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JUL 79   R H DICKHAUT, A L DUDLEY   DAAK10-77-C-0122

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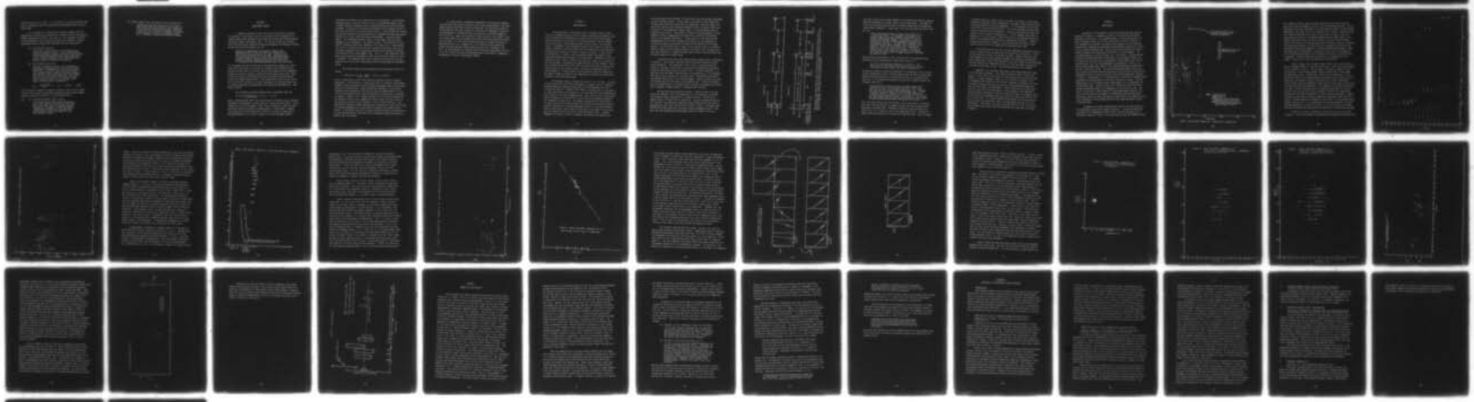

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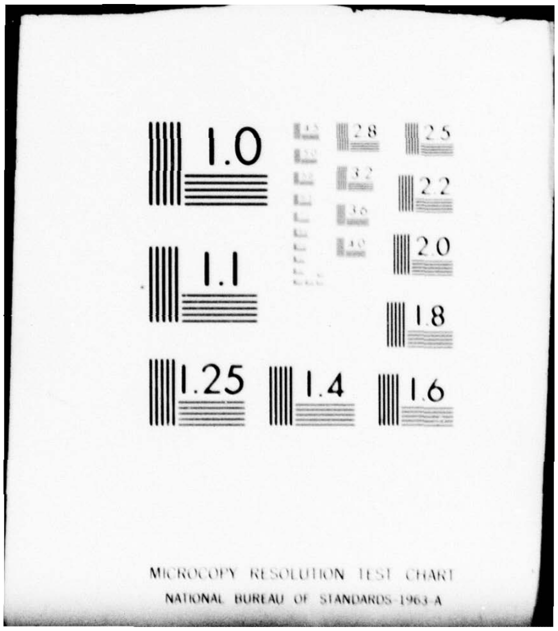
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An anaysis is presented of the long-term dormant storage test data experimentally accumulated on two microelectronic devices. All relevant information on the experimental test program was reviewed very carefully. The existence of error sources, anomalous data, and data acquisition discontinuities was identified. The unanticipated final result of the analysis was that the data collected was of an insufficient quality to enable the identification of any aging behavior as a function of time, temperature, or operational stress.

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SECTION 1
INTRODUCTION

The following document is the required report to AARADCOM on the Long-Term Dormant Storage of Microelectronics Components Contract No. DAAK10-77-C-0122. The statement of work committed R/M Systems Division of EX-CAL, Inc. to develop techniques for analyzing aging trends in the long-term dormant storage test data offered by Picatinny Arsenal on two microelectronics devices. These devices were the 2N3029 Silicon Controlled Rectifier (hereinafter referred to as the SCR) and the CD4007AD Tri-Inverter Integrated Circuit (hereinafter referred to as the IC). All relevant information on the experimental test program was critically reviewed stressing the data collection procedures, and the data previously stored and statistically processed. The existence of error sources, anomalous data, and data acquisition discontinuities were identified. Unfortunately, the data collected and forwarded to the contractor was of an insufficient quality to distinguish aging behavior as a function of time, temperature, or operational stress due to testing. This document will, in an intentionally abbreviated fashion, present the reasons for the situation. Extensive details are omitted so that the reader may understand the faults of data acquisition system and procedures, in a number of pages small enough to be read carefully.

Initially, a review of selected sections of the previous documentation important to our results is presented. The data is next analyzed in an outline form with indications of the detailed procedures necessary to absolutely prove the arguments offered. There is a discussion regarding the extent of the knowledge of the problems possessed by the experimenter. Finally the modifications required to collect reliable and reproducible evidence of aging are considered, including modifications to measurement methods, increased sensitivity, and the introduction of standards. It is our understanding that the material given here has prompted the complete abandonment of the original program of testing and no further data will come from the former data acquisition system. Consequently, a predictive analysis model for microelectronics aging is impractical since there is not now data which distinguishes aging trends and there will not be any from this system at any time in the future. The system under development at Picatinny Arsenal by P. Calella currently has our support as a system possibly efficient at evaluating dormant aging behavior. Prediction of eventual failures requires the data of a reliable system.

The references used in this work are given in an unorthodox manner. They are essentially complete because it is anticipated the reader may wish to consider them simultaneously. The notation used is as follows:

(1) 1973 document - Kobylarz, T.A., A Data Acquisition System for Determining Long-Term Deterioration of Electronic Devices, Engr Sci Div Information Report, Picatinny Arsenal, Dover, NJ August 1973.

(2) 1974 document - Kobylarz, T., Test Sets for Prototype Data Acquisition System, Engr Sci Div Information Report, Picatinny Arsenal, Dover, NJ, January 1974.

(3) 1975 document - Kobylarz, T., Long-Term Dormant Storage Data Analysis for Prototype Data Acquisition System, Engr Sci Div Information Report, Picatinny Arsenal, Dover, NJ, July 1975.

(4) IEEE Document - Kobylarz, T., and Graf, A., Long-Term Dormant Storage Testing, Initial Results, Proc 1976 Annual Rel. and Main Sym., IEEE, 1976.

(5) Unauthored Document - Report entitled Data Analysis on Dormant Stored Devices with unspecified author and data attributed by correspondence to P. Walsh.

SECTION 2

ERROR AND SENSITIVITY

There are frequent lines throughout the documentation concerning measurement errors due to the data acquisition system for the various physical parameters studied on the test devices. The vocabulary used in the documentation is unfortunate, because if it is not studied carefully the reader might presume that the response of the system is substantially more accurate than is claimed. The three words of concern are sensitivity, discrimination, and error. It is repeatedly indicated that the offset error portion alone of the absolute error is significantly larger than both the sensitivity and the discrimination for the measurements performed. Under these circumstances the distinction between sensitivity and discrimination is irrelevant, because only the absolute error should be considered for the data analysis. Consequently, if you intend to discuss the validity of the data in the environment of its statistical processing, then essentially all comments associated with the sensitivity or discrimination of the acquisition system should be disregarded and the appropriate absolute error analysis should be applied. Although numerous references could be cited here, no single concise one is available which demonstrates these arguments. However, the interested reader should cover the 2½ pages of text material in the 1975 document starting with the last paragraph of page 2-1 and continuing through page 2-5 ignoring table 2-1.

In regard to the absolute error of the system, the discussion below reviews a select (but completely representative) few of the results. The most conservative error estimates are also the most detailed documented pages. They follow directly from the error analysis of the system presented in chapters 2 and 3 of the 1974 document and are used by us as the guidelines for reproducibility judgments on the capabilities of the system. It should be stressed that these predictions are due to T. Kobylarz's calculations and intuition and not to any theoretical effort on our part. A comment with respect to this fact concludes this section.

Representative current measurement capabilities of the data acquisition system are estimated by equations 3-9 and 3-41 of the 1974 document. The total analysis of the SCR leakage current error gives

$$e_{TL} \approx (0.125 + \{5.84 + 0.67 \times 10^{-4} D_L\}\% I_L) \text{ na}$$

where I_L is the measured leakage current in na (nanoamperes) and D_L is the number of days since the last "balance" done during maintenance. Since the average recorded period between maintenance operations was approximately 30 days, a D_L value of 10 days was selected as representative. A typical independent measurement of leakage current was about 0.1 na. Consequently, an approximately average error of

$$e_{TL_{av}} \approx 0.125 + (5.84 + 0.67 \times 10^{-3})\% \, (0.1) \approx 0.13 \text{ na}$$

is anticipated, and an estimate for a value of a marginal measurement amplitude which is dependable is roughly twice this. That is, only measurements of leakage current (or any variable using a nanoampere sensitivity circuit) of magnitude 0.25 na or greater will be expected to be marginally reproducible in our discussions. The total analysis of the highest sensitivity circuit for the SCR gate trigger current error gives

$$e_{TG}(H) \approx (0.104 + 5.02\% \, I_G + 0.01 \, D_G) \text{ } \mu\text{a}$$

where I_G is measured gate trigger current in μa (microamperes) and D_G is the number of days since the last "balance." A typical independent measurement of gate current was about 0.3 μa and, again at 10 days, an approximate anticipated average error is

$$e_{TG_{av}} (H) \approx 0.104 + 5.02\% \, (0.3) + 0.1 \approx 0.25 \text{ } \mu\text{a}$$

Hence following the argument above, high sensitivity measurements of gate trigger current (or any variable using a microampere circuit) exceeding 0.5 μa are considered to be marginally reproducible. For the low sensitivity circuit the situation is somewhat worse.

The voltage measurements capabilities of the data acquisition system necessary for the IC dormant testing are estimated in the 1974 document equations 2-94 and 2-96. The total analysis for the high output error and the low output error yields

$$e_{HO} \approx (26.2 + 0.98\%\ V_o)\ \text{mv}$$

and

$$e_{LO} \approx (61 + 0.98\%\ V_o)\ \text{mv}$$

respectively, where V_o is the measured output voltage in mv (millivolts). Typical measurements for these values are 9.9 volts and 0.1 volts, and the approximated average errors are

$$e_{HOav} \approx 26.2 + (0.98\%)\ (9.9 \times 10^3) \approx 123\ \text{mv}$$

$$e_{LOav} \approx 61 + (0.98\%)\ (10^2) \approx 62\ \text{mv}$$

These estimates appear to be excessive when the data is visually examined. Therefore in this case, we shall presume the system actually can marginally reproduce voltage measurements on either output to within approximately 60 mv.

The four preceding estimates of marginally dependable measurements are generally viewed as order of magnitude calculations in this work. Recall that they are from T. Kobylarz's document and do not originate with the current authors. If the program leads to the continuation of data acquisition with the test sets now installed, it is our recommendation that these calculations be independently repeated. They appear comprehensive and are detailed, but have not, to our knowledge, been checked by anyone. The suggestion of their review is based on heuristic arguments only, since several items appear unusual. For example, examining the current sensitivities we observe a drift prediction of 1 μa in 10^2 days (~1/4 year) on measurements in the μa ranges as contrasted with an equivalent prediction of 10^6 days (~ 3000 years) for 1 na in the na range. Considering the na range is substantially more difficult to achieve, the results seem peculiar, although not mathematically impossible due to obvious circuit differences. Yet aside from these arguments, we use the marginal measurement results above for the data analysis which follows.

Before leaving this discussion, we review the issue of life testing versus dormant storage aging. The precautions instituted to distinguish these effects are believed to be sufficient and reliable whenever dependably reproducible magnitudes of the measured variables are encountered. However, according to the overall contention of this work, no aging has been actually measured to within reasonable error analyses. Consequently the question is moot and will not be further discussed with respect to the data stored on either the SCR or IC devices.

SECTION 3

MAINTENANCE AND NOISE

The routine maintenance procedure requires the adjustment of several feedback circuit resistances such that the acquisition system drift can be eliminated. The adjustment specifications are given with respect to a standard "calibrating mechanism", a digital voltmeter. Their accuracy depends on the stability of the voltmeter in a non-null measurement environment due to an assumption that the voltmeter is absolutely error-free. Empirical experience with such adjustments to arbitrary circuits suggests that two events should be anticipated. The equivalent zero value base line is shifted and there is a noisy period (of circuit dependent duration) following each feedback loop variation. The data from both the IC and SCR devices when correlated with the system's maintenance schedules (1975 document, tables 2-2 and 3-2) reflects both of these predictions. No particularly unusual values are seen in the data resulting from maintenance except perhaps for some excessive noise magnitudes immediately afterwards. However, we will demonstrate that the maintenance schedule and the resultant perturbations observed in the data (especially base line alterations) are critical to the mean-time-to-failure predictions when neither should be.

Speculation regarding the origins of data acquisition system noise whether dependent on, or independent of, maintenance is truly difficult without actual contact and experience with the system and its environment. Only from documentation and private communications, supplemented with intuition, can any relevant comments be made. Even then they must be viewed with considerable doubt. Although there is substantial evidence presented which attributes a large portion of the noise to the temperature dependence of the data acquisition system, we usually view noise as an experimental fact visible in the data itself and not attributable to some source. Without specific sources and knowledge of their noise spectra, no adjustments can be reasonably made to the statistical software package to account for them such that the physically relevant and theoretically modelable signal can be isolated. This circumstance is not important, however, unless the signal-to-noise ratio is small. In our opinion, as we shall discuss, the ratio is unbearably small for statistically based predictions to be seriously made.

It is worthwhile to reference the following comments from the documentation, because each exemplifies an important noise source besides ambient temperature variation. Note that it is an important contention of the documentation that averaging procedures are expected to remove discrepancies due to large noise variations from all such sources.

