PRODUCTION ENGINEERING MEASURE

2N1358A TRANSISTOR

QUARTERLY PROGRESS REPORT NO. 3
FOR THE PERIOD
OCTOBER 30, 1962 TO JANUARY 30, 1963

CONTRACT NO. DA-36-039-SC 86725
ORDER NO. 19047-PP-62-81-81

PLACED BY

U. S. ARMY ELECTRONICS MATERIEL AGENCY
PHILADELPHIA, PENNSYLVANIA

solid state
electronics

DELCO RADIO

General Motors Corporation
Kokomo, Indiana

COPY NO. 16

PRODUCTION ENGINEERING MEASURE TO IMPROVE PRODUCTION TECHNIQUES AND INCREASE THE RELIABILITY OF THE 2N1358A TRANSISTOR

QUARTERLY PROGRESS REPORT NO. 3 FOR THE PERIOD OCTOBER 30, 1962 TO JANUARY 30, 1963

OBJECT:
To modify production equipment to incorporate improved techniques and perform the necessary tests to demonstrate the capability of the improved production line.

CONTRACT NO. DA-36-039-SC 86725
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PREPARED BY: J.C. KUHNS
APPROVED BY: K.W. DOVERSBERGER

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1.0 ABSTRACT

This report is a review of the work during the third quarter, October 30, 1962, to January 30, 1963, of the contract. During this quarter, the second quarterly report was submitted, reviewed, approved and distributed. The fourth, and final, engineering sample group of transistors was submitted.

Of the 17 planned equipment and process modifications, 6 are in effect and being used as standard production, 3 are currently in the debugging phase and 4 are approaching the completion of their construction. The remaining 4 programs have been unsuccessful and substitute programs have been requested. The substitute programs are directed toward alterations of the processes that affect the conditions contributing to reliability type failures as ascertained by the PEM testing and failure analysis program.

During the third quarter, the Milestone II test completed 1,000 hours on test and the results are tabulated and included in this report. Also, additional manufacturing test results and special step-stress results are reported.

The failure analysis program has continued to yield information as to the nature of failures and provides a quantitative measurement of the various failure modes.

In the analytical-empirical surface study program additional experiments and results are providing insight into the influences of various processes. One of the substitute programs is predicated on these results.

2.0 PURPOSE

The purpose of this program is to improve the reliability of the 2N1358A transistor by specific improvements of manufacturing techniques. The program plan includes equipment and process modifications, a reliability test program, a failure analysis program, and an analytical-empirical surface study program.

In the endeavor to reach the failure rate objective, the following processes are to be improved:

1. Crystal Growing
2. Crystal Slicing
3. Automatic Scribe
4. Wafer Etching
5. Solders and Indium Separation
6. Collector Disc Etch
7. Wafer Flash Etch
8. Alloy Boat Assembly
9. Unitron Microscope
10. Alloy Boats
11. Alloy Furnace
12. Base Preparation Furnace
13. Mount Furnace
14. Automatic Test Set (Capper)
15. Continuous Cap Wash
16. Cap Date Coder and Pin Insulator Press
17. Manufacturing Building
18. Surface Treatment
19. Alloy Regrowth Process
20. Assembly Revision (Wisps)
21. Improved Wafer Gage

Requests have been initiated to delete items 3, 4, 6 and 8 and to add items 18, 19, 20, and 21.

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3.0 PROGRAM PROGRESS

Progress on the program is reported in this section under the headings of "Equipment and Process Modifications", "Reliability Testing", "Failure Analysis", and "Analytical-Empirical Surface Study".

3.1 EQUIPMENT AND PROCESS MODIFICATIONS.

During the third quarter three of the 17 items in the program were placed into production. The total modifications now in production is six. With the exception of four unsuccessful programs, the remaining items are progressing toward completion. Also, information is accumulating on the four requested substitutes and they are included in this section of the report.

3.1.1 Germanium Crystal Growing - H. G. Dohmen.

General. The objective of the crystal growing effort is to improve the germanium crystal quality by elimination of grain boundaries, reduced etch-pits, and finer resistivity control.

Engineering Status. Equipment suppliers' capabilities were reviewed and the order for the initial unit size grower was placed in early January. By providing the supplier with electrical equipment, construction time was expedited from 12 months to a promise of only 4 months. The peripheral equipment requirements are progressing quite well. A meltdown furnace has been received and installed. The monitoring system and the diameter control equipment has been received and the temperature control system is on schedule and approaching delivery.

Conclusions. It is believed that the facilities being assembled

will produce excellent quality germanium crystal; however, completion of the program will require several months beyond the desired date of April 30, 1963.

Program for the Next Quarter. The program for the next quarter will be to continue to follow up very closely on the undelivered facilities to make advance preparations for the installation of equipment as received and to prepare a program for operator training.

3.1.2 Crystal Slicing.

This program to convert the slicing from O. D. saws to I. D. saws has been completed.

3.1.3 Automatic Scribe

The program for automatic scribe facilities was obsoleted when the crystal improvement program was directed toward unit size crystals.

3.1.4 Wafer Etch

This program was basically one of mechanization. Machine builders refused to quote because of the process requirements of variable times in solutions and rapid transfers. To date, attempts to modify the process within machine limitations have not been successful. Fairly obviously, the problems are not going to be worked out within a reasonable time period as related to the contract. Therefore, the substitution of a more immediately beneficial program has been requested.

3.1.5 Solder and Indium Separation - G. M. Wagner.

General. To preclude the possibility of cross contamination

between solders and indium alloys, this program is to provide completely separate facilities located in separate rooms.

Engineering Status. The operations have been relocated in the new manufacturing building and the equipment is installed. The extrusion die and take-up reel for solders were unsatisfactory. These items have been redesigned and are being constructed. It is anticipated they will be ready to operate by the end of March.

Program for the Next Quarter. During the next quarter it is planned to finish the re-tooling that was required and to complete the program.

3.1.6 Collector Disc Etch

General and Engineering Status. Although there is evidence that the present etching operation on the collector discs (indium alloy) creates an undesirable oxide layer on the discs, attempts to eliminate the etching operation have not been satisfactory from a reliability standpoint. Physical examinations of alloyed units made from unetched indium reveal areas in which the indium failed to "wet" the germanium. Also, transistors produced in this manner performed very poorly on modulation life tests.

Conclusion. The program to eliminate the collector disc etch will not contribute to improved reliability of the transistors. Therefore, a substitute program has been requested.

3.1.7 Wafer Flash Etch

The program to provide facilities to flash etch the germanium wafers for cleaning purposes immediately, prior to the alloying operation has been successfully completed.

3.1.8 Alloy Boat Assembly - G. E. Dieterly.

General. The assembly of the germanium wafer, emitter and collector preforms, base ring, and center base contact into alloying boats was being done in room air in the old manufacturing building. Because of airborne contaminates including visable dust, it was proposed that this assembly operation be performed within a dust shield. Accordingly, a suitable dust shield was purchased and installed.

Engineering Status. Before the shield was fully evaluated the operation was relocated in the new manufacturing building which is supplied with electrostatically filtered air. Comparative dust counts, made on Hermacytometer Bright-Line counter chamber slides at 30 magnification, show an average of only 7.9 particles/mm^2/day in the alloy area of the new building as opposed to a count in excess of 200 in the previous location. Dust counts within the shield were only slightly better (5.2 particles/mm^2/day). The dust shield interferes with the operators' reach and view of their work.

Conclusions. The advantage of the protection by the dust shield is not of a sufficient magnitude to justify the inconvenience to the operators, nor the poor workmanship that inconvence might cause.

Program for the Next Quarter. A substitute program has been requested.

3.1.9 Unitron Microscope - G. E. Dieterly.

General. Presently certain dimensions on the graphite inserts in the alloy boats are very difficult to check with accuracy - after

the inserts have been inserted into the boats. Due to the rapid wear of the graphite, it is essential that these dimensions be checked regularly so they can be properly maintained. The Unitron microscope will supplement the air gages and comparator already available for this purpose.

Engineering Status. The microscope has been received and put to use by Process and Production in the alloy area (Fig. 3-1-A). Maintenance work is underway to erect a suitable room to house this equipment and other facilities used in checking graphite grain structure and alloy boat dimensions.

Conclusions. The microscope is presently set up in the alloy production area and is used by those concerned with the alloy process. Manuals describing the use of the Unitron have been compiled and distributed to those persons assigned to its use.

Program for the Next Quarter. The program is in effect. However, the setup will be improved by the addition of a special room and additional personnel training.

3.1.10 Alloy Boat - G. E. Dieterly.

Engineering Status. Development work with the first hydrokinetic boat designed for use with production type furnace equipment has been completed. Samples made with this boat were good. On the basis of the experience a revised design was made and construction of 10 additional boats is underway.

The unit size crystal program is a delaying factor for the hydrokinetic boat program. The change to hydrokinetic cannot economically be effected into production until production quantities of unit size crystals are available. Crystals from the unit size experimental equipment are adequate to complete the development

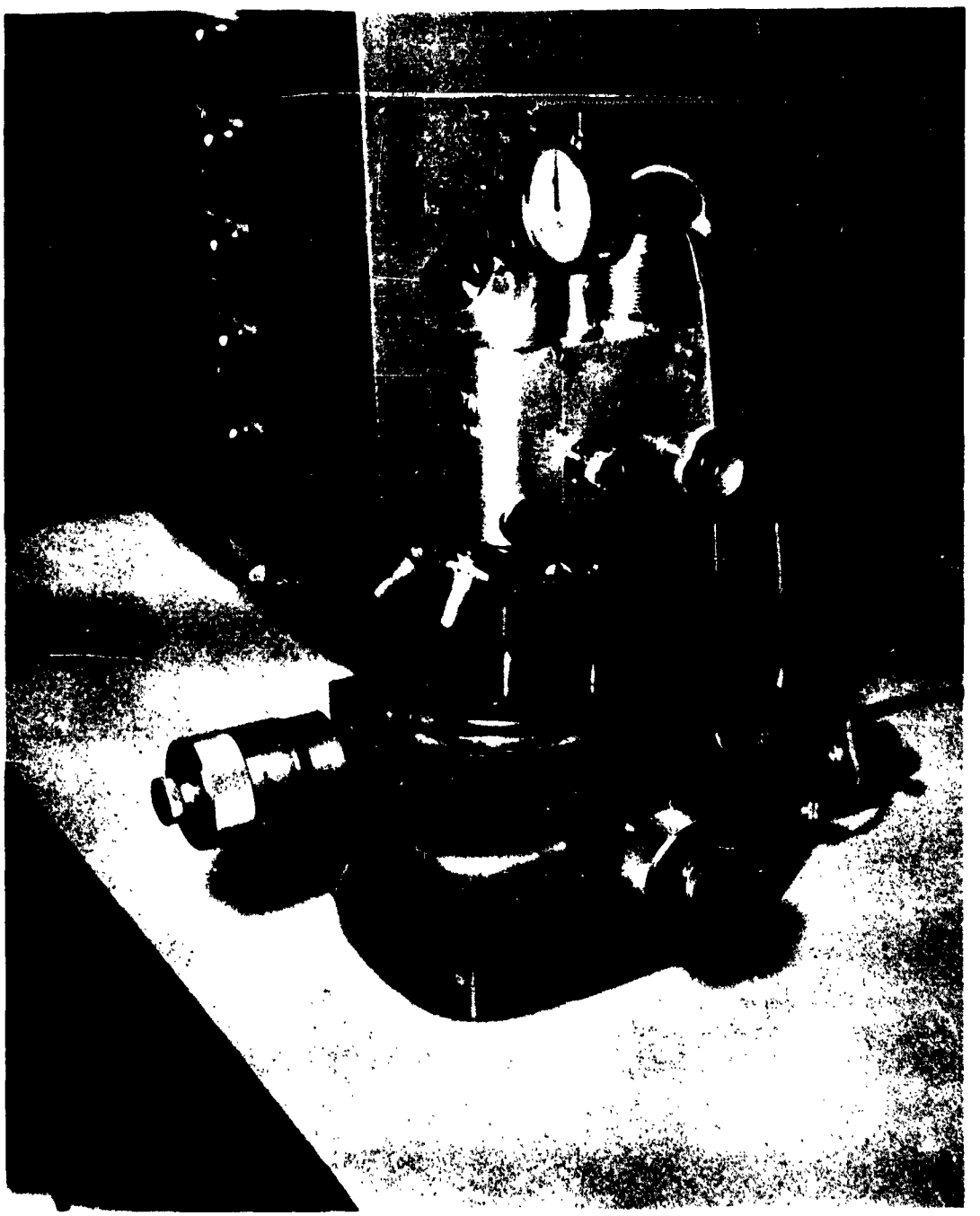

Fig. 3-1-A Unitron Microscope

of the alloy boats and to prove out the effectiveness of the boats, but not adequate to completely convert production to the unit size crystals.

Conclusions. The first 10 hydrokinetic boats will be ready for production trials before the end of March.

Program for the Next Quarter. A large production run will be made with the new alloy boats and evaluations of the results will be made.

3.1.11 Alloy Furnace - G. E. Dieterly.

General. In conjunction with the proposed hydrokinetic boat change (paragraph 3.1.10), modifications of the alloy furnace and the furnace belt were needed for both mechanical reasons and an optimum furnace heat curve (time versus temperature).

Engineering Status. A production alloy furnace was converted to run the new type hydrokinetic alloy boat. The optimum alloy furnace heat curve was set up and parts were alloyed in the one experimental boat. The parts were superior to the regular production parts.

Production schedules were increased to the point that the converted furnace was needed for regular production. A decision was then made to install and set up a new universal alloy furnace in the Process Lab for use with this program. The furnace has been installed and a special furnace belt has been ordered to be used with the hydrokinetic boat (Figs. 3-1-B, 3-1-C). The furnace has been brought up to heat and checked out and as soon as the ten new boats are built, an optimum furnace heat curve will be set.

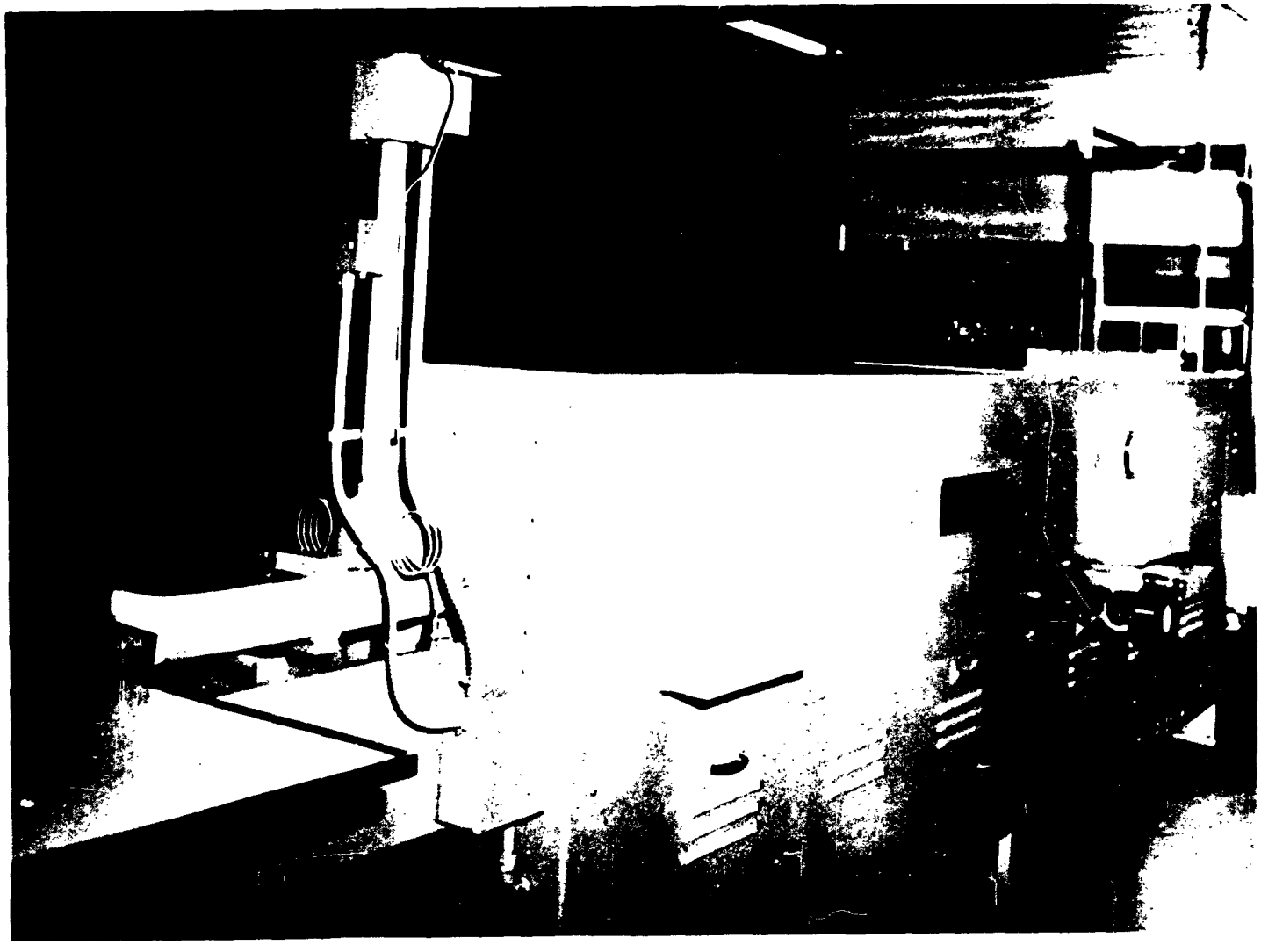

Fig. 3-1-B Alloy Furnace

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Fig. 3-1-C Alloy Furnace Control Panel

Conclusions. The furnace will be ready for use pending delivery of the furnace belt and the ten new hydrokinetic boats which should be approximately March 30, 1963.

Program for the Next Quarter. A large production-type run of parts will be made on the laboratory furnace using the ten new boats. An operator will be borrowed from production for the initial run. The resultant parts from this production-type run will be sent through regular production channels and evaluated.

3.1.12 Base Preparation Furnace - R. N. Goings.

General. The base preparation operation consists of soldering two terminal assemblies to the nickel plated copper base and pretinning the pedestal on the base. The previous method for this operation was to use rosin flux and solder the assembly in a furnace. The flux was then removed in a series of trichloroethylene baths. The program was to perform the same operations in a hydrogen atmosphere, eliminating the flux and associated contaminants.

Engineering Status. The hydrogen base preparation furnace was installed on the line during the first quarter of the contract and moved to the new manufacturing building during the third quarter of the contract.

Conclusions The yield from the base preparation furnace has improved since the move to the new manufacturing building.

Program for the Next Quarter. The investigation of combining the base preparation operation and the mounting operation is continuing.

3.1.13 Mount Furnace - R. N. Goings.

General. The mounting operation consists of mounting the transistor elements to the base and connecting the base and emitter contacts to the terminals. The mounting is done in a furnace with a hydrogen atmosphere. The plan is to develop a furnace with superheated hydrogen for superior fluxing action. In addition it is also planned to combine the base preparation operation (3.1.12) with the mounting.

Engineering Status. This furnace has been moved to the new manufacturing building and is being installed. It was found necessary to redesign the terminals to eliminate the solder from bridging across the glass seal to the terminal. Production equipment is now being modified to accept this new terminal design and to automatically assemble the components to permit the combination of the base preparation and mounting operations. A photograph of the superheated hydrogen furnace is shown in Figure 3-1-D.

Conclusions. The solder connections on units processed in this furnace are comparable to that of the present production equipment with exception of the emitter to the emitter connector. The emitter indium dewetting is greatly reduced using this process.

Program for the Next Quarter. When the furnace installation is completed units will be processed for engineering evaluation using the new terminal design.

3.1.14 Automatic Test Set (Capper) - H. E. Wright.

General. The purpose of this project is to reduce damage to the

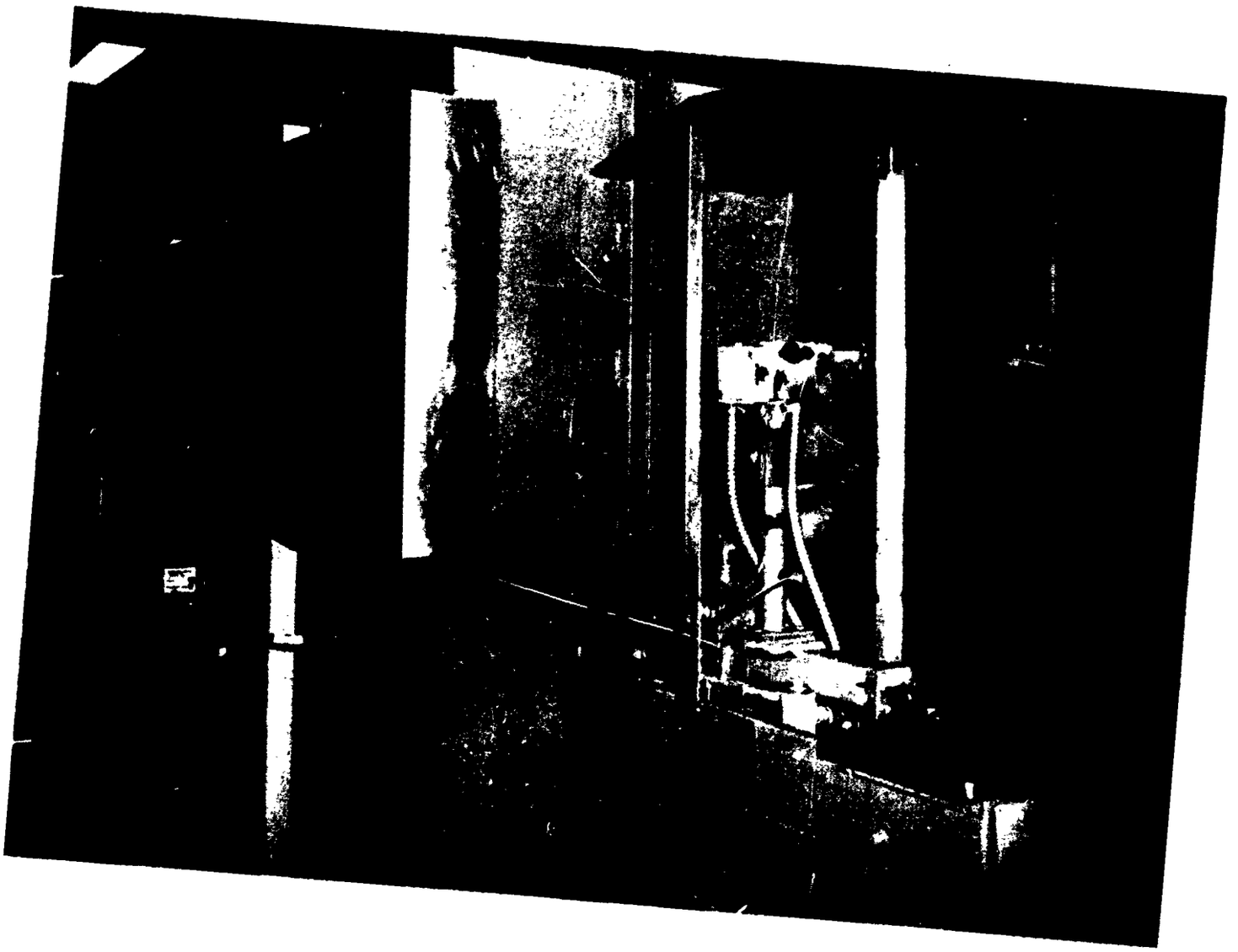


Fig. 3-1-D Mount Furnace

transistors by eliminating handling at the test after mount station. This will be accomplished by testing the transistors automatically rather than manually. In addition to the required production tests, a distribution will be made of the collector diode, emitter diode and gain parameters for use in quality evaluation of the process.

Engineering Status. Construction is about 75% complete.

Conclusions. To provide for usage on either of the two assembly lines, two test probe methods are being constructed. The first is a manual method which requires the use of an operator to place the probe. The second is an automatic probe (for use on the mechanized line). The mechanical design is completed on both designs.

