D180-26784-1

FINAL REPORT
ON
DEVELOPMENT OF DESIGN, QUALIFICATION, SCREENING,
AND
APPLICATION REQUIREMENTS
FOR
PLASTIC ENCAPSULATED SOLID-STATE DEVICES
FOR
SPACE APPLICATIONS

DECEMBER 23, 1981

PREPARED UNDER CONTRACT NAS8-33079

FOR

GEORGE C. MARSHALL SPACE FLIGHT CENTER

MARSHALL SPACE FLIGHT CENTER

ALABAMA 35812

BY

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1.0 INTRODUCTION

This report completes the effort performed under a NASA contract entitled "Development of Design, Qualification, Screening, and Application Requirements for Plastic Encapsulated Solid-State Devices for Space Equipment" (NAS8-33079) for NASA/Marshall Space Flight Center. The objectives of the overall program were to:

- o Define possible controls and documentation for successful utilization of plastic encapsulated solid-state devices in selected space applications.

The specific objectives of the effort covered by this report were to:

- o Determine the effectiveness and cost of selected screens as applied to linear circuits, CMOS circuits, bipolar circuits and transistors.
- o Identify test procedures and performance or design weaknesses of specific plastic encapsulated semiconductor devices.
- o Identify the effects of various operating temperatures on the overall performance of plastic encapsulated solid-state devices.
- o Obtain screening data on selected devices to augment the data previously gathered from industry users of plastic encapsulated semiconductors.

Test data were collected on 1035 plastic encapsulated devices and 75 hermetically sealed control group devices that were purchased from each of 5 different manufacturers (7 groups of parts) in the categories of

- o Low power Schottky TTL (bipolar) digital circuits
- o CMOS digital circuits
- o Operational Amplifier linear circuits
- o NPN Transistors

These parts were subjected to three different initial screening conditions, and then subjected to extended life testing, to determine any possible advantages or trends for any particular screen. In addition, several special tests were carried out in areas of flammability testing, humidity testing, high pressure steam (autoclave) testing and high temperature storage testing.

This report covers the latter portion of the effort on Contract NAS8-33079. The first portion of the effort (described in Boeing Document D180-25325-1) was concerned with a survey of the field usage failure rates of plastic encapsulated semiconductors and led to the determination that an experimental screening program was necessary to validate the survey findings. In addition, a previous contract was performed by Boeing for NASA that addressed the same type of questions from the standpoint of a wide range of alternative environmental stress tests. Table 1-1 summarizes the relationships of the relevant contracts.

Section 2 of the report is an executive summary of the program findings, Section 3 summarizes the initial screening program and the test approach, and Section 4 summarizes the results of the life test program and of the special tests.

Section 5 treats procurement and application considerations for use of plastic encapsulated semiconductors, and Section 6 summarizes the recommendations resulting from the program.

Appendix A contains a statistical analysis program that was written to analyze the log-normal distributions resulting from the life testing. Appendix B contains the data printouts resulting from operation of the statistical analysis program on the failure distribution data. Appendix C contains the detailed failure analysis results.

With the publication of this document, the objectives of contract NAS8-33079 have been met.

Table 1-1 PROGRAM INTERRELATIONSHIPS

Contract Number	Report Title	Date	Boeing Report Number	
NAS 8-31627	Evaluation Testing of Solid Encapsulated Microcircuits for Space Applications	June 1975 to May 1977	D180-20546-1	Accelerated Stress Testing of TTL, CMOS and Linear ICs
NAS 8-33079	Analysis of Field Usage Failure Rate Data for Plastic Encapsulated Solid State Devices (Interim Report)	Jan 1979 to March 1980	D180-25325-1	Data Gathering Survey on Field Usage Data
NAS 8-33079	Development of Design, Qualification Screening and Application Requirement for Plastic Encapsulated Solid State Devices for Space Applications (Final Report)	Jan 1980 to Dec 1981	D180-26784-1	Screening and Life Testing of TTL, CMOS, Linear ICs plus Transistors

2.0 EXECUTIVE SUMMARY

2.1 PROGRAM APPROACH

The program was conducted in four phases:

- o Parts Procurement
- o Initial Screening
- o Life Testing
- o Special Screening

Parts were procured in accordance with the following table

Basic Part Type	Manufacturer	Quantity Plastic	Quantity Hermetic
74LS194 TTL Bipolar	A	1035	75
4069 CMOS	B	1035	75
4069 CMOS	C	1035	75
741 Linear	B	1035	75
741 Linear	D	1035	75
2N2222 Transistor	B	1035	75
2N2222 Transistor	E	1035	75

Each group of 1035 plastic encapsulated parts and 75 hermetic parts was then subjected to three different types of initial screening representative of possible low cost screens that were identified in the Phase 1 program as applicable to plastic encapsulated semiconductors. See Figure 2-1. A total of 225 of the plastic encapsulated survivors from each screen (plus 15 of the hermetic survivors) were then separated into three life test groups of 75/5 each and subjected to life testing for 4000 hours with intermediate measurements made at logarithmic time intervals. Failure analysis was conducted on selected examples of failed parts. Finally, special tests were conducted on small samples of parts which had passed the initial screens. These special tests included

- o Flammability tests
- o Humidity cycling
- o Autoclave (high pressure steam)
- o High temperature storage

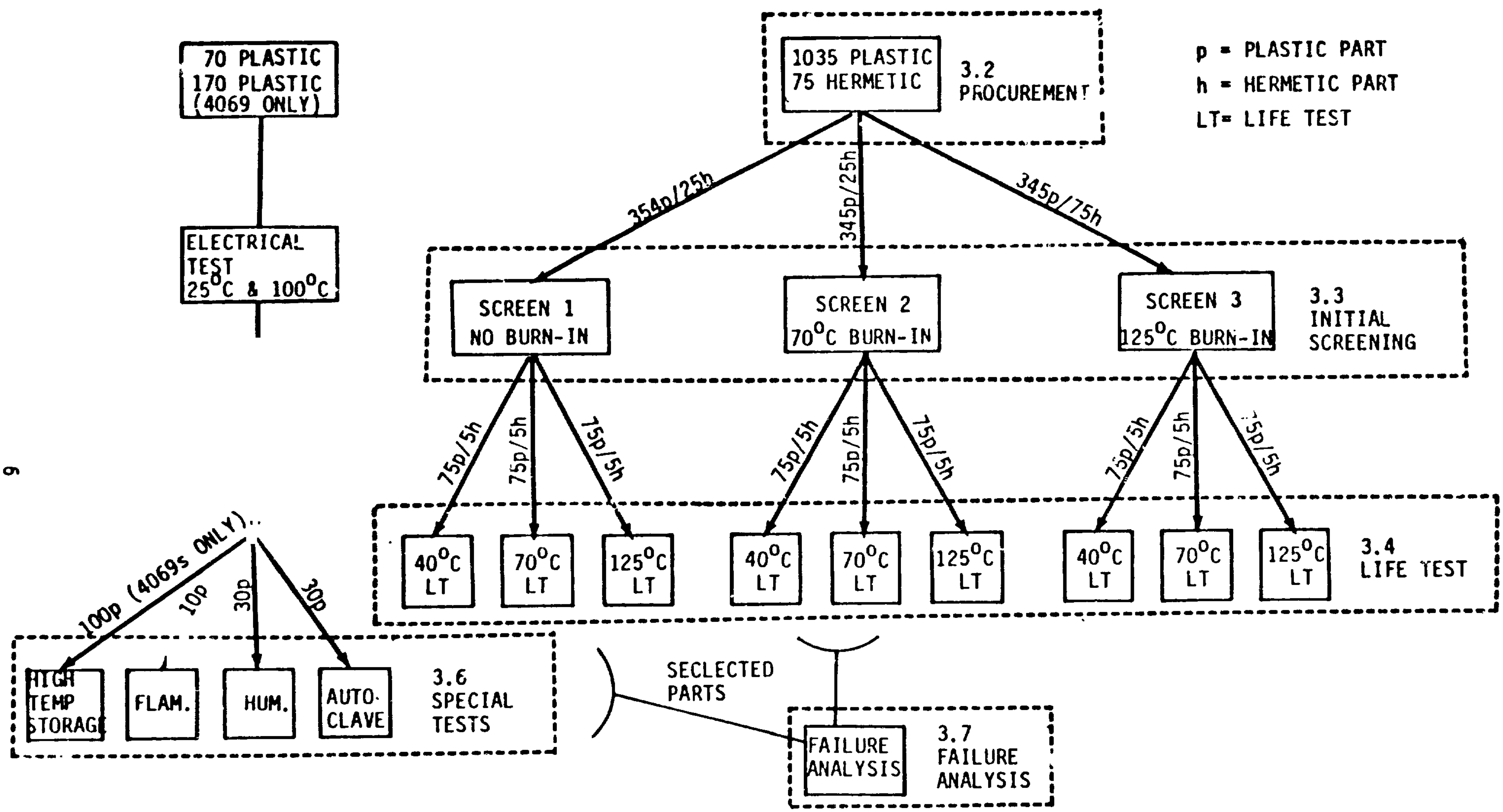

Figure 2-1 TEST PROGRAM PARTS FLOW SUMMARY FOR EACH PART TYPE

The test program was organized into initial screening followed by life testing to determine if there was a set of screening conditions that would result in an improvement in the usage-life reliability of plastic encapsulated semiconductors. The life test temperatures were chosen to be 40°C, 70°C and 125°C. In the previous contract performed for NASA, it was found that above 150°C there occurred serious disruptions of the plastic encapsulant that would not be typical of extended operation at any normal temperature, hence the upper life test temperature for this program was limited to 125°C. This also is the normal burn-in temperature for JAN-qualified hermetic semiconductors. The 70°C life test was chosen because this is the maximum rated operating temperature for most plastic encapsulated semiconductors. The 40°C life test temperature was chosen because of the concern that at lower temperatures any imbedded water content in the plastic encapsulant might not be driven off with the result that failures at 40°C might be more prevalent than at higher temperatures.

2.2 SUMMARY OF RESULTS

The results of both the screening program and the life test program were highly inconsistent in the area of screening tests versus resultant reliability and in the area of life test temperature versus median time to failure. There was no consistent indication of any one screen condition being superior in weeding out potentially defective devices. There was no consistent indication of there being an activation energy for the Arrhenius plots that could be used to make thermal extrapolations of median time to failure. And there was no indication that life testing at any one temperature was better than at any other temperature.

As can be seen in Table 2-1, six out of the seven part types suffered large numbers of screening and/or life test failures. Only the Manufacturer A TTL (bipolar) 74LS194 device type performed well. It can also be noted that each of the three Manufacturer B part types tested showed more failures than did the alternative manufacturer's parts. Therefore with the possible exception of bipolar TTL-type devices for JAN Class (type applications), the use of plastic encapsulated semiconductors is not recommended for use in NASA programs, as summarized in the program conclusions, Section 2.3.

Table 2-1 SUMMARY OF SCREENING AND LIFE TEST FAILURES

Screening Failures
(1035 Parts Each)

Part Type	Mfr A	Mfr B	Mfr C	Mfr D	Mfr E
74LS194	15				
4069		86	35		
741		401		81	
2N2222		133			84

Life Test Failures
(675 Parts Each)

Part Type	Mfr A	Mfr B	Mfr C	Mfr D	Mfr E
74LS194	9				
4069		416	101		
741		310*		71	
2N2222		115			84

*Started with only 450 parts because 125°C burn-in screen parts all failed.

2.2.1 Test Result Observations

Several significant observations resulted from the test program that cut across the lines of device type.

2.2.1.1 Screen Test Failures--It was observed that the initial screening did not produce the results that had been expected. Most of the screening failures were detected at the time of pre-burn-in electrical testing at 25°C and 100°C. No failure analysis was performed on screening failures. Only three parts failed at electrical measurement after burn-in (this is out of 5180 total parts subjected to burn-in screening.) Thus not only did post-burn-in double electrical post-burn-in measurement fail to have significant results, even single electrical measurement did not have any effect on screening yield. Since very few parts failed at electrical measurement after burn-in and few failed during the burn-in, the subsequent life testing findings were influenced. That is, because few parts were removed from the test parts as a result of burn-in, there could not be a strong impact of the use or non-use of burn-in on the subsequent life test cells. This seems to have been borne out by the life test results discussed below. Tables 2-2 and 2-3 present the same life test failure data from two viewpoints: influence of previous screening, and influence of life test temperature. These data are described in detail in Section 4.3.

2.2.1.2 Influence of Burn-in Screening on Life Test Failures--Table 2-2 summarizes the results of the life tests as a function of the burn-in screen that was applied to the parts prior to life testing. It can be seen that in only one case was there a significantly worse life test performance for the parts that had not been burned-in: The Manufacturer B part type 4069. In all the other cases, the number of failures for the non-burn-in case was less than or equivalent to the number of failures for the 75°C or 125°C burn-in.

2.2.1.3 Influence of Life Test Temperature on Life Test Failures--Table 2-3 summarizes the results of the life tests as a function of the temperature at which the life test was performed. Three anomalies are observed in this table. First, for the Manufacturer C part type 4069 parts, the number of life test failures at 40°C was significantly greater than the number of failures at 70°C. Second, for the Manufacturer B transistor 2N2222 the 40°C failure quantity

TABLE 2-2 Summary of Life Test Failures vs Prior Burn-In

Cumulative Failures — All Life Tests
(225 Parts in Each Life Test Group)

	Mfr A 74LS194	Mfr B 4069	Mfr C 4069	Mfr B 741	Mfr D 741	Mfr B 2N2222	Mfr E 2N2222
No Burn-In (Scr 1)	4	151	25	85	21	42	19
Burn-In at 70°C (Scr 2)	2	144	37	221	29	32	25
Burn-In at 125°C (Scr 3)	3	121	39	*	21	41	40
Total	9	416	101	306	71	115	84

*Test aborted during initial 125°C burn-in screening - parts began failing catastrophically — there were no survivors for life testing.

TABLE 2-3 Summary of Life Test Failures vs Life Test Temperature

Cumulative Failures — All Screens
(225 Parts in Each Life Test Group)

	Mfr A 74LS194	Mfr B 4069	Mfr C 4069	Mfr B 741 *	Mfr D 741	Mfr B 2N2222	Mfr E 2N2222
Life Test at 40°C	3	89	27	83	19	75	31
Life Test at 70°C	4	146	14	87	21	23	36
Life Test at 125°C	2	181	60	136	31	17	17
Total	9	416	101	306	71	115	84

*Screens 1 and 2 only - total of 150 parts in [illegible] group significantly exceeded both the 70°C and 125°C quantities. Finally, for the Manufacturer E transistor 2N2222 the number of 40°C and 70°C failures was significantly greater than the number of 125°C failures. These results are quite unexpected and are not explainable based on traditional Arrhenius rate relationships of time and temperature.

2.2.1.4 Arrhenius Curve Anomalies--As might be expected from Table 2-3, the Arrhenius curves of median time to failure (time for half the parts to fail under life test) plotted from the individual sets of data for each of the pre-screen conditions resulted in unusual curves. Figure 2-2 is an example of such a curve. This curve contradicts the usual Arrhenius relationship in which the longest median times to failure occur for the lowest temperatures. A curve such as the Screen 3 curve is an anomaly that is unexplainable in terms of the time-temperature relationship of normal semiconductor failure mechanisms.

2.2.1.5 Wearout Failures--For two of the part types, it was observed that the log-normal distributions deviated sharply from the low-sigma curves (freak population) before the conclusion of the 4000 hours of life test. Both the 741 op amps and the 2N2222 transistors from Manufacturer B gave indication of this type of distribution which is indicative of the parts going into wearout. In the case of the 741 op amps, the devices exhibited catastrophic failures resulting in ignition of the epoxy encapsulant due to internally generated heat. This severe destructive failure made failure analysis impossible. One of the parts that failed at the threshold of the onset of wearout was subjected to failure analysis to search for the possible cause of the wearout failure mechanism. The original cause of failure was that the open loop gain and the offset voltage were marginally out of limits. The part was baked at 150°C to see if it would recover. Upon retesting the part, it was found to be a catastrophic failure, meaning that the tester could not proceed past the first measurement because of a severe overrange condition. The part was dissected to search for the cause of the malfunction, but optical examination showed that there were no visible defects. Thus, the cause of the wearout failure mechanisms could not be determined.