(a) 1975 document, page 2-6:

> "One word of caution applies to the preceding and further discussions of data. It was discovered that the heavy equipment conveyors and other large machinery, in the testing environment, would induce large noise spikes. Hence, inordinately large magnitudes within the data should be viewed with reservation."

(b) 1974 document, page 2-15:

> "Because of extensive cabling, noise represents a particularly troublesome error source at low valued measurements. Through the use of extensive filtering, it was possible to reduce the noise content of the quiescent current equivalent voltage to somewhat less than 5mv, peak-to-peak amplitude. This represents an error of ± 2.5mv at the amplifier output. Since a measured current of 1 μa provides a 10v output, the noise error is bounded by:
>
> $$e_{N1} \leq \frac{2.5 \times 10^{-3} v}{10v} \times 1\ \mu a = 0.25\ na \qquad (2\text{-}40)"$$

(This last error estimate on quiescent current of the IC agrees identically with the marginal reproducible measurement done for the leakage current of the SCR in Section 2, Error and Sensitivity.)

and (c) Unauthored document, pages 7 and 8:

> "The voltage outputs show strong fluctuations over a wide range of days and almost no fluctuations over other days. The maximum range of fluctuation is perhaps ten times the minimum discrimination capability of the measuring system and this fluctuation appears to last over hundreds of days."

...The author suggests that "the source of the fluctuations is

> outside the measuring system and the fact that it has a repetition time of nearly 1 year suggests an origin related to seasonal variations, due either to seasonal use of electrical equipment introducing electrical noise or actual environmental change, such as humidity, affecting the measuring system."

SECTION 4

CONSISTENCY TESTING

T. Kobylarz performed a series of tests at the onset of operation to determine if the scanner, test set, and elapsed time chronometer functioned properly when connected to the interface console for SCR measurements. These were termed "consistency" tests. The results indicated the system had difficulties which remained uncorrected throughout the production testing. We note from the 1973 document, pg 7-53:

> "Because the measurements were taken at ambient room temperature (table 7-33), the SCR's had leakage current near the minimum magnitude of the range. Therefore, the values shown cannot be used to evaluate system performance. The gate trigger currents, however, are sufficiently large. Considering ambient temperature variation and tolerances, it is believed that the SCR measurements were quite consistent."

It is assumed that the installation of the temperature chamber was anticipated to be sufficient to alleviate the leakage current problem and that the gate current would be similarly large on the production test components. Neither of these was actually realized during the data acquisition. Consequently the system's performance should be evaluated by the consistency testing and judged unsatisfactory. Even though these tests did not involve the IC test set, the data file clearly indicates from the outset that similar testing would have indicated again the system was unsatisfactory. Some details follow.

The average gate current measured during consistency tests was

$$(7.3 \text{ units})\left(\frac{1\ \mu\text{a}}{5.46\ \text{unit}}\right) + 0.17\ \mu\text{a} \approx 1.5\ \mu\text{a}$$

which is approximately three times the previously estimated value of marginal measurement and therefore could be expected to show some consistency. Visual inspection of the 1973 document, table 7-33, indicates the larger the measured value the more consistent the measurement, as anticipated. However, the average gate current measured over the first 30 days on component #9 was approximately 0.12 μa which is about 1/4 of the estimated marginal measurement and therefore no consistency is to be expected. In our opinion absolutely none is seen for this unit, yet the unauthored document claims a greater than 99% confidence level of measureable aging on this particular component. We present an alternative explanation of the probable origin of this peculiar result in the data analysis section. Next consider the average gate current measured over the same period on component #15 which was approximately 6 μa, or well above the marginal measurement. Consistency does appear. The unauthored document claims a 0% confidence level for aging phenomena in this component. Our analysis agrees. There should be a high level of confidence that this component is not aging at all. Additionally, this result is uniformly true, but with decreasing confidence level as the individual components have average gate currents which approach from above the estimated marginal measurement value. That is, if the magnitude of the gate current exceeds the threshold of the data acquisition system, no aging is measured. All components which were claimed to statistically indicate aging did so on the basis of measurements entirely made below the threshold values.

The average leakage current measured during consistency tests on an SCR was

$$(-0.056 \text{ units}) \left(\frac{1}{20.48} \; \frac{\text{na}}{\text{unit}} \right) + 0.05 \text{ na} \simeq 0.047 \text{ na}$$

which is approximately 1/5 of the previously estimated value of marginal measurement. No consistency is expected and none is claimed in the document. (However, there does appear to be consistent measurements made on the tested resistors at about 100 na.) Again considering component #9, the average leakage current measured over the first 30 days was approximately 0.1 na or 1/2 of the estimated minimal value and therefore no consistency is expected or observed. However, this comment apparently can be applied uniformly for the leakage current of each component of the SCR group of devices and also the quiescent current of each component of the IC group of devices. The magnitudes of both the leakage and quiescent currents were always insufficient to establish dependability of measurement throughout the production test period. In particular there was no aging significant enough in either device to make the measurements consistent and no reasonable predictions based on these values can be made.

As a second check, completely independent of the previous argument, consider again the system's sensitivity for current measurements in the nanoampere range but with the IC test set installed. We note that according to the manufacturer the input current for the typical IC component is about 10 pa (picoamperes) or essentially zero as discussed in the 1974 document on pgs 2-17 and 18. Hence any variation of input current in an IC which is not in a failure mode can be considered error due to the data acquisition system, to first order. A visual scan of the data reveals a maximal-variation of approximately 18.5 na. Although this is an excessive value arbitrarily chosen from noisy periods, these periods are not at all uncommon in the data. By this argument the estimated value of marginal measurement of 0.25 na is a full 2 orders less than the observed maximal noise which is completely unacceptable in terms of experimental design.

SECTION 5

DATA ANALYSIS

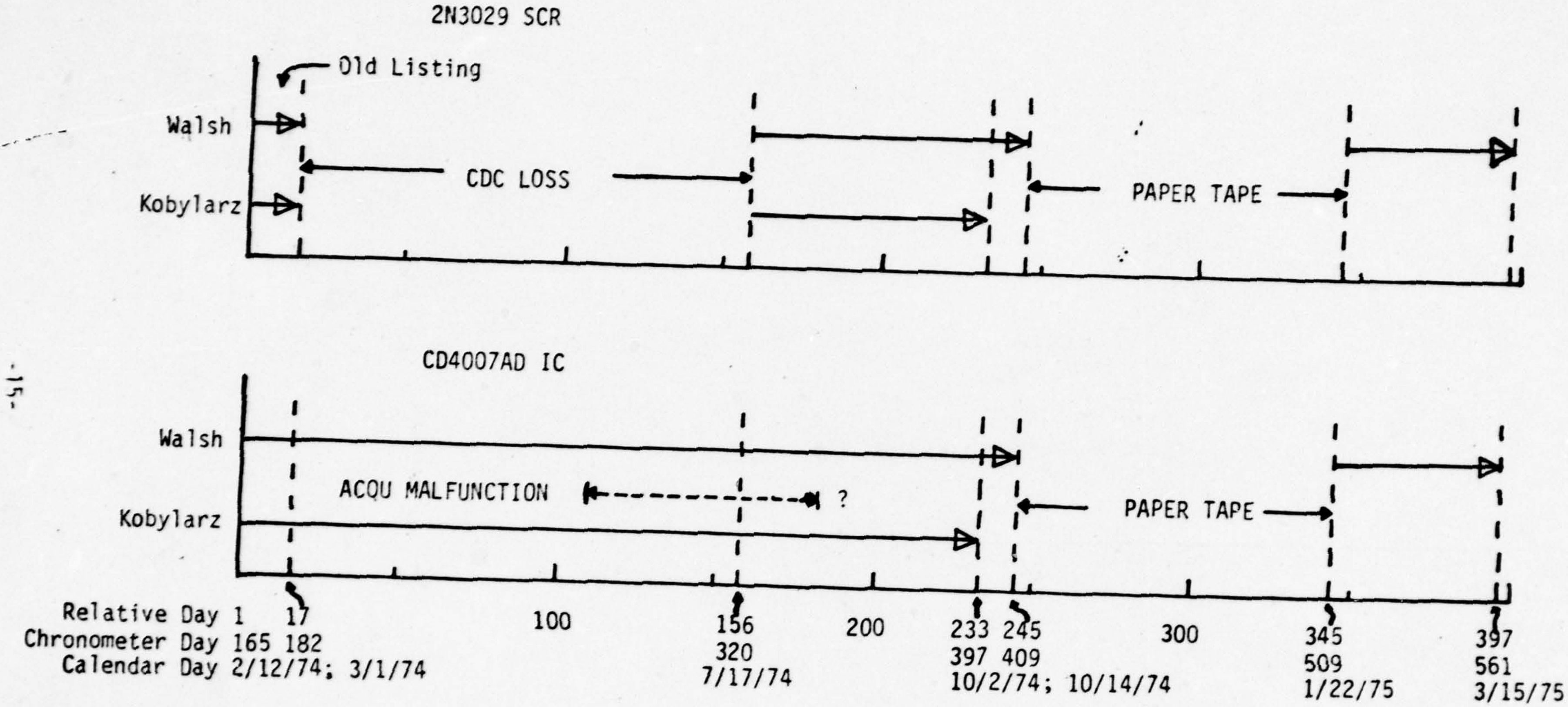
By presentation of the material from a different point of view, it will be demonstrated that the three input information requirements necessary to establish the predictions for mean-time-to-failure are the data acquisition periods, the effects of routine maintenance, and the temperature restrictions. Conspicuously absent from this list is the raw data itself. Consequently, the disturbing feature of this section is that we intend to outline a precise procedure for the demonstration that the actual data had almost nothing to do with a statistical process. In particular, as indicated by T. Kobylarz, only the medians (and/or the means) of the acquisition periods are relevant to the predictions. Afterwards it will be pointed out that a fourth critical item, the noise levels as calculated in the 1974 document, invalidates the reproducibility of these medians. Therefore, eventually we will be left with no reliable mean-time-to-failure predictions and, for our contract effort, absolutely no modelable data for aging phenomena. In addition what little meaningful data that appears will be shown to suggest no aging of the components of any device has even been measured by the acquisition system.

The sequence chosen to present the material is as follows. Initially the data acquisition periods are displayed in a graphic form for reference, distinguishing the separate periods used for the independent statistical calculations done by T. Kobylarz and P. Walsh. Both the gaps in, and density of, data acquisition are discussed as it is understood from the documentation, data listings, and private communications. Next, specific data is presented which has properties characteristic of each physical parameter measured on all components of each device. We compare and contrast our choices with all other data not similarly presented and correlate the routine maintenance schedule, along with its evident subsequent effects, to the data presented. Then an indication is made of how the data density and range of acquisition days are altered by the restriction of the temperature range. Seasonal arguments are offered, as well as comments concerning device physics and discussion about the differences in selection of data statistically processed by each individual author. At that point, the origins of the slopes used for mean-time-to-failure predictions are identified. The next issue is to recall the previous noise section and establish that the data's entire contribution to the generation of these slopes is totally unreliable due to excessive noise levels. The analysis of the two limited exceptions to this comment is shown to demonstrate the acquisition system has not measured aging in any component whatsoever. Finally there is a discussion of the consequences of all of this procedure with respect to the usefulness of the data for modeling the physics of aging in the SCR and IC solid state devices. The conclusion given is that, in our opinion, there is no experimental evidence of device aging contained in the data files currently available and, therefore, an attempt to model aging based on this particular data collection would be a wasted effort.

The periods over which the system actually acquired data is presented in Figure 1. The distinct intervals used for the two statistical efforts appear separately. The discussion of this figure is concerned with the origins of the gaps and the rates of acquisition throughout the productive period for which data resides in current files. To avoid confusion, it is important that the reader recognize that all documentation is in chronometer days and all data listings are in relative days. Occasionally the distinction between these terms is not strictly obeyed. They are related such that the relative day plus 164 equals the chronometer day. A third day designation, the computer day, is not particularly relevant to anything that follows and is ignored, although nothing is altered by this omission.

We begin with the acquisition periods T. Kobylarz used in his own statistical package. All of the references for this portion are from the 1975 document except those explicitly stated otherwise. Initially the general density of acquisition is considered. During the production period of collection, the system was operational approximately 30% of the time as determined by a day count from the data listings. Table 1-1 indicates that 105,218 total data items were collected through chronometer day 397. However, the test breakdown per measurement sections of Table 2-2 and 3-2

Figure 1. Data Acquisition Periods.



The average accumulation density within the continuously drawn acquisition periods is approximately 30%. Other restrictions on the data further reduces this amount by factors of 2 to 8 dependent on the statistical procedure applied.

show that actually only 23,568 (9(2009) IC and 3(1850) SCR) physical measurements (of temperature, voltage, and/or current) were taken. The number of statistically processed data values is severely reduced by the temperature restrictions introduced. In particular, from the IEEE paper pg 176 (or from pg 1-1),

> "The storage deterioration for these eight months is by-in-large quite small. The parameters manifested much greater random variations, probably attributable to temperature and humidity changes. Furthermore, it was discovered that the mean testing temperature depended upon the season of the year. The room (mean) temperature was cooler during the winter, probably due to heating at low humidity. Hence, the use of data at all temperatures would inflict a bias on analysis results. In order to minimize such a bias, only data confined to the temperature range of 23°C to 25°C, or about one-half of the total, has been utilized."

The qualified justification of this limitation will be considered later. Concerning the gap labeled paper tape we note from pg 1-1:

> "Not all of the data was available for retrieval. The data collected from October 1974 through January 1975 was stored only on paper tape at the time of the analysis."

The specific width of the gap was determined by examination of the listings. Private communication with P. Calella suggests that the data on these paper tapes may be both sparse and of insufficient quality to be added to the data file. For the regions labeled CDC loss and old listing, consider the reference from pg 3-5:

> "A malfunction occurred within the CDC-6600 computer while transferring data to the permanent data file. All of the data from day 165 to day 311 was consequently lost. Although this data can be recovered from existing paper tapes, it is a laborious process. However, such a recovery will be pursued when funds become available. Fortunately, an old listing for data between days 164 and 182 was discovered. This listing was used to provide the needed information for interval 1."