Program for the Next Quarter. During the next quarter the electrical drawings for the test probe will be completed, all building will have been completed and debugged.

3.1.15 Continuous Cap Wash - R. N. Goings.

General. The cap washing facilities were in a different department than the capping press. The caps were washed and then stored for varying lengths of time before usage. The new washing will be directly on the capping line reducing the chances of contamination before use. This system includes a baking operation to insure dry caps.

Engineering Status. This equipment has been moved to the new manufacturing building and is installed on the production line and is in use. The equipment is shown in Fig. 3-1-E.

Fig. 3-1-E Cap Washer

Conclusions. No discernable influence on yield has been noted. Reliability data has not yet been acquired.

Program for the Next Quarter. Manufacturing reliability data will be studied to determine if the improvement is measurable.

3.1.16 Cap Date Coder and Pin Insulator Press - F. R. Gustin.

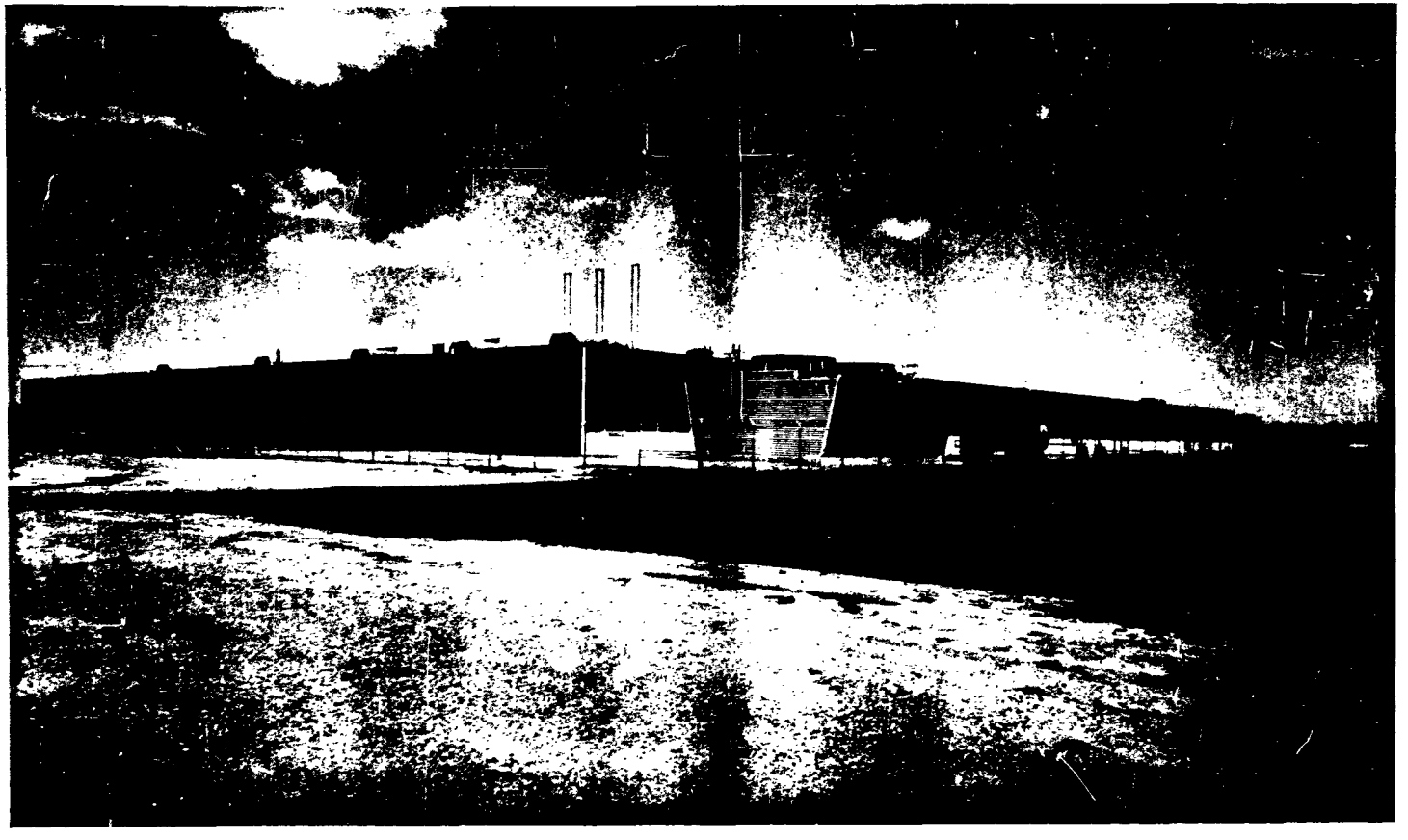
General. Transistor caps are date coded on an automatic marking machine prior to assembly on the transistors. The possibility of cap contamination exists. Nylon insulators are assembled to the locator pin, when required, with an arbor press. Handling damage can occur. This program is to provide an automatic machine in line with the capping press to perform both the coding and the insulator assembly.

Engineering Status. During the third quarter, construction of this machine was completed, trial runs were made in the shop, and the machine was installed on the production line. Trouble was encountered with the static control electrical system and the feeding mechanism occasionally abraded the parts. Work is now underway to correct these difficulties.

Program for the Next Quarter. The debugging will be completed and the machine will be in use as a standard operation.

3.1.17 Manufacturing Building - G. M. Wagner.

General. The manufacturing of semiconductors has been completely moved and is operational in the new manufacturing building which has been specifically designed for semiconductor fabrications. It has many features such as electrostatically filtered atmosphere for both internal and make-up air, oil free



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air compressors, a central vacuum cleaning system, a combined heating-air conditioning system for better temperature and humidity control, a higher purity and large volumes of deionized water and also all materials used in construction of this building were designed with an intent for keeping an area cleaner for greater reliability of devices (Photograph Fig. 3-1-F).

In addition, other desirable effects have occurred: The relocation of incoming inspection to the new building has greatly increased the control and quality of parts used in fabrication. An improved acid mix area for chemicals used in manufacturing and a more efficient chemical disposal system is providing for better control of operating supplies.

Engineering Status. All germanium activities as of the end of January are operational in the new manufacturing building.

Conclusions. Relocation of facilities with a minimum disruption of production has been complicated but is accomplished.

Program for the Next Quarter. No planned program.

3.1.18 Surface Treatment - R. N. Goings.

General. Early in the PEM Program, failure analysis results made it rather obvious that to meet the failure rate goals of the contract, positive action would have to be taken in production to correct, or at least alleviate, the condition contributing to collector diode degradation. Although a number of the proposed production changes could influence the condition; notably the new alloy boat, hydrogen base preparation, super heated hydrogen mounting and the cap washing facilities; none of them are known to be positive corrective action. Also, the surface study program in the contract was directed toward an understanding of the conditions causing this failure mechanism. But,

to be effective toward meeting the desired goals, it would have to be accelerated and expanded beyond a study program.

Accordingly, the empirical surface study program was accelerated to allow time for process improvements in production if success were achieved. From these studies, there is adequate evidence (Section 3.4.7) to show that an appreciable improvement in diode stability can be achieved by increased precap baking. Therefore, a program of the implementation of a surface treatment program has been requested as a substitute.

Engineering Status. The necessary process development work has been completed and a suitable production process derived. Equipment needs have been reviewed and consultation with potential suppliers is in progress.

Conclusions. Appreciable improvements on high temperature storage tests can be realized with the addition to production of increased precap baking.

Program for the Next Quarter. During the next quarter it is anticipated the additional equipment required will be specified, ordered, and the construction approaching completion.

3.1.19 Alloy Regrowth Process - R. P. Anjard and W. H. Lynch.

General and Engineering Status. Based on the theoretical analysis and the experimental results presented in the previous Quarterly Report, approximately 1,000 elements were alloyed utilizing thinner indium for both the collectors and

emitters. Using the basic wafers and alloy composition, the alloy temperature was increased to produce the normal base width and regrowth thickness.

The number of devices with spur regrowths was reduced 95%. When spurs were present, they were smaller. Spur lengths were measured from the tip of the spur to the inside edge of its associated void. The normal spur length was determined to be 4.8 mils; the spur length resulting from thinner indium was 1.3 mils. The spur length (average) was reduced 73%.

During alloy, the furnace belt stalled for a short period and some of the boats were over-heated. During mounting, some dewetting of the emitter was noted.

The devices were sorted and submitted for life testing, thermal shock and thermal resistance measurement. A control group is being evaluated for comparison. Because of the emitter dewetting, a group of elements was alloyed using thick emitters and thin collectors.

Program for the Next Quarter. The transistors alloyed with thin emitters and collectors will be analyzed upon completion of the indicated tests. The elements alloyed with a thinner collector and normal emitter will be processed and submitted for life testing.

3.1.20 Assembly Revision (To reduce wisps) - R. P. Anjard.

General and Engineering Status. The percentage of wisps was reduced 60% on units alloyed with thinner indium. The origin of the wisps was as follows:

DESCRIPTION	% Of All Wisps	% Of Class Which Touched	
		Germanium	Base Ring
Solder from Indium mass at dewet area	5	0	0
Solder continuum on periphery at dewet area	31	25	8
Interrupted solder continuum on periphery at dewet area	49	26	0
Solder continuum on periphery at non-dewet area	3	100	0
Non-dewet area	12	60	20
	100		

In the second Quarterly Report, normalized values for wisp frequency were presented for various etch conditions. Additional experiments were processed using lighter etches. For etch "A", the normalized wisp frequency was 0.72. For etch "B" (an etch heavier than "A" but lighter than standard) the normalized frequency was .85. However, with lighter etching, the diode breakdown voltage significantly decreased.

Code

Etch time comparison:

Std. - 1.00
A - .50
B - .66

The origin for the wisps were as follows:

DESCRIPTION	% Of All Wisps		% Of Class Which Touched Germanium		% Of Class Which Touched Base Ring	
	Etch A	Etch B	A	B	A	B
Solder from mass at dewet area	26	55	75	83	12	0
Solder continuum on periphery at dewet area	23	27	14	100	72	0
Interrupted continuum at dewet area	6	0	100	0	0	0
Solder continuum on periphery at non-dewet area	0	0	0	0	0	0
Non-dewet area	45	18	43	100	50	0

Small additions of Al were made to the emitter indium. When etched with the standard etch, the elements were free of wisps. Very low aluminum concentrations (0.005 - .01%) did not produce irregular junctions; however, dewetting and wisp generation was not completely eliminated. The normalized wisp frequency was 0.58.

Program for the Next Quarter. Additional experiments will be performed utilizing low aluminum concentrations. The transistors alloyed with a thick emitter, thin collector will be evaluated for wisp frequency.

3.1.21 Wafer Gaging - G. M. Wagner.

General. At present the germanium wafers are gaged for thickness with Delco designed roller gages. The recent acquisition for another transistor line of a marketed automatic probing type gage has provided the opportunity for comparisons to be made. Studies indicate an improvement of dimensional control of 2 - 3 times is possible. This improved control will be reflected directly in better base width control with obvious advantage to gain control and operating life characteristics. It has, therefore, been requested to include the acquisition of new gaging equipment for the 2N1358A transistor as a substitute program for one of the lesser successful items.

Engineering Status. To date, an assessment of the capabilities of the proposed equipment has been made and the quotation and delivery time have been acquired.

Conclusions. Use of improved wafer gaging facilities would improve the product control.

Program for the Next Quarter. It is anticipated that during the next quarter the equipment can be acquired, installed, and put into production usage.

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3.2 RELIABILITY TEST PROGRAM.

3.2.1 Failure Rate Goals - L. V. Ingle.

General and Engineering Status. Milestone II units recently completed 1,000 hours on the 40V-90°C-.5 A operating and 135°C storage tests. Forty-nine units failed of the 387 placed at the storage condition which resulted in a failure rate of 15.85% per 1,000 hours at 90% confidence. This rate is slightly over five times the Milestone II goal and more than twice the rate obtained from Milestone I. Of 298 units completing 1,000 hours on the operating condition, 14 devices failed. The subsequent rate is 6.91% per 1,000 hours which is 1% below Milestone I results but short of the 3.6% goal. Several improvements in the testing procedure and equipment are being and have been made in an attempt to place equipment reliability near or above unit reliability. Since this represents no modest goal, the equipment and units must be monitored constantly to reveal system and procedure faults. A discussion of some of these aspects and analysis of all the failed units is contained in Section 3.3 of this report. The parameter distributions will appear with discussions in the next report.

Conclusions. Milestone II goals were not attained on either storage or operating tests.

Program for the Next Quarter. Milestone III units will be placed on test and the 1,000 hours completed. A portion of these devices will have received a special baking cycle as discussed in the Section 3.1.18. Parameter distributions for Milestone II will be analyzed.

3.2.2 Manufacturing Control Reliability Test - L. V. Ingle.

General. Normalized yield and cumulative per cent failed are shown for lots 50 thru 100 by Figures 3.2.A and 3.2.B. Variation still exists for both plots as previously noted; however, both show trends in the desirable directions.

Using the parameter data from lots 7 to 55 for input, a multiple regression analysis was completed which incorporated failure rate as the dependent variable. Selected lot means and mean shifts showed correlation both among themselves and with failure rate; however, the resultant prediction equations proved inefficient as it estimated most lot failure rates near the mean of all the failure rates.

Program for the Next Quarter. The group will continue to sample daily production with information from the new manufacturing building becoming available.

3.2.3 Special Reliability Experiments - L. V. Ingle.

General. A third temperature step-stress experiment was completed on 24 units during the third quarter. One-half of the group was from Milestone I material and the remainder like those supplied in November as Engineering Samples. Conditions were 2 hours per step with 10°C increments from 130° to280°C. Parameters and reject limits are shown below:

PARAMETER	CONDITION	REJECT LIMIT
ICBO	V = -15 V	2.0 ma
β	V = -6 V, I = 100 ma	1.5 times β initial
ICBO	V = -80 V	10 ma
VCBO	IC = 4 ma	60 V
IB_2	IC = 5 A, V = -2V	1.33 times IB_2 initial

Figure 3.2.A
Mfg. Control Daily Sampling for 135°C Storage
Normalized Yield vs. Lot Number

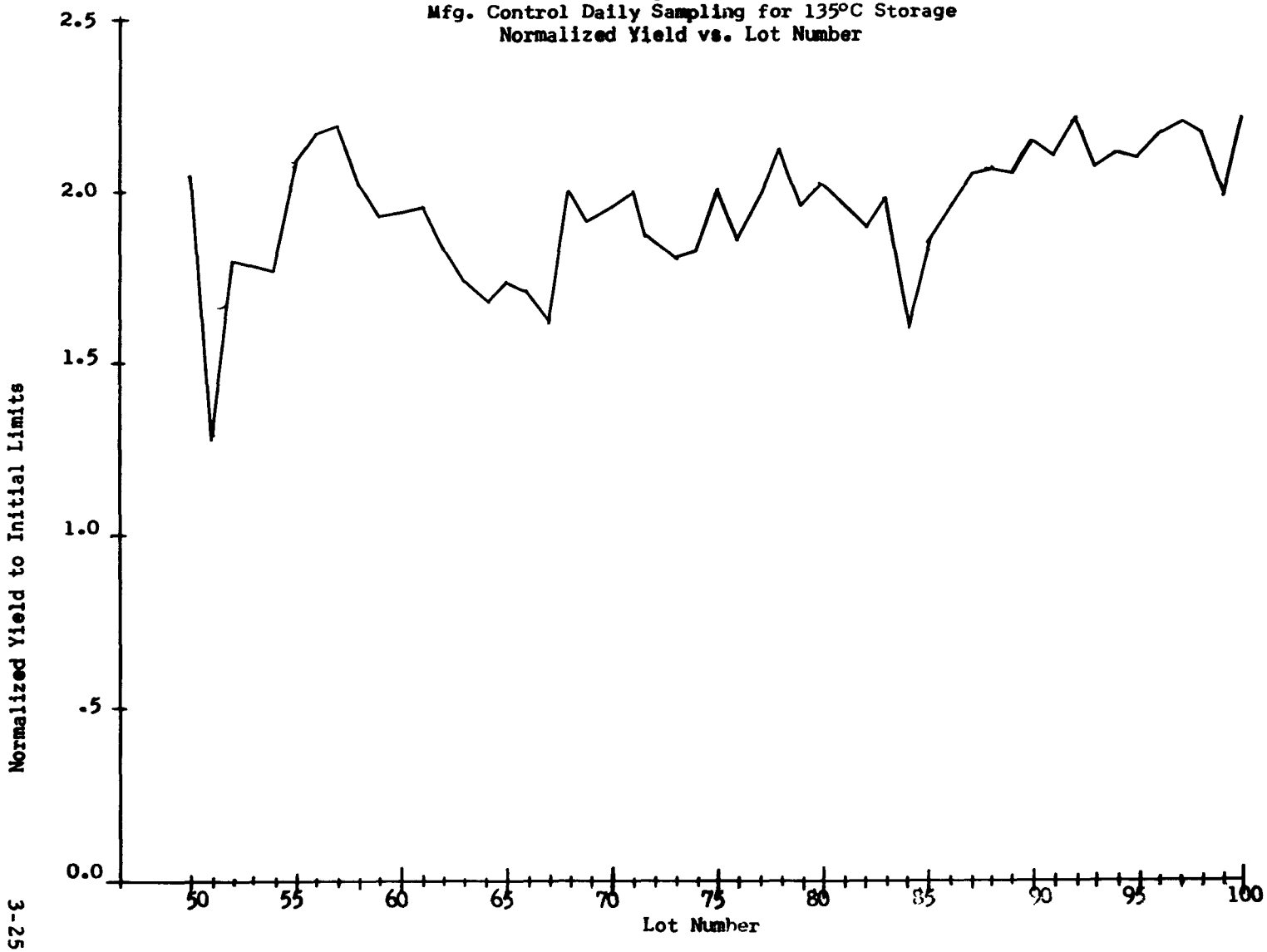
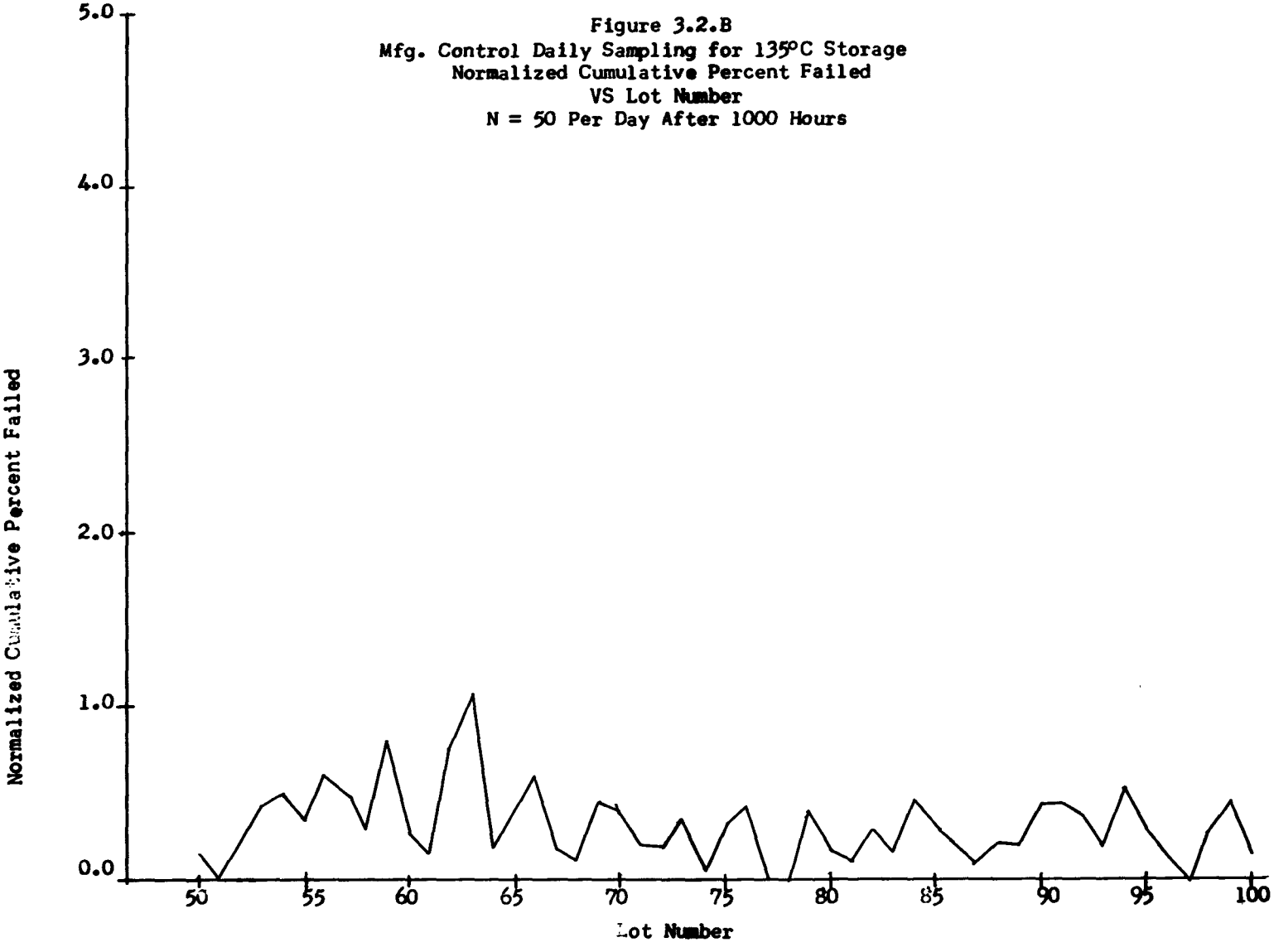


Figure 3.2.B
Mfg. Control Daily Sampling for 135°C Storage
Normalized Cumulative Percent Failed
VS Lot Number
N = 50 Per Day After 1000 Hours



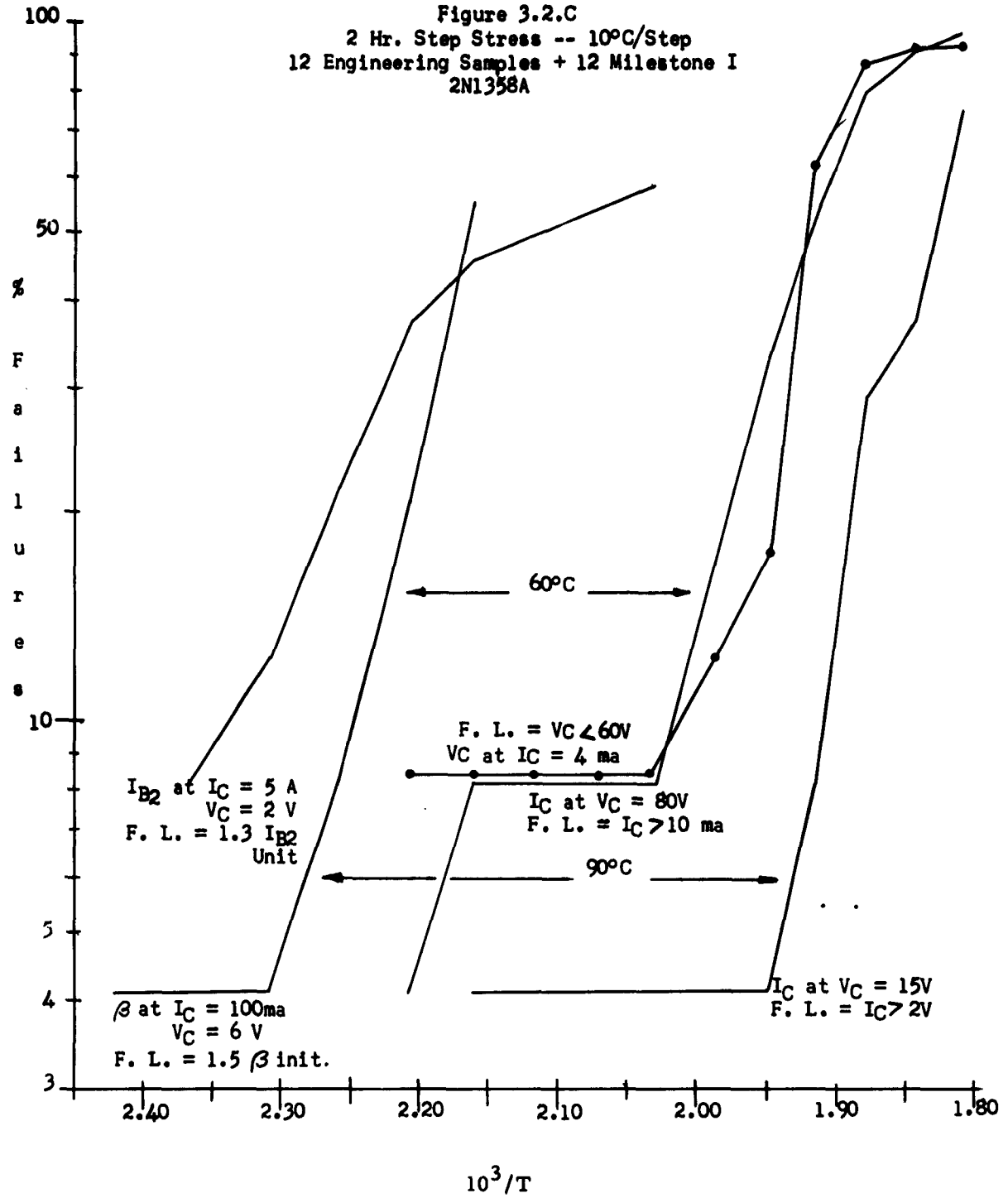
The resultant failure distributions by parameter are shown in Figure 3.2.C. As can be seen, the shift in β accurately described the ICBO at 80 V, ICBO at 15 V, and VCBO at 4 ma distributions before they occurred. Notice that only 55% of the sample ever failed the β limit. An attempt to relate individual β shift with time of diode failure was unsuccessful. The artificial limit imposed on IB_2 also depicted the later slopes (below 40% failed). Thus, the aging effect seen early in gain tests appears to be related to the phenomenon that later degrades the diodes.