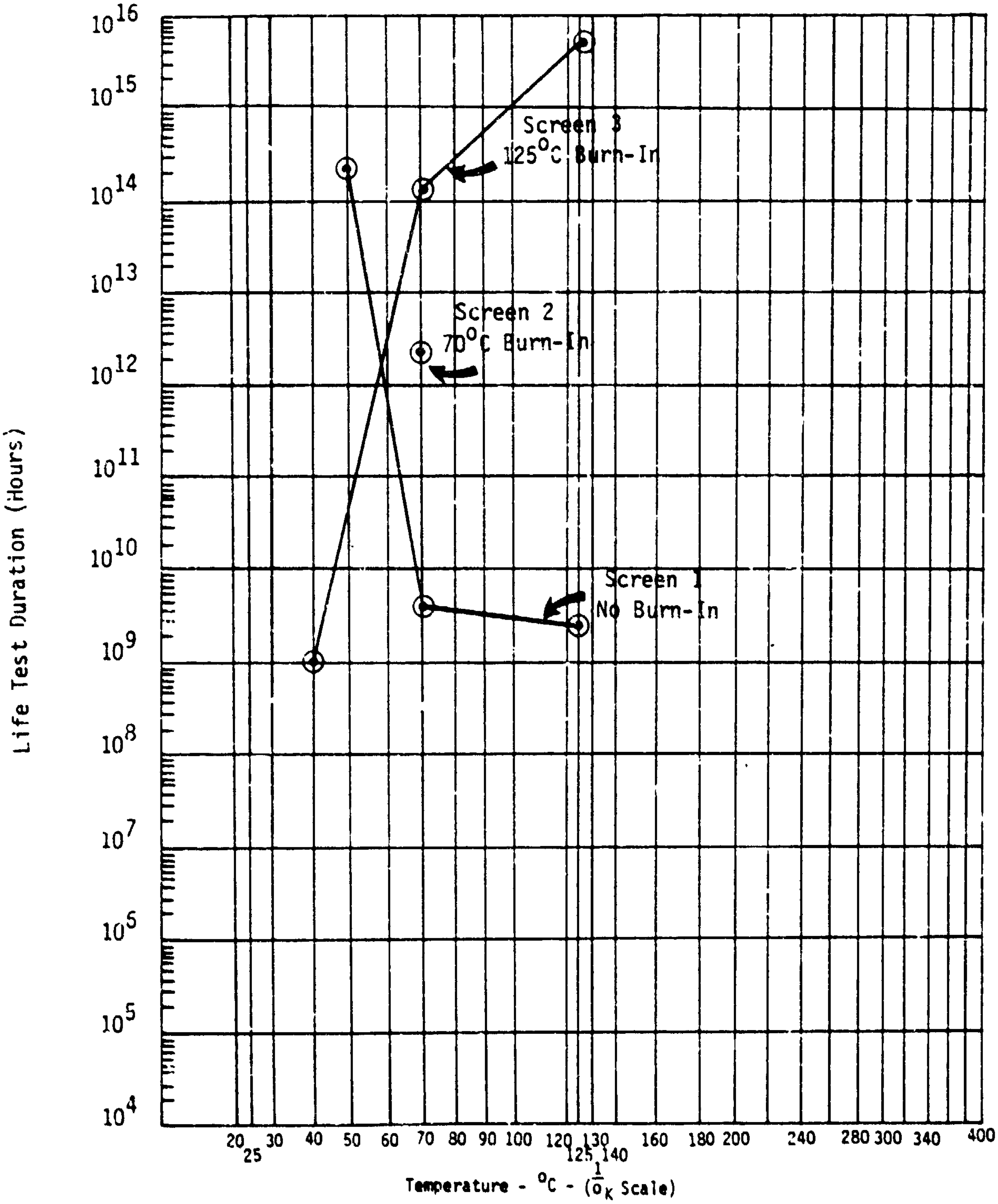

Figure 2-2

Arrhenius Curves For Median Time to Failure For Manufacturer B 2N2222 Transistor (4000 Hour Data Point Excluded)

2.2.2 Part Type Observations

Several significant observations were made from analysis of the results from individual part types. No effort was made to correlate the data from the hermetically sealed parts, since the quantities of these parts was so small, and they were included in the test program solely as a point of reference in case it was suspected that certain failures could have been caused by die-related causes rather than plastic-encapsulant-related causes. In general, very few hermetic parts failed at all.

2.2.2.1 Manufacturer A Part Type 74LS194--This TTL bipolar technology showed the fewest number of failures of any of the parts tested. It is felt that this is a mature, bulk silicon technology that is not influenced by surface parameters, with the result that the plastic encapsulation has little effect on the performance of the parts. This is essentially the same conclusion that was derived from the earlier NASA contract in which accelerated life testing was performed on plastic encapsulated bipolar, linear and CMOS part types. The most significant finding for the 74LS194 part type was that the type of prior burn-in screen or the life test temperature did not seem to make any difference in the number of failures that occurred.

2.2.2.2 Manufacturer B Part Type 4069 (CMOS)--This part type experienced the largest number of failures of any of the parts tested and demonstrated very low median times to failure. While the log-normal distributions appeared to have fairly high values of sigma, they did not appear to be in wear out. Instead it appears that the parts are particularly sensitive to the presence of the plastic encapsulant and failed because of this sensitivity. Failure analys s of representative samples of the failed parts showed that the catastrophic failures all appeared to be caused by excessive current flowing out of the ground lead of the device, as if the internal leakages became excessive and the device went into thermal runaway. This is borne out by the fact that the non-catastrophic failures exhibited out-of-limit power supply currents, indicative of the increase of internal leakage currents perhaps caused by threshold voltage shifts in the series transistors. The non-catastrophic failures were baked out and the failures went away, indicating that the failures were caused by surface effects, which is an indictment of the plastic encapsulant, since this failure mode was not observed in the hermetically sealed control parts.

2.2.2.3 Manufacturer C Part Type 4069 (CMOS)--While the number of life test failures that occurred for this manufacturer's 4069 was considerably less than for the Manufacturer B equivalents, there was still a significant number of failures that occurred, particularly for the 125°C test cells. Most significant, however, was the finding that the median time to failure for the 40°C life test was significantly less than it was for the 70°C life test, resulting in another anomalous Arrhenius curve. This also was evident in the total number of part failures at 40°C being greater than at 70°C as discussed in paragraph 2.2.1.2.

2.2.2.4 Manufacturer B Op Amp 741--This part type suffered from early wearout as described in 2.2.1.5. In fact, failure analysis showed that the failures that occurred prior to wearout were primarily caused by corrosion of the external device leads, and as such should not properly be called failures at all since after the external leads were cleaned the failed parts all retested OK. This makes the wearout failure mode all the more surprising.

2.2.2.5 Manufacturer D Op Amp 741--The only two anomalies that occurred for this part type were that the no-burn-in, 40°C life test cell showed significantly greater number of failures than did the 70°C and 125°C life test cells for no burn-in, and that the median-time-to-failure for the 125°C burn-in, 70°C life test cell showed an abnormally low median time to failure. The reasons for these anomalies are not known. Even though the failure distributions were less unusual for this part type than for the Manufacturer B equivalent, the total number of failures was still markedly greater than it was for the bipolar TTL devices.

2.2.2.6 Manufacturer B Transistor Type 2N2222--The part type from Manufacturer B exhibited undesirable early wearout as discussed above. This was the third part type of Manufacturer B tested, and results from all three part types showed unsatisfactory performance.

2.2.2.7 Manufacturer E Transistor Type 2N2222--Although the number of life test failures for this part type was relatively small, it was still significantly larger than was observed for the bipolar TTL digital part type from Manufacturer A. It appears from the failure analysis results that the failures were caused by surface channelling which results from the presence of the plastic encapsulant. Plotting of the Arrhenius curves again showed anomalous results that discourage the application of the time-temperature rate relationship.

1.3 PROGRAM CONCLUSIONS

- Plastic encapsulated semiconductors are probably not cost effective for use in NASA programs because the cost of parts engineering and management added to the cost of minimal 100% screening would offset any advantage of purchase price over comparable hermetically sealed parts.

- Serious reliability problems exist in the use of plastic encapsulated CMOS microcircuits, and these problems appear to be unscreenable.

- The linear microcircuits tested (741 op amps) appear to have serious reliability problems in the plastic encapsulated form, causing (for one manufacturer) catastrophic failures that ignited the epoxy. These devices are unsuitable for use in NASA applications.

- There are significant differences between manufacturers in their ability to manufacture reliable semiconductors in plastic encapsulated form, with the consequence that any use of plastic encapsulated parts must be accompanied by an intensive parts engineering effort to assure the integrity of the parts.

- The findings of the phase I program are contradicted by the accelerated life test results, particularly for CMOS, linear and transistor part types. Only for the bipolar TTL technology was there indication of availability of high integrity product in plastic encapsulated form.

- Operation at 40°C in some cases appears to be more deleterious to plastic encapsulated parts than operation at higher temperatures.

- The time-temperature-dependent failure distribution characteristic of typical hermetically sealed semiconductors was not observed for the plastic encapsulated semiconductors, and the Arrhenius rate relationship does not appear to be valid. Thus extrapolation of failure rate versus temperature would not be possible with plastic encapsulated semiconductors. This seems to be caused by the influence of the plastic encapsulant.

3.0 TEST PROGRAM DESCRIPTION

3.1 SUMMARY OF TEST APPROACH AND INTENT

The objective of this test program was to determine the effectiveness and cost of selected screens as applied to linear circuits, CMOS circuits, bipolar circuits, and transistors. This test program was intended to identify test procedures and performance/design weaknesses of specific plastic encapsulated semiconductor devices. It was an additional objective of this program to identify the effects of various operating temperatures on the overall performance of plastic encapsulated solid-state devices.

3.1.1 Investigation of Screening Effectiveness

The first phase of this program, that of gathering actual field usage data on the in-service failure rates of plastic encapsulated semiconductors, revealed that a test program was required to validate proposed screens for NASA plastic encapsulated parts. Phase I of the program identified three potential screens that were candidates for NASA devices. These screens were developed by making the maximum use of data from government sponsored programs, manufacturers, and military and commercial users. Figure 3-1 shows a summary of the flow of parts through the test program.

Screen 1 was intended to represent the minimal test that could be performed on plastic encapsulated parts, and the emphasis in this screen was on the electrical measurement at 25°C and 100°C, without performing any type of burn-in. Screen 2 was performed to represent nominal burn-in conditions coupled with temperature cycling found by device manufacturers to be effective. Screen 3 represented a maximal burn-in condition coupled with temperature cycling. Both screens 2 and 3 incorporated double electrical testing following burn-in since this was found to be effective by some users of plastic encapsulated semiconductors in reducing the incidence of "parts that never worked."

It was the intent of the screening program to subject the parts to these experimental screens and then determine the effectiveness of the three screens by subsequent life testing.

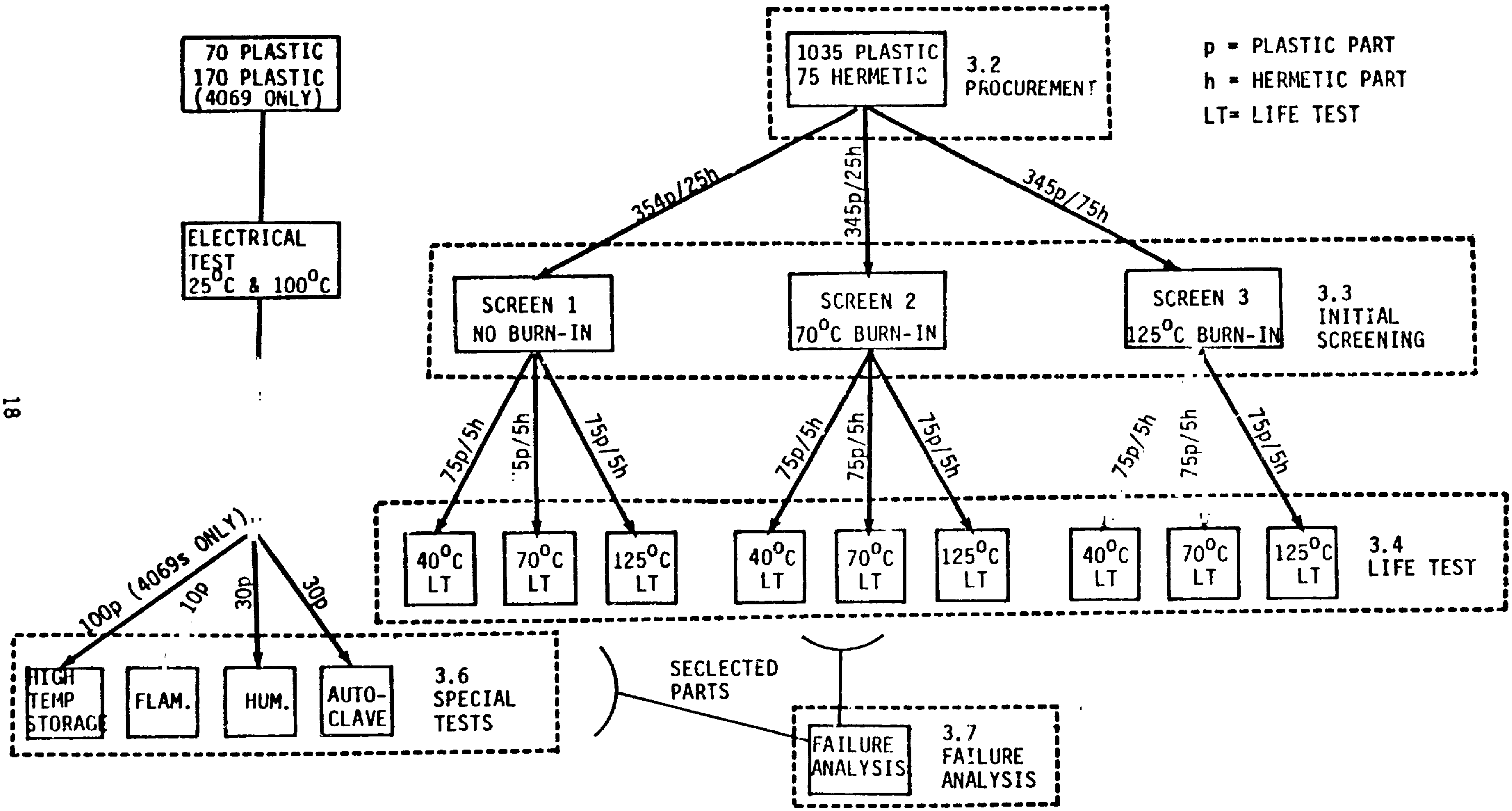

Figure 3-1 TEST PROGRAM PARTS FLOW SUMMARY FOR EACH PART TYPE

3.1.2 Life Testing To Verify Screening Effectiveness

Extended life testing at accelerated stress temperatures was performed to determine if any of the initial screens were effective in improving the reliability performance of plastic semiconductors. Figure 3-1 shows that the screened parts were separated into three separate life test groups to be life tested under military specification burn-in conditions for 4000 hours at 40°C, 70°C and 125°C. The intent was to cause enough failures to occur that log-normal distributions of failure could be plotted for each of the screening conditions and thereby a determination could be made of the validity of each of the screening conditions.

3.1.3 Special Test Objectives

Many users of plastic encapsulated semiconductors employ special destructive tests on qualification samples of parts to measure the relative integrity of the basic processes by which the parts are made and encapsulated. These tests generally consist of humidity tests and autoclave (or pressure cooker) tests. The results of such tests are used in a gross manner to determine if there are unusual problems in a specific group of parts.

For this reason, tests were performed on small samples of parts from each type. The tests included flammability, humidity, autoclave and high temperature storage. The high temperature storage tests were performed to determine if bake out of the parts prior to life testing could improve reliability by driving out latent water buried in the plastic encapsulant.

3.2 PARTS PROCUREMENT

The TTL, CMOS, Linear and Discrete Devices listed in Table 3-1 were procured in quantities of 1035 plastic encapsulated and 75 hermetic parts each. Hermetic parts were included in the life tests to determine if surface and die failures were common only in the plastic encapsulated parts or in both plastic and hermetic parts.

The choice of part types was made by NASA based on the results of the previous NASA screening contract. This prior contract indicated that while TTL devices showed good potential for meeting NASA performance requirements, CMOS and linear showed questionable or poor performance in accelerated stress testing. However, the Phase 1 portion of the present contract appeared to contradict these findings, showing instead that there was no significant difference in field usage failure rate between bipolar and CMOS or linear SSI devices. Thus this second phase program was intended to validate the previous findings by stress testing performed on CMOS and linear microcircuits and on NPN transistors, as well as on the bipolar low power Schottky TTL technology devices.

Table 3-1 Parts Procured

BASIC TYPE	MANUFACTURER
74LS194 TTL	A
4069 CMOS	B
4069 CMOS	C
741 LINEAR OP AMP	B
741 LINEAR OP AMP	D
2N2222 TRANSISTOR	B
2N2222 TRANSISTOR	E

3.3 INITIAL SCREENING

The 1035 plastic encapsulated parts and 75 hermetic parts of each type/manufacturer were separated into three initial screening groups (#1, #2, and #3) of 345 plastic encapsulated and 25 hermetic parts each. These three groups were subjected to the three initial screening tests shown in Figure 3-2: no burn-in, burn-in at 70°C, and burn-in at 125°C in addition to electrical measurements at 70°C and 100°. Two-hundred twenty-five of the plastic encapsulated parts and 15 hermetic parts passing each screen were then subdivided into three subgroups (A, B, and C) of 75 plastic encapsulated parts and 5 hermetic parts from each of the initial screening flows.