This last event affects only the SCR data. Even though this is a 156 day span, due to the low density it appears unlikely that the recovery should have been a laborious task. Additional references about this matter are found on pg 1-3, in Table 3-2, and in the IEEE paper pg 179. The last of these states that about 40% of the total SCR data was lost. The last region of interest does not involve a gap in the data, but rather a period where completely erroneous current measurements, of unknown initial date and duration, were acquired for the IC components. It is designated on the figure by the term "acquisition malfunction." All of the erroneous data was left intact for the statistical processing. We stress that both the extent and location of this region is unknown to us. Private communications with W. Doremus and A. Graf through P. Calella have led to the proposed limits presented. We understand that there was a memorandum written by T. Kobylarz concerning this matter; however, no one has been able to locate a copy. Further discussion of this region will be deferred until later.

The acquisition periods used for the independent statistical processing of P. Walsh reflect the same gaps and malfunctions noted above. There are two additional acquisition periods included. However, there are also three further restrictions imposed throughout the production period which again dramatically reduces both the density and total amount of data processed. The extra periods are immediately before and after the paper tape gap and introduce 64 more days of data. The new restrictions are as follows.

Generally, only the data found within the narrow temperature range of 23^o-24^oC was considered. (The single exception to this is even more severe.) Only the first data point in this range during a specific day was taken for a given component. Only 6 of the individual components and 3 IC components were tested from the 50 total components recorded in the file. The details of these additions are given in the unauthored document pgs 1 and 2, and the tables included there. These limitations have significant effects on the statistical processing. The narrowing of the temperature range decreases the density of data so dramatically that, for example, there are no physical measurements used in the statistics before day 320 for 4 of the 6 SCRs tested. If a given component was measured several times during the day within the temperature range, all measurements but the first are disregarded. And finally, only 20% of the SCRs and 15% of the ICs are processed anyway, which means that from the outset more than 80% of the data is ignored.

SECTION 6

DATA DETAILS

The details of the material in the stored data bank will soon be presented in terms of a sequential analysis of the physical parameters measured on each device. For component number 9 of the SCR devices, the plot of leakage current (I_L) versus relative day is given in Figure 2. This component was selected for display simply because in the unauthored document this component was purported to show definite aging with a statistical confidence exceeding 99%. Notice that the data plotted in Figure 2 visually suggests that nothing more than noise is being recorded. The recorded magnitudes oscillate around zero. The physics of leakage current processes preclude alternation of the direction of leakage current flow. The majority of the points are concentrated in approximately the first 15 discrimination "bins" of the measurement instrumentation. That is, all points reflect magnitudes right at the threshold measurement capability of the data acquisition system. The minimum measurement capability and the noise sources associated with the data acquisition system are sufficient to completely account for both the positive and negative magnitudes recorded in Figure 2. Consequently it is not practical to construct an argument which represents the plotted points as real data indicative of aging. The same remarks apply to all leakage current "measurements" on all components for the SCR device type. They also apply to all quiescent current and input current measurements made on all components for the IC device type. The result is that none of these specific current measurements record a real signal and hence they are incapable of representing aging perturbations. Accordingly, there was never any technical justification for applying statistical techniques to the recorded points for the above-mentioned currents in the data bank.

Irrespective of these considerations, statistical studies were in fact performed on the points plotted in Figure 2. The points underlined correspond to the temperature range 23-24^{o}C, and were the subject of a statistical study by P. Walsh. The conclusion was that the leakage current

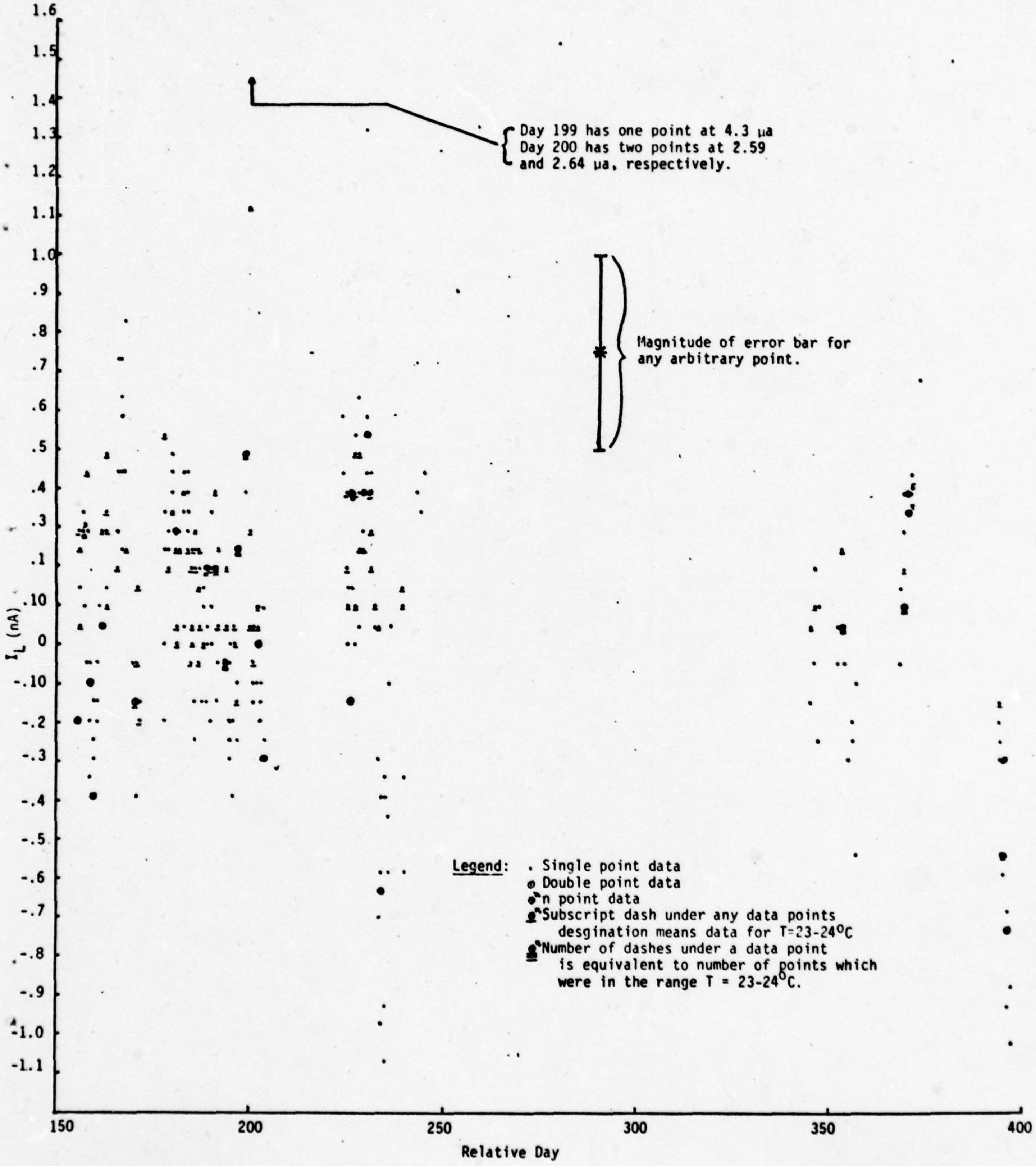


Figure 2. Device Type 3029: Component No. 9 - Leakage Current vs. Relative Day.

had a negative slope of about 9 na/day, which means that the current was decreasing and the component could be said to be improving with age. Similar analyses on five other components also yield negative slopes, and the average magnitude of the slope for all six components was 9 na/day. An earlier study by T. Kobylarz examined similar data to that given in Figure 2, but for a larger group of devices a two-degree temperature space from 23-25^{0}C, and a shorter time span of only the first 233 days, and he found that the mean value of the slope for all devices was positive and had a value of .64 pa/day. The conflicting findings are consistent with instrumentation difficulties associated with baseline anomalies, threshold magnitude measurements, temperature sensitive instrumentation, low signal-to-noise ratio, perturbations due to maintenance procedures, and different time intervals over which data is assessed. Further discussion of this matter is postponed until the reader is more familiar with the contents of the data bank.

Figure 3 shows a plot of gate trigger current (I_{GT}) versus relative day for component number 9 of the SCR device type. This is the same component as was examined in Figure 2, and once again, non-physical negative values can be noted. The plot shows general features reminiscent of both random and determinate noise. Although the vertical range of magnitudes could be expected to result from random processes associated with the earlier analysis discussion, the apparent periodic discontinuities in overall magnitudes (such as those occurring immediately after the date arrows along the abscissa) are associated with the completion of instrumentation maintenance adjustments. The result is data clustering due to the baseline measurement value being altered. Also at days 199 and 234, extremes of high and low temperatures, respectively, contribute dramatically to these maximal measurements, suggesting that the data might be strongly temperature dependent rather than truly random. No maintenance date information is available for time periods beyond relative day 218, but it is expected that the relative movement of the data baseline magnitudes in clusters of points is at least partially associated with the instrumentation perturbations accompanying any maintenance procedure.

Figure 4 is a plot of temperature versus relative day for the SCRs of group 1. This graph supports the arguments made regarding the previous two

Figure 3. Device Type 3029: Component No. 9 - Gate Trigger Current (I_{GT}) vs. Relative Day.

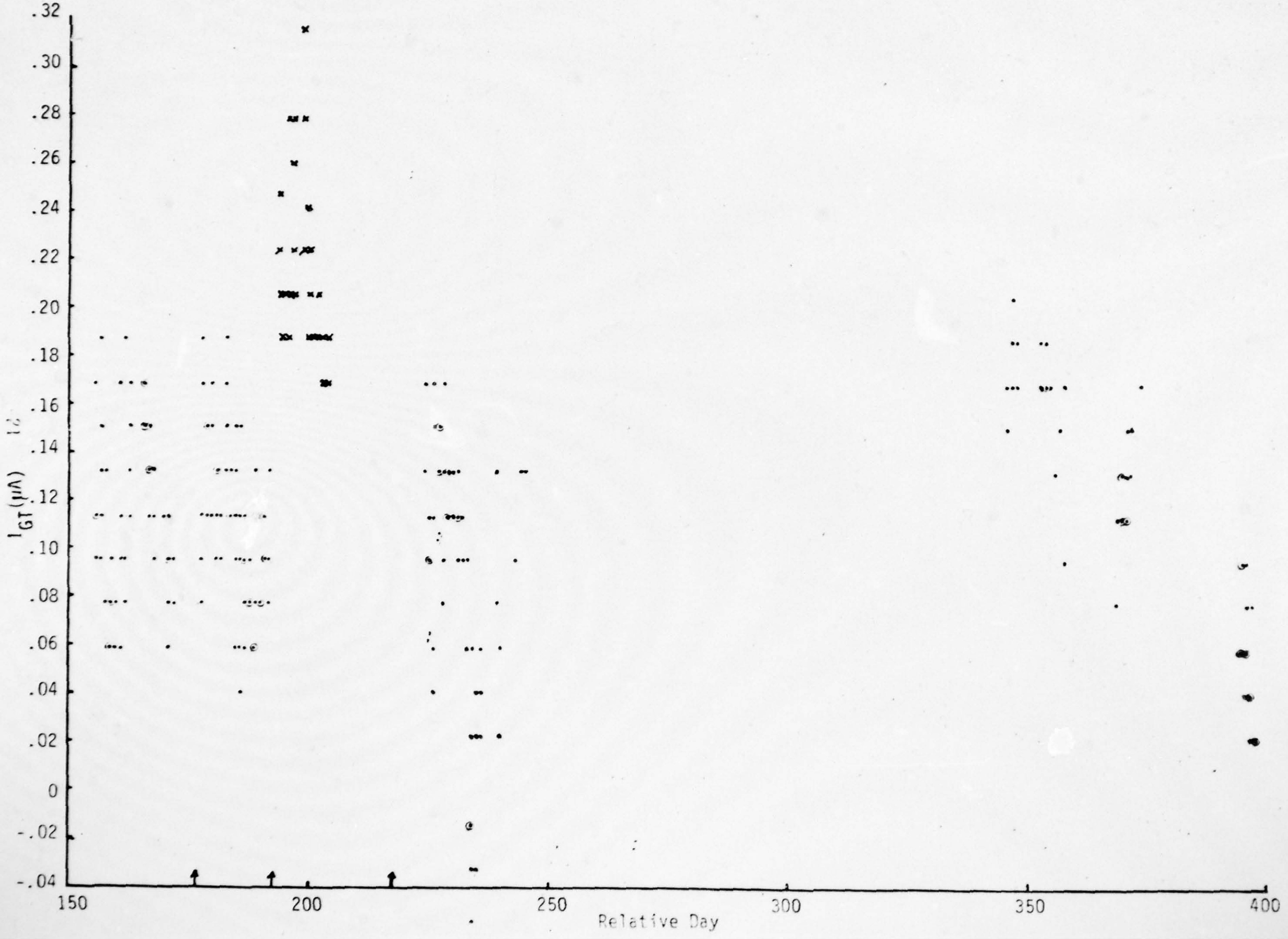
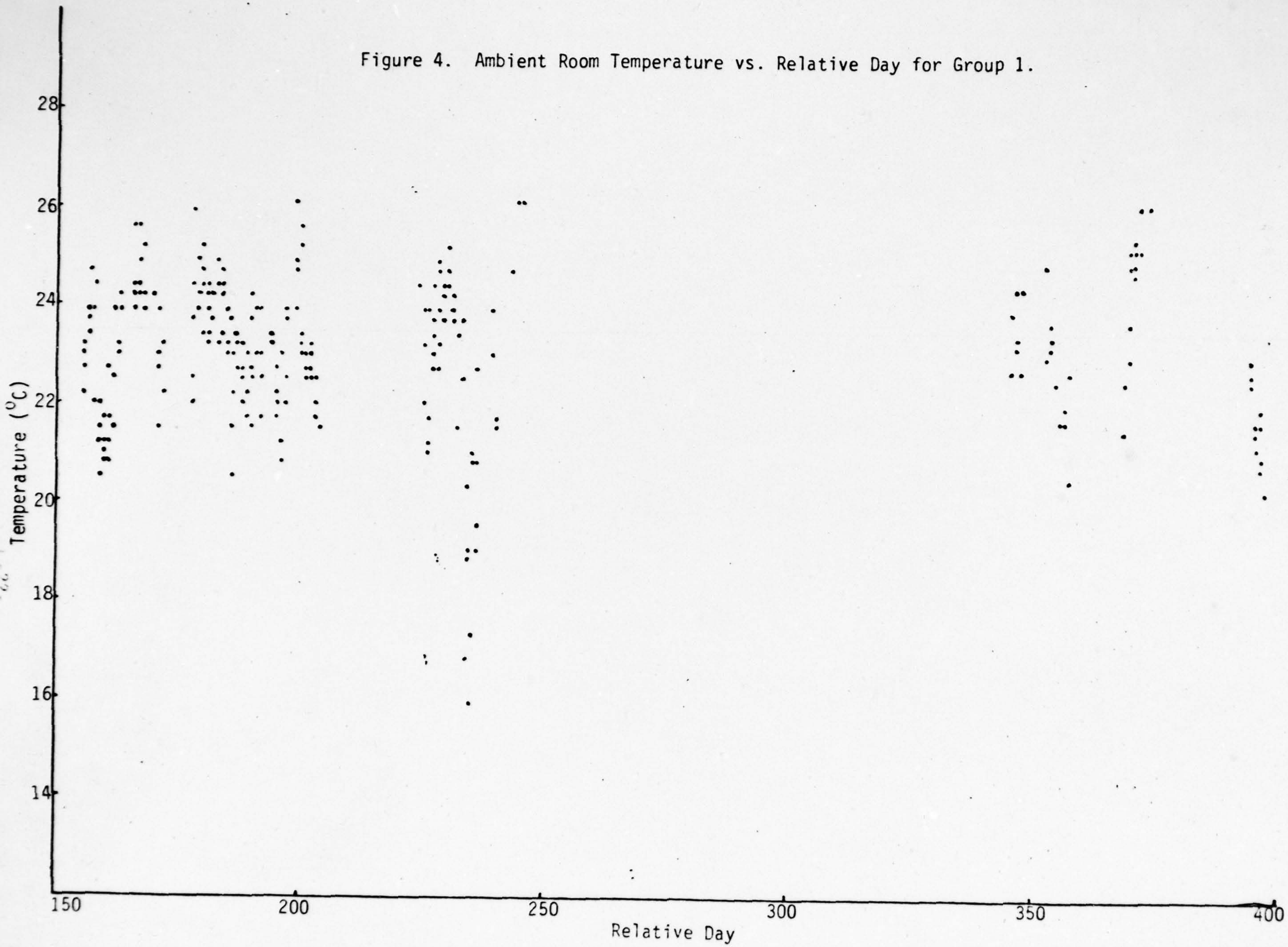