In order for these results to attain other than experimental usefulness, the transformation must be made to lower temperature use conditions. If (1) the relationship established during the Minuteman matrix is valid above 135°C; and (2) time is accelerable by the same factor; a group of units placed at 158°C should exhibit the same per cent failure after 170 hours as a sample allowed 1,000 hours at 135°C. This was tried for Manufacturing Control lots 68 through 72. Success was undeniably attained as the 158°C group had .44 fail versus .46 (normalized) for the control. A fractional factorial experiment will begin soon which will test the relationship to 225°C and perhaps provide a shorter feedback time for monitoring day to day production reliability. In the meantime, 100 hours at 175°C is being used for quicker process evaluations.

Conclusions. Step-stress experimental results have led to the probable extention of storage temperature testing with validity.

Program for the Next Quarter. Further testing will be completed to determine the time-temperature-failure dependency from 135° to 225°C. The second of four pulse life experiments will be completed using units from the Milestone III lot.

Figure 3.2.C
2 Hr. Step Stress -- 10°C/Step
12 Engineering Samples + 12 Milestone I
2N1358A



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3.3 FAILURE ANALYSIS PROGRAM - J.R. Bevington

During the past quarter, the Failure Analysis Group has performed analysis on all failures from the 135°C daily sampling program. The results of these analyses have been reported to responsible Manufacturing, Engineering, Process, and Quality Control personnel through the weekly PEM technical meetings. Also completed has been an analysis of the failures and data from the Milestone II storage life and operating life tests. Special studies on mechanisms of interest have continued.

3.3.1 Facilities and Capabilities

General and Engineering Status. The program for establishing X-ray radiographic capabilities is 75% complete and is on a critical path schedule for completion during the next quarter.

An X-ray diffraction instrument has been obtained and is operational on a limited basis. This instrument will assist in the identification of unknown compounds and greatly extend the analytical capabilities of the group.

An ultraviolet microscope illuminator has been obtained which makes possible the detection of fluorescing contaminants at a micro-level.

Initial experiments have been performed using wet-chemical analysis techniques. A chemist had been added to the group. He will have the development of chemical analysis techniques as one of his major assignments.

Conclusions. Laboratory capabilities have been increased through the installation of X-ray diffraction equipment and the purchase of an ultraviolet illuminator for microscopic work.

A chemist recently added to the group will allow further development of chemical analysis techniques.

Program for the Next Quarter.

1. Complete evaluation of X-ray radiographic capabilities, obtain military certification, and achieve full compliance with ASTM recommended procedures.

2. Make X-ray diffraction equipment fully operational for routine determination of unknown contaminants.

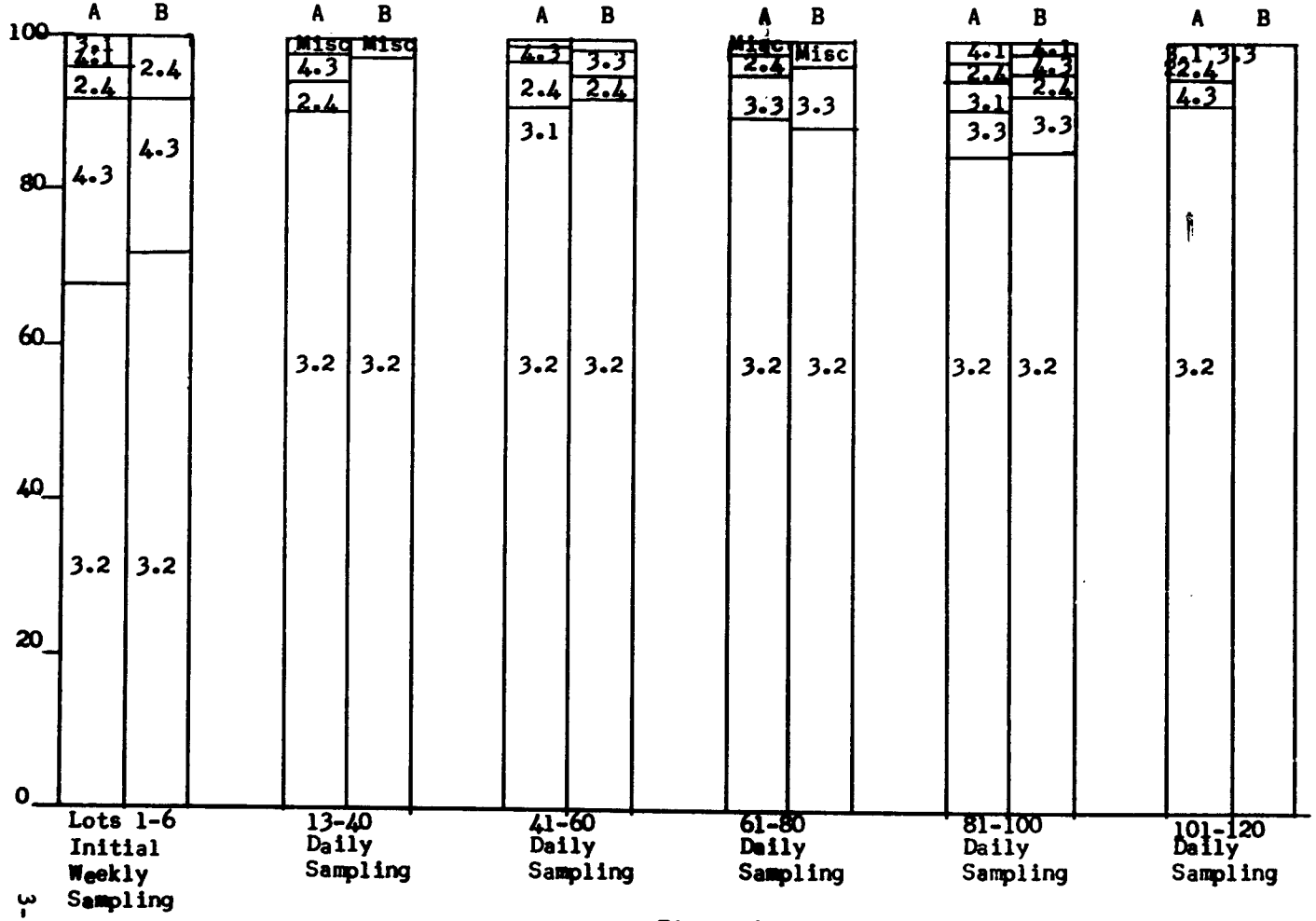
3. Continue development of chemical analysis techniques.

3.3.2 Failure Analysis - 135°C Daily Sampling Program

General and Engineering Status. All device failures from the daily sampling program have been logged, analyzed, and assigned a mode of failure. Table #1 shows the normalized defects per 1000 for each mode for each manufacturing period of 20 lots or 1000 devices. A quality index is determined as the sum of the various contributions. Figure 3-3-A represents failure mode % contribution for each manufacturing period and compares contributions in the first 500 hours of test with those in the second 500 hours of test.

As indicated by the most recent tabulated data (lots 101-120), mode 3.2 (collector diode degradation) continues to represent the major mechanism of failure. This mechanism involves conditions on the crystal surface and are discussed in more detail in section 3.4, "Analytical - Empirical Surface Study Program."

Failure Mode Percent Contribution
135°C Storage Life
Sampling Program



Letter Code

A = 0 - 500 hrs
B = 501-1000 hrs

Number Code

2.4 Vebo degradation surface defects.
3.1 Gain degradation
3.2 Vcbo degradation surface contamination.
3.3 Vebo degradation surface contamination.
4.1 Crystal fracture
4.3 Regrowth fracture

Quality Index

$QI = \frac{\text{Defects}}{100\ N}$

(N = normalizing factor)

Lots	QI
13-40	2.05
41-60	3.69
61-80	2.62
81-100	2.13
101-120	

Figure 3-3-A

Normalized Failure Mode Contribution
by Manufacturing Periods
135°C Storage - Daily Sampling

Fail Mode / Lots	2.4	3.1	3.2	3.3	4.3	Misc.	QI
21-40	.06	--	1.93	--	.04	.02	2.05
41-60	.16	.16	3.26	.05	.04	.02	3.69
61-80	.05	--	2.34	.18	.03	.02	2.62
81-100	.05	.06	1.81	.15	.02	.04	2.13

$$QI \text{ (Quality Index)} = \frac{\text{Detects}/100}{N}$$

N = Normalizing factor

TABLE #1

Aside from the approximate 90% contribution from mode 3.2, the major remaining problem is emitter diode degradation, mode 3.3. In some cases this condition results from the same mechanism that degrades the collectors. However, on a portion of these units, the degradation has been traced to a film residue on the emitter base surface. This film exhibits interference colors when observed under vertical illumination at high magnification. A tentative identification of this material has been made using diffraction techniques and it appears to be an oxide of tin. As tin is present in the base-ring solders and the film tends to emanate from the base-ring area, this result was considered significant and has been reported to the proper groups for follow-up and necessary corrective action.

Mode 2.4 which is related in most cases to indium micro-filaments, and mode 4.3 which is related to regrowth defects have indicated a reduced contribution during the past quarter. Each of these areas is the subject of extensive investigations and further improvements are expected with the possible implementation of several proposed process improvements.

The occasional incidence of devices with gain degradation (3.1) is related to a random condition whereby the base width is initially too large or too small. With a gain shift which might be tolerable on a device in the center of the distribution, these devices will be out of limits after a period of elevated temperature storage. A process improvement expected to reduce the occurrence of this random condition is the automatic wafer sorting equipment which has demonstrated a capability of tighter wafer thickness distributions.

Conclusions. The major mechanism of failure in 135°C storage life continues to be that of surface conditions resulting in collector diode degradation (mode 3.2). An increase in per cent contribution of mode 3.3 and a reduction on modes 2.4 and 4.3 is noted.

Program for the Next Quarter.

1. Analysis of failures from the 135°C storage life sampling program will continue to provide informational feedback to the Manufacturing, Process, Engineering, and Quality Control groups.

2. Specific investigations of mechanisms involving modes 3.2, 2.4, and 4.3 are being conducted by specially assigned groups. The failure analysis efforts in these areas will be to assist the assigned groups as required and to monitor improvements.

3.3.3 Failure Analysis - Milestone II

General and Engineering Status. Retests after the completion of the Milestone II 135°C storage life and the 40V-90° C operating life tests indicated 49 and 24 failures respectively.

An analysis of the 49 storage life failures established that all had failed by collector diode degradation (mode 3.2). This is the expected mode of failure on storage life as approximately 90% of the failures on the daily sampling program are related to this mechanism. Investigations of this mechanism are discussed in more detail in section 3.4.

In the analysis of the 24 reported failures on operating life, several factors influencing failure were identified of which two external conditions in the test setup accounted for 10 of these failures. Breakdown of these failures by general category, by failure mode, and by failure cause follows::

General Breakdown

	No.	% Contribution
Failure caused by external conditions (not the fault of the device)	8	33.3%
Device OK - Rejected in error	2	8.3%
Device Fault	14	58.4%
	24	100 %

MILESTONE NO. II OPERATING LIFE FAILURES

	Serial No.	Hours At Failure	Failure Mode	Description	Remarks
1	3067	0	0.0	Good device	Rejected in error
2	3197	666	0.0	Good device	Rejected in error
3	3094	0	2.1T	Collector to emitter short	Flux on mtg. surface prevented
4	3106	0	2.1T	Collector to emitter short	proper seating resulting in
5	3188	0	2.1T	Collector to emitter short	poor heat transfer to the test
6	3270	0	2.1T	Collector to emitter short	tray.
7	3352	1000	3.2T	Collector diode degradation	"
8	3386	1000	2.1T	Collector to emitter short	"
9	3033	666	3.2T	Collector diode degradation	Emitter lead loose
10	3130	666	2.6T	Collector to base short at center base contact	Emitter lead off
11	3251	333	2.1	Collector to emitter short	Characteristics similar to those which failed due to flux on mtg. surface but not proven as such.
12	3337	333	2.6	Collector to base short at center base contact	Characteristics similar to those which failed due to loose emitter connection but not proven as such.
13	3006	0	2.6	Collector to base short at base	Dynamic characteristics indicated
14	3022	0	2.6	ring "	high resistance shunting of
15	3055	333	2.6	"	collector and/or emitter diode
16	3111	1000	2.6	"	initially. "
17	3196	666	2.6	"	"
18	3212	0	2.6	"	"
19	3212	333	2.6	"	"
20	3215	0	2.6	"	"
21	3271	666	2.6	"	"
22	3029	666	3.2	Collector diode degradation	Multi-colored film residue on
23	3115	666	3.2	"	crystal surface
24	3152	666	3.2	"	"

Note: Units 1-12 had no pre-failure indicators. Units 13-24 exhibited pre-failure indicators related to device anomolies.

Breakdown by Failure Modes

Mode	Description	No.	% Contribution
2.1T	Collector to emitter short-foreign material on mounting surface	5	20.8
3.2T	Collector diode degradation-foreign material on mtg. surface or poorly soldered test load	2	8.3
2.6T	Collector to base short - Emitter lead not connected	1	4.2
0.0	Good device	2	8.3
2.6	Collector to base short-device fault	10	41.7
2.1	Collector to emitter short-device fault	1	4.2
3.2	Collector diode degradation	3	12.5
		24	100%

Breakdown by Probable Cause of Failure

Cause	No.	% Contribution
Flux on mounting surface of test tray prevented proper seating	6	25.0
Emitter test load not properly connected	2	8.3

High resistance shorting from indium wisp or similar condition at emitter of collector junction	9	37.6
Multi-colored film residue on crystal surface	3	12.5
Cause of failure could not be confirmed	2	8.3
Device good - Rejected in error	2	8.3
	24	100%

Discussion of conditions resulting in failure

Of the 22 devices which were actual failures, 20 could be accounted for as resulting from one of four conditions. These conditions are discussed in the following paragraphs.

A. Flux on mounting trays

If small flux droplets are present on the mounting surface of the test tray, this will interfere with proper mounting of a device. This results in poor heat transfer to the tray and coolant and raises the temperature of the device. This elevated temperature under operating conditions will result in a breakdown collector to emitter. Of the six devices which failed collector to emitter, five had evidence of flux on the mounting surface. Conversely 5 of 6 devices which had evidence of flux, failed by this mechanism with the remaining device failing by collector diode degradation (Mode 3.2T). The activity causing degradation is accelerated exponentially with temperature rise, therefore all 6 could be related to the observed conditions. The single exception which failed collector to emitter on which flux traces were not found may have been caused by flux as the detection was based on an ultraviolet inspection of the mounting surface on the device to detect material transferred from the test tray.

A second factor which tends to confirm this hypothesis is as follows. The 24 failures could be divided into two groups, 12 devices which exhibited unique initial conditions which could cause failure and 12 in which no unique conditions were present on initial tests. If the flux did not contribute to failure in any way, we would have expected that the six devices on which flux was found to be divided between the two groups at approximately the 12-12 ratio. However, all six devices were in the group of 12 units with no pre-failure indicators and none were from the other group. Since the devices with no pre-failure indicators were typical of 80-90% of the distribution and we can assume random occurrence of flux on a mounting surface,we would expect that most of these would be on units with no pre-failure indicators.

B. Loose Leads

Loose emitter leads were found on two of the devices under test. On one device, the unit failed by degradation of the collector mode and on the second, in which the emitter lead was completely off, the failure was a shorting of the collector diode. This is felt to be caused by a change in operating point during the test generated by the intermittency of the emitter connection. It was interesting to note that there were no indicated defects in the initial parameters of these two devices and that the collector to base failure was at the center base contact which is a rare occurrence in DC operating life failures giving us a unique effect associated with a unique cause.

C. Collector to base shorts resulting from localized resistive shorting conditions

Nine devices failed by collector to base shorting with a protuberance development at the base ring. All nine were from the group

of 12 failures which had pre-failure indicators of a type representing 10 to 15% of the original distribution. None were from the 85-90% of the distribution which had no initial indicators. On all of these devices the presence of a very high resistance shunting of the emitter or collector diode was indicated initially on dynamic curve trace analysis. The resulting leakage at VCBO, 80V or VEBO, 40 volts was 1.0 to 4.0 ma which is within the initial parameter limits but considerably larger than the mean value.

Previous studies have related most of these unique trace conditions to indium micro filaments bridging the junction. The high resistance is generated by the contact resistance of the filament to the base region. A major process improvement program to reduce the presence of these micro filaments or wisps is a portion of the PEM contract. The results of these efforts should reflect in a reduction of this failure mode.

D. Surface film residue

Three devices failed by collector diode degradation. This degradation involved degradation of BVCBO and did not reflect changes in ICBO leakage. (The typical diode degradation failure test on storage life has an increasing ICBO leakage to the point of failure). Internal examination of these units revealed a visible multi-colored film residue using a metalurgical microscope. This condition has been noted previously on a small percentage of the devices and has been correlated to unique forms of emitter diode degradation in many cases. Initial indications of this condition can be found in their relatively lower BVCBO and/or higher leakage at 2 volts VCBO.

This condition is under investigation as part of the surface study program. Initial analytical investigation of this residue using diffraction indicates that this material is tin-oxide. Tin is one of the constituents of the base ring solders from which this residue appears to emanate. It is expected that this condition will be corrected with the implementation of proposed process improvements relating to surface cleanliness and stability.

Conclusions. Milestone II failures from the 135°C storage test were related to surface conditions resulting in collector diode degradation in all cases. This follows the pattern of previous analysis of failures from this test.

On operating life several mechanisms were involved. Of 24 reported failures, eight were traced to the presence of flux particles on the tray mounting surface or to poor connections (external) to the emitter terminal. Two additional devices were found to have been rejected in error. Of the remaining 14 units, 9 of the rejects were traced to a condition which is believed to be related to micro-filaments bridging the diode junctions. Another three devices were traced to visible surface film residue tentatively identified as tin oxide. The remaining two failures had some evidence that they failed due to external conditions but this could not be confirmed. Therefore, for calculation of failure rate, they have been considered as failing because of device faults.

Of 12 devices which had no initial indication of potential failure, 10 were traced to external defects not related to device quality. The two remaining devices were those for which external fault was suspected but not proven.

Of the 12 devices which had initial indication of potential conditions, failure occurred by either one of two modes relating to the original indicators. These 12 devices were from a portion of the lot distribution representing 10-15% of the material.

Program for the Next Quarter.

1. Failure analysis will be performed on all milestone test failures generated during the 4th quarter.

2. Further studies of pre-failure indicators will be made on Milestone III material.

3.4 ANALYTICAL - EMPIRICAL SURFACE STUDY PROGRAM.

3.4.1 Surface State Analysis - M. E. Stanton.

A. Field Effect Measurements.

General and Engineering Status.

1. Apparatus.[1] Difficulties with the apparatus which were described in the second quarterly report have delayed field effect experiments. Trial computations indicated that the use of penetrating light would be desirable. To do this made a modification of the optical system necessary. Also it was found that the positioning of the sample could not be repeated adequately in the original setup and so the apparatus was reconstructed with all parts mounted on a common base. A picture of the apparatus and the sample holder is shown in Fig. 3-4-A. Provision for temperature control of the sample was not included; however, provision for monitoring the sample temperature is included. Stray light shielding can be included but it was found that this is not necessary for the qualitative experiments which are planned.

The light source is a DLG projection bulb with a parabolic reflector in the envelope. The use of this type bulb minimizes glass optics and gives increased infrared illumination at the sample. The slit and chopper blade are placed at the focal point of the bulb to maximize the available light traversing the slit. Using a 3600 rpm synchronous motor and a .010 in. slit, a cutoff time of 5 micro-seconds is obtained. The lens has a focal length of 5 cm and is fitted with an iris so that the f-number can be adjusted. One field plate of the sample holder is made of germanium to provide a filter which passes penetrating light.

[1] The apparatus design follows recommendations by W. A. Albers, Jr., General Motors Res. Lab.

Fig. 3-4-A Field Effect Apparatus

2. Analysis Procedure. The analysis procedure will be described in detail by going through the computation which was done on a chemically oxidized sample.

Physical Constants.

1. $q = 1.6 \times 10^{-19}$ coulomb
2. $K = 1.38 \times 10^{-23}$ joules/°K
3. $\epsilon_o = \frac{1}{36\pi 10^{11}}$ farad/cm
4. $\kappa = 16$

Sample properties (at 293° K) and dimensions

5. l = sample length between voltage probes = .317 cm
6. w = sample width = .317 cm
7. t = sample thickness = .0185 cm
8. A = area of capacitor plate = .317 cm^2
9. ρ = sample resistivity = 13.7 Ω cm
10. τ_s = sample bulk lifetime = 77 μ sec
11. μ_p [2] = hole mobility = 1875 cm^2/volt sec
12. μ_n [2] = electron mobility = 3935 cm^2/volt sec
13. n_i [2] = intrinsic carrier concentration = 1.52×10^{13} cm^{-3}

[2] Smith, R. A.; Semiconductors, Cambridge University Press.