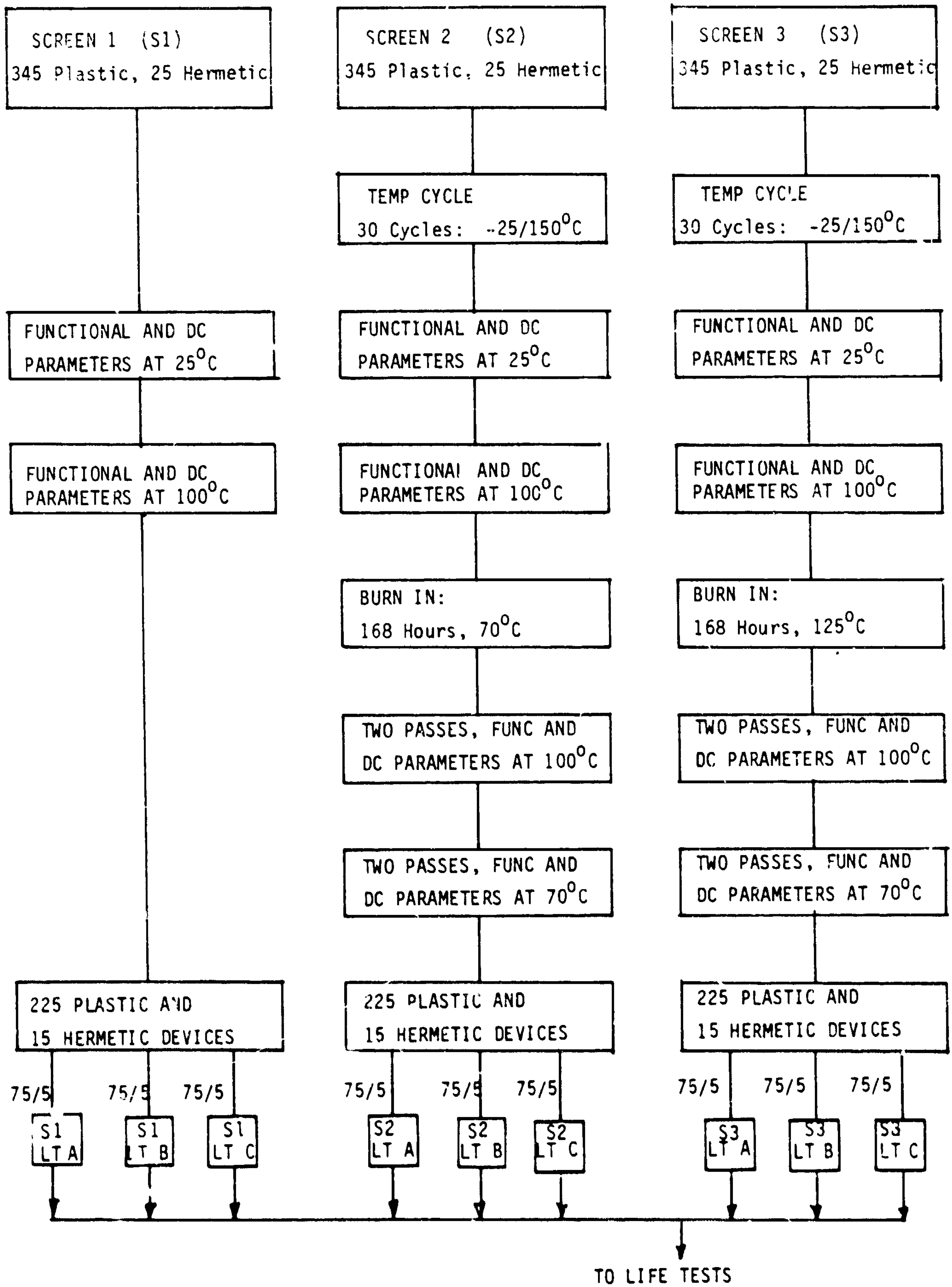

FIGURE 3-2 INITIAL SCREENING

3.4 LIFE TESTS

Figure 3-3 shows the organization of the life test cells. The life tests were performed at three different temperatures: 40°C, 70°C, and 125°C for 4000 hours. 40°C was chosen because it was felt that this lower temperature might not result in enough internal heat to drive off imbedded water and hence may result in excessive failures. 70°C was chosen because it is the manufacturers' temperature range upper limit, and 125°C was chosen because it is the MIL STD 883 temperature range upper limit. The burn-in and life test circuits used are shown in Figure 3-4. Both burn-in and life tests were performed in the Boeing Part Test Laboratory's Blue-M burn-in ovens. Since the purpose of the life test was to determine the effectiveness of the screens, determination of failure was on a Go/No-Go basis. Failed parts were retested only to gather additional data as an aide in determining failure modes. The criteria for device failure were the DC and functional test requirements as defined by:

- MIL-M-38510/17401 for the CD4069
- MIL-M-38510/10101 for the 741
- MIL-M-38510/30601 for the 74LS194A
- MIL-S-19500/251 for the 2N2222

Test measurements as defined by these specifications were modified as necessary for plastic encapsulated devices with prior approval from NASA/MSFC. A variety of test equipment was used to perform these measurements. The CD4069s were tested on a Teradyne J2 digital test system, the 74LS194As were tested on a Teradyne J283/S157 digital test system, and the 2N2222s were tested on a Fairchild series 600 transistor/diode tester. These testers are located in the Boeing Part Test Laboratory. The 741 OP AMPS were tested on a Tektronix S3260 test system with a linear microcircuit adapter at the Boeing Radiation Effects Laboratory.

3.5 DATA PROCESSING TECHNIQUES

As shown in Figure 3-3 the parts undergoing life test were electrically tested at 2, 8, 16, 64, 256, 1000, 2000, and 4000 hours. A log normal plot of percent failures versus log time was prepared for each part/life test/burn-in combination. A linear regression program written for a Fluke 1720A Controller/Computer

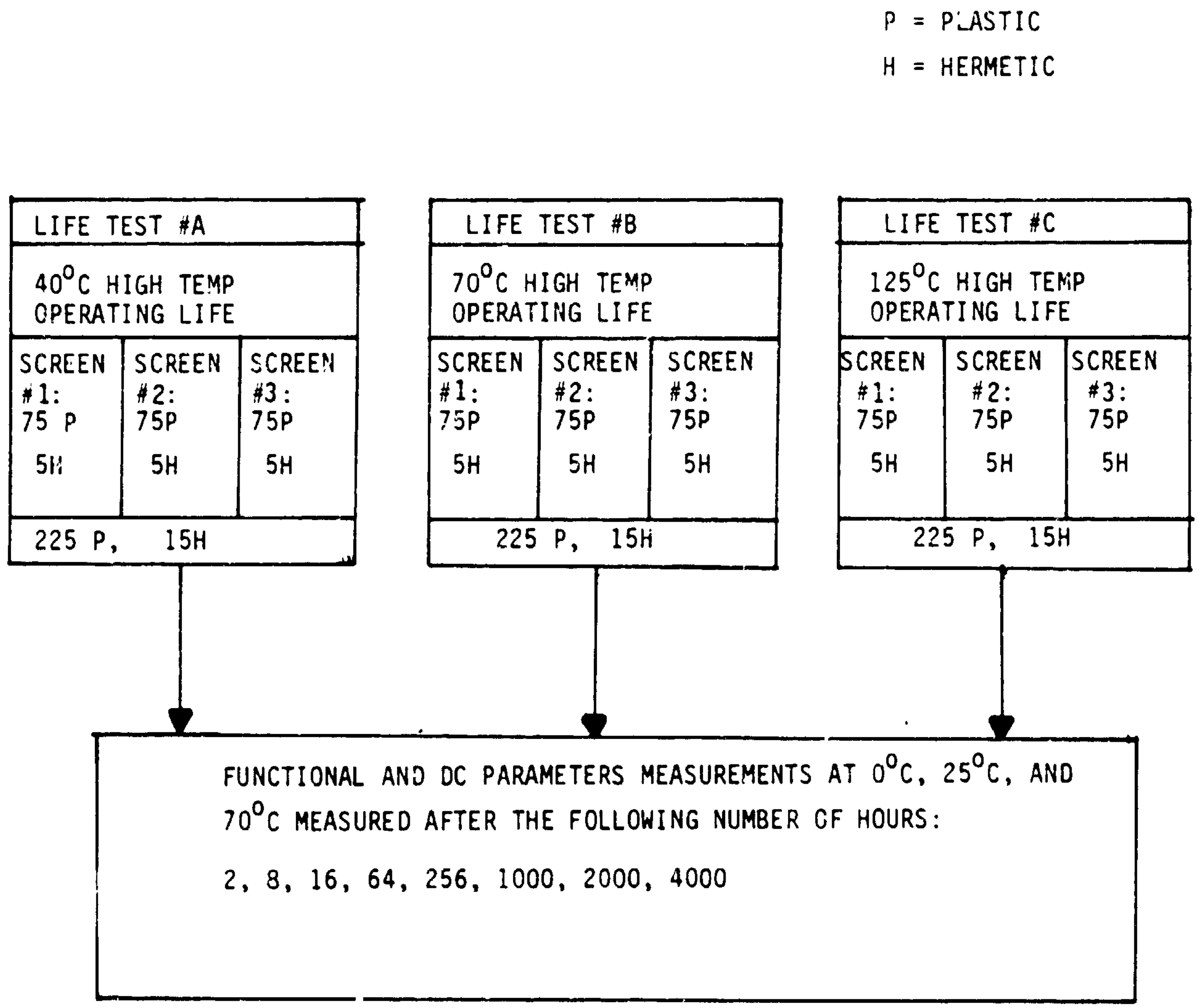

FIGURE 3-3 LIFE TESTS

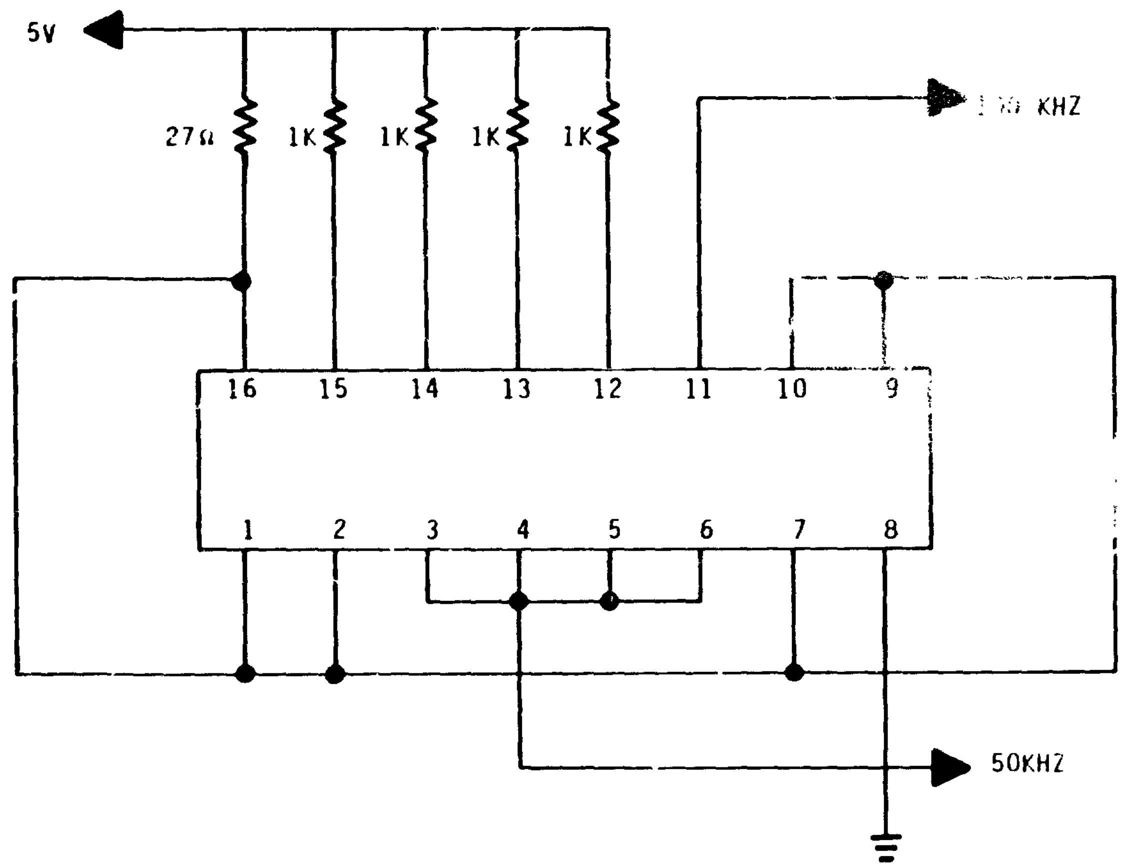

FIGURE 3-4A TYPICAL OPERATING LIFE TEST AND BURN-IN CIRCUIT FOR THE 74LS194

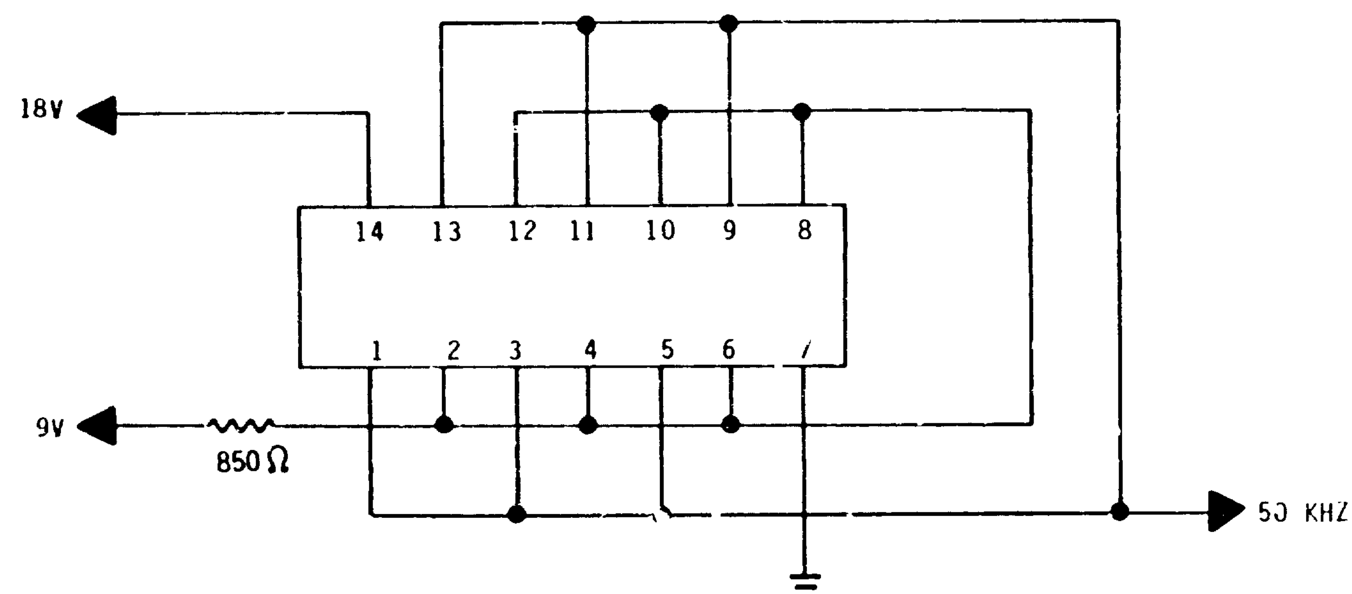

FIGURE 3-4B TYPICAL OPERATING LIFE TEST AND BURN-IN CIRCUIT FOR THE CD4069

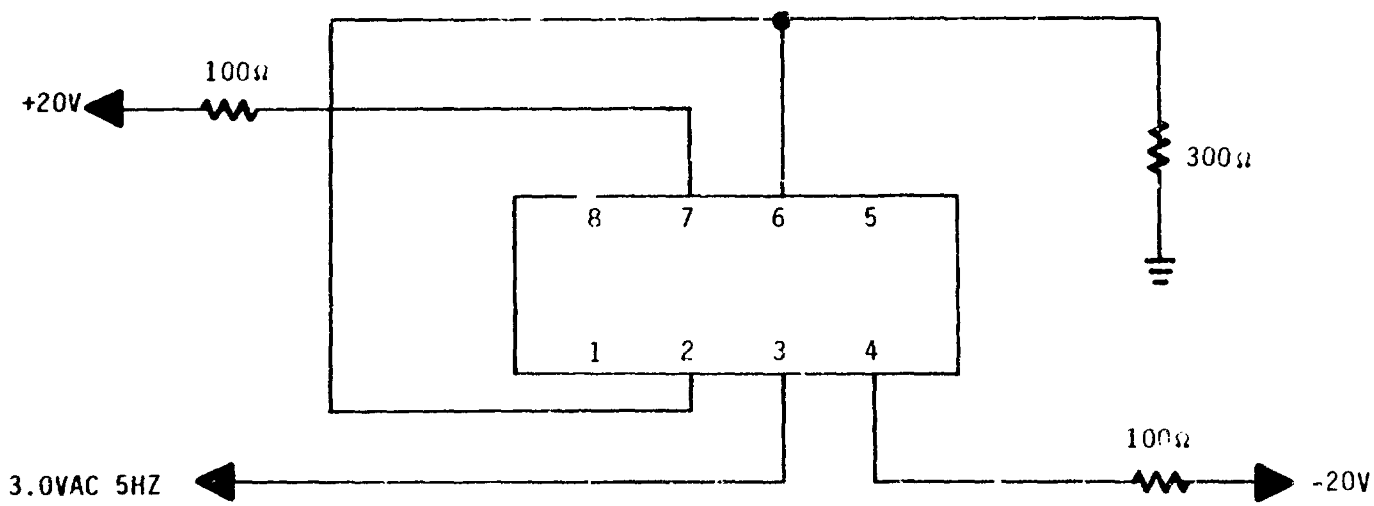

FIGURE 3-4C TYPICAL OPERATING LIFE TEST AND BURN-IN CIRCUIT FOR THE 741

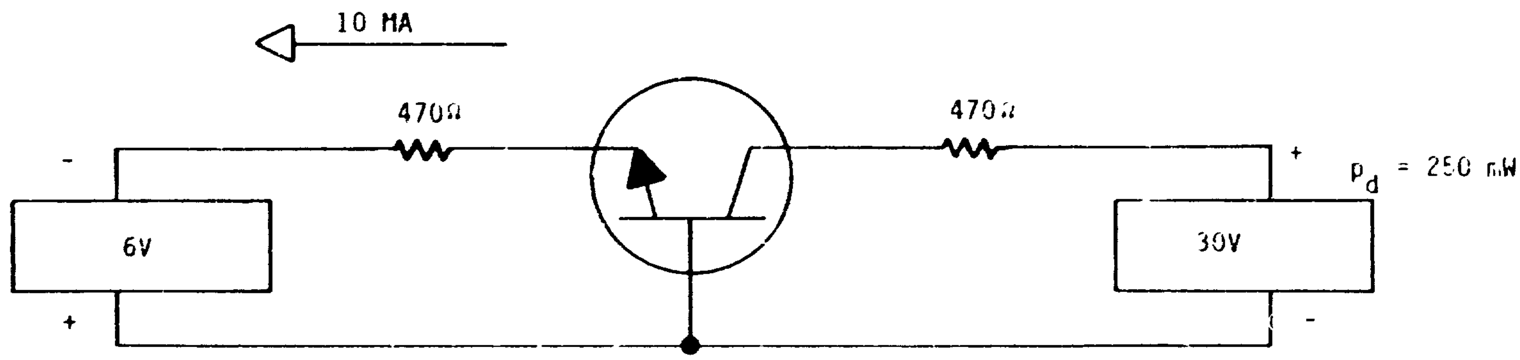

FIGURE 3-4D TYPICAL OPERATING LIFE TEST AND BURN-IN CIRCUIT FOR THE 2N2222A was used to test the validity of data and extrapolate the log normal plots to 50% failure in order to arrive at a median time to failure (MTTF) for each part/life test/burn-in combination. Appendix A contains a complete description of this program. This program was modified to eliminate output of data not necessary to this application. The statistical algorithms were not modified. These computer generated MTTFs were then plotted against life test temperature to form an Arrhenius curve for each manufacturer/part type.

