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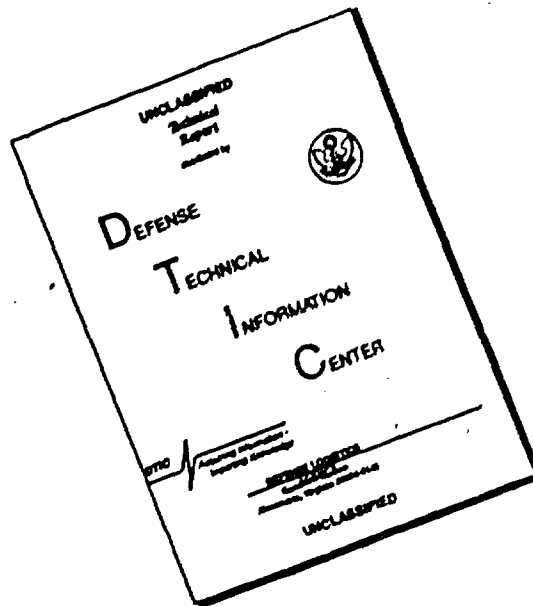
SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA



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63-4-5

U. S. ARMY

ELECTRONICS MATERIEL AGENCY

PRODUCTION ENGINEERING MEASURE

DA - 36 - 039 - SC - 86727

SILICON PLANAR EPITAXIAL TRANSISTOR

TYPE 2N2193

SILICON GROWN DIFFUSED TRANSISTOR

TYPE 2N336

GENERAL  ELECTRIC

DDC
AUG 27 1963
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U. S. ARMY

ELECTRONICS MATERIEL AGENCY

PRODUCTION ENGINEERING MEASURE

DA - 36 - 039 - SC - 86727

SILICON PLANAR EPITAXIAL TRANSISTOR

TYPE 2N2193

FOURTH QUARTERLY REPORT

31 JANUARY 1963
30 APRIL 1963

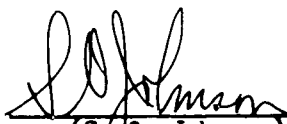

(S. O. Johnson)
PROJECT MANAGER

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I. AREA OF WORK - IMPROVED KPR RESOLUTION (C. LOGAN)

1 A. Work Item - Improved light collimation during KPR exposure.

This work item has been completed.

2 A. Work Item - Mask Wafer "Contact" Exposure Effects.

This work item has been completed.

3 A. Work Item - High Resolution masks.

This work item has been completed.

II. AREA OF WORK - CONTACT EVAPORATION AND ALLOYING (C. LOGAN)

1 A. Work Item - Improved Substrate Heater Design.

B. Abstract - Improved substrate heaters of the design described in the previous reports have been installed and are being used for vapor deposition processing. A number of analytical techniques were assessed for contact evaluation relative to process monitoring.

C. Purpose - Consistent and uniform aluminum contact surfaces and alloy necessitates controlled deposition and alloy temperatures. The improved heater design has been developed to minimize temperature gradient effects which are characteristic of large area electrical resistance heaters.

D. Narrative -- Work during this quarter has consisted of the evaluation of a number of analytical techniques for defining the quality of the contact process. The following techniques were evaluated:

1. Cross-sectioning,
2. Ultrasonic Vibration,
3. Physical Abrasion,
4. Dissolution of the contact metal followed by microscopic examination of the substrate.

A cross-sectioning technique was developed for measuring the degree of aluminum-silicon interaction, which involved angle-lapping of the transistor structure followed by high magnification microscopic viewing. Due to preferential abrasion of the aluminum which occurred under certain lapping conditions, the reproducibility of this technique was open to question. The feedback time for results was also too long for convenient use, so this technique was abandoned.

The regular clean-up which follows alloying has been expanded to include a high-energy ultrasonic vibration in a water medium. Wafers with marginal alloy quality are immediately recognizable, due to either partial or complete loss of the contacts. Wafers showing small isolated areas of lost aluminum are physically abraded with a sharp pointed instrument to distinguish between overall poor alloy due to some surface condition such as residual oxide or KPR.

A technique for the removal of the aluminum from the contact area using a chemical etch, either HF or HCl, and then viewing the aluminum-silicon interface at high magnification under dark field illumination has been established. This has proven to be a very desirable technique for determining contact alloy quality based on characteristically identifiable interface conditions such as dendrite or pit size and density, silicon regrowth formation and amorphous silicon deposits.

Backing up these analytical procedures is a pre-sampling plan, in which a small number of pellets is fabricated into devices and bondability (ease of thermocompression bonding), strength of the bond (drop test) and electrical resistance of the contact are assessed to establish contact quality.

With the exception of the first technique (cross-sectioning), all these procedures have been adopted to some degree and are being used for process monitoring.

E. Conclusions - The new infrared heater design has effected a significant improvement in the reproducibility and uniformity of the contact process. These improvements were verified and are being maintained, using the process monitoring techniques described above.

F. Program for next quarter - This work item has been completed.

2 A. Work Item - Temperature Control Improvements.

This work item has been completed.

3 A. Work Item - Regulated Leak Consideration.

This work has been pre-empted by the vacuum deposition process (See 4 A.)

4 A. Work Item - Vacuum Deposition Process.

B. Abstract - The elevated substrate temperature deposition process has become standard procedure for contact processing.

C. Purpose - To develop a constant process which would minimize the critical nature of TCB, Thermo Compression Bonding, and promote reproducibility of alloy regions having negligible effect on the electrical parameters.

D. Narrative and Data - Refer to "Narrative and Data" for "Work Item - Improved Substrate Heater Design", in "Area of Work - Contact Evaporation and Alloying", II 1 D.

E. Conclusions - The elevated temperature depositions, along with the improved substrate heater design, have resulted in improved reproducibility and uniformity of the contact process, and hence improved lead attachment. Process monitoring techniques, as discussed in II 1 D have verified this and will be used to ensure process control.

- F. Program - This work item has been completed.
for next
Quarter

III. AREA OF WORK - COLLECTOR ETCHING (C. LOGAN)

1 A. Work Item - Surface Masking.

This work item has been completed.

IV. AREA OF WORK - BORON DIFFUSION (A. R. DI HIEMO)

1 A. Work Item - Replace Present B_2O_3 Solid Source Process by a BCl_3 Gaseous Source Process.

This work item was terminated, as reported in Quarterly Report No. 3.

V. AREA OF WORK - PHOSPHORUS DIFFUSION (J. F. WHOLEY)

1 A. Work Item - Improved Source Heater for Phosphorus Diffusion.

This work item has been completed.

2 A. Work Item - Improved Technique of Loading Phosphorus Source Boats.

This work item has been completed.

VI. AREA OF WORK - COLLECTOR CONTACT TO THE HEADER (R.H. LANZL, J.L. DURSO, J. RICHARDSON)

1 A. Work Item - Reduction in Size of Preform.

The basic work item is the debugging of the preform mount equipment to provide rapid, accurate and reproducible attachment of preforms to headers prior to pellet mount and to optimize further the entire pellet mount process.

- B. Abstract - Work progressed to the point where preforms were being applied accurately at planned rates. The preform machine was then incorporated in the production line. The machine has subsequently experienced considerable downtime, due to maintenance problems, but work on this "first generation" machine is considered satisfactory and complete.

- C. Purpose - The goal during this period was to complete the debugging of the preform mounting equipment.

- D. Narrative and Data - Debugging work was completed. More accurate preform ribbon tooling was provided. In order to increase preform placement accuracy still further, a retractable hold-down was incorporated, to control the preform from the time of cutoff until welding took place.
 - E. Conclusions - The feasibility of this work item was substantiated. Continuing effort must be made to maintain placement accuracy and to minimize equipment downtime, but the basic work item is considered to be complete.
- 2 A. Work Item - Reduction of the Corroding Species by Improving Cleaning and Tighter Inspection of Purchased Material (F.K. GLASBRENNER, R.J. KOBLER).
- B. Abstract - During this period line experiments were conducted to determine the effect of thermal cycling on gold adhesion and samples obtained for comparison of "as received" versus "cleaned" parts and placed on high temperature storage tests (300°C. to 350°C. range).
 - C. Purpose - To determine if the inspection procedures and tests are adequate in controlling the quality of the gold plate, and to determine the effect of uncleaned headers on device performance.
 - D. Narrative and Data - Hitherto, work has been essentially concerned with determining how well the cap, preform and header meet the drawings, and the effectiveness of the incoming inspection and cleaning processes. Recognizing that the header and its finish play the major role in obtaining good alloying or adhesion of pellet to header, devices were fabricated with uncleaned headers, in an attempt to evaluate the effect on the collector contact.

The experiment with cleaned versus uncleaned headers was designed to determine if header cleanliness can contribute to a major mode of failure. After 1,000 hours of baking at both 300°C. and 350°C. on "as received" and "cleaned" parts, the results indicated that there were no opens of pellet to header contact in either group.

1. Cap and Preform.

No additional information was obtained in this area and no changes were made in the drawing, as processing is considered to be necessary at this time, to improve the quality of the product.

2. Header.

To date we have investigated the thickness of gold plate, the identification of base material and the effectiveness of the cleaning process, as determined by infrared analysis. Vendors have been approached on the subject of the purity of their gold plating, but they were unwilling to specify anything more specific than 24 K gold. The purity of the gold used is important, and control of contamination in the gold seems to be a constant problem in the plating processes.

It has been observed during experimentation that subtle variations

between plated parts could affect some line processing operations such as thermocompression bonding and could lead to rejections at this work station. These variations have not been detectable by incoming inspection procedures. Therefore, more inspection has been instituted, based on line usage processing, to ensure that poorly plated lots do not reach the production lines.

- E. Conclusions - It appears that the level of contamination present in the devices is low enough in magnitude to rule it out as a contributor to a major mode of device failure of collector contact, i.e., no opens in "cleaned" or control versus "uncleaned" header experiment. Therefore, no major changes in header drawings will be initiated.
- F. Program for next Quarter - This work item has been completed.

VII. AREA OF WORK - INTERCONNECTIONS.

1 A. Work Item - Improve Bonding Process (LANZL, DURSO, KOBLER).

- B. Abstract - 1. During this period tests were completed on units fabricated with wire from Vendor B. Results of a study of wire specifications and surface contamination were also completed.
2. Manufacturing (device fabrication) has been converted to a new wedge design which previously had better improved bond strength.
- C. Purpose - 1. To determine the effect of material from Vendor B on device strength, together with determining optimum wire specifications.
2. To obtain an optimum bonding process, using a new wedge design.
- D. Narrative and Data - 1. Second Source of Wire Supply (Vendor B).

Units fabricated with wire obtained from Vendor B have been subjected to a series of mechanical tests, and the results are as follows:

Figure 1

Vendor B Sample Size	Elongation		Number of Opens After					
	Per A.E %	Per Vendor %	Centrifuge	Shock	Centrifuge		Vibration	
			20 KG	1.5 KG	35 KG	50KG	Ratio	Var. Freq.
40	1.5	1	2	3	4	6	6	6/39
38	5.9	9	0	0	1	3	3	3/37
38	13.2	13	0	0	0	2	2/37	2/37
37	17.2	16	1	2	5	9	9	9

Our results indicated that failure rates for the 1% and 16% elongation wires were higher than those for the 5% and 13% elongation wires.

An order was therefore placed with Vendor B for 500 feet of wire to his 9% - 13% elongation value range (G.E. measured these elongations as 10% - 14%). When the material was received and tested for compliance with specification, it was found to be in the 15% - 16% range, and was returned for replacement. The vendor felt that 10% - 14% was too tight a range to produce consistently, and a compromise range of 9% - 15% was agreed upon.

Material to this range has been received and is being processed on the production line at the present time. Performance will be reported at a later date.

1b. Study of Wire Specifications

During this period an investigation was completed on the effect of re-annealing annealed wire on the elongation range and break load of wire from Vendor A. The results are as follows:

Figure 2

Elongation %		Breaking Load (Gms.)	
As Received	After Annealing	As Received	After Annealing
10.1 - 15.4	8.9 - 11	24.2 - 25.7	19.9 - 25.0

Therefore, since our results tend to indicate only a slight change in mechanical properties after re-coiling and wire on small spools and re-annealing, the elongation range of 9% - 15% appears to be a reasonable wire specification.

1c. Surface Contamination of Wire.

Wire from Vendor A, "as received", was checked for organic material by infrared analysis and was found to have 23 ± 10 ppm, which reduced to 8 ± 3 ppm after the cleaning operation. However, samples of material from Vendor B, which is estimated to have approximately the same "as received" ppm of organic material, were run on 300°C. storage for 1,000 hours with no resulting opens or failures. This may indicate that the difference in contamination levels was not significant enough to have any effect on device performance.

1d. The original objective of obtaining more uniform physical properties of wire has been realized by obtaining two vendors capable of producing material per the revised specifications. Standardization of gage length for elongation and specification of rate of pull will ensure that this uniformity is maintained.

Therefore, work in this area is complete.

2a. Results from wedge design experiments during the last quarter showed that a significant improvement in bond strength could be obtained by changing the wedge design. The device manufacturing line was converted to one of the new designs which has a 4-mil instead of a 2-mil bonding width. This new wedge

eliminates the second bond to the pellet and results in a considerable improvement in the bonding rate.

- 2b. The bonding process has been modified to accommodate the new wedge design and the first 1,500 (approx.) units fabricated have been used in the electrical screening experiments. The development of this process is considered to be complete, and a manufacturing process has been demonstrated which resulted in significant improvement in bonding strength.

- E. Conclusions - 1. Wire from Vendor B was seen to conform mechanically to that of Vendor A in the elongation range of 9% - 15%. This elongation range is seen to be that at which fewest failures are produced and which is best workable from a manufacturing standpoint. Surface contamination on "as received" material was not significantly different from that of "cleaned" material in its effect on device performance. Work in this area is complete.
2. The manufacturing line has been converted to a new bonding process which includes an improved wedge design. Work in this area is complete.

VIII. AREA OF WORK - RELIABILITY MEASUREMENT (J. E. JACOBS, A. FOX)

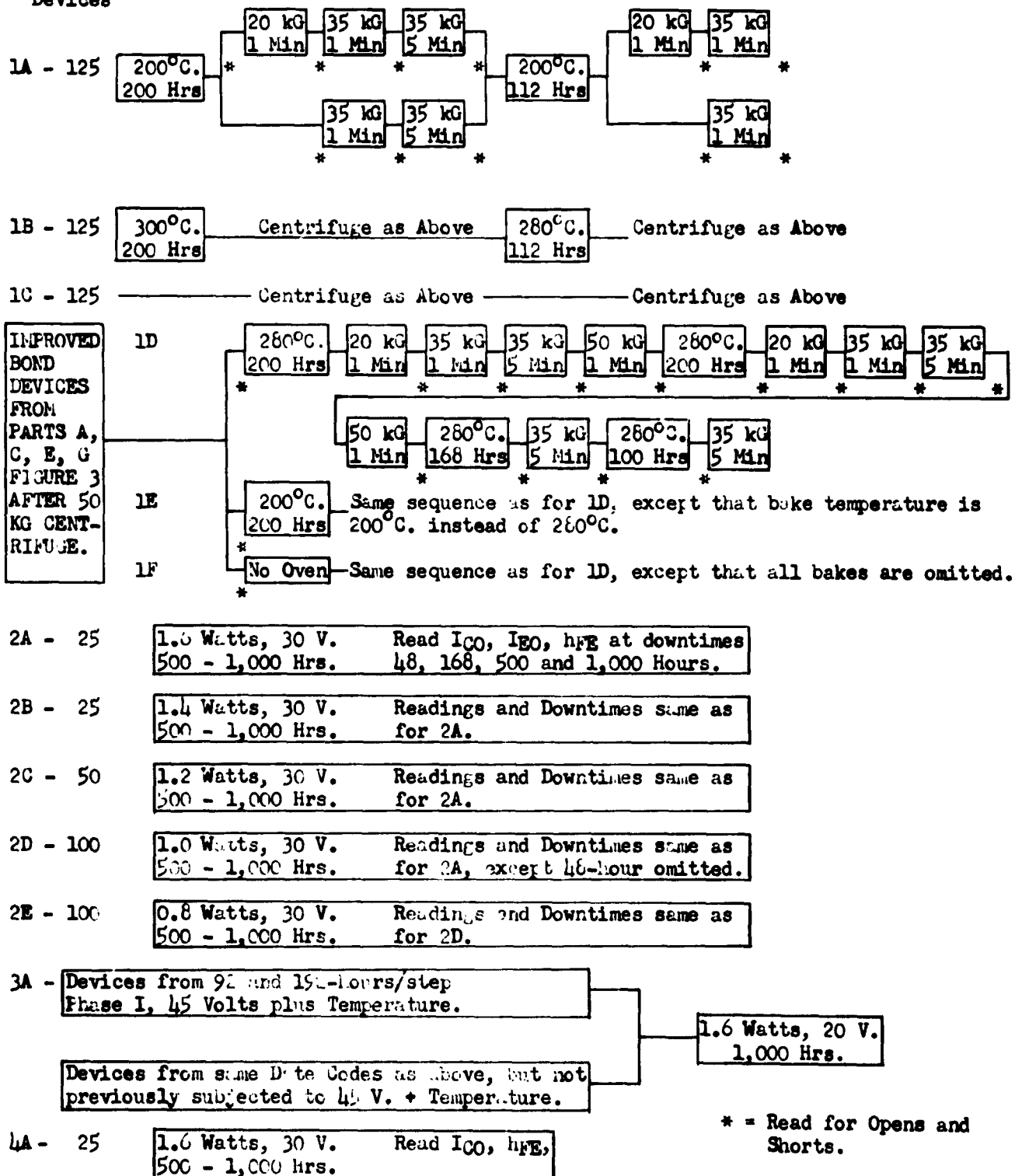
- 1 A. Work Item - Completion of Phase II Pre-Test Experiments, including the Addition and Completion of Several Other Pre-Tests not Previously Mentioned. Completion of Voltage plus Temperature Stress on the Phase II Screen Experiment.

- B. Abstract - Figure 1 shows all of the Phase II pre-test experiments, including those added since the third quarterly report was issued. Results are shown in Figures 2 through 10. Figure 11 shows the Phase II experiments. Figures 12 through 15 show the analysis of results to date.

- C. Purpose - 1. The pre-tests listed 1A through 1F in Figure 1 were designed to
- a. indicate whether a 100°C. or a 260°C. bake, ranging in time from 200 hours to 500 hours, would affect the mechanical strength of the gold wire-to-pellet bond. This would indicate how long a voltage plus temperature screen could be run before it affected mechanical strength.
 - b. determine whether the initial subjection of the devices to 20 KG centrifuge would affect their subsequent performance at a higher stress.
2. The pre-tests listed 2A through 2E were run to
- a. provide an estimate of accelerated operating life failure rates prevailing during the latter half of 1962. This, in turn, would enable us to make an efficient selection of sample sizes, operating life tests and proportionment of samples between tests.

FIGURE 1 - PROPOSED PRE-TEST EXPERIMENTS.

Approximate
Number of
Devices



3. The pre-test listed 3A was to

- a. determine whether those devices which had previously showed stability on an extended voltage plus temperature screen (stable Phase I devices from Temperature plus Voltage Step Stress - 92 hour and 192 hour treads) were significantly more stable when placed on 1.6 watts, 1,000 hour life than those devices from the same lots which had not previously been subjected to 45 Volts plus temperature.
4. 4A shows a 3 minute ON, 3 minute OFF cycled 1.6 watt operating life test. The purpose of this test was to determine whether power cycling produced a significantly larger percentage of legitimate failures than non-cycling (The 3 minutes ON time allowed the junction temperature, T_j , to arrive within 90% - 95% of its 1.6 watt steady state temperature).