Figure 4. Ambient Room Temperature vs. Relative Day for Group 1.

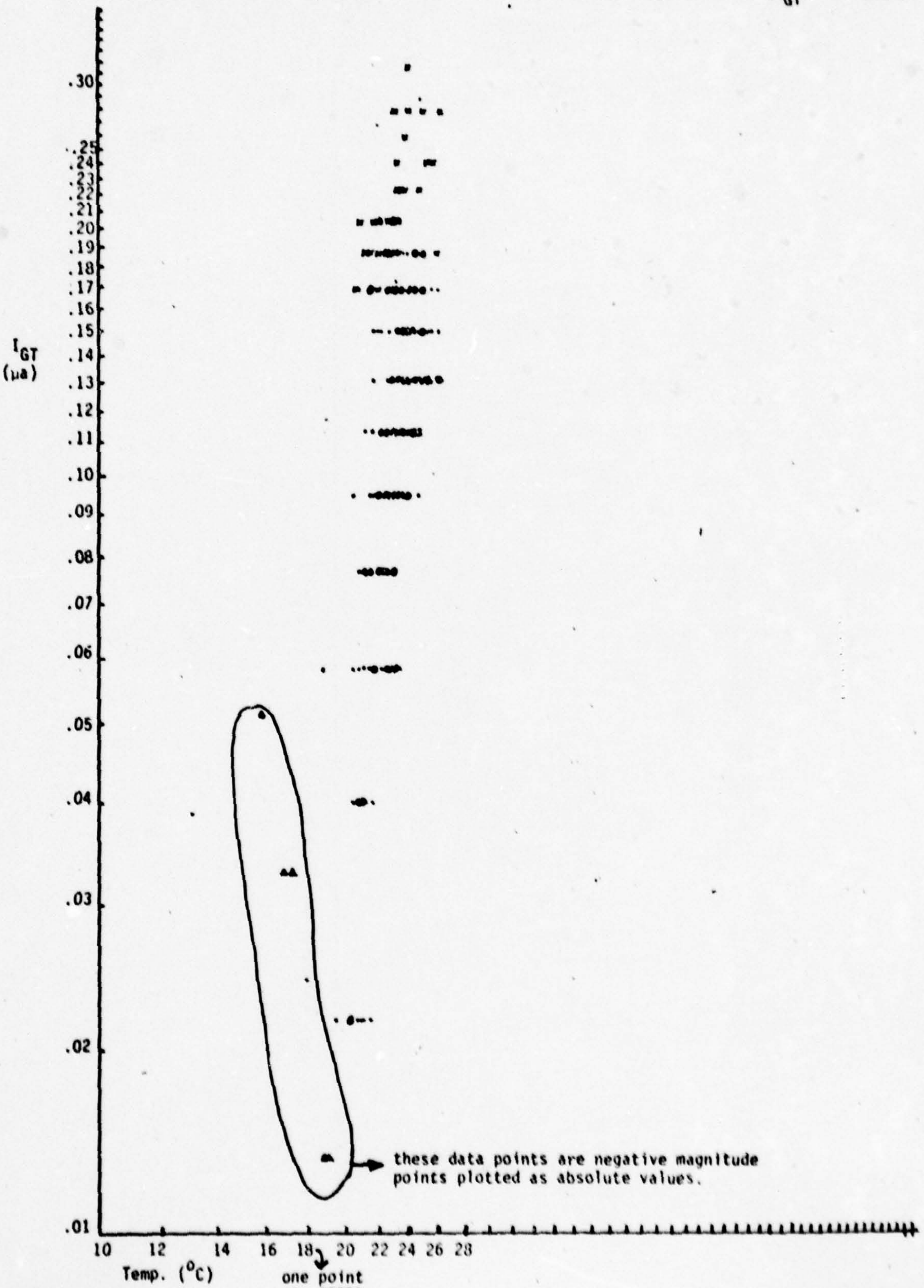


figures. There is an overall similarity between this figure and the previous one which is striking. Even the fundamental disparity between the two graphs from day 192 through day 205 lends credence to the view that this particular cluster was primarily associated with the results of maintenance procedures, and secondarily with temperature effects. The cluster can be shown to be uniquely determined by the two to well within the system's measurement error. The remaining data on Figure 4 clearly has a strong resemblance to its counterpart data in Figure 3. A short numerical effort is sufficient to demonstrate that temperature and maintenance effects, considered as determinate perturbations, are more than sufficient to mask any real signal.

There are two unusual features of Figure 5 which again presents component number 9. The first is the recurring negative magnitudes which are artificially displayed with absolute magnitudes and encircled points. Even a minimal exposure to semiconductor device physics should make a reader aware that this is an absurd result for SCR operation. These points must be attributed to noisy data acquisition. The second notable feature of Figure 5 is the positive slope of the gate trigger current versus temperature. Since the ordinate represents the magnitude of additional gate current necessary to trigger the SCR from its quiescent condition, the gate trigger current decreases with temperature due to ordinary thermal carrier generation mechanisms. The predicted, as well as unfailing empirical, result will always be a negative gate trigger versus temperature slope if indeed you are measuring a real device signal. Consequently, the fact that the slope is positive is clear evidence that something different than real device gate trigger signal is being measured. The temperature dependence of the data acquisition system is presumably the primary source of this result.

The measurements performed for component number 9 of the group of SCR devices have now been summarized by Figures 2, 3, and 5. Remember that this component, in the original documentation, was chosen as one of the outstanding examples demonstrating aging phenomena. In fact, as has been outlined, the measurement instrumentation is not even capable of detecting a physical useful signal for this component, let alone aging phenomena. It is unfortunately true that if one proceeds to examine the leakage current

Figure 5. Device Type 3029 : Component No. 9 - Gate Trigger Current (I_{GT}) vs. Temperature.



these data points are negative magnitude points plotted as absolute values.

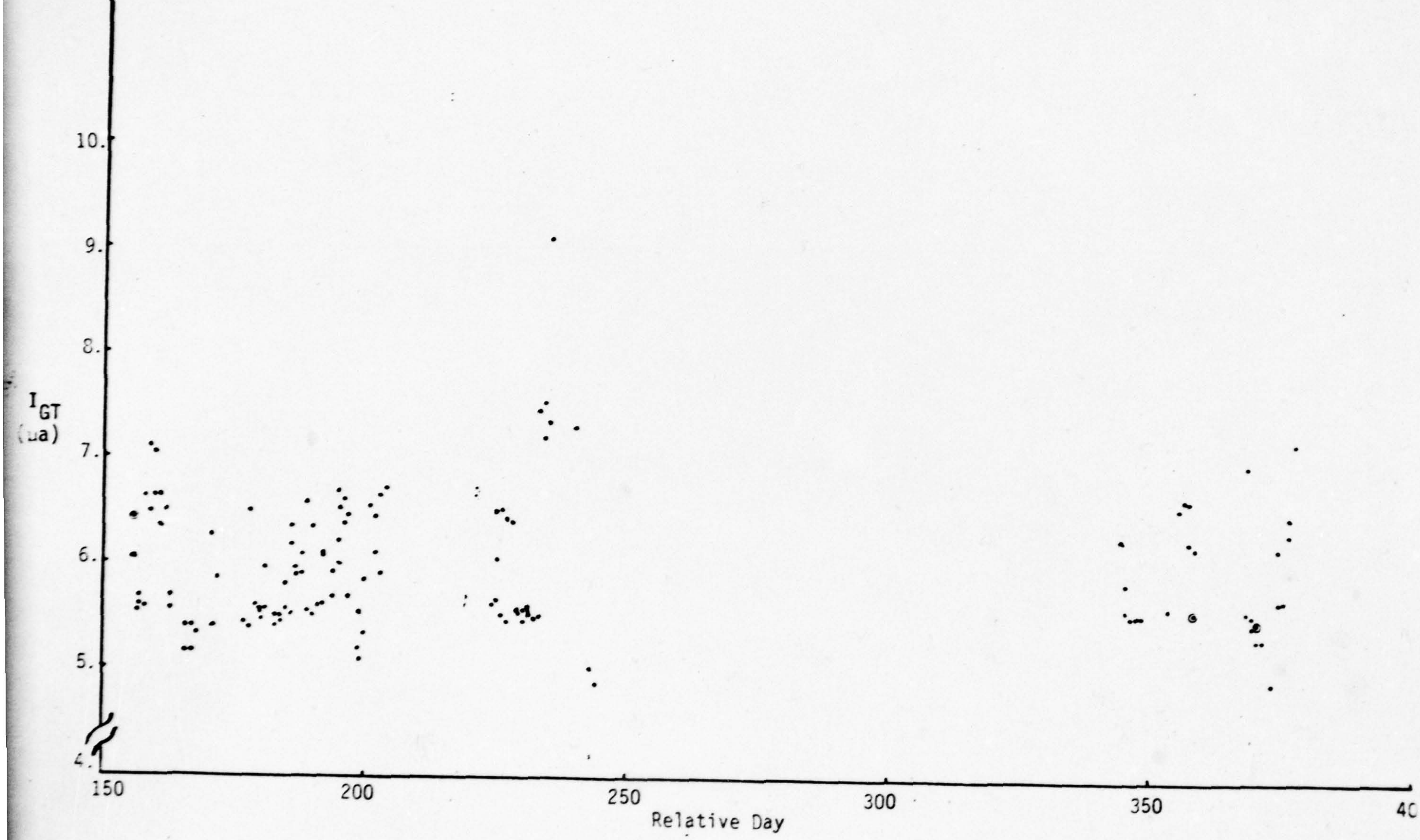
one point at .00351 for day 19

measurements for all the remaining SCR components, the same conclusions must be drawn. In essence this means that all SCR leakage current measurements are meaningless, regarding even the establishment of any normal electrical baseline performance and disregarding altogether any detection of possible aging effects. As will be noted later, these same comments apply to both the quiescent current and total current measurements for the IC triple-inverter device type. Thus, for the total production experimental program, none of the current measurements provided any reliable or credible data by either our arguments or those of the previous documents.

Figure 6 shows a plot of the gate trigger current versus relative day for component number 15. The results reflect environmental temperature variations as expected. Note the large excursion around day 235 when there was a particularly low temperature condition. Comparison of this figure with Figure 3 gives some idea of the appearance of the credible data relative to system noise anomalies for the gate trigger current measurement.