3.6 SPECIAL TESTS

3.6.1 Flammability

Ten plastic encapsulated devices of each type/manufacturer were subjected to flammability test as specified by MIL-STD-202F method 111A. This entailed application of a 2 in. flame from a propane torch to each part for 15 seconds, with observations made of the number of seconds it took for the plastic to ignite and the number of seconds before the flame died out after removal of the torch.

3.6.2 Humidity

Thirty plastic encapsulated devices of each type/manufacturer were subjected to 1000 hours of biased (5V) operation at 85°C and 85% relative humidity. Electrical testing at 25°C was performed at 2, 8, 16, 64, 256, and 1000 hours.

3.5.3 Autoclave

Thirty plastic encapsulated devices of each type/manufacturer were subjected to 96 hours of biased (5V) operation at 120°C and 15 psig steam. Electrical testing at 25°C was performed at 1, 4, 16, 32, 64, and 96 hours.

3.6.4 High Temperature Storage

Late in the program, a small experiment was performed to investigate the possibility that life performance could be improved by a pre-screen consisting of high temperature storage to drive out any latent water imbedded in the plastic encapsulant. Three high temperature storage cells were established for both the

Manufacturer B and C CMOS 4069 parts with 40 parts in each cell. The high temperature storage cells were as follows:

Screen #4	125 hours storage at 125^{o}C
Screen #5	125 hours storage at 175^{o}C
Screen #6	50 hours storage at 125^{o}C

A total of 120 Manufacturer B CMOS 4069 parts and 120 Manufacturer C 4069 CMOS parts were screened and then subjected to life testing under biased conditions for 1000 hours at 40^{o}C with electrical measurements after 4, 16, 64, 256 and 1000 hours.

3.7 FAILURE ANALYSIS

3.7.1 Selection of Failure Analysis Samples

Due to the large quantities of failed parts, it was not feasible to perform failure analysis on each failure. For this reason the failure data for each failed part was examined in an effort to categorize failure mode by the exhibited symptoms. Efforts were made to ensure that selected parts represented a cross section of all life test/screen combinations. In this manner out of over 1100 failed parts 75 were selected for failure analysis.

3.7.2 Failure Analysis Techniques

3.7.2.1 Initial Analyses--The basic steps followed prior to dissection of the parts were as follows:

1. The environment histories of the parts were studied to enable understanding of the various possible causes of failure.

2. The parts were electrically tested to verify the failure. This involved either bench testing or automatic testing of the parts, sometimes requiring environments comparable to those at which they failed, checking all significant parameters to ensure results similar to original test failures. Following confirmation of failures, careful pin to pin curve tracer measurements were made to localize or characterize the faults.

3. Thorough exterior examinations, aided by microscopes, were conducted to preclude the possibility of external faults causing failure.

4. When channeling was suspected (as a product of the electrical characterization), the technique applied was high temperature storage of varying times and temperatures (up to 22 hours at 175^{o}C, and up to 300 hours at 150^{o}C) followed by electrical testing. If self repair was evident following high temperature storage, channeling was inferred as the cause of failure.

3.7.2.2 Dissection Techniques--The dissection technique most frequently employed involved using emory paper sanding drums (1/2 inch diameter) to grind away an area directly above the die to a depth such that the leads were not disturbed. A frame was soldered to the external leads to provide a solid holder and the entire assembly was dipped for about 30 seconds in hot nitric acid (a 90% solution). For resin coated dice a five-second exposure to nitric acid and a 30-second exposure to hot sulfuric acid was used. The acid removed the epoxy evenly at all points, but exposed the die before totally exposing the lead frame. For both nitric and sulfuric acids, only acetone was employed as a rinse, since water would have caused excessive metallization damage. Another dissection technique infrequently employed was to use an acid resistant cement to coat the leads and package (except directly above the die) prior to acid exposure. Although these techniques worked well to expose the die and leads, entire removal of epoxy without damaging the die or lead frame was sometimes difficult if not impossible. This was particularly true of devices which for various reasons had shorted junctions or burned metallizations. In most cases though, epoxy removal was sufficient to enable identification of failure causes.

Following dissection of the parts, autopsy efforts proceeded using standard techniques such as visual inspection, micro-manipulator probing, and SEM examinations. Bond pulling, die shearing, metallurgical sectioning, and other destructive tests were performed as needed to provide supplemental information. Failure causes were identified and documented, and succeeding failures were analyzed to the point required to provide a high degree of confidence that the same failure cause as previously documented was repeated.

4.0 TEST RESULTS

4.1 SUMMARY OF RESULTS

Performance of the test program was accomplished in three separate phases, each of which resulted in significant findings. These phases were:

- o Initial screening
- o Life testing
- o Special tests

4.1.1 Summary of Initial Screening Results

Yields achieved in the initial screening ranged from 99% for the Manufacturer A bipolar 74LS194 microcircuits in the screen 2 group, to 56% for the Manufacturer B type 2N2222 transistors in the Screen 2 group. The use or non-use of burn-in turned out to be not significant, because the majority of screening failures occurred at the electrical measurements preceding burn-in, although there were some failures that occurred while the parts were actually under power in the burn-in ovens.

The important point is that there were no clear trends in the screening program which would point to any one screen as an important factor in the reliability assurance of plastic encapsulated semiconductors. Probably the most significant finding was that the double electrical screen espoused by some of the users of plastic encapsulated semiconductors turned out to be effective before burn-in (considering that measurement at 25°C and 100°C constitutes double electrical screening) but turned up only three part failures for just one part type when applied after burn-in. Thus the most effective screening practice apparent from the initial screening program was the use of electrical measurement at two temperatures: 25°C and 100°C. Burn-in did not seem to be a particularly effective screen, and burn-in at 125°C was particularly damaging to the Manufacturer B type 741 op amps, causing the entire group of 345 parts to fail catastrophically. The cost trade-off study performed on various screening options showed that if plastic encapsulated semiconductors were subjected to the three screens used on this program their cost would exceed the cost of JAN Class B hermetically sealed devices. See Section 4.2.2 for the detailed analysis.

4.1.2 Summary of Life Testing Results

Several significant findings resulted from the life test experiment. First, it was observed that there was no particular consistent improvement in life test reliability as a result of any one initial screen that was previously applied to the parts. This was particularly manifested by the fact that consistent Arrhenius curves could not be plotted for any of the part types. Instead it appeared that no matter what the previous screen had been, the log-normal failure distributions had completely independent median times to failure at each of the three life test temperatures of 40°C, 70°C and 125°C.

This inconsistency in the Arrhenius curves prevented any meaningful determination of the activation energies of the plastic encapsulated semiconductors tested, and tends to indicate that the failure mechanisms of plastic encapsulated semiconductors are unscreenable using accelerated temperature tests.

A second important observation was made for the Manufacturer B type 741 op amps, which appeared to demonstrate wearout failures in relatively short test times, even for the parts that were life tested at 40°C. This particular group of parts exhibited early catastrophic failures during the initial screening at 125°C burn-in, and thus it is not surprising that the poor performance of this part type as a whole carried over into the life testing. For this manufacturer, there appears to be a combinational effect between the linear microcircuit structure and the plastic encapsulant that induces early failure under the conditions of life testing or burn-in with bias voltage applied.

A final observation of interest is that for some of the part types the 40°C life test appeared to cause the largest number of failures. This is surprising because of the generally accepted belief that semiconductor failures are time temperature dependent. Apparently, for plastic encapsulated semiconductors, this time-temperature dependence is modulated by other failure mechanisms derived from the plastic encapsulant, such that the normal time-temperature

Arrhenius rate relationships are no longer valid. The impact of this result is that accelerated temperature stress screening (such as burn-in) which is predicated on this time-temperature dependence becomes invalid as a useful screen for plastic encapsulated semiconductors that behave in the manner observed on this program.

4.1.3 Summary of Special Test Results

4.1.3.1 Flammability—Although all of the part types could be made to ignite by application of the propane torch for 15 seconds, the duration of the flames after removal of the torch was quite variable from device type to device type. Most surprising was the observation that the Manufacturer B plastic encapsulant was the best at self-extinguishing the flame after removal of the torch: of the thirty parts tested, only one would show flame after removal of the torch and this only for one second. The other 29 parts all showed a flame duration of zero seconds, as compared to up to 6 seconds for several other part types. This is surprising because the Manufacturer B parts exhibited the highest incidence of catastrophic failures that caused ignition of the plastic encapsulant. Apparently, the ignition of the plastic during screen testing and life testing was caused by device failure considerations rather than a flammability proclivity of the encapsulant.

See Section 4.4.1 for the details of this test.

4.1.3.2 Humidity—The application of the humidity environment to 30 of each part type in biased operation resulted in no failures at all for the Manufacturer A bipolar 74LS194 devices but resulted in over half of each of the 2N2222 transistor types failing. Both CMOS types had nearly the same number of failures (4 and 5) and both 741 op amp types had nearly the same number of failures (3 and 1). These results proved to be inconclusive in terms of the use of humidity as a qualification screen, since it was not observed that the significant differences that occurred in life testing were reflected from the predictions that could be made from the results of the humidity testing. See Section 4.4.2 for the details of this test.

4.1.3.3 Autoclave—This test was performed with 30 parts of each part type biased at 5 volts, while exposed to an environment of 120°C and 15 psig of steam. Again, the results showed the manufacturer A bipolar 74LS194 device to be almost impervious to the environment, while the other part types experienced fair to poor performance. Again, the 2N2222 transistor types from both manufacturers experienced large numbers of failures (28 and 30). The CMOS types experienced larger numbers of failures than for the humidity test (18 and 9) and the 741 op amps also experienced more failures but of roughly the same order of magnitude (8 and 11). It was not seen that autoclave would be a meaningful qualification test, since it did not seem to predict the performance that occurred during the life testing portion of the program. See Section 4.4.3 for the details of this test.

4.1.3.4 High Temperature Storage—The results of the high temperature storage test disproved the hypothesis that pre-baking the parts at elevated temperature would drive out any possible contaminants and thereby improve the reliability of the parts. It was found instead that the most severe bake (125 hours at 175°C) resulted in the largest number of failures and these were due to channelling, apparently a result of the presence of contaminants derived from the plastic encapsulant. The other test cells used (125 hours at 125°C and 50 hours at 125°C) resulted in fewer failures, but channelling still did occur for all of the test conditions except for the Manufacturer C 4069 CMOS devices which experienced no life test failures after the bake at 125°C for 50 hours.

4.2 DETAILS OF SCREEN TEST RESULTS

4.2.1 Initial screening Program

All parts were subjected to electrical screening and two-thirds of the parts were subjected to additional environmental screening prior to committing the parts to the life test experiment. The intent of the screening was to investigate possible screens that could be applied to plastic encapsulated semiconductors. The life test experiment was intended to determine the effectiveness of each of the screening routines in reliability assurance of plastic encapsulated semiconductors.

The 1035 plastic encapsulated parts of each manufacturer type were divided into 345 parts for each of three screen conditions as described in section 3. Table 4-1 summarizes the failures that occurred in each of the screens, for each of the part/manufacturer types. It can be seen that with the exception of the 125°C burn-in screen for the Manufacturer B linear 741 op amps, the yield for all of the parts was quite high and easily produced the desired 225 good parts needed for the life test experiment.

It turned out that with the above-mentioned exception, the use or non-use of a burn-in had practically no effect on the number of parts that survived the screens. The electrical measurements made before burn-in intercepted nearly all of the failed parts, with only 3 parts failing at post-burn-in electrical measurement. An additional 33 parts failed during the actual burn-in and had to be removed from the ovens.

Figures 4-1 through 4-7 show the points in the screening flow at which the failures occurred. The most significant finding evident from these figures is that the measurement of functional and dc parameters at 100°C caught a sizable number of parts that had passed the 25°C measurements. None of the screening failures occurred at the post-burn-in measurement at 70°C following the 100°C measurement.

It appears from the screening data that the burn-in test was ineffective in intercepting freak population parts failures, but that the elevated temperature electrical measurements were very effective. This conclusion would be a very fortuitous circumstance for plastic encapsulated semiconductors, since elevated temperature electrical testing is much less expensive than is burn-in testing.

Table 4-1: Initial Screening Failures

	NUMBER OF FAILURES DURING INITIAL SCREENING		
Part Type	Screen (No Burn-In)	Screen 2 (70°C Burn-In)	Screen 3 (125°C Burn-In)
MFR A (74LS 194)	7	3	5
MFR B (4069)	12	36	38
MFR C (4069)	5	12	18
MFR B (741)	50	6	Aborted
MFR D (741)	41	35	13
MFR B (2N2222)	50	54	29
MFR E (2N2222)	9	6	5