In general, these pre-tests were performed in order to provide more information than had been obtained during Phase I, because of the high reliability of the product.

D. Narrative - 1. Pre-Tests to Determine the Effect of Temperature on Mechanical and Data Strength (Tests 1A through 1F).

Figure 2 shows the results on standard production line devices, manufactured during the second and third quarters of 1962, which were taken through experiments 1A through 1C. Only opens and shorts are classified as failures. From this data there is no reason to suspect that those devices which were previously subjected to a 20 KG stress experience significantly heavier failure rates at the 35 KG level than those devices which were not subjected to the prior 20 KG stress. Although some cases give a contrary indication (5 failures in lot 304208, which included 20 KG centrifuge, against 10 failures in lot 305111, which did not include 20 KG centrifuge), the overall results - 20 KG lots versus non-20 KG lots - indicate no significant difference. The data following the second temperature stress also supports this argument: no further failures.

The data also indicates that those devices which received oven stress for 312 hours, either at 200°C. or at 260°C., are apparently not significantly weaker mechanically than those devices which did not receive oven stress.

Statistical results supporting the two no-significance contentions stated above are as follows:

FIGURE 2

PHASE II PRE-TEST EXPERIMENTS

EFFECT OF OVEN STORAGE ON MECHANICAL STRENGTH

LOT NO.	NUMBER OF UNITS	FIRST TEMPERATURE STRESS FOR 200 HRS.	CENTRIFUGE 20 KG, 1 MINUTE	CENTRIFUGE 35 KG, 1 MINUTE	CENTRIFUGE 35 KG, 5 MINUTES	SECOND TEMPERATURE STRESS FOR 112 HRS.	CENTRIFUGE 20 KG, 1 MINUTE	CENTRIFUGE 35 KG, 1 MINUTE
304208	63	NO OVEN	1	4	5	NO OVEN	5	5
304207	63	200 °C	4	0	7	200 °C	7	7
304206	61	300 °C	3	6	6	200 °C	6	6
305111	62	NO OVEN		7	10	NO OVEN		10
305110	62	200 °C		4	4	200 °C		4
305109	62	300 °C		0	8	200 °C		8

TWO BY TWO CONTINGENCY TABLE FOR A CHI SQUARE TEST ON THE EFFECT OF 20 KG
PRE-CENTRIFUGE ON 35 KG MECHANICAL STRENGTH.

	DEVICES WITH NO PRIOR 20 KG EXPERIENCE.		DEVICES WITH PRIOR 20 KG EXPERIENCE.		MARGINAL TOTALS
	OBSERVED	EXPECTED	OBSERVED	EXPECTED	
CUMULATIVE NUMBER OF DEVICES FAILING BY (AND INCLUDING) THE 35 KG, 5 MINUTE LEVEL	22	20	16	20	40
CUMULATIVE NUMBER OF DEVICES PASSING BY (AND INCLUDING) THE 35 KG, 5 MINUTE LEVEL	104	100	109	107	333
MARGINAL TOTALS	100		107		373

$$T. H. X = \frac{\left\{ \left| \frac{f_{11}}{n_{11}} - \frac{f_{12}}{n_{12}} \right| - \left(\frac{n_{11}}{n} \right) \right\}^2 n}{(f_{11} + f_{12})(f_{21} + f_{22})(f_{11} + f_{12})(f_{11} + f_{12})} = 0.166$$

Chi square tables for one degree of freedom show that, assuming the 20 KG device failure rate to be the same as that for non-20 KG devices, there is a 60% chance of obtaining the results above. Furthermore, at the 5% and $\alpha = 10\%$ point, $X^2_{.10} = .71$. Therefore, based on these results, there is no reason to believe that 20 KG pre-stress influences the 35 KG results.

Similarly, for the effect of longer pre-stress conditioning, for 300 hours on 35 KG mechanical strength:

	DEVICES WITH NO OVER PRE-STRESS		DEVICES WITH 200 ⁰ C. OVER PRE- STRESS		DEVICES WITH 300 ⁰ C. OVER PRE- STRESS		MARGINAL TOTALS
	OBSERVED	EXPECTED	OBSERVED	EXPECTED	OBSERVED	EXPECTED	
CUMULATIVE FAILURES AT THE 35 KG LEVEL	15	13.4	11	13.4	14	13.2	40
CUMULATIVE NON- FAILURES AT THE 35 KG LEVEL	110	111.	114	111.6	109	109.8	333
MARGINAL TOTALS	125		125		123		373

$$\sum (X^2)_{Actual} = 1.111$$

Chi square tables show that if the processes are identical there is a 55% probability that the above differences would be observed. In this case, $X^2_{.10} = 4.61$ for two degrees of freedom. This information shows again that there

is no reason to believe that oven stressing for 300 hours will influence the performance of the devices at 35 KG.*

Experiments 1D, 1E and 1F are similar to the experiments just described except that the devices used were fabricated with improved wire and using improved bonding techniques, as described in the first column of Figure 3, the results table. The conclusions derived here do not conflict with those shown in Figure 2. Because of the improved bonding techniques, however, the failure rates are either small or non-existent. Note that a total of over 600 hours has been accumulated on these improved devices, with only the double-bonded, type "C" wire, devices showing the effect of the oven hours.

2. Pre-tests to Determine the Performance of the Product on Operating Life Stresses Above the Normal Power Rating for the Device.

Figures 4, 5, 6, 7 and 8 show scattergrams of I_{G0} at 60 V. and h_{FE} (via an I_B presentation: $I_C = 1$ mA.) stability over 1,000 hours of 1.6 W., 1.4 W., 1.2 W., 1.0 W. and 0.8 Watts respectively. (h_{FE} at 1 V.; 150 mA. was taken, but the zero-hour readings were found to be invalid).

Comparison of these figures indicates that no significant difference exists in the I_{G0} and h_{FE} shifts observed for the various stresses. The difference in percent failure between stresses is not significant either, no matter how the failure end-point is selected.

3. Pre-Tests to Determine the Effect of 1.6 Watt, 1,000-hour, Operating Life on Devices Which have Shown Stability on a Prior Long-Term Voltage Plus Temperature Test (Devices from Phase I, 45 V. + Temperature Step-Stress, 92 and 192-hour trends, versus Controls of 20 V. + Power, 1 and 4-hour trends).

See Figure 9. The 1,000-hour scattergram of I_{G0} shows no significant difference in failure rates between the 45 V. + Temperature devices and the "controls". Since reject analysis has not yet been performed on the devices, we cannot establish inversion layer troubles as the cause of failure. Regardless of the problem, however, the comparison is discouraging, since it would indicate that a voltage plus temperature screen might not be effective in reducing the major cause of failure.

Although the failure rates observed for this test may be compared to one another, they should not be compared to failure rates existing in the pre-tests previously described, unless the fact that these devices were obtained earlier is taken into account.

4. Pre-Tests to Determine the Effect of Cycling on Reliability.

These devices (Figure 1C) and the devices presented in Figure 4 were obtained from the same production lots. Although three minutes of ON cycle will allow the case and the junction of the device to reach 90% - 95% of its steady-state 1.6 Watt value - so that junction temperatures of the cycled devices are close to those of

* - Note that this information is not in conflict with information given in the third quarterly report, which stated that temperature aging for short periods of time (72 hours) appeared to improve the mechanical strength of the device.

FIGURE 3 - PHASE II PRE-TEST EXPERIMENTS

EFFECT OF OVEN STORAGE ON MECHANICAL STRENGTH

SOURCE MATERIAL LOT # 253	NO. OF UNITS	35 KG, 1 MIN.	50 KG, 1 MIN.	NO. OF UNITS	TEMPERATURE FOR 200 HRS.	20 KG, 1 MIN.	35 KG, 1 MIN.	50 KG, 1 MIN.	TEMPERATURE SECOND STRESS FOR 100 HRS.	20 KG, 1 MIN.	35 KG, 1 MIN.	50 KG, 1 MIN.	TEMPERATURE THIRD STRESS FOR 100 HRS.	35 KG, 5 MIN.	TEMPERATURE FOURTH STRESS FOR 100 HRS.	35 KG, 5 MIN.
A BAKED AND AGED WIDE WEDGE - ONE BOND ON TYPE "C" WIRE	20	1	1	8	NO OVEN	0	0	0	NO OVEN	0	0	0	NO OVEN	0	NO OVEN	0
					200°C	0	0	0	200°C	0	0	0	200°C	0	200°C	0
					260°C	0	0	0	260°C	0	0	0	260°C	0	260°C	0
C BAKED AND AGED SMALL WEDGE - TWO BONDS ON TYPE "C" WIRE	20	1	5	7	NO OVEN	0	0	0	NO OVEN	1	2	1	NO OVEN	1	NO OVEN	1
					200°C	0	0	0	200°C	0	0	0	200°C	0	200°C	0
					260°C	0	0	0	260°C	0	0	0	260°C	1	260°C	3
E BAKED AND AGED WIDE WEDGE - ONE BOND STANDARD WIRE	25	0	2	8	NO OVEN	0	0	0	NO OVEN	0	0	0	NO OVEN	0	NO OVEN	0
					200°C	0	0	0	200°C	0	0	0	200°C	0	200°C	0
					260°C	0	0	0	260°C	0	0	0	260°C	0	260°C	0
G BAKED AND AGED SMALL WEDGE - TWO BONDS STANDARD WIRE	25	1	3	7	NO OVEN	0	0	0	NO OVEN	0	0	0	NO OVEN	0	NO OVEN	0
					200°C	0	0	0	200°C	0	0	0	200°C	0	200°C	0
					260°C	0	0	0	260°C	0	0	0	260°C	0	260°C	0
B NO BAKE, AGED WIDE WEDGE - ONE BOND ON TYPE "C" WIRE	24	2	13													
D NO BAKE, AGED SMALL WEDGE - TWO BONDS ON TYPE "C" WIRE	28	16	25													
F NO BAKE, AGED WIDE WEDGE - ONE BOND STANDARD WIRE	24	3	17													
H NO BAKE, AGED SMALL WEDGE - TWO BONDS STANDARD WIRE	23	13	20													

K&E LOGARITHMIC 350-125G
 KEUFFEL & ESSER CO. MADE IN U.S.A.
 3 X 5 CYCLES

STRESS OP. LIFE @ 1.6W, 30V
 DESCRIPTION 11C403 ED-X; ST-1; SP-9; PG-1
 SAMPLE SIZE: 6, 6, 7 LOT NO. 304312

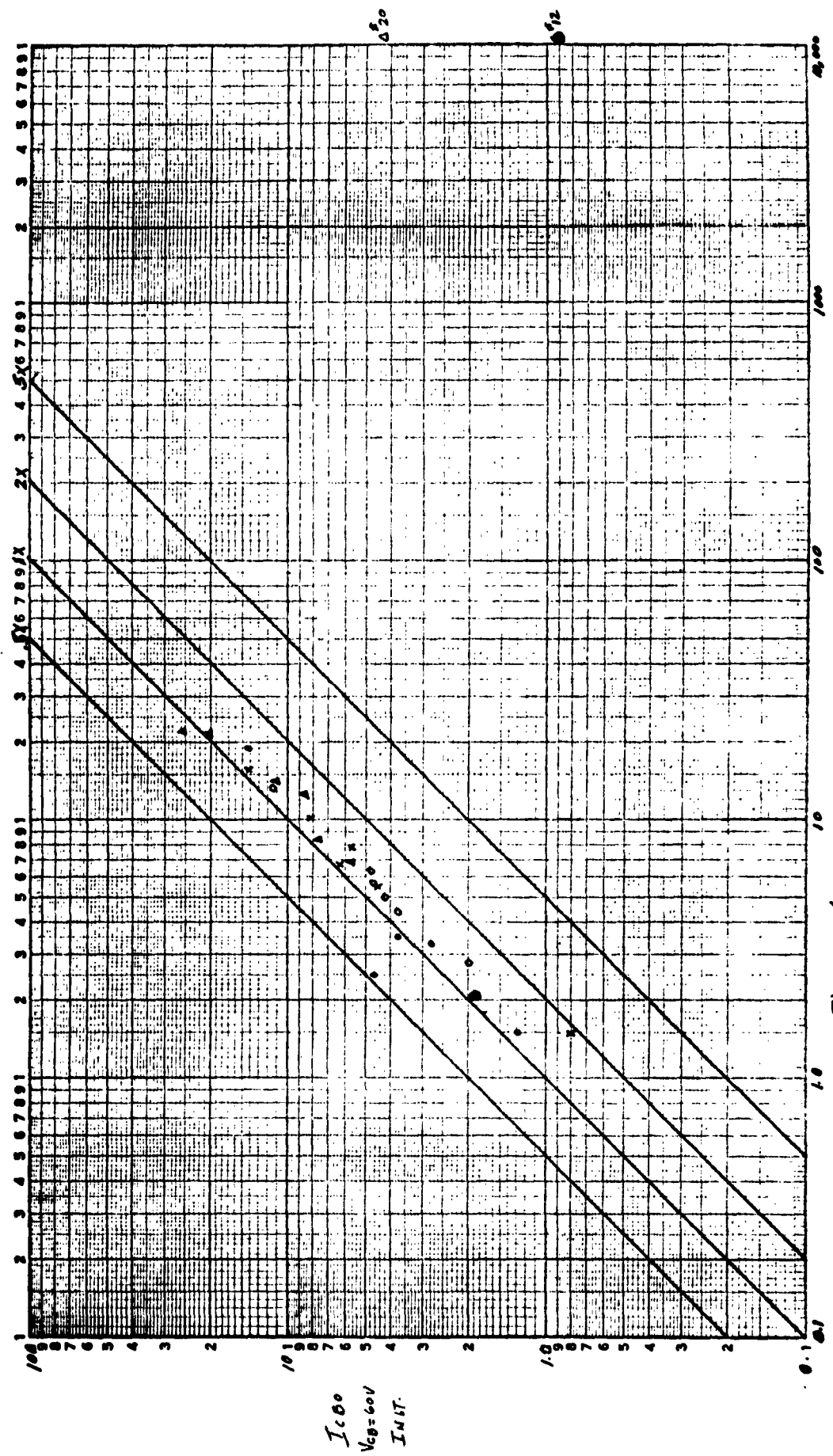
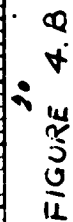


Figure 4.A.

I_{c00} @ $V_{CB} = 60V$ 1000 HRS.


$$I_A \times 10^{-6} \quad V_C = 10V \quad I_C = 1mA \quad @ 1000 HRS.$$

100% LG-ATOMIC 350-125G
100% LG-ATOMIC 350-125G
100% LG-ATOMIC 350-125G

STRESS: 0.1 LIFE @ 1.4W, 30V
DESCRIPTION 11C403 ED-X; SX-0, SP-0, PG-A
SAMPLE SIZE: 49 (12,13,12,12) LOT NO. 304314

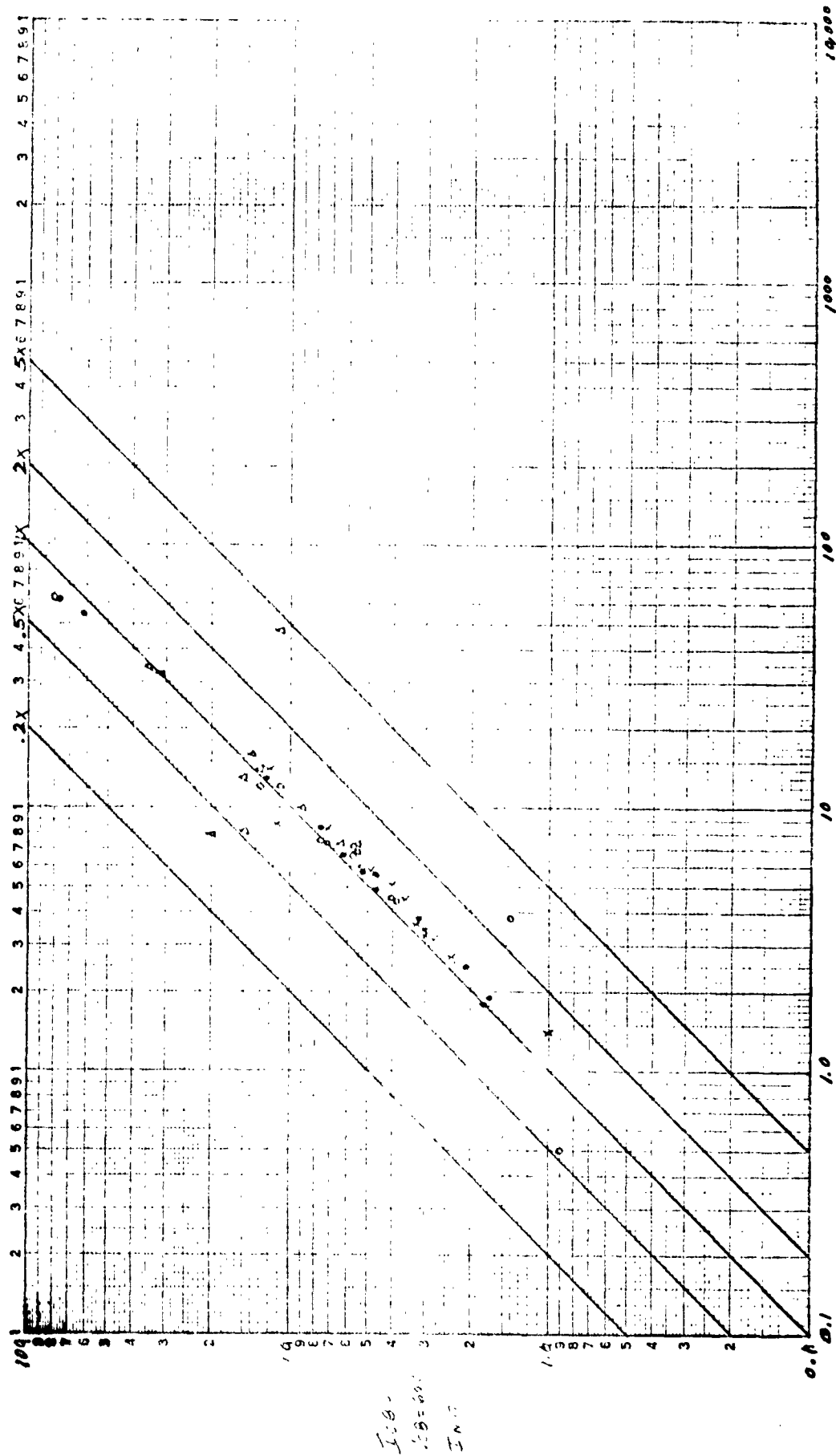
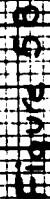


Figure 5A.