Figure 7 shows the experimental data for gate trigger current versus temperature. As can be seen, this data for component 15 shows a negative linear log-log slope, which is completely in accord with theoretical expectations based on proven physics of SCR operation. It is reasonable to ask what are the major differences between components 15 and 9 which give rise to such different results. One obvious answer is that the magnitude of the gate current for component 15 is significantly above the minimum discrimination capabilities of the measurement instrumentation. Thus it is easy to distinguish the presence of real signal, with its expected temperature dependence, from whatever associated noise exists during the experiment. This is not true of component number 9. Whatever may be the true magnitude of the gate current for component number 9, it is clear that it is indistinguishable from noise and is at least at, if not below, the measurement capabilities of the system. One would suspect in the normal circumstance that the 30 SCR components used in this study were part of a large population having some statistical distribution (more often than not, a normal distribution if unselected) with respect to the gate trigger current parameter. Further, one would suspect that perhaps component number 9 fell at the low end of the distribution

Figure 6. Device Type 3029 : Component no. 15 - Gate Trigger Current (I_{GT}) vs. Relative Day.



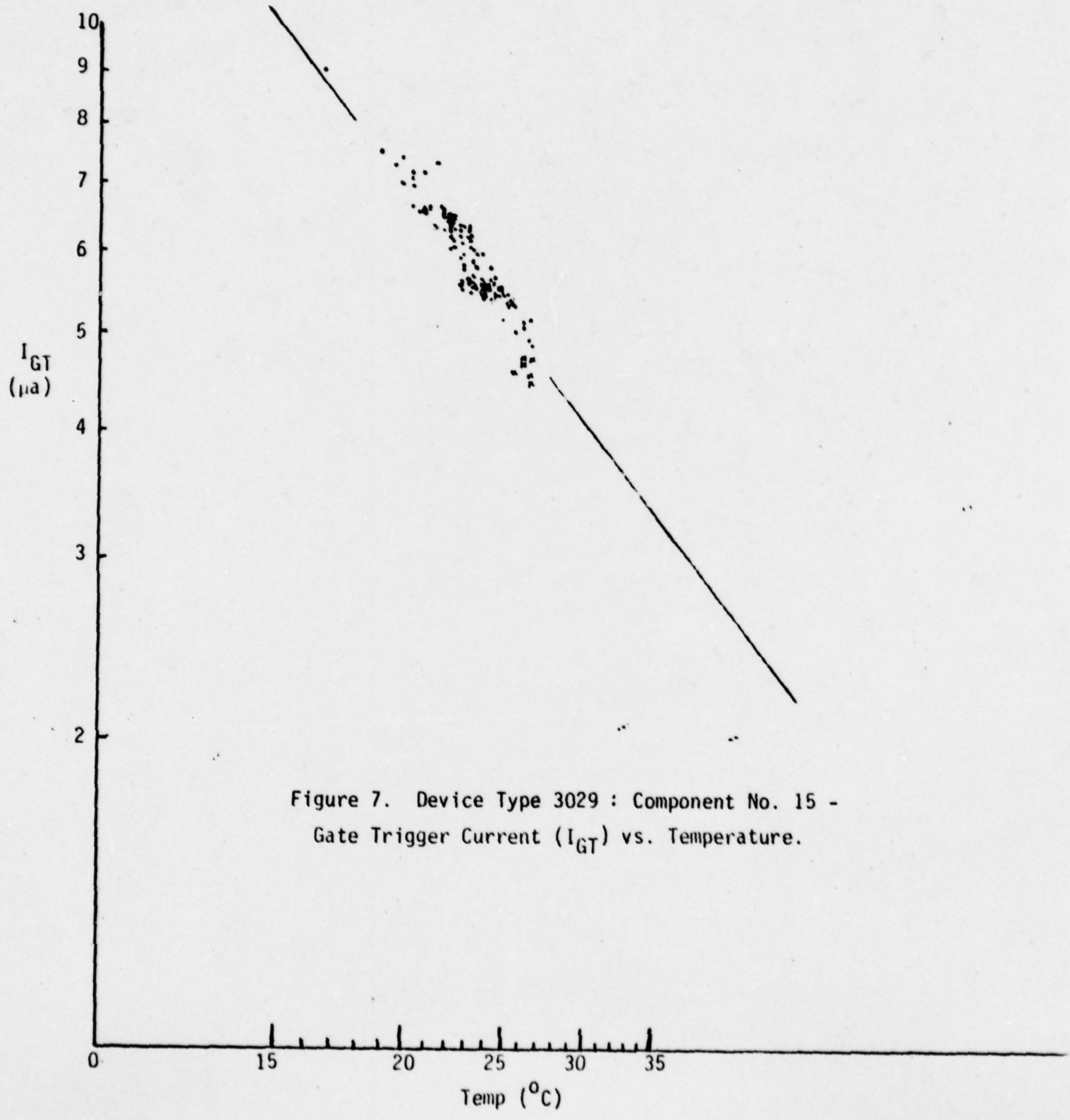


Figure 7. Device Type 3029 : Component No. 15 - Gate Trigger Current (I_{GT}) vs. Temperature.

with respect to gate trigger current magnitude, and that as the magnitude of this parameter increases for individual components, a transition between Figures 3 and 7 would be evident when comparing each component to all the others. This is precisely what does occur and the demonstration of this phenomenon is given in Figure 8. Starting with component number 8 at the extreme left in this series of plots of gate trigger current versus temperature, the reader finds an almost vertical dispersion of experimental points and a hint of a visual best guess as to an appropriate slope. As the sequence progresses, the data dispersion appears to be decreasing with increasing magnitude of gate trigger current and there is successive reduction in the magnitude of the positive slope, such that by plot 4 the data has passed through a zero slope condition to a negative slope condition. In the remaining plots of the sequence, also arranged in order of increasing current magnitude, the plots eventually attain a dispersion condition where a negative slope can be credibly fit. The preceding description, of course, is but a fanciful and shorthand way of describing the simple phenomena underlying the changes observed in the sequence of plots. In actuality, somewhere in the vicinity of 1 μ amp the current magnitude is sufficiently larger than the measurement system noise and error sources to indicate the expected gate trigger current characteristics with temperature. (Remember that the measurement represents only the <u>additional</u> amount of current necessary to trigger SCR action from an <u>off</u> to an <u>on</u> state.) The second trend which is noticeable in the sequence of plots is that the low temperature points rise more rapidly with increasing magnitude of I_{GT} than do the high temperature points. This accounts for what appears to be, upon cursory examination, a rotation of the slope as one steps through the sequence of plots.

The situation regarding SCR gate trigger currents is not quite so bad as that described for the other currents. Approximately half of the SCRs demonstrated measurement magnitudes which were sufficient to display temperature dependency consistent with the known physics of device operation. Recall that Figures 6 and 7 displayed the gate trigger current data for component number 15. This SCR component did produce credible data when tested with the measurement system used in this experimental program. This particular component was singled out in the unauthorized document as an example of a component

Figure 8. Device Type 3029: Series of Plots of I_{GT} vs. Temperature for 18 Individual Components.

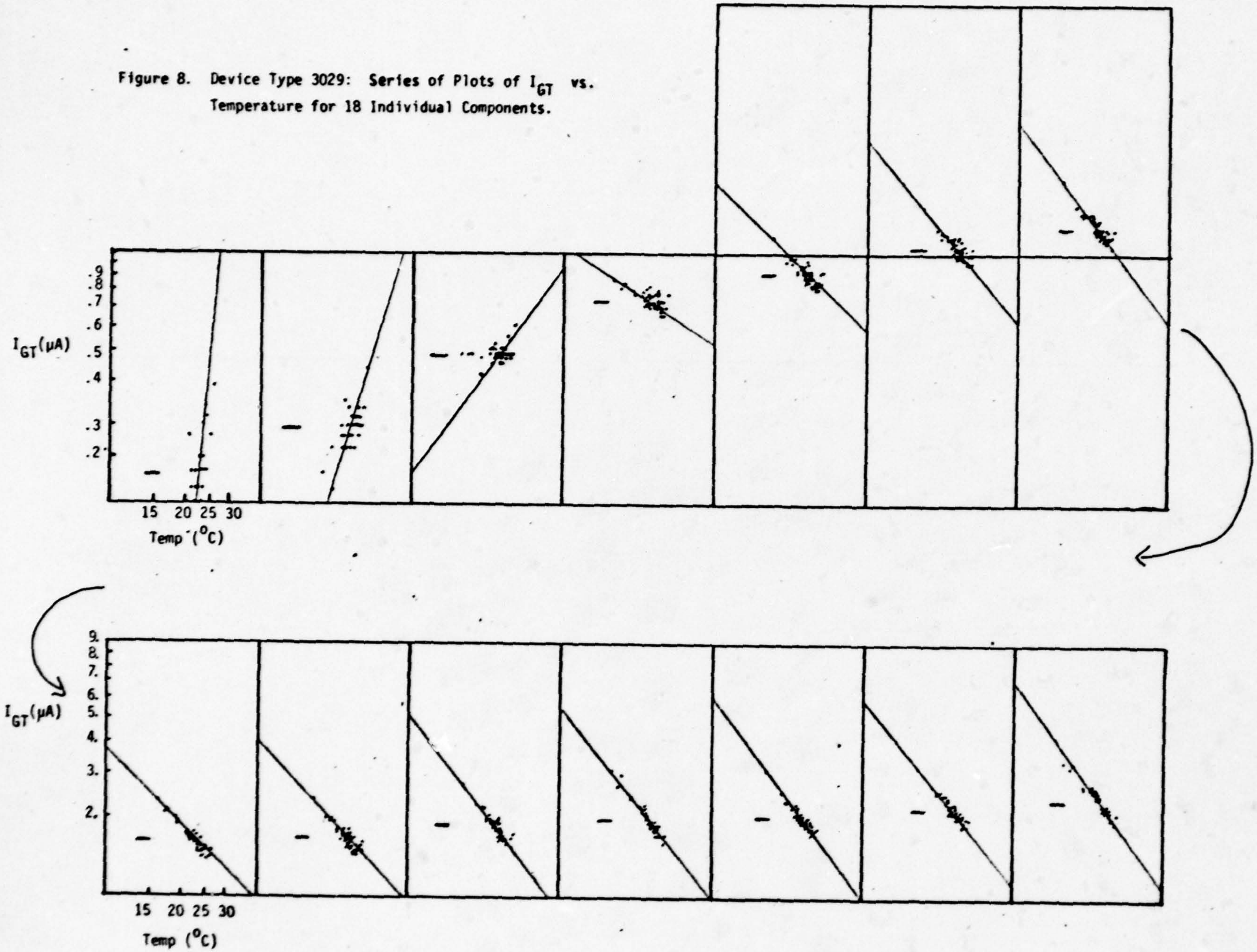
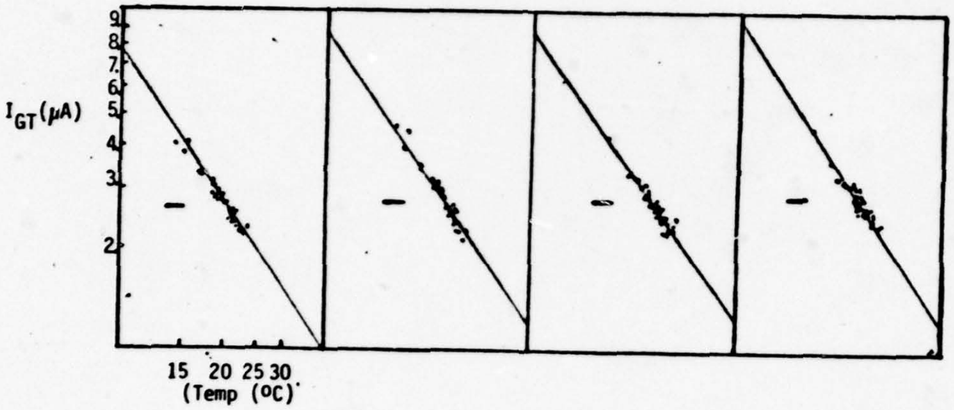


Figure 8. (Cont'd)



which did not show any aging. That is certainly the case. In fact, in none of the components which gave reproducible measurements could there be found any evidence of aging. However, it is curious that the other references single out precisely those components which show a high degree of noise as prime examples of aging phenomena. The reason for this has, we believe, been made abundantly clear by the preceding text.

The next series of figures all pertain to the triple inverter IC device type. The series is much abbreviated compared to the SCR device in order to avoid needless repetition of arguments offered previously. For example, current measurements were demonstrably useless. Two additional points can also be made. The first is that the low output voltage measurements for this device type are suspect for all the analogous reasons which pertained to low magnitude current magnitudes for the SCR devices. However, no definitive quantitative analysis was done which could support making a flat statement about the credibility of the low voltage measurements. The second point is that the triple inverter device type is highly temperature insensitive, both by design and in actuality, as compared to the SCR device type. Figure 9 shows an example data cluster for the low-output voltage of inverter number 3 of component number 5 versus temperature. Within the error and sensitivity limits of the measurement system, there are no surprises. The high output voltage data of this same component and inverter number is shown, in Figure 10, in an expanded linear-linear scale. This data, as the figure caption notes, is only given through relative day 200. Again, the scatter and clustering is what would be expected given the system capabilities and temperature insensitivity of the device. Figure 11 presents data similar to Figure 10 but through relative day 397. Visually, at least, there is nothing to suggest that any time- and/or temperature-dependent aging phenomena is involved. The extra 197 days of data added merely increase the overall density in most areas. Yet this particular component among the triple-inverters warrants closer attention, since it is one of the components noted for supposefly displaying distinctive aging phenomena.

Figure 12 shows the same high output voltage for the same component plotted versus relative day. The small vertical arrows along the abscissa indicate system maintenance days. As noted previously, system response and

Figure 9. Device Type 4007: Component No. 5 - Inverter No. 3 Low Output Voltage vs. Temperature.

