 100.

To compare sets of data—An additional useful application of arithmetic probability paper is the comparison of several sets of data to determine whether they were picked from the same or from different distributions. This is a general engineering problem since many situations occur where a design or process is changed and a decision must be made as to whether a real improvement has been obtained, i.e., an improvement that matches the economic factors involved.

Two heat treating methods gave the hardness results plotted in Fig 3. Although the variation in hardness produced by process A is no less than that produced by process B, a comparison of the arithmetic means ($\bar{X}$) shows that process A will consistently produce higher average hardness

values. Since the confidence envelopes do not overlap at the 50% ordinate, it can be stated with 95% confidence that the two heat treating processes are significantly different.

When data are not normally distributed

One major shortcoming of probability paper should be noted here. If the data do not fall on an approximately straight line when plotted on arithmetic probability paper, this method of analysis cannot be used. Radical deviation from a straight line indicates a skewed distribution (some types of data, such as measurements of interlaminar resistance or stress rupture, seem to be inherently skewed), whereas the scale of the abscissa has been based on a normal distribution. The case with which the arithmetic mean ($\bar{X}$) and the estimate of standard deviation (s) can be obtained sometimes leads to an artificial "fit" of a straight line to the data with the consequence that invalid data are obtained. If the data are skewed, then $\bar{X}$ and s must be calculated mathematically

or the distribution of logarithms of the observations must be considered.

If logarithms are used, two approaches are possible. In the first, the logarithms of the observations are plotted on arithmetic probability paper. This is often more convenient than using logarithmic probability paper because the scale of the abscissa can be chosen to fit each set of data, while the logarithmic probability paper has a fixed number of cycles. If logarithmic probability paper has a fixed number of standard deviation, s , is obtained by subtracting the log of the 50% value from the log of the value at 84% and expressing s as the difference in logs or in fractions of log cycles.

The confidence envelope—If the logarithms of a set of observations are plotted on arithmetic probability paper, the mechanics of determining the confidence envelope are the same as those noted in the box. If logarithmic probability paper is used, the method for calculating the limits of the confidence envelope is varied slightly. Rather than estimating s on the basis of log differences, measure the distance between the 30% ordinate and 16% or 84% ordinate as shown in Fig 4. This distance is representative of the value of s and may be substituted for s in the equation used to determine the limits of the confidence envelope (see box). Consult a statistician in planning experiments.

The graphical methods just described are excellent tools for evaluating properties of materials and processes after data have been obtained. If possible, the services of a statistician should be obtained before a program is run in order to obtain maximum benefits from a minimum of data.

The statistically designed experimental program, as opposed to the normal engineering "one at a time" approach, will vary several parameters at one time. A statistical design may evaluate the existence of interactions between several variables, usually one of the pitfalls of the "one at a

TABLE 1 FOR MULTIPLYING THE ESTIMATED STANDARD DEVIATIONS OF $\bar{X}$ AND s TO OBTAIN CONFIDENCE ENVELOPES

Probability Level, %	Sample Size			
	10-15	16-20	21-30	Very Large
90.....	1.78	1.73	1.71	1.65
95.....	2.17	2.10	2.06	1.95
99.....	3.03	2.88	2.79	2.58

The Confidence Envelope

Its significance

In Fig 1-4 note that an "envelope" has been drawn around the curve representing test observations. The confidence level chosen and the confidence envelope associated with it are used to answer the question, "How reliable are the statements that have been made?"

Note also that two sets of similar observations on the same material, plotted on probability paper, will give rise to slightly different distributions. The use of a confidence envelope, which takes into account errors in the mean ($\bar{X}$) and estimate of the standard deviation (s), becomes a necessity if the interval within which a distribution lies is to be determined.

The "confidence level" desired must be determined. For most engineering purposes, the 95% confidence level is generally chosen. The degree of certainty associated with this confidence level will satisfy almost all engineering requirements.

One danger of using too high a confidence level (such as the 99% level) arises from the fact that in many engineering investigations a great many observations cannot be made. Fig 5 on the next page indicates that the degree of reliability increases with the number of observations. It also increases when the confidence level is decreased. In other words, as the width of the confidence envelope decreases, the amount of scatter to be expected in data also decreases. By sacrificing some degree of certainty it is possible to actually increase the practical utility of a statement of material properties.

How to construct it

Drawing the confidence envelope is done on the basis of the following facts:

1. The true arithmetic mean lies within the interval $\bar{X} \pm ks / \sqrt{n}$
2. The true standard deviation lies within the interval $s \pm ks / \sqrt{2n}$

The constant, k , depends on the number of observations and desired confidence level, while n represents the number of observations. The accompanying table lists approximate values of k for different confidence levels and sample sizes.