$I_{CB} @ V_{CB} = 60V, 1000 HRS.$



STRESS: OP LIFE @ 12W, 30V
DESCRIPTION: 1E403 ED-X, SX-0, SP-0, PG-A
SAMPLE SIZE: 50, 13, 12, 13, 12, LOT NO. 504313

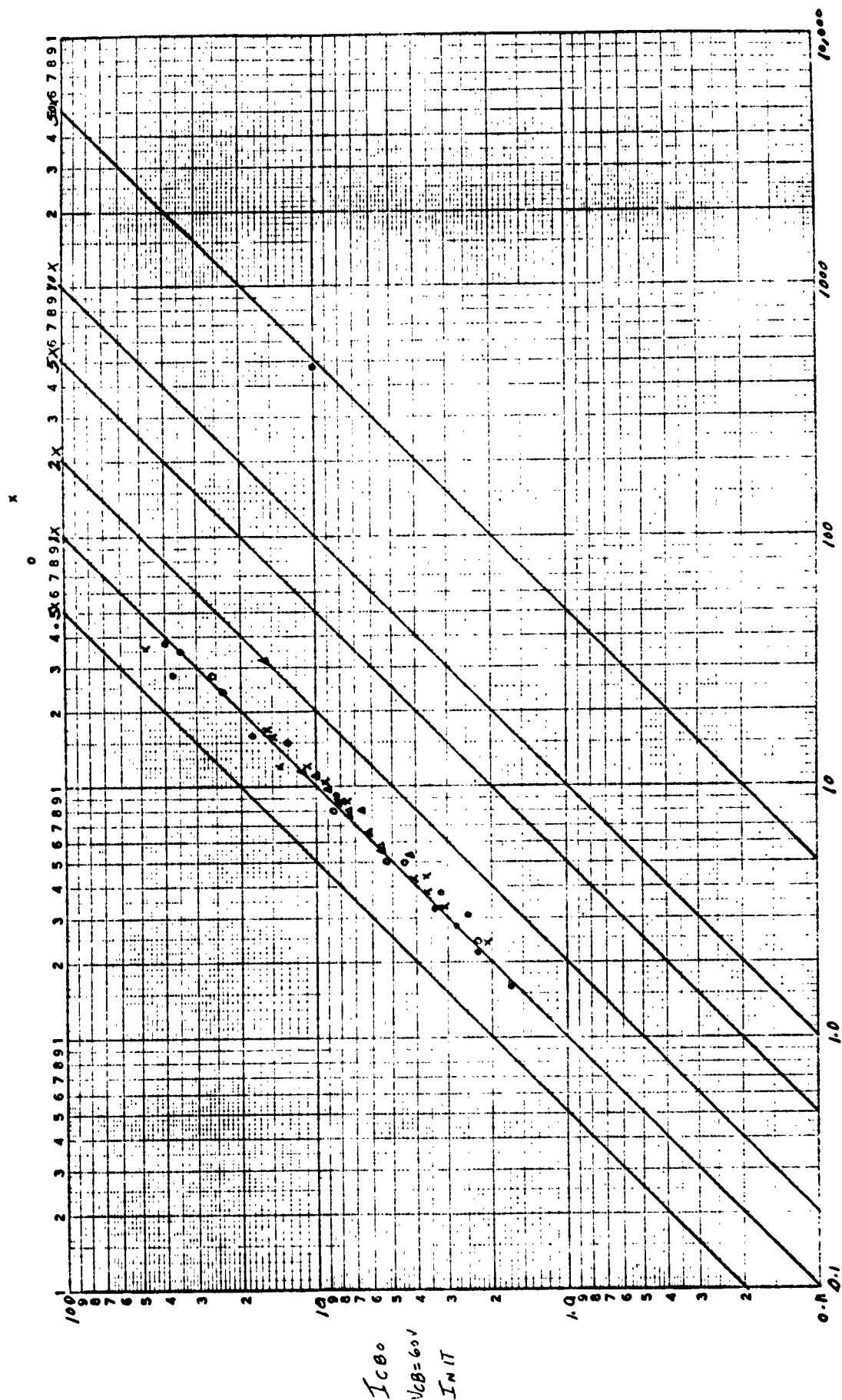


Figure 6A.

$$I_{CBO} \quad V_{CB} = 65V \quad 1000Hz.$$

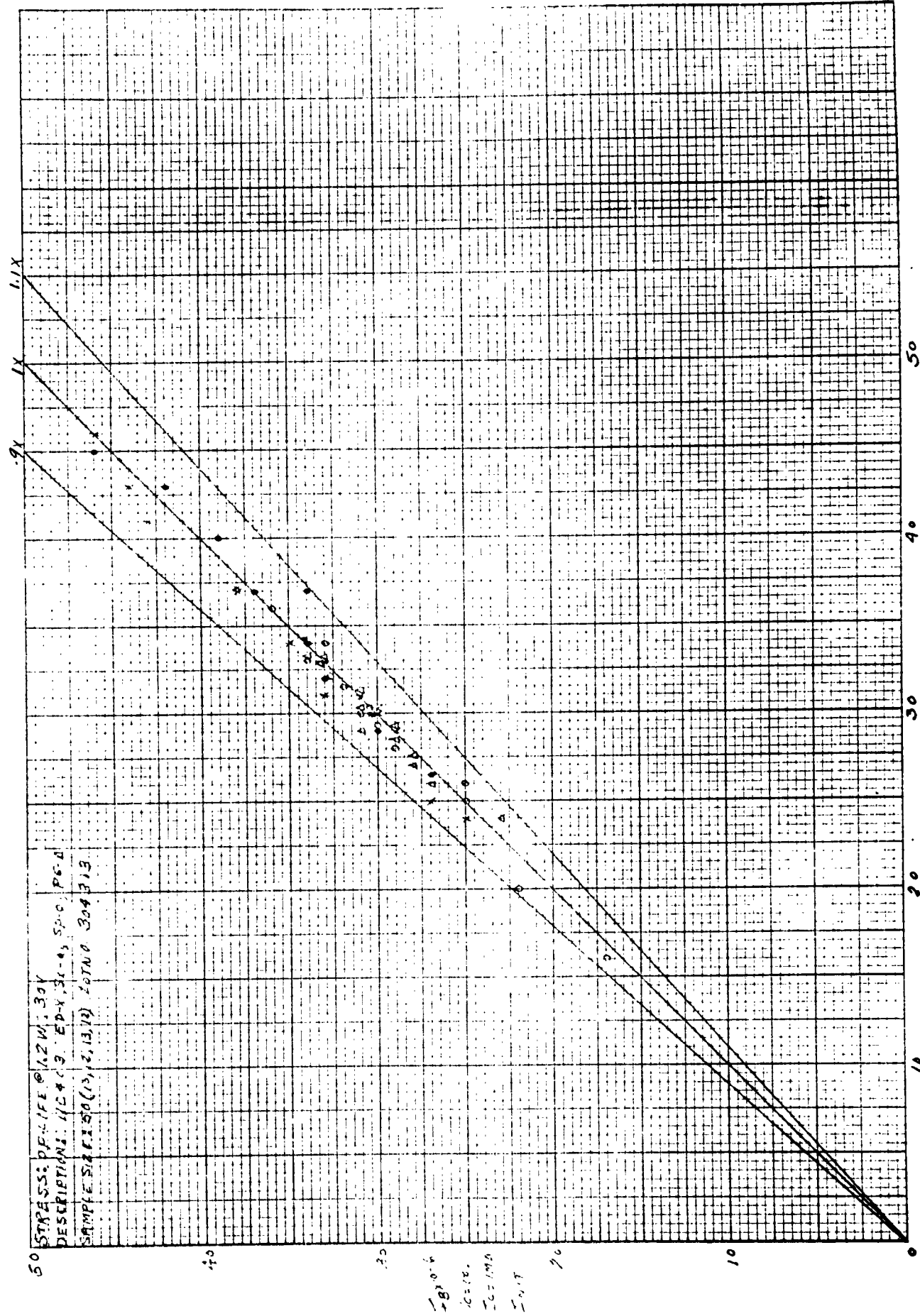
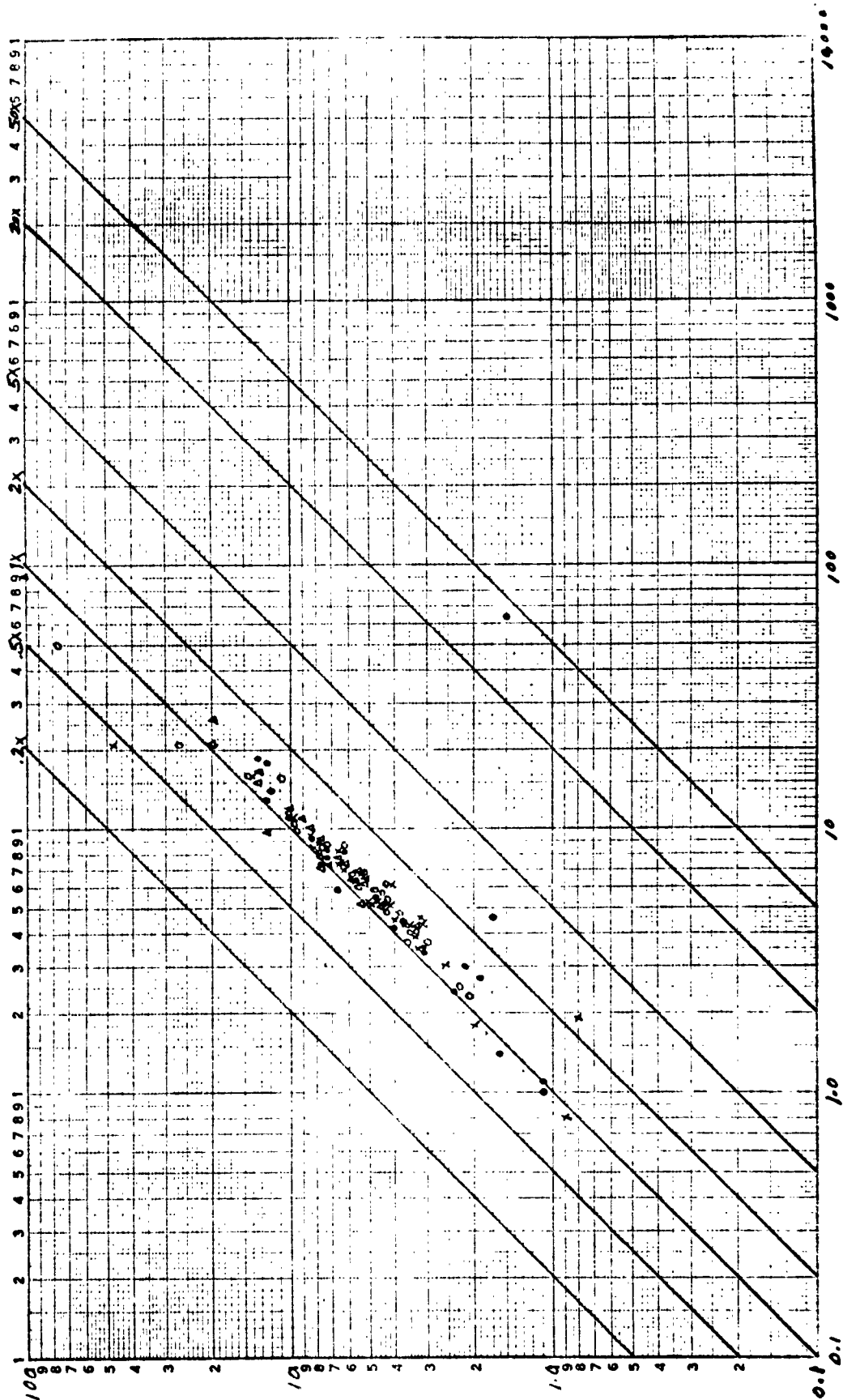


Figure 6B

$I_B \times 10^{-6}$ $V_C = 10V$; $I_C = 1MA$ @ 1000 HRS.

LOG LOGARITHMIC 350-125G
 NEWELL & NESSER CO. MILWAUKEE, WIS.
 3 X 5 Cycles

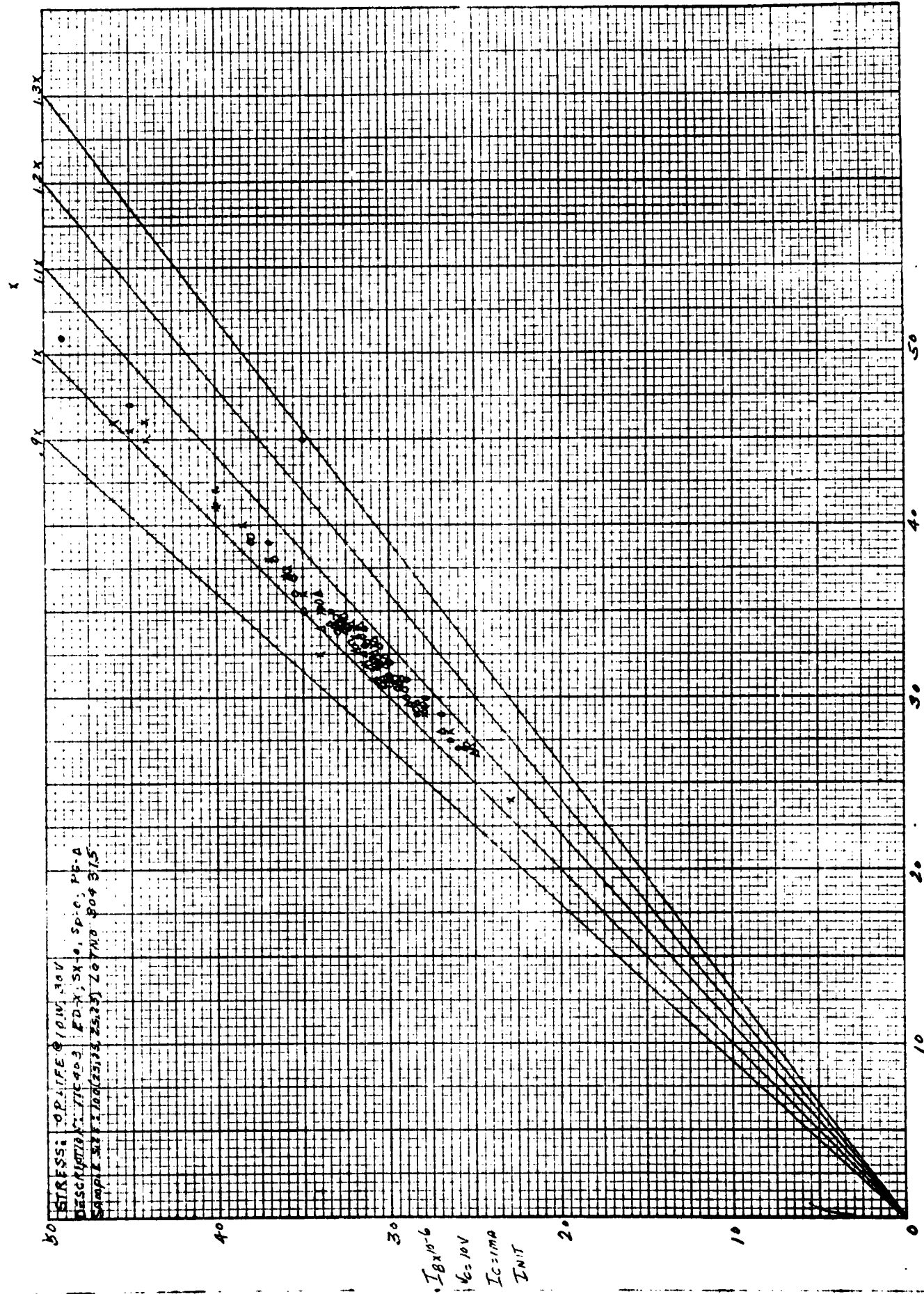
STRESS: OP LIFE @ 10W, 30V
 DESCRIPTION: 11C403 ED-X; SX-0; SP-0; PG-A
 SAMPLE SIZE: 100 (25, 25, 25, 25) LOT NO 304315



I_{CBO}
 @ $V_{CB}=60V$
 INI

Figure 7A

I_{CBO} @ $V_{CB}=60V$, 1000HRS.



$I_B = 10^{-6}$ $V_C = 10V$, $I_C = 1mA$ 1000 HRS.

LOG LOG PLOT 350-12-15
 100% RELATIVE HUMIDITY

STRESS: 0P-LIFE 0.5W, 20V
 DESCRIPTION: 11C403 ED-X; SX-0, SP-0, PG-4
 SAMPLE SIZE: 100 (25,25,25,25) LOTNO: 304317

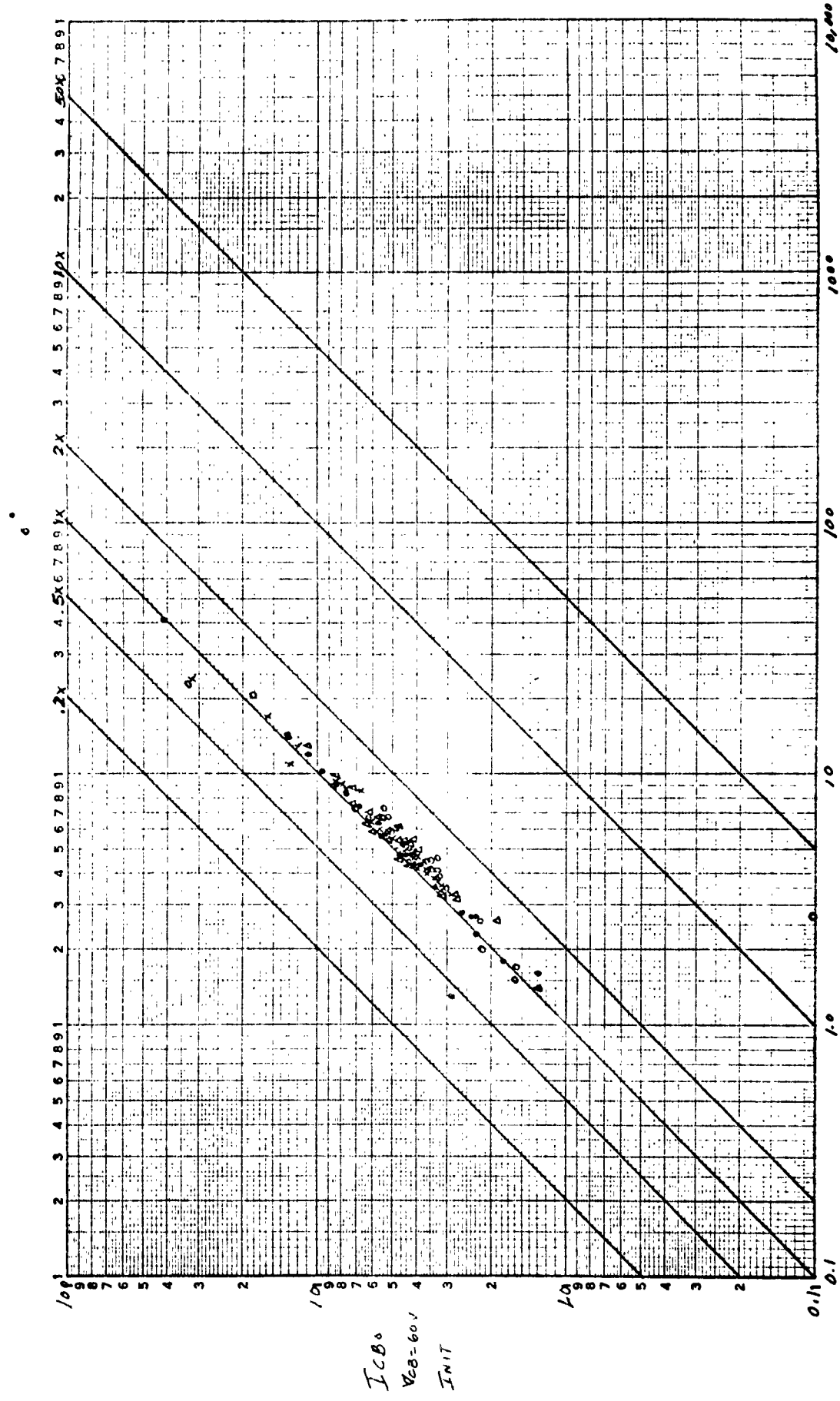


Figure 8A

ICB_0 @ $VCB=60V$ 1000HRS.