14. D = diffusion constant for holes = 44 cm^2/sec

Experimentally determined values

15. I_S = sample current = $.281 \times 10^{-3}$ amp.

16. V_S = sample voltage at voltage probes = .231 V

17. $R_S = \frac{VS}{IS} = 825\ \Omega$

18. C = total capacitance sample to field plate = $52\ \mu\mu f$

19. ΔV = change in sample voltage due to applied field

20. ΔV_I = change sample voltage under illumination

21. S_o = sample surface recombination velocity at O field = $\frac{(\tau_b - \tau \text{ measured})t}{2\tau_b \tau \text{ measured}} = S_o = 48$ cm/sec

22. V_a = voltage applied to field plates

Formulae for field effect omputation

23. $u = \frac{\text{fermi level - intrinsic fermi level}}{KT} = \frac{q\phi}{KT}$

24. Q_T = total charge per unit area in surface space charge region = $\frac{C}{2A}$ Va coulomb/cm^2 = $0.08\ 10^{-9} \times V_a$ coulomb/cm^2

25. $\Delta\sigma_T$ = total change in sample conductivity = $\frac{l \Delta V}{w R_s^2 I_2}$ $\frac{\text{mho}}{\text{square}}$

26. Q_{sc} = theoretical charge in space charge per unit area due to applied field =

$$2q\, n_i\, L_D\, \mu_n \left[-F(u_s, u_b)\right] = 0.419 \times 10^{-9} \left[-F(u_s, u_b)\right] \text{ coulombs/cm}^2$$

27. L_D = Debye length = $\left(\frac{\kappa \epsilon_o KT}{2q^2 n_i}\right)^{\frac{1}{2}} = 8.6 \times 10^{-5}$ cm

28. $F(u_s, u_b)$*③ $= \sqrt{2}\left(\sinh u_b \cdot (u_b - u_s) - \cosh u_b + \cosh u_s\right)^{\frac{1}{2}}$

and u_b = bulk potential in units of KT
u_s = surface potential in units of KT

③

29. $\Delta\sigma_{sc}$ = theoretical change in conductivity due to applied field = $q\mu_n \Delta n + q\mu_p \Delta p$ =

$$= qn_i\, L_D\, \mu_n\, G(-u_s, -u_b) + qn_i\, L_D\, \mu_p\, G(u_s, u_b)$$

$$= 0.39 \times 10^{-6}\, G(-u_s, -u_b) + .82 \times 10^{-6}\, G(u_s, u_b) \ \frac{\text{mhos}}{\text{square}}$$

where

Δn and Δp are changes in electron and hole concentrations respectively

30. $G(u_s, u_b) = \int_{u_s}^{u_b} \frac{(e^{-u} - e^{-u_b})}{F(u, u_b)}\, du$

4

*Correction for mobility at the surface has not been applied. Also, this gives $\Delta\sigma_{sc}$ due to one surface. When field is applied to both sides of the sample this value is multiplied by 2.

3 Kingston, R. H. and Neustadter, S. F.; Journal of Appl. Phy., Vol. 26, June 1955

4 Schrieffer, J. R.; Phy. Rev. Vol. 97, Feb. 1955

31. Q_S = charge in space charge due to surface traps
$= Q_T - Q_{sc}$

Formula for computation of surface recombination velocity S

32. $\Delta V_I \sigma^{-2} \overset{(5)}{=} I_s \frac{d}{tw} q \mu_p \left(\frac{\mu_n}{\mu_p} + 1\right) \bar{p}$

where

33. σ = sample conductivity

34. d = length of illuminated portion of sample

35. $\bar{p} \overset{(5)}{=} I \tau_B \frac{\frac{t}{L}}{\frac{t}{L} + \frac{2LS}{D}}$ assuming penetrating light, $\frac{LS}{D} \ll 1$, $\frac{t}{L} \ll 1$

36. I = illumination intensity

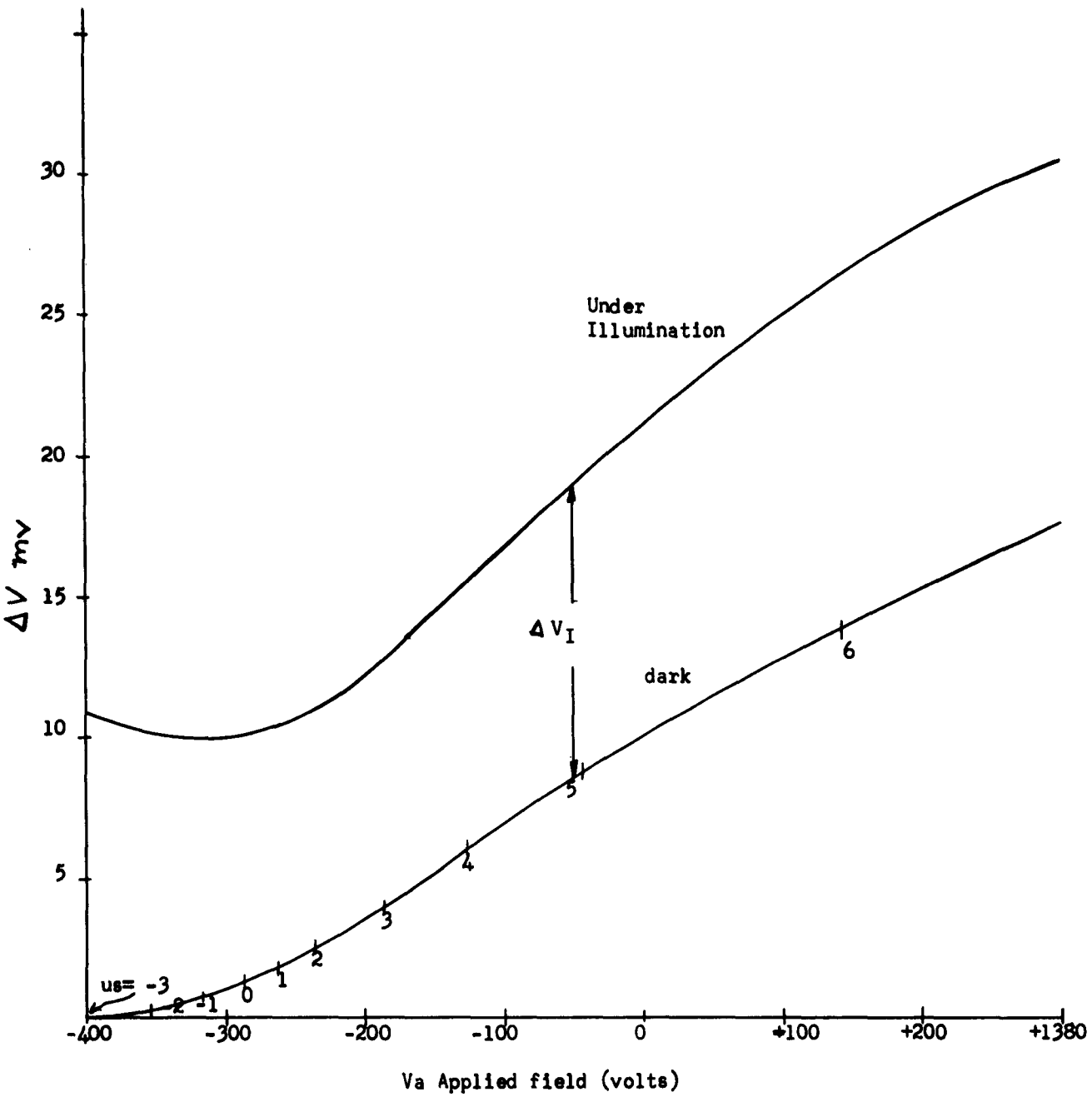
37. $L = \sqrt{D \tau_B}$

38. $\frac{\Delta V_I \text{ min}}{\Delta V_I} \left(\frac{\sigma_{min}}{\sigma}\right)^2 = \frac{\frac{t}{L} + \frac{2LS}{D}}{\frac{t}{L} + \frac{2LS}{D} \text{max}}$

The field effect curves which are displayed on the oscilloscope are shown in Fig. 3-4-B. By using equations 24 and 25, the dark curve is plotted in terms of Q_T and $\Delta \sigma_T$ as shown in Fig. 3-4-C (see App. I). Q_{sc} and $\Delta \sigma_{sc}$ shown in Fig. 3-4-C are computed by equations 26 and 29 (see App. II). The sample resistivity was chosen by using the graph of u_b vs. ρ in Appendix III to give u_b = 2 or 13.7 Ω cm material. Values of F and G functions are computed in reference 3.

[5] Bath, H. M. and Cutler, M.; Journal Phy. and Chem. Solids, Permagon Press, Vol. 5, 1958

Field Effect Curves
Figure 3-4-B



Appendix I
Computation of Q_T vs $\Delta\sigma$

V_a	$Q_T \times 10^{-9}$	$\Delta V \times 10^{-3}$	$\Delta\sigma \times 10^{-6}$
-400	-32.7	0	0
-300	-24.6	1	5.2
-200	-16.4	3.5	18.2
-100	-8.2	6.9	36.3
0	0	10.0	52.0
100	8.3	12.6	65.8
200	16.4	15.2	79.5
300	24.6	17.8	93.0
400	32.7	19.6	109.0

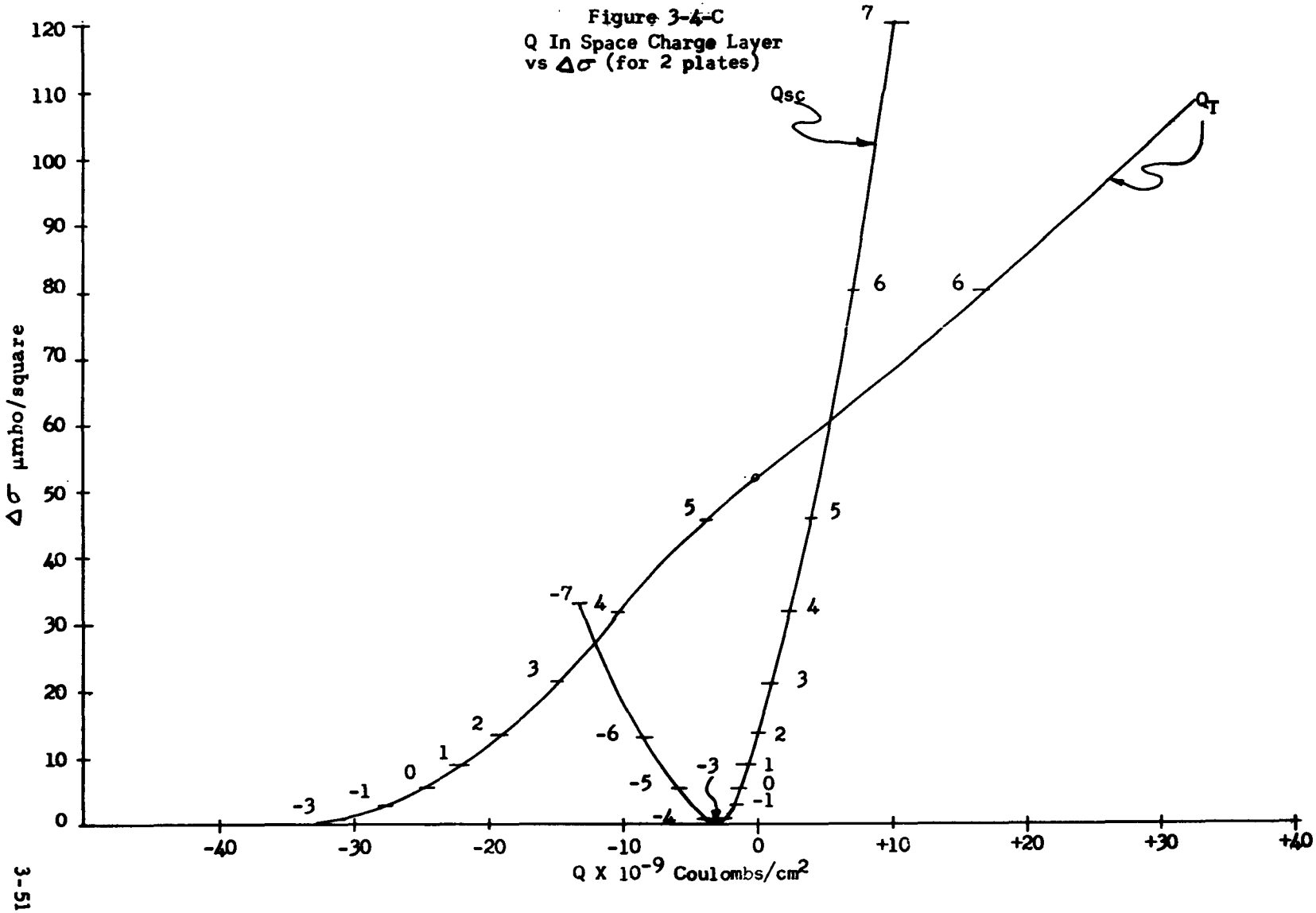
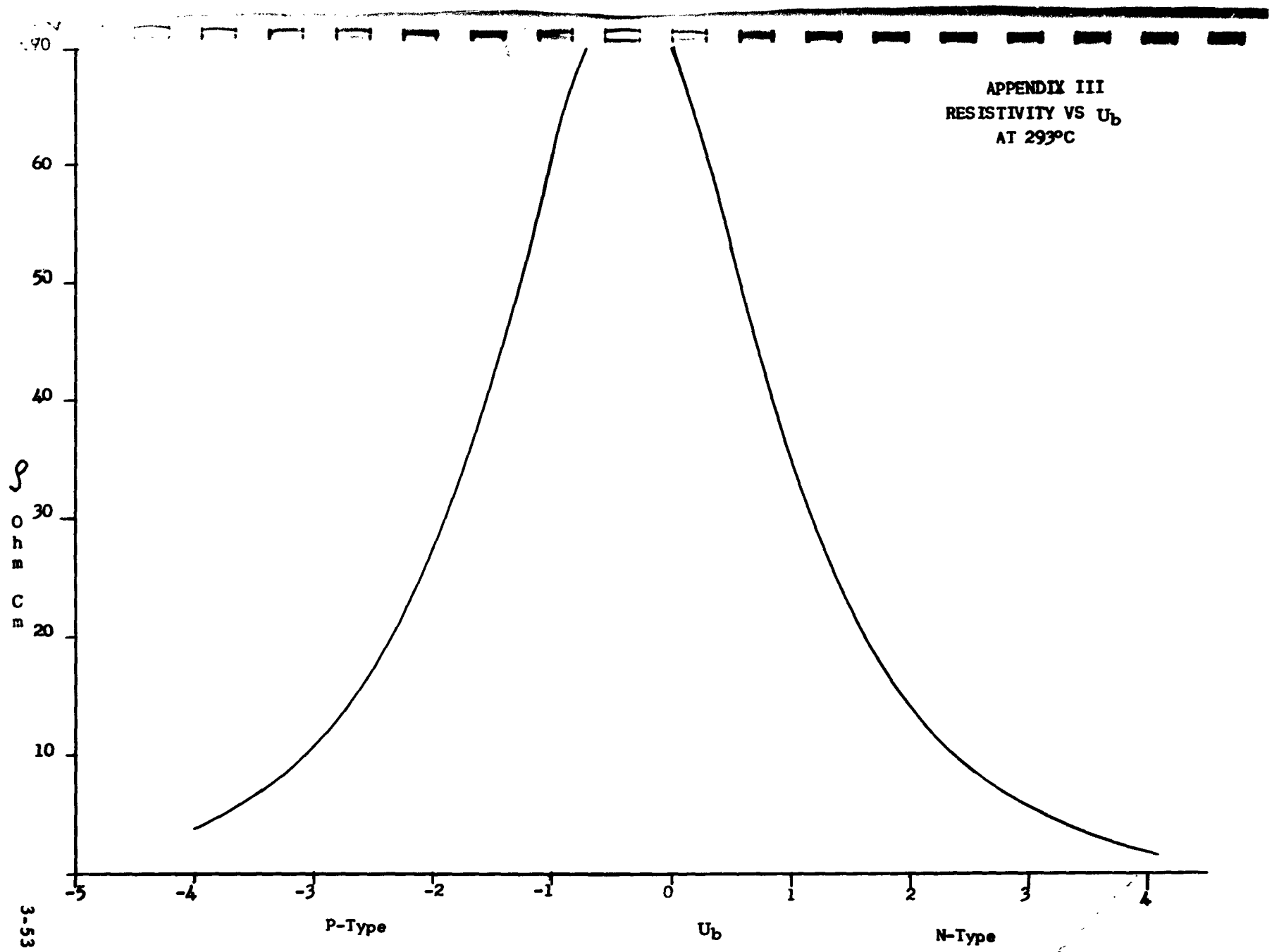


Figure 3-4-C
Q In Space Charge Layer
vs $\Delta\sigma$ (for 2 plates)

Appendix II

1	2	3	4	5	6	7	8	9	10	11	12	13	14
u_s	$-F(u_s, u_b)$	$G(-u_s, -u_b)$	$G(u_s, u_b)$	$X10^{-6}$ $qu_n n_i L_D X$ $G(-u_s, -u_b)$	$X\ 10^{-6}$ $qu_p n_i L_D X$ $G(u_s, u_b)$	$\Delta\sigma_{sc} X10^{-6}$	$X\ 10^{-6}$ $\Delta\sigma - \Delta\sigma_{min}$	$2\ X\ 10^{-6}$ $\Delta\sigma - \Delta\sigma_{min}$	$Q_{sc} X\ 10^{-9}$	$Q_T X\ 10^{-9}$	$X\ 10^{-9}$ $Q_s = Q_T - Q_{sc}$	u_s	V_a
7	31.0	65.0	-0.10	53.0		53.0	60.0	120.0	13.0				
6	19.0	40.0	-0.10	33.0		33.0	40.0	80.0	8.0	+11.5	3.5	6.0	142
5	11.0	20.0	-0.10	16.0		16.0	22.8	45.6	4.6	-3.5	-8.1	5.0	-43
4	5.5	11.0	-0.08	9.1		9.1	15.9	31.8	2.3	-10.2	-12.3	4.0	-126
3	2.3	4.4	-0.05	3.6		3.6	10.4	20.8	1.0	-15.0	-16.0	3.0	-185
2	0	0	0	0		0	6.8	13.6	0	-19.0	-19.0	2.0	-235
1	-1.7	-3.1	.10	-2.5		-2.5	4.3	8.6	-0.71	-22.0	-21.3	1.0	-264
0	-3.0	-5.4	.30	-4.3	0.12	-4.3	8.6	5.2	-1.2	-24.5	-23.3	0	-288
-1	-4.2	-7.2	.74	-5.9	0.29	-5.6	1.2	2.4	-1.7	-27.5	-25.8	-1.0	-318
-2	-5.5	-8.8	1.65	-7.2	0.64	-6.6	0.2	.4	-2.3	-31.0	-28.7	-2.0	-354
-3	-7.0	-10.0	3.5	-8.2	1.4	-6.8	0	0	-2.9	-32.7	-29.8	-3.0	-400
-4	-9.0	-11.0	6.0	-9.0	2.3	-6.7	0.1	0.2	-3.8				
-5	-14.0	-12.0	15.0	-9.8	5.8	-4.0	2.8	5.6	-5.8				
-6	-21.0	-12.5	25.0	-10.0	9.8	-0.2	6.6	13.2	-8.8				
-7	-30.0	-12.5	50.0	-10.0	20.0	+10.0	16.8	33.6	-13.0				

Col 1 - 10 Computation for Q_{SC} vs u_s
Col 11 - 13 Computation for Q_S vs u_s
Col 14 Computation for V_a vs u_s


APPENDIX III
RESISTIVITY VS U_b
AT 293°C
70
60
50
40
30
20
10
ρ Ohm Cm
-5
-4
-3
-2
-1
0
1
2
3
4
P-Type
U_b
N-Type

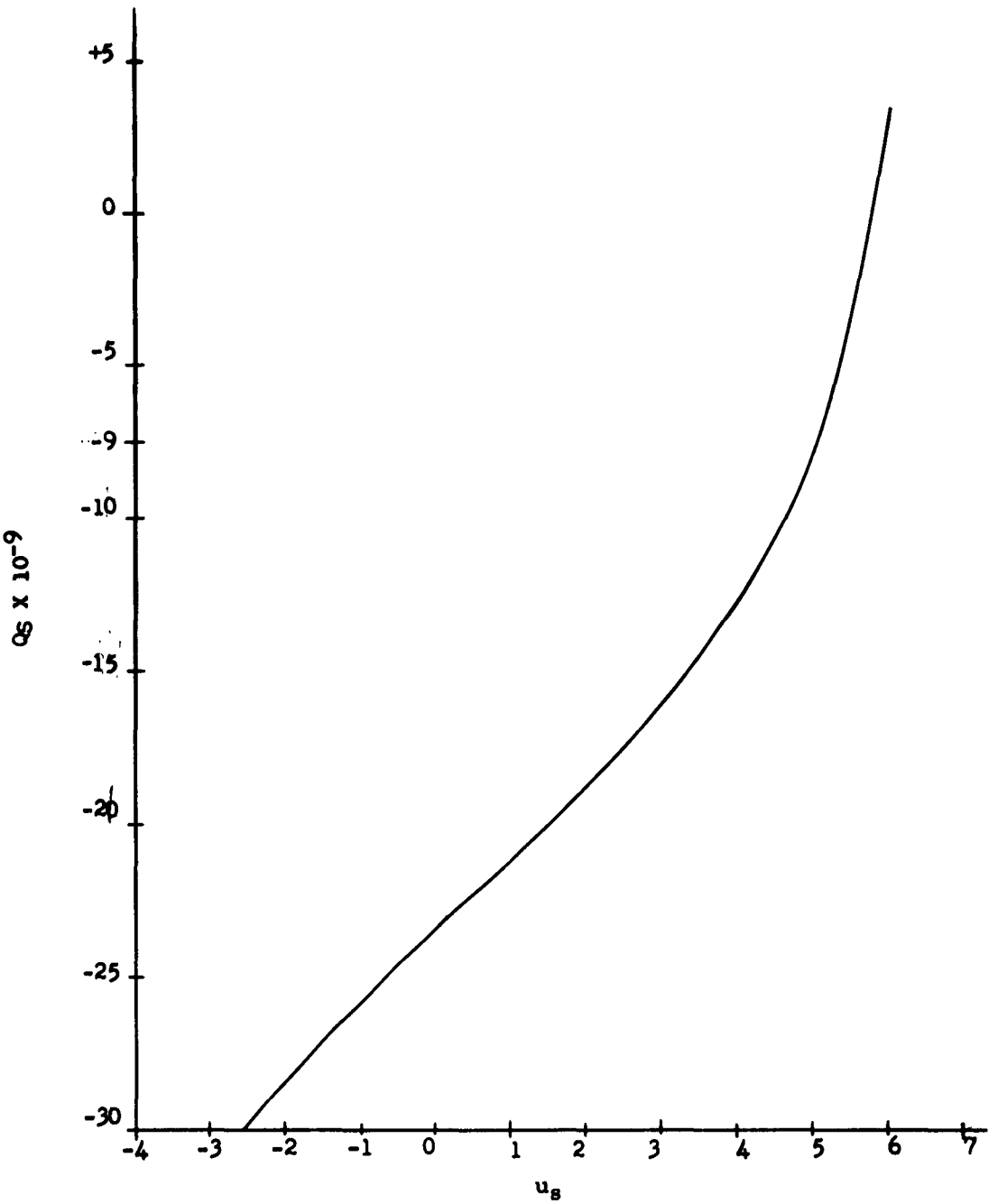
A graphic subtraction of $Q_T - Q_{sc}$ at selected values of u_s yields Q_s vs. u_s which is shown in Fig. 3-4-D.

The field effect curve under illumination can now be used to compute s vs. u_s. This is done by normalizing equation 32 by dividing by minimum value assumed by ΔV_I. The sample conductivity for the respective points are considered although the ratio of conductivity which appears in the normalized equation 38 is near one. Equation 38 can now be solved for s_{max}. providing a value for s is known under identical illumination conditions. This is done by photon induced carrier decay method at O field to get τ measured (shown in Fig. 3-4-E) and solving equation 21 to determine s. (It is important that the chopped light have a cutoff time which is short compared to τ measured.) With s_{max} thus determined equation 38 can be solved at other values of u_s to obtain a plot of s vs. u_s shown in Fig. 3-4-F. The computation is shown in Appendix IV.

3. Experimental Results. The procedure has been used to compare the effect of a gentle wash to a pressurized wash on a chemically oxidized surface. There was no change in the surface potential, s, or Q_s in this experiment. The values of s obtained must be regarded as comparative only because of the low sensitivity to surface recombination obtained by using material of only 77 μsec bulk lifetime. Material of >200 μsec has been prepared with the desired resistivity for use in further studies.

Program for the Next Quarter. In the next quarter the effects of metals used near the emitter junction will be studied.