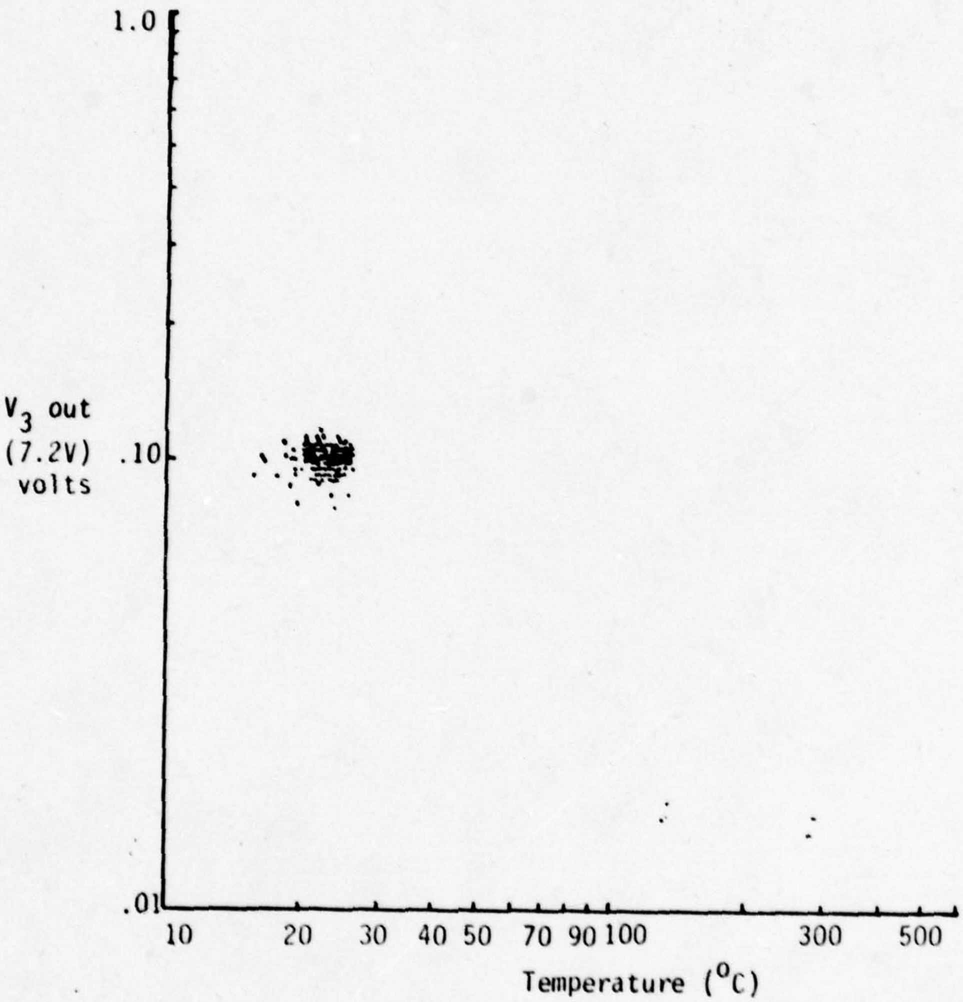


Figure 10. Device Type 4007: Component No. 5 - Inverter No. 3 High Output Voltage vs. Temperature (through relative day 200).

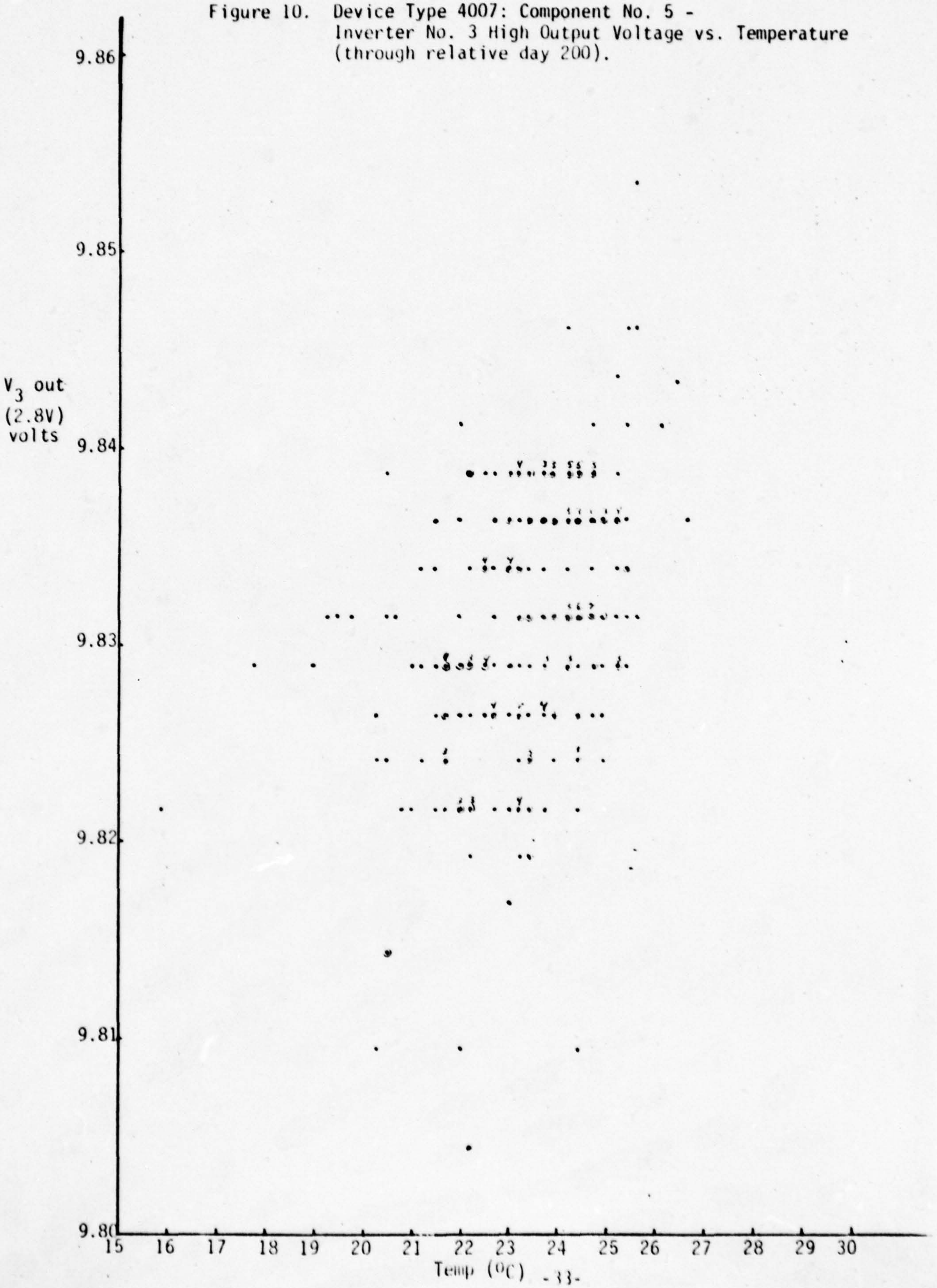
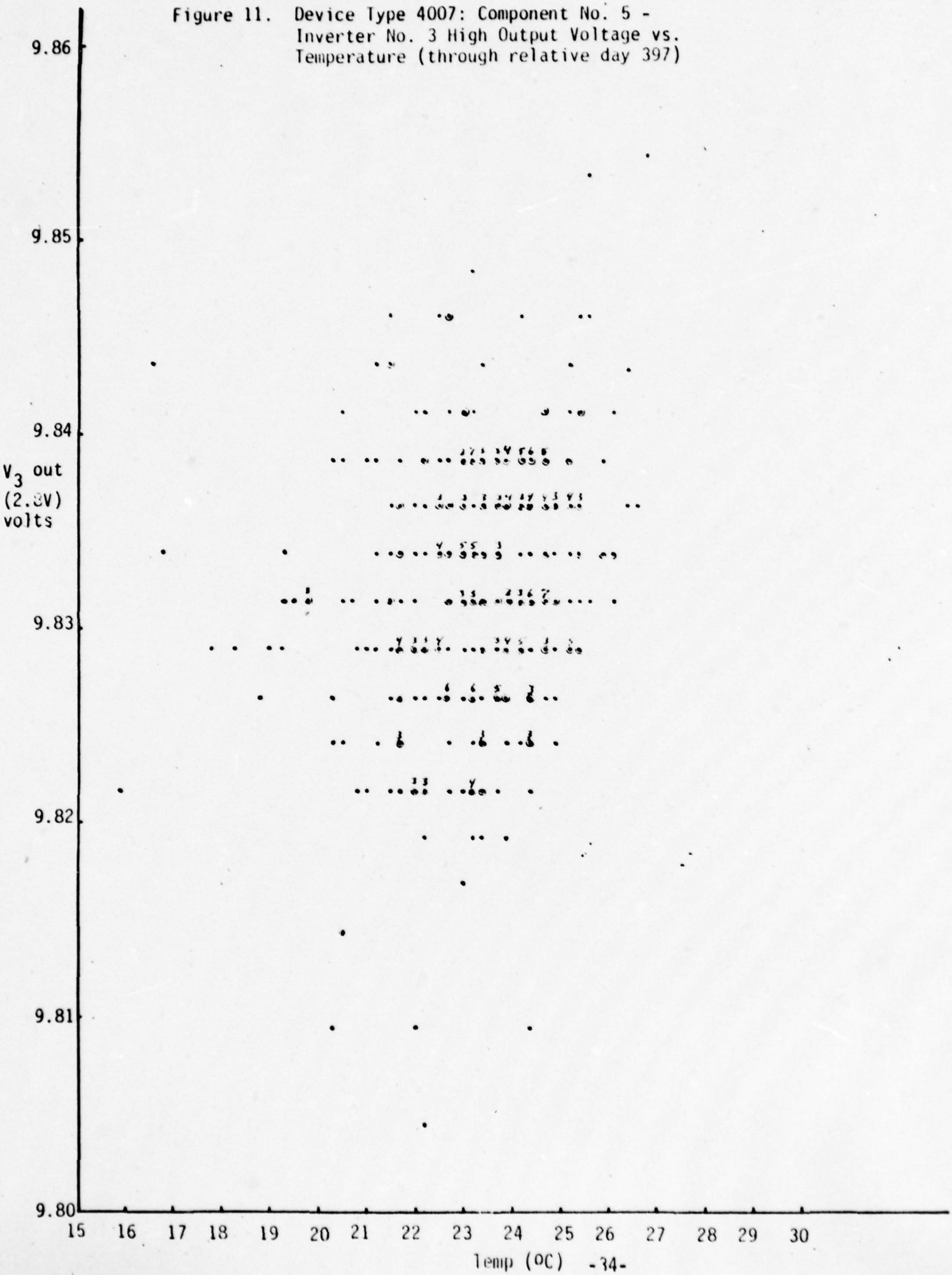


Figure 11. Device Type 4007: Component No. 5 - Inverter No. 3 High Output Voltage vs. Temperature (through relative day 397)



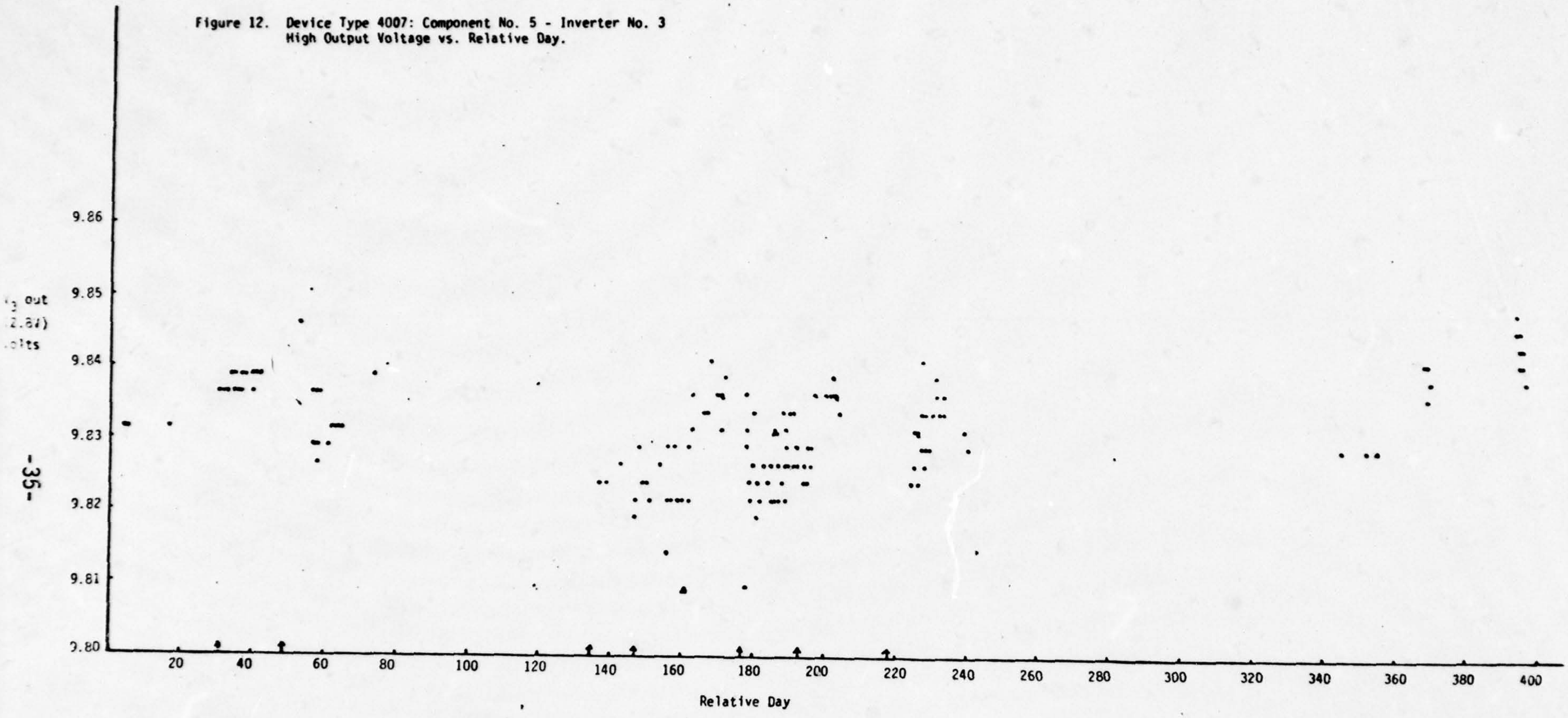
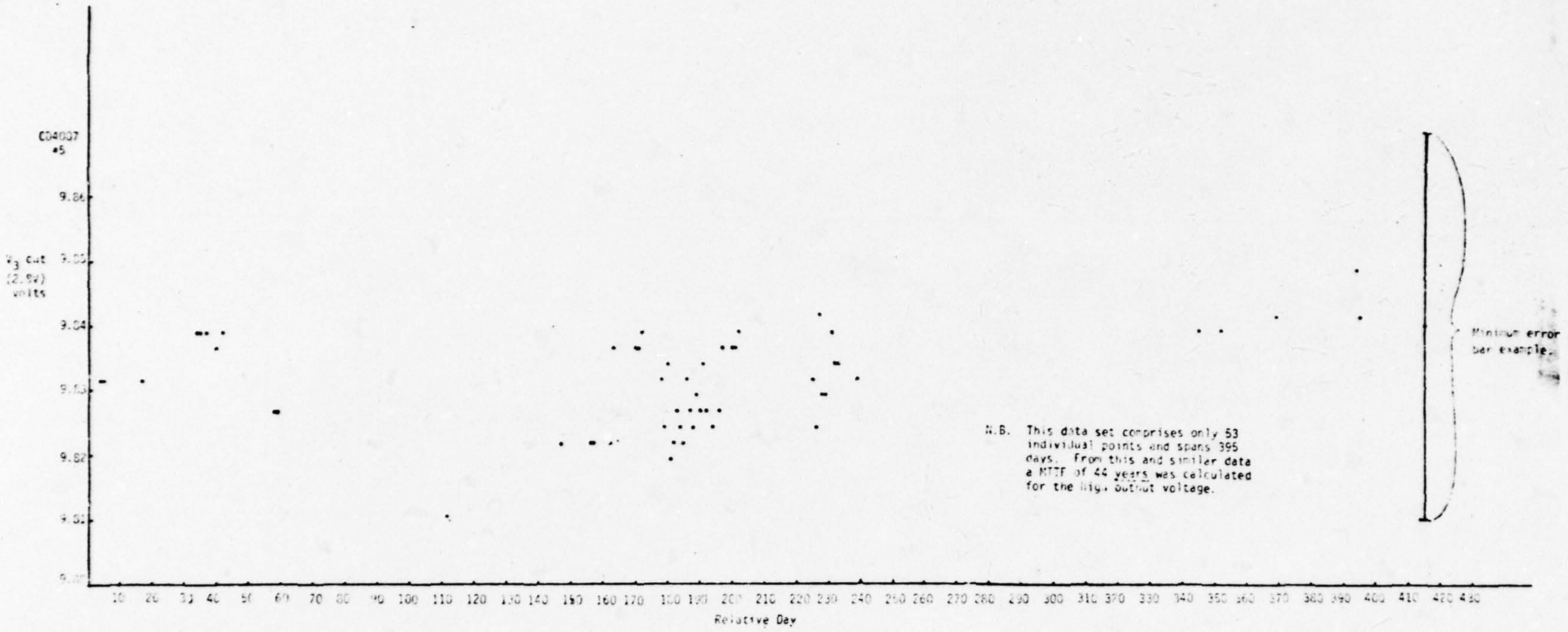