ANTHIMIC 350-125G
L. L. ESCHER CO. W. A. R. 2.2 A
3 X 5 CYCLES

X-2 RECOVERED TEMP. 445V STEP STRESS
83 " POWER 4V STEP STRESS

STRESS: OP. LIFE @ 1.6W, 30V
DESCRIPTION: 11C
SAMPLE SIZE: 50 (14, 11, 13, 12) Lot No 305205

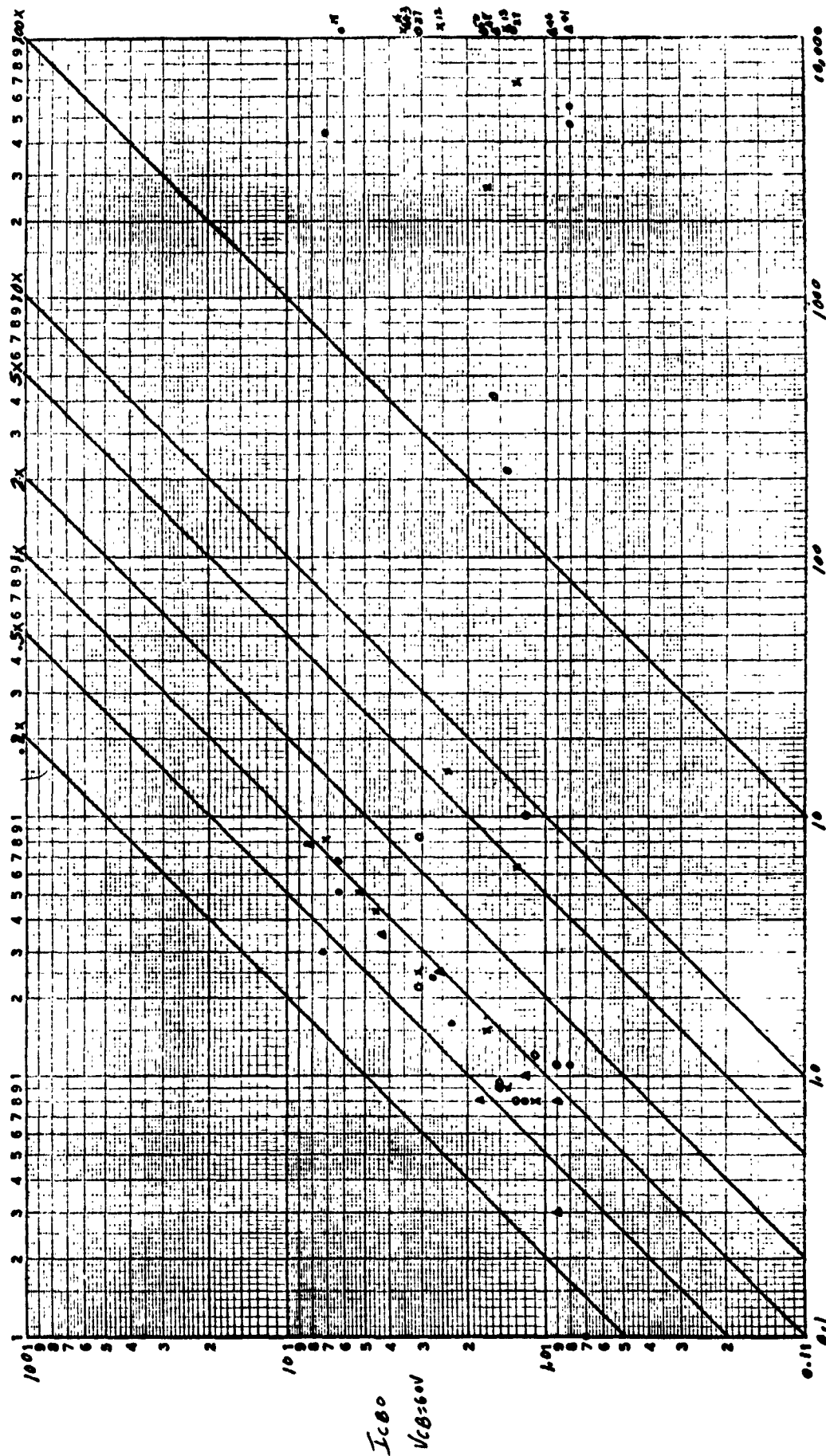


Figure 9

ICB0 VCB0 = 60V 1000HRS.

X

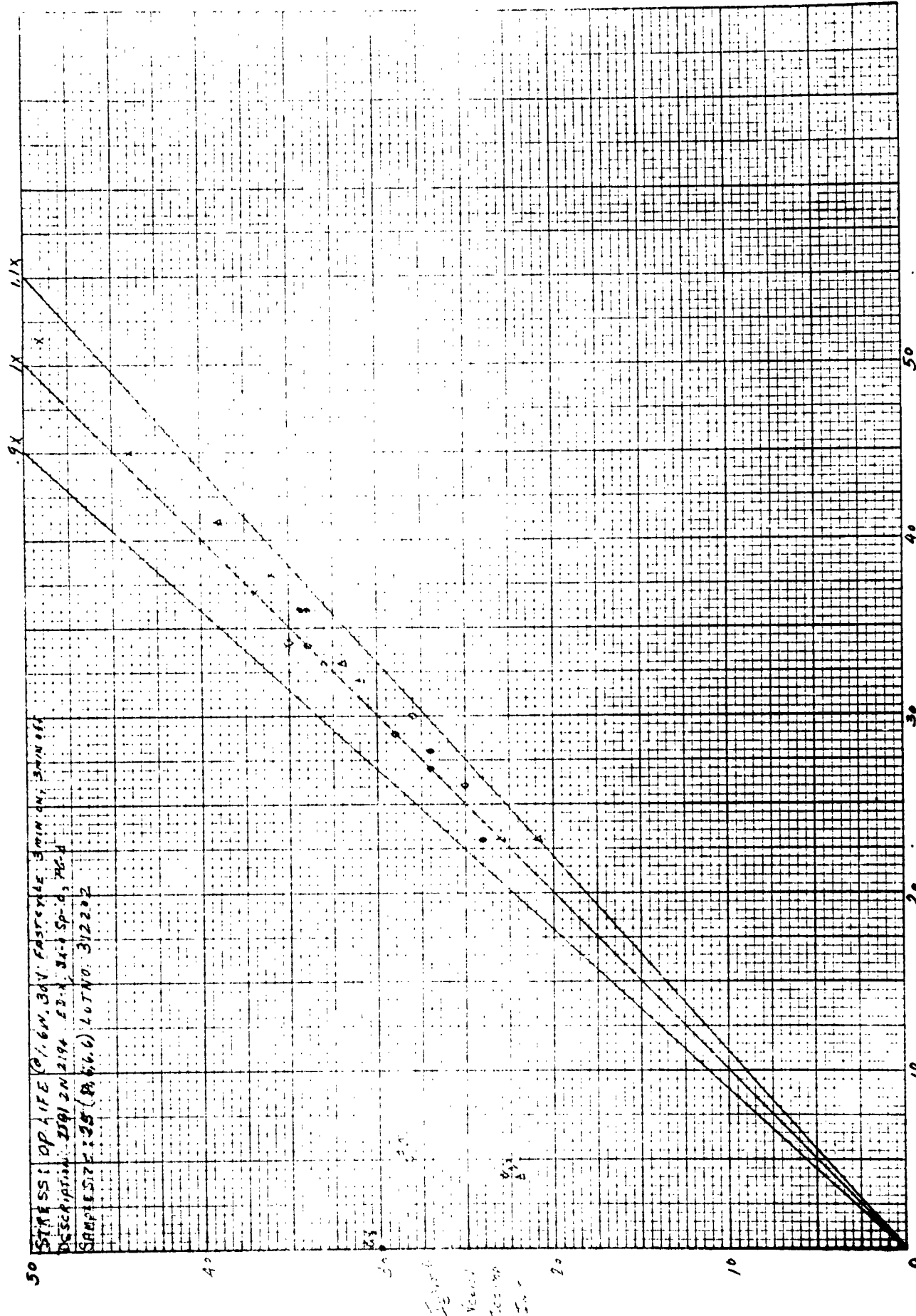


Figure 10B

100X160-6 $V_C = 10V, I_C = 1mA$ 1000 HRS.

the non-cycled devices, there was no significant difference in failure rates between the two tests. Therefore, since the LC combination used in the collector of the life test circuits (to suppress oscillation) presents a potential transient hazard (a 15-V. spike on the collector was seen on turn-off of the cycled devices), it has been decided to run the Phase II devices at the steady state so that neither purposely nor continually will they be exposed to this hazard.

11. Phase II Status and Data Analyses.

Electrical parameter stability analyses for devices undergoing the Temperature with Back-Bias Voltage screening has been performed. The units have been subjected to a total of 200 hours of such stress screening - namely, a balanced, homogeneous assignment of 480 devices each to 200°C. with 45 V. and to 280°C. with 45 V. as described in the third quarterly report under the Proposed Phase II Experiments (Figure 5B). The devices are presently undergoing the stabilization bake, to be followed by centrifuge, prior to an extended multi-level life test. An additional homogeneous group of 480 devices will not receive any pre-life test stress screening, so that the effectiveness and efficiency of the temperature with voltage and centrifuge screening can be evaluated on the life testing (See Figure 11 in this report).

Analyses based on the effects of 200 hours of temperature and voltage show devices from both stresses to be predominantly well-behaved. The charts and graphs following this discussion will reveal 1. Results of statistically testing for differences between the two stresses on ΔI_{CBO} at 0 V. (i.e., arithmetic shift from initial) in percentage shift from initial for I_{FE} , $V_{CE}(SAT)$ and $V_{BE}(SAT)$ were insignificant.

Figure 11 shows the distribution results of the ΔI_{CBO} test. This is a distribution-free test based on the maximum deviation between two independent sample cumulative step functions (known as the Kolmogorov-Smirnov test).

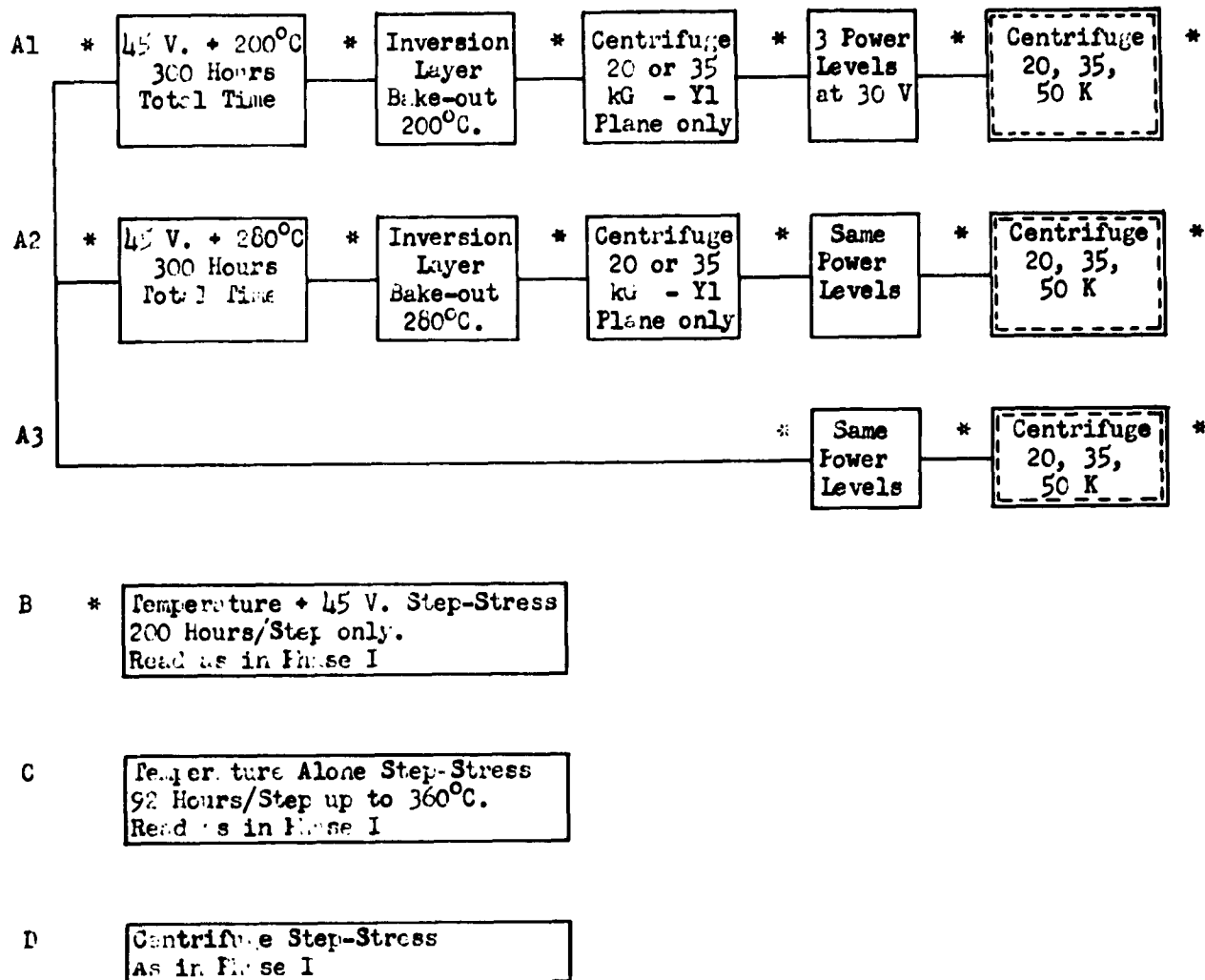
Figures 12 and 13 reveal the excellent fit of ΔI_{CBO} on the tail of the log-normal distribution for 200°C. with voltage and for 280°C. with voltage respectively. The charts show the points of shift for the early (6-hour) and the last (300-hour) read-outs. Examination of these curves show how extremely well-behaved these devices are with no appreciable degradation. The calculated least square line equations for the 6-hour and 300-hour read-outs are shown. The mean and standard deviations are also obtained from the equations. Use of these parameter estimates allows for the prediction of the proportion of devices lying outside any chosen limit of I_{CBO} degradation, i.e., ΔI_{CBO} , for the designated hours on test.

Figures 15, 16 and 17 show the percentiles of percentage shift for I_{FE} , $V_{CE}(SAT)$ and $V_{BE}(SAT)$ respectively for both screen stresses. The percentiles of shift for 480 devices per stress are given from the 1st to the 99th percentile. It can be seen here, again, that raising the temperature from 200°C. to 280°C. has little effect on the stability of these parameters for the 300 hours of testing. However, statistically significant results were obtained on the analysis based on BV_{CBO} percentage shift. While devices from neither stress degraded (lowered BV_{CBO}), the distribution of percentage shift of BV_{CBO} for the higher stress (280°C. with voltage) was significantly more to the right on the percentage shift axis. Figure 19 contrasts the histogram of BV_{CBO} percentage shift for both stresses for the early and the late read-outs. Above the histogram, the table and the results of the Kolmogorov-Smirnov two sample test is shown. The reasons for the tendency of

BVCBO to rise more sharply for the higher stress cannot as yet be explained. Figure 18 contrasts the percentiles of percentage shift between the two stresses.

Analysis of the Phase II program will continue and will be reported later.

FIGURE 11 - PROPOSED PHASE II EXPERIMENTS.



* = Read I_{CO} , h_{FE} , $V_{CE(SAT)}$, $V_{BE(SAT)}$, BV_{CEO} .

FIGURE 12.

DISTRIBUTION OF ΔI_{CBO} (I.C.B. CHANGE FROM INITIAL) IN
6.5 AND 300 HOURS FOR THE FOLLOWING TEMPERATURE
WITH BACK-BIAS VOLTAGE CONDITION:

AMBIENT TEMPERATURE: 200°C
COLLECTOR VOLTAGE: 45 V

ΔI_{CBO} 6.5 HOURS
 ΔI_{CBO} 300 HOURS

LEAST SQUARE CALCULATIONS OF ΔI_{CBO} INITIAL YIELD, SLOPE

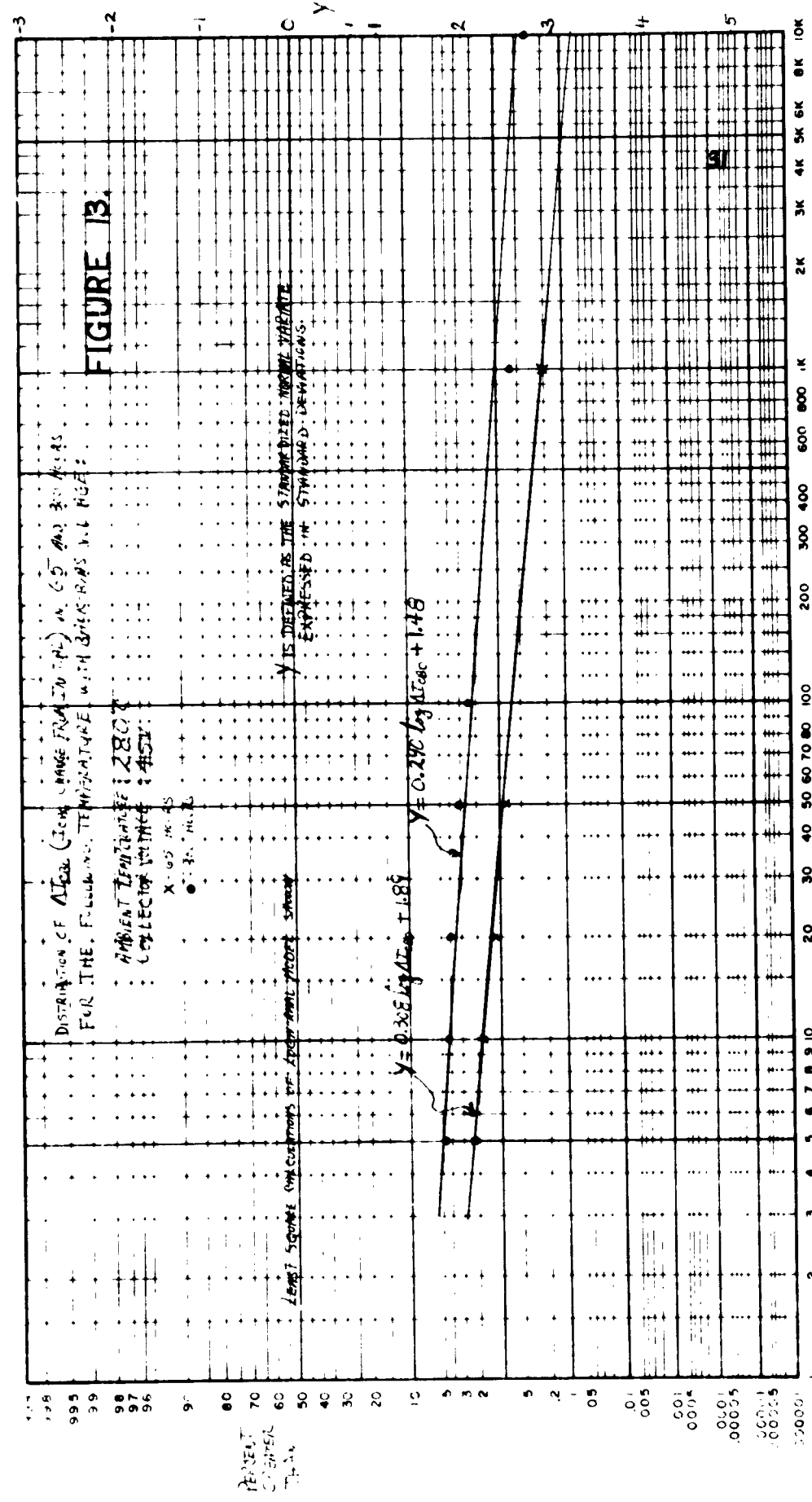
$y = 0.299 \log \Delta I_{CBO} + 1.64$
 $y = 0.285 \log \Delta I_{CBO} + 1.34$

y is defined as the standardized normal variate
EXPRESSED IN STANDARD DEVIATIONS

Y (Standard Deviations)	Percent Greater Than (6.5 hours)	Percent Greater Than (300 hours)
-2.5	0.0001	0.0000
-2.0	0.0005	0.0000
-1.5	0.001	0.0000
-1.0	0.005	0.0000
-0.5	0.01	0.0000
0.0	0.05	0.0000
0.5	0.2	0.0001
1.0	0.5	0.0005
1.5	2.0	0.001
2.0	5.0	0.005
2.5	10.0	0.01
3.0	20.0	0.05
3.5	40.0	0.2
4.0	60.0	0.5
4.5	80.0	2.0
5.0	90.0	5.0

 $\Delta I_{C8} \approx 60 \text{ V} \cdot \text{mA}$

LOG-NORMAL PROBABILITY CHART

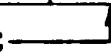


ΔT_{jdc} at 60V IN mW

FIGURE 14

Table Showing the Cumulative Percentages and Results of the Statistical Testing * for Significant Differences of Distribution of I_{CBO} Shift from Initial (ΔI_{CBO}) for 200°C. Temperature plus 45 V. Back Bias Stress and 260°C. Temperature plus 45 V. Back Bias Stress of 300 Hours Duration. (Balanced, homogeneous sample of 480 units at each stress).