Figure 3-4-D
Q_S vs u_s



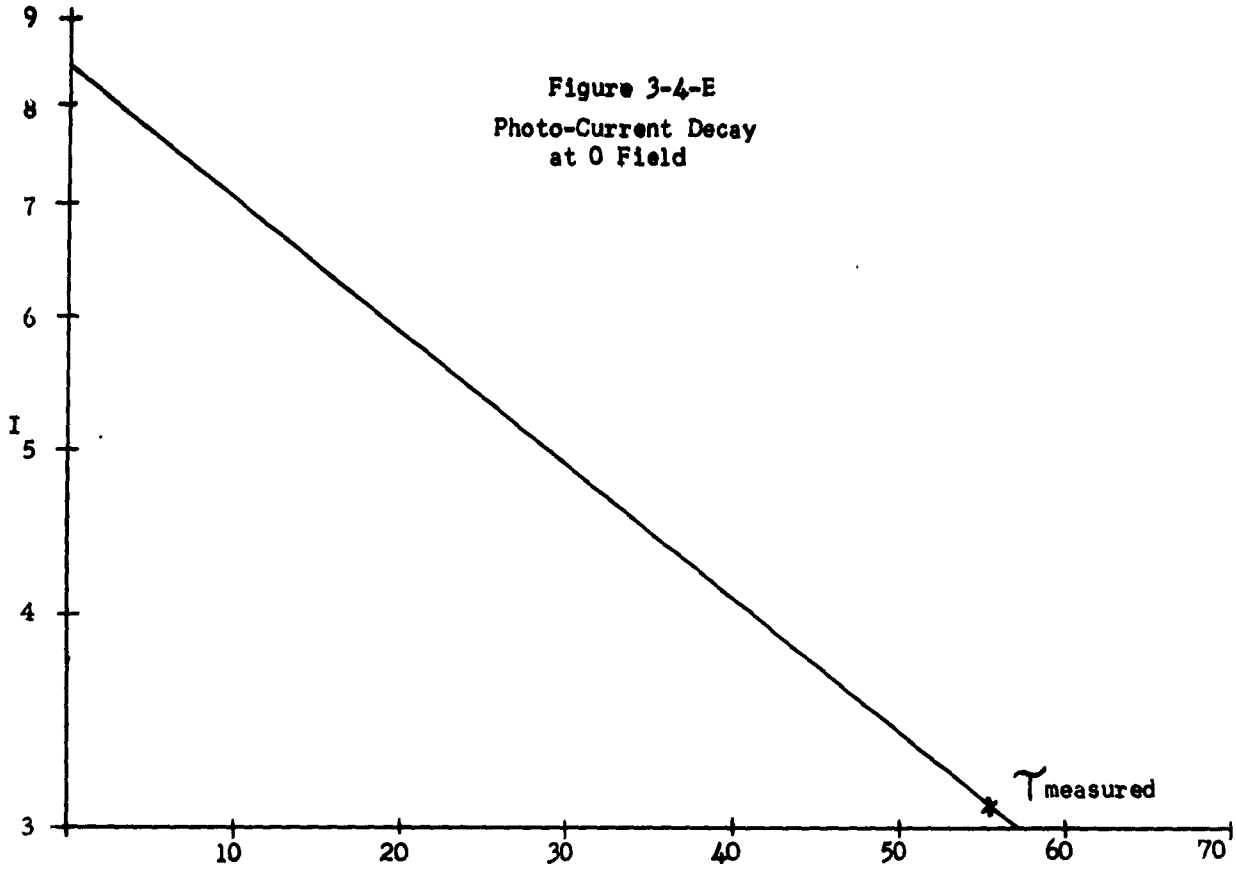


Figure 3-4-E

Photo-Current Decay
at 0 Field

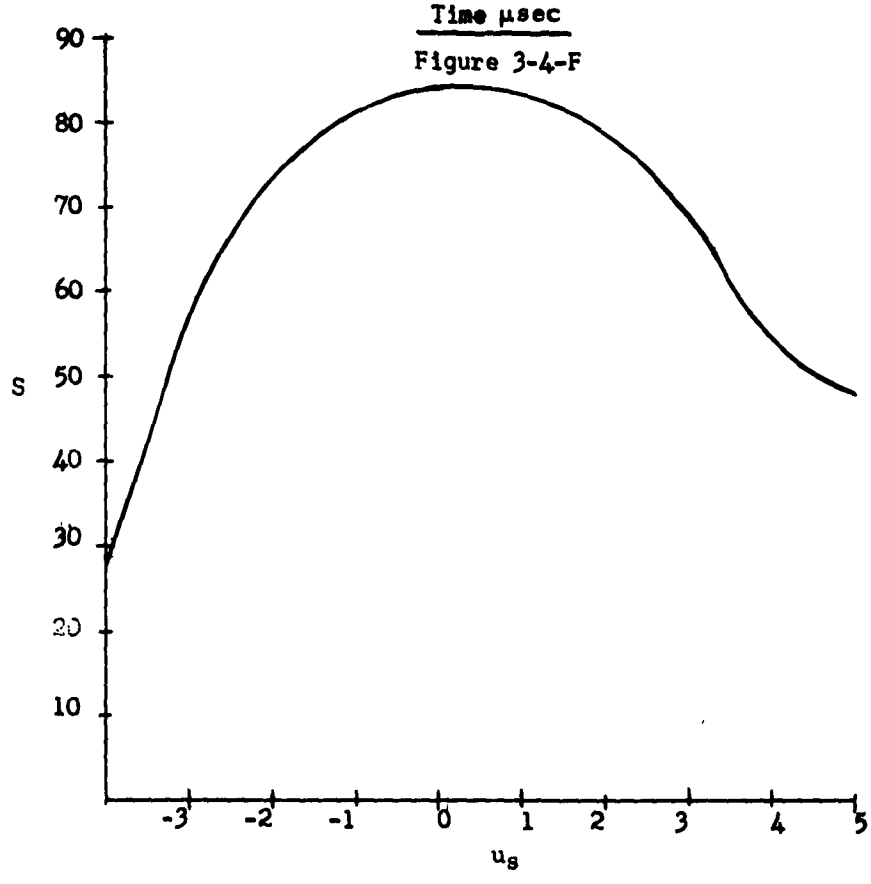


Figure 3-4-F

Appendix IV

Computation of S vs u_s

1	2	3	4	5	6	7
u_s	ΔV_I	$\frac{\Delta V_I \text{ min}}{\Delta V_I}$	$\frac{(\sigma_s \text{ min})}{\sigma_s}$	$\frac{(\sigma_s \text{ min})^2}{\sigma_s}$	$\frac{(\Delta V_I \text{ min})}{\Delta V_I}\frac{(\sigma_s \text{ min})^2}{\sigma_s}$	s
6.0	12.5	0.70	1.19	1.19	.83	50
5.25	11.0	.79	1.05	1.05	.83	50
5.0	10.4	.84	1.02	1.02	.85	52
4.0	9.1	.95	1.01	1.01	.95	73
3.0	8.8	.97	1.01	1.01	.97	77
2.0	8.7	1.0	1.0	1.0	1.0	83
1.0	8.7	1.0	1.0	1.0	1.0	83
0.0	8.7	1.0	1.0	1.0	1.0	83
-1.0	9.3	.94	1.0	1.0	.94	72
-2.0	10.0	.87	1.0	1.0	.87	57
-3.0	12.0	.72	1.0	1.0	.72	27

B. Time Variation of Excess Collector Current.

General and Engineering Status. The temperature variation of the excess current was studied. This experiment was not useful in studying the time constant behavior because with increasing temperature the time constants were no longer well defined. Also, above 40°C there was no measurable decay of collector current. This is shown in Fig. 3-4-G. The decrease in excess current with increasing temperature suggests a change in the equilibrium density at the surface of a constituent which takes part in the conductance process. This is further verified by the occurrence of a "hysteresis loop" when the maximum excess current is plotted through a complete temperature cycle.

Program for the Next Quarter. Units on Milestone III will be tested to determine the correlation between the time varying characteristic and device failure.

C. Two Volt Diode Current vs. Temperature.

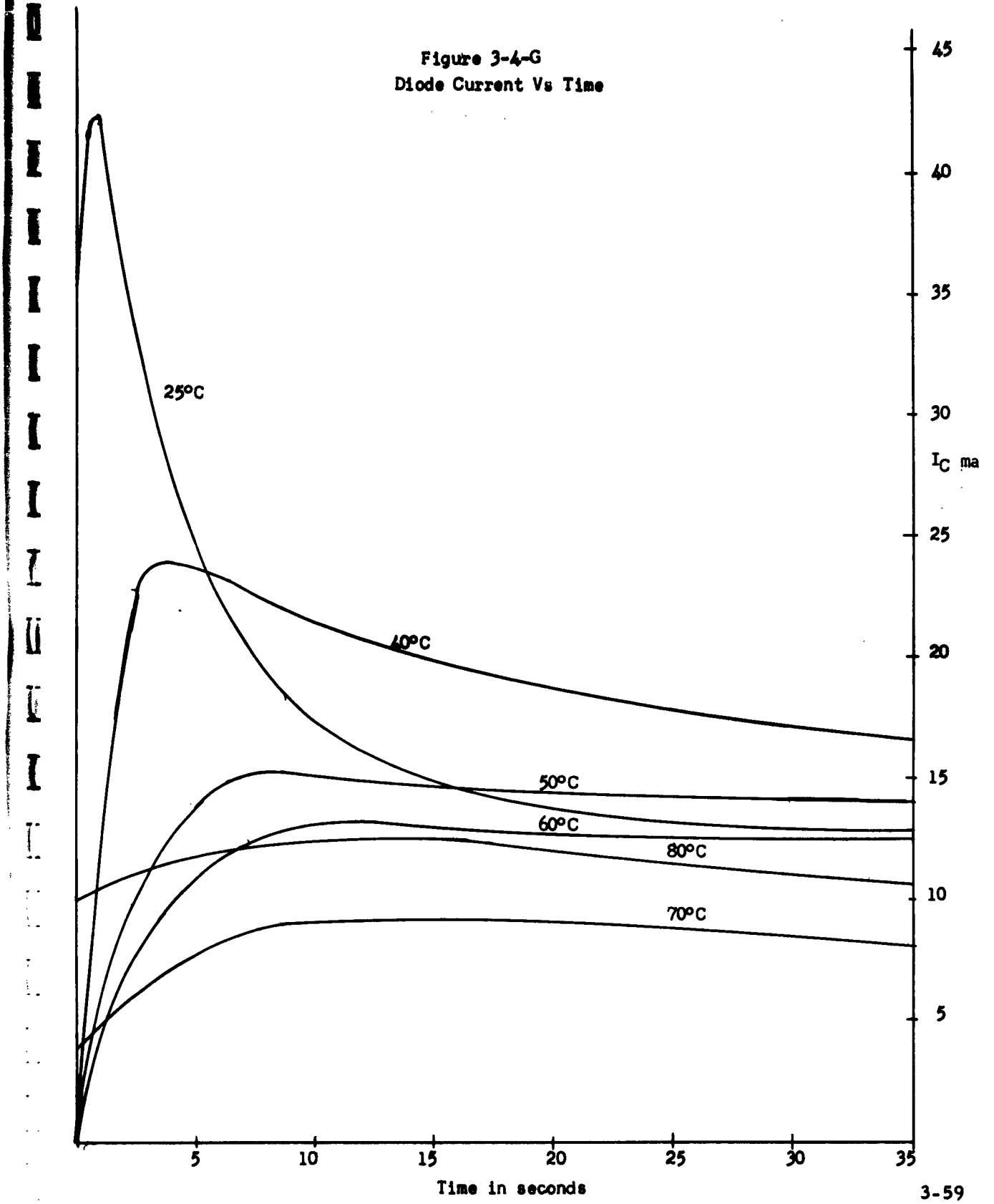
General and Engineering Status. Further analysis of the "dew point" measurement at a higher voltage has shown that the excess current occurs near O°C indicating that moisture is involved in the current increase process.

Program for the Next Quarter. Further experiments are not planned at the present time.

3.4.2 Residual Gas Analyzer - M. E. Stanton.

General and Engineering Status. As indicated in the second quarterly report, attempts to use the analyzer in failure analysis have been unsuccessful. Further experiments using

Figure 3-4-G
Diode Current Vs Time



the apparatus for failure analysis are not planned.

3.4.3 Infrared Spectrophotometer - M. E. Stanton.

General and Engineering Status. The colorimetric analysis procedure has been established as reported in the second quarterly report. The infrared analyses of the vycor disc have been discontinued because the H_2O absorption bands complicate the analysis to the extent that it is impractical to use the method for a routine analysis of the transistor ambient.

3.4.4 Polarigraph - M. E. Stanton

Program for the Next Quarter. Because of the difficulties encountered in the field effect apparatus the experiments with the polarigraph have been delayed until the fourth quarter.

3.4.5 Electron Probe Microanalyzer. The final report was in the second quarterly report.

3.4.6 Surface Coatings - R. P. Anjard.

General and Engineering Status. The basic theory concerning protective coatings was presented in the second quarterly report. This report contains the results of continuing the program previously outlined.

Data from the various surface coating experiments is summarized in the Data Summary Table, Fig. 3-4-H. The additional experiments performed since the last report follow:

Experiment No.	Experiment Description	After Cap	After Age	ICBO 2	ICBO 4	ICBO 6	ICBO A/C	ICBO A/A	IEBO 2	IEBO 4	IEBO 6	IEBO A/C
1-1	Sylgard 182	1.35 (2.8)	.53 (.51)	.41 (.37)	.39 (.37)	.39 (.38)	.94 (2.1)	.50 (.57)	.27 .29	.64	.23 (.27)	194.8 (19.3)
1-2	Chemically Oxidized with Sylgard 182	1.62 (1.5)	1.31 (.91)	1.38 (1.0)	1.98 (1.1)	2.70 (3.3)	1.72 (.66)	2.20	1.25 (.6)	1.43 (1.2)	1.40 (1.30)	104.1 (9.1)
1-5	XR6-1043 AS/emitter	.61 (.76)	.42 (.39)	4.7 (8.6)	>50							
1-6	Baked 97 Hours	1.27 (2.2)	.90 (1.0)	.78 (.93)	.85 (1.0)	1.14 (1.3)	.75 (.74)	.64 (.63)	.31 (.28)	.26 (.28)	.35 (.31)	239.8 (17.9)
1-7	SR98	1.22 (1.03)	1.13 (1.0)	.99 (.83)		.91 (1.19)	.52 (.7)	.48 (.71)	.45 (.62)		.60 (.79)	124.0 (30.0)
1-8	SR98	2.32	2.28	1.41 (.82)	1.17 (.69)	1.32 (.84)	.74	.79	.82 (.99)	.60 (.86)	.59 (1.18)	144.0
1-9	SR98 AS/ on entire element	1.21	1.1	.75	.75	.75	1.35	1.25	1.15	1.15	1.18	146.0
1-10	SR98 AS/ on emitter	1.76 (.96)	1.79 (1.0)	2.29 (1.40)	2.32 (2.00)	2.10 (1.42)	1.30 (.87)	1.28 (.98)	1.18 (1.28)	1.16 (1.29)	1.31 (1.51)	152.6 (33.6)
1-11	Sylgard 182 with Antimony Trioxide on element	2.15 (1.24)	1.93 (1.05)	3.61 (6.23)	2.52 (1.78)	4.53 (13.3)	.77 (1.33)	.50 (.32)	.64 (.62)	.49 (.32)	.68 (1.32)	164.3 (30.6)
1-12	Sylgard 182 with Antimony Trioxide and Barium Oxide	2.78 (2.6)	1.57 (.80)	1.58 (1.16)	1.66 (1.30)	1.59 (1.12)	.57 (.62)	.45 (.54)	.47 (.58)	.46 (.61)	.44 (.57)	162.5 (21.1)
1-13	SS4067 Silicone Grease	Discontinued										
1-14	SS4067 with Antimony Trioxide	3.15 -	2.25 -	11.75 -	3.0 -	3.5 -	.88 -	.76 -	3.3 -	4.0 -	4.0 -	60.0 -
1-15	Nu-Densoform	2.07 -	2.53 -	29.67 -	.70 -	.76 -	.81 -	.80 -	10.7 -	.22 -	.22 -	135.7 -
1-16	GESS4067	2.31 (1.64)	2.15 (1.30)	10.93 (9.81)	6.40 (8.21)		.68 (.79)	.40 (.33)	.74 (.91)	.81 (.98)		82.0 64.5
1-17	DC C-2-0168	1.56 (1.25)	1.38 (.83)	1.11 (.78)	2.05 (1.40)		.84 (1.06)	.50 (.38)	.54 (.52)	.63 (.68)		70.1 (13.2)

NOTE: ( ) Standard deviation of parameter

NOTES:
1. Gain rejects have not been dropped thereby providing a more complete understanding of the effects of the treatments.
2. V_{FL}, I_{CBO} and I_{EBO} are the parameters for which the failure rates have been computed.
3. Two experiments dropped utilized DCX6-1043 silicone varnish. (1-3, 1-4)

SURFACE COATINGS

				I_{EBO}					I_{B_2}					2 Volt Diode			Number Units After Age	Fa in
4	6	N/C	N/A	2	4	6	N/C	N/A	2	4	6	N/C	N/A	2	4	6		2
39 37)	.39 (.38)	.94 (2.1)	.50 (.57)	.27 .29	.64	.23 (.27)	194.8 (19.3)	212.4 (24.9)	220.5 (19.5)	202.5 (22.4)	204.9 (22.4)	108.7 (16.9)	94.7 (14.0)	124.0 (16.2)	62.3 (8.0)	65.8 (14.6)	21	0
98 1)	2.70 (3.3)	1.72 (.66)	2.20	1.25 (.6)	1.43 (1.2)	1.40 (1.30)	104.1 (9.1)	106.4 (11.0)	104.6 (11.3)	102.7 (11.4)	111.1 (13.8)	82.1 (17.6)	59.5 (10.5)	57.0 (10.7)	74.4 (17.0)	66.9 (13.8)	8	1
85 0)	1.14 (1.3)	.75 (.74)	.64 (.63)	.31 (.28)	.26 (.28)	.35 (.31)	239.8 (17.9)	231.3 (20.8)	212.6 (23.4)	209.7 (25.7)	217.1 (24.2)	102.5 (11.8)	101.4 (12.4)	80.6 (10.6)	64.5 (13.0)	68.1 (10.9)	18	1
	.91 (1.19)	.52 (.7)	.48 (.71)	.45 (.62)		.60 (.79)	124.0 (30.0)	161.8 (48.0)	172.7 (39.5)		170.5 (40.5)	72.4 (10.1)	91.9 (16.6)	135.8 (25.6)		110.8 (26.7)	22	1
17 69)	1.32 (.84)	.74	.79	.82 (.99)	.60 (.86)	.59 (1.18)	144.0	200.0	234.1 (24.9)	237.2 (19.8)	246.0 (21.2)	119.0	76.0	114.0 (20.7)	118.7 (19.9)	155.2 (25.2)	13	0
75	.75	1.35	1.25	1.15	1.15	1.18	146.0	171.0	206.5	207.5	230.0	114.0	65.5	75.5	70.0	103.5	2	0
32 00)	2.10 (1.42)	1.30 (.87)	1.28 (.98)	1.18 (1.28)	1.16 (1.29)	1.31 (1.51)	152.6 (33.6)	180.6 (29.4)	213.4 (26.0)	214.1 (16.0)	225.5 (33.8)	77.8 (20.6)	55.8 (9.9)	84.2 (14.2)	110.0 (22.0)	118.6 (38.9)	28	0
52 78)	4.53 (13.3)	.77 (1.33)	.50 (.32)	.64 (.62)	.49 (.32)	.68 (1.32)	164.3 (30.6)	165.2 (25.7)	180.9 (20.5)	185.4 (25.1)	186.9 (20.9)	91.6 (19.1)	77.5 (11.8)	97.5 (17.9)	96.1 (113.5)	86.6 (44.7)	43	2 ICBO
66 30)	1.59 (1.12)	.57 (.62)	.45 (.54)	.47 (.58)	.46 (.61)	.44 (.57)	162.5 (21.1)	191.3 (15.7)	204.6 (18.2)	201.6 (17.7)	186.9 (20.3)	106.0 (17.3)	95.2 (13.4)	115.2 (17.4)	88.6 (13.2)	92.2 (15.1)	18	0
.0 -	3.5 -	.88 -	.76 -	3.3 -	4.0 -	4.0 -	60.0 -	37.3 -	50.5 -	51.0 -	52.5 -	36.8 -	74.3 -	52.3	70.0	84.0	4	2 ICB
.70 -	.76 -	.81 -	.80 -	10.7 -	.22 -	.22 -	135.7 -	153.3 -	193.7 -	194.0 -	188.0 -	83.7 -	100.0 -	66.2	150.0	150.0	3	2 ICB
.40 .21)		.68 (.79)	.40 (.33)	.74 (.91)	.81 (.98)		82.0 64.5	101.6 (18.6)	116.3 (77.7)	122.0 (22.2)		74.5 (38.8)	90.2 (16.8)	116.3 (77.9)	154.3 (141.3)		9	4 ICB
.05 .40)		.84 (1.06)	.50 (.38)	.54 (.52)	.63 (.68)		70.1 (13.2)	141.5 (21.3)	173.6 (30.4)	188.5 (23.4)		61.6 (14.0)	125.6 (14.7)	208.8 (27.9)	149.0 (18.5)		20	0

rameter

been dropped thereby providing a
nding of the effects of the

the parameters for which the
n computed.
l utilized DCX6-1043 silicone

FIGURE 3-4-H

SURFACE COATINGS

BO				I_{B_2}					2 Volt Diode				Number Units After Age	Failure Report Failures Determined in Nth Week			Failure Rate %/1000 Hours
	4	6	N/C	N/A	2	4	6	N/C	N/A	2	4	6		2	4	6	
7 9	.64	.23 (.27)	194.8 (19.3)	212.4 (24.9)	220.5 (19.5)	202.5 (22.4)	204.9 (22.4)	108.7 (16.9)	94.7 (14.0)	124.0 (16.2)	62.3 (8.0)	65.8 (14.6)	21	0	0	0	4.75
5)	1.43 (1.2)	1.40 (1.30)	104.1 (9.1)	106.4 (11.0)	104.6 (11.3)	102.7 (11.4)	111.1 (13.8)	82.1 (17.6)	59.5 (10.5)	57.0 (10.7)	74.4 (17.0)	66.9 (13.8)	8	1 Vf1	0	0	N/A
																	100
1 8)	.26 (.28)	.35 (.31)	239.8 (17.9)	231.3 (20.8)	212.6 (23.4)	209.7 (25.7)	217.1 (24.2)	102.5 (11.8)	101.4 (12.4)	80.6 (10.6)	64.5 (13.0)	68.1 (10.9)	18	1 Vf1	0	0	11.5
5 2)		.60 (.79)	124.0 (30.0)	161.8 (48.0)	172.7 (39.5)		170.5 (40.5)	72.4 (10.1)	91.9 (16.6)	135.8 (25.6)		110.8 (26.7)	22	1 Vf1	0	0	10.5
2 9)	.60 (.86)	.59 (1.18)	144.0	200.0	234.1 (24.9)	237.2 (19.8)	246.0 (21.2)	119.0	76.0	114.0 (20.7)	118.7 (19.9)	155.2 (25.2)	13	0	0	0	7.7
5	1.15	1.18	146.0	171.0	206.5	207.5	230.0	114.0	65.5	75.5	70.0	103.5	2	0	0	0	N/A
8 8)	1.16 (1.29)	1.31 (1.51)	152.6 (33.6)	180.6 (29.4)	213.4 (26.0)	214.1 (16.0)	225.5 (33.8)	77.8 (20.6)	55.8 (9.9)	84.2 (14.2)	110.0 (22.0)	118.6 (38.9)	28	0	0	0	3.6
4 2)	.49 (.32)	.68 (1.32)	164.3 (30.6)	165.2 (25.7)	180.9 (20.5)	185.4 (25.1)	186.9 (20.3)	91.6 (19.1)	77.5 (11.8)	97.5 (17.9)	96.1 (113.5)	86.6 (44.7)	43	2 ICBO	0	0	7.6
7 8)	.46 (.61)	.44 (.57)	162.5 (21.1)	191.3 (15.7)	204.6 (18.2)	201.6 (17.7)	186.9 (20.3)	106.0 (17.3)	95.2 (13.4)	115.2 (17.4)	88.6 (13.2)	92.2 (15.1)	18	0	0	0	5.6
3	4.0 -	4.0 -	60.0 -	37.3 -	50.5 -	51.0 -	52.5 -	36.8 -	74.3 -	52.3	70.0	84.0	4	2 ICBO	0	0	N/A
7	.22 -	.22 -	135.7 -	153.3 -	193.7 -	194.0 -	188.0 -	83.7 -	100.0 -	66.2	150.0	150.0	3	2 ICBO	0	0	N/A
74 91)	.81 (.98)		82.0 64.5	101.6 (18.6)	116.3 (77.7)	122.0 (22.2)		74.5 (38.8)	90.2 (16.8)	116.3 (77.9)	154.3 (141.3)		9	4 ICBO	0		
54 52)	.63 (.68)		70.1 (13.2)	141.5 (21.3)	173.6 (30.4)	188.5 (23.4)		61.6 (14.0)	125.6 (14.7)	208.8 (27.9)	149.0 (18.5)		20	0	0		

FIGURE 3-4-H

ADDITIONAL TEST DATA

Experiment No.	Experiment Description	Test	Phase	Number Tested	I_{CBO} Shift (Av) µa	I_{EBO} Shift (Av) µa
1-1	Sylgard 182	Operating Life at 70°C -250 hours	After 1000 hours storage at 139°C	10	0.00	0.01
1-2	Chemically Oxidized with Sylgard 182	Same	Same	7	1.90	.18
1-6	Baked 97 Hours	Same	Same	10	0.08	0.00
1-8	SR98	Same	After 1000 hours storage at 139°C and 4 weeks at room temp.	14	-0.04	-0.02
1-10	SR98 AS/ on emitter	Same	After 1000 hours storage at 139°C and 2 weeks at room temp.	28	0.04	0.16

FIGURE 3-4-H

ADDITIONAL TEST DATA

...riment ...cription	Test	Phase	Number Tested	I_{CBO} Shift (Av) μa	I_{EBO} Shift (Av) μa	h_{FE} Shift μa	No. of Failures
...gard 182	Operating Life at 70°C -250 hours	After 1000 hours storage at 139°C	10	0.00	0.01	-8	0
...nically ...dized with ...gard 182	Same	Same	7	1.90	.18	-6	1 ICBO
...ed 97 Hours	Same	Same	10	0.08	0.00	-11	0
...8	Same	After 1000 hours storage at 139°C and 4 weeks at room temp.	14	-0.04	-0.02	-2	1 ICBO
...8 AS/ on ...tter	Same	After 1000 hours storage at 139°C and 2 weeks at room temp.	28	0.04	0.16	-1	1 ICBO

FIGURE 3-4-H

1-11. Dow Corning's Sylgard 182 with 4% Sb_2O_3 powder was applied to basic units after a one hour precap bake. The coating was not restricted to the emitter diode. A twenty-four hour cure at 120°C was used.