Figure 12. Device Type 4007: Component No. 5 - Inverter No. 3
High Output Voltage vs. Relative Day.

measurement anomalies have a tendency to be associated with maintenance activities, particularly at or near system threshold measurement capabilities, although unique combinations of adjustments during maintenance procedures could easily give rise to perturbations at higher signal magnitudes. These changes in baseline and the appearance of noise-like behavior in the measurement system for a few days after maintenance procedures are common to all test electronics, not only the system being used in these experiments. There is no evidence in the documentation that due account was ever taken of the phenomena noted above while the experiment was in progress and so we are left with unanswerable questions regarding the effects of system maintenance among and between the three sections of data shown in Figure 12. In fact, we know nothing whatsoever regarding system maintenance between day 240 and day 400. On the basis of previously analyzed data in this program, however, we are certainly justified in being skeptical as to whether the visual average of the points in each of the separated sections of data in Figure 12 represent apparent or real shifts with time. Previous experience suggests the shifts are not real and instead are associated with instrumentation anomalies, let alone the obvious difficulty of low density data in the data sections at either extreme of the time scale. The problems just noted are intensified when a decision is made to restrict data analysis to a one degree temperature band, because the density of data is cut by a significant amount.

Figure 13 shows the result of just such a temperature restriction for the component presented in Figure 12. Besides the difficulties already mentioned, we should be reminded that the error bars for each measurement point are at least ±30 mv (see example at righthand end of Figure 13), and which amounts to approximately three times the data magnitude spread in any section. Given the total situation, this is certainly not an instance in which a thoroughgoing statistical analysis, complete with least square fitting and multi-year extrapolation should be attempted. However, this is a typical example of the nature of the data for which all inverter statistical calculations and mean-time-to-fail predictions were performed. As noted earlier, this particular component was assessed as one demonstrating significant aging.

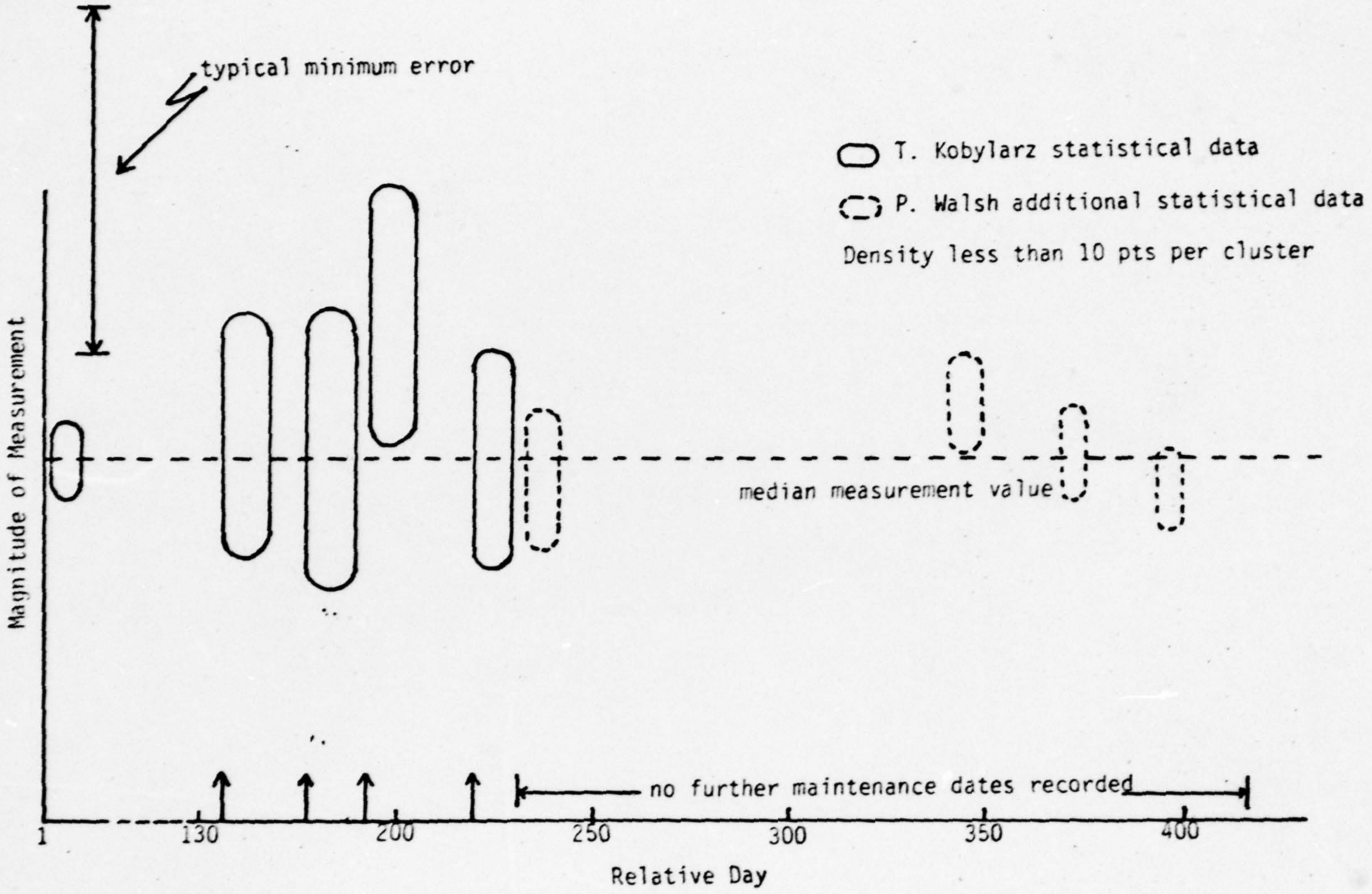
Figure 13. Device Type 4007: Component No. 5 - Inverter No. 3
High Output Voltage vs Relative Day (for T-23-24°C).



N.B. This data set comprises only 53 individual points and spans 395 days. From this and similar data a MTTF of 44 years was calculated for the high output voltage.

The particular data set shown in Figure 14 comprises only 53 individual points and spans 395 days. From this and similar data a MTTF of 44 years was calculated for the high output voltage (IEEE document). Based on the 120 mv error estimate of the documentation and their statistically derived slope, it would take approximately 13 years of production testing for the signal to climb out of the noise!

Figure 14. Typical Data Plot



SECTION 7

SUMMARY OF DATA ANALYSIS

The data analysis has been reviewed through each of the major points. Figure 14 is a symbolic plot of an arbitrarily chosen measured variable which previously was claimed to display aging phenomena. Notice, it is not suggested that this figure represents the few gate trigger current measurements which all documents agree are not aging, but rather those current or voltage measurements on components supposedly aging. The magnitude of the measured variable versus the relative day is presented. The reason that a single plot adequately describes all these measured variables is that the mean-time-to-failure predictions depend on the periods of data acquisition, the effects of maintenance, the temperature restrictions, and the noise level, but was emphatically independent of the measurement of a reliable signal. In Figure 14, the statistically processed data clusters, the typical error magnitude, and the dates of routine maintenance efforts are designated. The solid data clusters are those examined by T. Kobylarz and the dotted data clusters are the additional ones included for consideration by P. Walsh. The clustering itself is the result of routine maintenance early in the production testing period and is assumed to be responsible for the remainder, although no further dates are available to us. The data scatter within a cluster is an obvious reflection of the data acquisition system's measurement error. The variation of base line value within a cluster is the expected alteration caused by maintenance procedures. The average number of points per cluster in the temperature ranges statistically processed is less than 10. Consequently we have a very few points dominated by noise and maintenance. Next the cross-hatched cluster almost solely determines any slope drawn, since all others are near the median measurement value over the entire production period. Whether this region is above or below the median is a function of the parameter measured, but it is always pathologically displaced in an understood dependent manner. The statistical effort of T. Kobylarz evaluated a slope for each measured parameter which characterizes aging. That is, each parameter is claimed to manifest a time trend toward non-catastrophic failure modes through an unknown aging phenomenon. Believing Figure 14 leaves the reader with the conclusion that all of these predictions are due to an unfortunate maintenance shutdown which generated the environment for the crosshatched cluster. The statistical effort of P. Walsh found nearly identical results, except for the SCR leakage current, but the slopes were generally reduced in magnitude, implying a longer period before failure. The extended life interval is merely due to the addition of the later time data near the median measurement value. However, for the leakage current the slope actually reversed sign between the two calculations suggesting that this parameter now implies the SCR improves with age in this particular respect. This result, although not exclusively forbidden by the previous arguments, troubled us for some time since it is somewhat contradictory. It also surprised the previous workers and a considerable amount of time is spent in the unauthored document concerning possible physical sources of a reversing trend in aging. The answer is, as it turns out, simply due to the exclusion (as anomalous data) of the crosshatched cluster from the statistical processing of the leakage current only. The reference to the omission is the obscure footnote in the unauthored document, table I, pg 9. After excluding that region, the slope can be reasonably predicted to have either a positive or negative value as long as it remains small in magnitude. From all of the previous comments we must conclude that (1) there is absolutely nothing in the data bank which is sufficiently reliable to make mean-time-to-failure predictions, and (2) no reasonable theoretical physicist would consider attempting predictive modeling of such results.

With the summarization of the data analysis complete and the suggestion that the entire effort was unfortunate, it appears appropriate to inquire if T. Kobylarz was aware of the problems in both the acquisition system and the processing software before offering mean-time-to-failure predictions. We again interrogate the documentation. Rather than redundantly quote many items reviewed earlier we restrict ourselves to a group of three different items that indicate the extent of his knowledge. They are by no means exhaustive of the possible choices. They were selected to exemplify difficulties of various types including problems with the acquisition system, statistical packages, and both device types. It appears possible to accuse us of removing the quotes from context such that they leave an altered impression. Should the reader question anything presented here we invite him to carefully read all of the documentation and decide independently. Extreme caution should be exercised when reading for the subtle interrelationships between documents, equations, figures, and tables. All references should be read immediately when encountered.

In addition to the situation where the parameters measured for the IC were of insufficient accuracy to enable statistical evaluation of aging trends, there are references in the 1975 document to a malfunction of the IC test set. This malfunction, although not detailed, apparently was of sufficient magnitude to encourage the author to declare the data for the IC device unreliable and to state that his predictions for mean-time-to-failure were inaccurate. Specifically from that document note the following two passages:

(a) Footnote pg 1-24, immediately after his predictions:

> "It has been recently discovered that the subsystem utilized for measuring the total input current and quiescent current contained a malfunction. Therefore, these predictions are inaccurate. This information has not been omitted since it may be of interest in the future, when reliable data is analyzed."