Shifts of I_{CBO} in millimicroamps.	5	10	20	50	100	1,000	10,000	100,000
Percent of Units Shifting that indicated amount or less for 200°C. + 45 V.	94.2	95.0	95.4	95.6	96.0	98.75	99.38	99.8
Percent of Units Shifting that indicated amount or less for 260°C. + 45 V.	95.2	95.8	96.0	96.7	97.5	99.38	99.6	99.8
Absolute Differences of Cumulative Percentages	1.0	0.8	0.6	1.1	1.5	0.63	0.22	0.0

MAXIMUM DIFFERENCE 

** 5% Critical Value = 9

10% Critical Value = 8

RESULT: STATISTICALLY INSIGNIFICANT.

* = The distribution free Kolmogorov-Smirnov test based on maximum deviation between two independent sample cumulative step functions.

** = Statistically significant at the 5% critical level is equivalent to stating that the probability of obtaining that maximum difference observed under the assumption of no distribution differences between the parent populations is less than a 1 in 20 chance.

FIGURE 15

Percentiles of Percentage Shift for h_{FE} at $V_{CE} = 1$ V.; $I_C = 150$ mA. Shown for 200°C. with 45 V. and for 280°C. with 45 V. at Each Read-out Time.

	200°C. with 45 V.			
	HOURS			
	65	130	200	300
1%	- 7	- 7	- 7	- 7
2%	- 6	- 6	- 6	- 6
5%	- 4	- 5	- 5	- 5
10%	- 3	- 4	- 4	- 4
25%	- 1	- 2	- 3	- 3
50%	+ 1	- 1	- 2	- 2
75%	+ 2	0	0	0
90%	+ 3	+ 1	+ 1	+ 1
95%	+ 5	+ 2	+ 2	+ 2
98%	+ 6	+ 3	+ 2	+ 3
99%	+ 7	+ 4	+ 3	+ 3

	280°C. with 45 V.			
	HOURS			
	65	130	200	300
- 9	- 8	- 9	- 10	- 8
- 8	- 8	- 8	- 7	- 7
- 6	- 6	- 6	- 6	- 6
- 4	- 4	- 4	- 4	- 4
- 2	- 2	- 2	- 2	- 2
+ 1	- 2	- 2	- 2	- 2
+ 2	0	0	0	0
+ 4	+ 2	+ 2	+ 2	+ 2
+ 5	+ 3	+ 3	+ 3	+ 3
+ 6	+ 5	+ 4	+ 5	+ 5
+ 8	+ 6	+ 5	+ 7	+ 7

FIGURE 16

Percentiles of Percentage Shift for $V_{CE(SAT)}$ at 15 and 150 mA. Shown for 200°C. with 45 V. and for 280°C. with 45 V. at Each Read-out Time.

	200°C. with 45 V.			
	HOURS			
	65	130	200	300
1%	- 9	- 10	- 11	- 13
2%	- 7	- 12	- 10	- 10
5%	- 4	- 9	- 7	- 7
10%	- 3	- 6	- 6	- 5
25%	- 1	- 3	- 3	- 3
50%	+ 1	- 1	- 1	0
75%	+ 3	+ 2	+ 2	+ 2
90%	+ 5	+ 5	+ 5	+ 4
95%	+ 6	+ 6	+ 7	+ 6
98%	+ 9	+ 8	+ 12	+ 10
99%	+ 11	+ 10	+ 19	+ 27

	280°C. with 45 V.			
	HOURS			
	65	130	200	300
- 5	- 12	- 12	- 13	- 13
- 4	- 9	- 9	- 8	- 8
- 3	- 7	- 6	- 5	- 5
- 2	- 5	- 5	- 4	- 4
0	- 3	- 2	- 2	- 2
+ 2	0	0	+ 1	+ 1
+ 3	+ 2	+ 2	+ 3	+ 3
+ 5	+ 4	+ 4	+ 6	+ 6
+ 6	+ 6	+ 5	+ 8	+ 8
+ 6½	+ 8	+ 7	+ 11	+ 11
+ 7	+ 10	+ 8	+ 11	+ 11

FIGURE 17

Percentiles of Percentage Shift for $V_{BE}(SAT)$ at 15 and 150 mA. Shown for 200°C. with 45 V. and for 280°C. with 45 V. at Each Read-out Time.

	200°C. with 45 V.			
	HOURS			
	65	130	200	300
1%	- 6½	- 7	- 7	- 9
2%	- 4	- 4	- 3	- 6½
5%	0	- 1	- 1	- 1
10%	0	0	0	0
25%	+ 1	0	0	0
50%	+ 1	+ 1	+ 1	+ 1
75%	+ 2	+ 1	+ 1	+ 1
90%	+ 2	+ 2	+ 2	+ 2
95%	+ 2	+ 2	+ 2	+ 2
98%	+ 2	+ 2	+ 2	+ 2
99%	+ 2	+ 3	+ 3	+ 3

	280°C. with 45 V.			
	HOURS			
	65	130	200	300
- 5	- 7	- 7	- 7	
- 1	- 2	- 1	- 2	
0	0	0	0	
+ 1	0	0	0	
+ 1	+ 1	+ 1	+ 1	
+ 1	+ 1	+ 1	+ 1	
+ 2	+ 2	+ 2	+ 2	
+ 2	+ 2	+ 2	+ 3	
+ 2	+ 3	+ 3	+ 3	
+ 3	+ 3	+ 3	+ 4	
+ 3	+ 4	+ 3	+ 4	

FIGURE 18

Percentiles of Percentage Shift for V_{CEBO} at 100 uA. Shown for 200°C. with 45 V. and for 280°C. with 45 V. at Each Read-out Time.

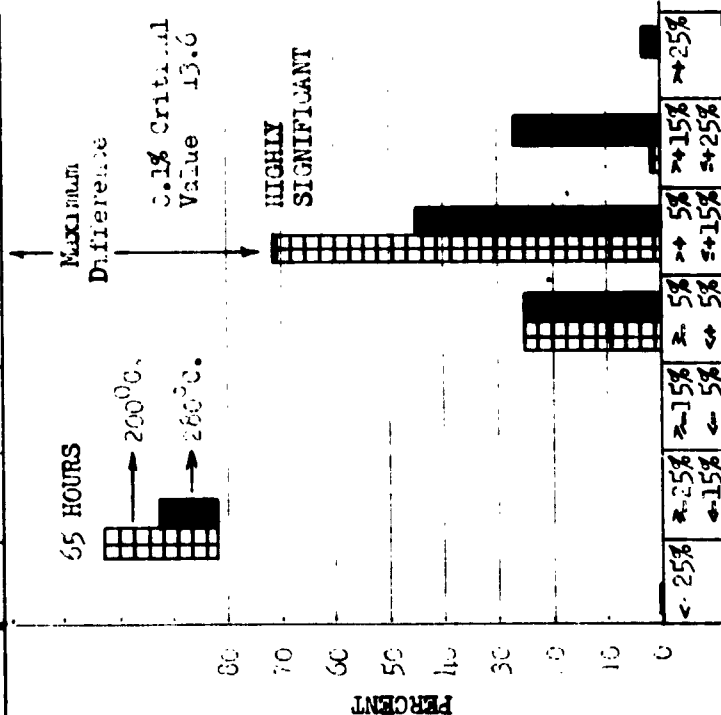
	200°C. with 45 V.			
	HOURS			
	65	130	200	300
1%	- 18	- 25	- 50	- 57
2%	+ 1	- 2	- 24	- 41
5%	+ 1	+ 1	+ 1	+ 1
10%	+ 1	+ 1	+ 1	+ 1
25%	+ 5	+ 5	+ 6	+ 6
50%	+ 7	+ 8	+ 9	+ 9
75%	+ 10	+ 10	+ 11	+ 11
90%	+ 12	+ 13	+ 13	+ 14
95%	+ 14	+ 14	+ 15	+ 16
98%	+ 16	+ 17	+ 17	+ 18
99%	+ 19	+ 20	+ 20	+ 20

	280°C. with 45 V.			
	HOURS			
	65	130	200	300
+ 1	- 1½	- 16	- 34	
+ 1	+ 1	+ 1	+ 1	
+ 1	+ 1	+ 1	+ 1	
+ 1	+ 1	+ 1	+ 1	
+ 5	+ 7	+ 7	+ 7	
+ 12	+ 14	+ 14	+ 14	
+ 17	+ 18	+ 19	+ 19	
+ 21	+ 23	+ 24	+ 24	
+ 24	+ 26	+ 27	+ 27	
+ 27½	+ 31	+ 32	+ 31	
+ 31	+ 34	+ 34	+ 34	

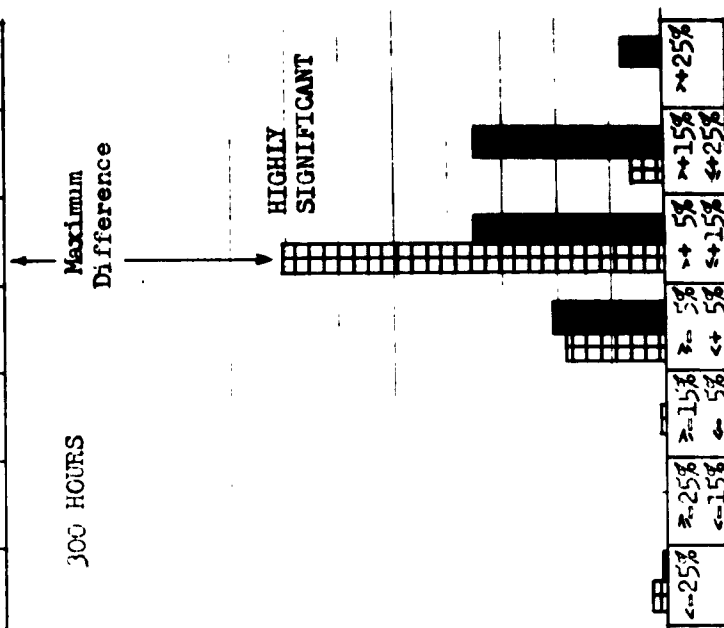
FIGURE 19 - BVCO PERCENTAGE SHIFT FROM INITIAL READING

The table shows the cumulative percent up to the grouping indicated.

STRESS	<-25%	-25% ←-15%	-15% ←-5%	-5% ←+5%	+5% ←+15%	+15% ←+25%	>+25%
200°C. + 45 V.	0.7	0.9	1.1	20.3	97.7	99.0	
280°C. + 45 V.	0.0	0.0	0.0	25.0	70.2	91.0	
Absolute Differences of the Cumulative Percentages	0.7	0.9	1.1	1.8	21.5	2.7	



STRESS	<-25%	-25% ←-15%	-15% ←-5%	-5% ←+5%	+5% ←+15%	+15% ←+25%	>+25%
200°C. + 45 V.	2.4	2.5	4.2	22.9	94.1	100	
280°C. + 45 V.	1.0	1.0	1.0	22.0	57.5	92.6	
Absolute Differences of the Cumulative Percentages	1.4	1.8	3.2	0.9	36.6	7.4	



- E. Conclusions - Pre-tests performed to date have indicated that:
1. Six hundred hours of 200°C. to 280°C. produces no significant mechanical degradation of the device (degradation defined here as an open or short after 35 KG centrifuge). As a result of this pre-test, both 200°C. with voltage and 280°C. with voltage are being used as screening tests in Phase II.
 2. No significant difference in 35 KG mechanical strength exists between those devices which had previously been stressed at 20 KG and those which had not.
 3. No significant difference in failure rates was observed between the 0.8, 1.0, 1.2, 1.4 and 1.6 Watt stresses. This means that either there is no difference or, more probably, that the sample size used was not large enough to detect the existing difference. It is interesting to note that devices operating at the 1.6, 1.4 and, to some extent, at the 1.2 Watt levels are actually operating in thermal runaway. The base lead of such a device is open (because of the back-biased diode in the life test circuit base connection), and the device is "trans-isting" because of thermally-generated base carriers. Since each device appears to seek its own power level, it is necessary to take periodic on-rack measurements of power and voltage on each device.
 4. There was no significant difference in 1.6 Watt, 1,000-hour, failure rate between those devices which had successfully passed an extended voltage plus temperature screen and those devices which had not been subjected to the screen. This offers some preliminary indication that voltage and temperature may not be an effective screen for this type of device. Phase II, however, should provide a better indication of this.
 5. Since the cycled test offered no evidence of higher failure rates than the non-cycled test, and since there is somewhat of a voltage transient problem on the operating life racks, Phase II tests will be conducted in the steady state.

F. Program - Continuance of the program proposed in the third quarterly report.
for next
Quarter

IX. AREA OF WORK - INSPECTION AND QUALITY CONTROL PLAN.

1 A. Work Item - Inspection and Quality Control Manual.

B. Abstract - During this work period, Process Flow Diagrams were coded for cross-reference to internal document identification. Sections I and II of the Manual were completed. Three copies of the Manual were forwarded to the Electronics Materiel Agency for approval.

- C. Purpose - The Inspection and Quality Control Manual outlines the total Quality Control plan to be implemented during the production run phase of this contract.
- F. Program for next Quarter - Complete, and revise where necessary, all documentation required for the implementation of the Inspection and Quality Control plan.

PROFESSIONAL PERSONNEL
and
TOTAL APPLIED EFFORT
for period covering
1 February, 1963 - 30 April, 1963.

<u>Personnel</u>	<u>Man-Hours</u>
H. M. Calder	4,220 total
Dr. A. R. DiPietro	
J. L. Durso	
A. Fox	
F. K. Glasbrenner	
T. E. Jacobs	
R. T. Kobler	
R. H. Lanzl	
C. E. Logan	
A. Poe	
J. C. Richardson	
R. E. Smith	
J. F. Wholey	

U. S. ARMY ELECTRONICS MATERIEL AGENCY.

Production Engineering Measure

DA-36-039-SC-86727

Silicon Grown Diffused Transistor

2N336

The purpose of the Production Engineering Measure Program is to improve the production techniques on the Silicon Grown Diffused Transistor type 2N336, with a maximum failure rate of 0.01% per 1,000 hours at a 90% confidence level at 25°C. as an objective.

Fourth Quarterly Report

31 January, 1963
30 April, 1963

General Electric Company
Semiconductor Products Department
Syracuse, New York.

P W Olski
Report Prepared by: P. W. Olski:

J R McLaughlin
Approved by: J. R. McLaughlin

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1. ABSTRACT

Passivation.

This phase of the contract is complete. Evaluation results are reported below.

High Temperature Main Sealing.

This phase of the contract is complete, with a production capacity of 1,200 units per hour attainable without automatic cap loading.

Experimentation and Evaluation.

A statistically designed experiment, involving 400 units, to analyze the rotary cap welder is in progress. The experiment is based on the results of the encapsulation experiment and is aimed toward optimization of gas flow rate with respect to reliability.

The evaluation of the automatic passivation experiment reveals that there is no significant difference between the automatic system and the prototype. The automatic system is therefore recommended for installation in the production line. During the experiment, it was determined that a high temperature, back-bias voltage (200°C.; 45 V. V_{CB}) screen gives statistically significant results in permitting early detection of ICBO up-shifters on high power life tests. It was also determined that 250°C. and 300°C. storage produce failures in the bulk which degrade the breakdown voltage. Power failures are surface-connected.

Characteristic Distribution.

Weekly parameter distributions of h_{fcb} , h_{rb} , h_{ob} , NF, V_{CE} , C_{ob} , h_{fe} (+25°C. and -55°C.), BV_{CBO} , BV_{EBO} , ICBO (+25°C. and +150°C.) are included for weeks 1 through 20 of 1963.

2. PURPOSE

The purpose of the Production Engineering Measure Program is to improve the production techniques on the Silicon Grown Diffused Transistor type 2N336, with a maximum failure rate of 0.01% per 1,000 hours at a 90% confidence level at 25°C. as an objective.

In the fabrication of semiconductor devices there are inevitably critical process steps which, due to process variability, exert an influence on test yields and also on long range reliability. In order to achieve the reliability objective of this program, two key process steps have been singled out to maximize process control. By redesign of initial production equipment in these two areas, the latest processing techniques can be incorporated, while minimizing process variability, and at the same time greatly increasing production capability. The two specific work areas referred to above are Surface Passivation and High Temperature Main Sealing.

The objectives of this report are now noted.

2.1 PASSIVATION

Installation of equipment which will:

1. Permit the incorporation of the latest processing techniques.
2. Minimize process variability.
3. Increase production capability.

2.2 HIGH TEMPERATURE MAIN SEALING.

Installation of main seal welding equipment which will meet the process requirements, defined as necessary to achieve highly reliable device performance, and which will also provide for volume production.

2.3 EXPERIMENTATION AND EVALUATION

2.3.1 Reliability Experiment.

Determination of the reliability of the automatic passivation process versus the prototype method.

2.4 CHARACTERISTIC DISTRIBUTIONS

The establishment of a system to monitor the electrical parameter distributions on the 4JD4C line where the 2N336 is produced.

3. NARRATIVE AND DATA

3.1 PASSIVATION

The automatic passivation equipment was installed, as reported in the second quarterly report, and the evaluation of the equipment is reported below.

3.2 HIGH TEMPERATURE MAIN SEALING

Analysis of the high temperature main sealing process is in progress.

A total of 400 devices, fabricated over a period of several weeks, has been encapsulated using both the new rotary cap welding design and the present standard encapsulation system. The high temperature and the duration of purging time are maintained for both systems at constant levels, as established from previous experimentation.