1-12. Transistors were processed as in 1-11 except that the coating was applied only to the emitter. Barium oxide was placed in the device just prior to encapsulation.

1-13. General Electric Silicone Grease SS4067 was applied directly from the tube to the emitter.

1-14. Devices from the production lot used for experiment 1-13 were processed as in 1 -13 except that loose antimony trioxide powder was placed on the element just prior to the addition of SS4067.

1-15. Nu-Densoform (Cosmos) was applied to transistors after a one hour precap bake. After curing 24 hours at 120°C, all the transistors were capped except three. Two groups were generated in this experiment.

1-16. GE SS4067 (see Exp. 1-13) was placed in transistor caps. After being baked at 350°C for 44 hours, the caps were seated to 2N1358 units.

1-17. Dow Corning C-2-0168 compound is rated as a semiconductor grade potting material. Dow Corning suggested its use as a getter. C-2-0168 was placed in transistor caps and activated at 350°C for 44 hours prior to encapsulation.

The results of the experiments are outlined below:

a. Units coated with SR98 (Exp. 1-8, 1-9, 1-10) did not fail during 1, 000 hours at 135°C. No increase in gain was noted.

b. Devices coated with SR98 showed a continual increase in the 2 volt collector diode leakage.

c. Devices coated with SR98 containing arsenic exhibited a higher emitter diode current. This would be expected from the theory outlined.

d. Using Sylgard 182 which had previously exhibited desired gain stability with antimony trioxide, high gain did not result.

e. The addition of barium oxide desiccant to devices coated with Sylgard 182 containing arsenic caused the gain to behave similarly to standard production units.

f. Very high gain resulted after aging devices sealed with GE silicone grease SS4067. However, Exp. 1-13 was dropped because of excessive collector diode rejects generated during aging.

g. Devices sealed with GE silicone grease SS4067 and antimony trioxide (Exp. 1-14) exhibited high gain after aging. Diode degradation was the primary cause for the very low yield after aging. Fifty per cent (2 units) failed during the first 333 hours at 135°C.

h. Only limited data is available for GE SS4067 baked at 350°C.

i. Devices sealed with DC grease C-2-0168 exhibited a normal gain level after aging. There is a continual tendency toward lower gain during storage.

j. Transistors coated with Sylgard 182 (Exp. 1-1) were modulation life tested for 250 hours after the completion of 1, 000 hours storage at 135°C. Both the emitter and collector diodes were stable. The gain shifted toward higher gain. Refer to Fig. 3-4-H.

k. Chemically oxidized units coated with Sylgard 182 were evaluated as in j. The gain shifted higher although the emitter diode was stable; the collector diode degraded approximately 30% on high voltage modulation life testing.

l. Devices precap baked for 97 hours (Exp. 1-6) exhibited stable diodes after being tested as in j. The gain shifted toward higher gain.

m. Although devices coated with SR98 were stable during storage, an index failure rate of .280 was observed after operating life testing.

Conclusions. Of the element coatings evaluated, only Sylgard 182 significantly reduced the failure rate at the high temperature storage. Although an improvement was obtained, the variations in material purity and the difficulty in consistent application render this approach to reliability improvement undesirable. The addition of arsenic or antimony to varnishes on the emitter did not result in the expected improvement and stabilization of gain. GE SS4067 silicone grease applied to the element actually increased the failure rate compared to the current manufacturing process.

Program for the Next Quarter. The analysis of the experimental group will be completed.

3.4.7 Precap Aging and Desiccant Experiments - R. P. Anjard.

General and Engineering Status. Theories relating to oxidation and ambient control were presented in the second Quarterly Report. Experimental data is shown in Figures 3-4-I and 3-4-J. An outline of additional experiments follows:

Precap baking and chemical treatment experiments.

2-22. Production caps were nickel plated and gold plated (0.0001") and cleaned by the standard process prior to encapsulation.

2-23. Boiling Solvent "E". The same as 2-10 except the solvent was different.

2-24. Boiling Solvent "B". The experiment was reported to generate additional parts for evaluation of reproducibility and reliability.

2-25. Boiling Solvent "B". This experiment is the same as 2-10 except that a one hour precap bake in dry air was used prior to encapsulation.

2-26. Boiling Solvent "D". This experiment was the same as 2-13 except that barium oxide was added just prior to encapsulation.

2-27. Vacuum bake at 6×10^{-6} mm Hg at 170°C for 4 hours. The experiment is the same as 2-17 except that the

Code

A - Alcoholic Chelating Agent
B - Amine
C - Organic Acid
D - Amine
E - Hydrocarbon

Experiment No.	Experiment Description	After Cap	After Age	ICBO 2	ICBO 4	ICBO 6	ICBO A/C	ICBO A/A	IEBO 2	IEBO 4	IEBO 6	IEBO A/C
2-1	10 Microns- 1 Hr. Bake	.74 (.45)	1.1 (.78)	.96 (.88)	.79 (.90)	.76 (.99)	.49 (.44)	.64 (.45)	.71 (.8)	.68 (.97)	.67 (.99)	154.2 (29.4)
2-2	10 Micron- 13 Hr. Bake	.65 (.61)	1.48	.87 (.84)	.68 (.65)	.75 (.71)	.55 (.43)	.87	.67 (.46)	.64 (.42)	.52 (.40)	190.0 (27.3)
2-3	Approx. 145 Microns 1 Hour Bake	1.36 (.96	1.72 (1.06)	1.38 (1.04)	1.64 (1.59)	1.65 (1.57)	.76 (.66)	.96 (.62)	.82 (.63)	.98 (1.01)	.83 (.90)	138.7 (20.8)
2-4	Approx. 145 Microns 13 Hour Bake	1.5 (.9)	2.4 (.96)	.89 (.62)	.74 (.57)	.78 (.61)	.25 (.23)	.37 (.34)	.36 (.4)	.35 (.32)	.33 (.30)	131.2 (28.0)
2-5	3/4 Hour Air Bake	1.0 (.89)	1.6 (1.1)	1.5 (1.0)	1.86 (1.50)	2.03 (1.82)	.46 (.38)	.52 (45.0)	.51 (.42)	.54 (.51)	.70 (.96)	154.8 (21.0)
2-6	1-Hour Air Bake	3.13 (5.6)	2.4 (1.26)	1.88 (1.1)	2.10 (1.26)	2.83 (1.17)	2.14 (5.8)	.92 (.87)	.83 (1.0)	1.01 (1.15)	.90 (.89)	179.3 (25.3)
2-7	1-Hour Bake, Cap Hot	1.32 (1.1)	1.92 (1.1)	1.41 (1.0)	1.67 (1.48)	1.46 (1.22)	.76 (.75)	.62 (.72)	.58 (.73)	.50 (.62)	.55 (.73)	156.5 (19.8)
2-8	Boiling Solvent "A"	1.80 (1.3)	1.57 (1.2)	1.50 (1.3)	1.87 (1.65)	3.99 (2.30)	.62 (.78)	.65 (.67)	.52 (.52)	.60 (.53)	1.25 (1.84)	172.9 (21.8)
2-9	Chemically Oxidized 1 Hour Bake	1.17 (1.30)	.98 (1.1)	1.35 (1.3)	1.71 (1.96)	1.91 (1.96)	.58 (.59)	.69 (.61)	.69 (.63)	.74 (168)	.69 (.61)	117.5 (23.6)
2-10	Boiling Solvent "B"	1.5 (1.04)	1.86 (1.28)	1.74 (1.42)	2.68 (2.34)	7.25 (9.86)	1.39 (1.05)	1.44 (1.04)	1.28 (.99)	1.84 (.99)	5.85 (8.79)	141.4 (21.6)
2-11	Chemical Oxidized Mod. Process	1.6 (.98)	1.79 (1.0)	1.90 (1.29)	2.76 (2.34)	5.65 (7.14)	3.93 (7.6)	1.43 (.75)	1.42 (.69)	1.11 (1.47)	8.7 (11.27)	125.0 (21.3)
2-12	Boiling Solvent "C"	2.6 (1.50)	1.83 (.98)	1.51 (1.04)	1.64 (1.41)	7.06 (8.24)	1.17 (.45)	1.43 (.94)	.74 (.54)	.34 (.29)	2.32 (3.10)	101.2 (14.6)
2-13	Boiling Solvent "D"	2.35 (1.78)	1.77 (1.23)	1.67 (1.28)	2.27 (1.79)	8.81 (10.16)	1.81 (4.75)	.85 (.54)	.72 (.53)	.42 (.38)	2.28 (2.62)	119.9 (13.6)
2-14	Chemically Oxidized Boiling Solvent "B"	1.32 (.88)	1.63 (1.16)	2.10 (1.69)	2.12 (2.02)	2.28 (2.06)	1.24 (.84)	1.43 (.79)	1.70 (.87)	.63 (.37)	1.62 (.99)	132.0 (20.4)
2-15	10^{-6} Vacuum Bake 2 Hrs. 135°C	2.83	3.30	6.73	3.20	2.13	.63	.47	.60	.23	.53	265.3
2-16	Re-run 2-1	2.45	2.42	2.0	1.50	1.45	.45	.40	.33	.47	.43	134.3
2-17	10^{-6} Hr. at 135°C	4.00	1.20	1.30	.91	.90	2.1	2.5	1.9	1.9	1.85	157.0

Figure

				IEBO					IB_2					2 Volt Diode			Number Units After Age	Failu in Nt
4	6	A/C	A/A	2	4	6	A/C	A/A	2	4	6	A/C	A/A	2	4	6		2
79 90)	.76 (.99)	.49 (.44)	.64 (.45)	.71 (.8)	.68 (.97)	.67 (.99)	154.2 (29.4)	166.8 (37.7)	204.1 (30.7)	190.0 (29.4)	198.0 (32.5)	102.3 (25.4)	77.0 (15.2)	75.5 (16.7)	79.4 (17.3)	83.4 (18.0)	15	0
68 65)	.75 (.71)	.55 (.43)	.87	.67 (.46)	.64 (.42)	.52 (.40)	190.0 (27.3)	194.3 (43.2)	247.0 (44.1)	237.8 (35.4)	230.4 (38.3)	103.0 (24.2)	74.2 (19.4)	72.3 (12.6)	77.0 (13.5)	73.3 (13.4)	11	0
64 59)	1.65 (1.57)	.76 (.66)	.96 (.62)	.82 (.63)	.98 (1.01)	.83 (.90)	138.7 (20.8)	144.8 (24.6)	185.4 (33.4)	172.2 (24.1)	178.0 (23.7)	83.1 (14.9)	45.1 (7.5)	44.0 (7.4)	54.8 (20.4)	50.4 (18.6)	16	0
74 57)	.78 (.61)	.25 (.23)	.37 (.34)	.36 (.4)	.35 (.32)	.33 (.30)	131.2 (28.0)	169.0 (39.5)	187.9 (40.0)	177.6 (37.4)	182.0 (38.2)	72.9 (9.6)	58.2 (19.2)	47.9 (17.2)	50.1 (14.1)	45.5 (11.2)	8	0
86 50)	2.03 (1.82)	.46 (.38)	.52 (45.0)	.51 (.42)	.54 (.51)	.70 (.96)	154.8 (21.0)	188.4 (20.6)	204.8 (25.0)	209.1 (26.1)	195.5 (24.0)	125.3 (88.7)	88.9 (15.0)	87.6 (14.2)	98.2 (16.2)	102.0 (28.9)	19	0
10 26)	2.83 (1.17)	2.14 (5.8)	.92 (.87)	.83 (1.0)	1.01 (1.15)	.90 (.89)	179.3 (25.3)	196.4 (22.2)	205.4 (28.1)	209.1 (28.3)	195.7 (21.5)	105.2 (80.0)	83.5 (16.5)	86.2 (17.1)	96.4 (19.1)	97.9 (18.6)	19	0
67 48)	1.46 (1.22)	.76 (.75)	.62 (.72)	.58 (.73)	.50 (.62)	.55 (.73)	156.5 (19.8)	184.0 (27.7)	207.9 (25.4)	206.9 (25.2)	182.1 (28.9)	101.0 (75.8)	90.6 (29.4)	84.5 (21.7)	85.8 (29.0)	95.5 (37.3)	19	0
87 65)	3.99 (2.30)	.62 (.78)	.65 (.67)	.52 (.52)	.60 (.53)	1.25 (1.84)	172.9 (21.8)	190.7 (24.4)	212.0 (28.0)	211.0 (25.9)	196.4 (25.5)	88.9 (12.4)	94.2 (15.4)	90.6 (13.8)	100.0 (15.4)	108.5 (18.0)	21	0
71 96)	1.91 (1.96)	.58 (.59)	.69 (.61)	.69 (.63)	.74 (168)	.69 (.61)	117.5 (23.6)	109.0 (18.5)	104.8 (17.9)	111.0 (19.2)	105.0 (16.8)	65.4 (8.4)	41.2 (21.6)	49.7 (21.5)	60.9 (19.7)	57.0 (19.6)	27	0
68 34)	7.25 (9.86)	1.39 (1.05)	1.44 (1.04)	1.28 (.99)	1.84 (.99)	5.85 (8.79)	141.4 (21.6)	117.3 (15.9)	126.4 (17.0)	122.3 (15.3)	126.4 (15.5)	68.6 (10.4)	44.2 (9.3)	57.6 (14.7)	56.3 (16.2)	64.0 (18.0)	16	0
76 34)	5.65 (7.14)	3.93 (7.6)	1.43 (.75)	1.42 (.69)	1.11 (1.47)	8.7 (11.27)	125.0 (21.3)	117.2 (21.5)	128.0 (28.3)	125.8 (31.9)	130.0 (32.6)	69.4 (25.1)	52.1 (20.3)	76.1 (21.5)	78.3 (20.0)	76.7 (16.9)	10	0
64 41)	7.06 (8.24)	1.17 (.45)	1.43 (.94)	.74 (.54)	.34 (.29)	2.32 (3.10)	101.2 (14.6)	112.0 (13.7)	127.9 (15.7)	127.3 (28.4)	137.8 (31.2)	51.0 (8.6)	42.5 (8.2)	74.0 (15.2)	79.7 (14.0)	79.1 (16.5)	19	0
27 79)	8.81 (10.16)	1.81 (4.75)	.85 (.54)	.72 (.53)	.42 (.38)	2.28 (2.62)	119.9 (13.6)	118.3 (11.6)	121.0 (24.9)	115.1 (15.3)	117.3 (15.7)	71.7 (7.6)	43.1 (7.7)	66.9 (17.2)	68.6 (11.9)	91.4 (15.0)	26	0
12 02)	2.28 (2.06)	1.24 (.84)	1.43 (.79)	1.70 (.87)	.63 (.37)	1.62 (.99)	132.0 (20.4)	107.7 (18.6)	109.6 (18.6)	105.6 (18.3)	111.1 (19.0)	80.0 (19.2)	46.4 (10.6)	61.3 (13.2)	65.3 (15.1)	64.9 (15.8)	20	0
20	2.13	.63	.47	.60	.23	.53	265.3	265.7	279.3	263.3	268.0	120.3	124.7	197.7	161.0	180.0	3	0
50	1.45	.45	.40	.33	.47	.43	134.3	160.2	228.5	226.8	227.5	110.7	61.0	107.0	115.5	144.5	6	0
91	.90	2.1	2.5	1.9	1.9	1.85	157.0	150.0	206.0	212.0	216.0	590.0	87.0	138.0	147.0	150.0	1	0

Figure 3-4- I

				IB_2					2 Volt Diode			Number Units After Age	Failure Report Failures Determined in Nth Week			Failure Rate %/1000 Hours
	6	A/C	A/A	2	4	6	A/C	A/A	2	4	6		2	4	6	
)	.67 (.99)	154.2 (29.4)	166.8 (37.7)	204.1 (30.7)	190.0 (29.4)	198.0 (32.5)	102.3 (25.4)	77.0 (15.2)	75.5 (16.7)	79.4 (17.3)	83.4 (18.0)	15	0	0	0	6.7
)	.52 (.40)	190.0 (27.3)	194.3 (43.2)	247.0 (44.1)	237.8 (35.4)	230.4 (38.3)	103.0 (24.2)	74.2 (19.4)	72.3 (12.6)	77.0 (13.5)	73.3 (13.4)	11	0	0	0	9.0
)	.83 (.90)	138.7 (20.8)	144.8 (24.6)	185.4 (33.4)	172.2 (24.1)	178.0 (23.7)	83.1 (14.9)	45.1 (7.5)	44.0 (7.4)	54.8 (20.4)	50.4 (18.6)	16	0	0	0	6.2
)	.33 (.30)	131.2 (28.0)	169.0 (39.5)	187.9 (40.0)	177.6 (37.4)	182.0 (38.2)	72.9 (9.6)	58.2 (19.2)	47.9 (17.2)	50.1 (14.1)	45.5 (11.2)	8	0	0	0	N/A
)	.70 (.96)	154.8 (21.0)	188.4 (20.6)	204.8 (25.0)	209.1 (26.1)	195.5 (24.0)	125.3 (88.7)	88.9 (15.0)	87.6 (14.2)	98.2 (16.2)	102.0 (28.9)	19	0	0	0	5.2
)	.90 (.89)	179.3 (25.3)	196.4 (22.2)	205.4 (28.1)	209.1 (28.3)	195.7 (21.5)	105.2 (80.0)	83.5 (16.5)	86.2 (17.1)	96.4 (19.1)	97.9 (18.6)	19	0	0	2 ICBO	15.8
)	.55 (.73)	156.5 (19.8)	184.0 (27.7)	207.9 (25.4)	206.9 (25.2)	182.1 (28.9)	101.0 (75.8)	90.6 (29.4)	84.5 (21.7)	85.8 (29.0)	95.5 (37.3)	19	0	0	0	5.2
)	1.25 (1.84)	172.9 (21.8)	190.7 (24.4)	212.0 (28.0)	211.0 (25.9)	196.4 (25.5)	88.9 (12.4)	94.2 (15.4)	90.6 (13.8)	100.0 (15.4)	108.5 (18.0)	21	0	0	2 ICBO	14.3
)	.69 (.61)	117.5 (23.6)	109.0 (18.5)	104.8 (17.9)	111.0 (19.2)	105.0 (16.8)	65.4 (8.4)	41.2 (21.6)	49.7 (21.5)	60.9 (19.7)	57.0 (19.6)	27	0	0	1 ICBO	7.4
)	5.85 (8.79)	141.4 (21.6)	117.3 (15.9)	126.4 (17.0)	122.3 (15.3)	126.4 (15.5)	68.6 (10.4)	44.2 (9.3)	57.6 (14.7)	56.3 (16.2)	64.0 (18.0)	16	0	1 ICBO	3 ICBO	32.7
)	8.7 (11.27)	125.0 (21.3)	117.2 (21.5)	128.0 (28.3)	125.8 (31.9)	130.0 (32.6)	69.4 (25.1)	52.1 (20.3)	76.1 (21.5)	78.3 (20.0)	76.7 (16.9)	10	0	0	3 ICBO	40 0
)	2.32 (3.10)	101.2 (14.6)	112.0 (13.7)	127.9 (15.7)	127.3 (28.4)	137.8 (31.2)	51.0 (8.6)	42.5 (8.2)	74.0 (15.2)	79.7 (14.0)	79.1 (16.5)	19	0	0	5 ICBO	39.6
)	2.28 (2.62)	119.9 (13.6)	118.3 (11.6)	121.0 (24.9)	115.1 (15.3)	117.3 (15.7)	71.7 (7.6)	43.1 (7.7)	66.9 (17.2)	68.6 (11.9)	91.4 (15.0)	26	0	0	4 ICBO	19.2
)	1.62 (.99)	132.0 (20.4)	107.7 (18.6)	109.6 (18.6)	105.6 (18.3)	111.1 (19.0)	80.0 (19.2)	46.4 (10.6)	61.3 (13.2)	65.3 (15.1)	64.9 (15.8)	20	0	0	0	5.0
)	.53	265.3	265.7	279.3	263.3	268.0	120.3	124.7	197.7	161.0	180.0	3	0	0	0	N/A
7	.43	134.3	160.2	228.5	226.8	227.5	110.7	61.0	107.0	115.5	144.5	6	0	0	0	N/A
	1.85	157.0	150.0	206.0	212.0	216.0	590.0	87.0	138.0	147.0	150.0	1	0	0		N/A