Using the values of $\bar{X}$ and s derived from Fig 1, the confidence envelope for these observations was derived as follows:

The arithmetic mean lies within the range $\pm ks / \sqrt{n}$. From Fig 1, we note that $\bar{X} = 2550$ psi. From the accompanying table, on the basis of a 95% confidence level and 22 observations, $k = 2.06$. Therefore, $ks / \sqrt{n} = \pm (2.06) (2550) / \sqrt{22} = \pm 1120$ psi.

The range of the estimate of the standard deviation is $\pm ks / \sqrt{2n}$. Since k and s remain the same, the interval is $\pm (2.06) (2550) / \sqrt{44} = \pm 790$ psi.

To construct the confidence envelope, at 50 cumulative percent plot two points: one 1120 psi above and one 1120 psi below the curve. At 16 and 84 cumulative percent, plot points 1910 psi (1120 psi + 790 psi) above and below the curve. Connecting the points produces the confidence envelope.

ϕ 50% plot $\bar{X} \pm ks / \sqrt{n}$
 ϕ 16 plot $(\bar{X} - s) \pm (ks / \sqrt{n} + ks / \sqrt{2n})$
 ϕ 84 plot $(\bar{X} + s) \pm (ks / \sqrt{n} + ks / \sqrt{2n})$

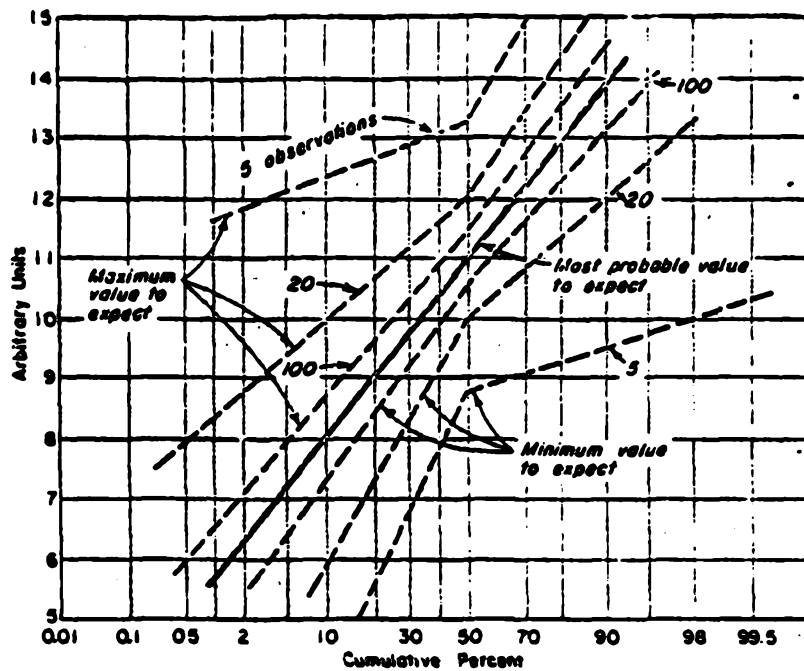
time" approach.

Statistical techniques permit the engineer to decide the minimum number of observations necessary to make a reliable decision. Since the cost of making each observation is usually fixed, such knowledge can save the engineer both time and money.

The importance of statistics as a tool for all engineers cannot be overemphasized. It is a particularly valuable tool for those who are required to predict results or formulate additional, and possibly expensive, programs on the basis of a few test results. Large evaluation errors may be made when only a few samples can be taken. Consider, for example, these two diametrically opposed extremes of evaluation errors:

1. A positive result is obtained on the first trial when the probability of obtaining such a result is relatively low. This is an unfortunate situation since a large effort may be expended in an attempt to obtain the original result.

2. The reverse may occur and a negative result is obtained when the probability of obtaining a



S—Reliability increases as the number of observations increases. A similar effect results when the confidence level is decreased.

positive result is relatively high. This places the predictor in the position of, perhaps, discontinuing a potentially successful project. The unfortunate corollary is

that a large and wasteful effort may be made to develop another method when the first would have been the most satisfactory one.

(more E&D on p 171)

What Is Probability Paper?

The development of arithmetic probability paper can be visualized as follows: Assume that A represents the standard normal distribution curve of a set of data, the familiar "bell-shaped" curve defined by $\phi(t) = (1/\sqrt{2\pi})e^{-t^2/2}$. Integrating $\phi(t)$ results in a curve similar to B on which is plotted the cumulative percent of observations at or below a given value, against that value. If the abscissa of B is now stretched symmetrically, but nonlinearly, about the 50% value, the curve becomes a straight line (C) and the scale of the abscissa becomes a probability scale. Cumulative

percent is plotted on the probability scale since the probability curve represents the integral of the area under the normal probability curve. Cumulative percentages for varying numbers of observations are given in Table 1.

Getting the paper

Two sources for probability paper are: Codex Book Co., Norwood, Mass. (arithmetic—No. 3127, logarithmic—No. 3128), and Koussell & Esser Co., New York City (arithmetic—No. 359-23, logarithmic—No. 359-22G).