Note: Each cell started with 345 parts

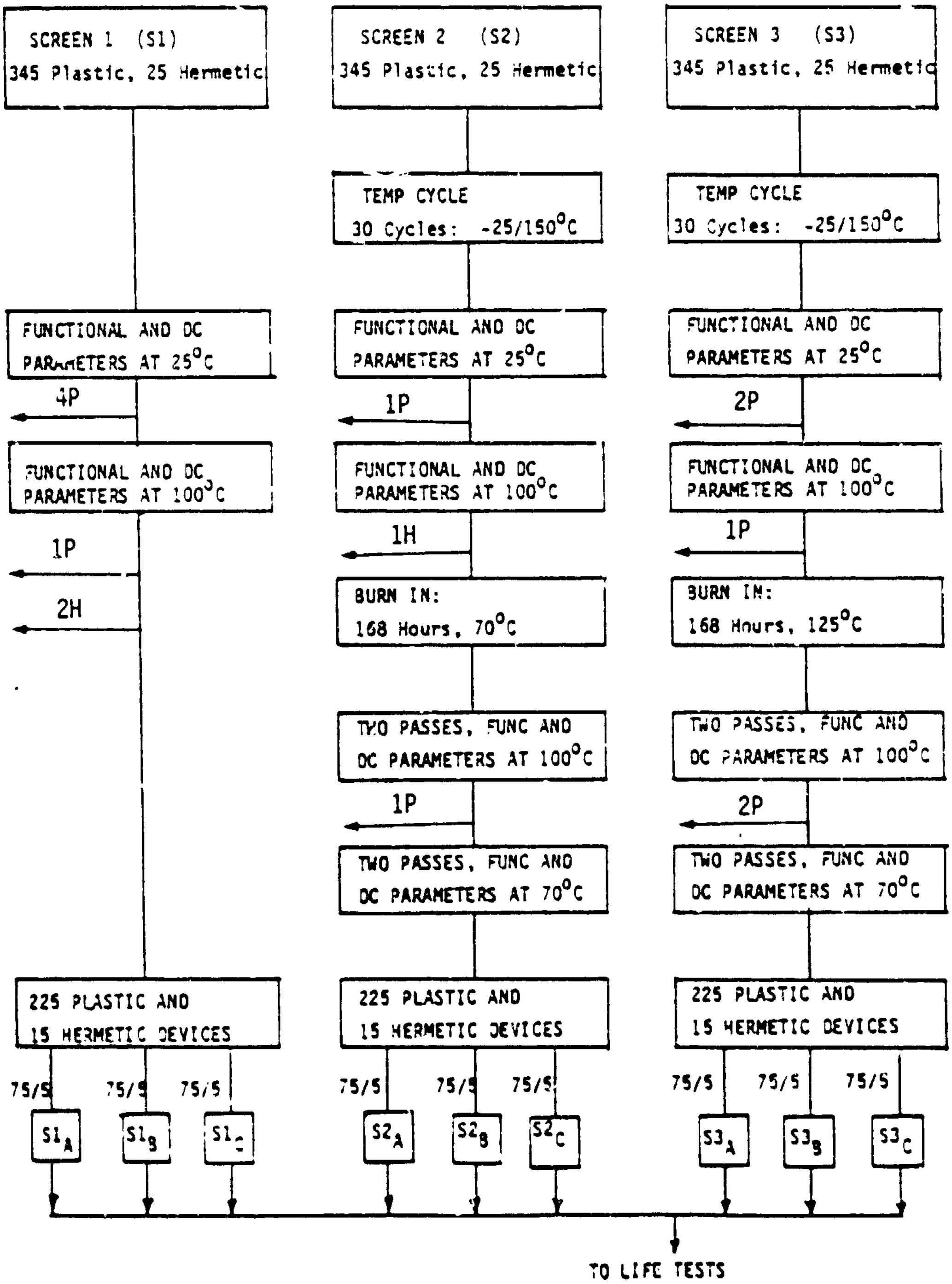

Figure 4-1 MFR. A 74LS194 Initial Screening Failures

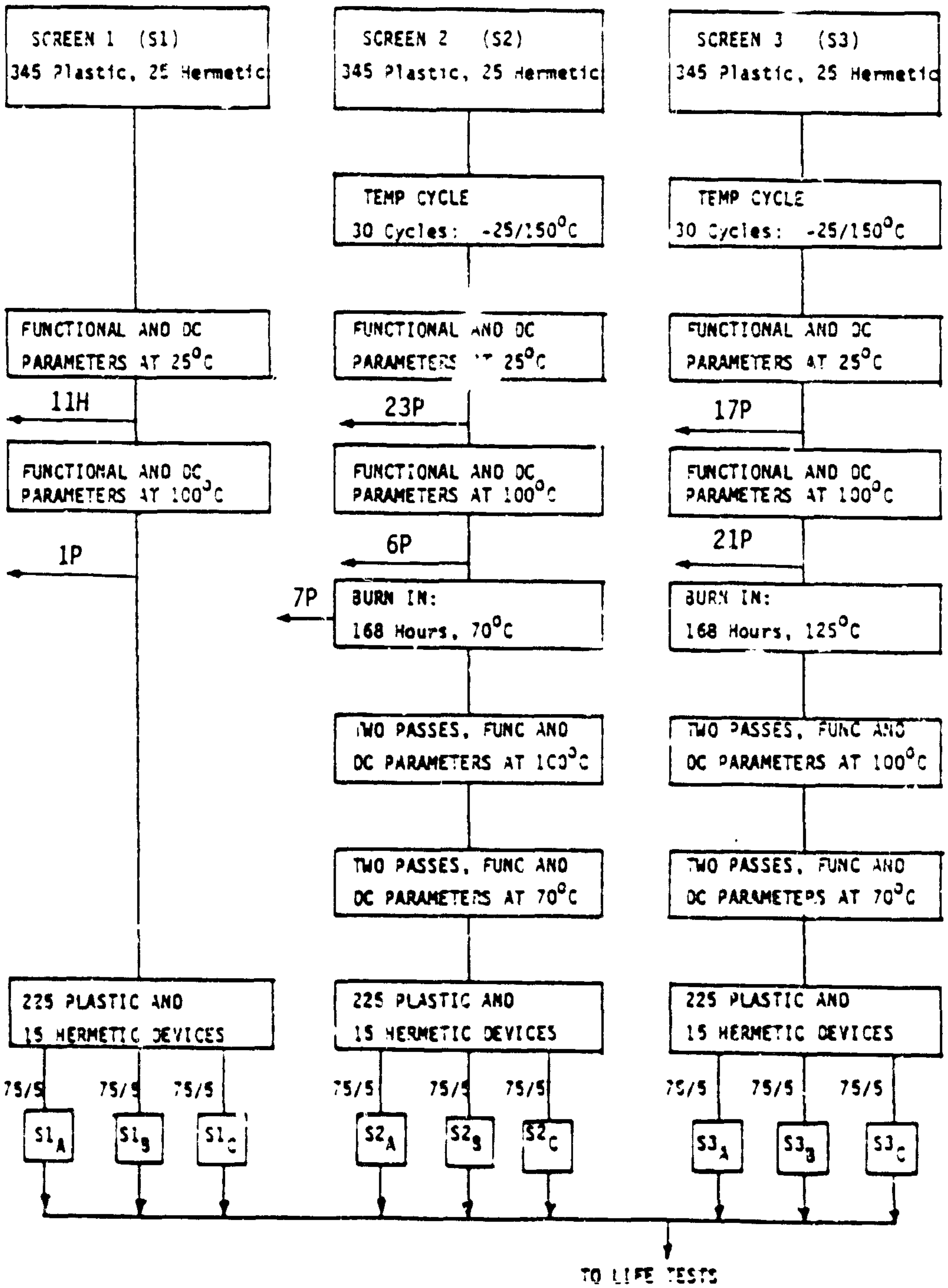

Figure 4-2 MFR. B CD4069 CMOS Initial Screening Failures

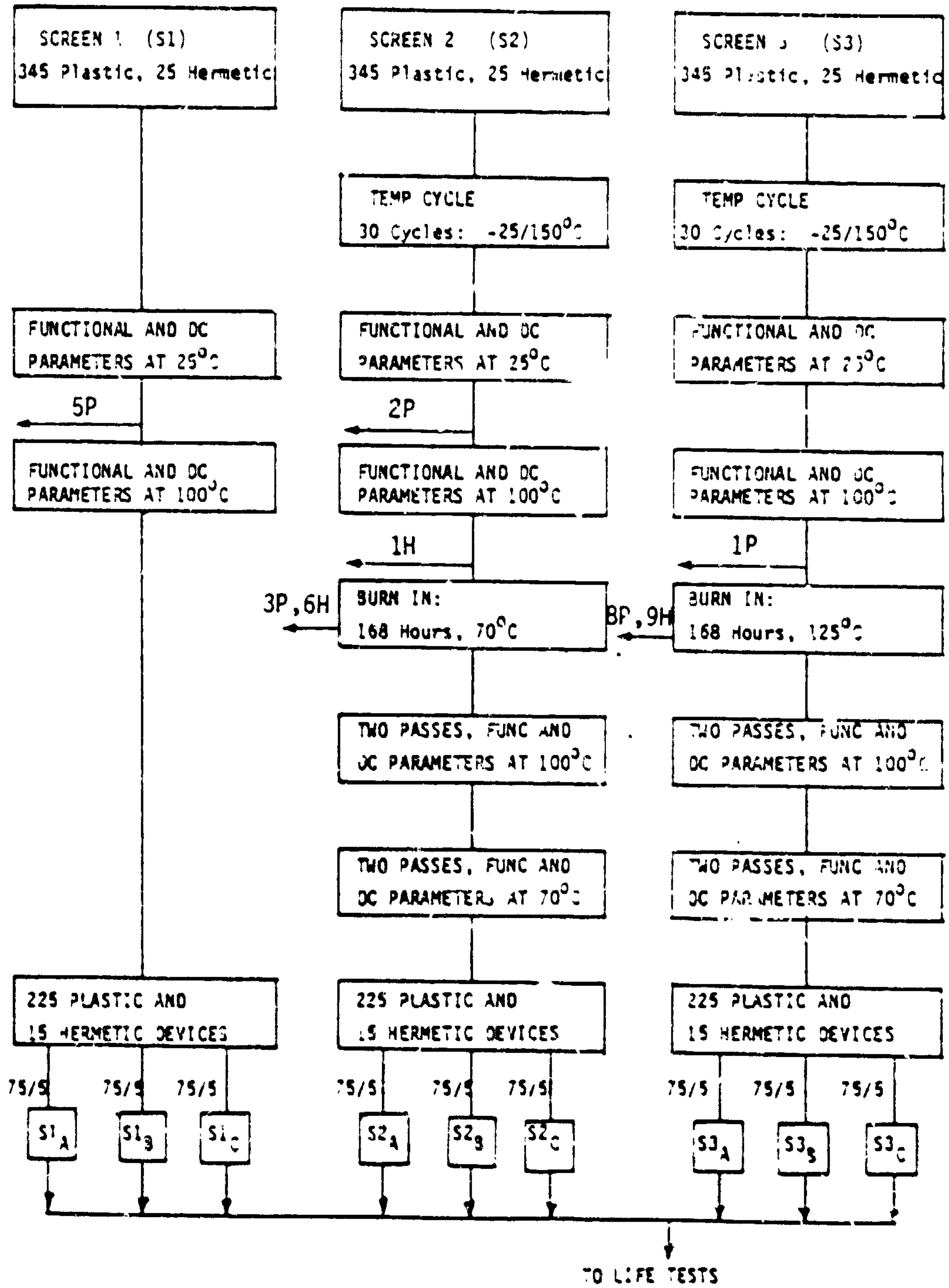

Figure 4-3 MFR. C CD4069 CMOS Initial Screening Failures

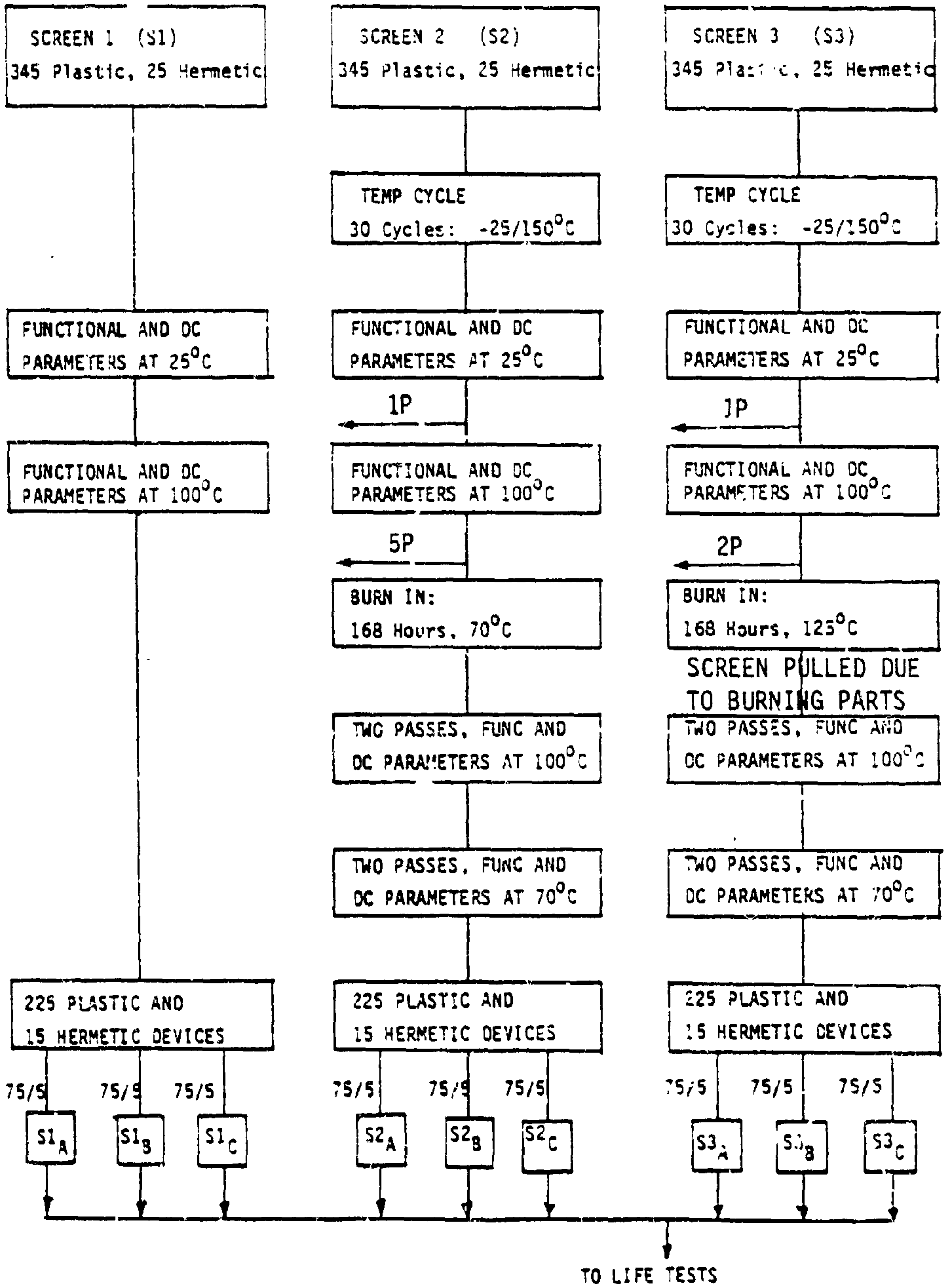

Figure 4-4 MFR. B 741 OP AMP Initial Screening Failures

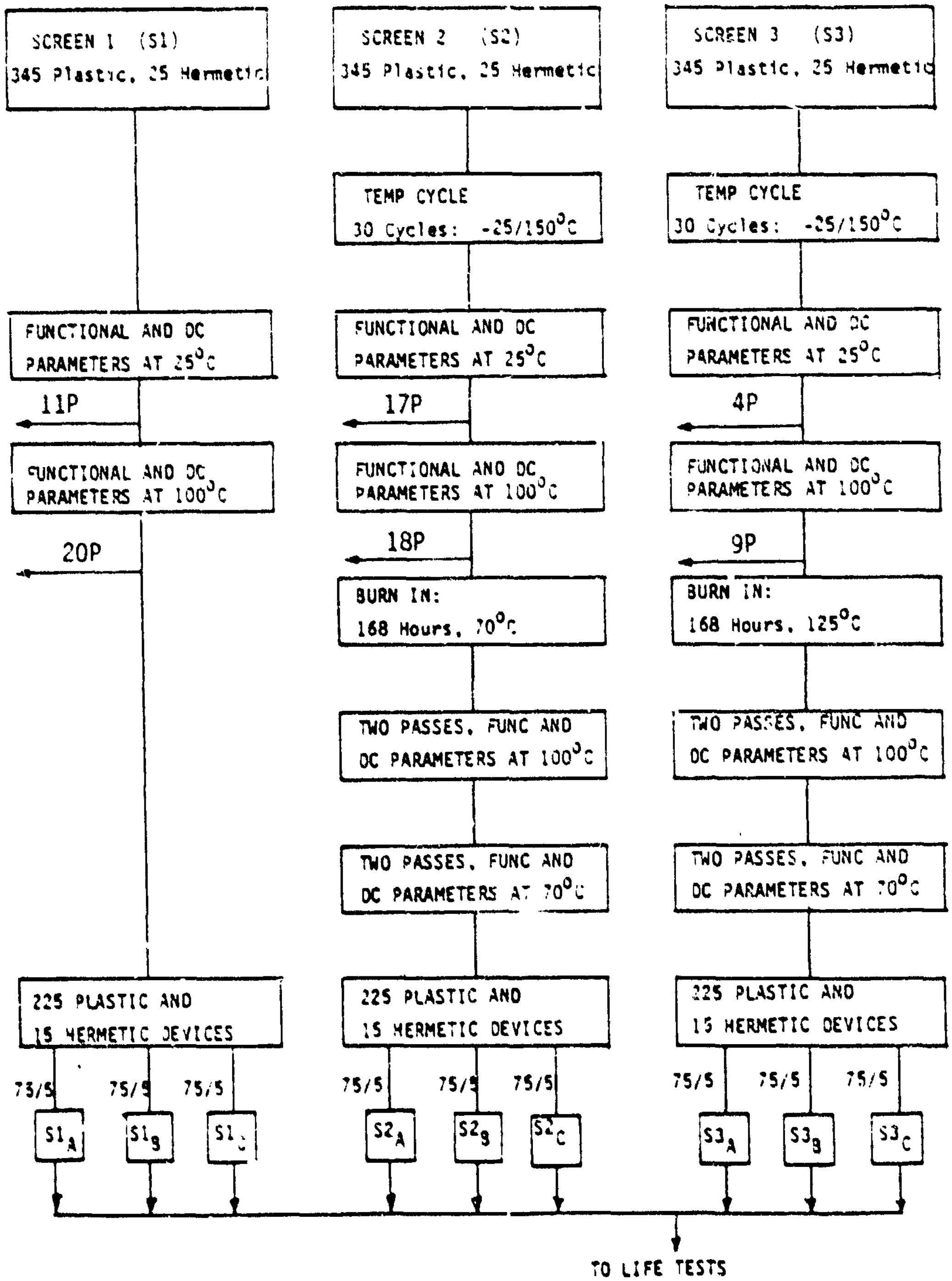

Figure 4-5 MFR. D 741 OP AMP Initial Screening Failures

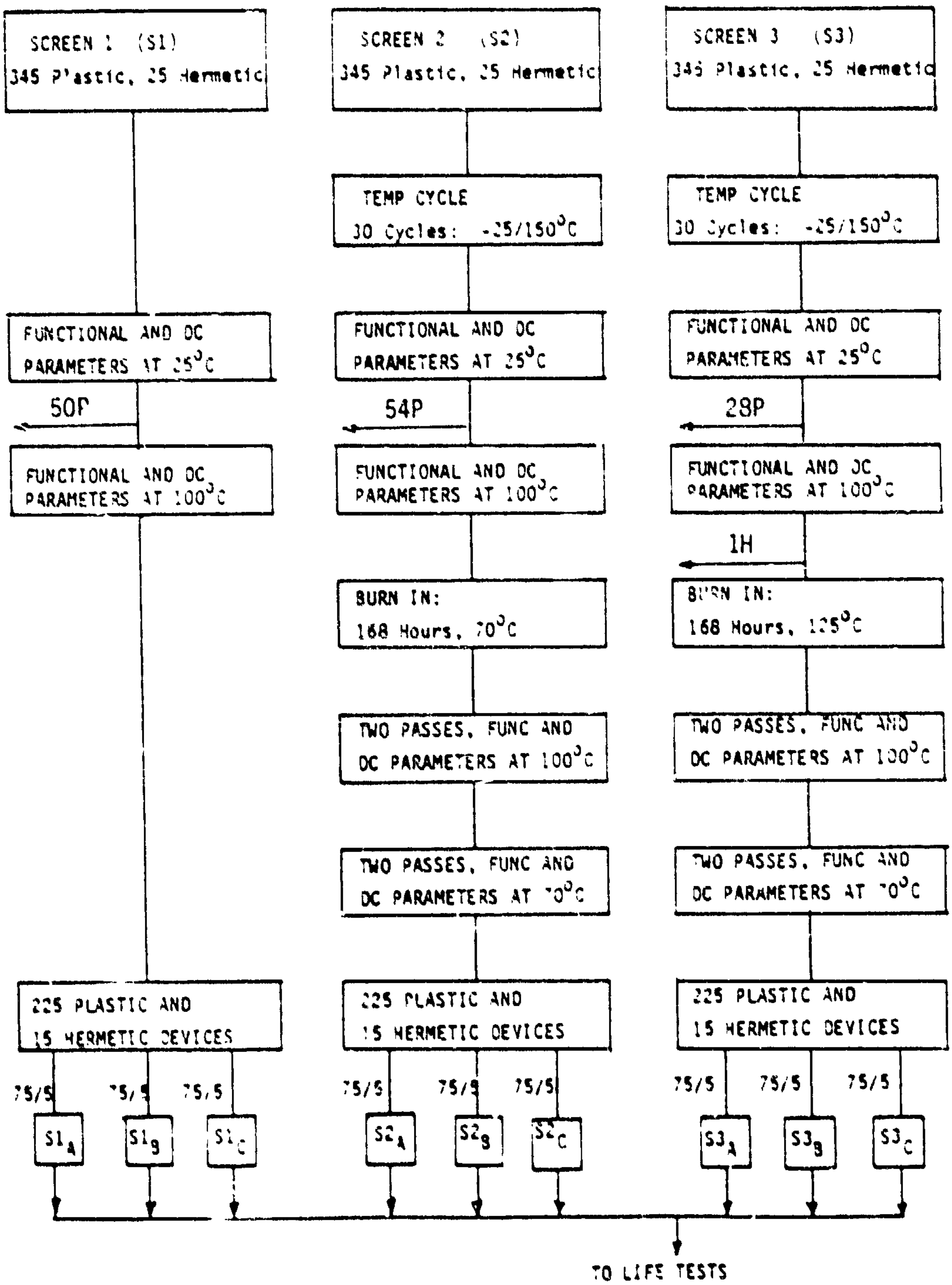

Figure 4-6 MFR. B 2N2222 Transistor Initial Screening Failures

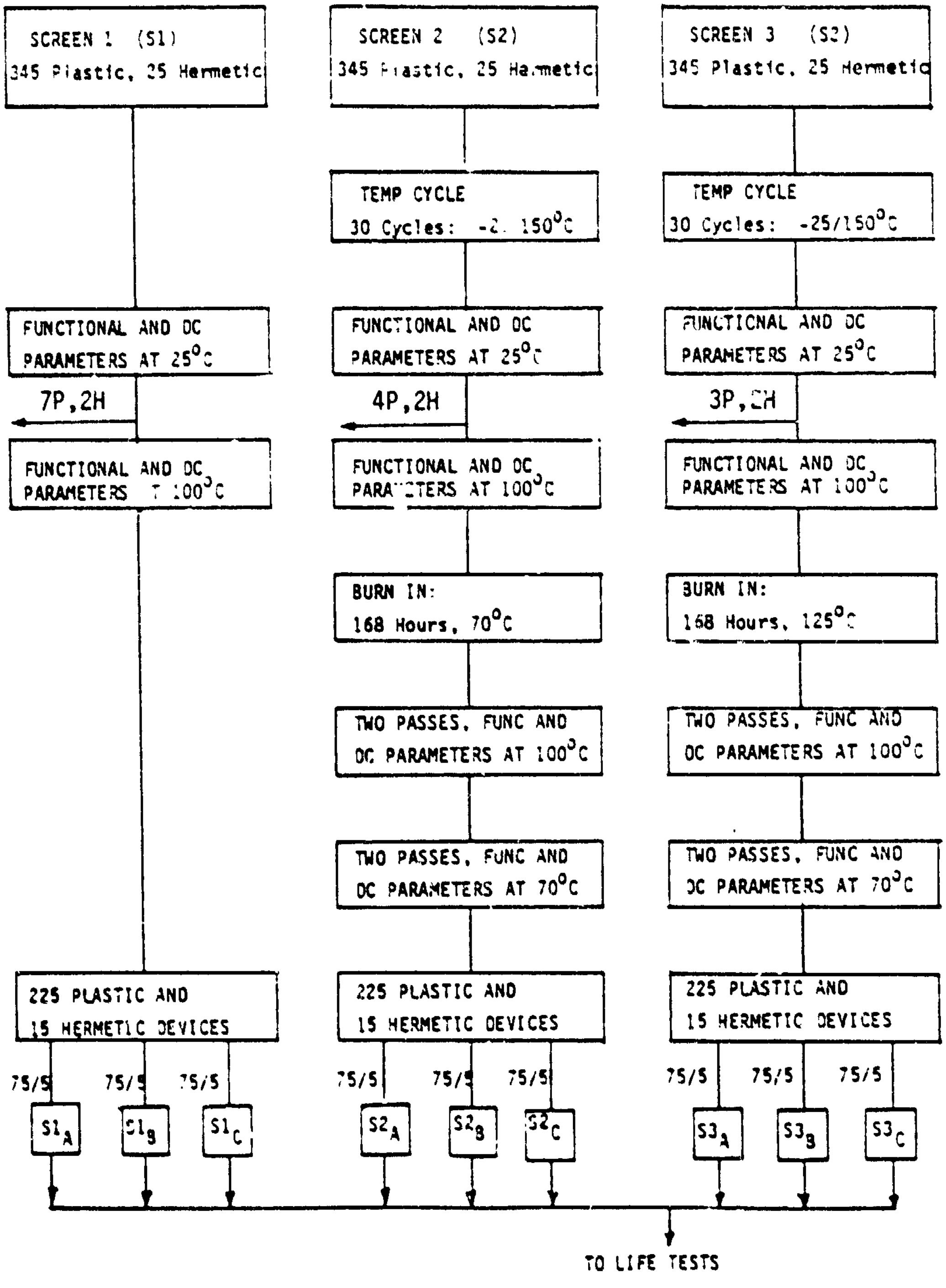

Figure 4-7 MFR. E 2N2222 Transistor Initial Screening Failures

4.2.2 Screening Cost Analysis and Trade Study

As a vehicle to scope the cost advantages of the use of plastic encapsulated semiconductors, a cost study was performed on the relative costs of procuring semiconductors in hermetically sealed JAN (Class B) form versus the cost of use of the same device types in plastic encapsulated form.

In the case of JAN parts, there is little additional work that must be performed after purchase of the parts, since they come already screened to stringent military specification requirements. Generally, even JAN parts are subjected to a 100% measurement of electrical parameters and functionality at 25^{o}C as a part of incoming receiving inspection. The total cost of these parts by the time they are in manufacturing stores ready for production use is thus the total of the purchase price plus the electrical test cost.

Using high speed automatic testers, the typical test cost at receiving inspection is 20¢ per part for digital microcircuits and transistors and 50¢ per part for linear microcircuits. Thus, the total in-bin cost for JAN versions of the four device types employed on this program would be as follows:

JAN Part	Part Type	JAN Class B 1000 Quantity Purchase Cost Per Part	Per Part Test Cost	JAN Class B Total Cost Per Part
M38510/30601	54LS194A	$ 4.50	$ 0.20	$ 4.70
M38510/17401	CD4069	$15.00	$ 0.20	$15.20
M38510/10101	741	$ 5.00	$ 0.50	$ 5.50
JANTXV2N2222A	2N2222	$ 1.05	$ 0.20	$ 1.25

These costs can be compared to the comparable costs to procure and test plastic encapsulated semiconductors in such a manner that a similar degree of reliability assurance is provided. An analysis was made of the cost of performing each of the three screens described in this test program.

Assume that 1000 parts are to be subjected to a screen. The cost to perform the screen would be as follows:

	Cost Per Part: 74LS194 CD4069 2N2222	Cost Per Part: 741
Screen #1		
Electrical Measurement at 20°C	$ 0.20	$ 0.50
Electrical Measurement at 100°C	2.00	2.30
Total Cost per part (Screen #1)	$ 2.20	$ 2.80
Screen #2 or Screen #3		
Electrical Measurement at 25°C	$ 0.20	$ 0.50
Electrical Measurement at 100°C	2.00	2.30
Temperature Cycle	.06	.06
Burn-in Board Fab (2 parts per socket)	10.72	10.72
Burn-in at 70°C or 125°C	1.91	1.91
Double Electrical Measurement @ 100°C	4.00	4.60
Double Electrical Measurement @ 70°C	4.00	4.60
Total Cost per part (Screen #2 or #3)	$22.89	$24.69

The total in-bin cost for the four plastic encapsulated device types employed on this program would be as follows:

Part Type	1000 Quantity Purchase Cost	Screening Cost: Screen #1	Screening Cost: Screen #2 or 3	Total Cost: Screen #1	Total Cost: Screen #2 or #3
4LS194	$ 2.55	$ 2.20	$22.89	$ 4.75	$25.44
CD4069	0.22	2.20	22.89	2.42	23.11
741	0.27	2.80	24.69	3.07	24.96
2N2222	$ 0.11	$ 2.20	$22.89	$ 2.31	$23.00

The cost of the plastic encapsulated version can then be compared to the cost of the equivalent hermetically sealed version, as follows:

Part Type	JAN Equivalent	In-Bin Cost: Plastic Encapsulated Screen #1	In-Bin Cost: Plastic Encapsulated Screen #2 or #3	In-Bin Cost: Hermetically Sealed JAN "B"
74LS194	M38510/30601	$ 4.75	$25.44	$ 4.70
CD4069	M38510/17401	2.42	23.11	15.20
741	M38510/10101	3.07	14.96	5.50
2N2222	JANTXV2N2222A	2.31	23.00	1.25

It should be noted that these costs do not include the normal parts engineering support costs associated with operating a NASA reliability-assured program. While it is expected that these costs would be greater for the plastic encapsulated parts because of uncertainties in the continuing quality of plastic encapsulated devices, these costs could not be estimated in a meaningful way that would not bias the cost analysis, and hence the parts engineering costs were ignored.

The cost analysis shows that for the 74LS194 and the 2N2222, the burned-in JAN Class B versions would be less expensive to use than plastic encapsulated parts screened to the minimal screen of Screen #1 (no burn-in). For CD4069 and the 741 the Screen #1 plastic encapsulated parts would be less expensive than the JAN Class B equivalents.

If burn-in screen were added to the plastic encapsulated parts (Screen #2 or #3) they would in all cases be more expensive than JAN Class B hermetically sealed parts. This cost desparity is primarily due to the small quantity handling and setup costs for screening single lots of parts as opposed to the large quantity production runs made by manufacturers of JAN Class B parts.

The earlier interim report on this contract indicated that if the manufacturer performed the screening of plastic encapsulated parts, there would be a 2:1 cost advantage in favor of plastic encapsulated MSI bipolar TTL parts. ($2.99 as compared to $6.00 for JAN class B parts). This difference disappears when screening must be performed by the NASA user for small quantities of parts.

The conclusion evident from this cost analysis is that the purported cost advantage of plastic encapsulated semiconductors disappears when even minimal reliability assurance screening is applied, thus negating the principal advantage to the use of plastic encapsulated devices.

4.3 DETAILS OF LIFE TEST RESULTS

4.3.1 74LS194 (Manufacturer A)

4.3.1.1 Life Test Results—Table 4-2 summarizes the results of the life tests performed on the Manufacturer A 74LS194 devices. These parts were TTL bipolar devices and as can be seen, there were very few failures in any of the test cells. At 40°C, it appears that the Screen 1 cell (no burn-in) performed better than the cells which had had a burn-in performed prior to life testing. However, it is felt that this is a statistical anomaly, since this situation is reversed at 70°C life test, and at 125°C life test it can be seen that the effect of the prior burn-in is indeterminant. The very small number of part failures that occurred with the 74LS194 devices prevented the plotting of the log-normal distributions for the various cells. Instead, the results point to the fact that the bipolar LSTTL technology appears to be well capable of being used in high reliability applications in the plastic encapsulated form. The quantity of failures that occurred is well within the number that could be expected from any hermetic parts subjected to 4000 hours of life test under similar conditions. The difference, of course, is that it is generally believed that burn-in at 125°C is necessary for the reliability assurance of hermetic devices. In the case of the plastic encapsulated devices, no such clear cut conclusions can be drawn based on the experimental data. The distribution of failures was very nearly the same for the case of no burn-in, burn-in at 70°C, and burn-in at 125°C.