Figure 3-4- I

Experiment No.	Experiment Description	After Cap	After Age	ICBO 2	ICBO 4	ICBO 6	IEBO A/C	IEBO A/A	IEBO 2	IEBO 4	IEBO 6	
2-18	Chelating agent in Oxidizer	2.0	>25.0				.6	>25.0				
2-19	50 Microns- 2 Hrs	1.57 (.97)	2.36 (.93)	2.61 (1.56)	2.67 (1.70)	2.05 (1.48)	1.30 (.98)	1.0 (.95)	1.03 (.90)	1.02 (.88)	.97 (.84)	108 (14
2-20	90 Microns - 2 Hrs	2.18	1.83	4.03	3.6	2.95	.20	.30	.38	.45	.47	122
2-21-a	Chemically Oxidized Rewash in Solvent "E"	.89 (.84)	1.59 (1.14)	2.31 (1.62)	2.16 (1.57)	2.60 (2.18)	.59 (.55)	.71 (.59)	.91 (.94)	1.04 (1.41)	1.36 (1.59)	86 (12
2-21 b and c*	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Sa
2-22	Gold Plated Caps	1.54 (1.04)	1.77 (1.02)	4.62 (4.39)	7.43 (7.98)	3.71 (2.93)	.54 (.50)	.61 (.49)	.71 (.50)	.81 (.58)	.71 (.53)	89 (17
2-23	Boiling Solvent "E"	1.78 (1.15)	1.74 (.93)	.83 (.70)	1.81 (1.40)	2.00 (3.02)	.62 (.56)	.59 (.43)	.73 (.52)	.75 (.78)	.78 (.77)	9 (1
2-24	Boiling Solvent "B"	1.94 (.97)	1.92 (.93)	1.74 (.91)	1.87 (1.82)	1.63 (.86)	.88 (.87)	1.02 (.85)	1.02 (.83)	1.03 (.88)	1.04 (.75)	9 (1
2-25	Boiling Solvent "B"	1.46 (.90)	1.43 (.94)	1.30 (.94)	2.12 (3.90)	1.76 (1.85)	.85 (.88)	.78 (.79)	.84 (.92)	1.25 (1.59)	2.33 (3.10)	9 (1
2-26	Boiling Solvent "D"	2.17 (1.29)	2.15 (1.14)	2.10 (1.37)	2.23 (1.54)	3.00 (4.29)	.41 (.38)	.38 (.26)	.41 (.29)	.45 (.33)	.59 (.23)	12 (1
2-27	10^{-6} for 4 Hours at 170°C	2.08 (1.59)	2.11 (1.22)	2.93 (2.71)	2.82 (2.75)		.31 (.22)	.61 (.58)	.68 (.61)	.65 (.70)		13 (3
2-28	10^{-4} for 4 Hours at 90°C	1.05 (.82)	2.55 (1.15)	4.20 (3.60)	3.19 (2.22)		.38 (.32)	.59 (.40)	.83 (.59)	1.02 (.67)		7 (1
2-29	$5X10^{-6}$ for 4 Hours at 135°C	1.94 (1.62)	2.10 (1.00)	2.85 (2.39)	16.4 (55.73)		.39 (.28)	.40 (.25)	.77 (.69)	1.00 (1.42)		9 (1
2-30	Boiling Solvent "D" Vacuum Bake at $5X10^{-6}$	12.1 (9.99)	2.14 (1.30)	3.22 (4.19)	4.12 (5.04)		1.34 (.97)	.75 (.74)	.89 (.80)	.93 (.62)		11 (2
2-31	Pre-Cap Bake-1 Hour at 118°C	.73 (.66)	1.22 (1.27)	Accelerated Stress 175°C		7.00 (8.03)	.46 (.51)	.61 (.61)	Accelerated Stress 175°C		.91 (1.29)	11 (2

*Transistors subjected to 168 Hours Modulation Life Testing prior to storage.
**Transistors subjected to 500 Hours Operating Life Testing prior to storage

Figure 3-4- I

				IEBO					IB_2					2 VOLT DIODE			Number Units After Age	Fa in 2
4	6	N/C	N/A	2	4	6	N/C	N/A	2	4	6	N/C	N/A	2	4	6		
		.6	>25.0									76.0					0	
2.67 (1.70)	2.05 (1.48)	1.30 (.98)	1.0 (.95)	1.03 (.90)	1.02 (.88)	.97 (.84)	108.2 (14.2)	159.8 (13.9)	194.7 (22.8)	208.5 (19.3)	209.2 (13.5)	62.1 (18.2)	91.9 (18.1)	98.7 (17.0)	105.9 (17.4)	209.2 (57.2)	12	0
3.6	2.95	.20	.30	.38	.45	.47	122.2	155.5	178.8	190.3	195.2	56.3	82.0	86.5	92.3	186.2	4	0
2.16 (1.57)	2.60 (2.18)	.59 (.55)	.71 (.59)	.91 (.94)	1.04 (1.41)	1.36 (1.59)	86.8 (12.5)	99.0 (16.9)	111.9 (21.5)	114.0 (23.0)	117.1 (23.4)	60.0 (9.1)	53.2 (9.1)	85.6 (21.9)	83.6 (22.0)	83.1 (34.0)	34	0
Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	60	
7.43 (7.98)	3.71 (2.93)	.54 (.50)	.61 (.49)	.71 (.50)	.81 (.58)	.71 (.53)	89.3 (17.3)	149.3 (24.7)	161.6 (26.4)	168.7 (28.0)	161.7 (28.5)	67.5 (11.4)	77.3 (30.2)	101.1 (24.7)	102.9 (37.6)	134.5 (54.2)	49	2
1.81 (1.40)	2.00 (3.02)	.62 (.56)	.59 (.43)	.73 (.52)	.75 (.78)	.78 (.77)	93.2 (13.1)	163.4 (16.2)	179.1 (17.5)	176.0 (17.1)	164.7 (19.4)	65.8 (9.2)	71.3 (12.8)	133.7 (20.7)	89.8 (21.3)	120.9 (31.4)	29	0
1.87 (1.82)	1.63 (.86)	.88 (.87)	1.02 (.85)	1.02 (.83)	1.03 (.88)	1.04 (.75)	90.1 (11.7)	164.1 (17.9)	189.6 (22.9)	183.1 (21.8)	176.7 (20.1)	55.6 (7.8)	94.8 (15.6)	117.7 (19.4)	114.8 (26.8)	146.1 (33.5)	59	0
2.12 (3.90)	1.76 (1.85)	.85 (.88)	.78 (.79)	.84 (.92)	1.25 (1.59)	2.33 (3.10)	91.2 (10.7)	143.5 (17.3)	167.0 (19.7)	166.2 (19.8)	164.4 (22.2)	83.4 (48.8)	85.1 (10.7)	79.1 (19.7)	114.0 (16.6)	149.5 (32.5)	24	0
2.23 (1.54)	3.00 (4.29)	.41 (.38)	.38 (.26)	.41 (.29)	.45 (.33)	.59 (.23)	121.8 (19.8)	157.3 (19.2)	173.0 (18.8)	173.5 (21.3)	175.5 (22.5)	86.2 (13.5)	117.0 (14.6)	134.1 (18.8)	150.3 (27.2)	220.4 (129.7)	35	0
2.82 (2.75)		.31 (.22)	.61 (.58)	.68 (.61)	.65 (.70)		133.3 (30.6)	143.7 (41.4)	157.8 (20.8)	192.2 (39.9)		101.2 (20.3)	120.2 (22.3)	157.8 (20.8)	130.0 (17.4)		18	1
3.19 (2.22)		.38 (.32)	.59 (.40)	.83 (.59)	1.02 (.67)		74.4 (12.4)	124.3 (18.2)	163.3 (26.5)	170.5 (25.8)		64.0 (10.4)	110.6 (15.8)	132.6 (22.8)	120.3 (19.0)		17	1
16.4 (55.73)		.39 (.28)	.40 (.25)	.77 (.69)	1.00 (1.42)		96.5 (16.2)	146.6 (20.5)	197.8 (27.1)	206.5 (23.9)		76.1 (24.0)	109.9 (21.0)	141.4 (27.6)	1661.8 (5564.6)		14	0
4.12 (5.04)		1.34 (.97)	.75 (.74)	.89 (.80)	.93 (.62)		111.4 (20.9)	116.3 (18.5	119.0 (24.3)	108.9 (23.8)		53.3 (7.3)	57.3 (7.6)	60.0 (14.0)	47.5 (9.0)		12	0
ed 5°C	7.00 (8.03)	.46 (.51)	.61 (.61)	Accelerated. Stress 175°C		.91 (1.29)	110.9 (24.3)	158.3 (23.1)	Accelerated Stress		176.6 (29.8)	102.1 (24.7)	139.5 (32.3)			255.7 (196.5)	109	

e Testing prior to storage.
Testing prior to storage

Figure 3-4- I

			IB_2					2 VOLT DIODE			Number Units After Age	Failure Report Failures Determined in Nth Week			Failure Rate %/1000 Hours
6	N/C	N/A	2	4	6	N/C	N/A	2	4	6		2	4	6	
						76.0					0				
.97 (.84)	108.2 (14.2)	159.8 (13.9)	194.7 (22.8)	208.5 (19.3)	209.2 (13.5)	62.1 (18.2)	91.9 (18.1)	98.7 (17.0)	105.9 (17.4)	209.2 (57.2)	12	0	0	0	8.3
.47	122.2	155.5	178.8	190.3	195.2	56.3	82.0	86.5	92.3	186.2	4	0	0	0	N/A
1.36 (1.59)	86.8 (12.5)	99.0 (16.9)	111.9 (21.5)	114.0 (23.0)	117.1 (23.4)	60.0 (9.1)	53.? (9.1)	85.6 (21.9)	83.6 (22.0)	83.1 (34.0)	34	0	0	0	2.9
Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	60			3 ICBO 1 Vf1	
.71 (.53)	89.3 (17.3)	149.3 (24.7)	161.6 (26.4)	168.7 (28.0)	161.7 (28.5)	67.5 (11.4)	77.3 (30.2)	101.1 (24.7)	102.9 (37.6)	134.5 (54.2)	49	2 ICBO	11 ICBO	0	31.8
.78 (.77)	93.2 (13.1)	163.4 (16.2)	179.1 (17.5)	176.0 (17.1)	164.7 (19.4)	65.8 (9.2)	71.3 (12.8)	133.7 (20.7)	89.8 (21.3)	120.9 (31.4)	29	0	0	1 ICBO	6.9
1.04 (.75)	90.1 (11.7)	164.1 (17.9)	189.6 (22.9)	183.1 (21.8)	176.7 (20.1)	55.6 (7.8)	94.8 (15.6)	117.7 (19.4)	114.8 (26.8)	146.1 (33.5)	59	0	1 ICBO	0	3.4
2.33 (3.10)	91.2 (10.7)	143.5 (17.3)	167.0 (19.7)	166.2 (19.8)	164.4 (22.2)	83.4 (48.8)	85.1 (10.7)	79.1 (19.7)	114.0 (16.6)	149.5 (32.5)	24	0	1 ICBO	0	8.6
.59 (.23)	121.8 (19.8)	157.3 (19.2)	173.0 (18.8)	173.5 (21.3)	175.5 (22.5)	86.2 (13.5)	117.0 (14.6)	134.1 (18.8)	150.3 (27.2)	220.4 (129.7)	35	0	I ICBO	1 ICBO	8.6
	133.3 (30.6)	143.7 (41.4)	157.8 (20.8)	192.2 (39.9)		101.2 (20.3)	120.2 (22.3)	157.8 (20.8)	130.0 (17.4)		18	1 ICBO	1 ICBO		
	74.4 (12.4)	124.3 (18.2)	163.3 (26.5)	170.5 (25.8)		64.0 (10.4)	110.6 (15.8)	132.6 (22.8)	120.3 (19.0)		17	1 ICBO	0		
	96.5 (16.2)	146.6 (20.5)	197.8 (27.1)	206.5 (23.9)		76.1 (24.0)	109.9 (21.0)	141.4 (27.6)	1661.8 (5564.6)		14	0	2 ICBO		
	111.4 (20.9)	116.3 (18.5	119.0 24.3)	108.9 (23.8)		53.3 (7.3)	57.3 (7.6)	60.0 (14.0)	47.5 (9.0)		12	0	1 ICBO		
.91 (1.29)	110.9 (24.3)	158.3 (23.1)	Accelerated Stress		176.6 (29.8)	102.1 (24.7)	139.5 (32.3)			255.7 (196.5)	109			33	31.2

gure 3-4- I

Experiment No.	Experiment Description	After Cap	After Age	ICBO 2	4	6	A/C	IEBO A/A	2	4	6	A/C
2-32	Production Group		1.11 (0.99)	Accelerated Stress 175°C		14.66 (9.59)		.69 (.66)	Accelerated Stress 175°C		1.99 (3.71)	
2-33	Pre-Cap Bake 1 Hour at 143°C		1.35 (1.16)	Accelerated Stress 175°C		17.49 (8.48)		.73 (1.26)	Accelerated Stress 175°C		2.72 (4.68)	109.3
2-34	Production Group		1.48 (1.22)	Accelerated Stress 175°C		17.86 (9.63)		.93 (.68)	Accelerated Stress 175°C		4.98 (6.36)	
2-35	Pre-Cap Bake 1 Hour at 135°C		1.53 (1.04)					.85 (.80)	Accelerated Stress 156°C			
2-36	Pre-Cap Bake 1 Hour at 135°C											
2-37	Production Group											

Fig

			IEBO						IB2				2 Volt Diode				Number Units After Age	Fail in 1
4	6	N/C	N/A	2	4	6	N/C	N/A	2	4	6	N/C	N/A	2	4	6		
ed 75°C	14.66 (9.59)		.69 (.66)	Accelerated Stress 175°C		1.99 (3.71)		166.3 (24.7)			189.8 (34.2)		147.8 (72.1)			297.0 (163.2)	62	
ed 75°C	17.49 (8.48)		.73 (1.26)	Accelerated Stress 175°C		2.72 (4.68)	109.3	152.2 (23.7)			184.7 (34.4)		147.4 (30.3)			328.0 (208.9)	195	
ed 75°C	17.86 (9.63)		.93 (.68)	Accelerated Stress 175°C		4.98 (6.36)		149.1 (22.0)			178.2 (34.1)		151.4 (33.9)			264.5 (78.3)	81	
			.85 (.80)	Accelerated Stress 156°C				181.4 (24.1)					220.3 (87.8)				67	5 I
																	120	
																	89	

Figure 3-4-2

IB_2							2 Volt Diode				Failure Report			
6	A/C	A/A	2	4	6	A/C	A/A	2	4	6	Number Units After Age	Failures Determined in Nth Week 2	4	6	Failure Rate % 1000 Hours
1.99 (3.71)		166.3 (24.7)			189.8 (34.2)		147.8 (72.1)			297.0 (163.2)	62			40	66.1
2.72 (4.68)	109.3	152.2 (23.7)			184.7 (34.4)		147.4 (30.3)			328.0 (208.9)	195			131	66.7
4.98 (6.36)		149.1 (22.0)			178.2 (34.1)		151.4 (33.9)			264.5 (78.3)	81			63	79.0
		181.4 (24.1)					220.3 (87.8)				67	5 ICBO	5 ICBO		
											120				
											89				

Figure 3-4-1

ADDITIONAL LIFE TEST DATA

Experiment No.	Experiment Description	Test	Phase	Number Tested	I_{CBO} Shift (Av) Ma	I_{EBO} Shift(Av) Ma
2-5	3/4 Hour Air Bake	6 Weeks Room Temp.	After 1000 hrs at 135°C.	19	0.08	0.04
2-6	1 Hour Air Bake	Operating Life 250 Hours at 70°C.	After 1000 hrs at 135°C and 6 wks stor. at RT.	17	0.10	-0.05
2-7	1 Hour Bake-Cap Hot	6 Weeks Room Temp.		19	-0.02	0.03
2-8	Boiling Solvent "A"	Operating Life 250 Hours at 70°C.		19	.00	-0.10
2-9	Chemically Oxidized 1 Hour Bake	6 Weeks Room Temp.		26	0.17	0.00
2-10	Boiling Solvent "B"	Operating Life 250 Hrs at 70°.	After 1000 hrs at 135°C.	11	1.43	3.40
2-11	Chemical Oxidized Mod. Process	Operating Life 250 Hrs at 70°.	After 1000 hrs at 135°C.	7	-.25	-.25
2-12	Boiling Solvent "C"	Operating Life 250 Hrs at 70°.	After 1000 hrs at 135°C	14	0.25	1.14
2-13	Boiling Solvent "D"	Operating Life 250 Hrs at 70°.	After 1000 hrs at 135°C	21	1.38	0.23
2-14	Chemically Oxidized Boiling Solvent "B"	Operating Life 250 Hrs at 70°.	After 1000 hrs at 135°C	21	2.50	0.15
2-15	10^{-6} Vacuum Bake, 2 Hrs. 135°C	Operating Life 250 Hrs at 70°	After 1000 hrs at 135°C	3	-0.26	-0.10
2-21 a	Chemically Oxidized Rewash in Solvent "E"	100 Hrs. Storage at 176°C+	After 1000 hrs at 135°C	34	Not available	
2-21 b*	"	168 Hrs-Mod. Life	After Age	30	0.33	0.12
2-21 c*	"	500 Hours Operating Life at 70°C	After Age	30	0.66	0.25

*Note- After completion of testing, units were placed on the 135°C Storage Test.

ADDITIONAL LIFE TEST DATA

›eriment ›cription	Test	Phase	Number Tested	I_{CBO} Shift (Av) Ma	I_{EBO} Shift(Av) Ma	I_B Shift Ma	No. of Failures
; Hour Air Bake	6 Weeks Room Temp.	After 1000 hrs at 135°C.	19	0.08	0.04	1.5	0
Hour Air Bake	Operating Life 250 Hours at 70°C.	After 1000 hrs at 135°C and 6 wks stor. at RT.	17	0.10	-0.05	-2.0	0
Hour Bake-Cap Hot	6 Weeks Room Temp.		19	-0.02	0.03	-16.1	0
lling Solvent "A"	Operating Life 250 Hours at 70°C.		19	.00	-0.10	-5.5	1 IEBO
emically Oxidized Hour Bake	6 Weeks Room Temp.		26	0.17	0.00	2.0	0
lling Solvent "B"	Operating Life 250 Hrs at 70°.	After 1000 hrs at 135°C.	11	1.43	3.40	6.1	1 ICBO 1 IEBO
emical Oxidized d. Process	Operating Life 250 Hrs at 70°.	After 1000 hrs at 135°C.	7	-.25	-.25	-6.0	0
lling Solvent "C"	Operating Life 250 Hrs at 70°.	After 1000 hrs at 135°C	14	0.25	1.14	-22.5	0
lling Solvent "D"	Operating Life 250 Hrs at 70°.	After 1000 hrs at 135°C	21	1.38	0.23	-22.0	2 ICBO
emically Oxidized lling Solvent "B"	Operating Life 250 Hrs at 70°.	After 1000 hrs at 135°C	21	2.50	0.15	-2.3	1 ICBO
-6 Vacuum Bake, Hrs. 135°C	Operating Life 250 Hrs at 70°	After 1000 hrs at 135°C	3	-0.26	-0.10	-5.0	0
emically Oxidized wash in Solvent "E"	100 Hrs. Storage at 176°C+	After 1000 hrs at 135°C	34	Not available			3 ICBO
"	168 Hrs-Mod. Life	After Age	30	0.33	0.12	-11.7	0
"	500 Hours Operating Life at 70°C	After Age	30	0.66	0.25	-3.7	0

:e- After completion of testing, units were placed on the 135°C Storage Test.

2

temperature was lower.

2-29. Vacuum bake at 5×10^{-6} mm Hg at 135°C for 4 hours. This experiment is a repeat of 2-17 for additional failure rate data.

2-30. Boiling Solvent "D" followed by a vacuum bake at 5×10^{-6} mm Hg at 135°C for 4 hours. After standard production etching and washing, devices were transported in deionized water to the pilot facilities. After subjection to boiling Solvent "D" for 45 minutes, the devices were washed and vacuum baked.

2-31. Precap bake - 1 hour at 118°C. This experiment is another group processed per 2-6.

2-32. Control Group. These transistors are production units processed with 2-31.

2-33. One hour bake at 143°C max. These units were processed per 2-6.

2-34. Control Group. These are current production units processed with 2-33.

2-35. One hour precap bake at 135°C. These units were processed per 2-6.

2-36. One hour precap bake at 135°C. Refer to 2-6.

2-37. Control Group. Devices processed with 2-36.

The following experiments are concerned with the use of desiccants.

3-8. Vacuum bake at 10^{-4} mm Hg with Vycor desiccant for 4 hours. Unactivated Vycor preforms were placed in 2N1358 basic units and vacuum baked in the pilot line facility. This experiment was in general performed per 3-6.

3-9. Boiling Solvent "O" vacuum baked and encapsulated with barium oxide. Same as 2-30 except barium oxide was placed in the transistors just prior to encapsulation.

3-10. Cabot's Cab-O-Sil M-5 (Silica - 200 sq. meters per gram) was compressed (30:1 ratio) into discs. After an air bake at 350° for 44 hours these parts were placed in 2N1358 basic units just prior to encapsulation.

3-11. Cab-O-Sil (refer 3-10), Cabot's Alon C (Alumina-50 sq. meters per gram) and Minnesota Mining & Manufacturing Company's fluorocarbon FC43. Four parts by volume of Cab-O-Sil were mixed with one part of alumina. This mix was air baked 44 hours at 325°C. The container was sealed in the oven and transported into the encapsulation chamber. Three parts of FC43 by volume were added to make a paste. This was placed inside the transistor cap just prior to encapsulation.

3-12. Standard Production units encapsulated with Vycor. This is a repeat of 3-3; but instead of activation by air baking, the preforms were vacuum baked at 6×10^{-6} mm Hg for 20 hours. The parts were sealed in a container, placed

Experiment No.	Experiment Description	After Cap	After Age	ICBO 2	ICBO 4	ICBO 6	ICBO A/C	IEBO A/A	IEBO 2	IEBO 4	IEBO 6	IEBO A/C
3-1	1 Hour Bake plus Vycor	1.9 (1.2)	2.0 (.9)	1.68 (.85)	1.87 (.83)	1.69 (.78)	1.0 (.7)	1.0 (.77)	1.64 (1.5)	.93 (.66)	.79 (.59)	156.7 (27.1)
3-2	Chemically Oxidized plus Vycor	1.45 (.9)	1.90 (1.6)	1.90 (1.13)	2.33 (1.34)	2.25 (1.29)	.8 (.88)	.94 (.89)	.99 (.85)	1.26 (1.17)	1.31 (.95)	117.9 (24.0)
3-3	Regular production plus Vycor	1.45 (.9)	1.89 (1.1)	1.67 (1.04)	1.54 (.86)	2.10 (1.78)	1.1 (1.4)	.9 (.9)	.98 (1.17)	.96 (1.14)	1.29 (1.90)	94.5 (13.3)
3-4	Regular production plus 5A	1.56 (.87)	1.42 (.89)	2.54 (4.26)	1.84 (1.17)	1.98 (1.2)	.87 (.64)	.89 (.73)	.83 (.66)	.75 (.62)	.97 (.70)	189.0 (35.1)
3-5	10^{-6} Bake 1 Hour with Vycor	1.51	3.25	5.3	2.73	3.07	.30	1.78	.22	.25	.22	236.5
3-6	Baked W/Vycor 1 Hr. at 135°C	3.48	2.75	1.53	1.06	1.43	.21	2.23	.31	.27	.27	148.4
3-7	Barium Oxide	1.54 (.89)	1.73 (.89)	4.04 (7.30)	3.93 (4.52)	19.33 (24.4)	.52 (.07)	.73 (.76)	.89 (.81)	.87 (.90)	1.11 (.93)	103.1 (15.5)
3-8	10^{-4} Bake with Vycor for 4 hours	1.46 (1.68)	1.41 (.88)	1.72 (1.52)	2.60 (2.81)		.34 (.37)	.51 (.50)	1.19 (.87)	1.48 (.91)		86.5 (15.5)
3-9	Boiling Solvent "D" Vacuum Bake plus Barium Oxide	14.87 (13.0)	2.49 (1.24)	13.26 (30.9)	39.11 (81.74)		1.96 (1.25)	1.05 (.68)	1.94 (1.05)	3.81 (5.71)		136.1 (15.7)
3-10	Cab-O-Sil	1.07 (.92)	1.15 (1.12)	1.47 (1.82)	1.50 (1.55)		.34 (.33)	.45 (.29)	.42 (.31)	1.14 (2.00)		83.5 (14.8)
3-11	Cab-O-Sil Alumina FC43	2.73 (1.09)	2.18 (.91)	6.27 (5.03)	7.77 (6.25)		1.34 (1.30)	1.03 (1.20)	1.50 (1.42)	1.86 (1.72)		77.2 (9.0)
3-12	Regular Production plus Vycor	1.25 (1.29)	1.08 (.98)	1.90 (1.37)	1.35 (1.29)		.57 (.76)	.64 (.74)	.54 (.52)	.54 (.69)		97.3 (17.3)
3-13	Germanium Oxide	2.38 (1.58)	.66 (.41)				.66 (.42)	.66 (.61)				50.2 (3.4)

NOTE: ( ) - Standard deviation of parameter.