Three levels of gas flow rate will be used for the rotary welder to establish an optimum. All other materials, process steps and equipment preceding and following encapsulation have been kept identical. The units have been identified so that the period of production as well as the encapsulation system (and the different flow rates for the rotary system) can be established.

All units will be processed through a temperature and back-bias voltage screen and put on an extended accelerated power life test

Results from this experiment will be reported in due course.

Since the production rate of 1,200 units per hour, as presented in the proposal, is attainable without automatic cap loading, this phase of the process has been dropped.

3.3 EXPERIMENTATION AND EVALUATION

The following pages contain the report on:

3.3.1 RELIABILITY EXPERIMENT

OBJECTIVE.

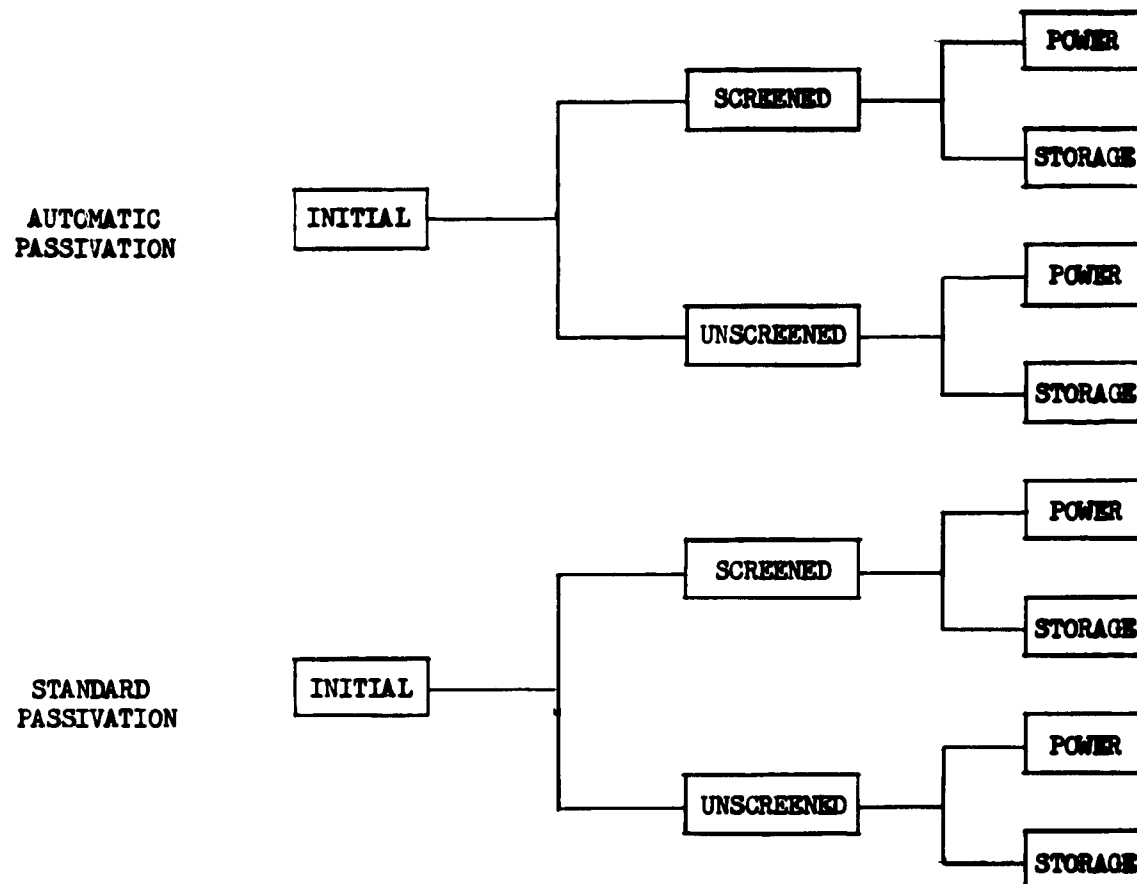
The primary purpose of the Passivation Experiment is to allow a valid comparison to be made between the new automated surface passivation system (as described in previous reports) and a prototype of the proposed system (referred to as the standard passivation system). The comparison will be based on the reliability and distribution performance on accelerated power and temperature storage conditions for devices processed through both passivation systems.

A secondary purpose is the demonstration of the effectiveness of a short time (100 hours) of 100% stress screening of temperature (200°C.) with back-bias collector voltage (45 V.) in culling out potential n-inversion failures on long-term high power tests.

EXPERIMENT DESIGN.

A total of 500 devices, fabricated over a period of several weeks, is used in this experiment. All material, process steps and equipment used in fabrication are identical, except for the passivation processes. The passivation procedure, using both systems, has been performed at several production periods to assure adequate replication of the experimental design.

Figure 1 shows how the devices are allocated throughout the experiment in a balanced fashion. Thus, the design reduces to a replicated 2^3 full factorial, viz. 3 variables, each at two levels, as shown in the figure.



SCREENING CONDITIONS.

200°C.; 45 V. V_{CB}
for 100 Hours.

Stabilization Bake
50 Hours.

LIFE TEST CONDITIONS.

POWER:

760 mw.; 30 V. V_{CB} ; 25°C. ambient temperature
Emitter current cycled 50 minutes ON, 10 minutes OFF.

STORAGE:

250°C. ambient temperature.

Minimum 1,000 Hours.

FIGURE 1 - EXPERIMENTAL DESIGN.

TEST CONDITIONS AND MEASUREMENTS.

All devices are measured initially and parameter screened before being considered as experimental potential, i.e., I_{CBO} at 30 V. $V_{CB} < 50$ mA, and I_{CEO} at 25 V. < 100 mA. This is followed by a 100-hour stress screen of temperature (200°C.) with back-bias collector voltage (45 V.) applied to a random balanced half of the total devices. The stress-screened units are parameter screened and subjected to a 50-hour stabilization bake, then parameter screened again.

Both stress-screened and non-stress-screened devices are then divided, again in a random balanced manner, between a 1,000-hour accelerated power test (760 mw.; 30 V. V_{CB} ; 25°C. ambient temperature with emitter current cycled 50 minutes ON, 10 minutes OFF) and an accelerated temperature storage test (250°C.).

(The life testing of automatic passivation units is to be extended to provide further information, depending on socket availability).

CONCLUSIONS AND RECOMMENDATIONS.

Statistical analyses (both on an attribute and on a variables basis) comparing the two passivation systems showed no statistical significance, either during stress screening or during extended accelerated power and temperature storage tests.

Tables 1, 2 and 3 show the percentiles of I_{CBO} leakage, hfg percent shift from initial reading and BVC_{BO} degradation respectively for different combinations of passivation system, stress screening and accelerated life test. In the case of stress-screened units, "initial" reading is the reading after the stabilization bake, immediately prior to life test. The data is shown for each successive readout time on the accelerated life tests.

Table 4 and Tables 5, 6 and 7 show the Contingency Tables and summarized Chi-square test results. These demonstrate statistically significant differences (at the 0.05 level) between stress-screened and non-stress-screened product and the different life tests both on an attribute (Table 4) and on a variables (Tables 5, 6 and 7) basis, while non-statistically significant results are obtained between the two passivation systems.

Figure 2 demonstrates the very positive correlation between I_{CBO} "up-shifters" on short-term (100 hours) temperature plus back-bias voltage screening and long-term (1,000 hours or more) accelerated power testing. This correlation is not evident between temperature and back-bias screen and accelerated temperature storage life test, as can be seen in Figure 3.

Reject analysis reveals that the failures on 250°C. storage life test show an extreme breakdown voltage degradation which is very much time-dependent as well as temperature-dependent, and independent of temperature and back-bias voltage screening. Weibull plots of failure-in-time give a slope (β) of 1, showing a constant failure rate. For 250°C., this degradation occurs in the neighborhood of 1,000 hours; raising the temperature to 300°C., for example, will more than halve the time at which degradation occurs. These failures are not recoverable on re-etching and appear to exhibit a non-surface phenomenon.

The few failures occurring on the 760 mw. life test (in the neighborhood of 1%) are recoverable on re-etching, however, and appear to be of the surface contamination type.

RECOMMENDATION.

Based on the results of this experiment, the new automatic passivation system is recommended for installation in the production line.

TABLE 1

10, 50 and 90 Percentiles of I_{CB0} at $V_{CB} = 30$ V. at Initial (Value after Bake for screened units) and after 20, 160, 500 and 1,000 Hours of Accelerated Life Testing.

		ACCELERATED POWER (760 mw.; 25°C. ambient temperature; cycled emitter current 50 min. ON, 10 min. OFF).									
		SCREENED					UNSCREENED				
		LIFE TEST HOURS					LIFE TEST HOURS				
		Init	20	160	500	1000	Init	20	160	500	1000
Automatic Passivation System	10%	0	0	0	0	1	0	0	0	0	1 μ A.
	50%	2	2	3	3	5	2	3	5	7	10 μ A.
	90%	9	9	10	15	23	19	15	29	90	134 μ A.
Standard Passivation System	10%	0	0	0	0	1	0	0	0	1	2 μ A.
	50%	2	3	2	3	5	2	3	3	6	8 μ A.
	90%	13	17	17	17	34	15	13	30	42	58 μ A.

		ACCELERATED TEMPERATURE STORAGE (250°C.)									
		SCREENED					UNSCREENED				
		LIFE TEST HOURS					LIFE TEST HOURS				
		Init	20	160	500	1000	Init	20	160	500	1000
Automatic Passivation System	10%	0	0	0	0	1	0	0	0	0	1 μ A.
	50%	2	3	2	2	2	2	2	1	2	3 μ A.
	90%	10	13	8	8	15	15	13	9	21	10 μ A.
Standard Passivation System	10%	0	1	0	0	1	0	1	0	0	1 μ A.
	50%	2	3	2	2	2	3	3	3	4	3 μ A.
	90%	18	29	12	10	12	12	32	18	18	46 μ A.

TABLE 2

10, 50 and 90 Percentiles of h_{FE} % Shift from Initial (Value after Bake for screened units) at $V_{CE} = 5.0$ V.; $I_C = 1.0$ mA. at 20, 160, 500 and 1,000 Hours of Accelerated Life Testing

		ACCELERATED POWER (760 mW.; 25°C. ambient temperature; cycled emitter current 50 min. ON, 10 min. OFF).									
		SCREENED					UNSCREENED				
		LIFE TEST HOURS					LIFE TEST HOURS				
		20	160	500	1000		20	160	500	1000	
Automatic Passivation System	10%	3	6	9	4		2	-24	5	-4	
	50%	12	16	23	17		10	15	25	16	
	90%	19	28	36	26		20	33	46	35	
Standard Passivation System	10%	0	0	0	-4		2	7	8	1	
	50%	13	15	19	14		14	19	24	16	
	90%	21	24	33	26		26	34	41	31	

		ACCELERATED TEMPERATURE STORAGE (250°C.)									
		SCREENED					UNSCREENED				
		LIFE TEST HOURS					LIFE TEST HOURS				
		20	160	500	1000		20	160	500	1000	
Automatic Passivation System	10%	-2	-24	-30	-36		-2	-25	-33	-43	
	50%	5	2	-4	-10		3	-3	-5	-12	
	90%	13	18	22	24		13	18	38	46	
Standard Passivation System	10%	-2	-23	-33	-39		-2	-27	-31	-36	
	50%	5	-2	-6	-12		5	-4	-6	-11	
	90%	11	12	20	17		14	15	23	22	

TABLE 3

10, 50 and 90 Percentiles of BV_{CBO} at $I_C = 50 \mu A$. at Initial (Value after Bake for screened units) and After 20, 160, 500 and 1,000 Hours of Accelerated Life Testing.

		ACCELERATED POWER (760 mw., 25°C. ambient temperature, cycled emitter current 50 min. ON, 10 min. OFF).									
		SCREENED					UNSCREENED				
		LIFE TEST HOURS					LIFE TEST HOURS				
		Init	20	160	500	1000	Init	20	160	500	1000
Automatic Passivation System	10%	81	81	83	82	84	76	75	77	79	77 V.
	50%	113	112	114	112	116	114	115	118	118	122 V.
	90%	162	161	166	161	161	152	152	193	159	159 V.
Standard Passivation System	10%	70	71	67	67	67	66	66	76	77	78 V.
	50%	122	123	125	127	126	116	120	123	124	123 V.
	90%	169	169	170	169	169	162	162	162	162	162 V.

		ACCELERATED TEMPERATURE STORAGE (25°C.)									
		SCREENED					UNSCREENED				
		LIFE TEST HOURS					LIFE TEST HOURS				
		Init	20	160	500	1000	Init	20	160	500	1000
Automatic Passivation System	10%	93	94	90	67	71	80	82	78	51	27 V.
	50%	124	127	124	118	120	111	129	118	110	102 V.
	90%	178	178	179	175	160	161	162	160	158	155 V.
Standard Passivation System	10%	76	81	85	79	59	80	83	82	77	39 V.
	50%	128	128	130	125	109	122	126	127	116	111 V.
	90%	163	164	163	160	159	165	165	164	164	154 V.

TABLE 4

Two by Two Contingency Tables on Failures* Showing Chi-Square Test Results Comparing Separately:

- A. Automatic versus Standard Passivation.
 B. Stress-Screen versus Non Stress-Screen.
 C. Accelerated Power Life Test versus Accelerated Temperature Storage Life Test.

A.	AUTOMATIC PASSIVATION	STANDARD PASSIVATION	MARGINAL TOTALS
No. of Non-Failed Devices	182	205	387
No. of Failed Devices	10	6	16
Marginal Totals	192	211	403
Calculated Chi-Square = 0.91 STATISTICALLY INSIGNIFICANT			

B.	STRESS SCREENED	NON-STRESS SCREENED	MARGINAL TOTALS
No. of Non-Failed Devices	207	180	387
No. of Failed Devices	4	12	16
Marginal Totals	211	192	403
Calculated Chi-Square = 4.92 5% Critical Chi Square (1 degree of Freedom) = 3.84 STATISTICALLY SIGNIFICANT AT THE 0.05 LEVEL.			

C.	POWER	STORAGE	MARGINAL TOTALS
No. of Non-Failed Devices	193	194	387
No. of Failed Devices	5	11	16
Marginal Totals	198	205	403
Calculated Chi-Square = 4.75 5% Critical Chi Square (1 degree of Freedom) = 3.84 STATISTICALLY SIGNIFICANT AT THE 0.05 LEVEL.			

* : Failures are defined as those devices which exceed 1 uA. for I_{CBO} at $V_{CB} = 30$ V. on Life Test.

All devices have passed the multi parameter (I_{CBO} and I_{CEO}) screening criteria.

"Statistically significant at the 0.05 level" is equivalent to stating that the probability of observing a break-up between failures and non-failures under the assumption of no difference between the two types of devices is less than a 1 in 20 chance.

TABLE 5

Contingency Tables, Showing Chi-Square Test Results Comparing the 30-V. VCB ICBO Distribution Separately for:

A. Stress-Screened versus Non-Stress-Screened.

B. Accelerated Power Life Test versus Accelerated Temperature Storage Life Test.

After 1,000 Hours on Life Test.

A. Frequency Class mA.	STRESS-SCREENED		NON-STRESS-SCREENED		MARGINAL TOTALS
	Observed	Expected	Observed	Expected	
> 0 ≤ 5	14	19.3	11	126.7	266
> 5 ≤ 10	3	20.9	17	19.1	40
> 10 ≤ 50	20	34.0	38	31.4	66
> 50 ≤ 1000	2	6.4	14	7.6	16
> 1000	4	7.2	11	7.2	15
Margin 1 Totals	44		192		403
Calculated Chi-Square = 19.6 1% Critical Chi-Square (4 degrees of Freedom) = 13.3 HIGHLY SIGNIFICANT.					

B. Frequency Class mA.	POWER		STORAGE		MARGINAL TOTALS
	Observed	Expected	Observed	Expected	
> 0 ≤ 5	103	129.4	103	136.6	206
> 5 ≤ 10	29	19.4	11	20.6	40
> 10 ≤ 50	50	32.1	10	33.9	66
> 50 ≤ 1000	11	7.6	5	8.2	16
> 1000	3	7.3	12	7.7	15
Margin 1 Totals	196		207		403
Calculated Chi-Square = 46.7 1% Critical Chi-Square (4 degrees of Freedom) = 13.3 HIGHLY SIGNIFICANT.					

All devices have passed the multi parameter (ICBO and ICEO) screening criteria.

"Highly significant at the 1% level" is equivalent to stating that the probability of observing a break-up between frequency classes under the assumption of no difference between the two types of devices is less than a 1 in 100 chance.

TABLE 6

Contingency Tables, Showing Chi-Square Test Results Comparing the h_{FE} Percent Shift from Initial Life Test Value at V_{CE} = 5 V.; I_C = 1.0 mA. Distribution Separately for:

A. Stress-Screened versus Non-Stress-Screened.

B. Accelerated Power Life Test versus Accelerated Temperature Storage Life Test.

After 1.000 Hours on Life Test.

A. Frequency Class %	STRESS-SCREENED		NON-STRESS-SCREENED		MARGINAL TOTALS
	Observed	Expected	Observed	Expected	
> 40	7	6.3	5	5.7	12
30 - 40	10	12.6	14	11.4	24
20 - 30	20	19.3	17	17.7	37
10 - 20	25	22.5	18	20.5	43
0 - 10	28	26.7	23	24.3	51
0 + 10	33	35.0	34	32.0	67
+10 + 20	47	44.5	38	40.5	85
+20 + 30	28	24.1	18	21.9	46
+30 + 40	5	8.9	12	8.1	17
+40	8	11.0	13	10.0	21
Marginal Totals	211		192		403
Calculated Chi-Square = 9.2 10% Critical Chi-Square (9 degrees of Freedom) = 14.7 STATISTICALLY INSIGNIFICANT.					

B. Frequency Class %	POWER		STORAGE		MARGINAL TOTALS
	Observed	Expected	Observed	Expected	
> 40	0	5.8	12	6.2	12
30 - 40	0	11.7	24	12.3	24
20 - 30	1	18.0	36	19.0	37
10 - 20	6	20.9	37	22.1	43
0 - 10	12	24.8	39	26.2	51
0 + 10	39	32.6	28	34.4	67
+10 + 20	79	41.3	6	43.7	85
+20 + 30	38	22.4	8	23.6	46
+30 + 40	12	8.3	5	8.7	17
+40	9	10.2	12	10.8	21
Marginal Totals	196		207		403
Calculated Chi-Square = 193.0 1% Critical Chi-Square (9 degrees of Freedom) = 21.7 HIGHLY SIGNIFICANT.					