(b) And later in the error discussion, pg 2-6:

> "A final, but very important comment concerning error, must be included within this section. Subsequent to the analysis, a malfunction was discovered within the current measuring subsystem of the IC test set. Erroneous data was generated which escaped detection by various checking features established for the data acquisition system. As a consequence, analysis was unknowingly performed with an appreciable amount of erroneous data. Although it most certainly has effected analysis results, the extent is yet to be determined."

Both of these comments clearly indicate that although at least a significant portion of the data was totally unrelated to the device in question, the statistical package processed all data for mean-time-to-failure calculations regardless of its nature. Details of this malfunction, particularly its nature, duration, and dates of discovery and repair, would be critical to any theoretical modeling efforts for this device. A private telephone conversation with T. Kobylarz on September 2, 1977 suggested a memorandum concerning this matter was written presumably sometime during 1975, but we have no copy available for reference. His brief oral description of the malfunction left unclear how extensively the problem damaged the IC data.

The next passage is considerably more subtle and involves the application of the mathematics discussed in the 1975 document to the statistical software. In section 1.2.1 there is a discussion of the technique used to compute the median that was applied "to somehow average the data and thereby 'filter' random perturbations." The algorithm for a modified linear least squares curve fit to the weighted median data is presented in section 1.2.2, and it is admitted that "variations in the measurements are primarily due to noise perturbations and a measured parameter is essentially constant at its mean value." Assuming that the median computations are representative of mean behavior, the routine which exponentially extrapolates the slope determined by the curve fit is presented as the model for prediction of mean-time-to-failure in section 1.2.3. Now at the beginning of section 1.2.4 (1975 document, pg 1-19), we encounter the comment:

> "Several parameters were usually at extremely small values near the system sensitivity limit. As a consequence, sizable error exists within such measurements and the time variation computations, described in section 1.2.1, cannot be reliably applied. Histograms (5) were used to derive trends from such data."

Recall that the system's sensitivity limit is substantially below its absolute error. Consequently, the author has said his most reasonable form of the prediction algorithms cannot be reliably applied due to insufficient measurement magnitudes on several parameters. Next, it is reasonable to inquire how the use of histograms altered the evaluation of the means from the data. Regarding this we note the same document, pg 1-21:

> "The parameters which had histograms were divided into two time periods. That is, histograms were determined for a first half time period and a second half time

> period. Knowledge of the means for each time period permits extrapolation as was described in section 1.2.3. The program shown in tables 1-2 and 1-3 are run as usual, having only two time intervals (periods)."

Reexamining Figure 14 for the solid data clusters and dividing those clusters into only two histograms, it is especially clear that the cross-hatched region determines the slope used for exponential extrapolation.

The last reference to be considered in this discussion is a simple admission that throughout the production testing the system was unable to accurately measure the leakage current of an SCR. The comments are similar to those previously reviewed in the section on first consistency testing. From the 1975 document, pgs 3-1 and 3-4, we have:

> "Although the data acquisition system measurement capabilities exceed the typical-to-maximum range, it is not believed that measurements can be accurately made in the neighborhood of the minimum leakage current."

Also, the author points out that the computed means were approximately equal to the offset error and hence the histogram approach was employed for the leakage current.

ADDENDUM I

LITERATURE ON SEMICONDUCTOR AGING PHENOMENA

INTRODUCTION

The following examples provide instances of the typical kind of information which can be found having some bearing on the dormant aging problem. There is a paucity of relevant information, as will be seen, particularly with respect to non-stressful experimental conditions. However, some aspects of the physics mechanisms which were attributed to the observed device failures are likely to be points worthwhile remembering in setting up, and in interpreting, data from dormant aging experiments. So far, there does not appear to be any aging phenomena which would require the postulation of new physics principles.

2. LONG-TERM LIFE-TESTS OF INDUSTRIAL POWER THYRISTORS (SCR'S).

Schwickardi, G.G (1976). IEEE Transactions on Reliability,
vol. R-25, No. 2.

A long-term life-test of over 50,000 hours was performed on 72 SCRs. Samples (150A rating) were drawn from the 9 most important producers of these devices in Europe, Japan, and the USA. The types tested had four layer P-N-P-N construction and P-gate formation, with a diffused P-N-P wafer and an alloyed, mostly gold-antimony cathode. At the beginning of the investigation, a wide range of mechanical, chemical, thermal, and static electrical tests were performed on all samples. During the investigation, all devices were tested under characteristic conditions corresponding with manufacturer's data sheets. Measurements were made at 2000 hr. intervals.

The main test results included decreasing or increasing forward blocking voltage, instabilities, and hysteresis effects of the reverse and forward blocking voltage, changes in forward gate current, some groups with no typical failure effects, and some groups, with little, if any, parameter drifting. Examination of the physical devices showed that there were technological faults which could account for the observed electrical phenomena. The failures of the reverse and blocking characteristics were found to be caused by badly constructed surfaces and cathode contacts, badly contacted gate points, and microcracks in the bulk material. Changes in the on-state characteristic resulting in failure were caused by improper and faulty solder contacts or alloying layers, irregularities in the alloying layer, and badly contacted pressing contacts. Failures in firing characteristics were caused by improper surfaces, too narrow space between cathode and gate contact, and localized burning spots in the gate region. There does not appear to be any mechanism uncovered in this study which is suggestively related to dormant aging. The physical failures and drifting out of tolerances of parameters to a failure condition appeared sporadically and were not predictable at the beginning of the study. Lessons learned from this study which may be relevant to dormant aging investigations are that extrapolation from short times would have given wrong results, systematic flaws were found to have an unknown time constant for appearance, no correlation was found between short-term test results and long-term reliability, and it was not found possible to specify an exact measurable parameter that shows from short-term life-testing which devices will be good and which ones will be bad.

3. STORAGE RELIABILITY OF CHIP AND BOND WIRE ELECTRONIC DEVICES

Frank, R., McTigue, L., and Provence R. (1976) 26th Electronic
Components Conference, San Francisco, April 26-28, 1976.

An eight-year dormant storage reliability and parameter drift study was performed on over 10,027 MINUTEMAN chip and bond wire Resistor-Transistor Logic (RTL) devices. Each of these function-isolated Motorola components was burned in (168 hours at 125° C) and then tested to record the performance of each parameter before storage. The components also received additional screening and qualification tests. After the storage time was completed, all parts were subjected to GO/NO-GO testing to detect failed parts. A random sample of 2573 parts passing the GO/NO-GO testing were subjected to the parameter drift test program. This program encompassed measuring and recording selected currents and voltages representing resistor characteristics, transistor currents, voltages, and leakages current rates.

Three parts failed the go/no-go test as a result of the eight years of storage, and the failure causes were traced to oxide defects which allowed the deposited aluminum metalization to contact the active silicon of the die and short to ground. There were no bond wire failures, corroded or broken external leads, or package problems. The parameter drift measurements showed that the resistor elements were virtually unchanged from their original values. The transistor elements, however, showed a significant degradation in output voltage characteristics which was traceable to a loss of gain. The gain changes were attributed to growth of a "parasitic transistor" condition and/or to changes in the gold doping profile. About 2% of the parts measured had drifted close enough to the specification limits to be labeled as "incipient failures."

The parameter drift test program encompassed measurement of seven different parameters on each of the seven types of logic functions (twin buffer, adder, double gate, 4-input gate, half adder, register, and expander). Only the transistor elements showed a measurable loss of performance during the eight years of storage. The degradation appeared in the output voltage characteristics. Two of the devices, the Expander and Double Gate, showed statistically significant increases in both mean and standard deviation at the 99% confidence level. These demonstrated drift rates of 0.5 - 1% per year in mean value and 2-4% per year in standard deviation. Based on the author's choice of specification limit, they estimated overall that approximately 2% of 10,027 parts could be classified as incipient failures due to dormant aging drift phenomena in an approximate 10 year time frame. Although transistor gain was not one of the logic function output parameters and was not measured directly during testing, the only parameters demonstrating significant drift were those dependent on transistor gain. Using an analytical method to derive the gain values, the loss in gain after 8 years storage was computed for each one of a statistical sample of 78 parts. A plot of the results indicated that the highest rate of drift occurred in the parts with the lowest initial gain. A least squares fit to the data showed an average of 20% change in gain for the low gain devices, decreasing to about 10% for the high gain devices.. The dormant storage-induced gain changes in these parts were attributed to canges in the gold doping and/or changes in the "parasitic transistors."

This study does have direct relevance to the dormant aging problem we are addressing. It may well be able to serve as a benchmark as to what might be expected in the dormant storage testing program. In other words, the magnitude of the parameter changes in the reported study may be representative. At the very least, because the physics principles acting to product the aging phenomena are expected to be the same, comparable magnitude changes might be anticipated and planned for in the present testing program. It is also evident that a priori there is not now available any way to judge whether the Stinger devices will show more or less parameter drift and catastrophic failures.

4. Informal comments from Dr. Savorio Gaudiano, Experimental Systems Division, Johnson Space Center, Houston, Texas

Integrated circuits had proven less worrisome than hybrids during test evaluation supported by Marshall Space Flight Center. Humidity appeared to be the greatest problem. On one type of hybrid some failures developed in as short a time as a few weeks. The combination of moisture, containment, and applied voltage were required to bring about the failure problems.

5. WHO WANTS RELIABLE PLASTIC SEMICONDUCTORS

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This paper reports the results of an experimental reliability study on plastic devices. Variables in the study included the metal contact system, humidity, temperature, and salt concentration. Gold contacts proved to be a factor five better than Al contacts with respect to humidity. At all conditions, when the failures were catastrophic, failure analysis indicated Al corrosion or dissolution. On the other hand, all gold contact failures were associated with increase in leakage current or degradation of dc gain. In a salt environment, the failure rate increased by a factor of ten for an order of magnitude increase in the salt concentration for small signal silicon devices, with or without bias applied. The failure rate was two times worse without bias conditions, presumably due to some sort of electrophoresis effect.

The reason for mentioning this study is the need to keep alert to the possible perturbations to dormant storage aging phenomena with respect to different storage conditions worldwide. In regard to different manufacturing processes of IC's, there is a possibility of different failure rates according to differing temperature, humidity, and salt concentration environments.

6. INTERFACE INSTABILITIES

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This study is concerned with fixed oxide charge and interface trap densities changes under accelerated aging conditions. Although accelerated aging is outside our immediate concern, it is worthwhile noting that changes in the fixed charge and interface trap densities are next in importance after sodium drift in the oxide. The relevance of these findings to the dormant aging program is that in the practical situation with which we are faced, we can probably ignore the relatively negligible contribution to aging phenomena from changes in the fixed charge and interface trap densities.

ADDENDUM II

DORMANT STORAGE TESTING TECHNICAL CONSIDERATIONS

The following comments encompass some general technical suggestions which should be taken into consideration in the redesign and redirection of dormant storage testing.

An important consideration in the overall experimental design is the existence and utilization of absolute reference test standards, either in the form of test sets or circuits. Current and voltage test standards should be available for calibration reference in the same range of operating voltages and currents anticipated to be observed in the testing.

A second important consideration in the experimental environment is definitive knowledge of the sensitivity limits of the instrumentation since the changes to be observed are expected to be small. For the dormant storage program, the sensitivity needs to be at the state-of-the-art limits in order to be able to reliably measure any storage-induced changes over a period of six months or a year. The inherent instrumentation error should be guantified in terms of absolute and relative error on repeatable measurements. A further refinement involves quantifiation of the sensitivity limits as a function of temperature, plus an experimentally determined knowledge of the amplitudes of electrical and other noise perturbations affecting experiments.

Since maintenance effects on the system performance figured so heavily in previous experiments, experimental information on system response should be part of the baseline data. Presumably this system response data could be gathered periodically with no devices in the test jig and under appropriately varying conditions, such as to gather, over a year's time, all performance data relevant to all variable environmental and time conditions. The knowledge of such systematic perturbations could be incorporated into the experimental design to allow optimal scheduling or rational analysis of the data base (e.g. modifications due to impulse effects, exponential decay, baseline shifts).

With respect to device measurements, some possibility for computer-controlled and digitized ac measurements is desirable in addition to the usual array of dc measurements. AC measurements are particulary pertiment to physical properties related to surface states. When available, informative specification sheet data can be used in designing appropriate tests for potentually extracting information related to dormant storage aging.

With respect to actual tests to be made on devices, it is desirable to make as many physics-related measurements as possible in addition to standard engineering measurements suggested by the operation and/or function of the device in the circuit. Measurements of parameters should be made in their usual operating range. This overall approach increases the possiblity of uncovering potential dormant aging mechanisms and increases the scope for mathematical modeling of the effects. Suggested measurements for discrete devices include temperature charactistics, leakage current, I-V characteristic, V_{SAT}, V_{BV}, electrical storage time, and h_{FE} as a function of I_C. Integrated circuits may be divided for convenience into the categories of digital and analog. For the digital circuits, suggested measurements include a full raster sweep through the forbidden region (both directions), together with measurements of t_{on}, t_{off}, t_s, V_{on}, and V_{off}. Analog measurements suggested are I_{in}, I_{out}, and open loop gain. The overall signal/noise ratio for the instrumentation which makes these measurements should be a minimum of 10/1.

Use of a temperature-controlled chamber will alleviate some of the difficulties seen in the previous test program. A minimum temperature of 27° plus or minus .5° C is suggested (i.e., a clear and determinate increase over ambient room conditions). A periodic ramp test for temperature sensitive devices may be useful, e.g., encompassing a 30° range in 1° increments once every 100 days.

With regard to the software aspects of the experimental program, a minicomputer control and data acquisition system with demountable disc packs is recommended. The data bank software needs to be carefully and efficiently written to prevent gross mishandling of the data, as well as rational handling of normal contingencies. A record should be retained of all raw data. The formal plan for handling data should include details of the data bank organization; data storage, update, and manipulation; method of selecting data for examination; analysis algorithms, computer plotting subroutines for raw data, analyzed data, and characteristic curves; and flexibility in selecting different dependent and independent parameter choices.