TABLE 4-2
74LS194 (Manufacturer A) Life Test Summary

	Cumulative Failures		
	Screen 1 (No Burn-In)	Screen 2 (70°C Burn-In)	Screen 3 (125° Burn-In)
Life Test at 40°C	0	1	2
Life Test at 70°C	3	1	0
Life Test at 125°C	1	0	1

Thus, it would be recommended that for plastic encapsulated LSTTL microcircuits, the cost of burn-in could be avoided in keeping with the cost saving motivation in using plastic encapsulated parts in the first place. The important test performed as a prescreen would be the use of 100% electrical test at two temperatures, 25°C and 70°C.

An additional finding that can be concluded from the results of the life test on the 74LS194 devices is that the use of double electrical tests did not seem to affect the reliability of the parts in subsequent life testing. Screen 1 parts were subjected only to one pass of electrical measurements at each of the two temperatures (25°C and 100°C), while the Screen 2 and 3 parts were subjected to two passes of electrical measurement at each of the test temperatures of 70°C and 100°C after burn-in in addition to the single pass 25°C and 100°C electrical measurements before burn-in. Yet there seems to be no difference in the number of failures that occurred in the subsequent life testing.

The conclusion that can be drawn from the 74LS194 life test experiment is that:

- LSTTL devices are suitable for use in plastic encapsulated form.
- Burn-in is not necessary as a reliability assurance technique for plastic encapsulated LSTTL devices.
- Double electrical testing seems to have no effect in improvement of subsequent life test reliability.
- The most important single screen that should be invoked for plastic encapsulated LSTTL devices is 100% electrical measurement at two temperatures.

4.3.1.2 Failure Analysis Results for Manufacturer A Bipolar 74LS194—Of the 9 Manufacturer A parts that failed on life test, 6 were subjected to failure analysis with the result that all of them retested good when they were electrically tested as the initial step in failure analysis. It can only be postulated that the parts experienced recovery from the influence of the life test environment in the time period between removal from life test and submittal to failure analysis. The possibility that the parts were erroneously measured as failures was discounted by the fact that each part that failed was subjected to several cycles of socket insertion and retest before being declared to be a failed part.

The failure analysis results reinforce the conclusion that the bipolar technology represents a high integrity technology in the plastic encapsulated configuration.

4.3.2 CMOS 4069 (Manufacturer B)

4.3.2.1 Life Test Results—Table 4-3 summarizes the results of the life tests performed on the CMOS 4069-type devices manufactured by Manufacturer B. Two significant findings can be concluded from this table. First, it can be seen that for the life tests performed at 40°C and 70°C, there is a marked decrease in the number of failures that occurred in the cells that were burned in at 125°C prior to life testing. This implies that a 168 hour burn-in at 125°C would be a necessary screen test to be applied to this manufacturer's CMOS parts. However, there is a hazard in applying this finding. For the life test cell that was life tested at 125°C, the cell that was previously burned in at 125°C experienced a large number of failures after only two hours of life test. This implies that the 125°C stress probably is too severe for either the plastic encapsulant or the die itself.

TABLE 4-3

Life Test Data Summary for Manufacturer B CMOS 4069

	Cumulative Failures		
	Screen 1 (No Burn-In)	Screen 2 (Burn-In at 70°C)	Screen 3 (Burn-In at 125°C)
Life Test at 40°C	34	38	17
Life Test at 70°C	59	55	32
Life Test at 125°C	58	51	72

Most significantly, of course, the large number of failures that occurred in each of the test cells indicates that the plastic encapsulated CMOS devices from Manufacturer B should not be used at all in high reliability applications.

This position is borne out by analysis of the log-normal distribution plots made from the statistical analyses of the failure data. Table 4-4 shows the results of the life test at each electrical measurement increment in time. From these data, a statistical analysis was made of the shape of the log-normal distribution, and the median time-to-failure was computed. The log-normal distributions are shown in Figures 4-8 through 4-10. The computer printouts of the log-normal distribution analyses are located in the appendix. The summary of the median times to failure is shown in Table 4-5.

TABLE 4-5

Median Time-to-Failure for Manufacturer B CMOS 4069

	Median Time-to-Failure (Hours)		
	Screen 1 (No Burn-In)	Screen 2 (70°C Burn-In)	Screen 3 (125°C Burn-In)
Life Test at 40°C	1.01×10^4	7.59×10^4	1.41×10^9
Life Test at 70°C	6.05×10^2	6.53×10^2	2.78×10^4
Life Test at 125°C	4.95×10^2	4.31×10^2	1.8

In Figure 4-8, it can be seen that for the parts that were life tested at 40°C, the 70°C prior bur in seemed to result in the least reliable parts. Failures occurred the earliest for this cell. Next in failure occurrence was the cell that was burned-in at 125°C, although this cell experienced the highest median time to failure, 1.4×10^9 hours. Finally, the cell that experienced no burn-in showed the lowest initial rate of failure, although the median time-to-failure was the lowest because of a large number of failures that occurred later in the testing. This same trend also occurred with the 70°C and 125°C life test groups, where the 125°C burn-in or the 70°C burn-in cells experienced the largest number of early failures. In fact, as can be seen from Figure 4-3, the 125° burn-in resulted in an exorbitant number of failures in the 125°C life test cell, indicating that either the plastic encapsulant or the basic semiconductor die structure is not suited for operation at 125°C. Figure 4-11 is an Arrhenius plot of the data resulting from the Manufacturer B CMOS 4069-type devices.