TABLE 7

Contingency Tables, Showing Chi-Square Test Results Comparing the BV_{CBO} ($I_C = 50 \mu A.$) Distribution Separately for:

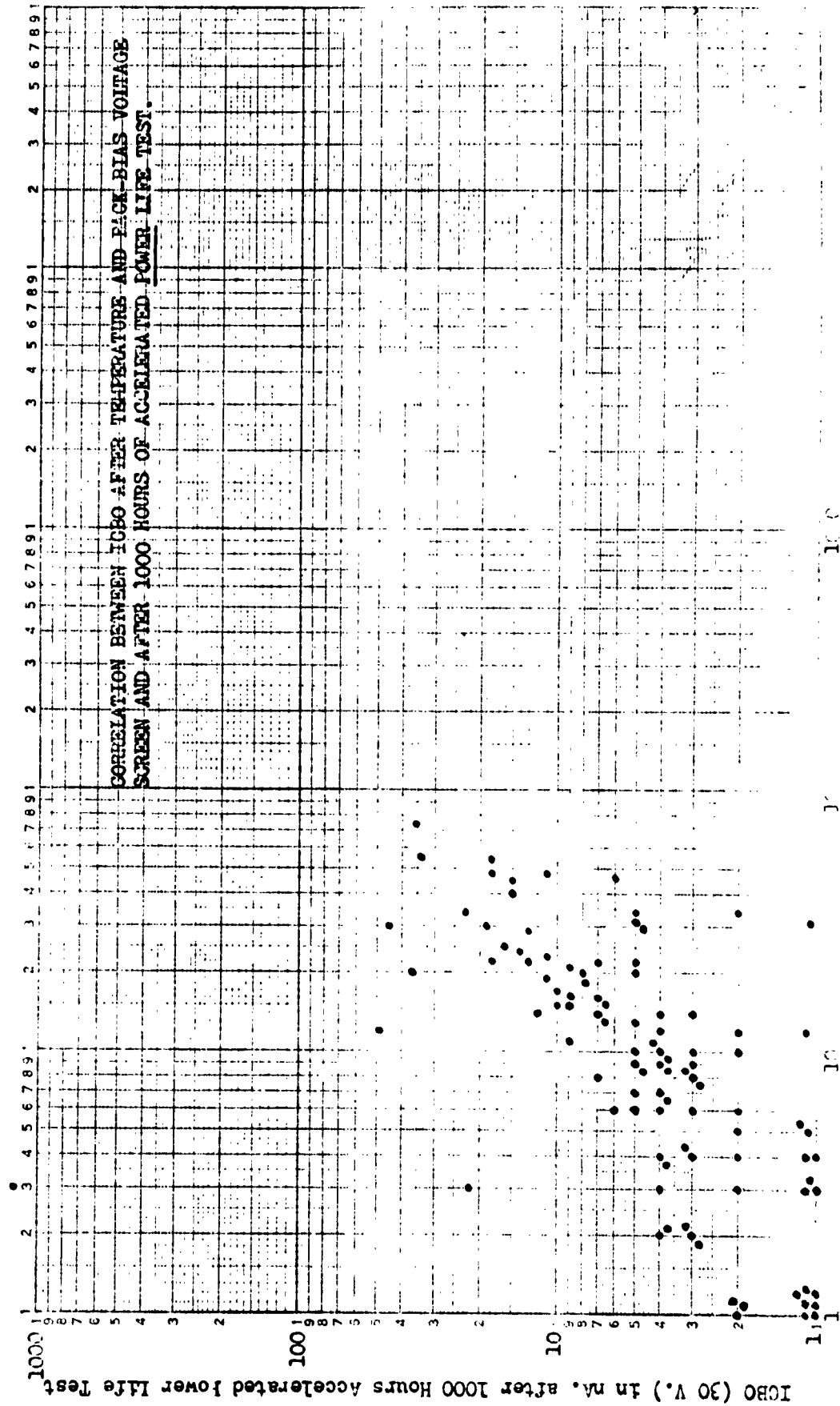
A. Stress-Screened versus Non-Stress-Screened.

B. Accelerated Power Life Test versus Accelerated Temperature Storage Life Test.

After 1,000 Hours on Life Test.

A. Frequency Class V.	STRESS-SCREENED		NON-STRESS-SCREENED		MARGINAL TOTALS
	Observed	Expected	Observed	Expected	
> 0 ≤ 40	5	9.4	13	8.6	18
40 80	22	25.1	26	22.9	48
80 120	72	72.8	67	66.2	139
120 160	92	85.9	72	78.1	164
160 200	16	15.7	14	14.3	30
200	4	2.1	0	1.9	4
Marginal Totals	211		192		403
Calculated Chi-Square = 9.8 10% Critical Chi-Square (5 degrees of Freedom) = 9.24 5% Critical Chi-Square (5 degrees of Freedom) = 11.1 STATISTICALLY SIGNIFICANT AT THE 10% LEVEL.					

B. Frequency Class V.	POWER		STORAGE		MARGINAL TOTALS
	Observed	Expected	Observed	Expected	
> 0 ≤ 40	1	8.8	17	9.2	18
40 80	20	23.3	28	24.7	48
80 120	60	67.6	79	71.4	139
120 160	96	79.8	66	84.2	164
160 200	17	14.6	13	15.4	30
200	2	1.9	2	2.1	4
Marginal Totals	196		207		403
Calculated Chi-Square = 23.2 1% Critical Chi-Square (5 degrees of Freedom) = 15.1 HIGHLY SIGNIFICANT.					



3.4 CHARACTERISTIC DISTRIBUTIONS

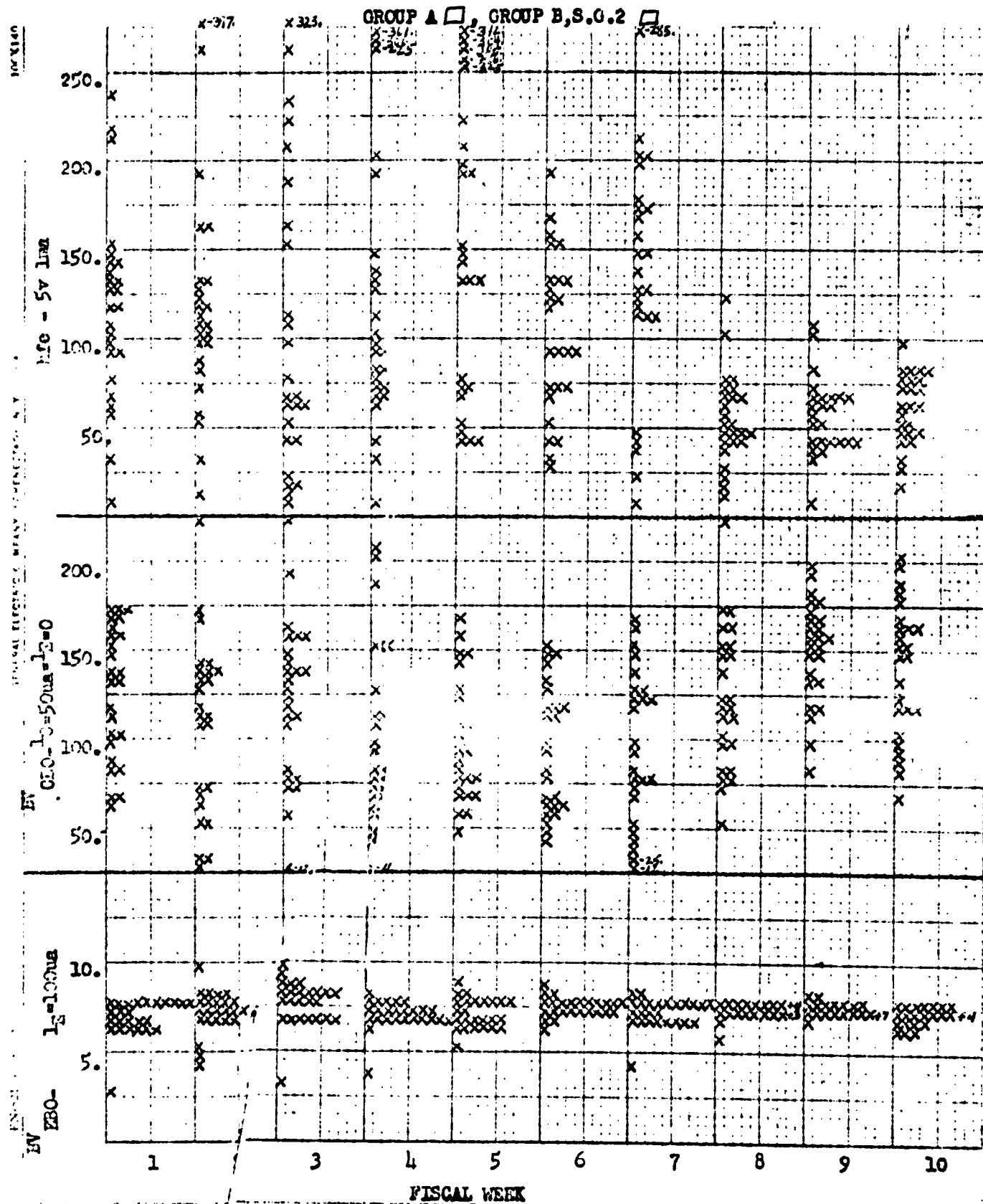
The attached report gives the weekly parameter distributions of BV_{EBO} , BV_{CBO} , h_{fe} , I_{CBO} at 25°C . and 150°C ., and h_{fe} at -55°C . As stated in the last report, current gain h_{fe} has been recorded rather than h_{fb} , and BV_{EBO} at $I_E = 100$ microamperes has been recorded rather than I_{EBO} at $V_{EB} = 1$ Volt.

The Quality Control Report describing the quality practices exercised by the General Electric Company in the construction of 2N336 transistors for the U.S. Army Electronics Materiel Agency was sent to the Agency on 2-19-1963. A request for additional forms was filled on 4-12-1963. The manual will be used when the production run is begun.

PARAMETER DISTRIBUTION BY WEEK

1963 - LWD4C LINE, (2W332, 2W333, 2W335, 2W336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A



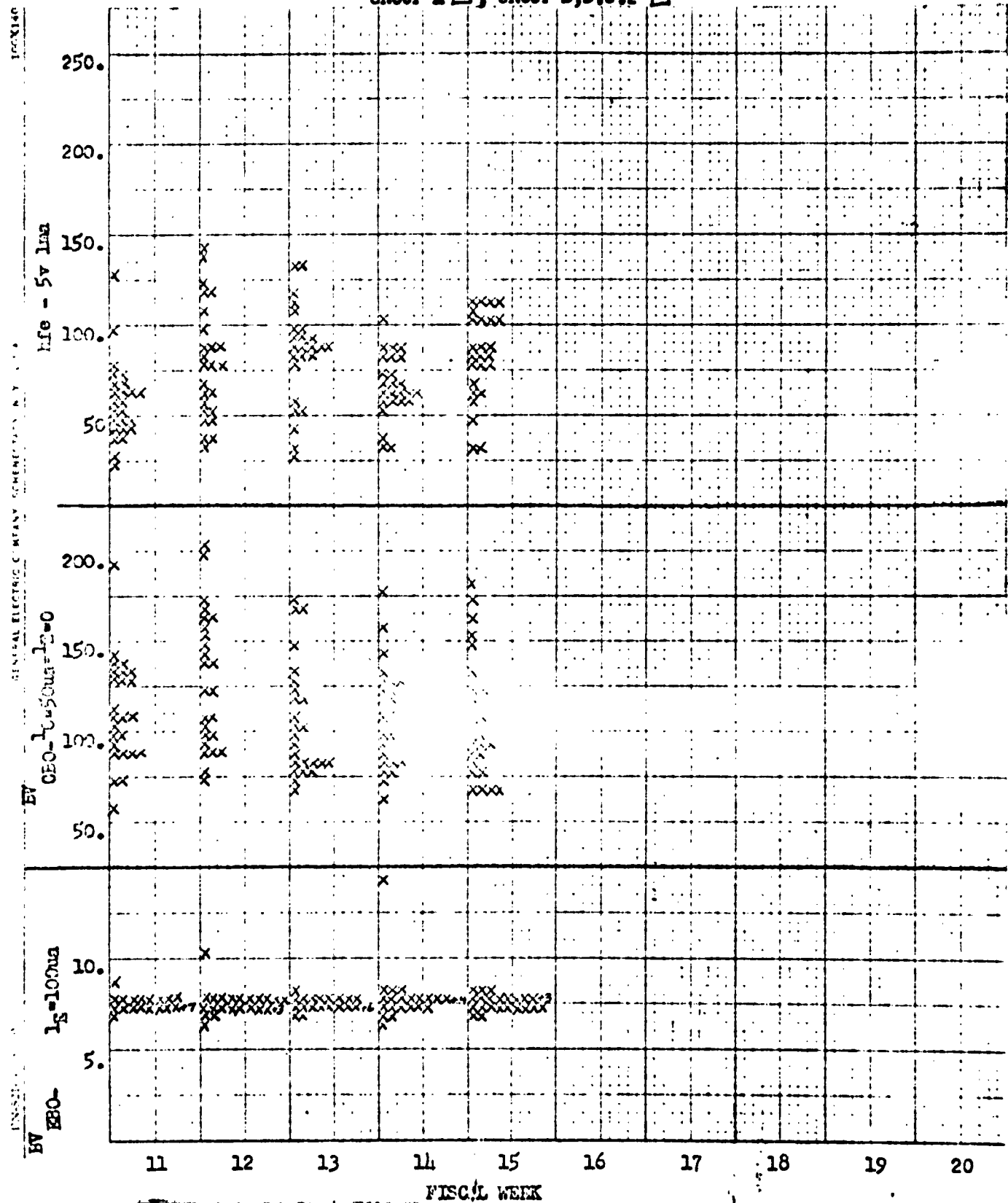
PARAMETER DISTRIBUTION BY WEEK

17

1963 - LJD4C LINE, (2W352, 2W333, 2W335, 2W336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A $\square$, GROUP B, S.O.2 $\square$

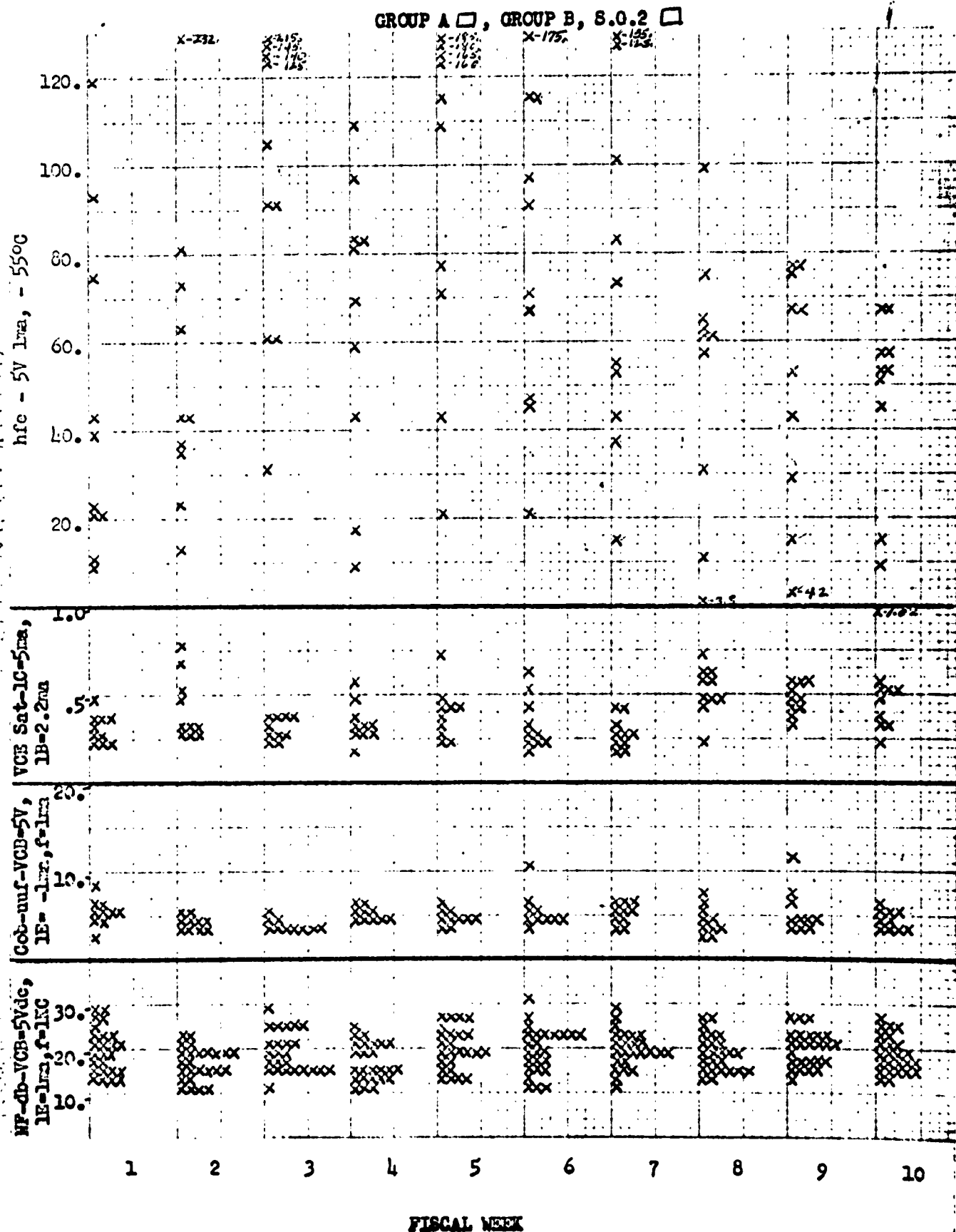


PARAMETER DISTRIBUTION BY WEEK

1963 - LJDLC LINE, (2N332, 2N333, 2N335, 2N336)

18

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

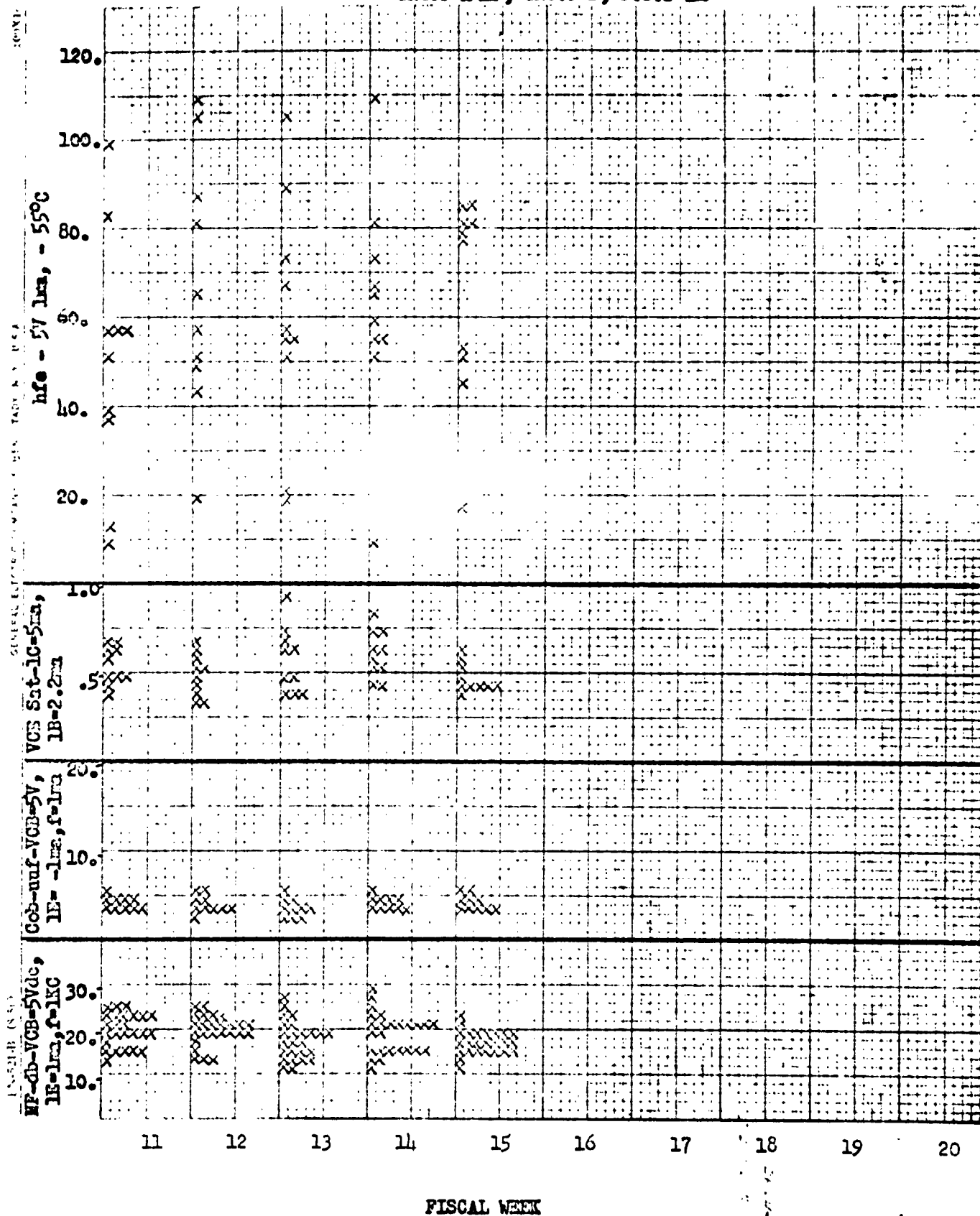


PARAMETER DISTRIBUTION BY WEEK

1963 - LUDLC LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A ☐, GROUP B, S.O.2 ☐