Figure 3-4- J

		IEBO						I_{B_2}				2 Volt Diode					Number Units After Age	Failures in Nth W
4	6	A/C	A/A	2	4	6	A/C	A/A	2	4	6	A/C	A/A	2	4	6		2
37 33)	1.69 (.78)	1.0 (.7)	1.0 (.77)	1.64 (1.5)	.93 (.66)	.79 (.59)	156.7 (27.1)	189.1 (31.7)	174.3 (43.8)	188.4 (30.8)	185.7 (30.6)	97.6. (19.7)	92.1 (13.8)	146.7	67.0 (15.4)	85.4 (15.3)	22	0
33 34)	2.25 (1.29)	.8 (.88)	.94 (.89)	.99 (.85)	1.26 (1.17)	1.31 (.95)	117.9 (24.0)	97.2 (16.6)	101.2 (24.7)	104.4 (26.6)	106.5 (27.0)	77.0 (11.0)	49.4 (7.9)	65.0 (13.6)	75.2 (17.7)	81.3 (21.7)	20	0
54 36)	2.10 (1.78)	1.1 (1.4)	.9 (.9)	.98 (1.17)	.96 (1.14)	1.29 (1.90)	94.5 (13.3)	191.2 (25.7)	188.7 (31.4)	187.9 (26.0)	199.4 (30.0)	66.5 (28.8)	82.2 (30.9)	126.6 (26.8)	86.0 (19.0)	75.7 (13.5)	26	0
84 17)	1.98 (1.2)	.87 (.64)	.89 (.73)	.83 (.66)	.75 (.62)	.97 (.70)	189.0 (35.1)	195.4 (21.4)	186.8 34.0	180.0 31.9	174.2 (30.0)	111.7 (23.9)	53.6 (12.7)	84.3 (18.3)	84.0 (19.3)	68.3 (14.7)	24	I ICBO
73	3.07	.30	1.78	.22	.25	.22	236.5	229.0	226.0	233.3	233.3	179.5	161.5	147.5	123.3	97.3	4	I ICBO
06	1.43	.21	2.23	.31	.27	.27	148.4	213.7	213.9	208.8	204.3	88.0	125.5	107.3	97.3	77.5	4	0
93 52)	19.33 (24.4)	.52 (.07)	.73 (.76)	.89 (.81)	.87 (.90)	1.11 (.93)	103.1 (15.5)	251.1 (15.1)	228.7 (45.6)	239.7 (45.4)	207.2 (43.9)	61.6 (8.6)	117.1 (15.1)	129.4 (37.0)	99.2 (38.3)	77.0 (36.1)	29	2
60 81)		.34 (.37)	.51 (.50)	1.19 (.87)	1.48 (.91)		86.5 (15.5)	125.9 (16.5)	150.8 (24.4)	132.4 (23.1)		75.0 (3.4)	136.8 (17.6)	121.4 (13.7)	94.4 (25.6)		8	0
11 74)		1.96 (1.25)	1.05 (.68)	1.94 (1.05)	3.81 (5.71)		136.1 (15.7)	196.2 (23.2)	185.0 (24.5)	175.5 (24.2)		84.6 (13.8)	135.2 (24.3)	87.0 (10.8)	61.6 (14.6)		14	2 ICBO
50 55)		.34 (.33)	.45 (.29)	.42 (.31)	1.14 (2.00)		83.5 (14.8)	188.2 (25.9)	199.6 (15.7)	184.5 (17.7)		63.1 (21.5)	128.4 (17.0)	111.8 (16.8)	85.9 (9.9)		11	0
77 25)		1.34 (1.30)	1.03 (1.20)	1.50 (1.42)	1.86 (1.72)		77.2 (9.0)	136.8 (15.3)	301.9 (182.4)	271.9 (150.2)		58.2 (23.2)	125.8 (22.1)	175.8 (46.6)	143.8 (66.7)		12	2 ICBO
35 29)		.57 (.76)	.64 (.74)	.54 (.52)	.54 (.69)		97.3 (17.3)	203.0 (29.4)	230.1 (34.0)	233.0 (33.2)		66.0 (16.1)	140.7 (20.5)	149.4 (21.1)	134.3 (21.8)		84	0
		.66 (.42)	.66 (.61)				50.2 (3.4)	103.2 (12.7)				66.5 (9.1)	101.0 (11.1)				6	0

Figure 3-4- J

				BB_2					2 Volt Diode			Number Units After Age	Failure Report: Failures Determined in Nth Week			Failure Rate %/1000 Hours
	6	A/C	A/A	2	4	6	A/C	A/A	2	4	6		2	4	6	
93 66)	.79 (.59)	156.7 (27.1)	189.1 (31.7)	174.3 (43.8)	188.4 (30.8)	185.7 (30.6)	97.6. (19.7)	92.1 (13.8)	146.7	67.0 (15.4)	85.4 (15.3)	22	0	0	0	4.5
26 17)	1.31 (.95)	117.9 (24.0)	97.2 (16.6)	101.2 (24.7)	104.4 (26.6)	106.5 (27.0)	77.0 (11.0)	49.4 (7.9)	65.0 (13.6)	75.2 (17.7)	81.3 (21.7)	20	0	0	0	5.0
96 14)	1.29 (1.90)	94.5 (13.3)	191.2 (25.7)	188.7 (31.4)	187.9 (26.0)	199.4 (30.0)	66.5 (28.8)	82.2 (30.9)	126.6 (26.8)	86.0 (19.0)	75.7 (13.5)	26	0	0	0	3.5
75 62)	.97 (.70)	189.0 (35.1)	195.4 (21.4)	186.8 34.0	180.0 31.9	174.2 (30.0)	111.7 23.9)	53.6 (12.7)	84.3 (18.3)	84.0 (19.3)	68.3 (14.7)	24	I ICBO	0	0	8.6
25	.22	236.5	229.0	226.0	233.3	233.3	179.5	161.5	147.5	123.3	97.3	4	I ICBO	0	0	N/A
27	.27	148.4	213.7	213.9	208.8	204.3	88.0	125.5	107.3	97.3	77.5	4	0	0	0	N/A
87 90)	1.11 (.93)	103.1 (15.5)	251.1 (15.1)	228.7 (45.6)	239.7 (45.4)	207.2 (43.9)	61.6 (8.6)	117.1 (15.1)	129.4 (37.0)	99.2 (38.3)	77.0 (36.1)	29	2	0	8	40
.48 .91)		86.5 (15.5)	125.9 (16.5)	150.8 (24.4)	132.4 (23.1)		75.0 (3.4)	136.8 (17.6)	121.4 (13.7)	94.4 (25.6)		8	0	0		
.81 .71)		136.1 (15.7)	196.2 (23.2)	185.0 (24.5)	175.5 (24.2)		84.6 (13.8)	135.2 (24.3)	87.0 (10.8)	61.6 (14.6)		14	2 ICBO	4 ICBO		
.14 .00)		83.5 (14.8)	188.2 (25.9)	199.6 (15.7)	184.5 (17.7)		63.1 (21.5)	128.4 (17.0)	111.8 (16.8)	85.9 (9.9)		11	0	1 Vfl		
.86 .72)		77.2 (9.0)	136.8 (15.3)	301.9 (182.4)	271.9 (150.2)		58.2 (23.2)	125.8 (22.1)	175.8 (46.6)	143.8 (66.7)		12	2 ICBO	2 ICBO		
.54 .69)		97.3 (17.3)	203.0 (29.4)	230.1 (34.0)	233.0 (33.2)		66.0 (16.1)	140.7 (20.5)	149.4 (21.1)	134.3 (21.8)		84	0	0		
		50.2 (3.4)	103.2 (12.7)				66.5 (9.1)	101.0 (11.1)				6	0			

Figure 3-4- J

ADDITIONAL LIFE TEST DATA

Experiment No.	Experiment Description	Test	Phase	Number Tested	I_{CBO} Shift (Avg) Ma	I_{EBO} Shift (Av) Ma
3-1	1 Hour Bake plus Vycor	Operating Life at 70°C for 250 Hours.	After 1000 hrs at 135°C and 4 weeks R. T.	22	.30	-0.11
3-2	Chemically Oxidized plus Vycor	Operating Life at 70°C for 250 Hours.	After 1000 Hrs at 135°C and 4 weeks R. T.	21	18.31	-.11
3-3	Regular production plus Vycor	Operating Life at 70°C for 250 Hours.	After 1000 Hrs at 135°C and 4 weeks R.T.	27	-.19	-.32
3-4	Regular production plug 5A	Operating Life at 70°C for 250 Hours.	After 1000 Hrs. at 135°C and 4 weeks R.T.	23	0.00	.11
3-5	10^{-6} Bake 1 Hour with Vycor	Operating Life at 70°C for 250 Hours.	After 1000 Hrs at 135°C and 4 weeks R.T.	3	0.00	.03
3-6	Baked W/Vycor 1 Hr. at 135°C	Operating Life at 70°C for 250 Hours.	After 1000 Hrs at 135°C and 4 weeks R.T.	4	-0.6	-.01
3-7	Barium Oxide	Operating Life at 70°C for 250 Hours.	After 1000 Hrs at 135°C and 4 weeks R.T.	19	-0.10	0.00
3-7	Barium Oxide	Cummulative low and high freq. vibration and centrifuge	After operating life.	19	-0.27	0.00

Figure 3-4-J

ADDITIONAL LIFE TEST DATA

Experiment Description	Test	Phase	Number Tested	I_{CBO} Shift (Avg) Ma	I_{EBO} Shift (Av) Ma	IB.Shift Average	Number of Failures
1 Hour Bake plus Vycor	Operating Life at 70°C for 250 Hours.	After 1000 hrs at 135°C and 4 weeks R. T.	22	.30	-0.11	+ 5.3	0
Chemically Oxidized plus Vycor	Operating Life at 70°C for 250 Hours.	After 1000 Hrs at 135°C and 4 weeks R. T.	21	18.31	-.11	-0.5	.3 ICBO
Regular production plus Vycor	Operating Life at 70°C for 250 Hours.	After 1000 Hrs at 135°C and 4 weeks R.T.	27	-.19	-.32	-3.8	0
Regular production plug 5A	Operating Life at 70°C for 250 Hours.	After 1000 Hrs. at 135°C and 4 weeks R.T.	23	0.00	.11	14.5	0
10^{-6} Bake 1 Hour with Vycor	Operating Life at 70°C for 250 Hours.	After 1000 Hrs at 135°C and 4 weeks R.T.	3	0.00	.03	0.0	0
Baked W/Vycor 1 Hr. at 135°C	Operating Life at 70°C for 250 Hours.	After 1000 Hrs at 135°C and 4 weeks R.T.	4	-0.6	-.01	-2.0	0
Barium Oxide	Operating Life at 70°C for 250 Hours.	After 1000 Hrs at 135°C and 4 weeks R.T.	19	-0.10	0.00	10.0	0
Barium Oxide	Cummulative low and high freq. vibration and centrifuge	After operating life.	19	-0.27	0.00	15.0	0

Figure 3-4-J

in desiccant and transported to the production facility. The vycor preforms were placed in production units approximately 1.5 hours after completion of the activation.

3-13. Germanium oxide - powdered Ge oxide, 50 microns, was heated in air for 40 hours at 175°C. The container was sealed and transferred to the encapsulation chamber. The powder was placed in the transistor immediately prior to capping.

Results of the experiments are outlined below.

Precap Baking.

a. Consideration of Experiments 1-6, 2-5, 2-6, and 2-7 indicated that further extensive investigation of a one hour precap baking at 135°C was necessary. Experiments 2-31, 2-32, 2-33, 2-34, 2-35, 2-36, and 2-37 were processed. Experiments 2-31, 2-32, 2-33, and 2-34 were evaluated after aging by an accelerated stress technique (175°C for 100 hours). Although there was a significant improvement with a one hour precap bake (Exp. 2-31), the failure rates obtained for these experiments was significantly greater than normally obtained based on extrapolation from lower temperature failure rates. A lower gain and an exceedingly high 2 V collector diode were observed. As a result, it was decided to store Exp. 2-35 at 156°C for 168 hours. The collector diodes were tested after 68 and 132 hours. After the first measurement, 7.3% were collector rejects; after 132 hours, 15% had failed. As this failure rate is significantly greater than that anticipated, additional evaluation of the step-stress and of the hour precap bake will be necessary.

b. These recent experiments reaffirmed previous data which showed that the gain shift during aging was reduced with a one hour precap bake. After aging, there is no difference in diode or gain levels. The additional shift of devices precap baked one hour is attributed to the establishment of equilibrium conditions. Devices baked for 24 hours exhibit a very negligible shift to lower gain during aging. Extended baking periods, i. e. 97 hours (Refer 1-6) produced low gain. However, during storage the gain tended to higher values and approached the normal level. This would further indicate the establishment of equilibrium conditions.

c. As indicated in 3. 4. 6., the diodes of Exp. 1-6 were stable. These devices continued their tendency toward higher gain as a function of increased high temperature storage time. Transistors precap baked 45 minutes were stable after 6 weeks at room temperature. Devices precap baked one hour (Exp. 2-6) were stable after 250 hours of operating life testing. Transistors which were transported through room air to the encapsulation chamber after a one hour precap bake shifted to slightly higher gain after 6 weeks at room temperature. These diodes were also stable. This data in Fig. 3-4-I.

d. Combining precap Experiments 1-6, 2-5, 2-6, and 2-7 , the failure rate per 1, 000 hours at 135°C was about 5%.

Vacuum Baking.

a. The combined failure rate for vacuum baked transistors was 3. 6%/1000 hours. Of the nine groups processed, all rejects were generated in Experiment 2-29. In all groups,

however, after aging, the collector diode leakage was high. Lower gain levels were observed with either higher vacuums or longer baking periods. The gain stability for all groups was not satisfactory and has been related to encapsulation variables.

Chemical Oxidation.

a. Devices chemically oxidized and baked one hour exhibited desirable gain and diode stability on 135°C storage and after 6 weeks storage at room temperature. The gain median of aged transistors was high and I_B shifted a maximum of 6 ma during high and room temperature storage. The population distribution remained constant as evidenced by the standard deviation which varied only 2.4. However, 30% collector diode voltage degradation resulted after 250 hours of high voltage operating life at 70°C.

b. To determine if this degradation was caused by entrapped ambients, devices were coated with Sylgard 182 (Exp. 1-2). As shown in Fig. 3-4-H, the gain stability was typical for chemical oxidation. No diode failures occurred at 135°C storage. These devices were placed on operating life and the degradation was similar to uncoated devices. Further substantiation that ambient is not the cause for degradation was provided in Exp. 3-2. Vycor desiccant was placed in devices processed per 2-9. The gain level was not affected by the Vycor. During high temperature storage, the diodes and gain were stable. However, 67% of these units failed on operating life testing due to collector diode degradation. The gain shift (I_B) averaged 2 ma.

c. Transistors chemically oxidized with a modified oxidizer

(Exp. 2-11) exhibited a high failure rate after 1,000 hours storage 135°C. The gain was lower than that obtained in the previously discussed process.

d. The use of boiling solvent "B" after chemical oxidation resulted in high gain. The 2 V collector diode was more typical of the results obtained with chemical oxidation. The median I_B of aged devices shifted 5.5 and the standard deviation varied only 0.7. No failures occurred during storage at 135°C.

e. Rewashing after chemical oxidation in solvent "E" produced devices with the highest initial gain. During aging, there was a very small but definite tendency toward lower gain. The gain level was similar to devices chemically oxidized (Exp. 2-9 and 2-14). The 2 V collector diode was approximately 20 μa higher; however, there were no failures at elevated temperature storage. A portion of the experiment (2-21) was placed on 168 hours high voltage modulation life testing before high temperature storage. Although the average collector diode shifted .31 ma at 80 V, all 30 units met the specified end-of-life limit. The gain shifted higher, i.e. - 11.7 ma at I_C = 5 A. Group B was placed on 70°C operating life testing for 500 hours prior to storage. The collector diode shift was 0.66 ma (average). The gain tended toward a higher value, 3.7 ma. No failures occurred. These two groups were placed on 135°C storage.

The combined failure rate which does not consider sequential testing was 4.4%/1000 hours.

Boiling Solvents.

a. The data previously reported was incomplete. The group of

experiments utilizing boiling solvents generally produced high failure rates. Particularly high failure rates occurred for experiments which exhibited high gain and low 2 V diodes. In the latest series, Exp. 2-23, 2-24, 2-25, and 2-26, the gain and 2 V diode were relatively normal. Their failure rates were significantly lower. Fifteen experiments were processed to determine their producibility and the effects of process variables. In general, the gain and diode levels were not reproducible. For example, the gain varied from 62.5 to 27 at I_C = 5 A. After completion of 1,000 hours storage, a limited number of devices from Experiments 2-8, 2-10, 2-12, 2-13, and 2-14 were placed on operating life test for 250 hours. The resultant failure rate was high. Gain instability or diode degradation was noted.

b. Vacuum baking after processing with a boiling solvent resulted in high leakage of the collector diodes, high gain and low 2 V collector diode.

Absorptive Characteristics of Plating.

a. Transistors were capped with parts which were gold plated after nickel plating. A high failure rate, .318, resulted. 84.6% of the rejects occurred between 333 and 666 hours at 135°C storage.

Conclusions.

Surface Oxidation.

a. Precap baking at 135°C for one hour does not affect parameter levels. However, it establishes a stable surface

prior to encapsulation. It also causes out-gassing from the Ge oxide, plating and integral components. The gain shift during aging is reduced but still exists due to the establishment of equilibrium conditions. The gain shift after high temperature storage is reduced. Significant reliability improvement can be attained by this method.

b. Boiling solvents occasionally produced high gain devices. However, the reproducibility and reliability attained does not warrant further consideration.

c. Vacuum baking did produce gain stability as expected, higher collector leakage, lower gain and higher 2 V collector diode resulted. The failure rate was improved significantly.

d. Chemical oxidation produced very stable parameters during storage at 135°C. However, collector diode degradation occurred during high voltage operating and modulation life testing. This change was not caused by ambient conditions in the package. Higher gain and improved stability resulted from a rewash in solvent "E".

e. Usage of gold plating to reduce moisture absorption did not improve reliability. Actually, a high failure rate resulted.

Ambient Control.

a. Barium oxide did not produce stability or reliability according to Experiments 3-7 and 3-9. The I_B median varied 34 and 21 ma respectively during 1, 000 hours at 135°C. The diode stability of barium oxide during operating life and environmental testing was excellent for Exp. 3-7. However, the

gain I_B changed 25 ma. The failures exhibited a significant change to higher gain. It was theorized that the entrapment of the desiccant at the weld generated leakers; however, this was not verified by either helium or dye checks. Concerning Experiment 1-12 which was a combination of barium oxide and a varnish, there were no failures. However, the I_B median varied 18 ma during high temperature storage.

b. Production devices and transistors baked one hour and encapsulated with Vycor (activated by air baking) exhibited the same gain after age and during age. The I_B median varied 14.8 ma and 11.5 ma on approximately 7%. There were no failures. These devices were stable after operating life testing at 70°C.

c. Activation of Vycor by vacuum baking increased the I_B level approximately 40 ma when compared to an air bake activation.

d. The combined failure rate to date for both production and one hour precap baked devices encapsulated with Vycor was 0.96% per 1,000 hours at 135°C from the available data. If the additional life testing is considered without correction for sequential testing, the overall failure rate is 0.86% per 1,000 hours.

e. Experiments were processed to cause moisture entrapment utilizing Vycor desiccants. In Exp. 3-6, transistors were baked one hour at 135°C with a desiccant. There were no failures and the gain was lower than the normal production value. The characteristics were similar to those obtained by air activation of Vycor.

Other parts were vacuum baked with Vycor at 10^{-4} mm Hg for 4 hours. The gain of these units was not typical for desiccants and was higher than normal production. The diodes show a tendency toward degradation although no failures have resulted.

f. Linde 5 A was encapsulated in regular production units. The gain median during storage continually shifted higher; the total I_B change was 21.2 ma. The I_B shift during operating life was 14.5 ma compared to 5 and 4 ma achieved with Vycor. There was one failure which occurred within 333 hours at 135°C.

g. Pressed Cab-O-Sil functioned as a desiccant. One Vfl failure occurred which may have been caused by breakage from the disc.

h. Cab-O-Sil, alumina and fluorocarbon produced very low gain - the lowest of any groups evaluated. The failure rate will be very high however.

i. Germanium oxide did not function as a desiccant. The gain achieved was significantly higher than typical for production units.

j. Barium oxide used in conjunction with boiling solvents and vacuum baking did not produce diode or gain stability. A high failure rate will result.

Ambient Control.

a. Barium oxide did not produce gain or diode stability. The

handling difficulties incurred suggest limitations with powder desiccants.

b. A loose desiccant did not cause measurable degradation by abrasion.

c. Vycor produced very stable and reliable transistors. (Failure rate less than .86% per 1,000 hours at 135°C)

d. The gain level can be adjusted by control of the moisture content. Selective usage of desiccants and activation conditions will produce this.

e. Gain stability was not achieved with Linde 5 A.

f. Pressed Cab-O-Sil may be considered as a desiccant. However, the combination of Cab-O-Sil, alumina and FC43 resulted in units with a high failure rate.

The conclusion of these studies is that the most promising and most practical approaches to further reduction in the high-temperature-storage failure rate are chemical oxidation with a one hour precap bake.

Program for the Next Quarter. On the basis of the data presented in this report and other data, a large production lot will be processed utilizing a one hour precap bake. It will be included in Milestone III. Vycor desiccant has exhibited a very low failure rate and excellent stability. A large lot may be processed combining Vycor and a one hour precap bake.

Chemical oxidation has produced low failure rates and stable characteristics. Extensive investigations will be continued to determine the cause and solution for diode degradation

during high voltage modulation and operating life testing.

3.4.8 Contamination Studies - R. P. Anjard, R. M. Matuska.

General and Engineering Status. Modified bases have been produced so that furnace soldering of the element will not be required.

Extensive investigations were made to obtain molybdenum base rings.

Program for the Next Quarter. Molybdenum base rings will be obtained and solder coated with 95% Sn - 5% Sb. Transistors will be processed as outlined in the second Quarterly Report.

3.4.9 Other Advanced Techniques - M. E. Stanton.

General and Engineering Status. Samples submitted for mass spectrographic analysis have not been returned.

The dark field illuminator has been investigated. This method of illumination can improve the observation of particles on a highly reflecting surface. The proper utilization of such apparatus would require more time than is presently available in this portion of the program.

DELCO RADIO

4.0 IDENTIFICATION OF PERSONAL

4.1 Personnel Changes.

Technical personnel, not previously identified, who actively participated in the program during the third quarter were:

G. R. Pepka
D. Kochenderfer

4.2 Engineering Time.

From November 1, 1962, through January 31, 1963, there were 6,092 hours spent by Delco Radio personnel on the engineering efforts toward fulfilling the contract committments.

4.3 Personnel Biographies.

Personnel biographies not included in the proposal or previous reports are included in this report on the following pages.

G. R. Pepka - (B. S. St. Louis University) - Jr. Chemist

Mr. Pepka was first employed by Delco Radio in 1955 as a stock supplier of radio parts in Dept. 306. Upon joining the U. S Marine Corps in August of 1956, he completed a service school course on the operation of a communications center and worked as a teletype operator until completion of his tour of duty in August, 1958.

Following graduation Mr. Pepka was employed at the Center Spring Company as a sales representative. He is presently engaged in studies at Indiana University. He rejoined Delco Radio in January of 1963 and was assigned to the Failure Analysis Group as a Junior Chemist. One of his major assignments in this group will be to conduct analytical investigations under the direction of the project engineer.

Donald D. Kochenderfer - (Valporaiso Technical Institute, - two year technical certificate, 1958) - Process Technician.

Mr. Kochenderfer started work with Delco in January, 1959, as a process technician. His work has been exclusively in the area of designing,

developing, troubleshooting, and calibrating test equipment for semiconductors. Mr. Kochenderfer has made many worthwhile contributions to existing equipment designs.