TABLE 4-4 INCREMENTAL FAILURE DISTRIBUTION FOR MANUFACTURER B 4069 CMOS

LIFE TEST FAILURES

40°C LIFE TEST INCREMENT (HOURS)	SCREEN 1 (NO BURN-IN)	SCREEN 2 (70°C BURN-IN)	SCREEN 3 (125°C BURN-IN)
2	3	13	7
8	2	1	0
16	2	4	0
64	10	0	0
256	1	3	2
1000	3	0	0
2000	3	3	6
4000	10	14	2
TOTAL	34	38	17
70°C LIFE TEST INCREMENT (HOURS)			
2	4	14	3
8	1	0	1
16	1	8	1
64	3	21	3
256	2	3	4
1000	43	0	6
2000	2	1	3
4000	3	8	11
TOTAL	59	55	32
125°C LIFE TEST INCREMENT (HOURS)			
2	4	12	46
8	2	0	0
16	0	12	6
64	3	5	10
256	36	8	10
1000	0	4	0
2000	4	2	0
4000	9	8	0
TOTAL	58	51	72

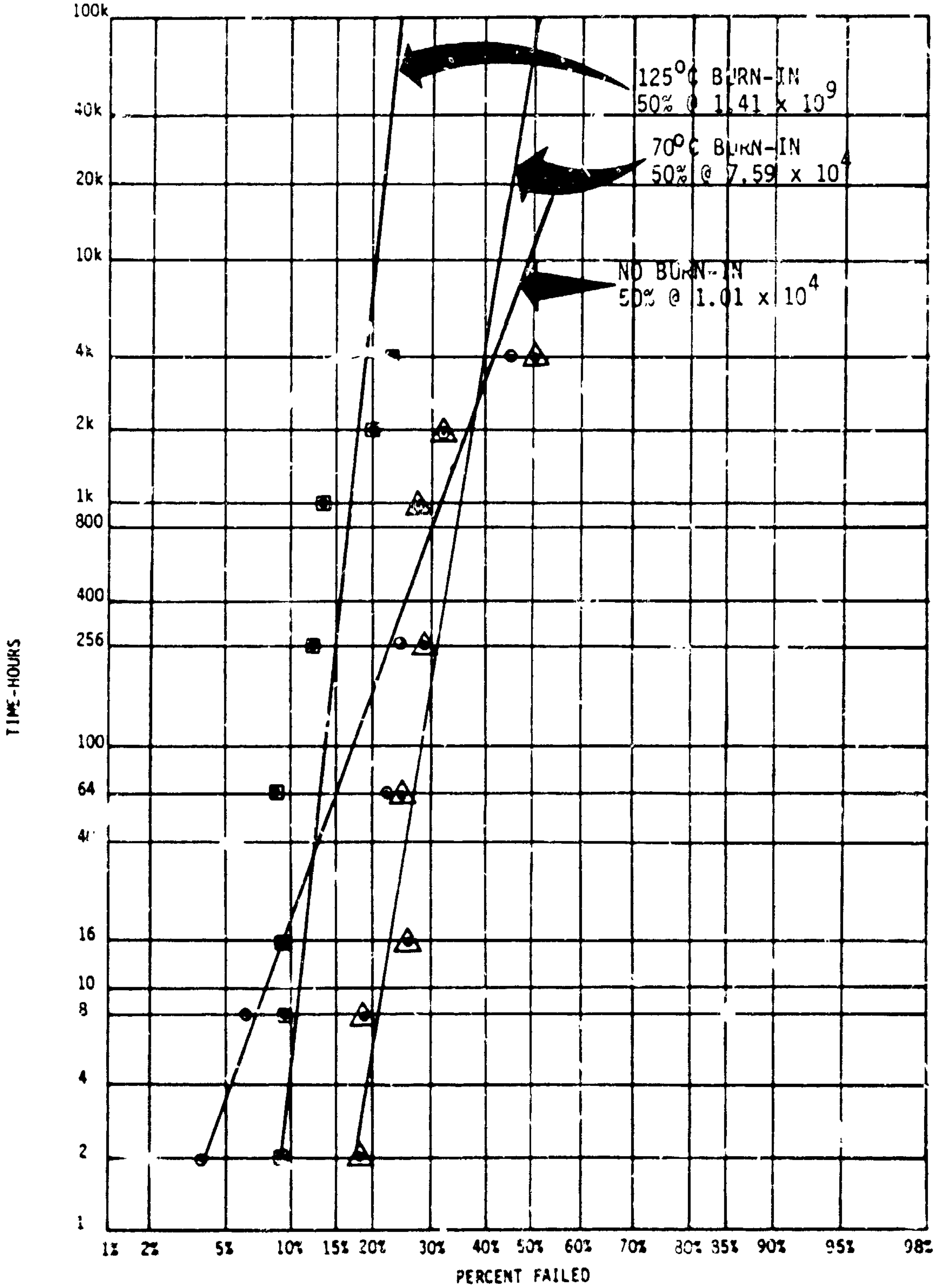

Figure 4-8 MFR B 4069 CMOS 40°C Life Test

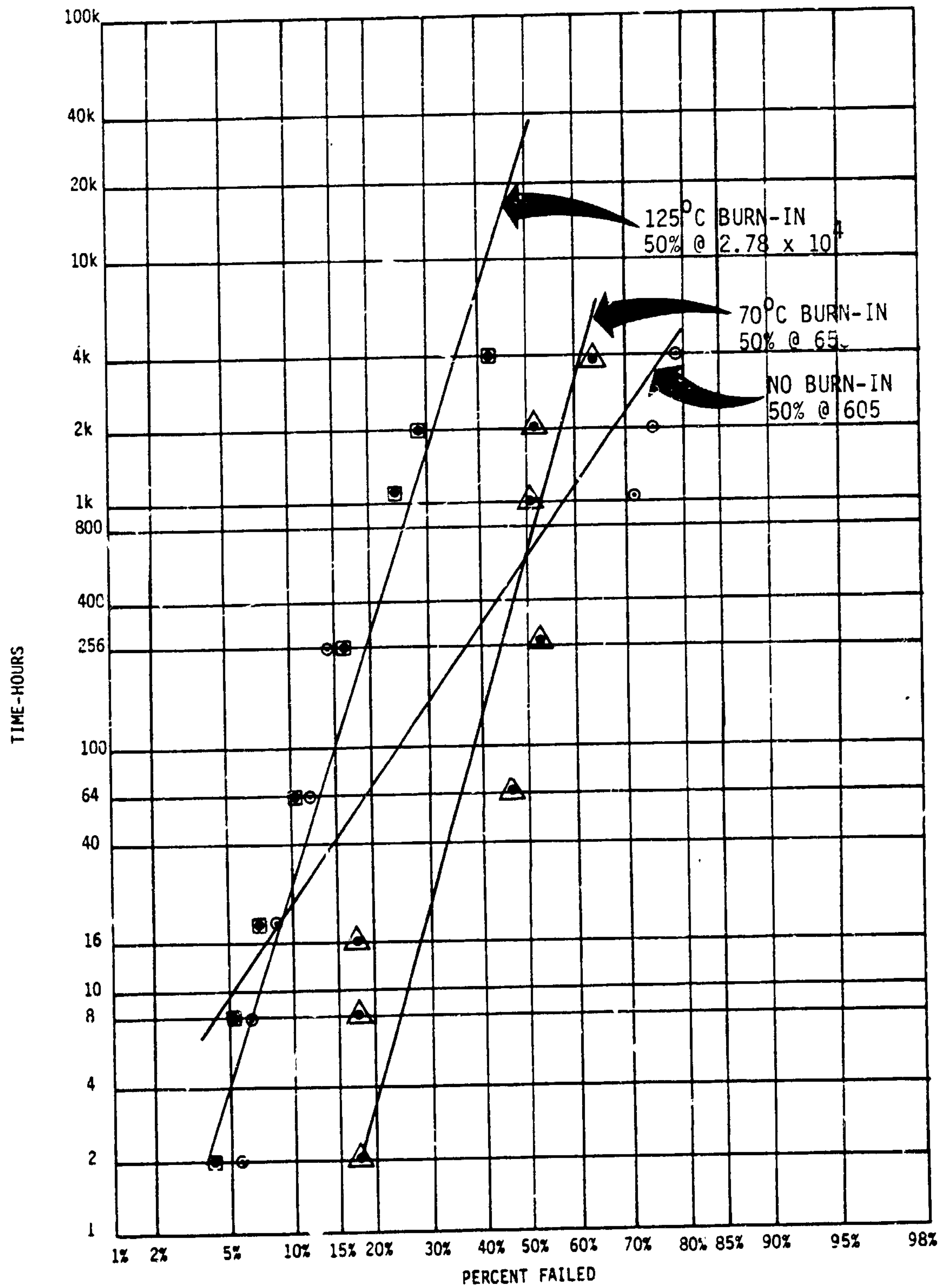

Figure 4-9 MFR B 4069 CMOS 70°C Life Test

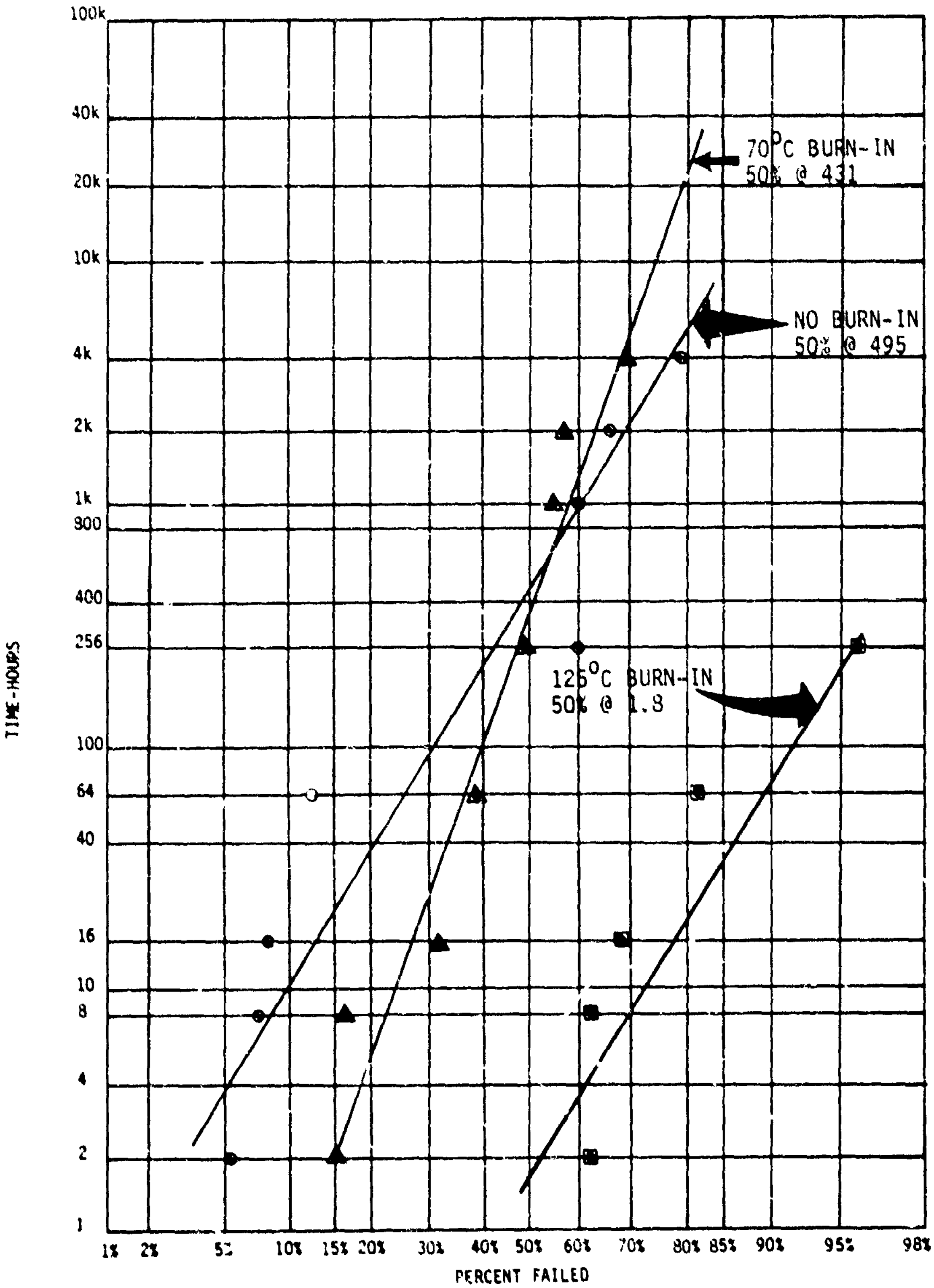

Figure 4-10 MFR B 4069 CMOS 125°C Life Test

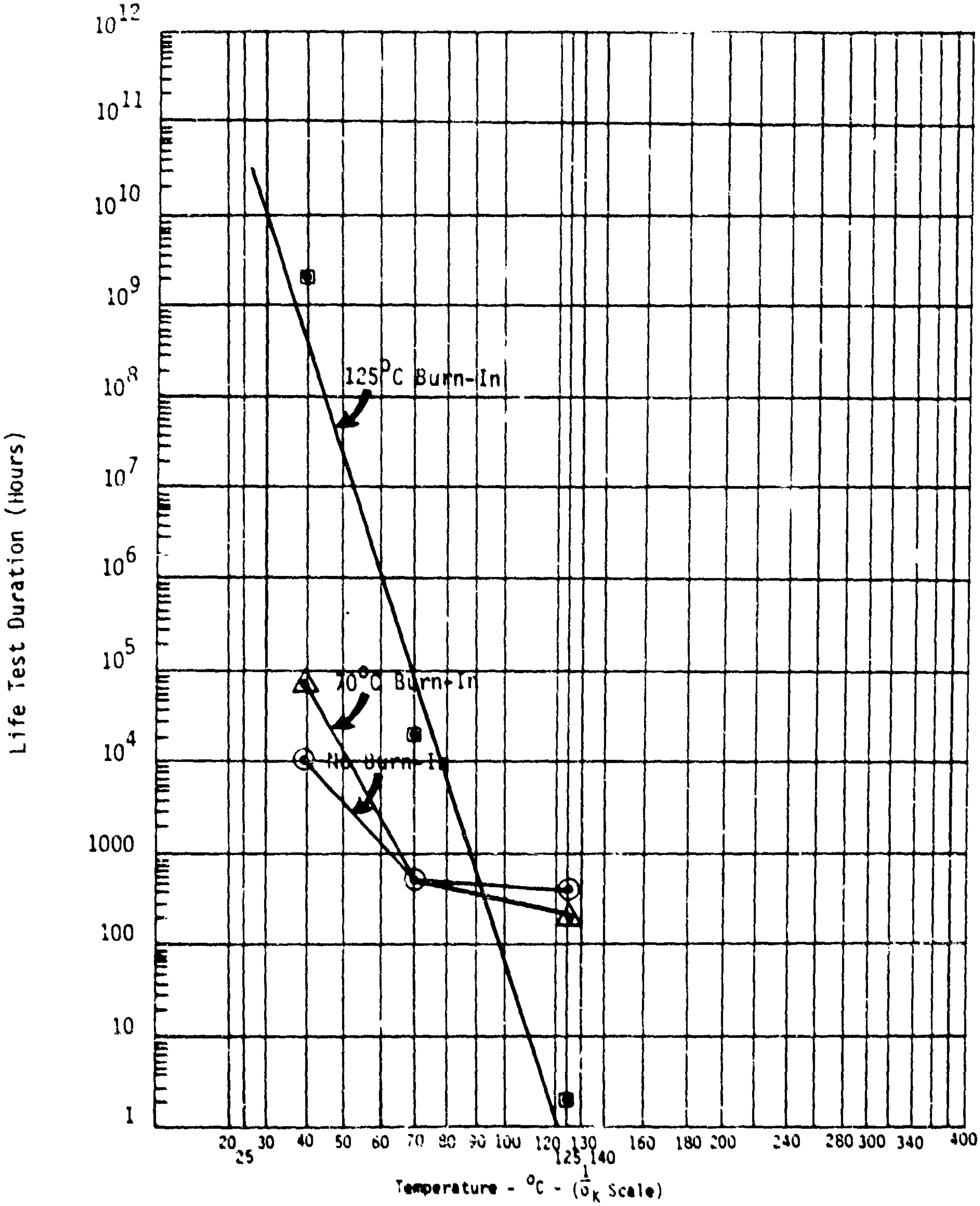

Figure 4-11
Arrhenius Curves of Median Time to Failure For Manufacturer B 4069 CMOS

It can be seen that only the 125^{o}C burn-in data presents a reasonable Arrhenius plot. For the other burn-in temperatures, the data are inconclusive as to the activation energy of the part type. This inconsistency in the Arrhenius plot for two out of three burn-in conditions tends to indicate that there is no unifying pattern to the performance of the Manufacturer B CMOS device types as a result of the experiment. This degree of inconsistency would not be expected at all for predictably well made parts of a hermetic encapsulation, and reinforces the position that the CMOS technology is unsuitable for high reliability applications in the plastic encapsulated configuration.

4.3.2.2 Failure Analysis Results—Of the total of 416 Manufacturer B CMOS 4069 parts that failed during life testing, 17 were selected for failure analysis based on the number of parts that failed at each increment of time. Failure analysis was performed for one part from each cell and time increment for which the number of failures was 10 or more parts. The breakdown of the failure analysis results showed the following:

o Open metallization - ground or Vdd line	11 parts
o Surface inversion or channeling (retested good after baking out)	4 parts
o Catastrophically burned - unable to analyze	1 part
o Kirkendall voiding	1 part

The reason for the open metallization stripes could not be determined. It was postulated that the internal leakage current caused by channelling could have progressed to the point where PNPN action could have taken place in the internal diffused structures.