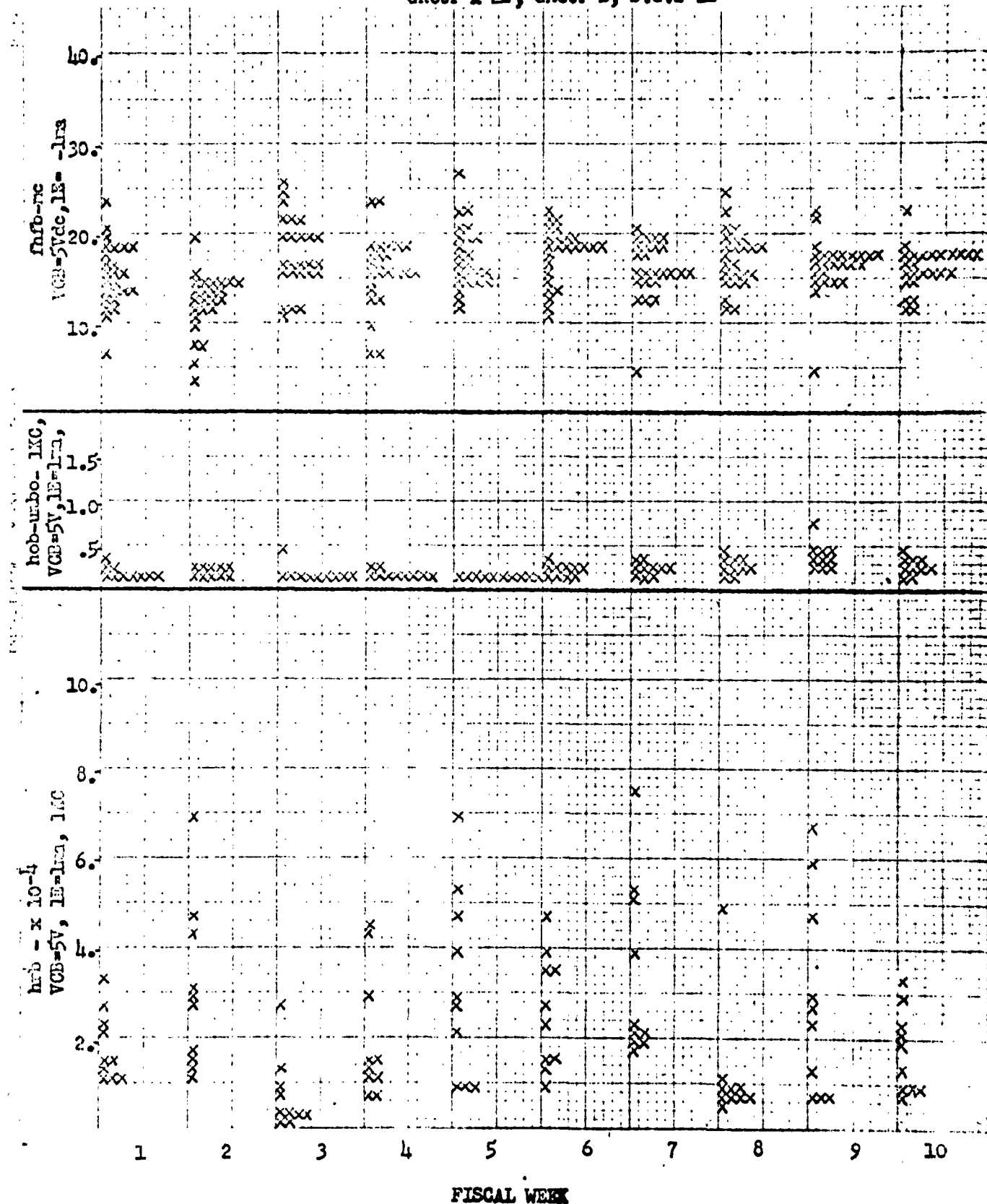
PARAMETER DISTRIBUTION BY WEEK

20

1963 - LJDLC LINE, (2N332, 2N333, 2N335, 2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A ☐, GROUP B, S.G.2 ☐

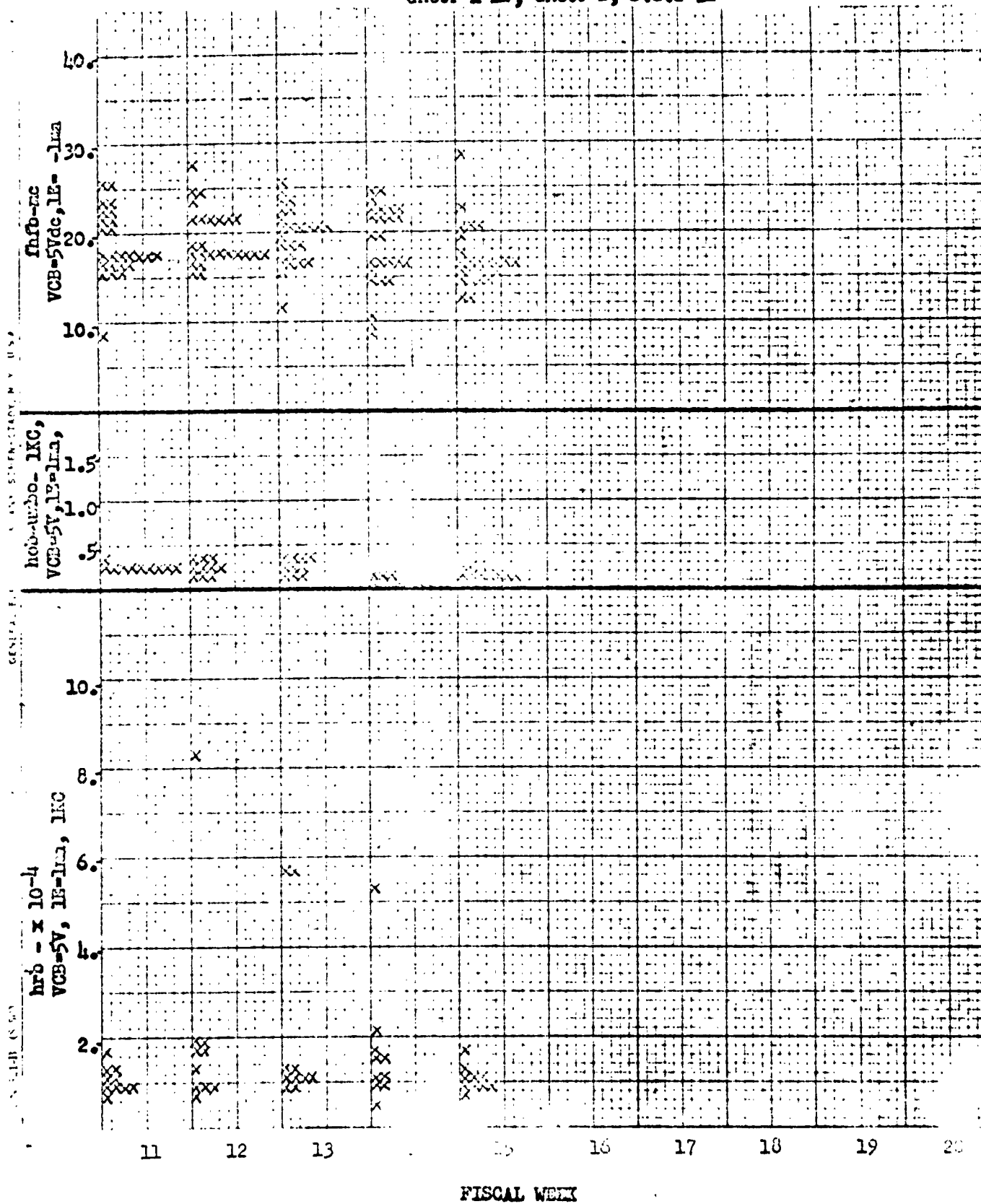


PARAMETER DISTRIBUTION BY WEEK

1963 - LJD4C LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS FOR MILT 19500/37A

GROUP A ☐, GROUP B, S.G.2 ☐



INTER-DEPARTMENTAL

1963 - 1964 (2000, 2000, 2000, 2000)

ELECTRONIC RESEARCH AND DEVELOPMENT

1000

GROUP A, GROUP B, S.O.2

1000-300

	10	9	8	7	6	5	4	3	2	1
10										
9										
8										
7										
6										
5										
4										
3										
2										
1										

1000

1000

10

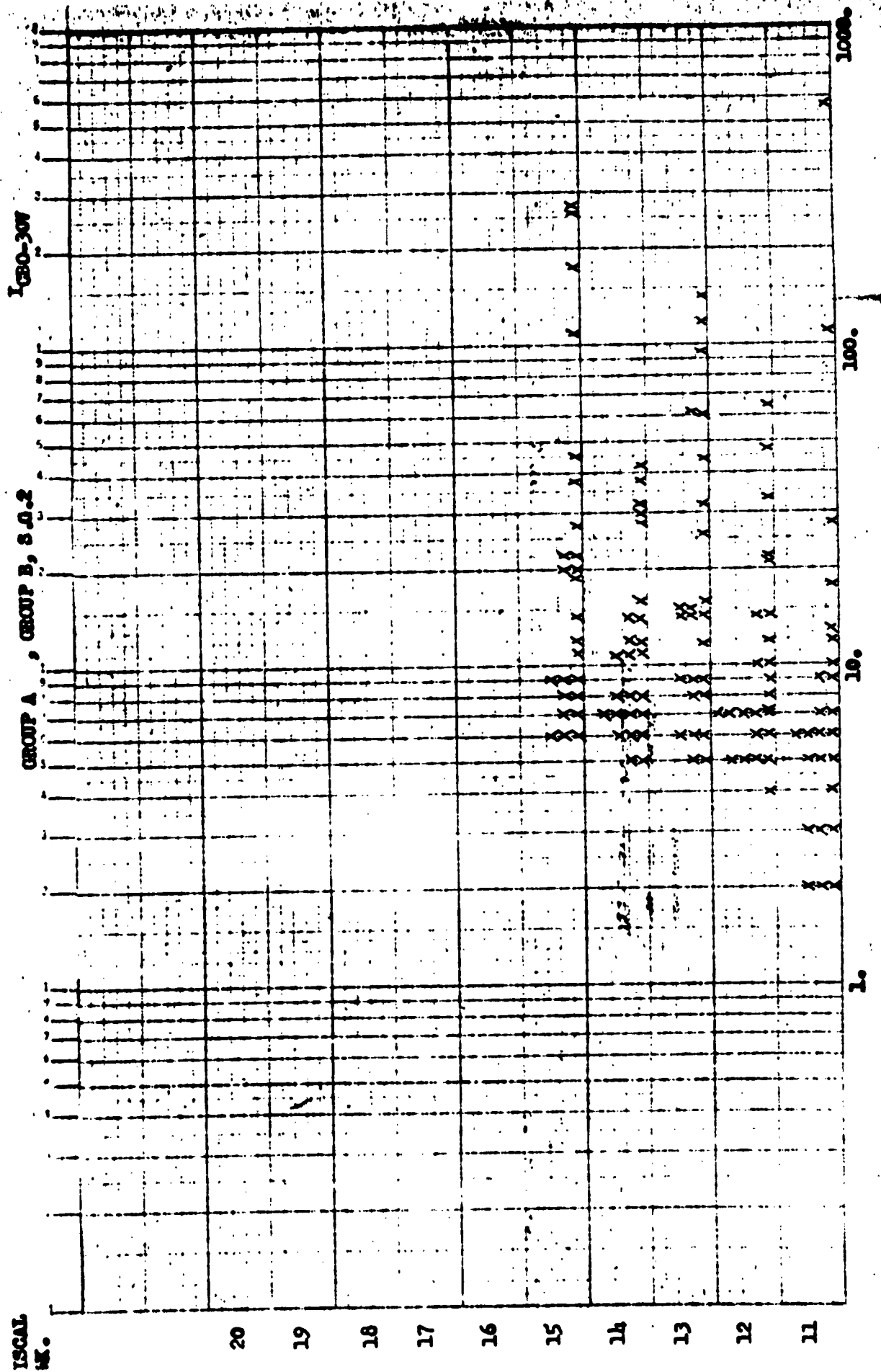
1

1000

PARAMETER DISTRIBUTION BY WEEK

1963 - JUDGE LINE, (2H332, 2H333, 2H335, 2H336)

ELECTRICAL MEASUREMENTS PER MILIT 19500/37A



PARAMETER DISTRIBUTION BY WEEK

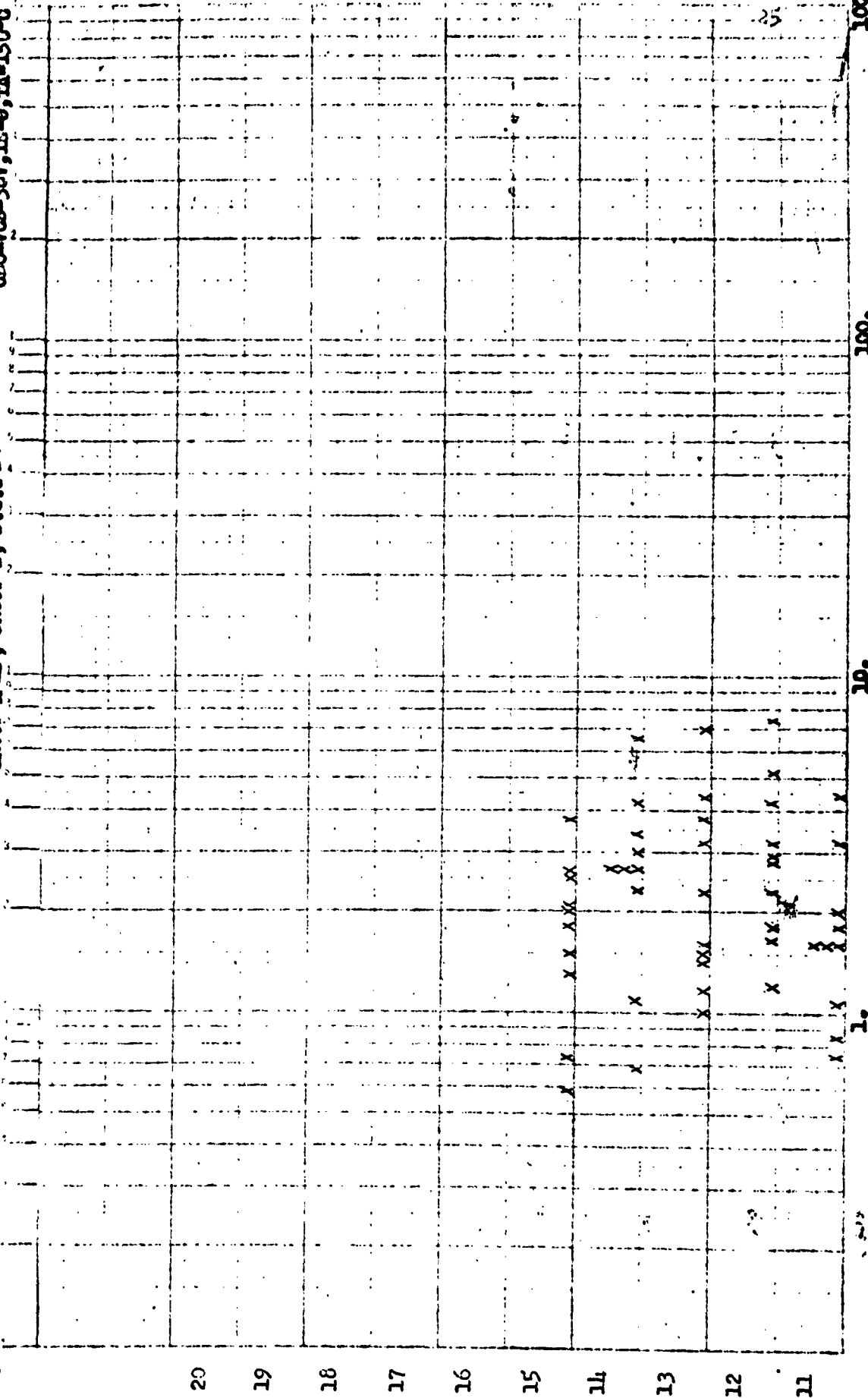
1963 - 4JDLG LINES, (2H332, 2H333, 2H335, 2H336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

FISCAL
WK.

GROUP A ☐, GROUP B, S.O.2 ☐

ICBO-VCB-307, 1E-9, 1A-1500g



4. CONCLUSIONS

The passivation experiment has shown that the automatic equipment is not significantly different from the prototype, and its installation in the production line is fully justified. The reliability study performed during this experiment has shown a significant statistical difference between those units which have been subjected to a temperature and back-bias voltage screen and those which have not. This screen has the ability to remove the potential ICBO up-shifters on both power and operating life tests. The failure mechanism appears to be surface-oriented. High temperature stresses of 250°C. and 300°C. appear to produce bulk failure mechanisms which are irreversible.

A main seal welding experiment is in progress to optimize the flush time and to check the reliability of the equipment. The automatic cap-loader has been abandoned, since the proposed production rates are attainable without it.

5. PROGRAM FOR NEXT QUARTER

5.1 PASSIVATION

This part of the program is complete.

5.2 HIGH TEMPERATURE MAIN SEALING

This part of the program is complete.

5.3 PRODUCTION RUN

This part of the program is ready and can be started as soon as authorization is given by the Agency.

5.4 EXPERIMENTATION AND EVALUATION

Evaluation of the rotary cap welder will be continued.

Evaluation of the production run will begin as soon as this part of the program is authorized.

5.5 CHARACTERISTIC DISTRIBUTIONS

The monitoring of the electrical parameter distribution of the 4JD4C line will continue. Parameters will be added as necessary or dropped, if it is found that they can be controlled via correlation with other parameters.

6. PUBLICATIONS AND REPORTS

6.1 Formal Quarterly Report.

The Third Quarterly Report was completed, approved, and distributed.

PROFESSIONAL PERSONNEL

and

TOTAL APPLIED EFFORT

for period covering

31 January 1963 - 30 April 1963

PERSONNEL

F. J. Potter
P. W. Olski
D. F. Smith
T. E. Gates
C. L. Jeffers
F. Marapodi
W. A. Scherff
A. Fox

MAN-HOURS

1,096