The incidence of channelling as evidenced by the recovery of the four parts after being baked for 16 to 450 hours is felt to be a significant detriment to the use of CMOS devices in plastic encapsulated configuration. Apparently there are contaminants buried in the plastic encapsulant that can be driven into the CMOS structure sufficiently to alter the normal CMOS bias conditions. It appears that this condition was aggravated by the fact that CMOS devices operate at extremely low levels of bias current, which caused the additional leakage currents to create major disruptions in the normal operating conditions of the CMOS structures.

The Kirkendall voiding failure probably was caused by a combination of high Idd current and high temperature at the bond site due to the high current. The fact that Kirkendall voiding could occur at all is a reminder that gold-aluminum bonds are prevalent in plastic encapsulated semiconductors and represent an uncontrolled source of failures not generally present in high integrity hermetically sealed parts.

4.3.3 CMOS 4069 (Manufacturer C)

4.3.3.1 Life Test Results--

Table 4-6 summarizes the life test results for the Manufacturer C CMOS 4069 parts. The number of failures in each cell was significantly less than for the Manufacturer B CMOS 4069 parts, and the distribution of failures was much as would be expected, with the 125°C life test showing the largest number of failures. A significantly larger number of failures occurred for the 40°C life test parts that had previously been burned-in at 125°C, than for the parts that had not been burned-in or had been burned-in at 70°C.

TABLE 4-6

Life Test Data Summary for Manufacturer C CMOS 4069

	Cumulative Failures		
	Screen 1 (No Burn-In)	Screen 2 (Burn-In at 70°C)	Screen 3 (Burn-In at 125°C)
Life Test at 40°C	4	6	17
Life Test at 70°C	3	6	5
Life Test at 125°C	18	25	17

The distribution of failures as a function of time is tabulated in Table 4-7 and plotted in Figures 4-12 through 4-14. For the 40°C life test (Figure 4-12), the

TABLE 4-7 INCREMENTAL FAILURE DISTRIBUTION FOR MANUFACTURER C 4069 CMOS

LIFE TEST FAILURES

40°C LIFE TEST INCREMENT (HOURS)	SCREEN 1 (NO BURN-IN)	SCREEN 2 (70°C BURN-IN)	SCREEN 3 (125°C BURN-IN)
2	0	1	3
8	0	0	1
16	0	0	2
64	0	0	1
256	1	4	1
1000	1	0	3
2000	2	0	4
4000	0	1	2
TOTAL	4	6	17
70°C LIFE TEST INCREMENT (HOURS)			
2	0	3	0
8	0	0	0
16	0	0	0
64	0	1	0
256	0	2	3
1000	0	0	1
2000	3	0	0
4000	0	0	1
TOTAL	3	6	5
125°C LIFE TEST INCREMENT (HOURS)			
2	3	0	0
8	1	1	1
16	0	1	1
64	4	2	0
256	5	7	10
1000	4	5	2
2000	1	9	1
4000	0	0	2
TOTAL	18	25	17

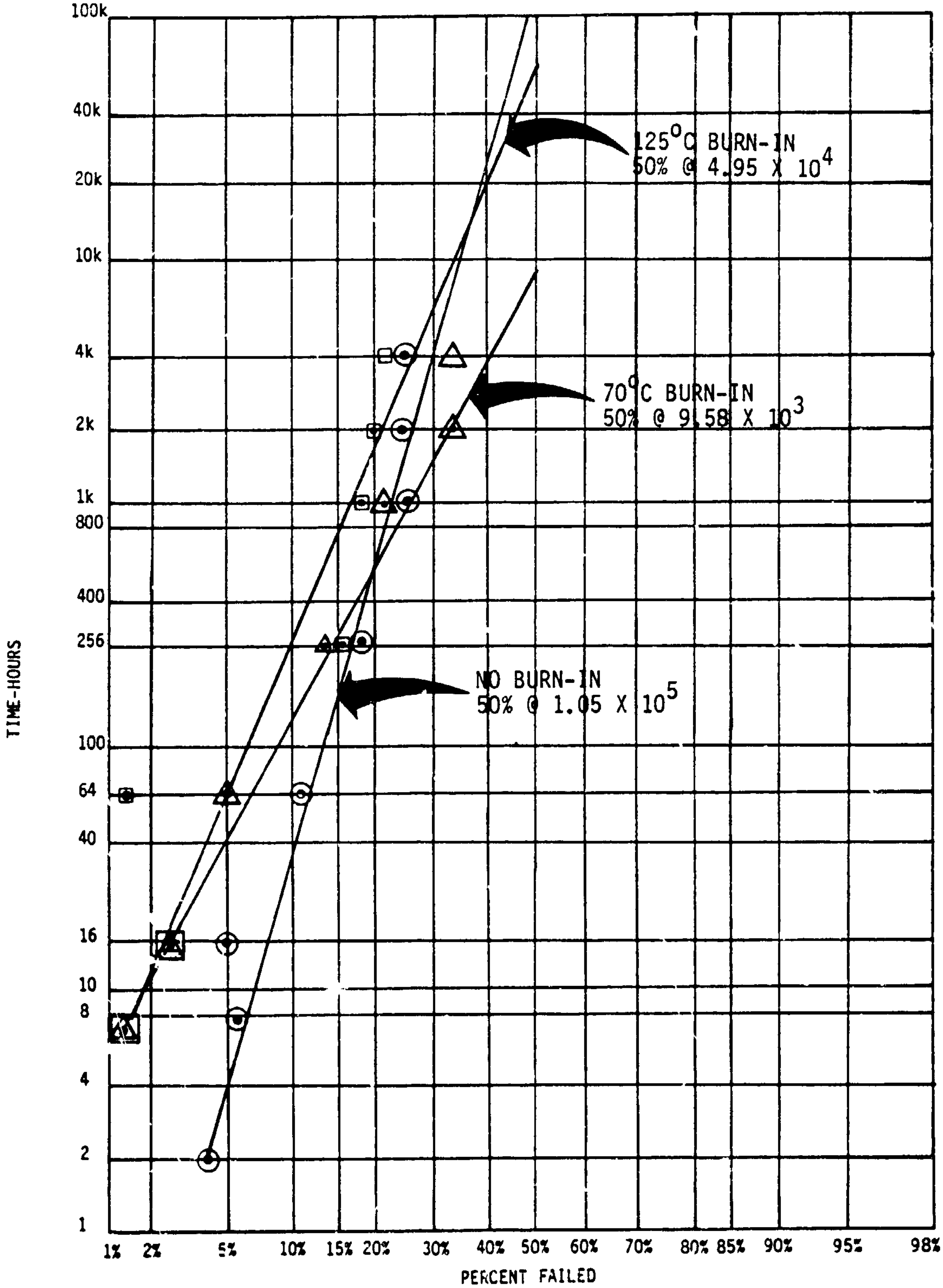

Figure 4-14 MFR.C 4069 CMOS 125°C LIFE TEST

distribution of failures is as would be expected. The 125°C burn-in parts failed at a greater rate than did the 70°C burn-in parts, and the no-burn-in parts failed at a much slower rate. However, calculation of the median times to failure using the statistical analysis program resulted in anomalous findings as shown in Table 4-8. It was found that for the 70°C and 125°C burn-in screen parts, the median time-to-failure was greatest for the parts life tested at 70°C, with the result that the Arrhenius curves have the meaningless shapes shown in Figure 4-15. Thus there can be no conclusions concerning the relative merit of burn-in as a pre-screen used prior to life testing.

TABLE 4-8

Median Time-to-Failure for Manufacturer C CMOS 4069

	Median Time-to-Failure (Hours)		
	Screen 1 (No Burn-In)	Screen 2 (70°C Burn-In)	Screen 3 (125°C Burn-In)
Life Test at 40°C	5.3×10^6	1.7×10^9	2.6×10^6
Life Test at 70°C	*	1.6×10^{11}	2.4×10^{11}
Life Test at 125°C	1.1×10^5	9.6×10^3	5.0×10^4

* Insufficient number of failures to predict.

The unexpectedly low median time-to-failure for the 40°C life test parts may possibly be attributed to the fact that for CMOS the internally generated heat is so low that in a 40°C life test there is insufficient heat to drive off any internal contaminants.

4.3.3.2 Manufacturer C 4069 Failure Analysis Results—Of the 101 Manufacturer C 4069 CMOS parts that failed during life testing, 9 were subjected to failure analysis, one from each of the life test cells and time increments that had 3 or more failures. The breakdown of the failure analysis results is as follows:

- Open Metallization - Ground or Vdd Line — 4 parts
- Burned package — 1 part
- Surface inversion or channelling — 4 parts

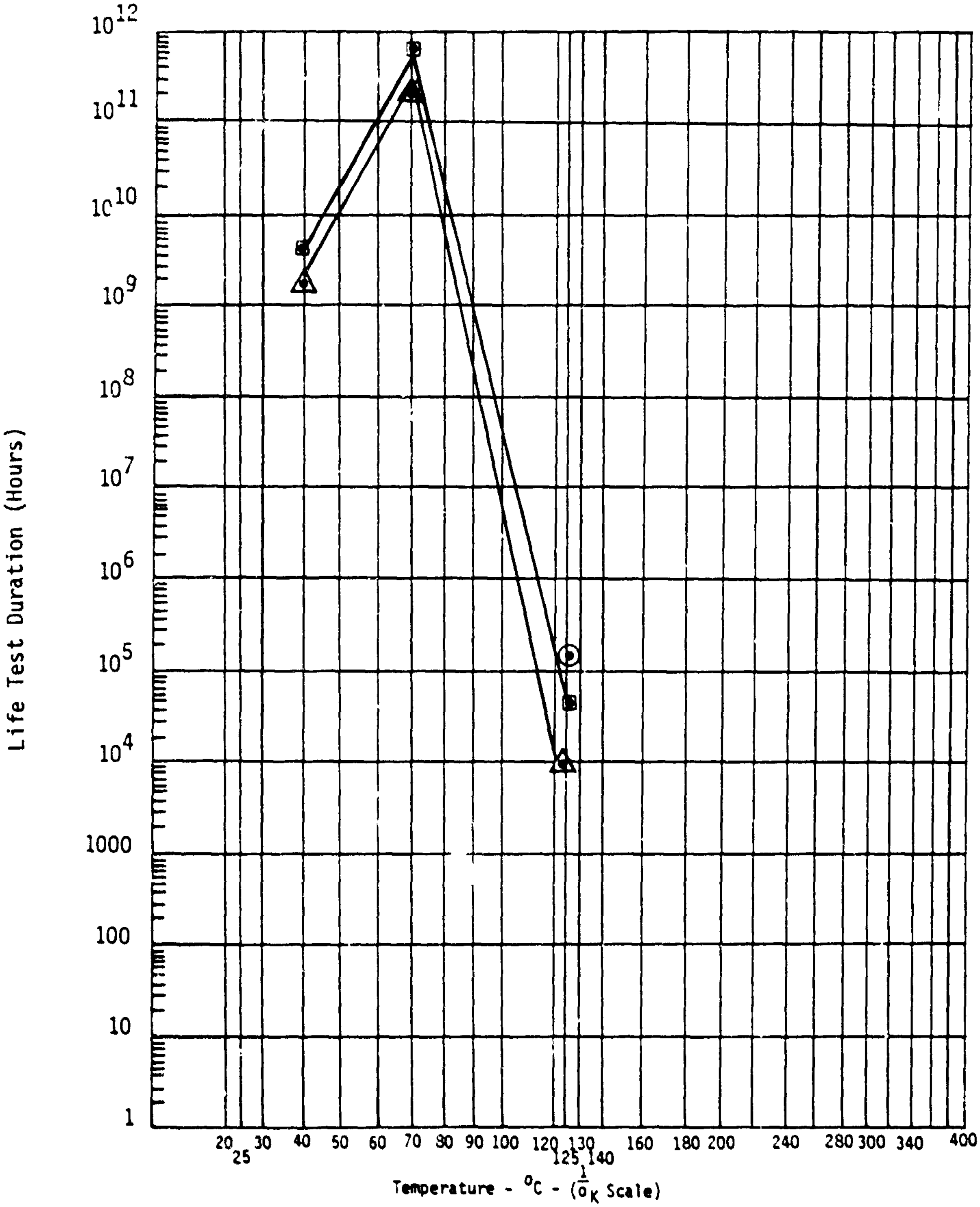

Figure 4-15
Arrhenius Curves Median Time to Failure For Manufacturer C 4069 CMOS

As in the previous case, the channelling is indicative of a serious problem in the use of plastic encapsulation for CMOS parts, since it appears that some contaminant resulting from the plastic encapsulant is influencing the performance of the CMOS devices. The open metallization failures are again felt to be a possible result of the increased leakage currents in the CMOS structures caused by contamination, and the burned part was merely a result of the heating caused by the high currents that were manifested in some devices by open metallization.

4.3.4 741 Operational Amplifier (Manufacturer B)

4.3.4.1 Life Test Results—Table 4-9 summarizes the life test results for the Manufacturer B 741 op amps. Only the screen 1 and screen 2 parts were available for life testing, since none of the screen 3 (125^{o}C burn-in) parts survived the initial burn-in screen. As a result, it is not surprising that extended life testing performed on the 70^{o}C burn-in parts resulted in the test being aborted early in the life test due to the parts catastrophically catching fire in the life test ovens. Table 4-10 shows the way the life test failures were distributed with time.

TABLE 4-9

Life Test Data Summary for Manufacturer B 741 Op Amps

	Cumulative Failures		
	Screen 1 (No Burn-In)	Screen 2 (70^{o}C Burn-In)	Screen 3 (125^{o}C Burn-In)
Life Test at 40^{o}C	12	71	2/
Life Test at 70^{o}C	12	1/	2/
Life Test at 125^{o}C	61	1/	2/

1/ Test aborted - parts began catching fire

2/ No parts survived Burn-In at 125^{o}C

TABLE 4-10 INCREMENTAL FAILURE DISTRIBUTION FOR MANUFACTURER B 741 OP AMP

LIFE TEST FAILURES

40°C LIFE TEST INCREMENT (HOURS)	SCREEN 1 (NO BURN-IN)	SCREEN 2 (70°C BURN-IN)
2	0	0
8	0	0
16	3	0
64	0	0
256	1	0
1000	1	5
2000	1	21
4000	6	45
TOTAL	12	71
70°C LIFE TEST INCREMENT (HOURS)		
2	0	0
8	0	1
16	1	0
64	2	1
256	0	37
1000	1	-
2000	0	-
4000	8	-
TOTAL	12	39 (Test aborted)
125°C LIFE TEST INCREMENT (HOURS)		
2	0	1
8	0	1
16	3	4
64	2	43
256	1	22
1000	10	-
2000	22	-
4000	23	-
TOTAL	61	71 (Test aborted)

The 70°C burn-in parts that were life tested at 40° experienced no failures until 1000 hours, at which time five failures occurred. Then at 2000 hours an additional 21 parts failed, and after 4000 hours an additional 45 parts failed, bringing the total to 71 parts. This indicates that the parts went into wear out at around 1000 hours. Apparently, there is a fundamental failure mechanism in the plastic/linear semiconductor structure that leads to regenerative degradation in such a manner that in time the parts overheat to the point of ignition of the plastic encapsulant. This pattern of early wear out was also observed for the other five test cells that survived initial burn-in. Figures 4-16 through 4-18 depict the log-normal distributions for the 40°C, 70°C and 125°C life test cells using parts with no burn-in and burned-in at 70°C. It can be seen that in each case plotted, the parts went into wear out before the end of the 4000 hour life test. Table 4-11 summarizes the median time to failure for each distribution, and Table 4-12 summarizes the estimated points on the log-normal distribution curves where wearout began. These points were plotted on an Arrhenius curve with the results shown in Figure 4-19.

In order to analyze the performance of the Manufacturer 3 741 op amps without the disturbing influence of the wear out mechanism, the log-normal distributions were subjected to statistical analysis with the wear out failures removed. This resulted in calculation of the median times to failure shown in Table 4-13. These data were then plotted on an Arrhenius curve (Figure 4-20) to show the extrapolated performance of the parts when operated within reduced temperature limits such that the wear out mechanism would not be activated.

TABLE 4-11

Median Time-to-Failure with Wearout Failures Included.

	Median Time-to-Failure (Hours)		
	Screen 1 (No Burn-In)	Screen 2 (70°C Burn-In)	Screen 3 (125°C Burn-In)
Life Test at 40°C	1.9×10^8	Screens 2 and 3 cells aborted due to parts catching fire.	
Life Test at 70°C	1.0×10^7		
Life Test at 125°C	2.0×10^3		

TABLE 4-12

Onset of Wear Out for Manufacturer B 741 Op Amps

	Wear Out Begins (Hours)	
	No Burn-In	70°C Burn-In
40°C Life Test	3500	1000
70°C Life Test	2500	64
125°C Life Test	600	8

TABLE 4-13

Median Time-to-Failure for Manufacturer B 741 Op Amps

With Wearout Failures Removed

	Median Time-to-Failure (Hours)		
	Screen 1 (No Burn-In)	Screen 2 (70°C Burn-In)	Screen 3 (125°C Burn-In)
Life Test at 40°C	4.59×10^{11}	Screens 2 and 3 cells aborted due to parts catching fire.	
Life Test at 70°C	2.1×10^{9}		
Life Test at 125°C	1.6×10^{8}		

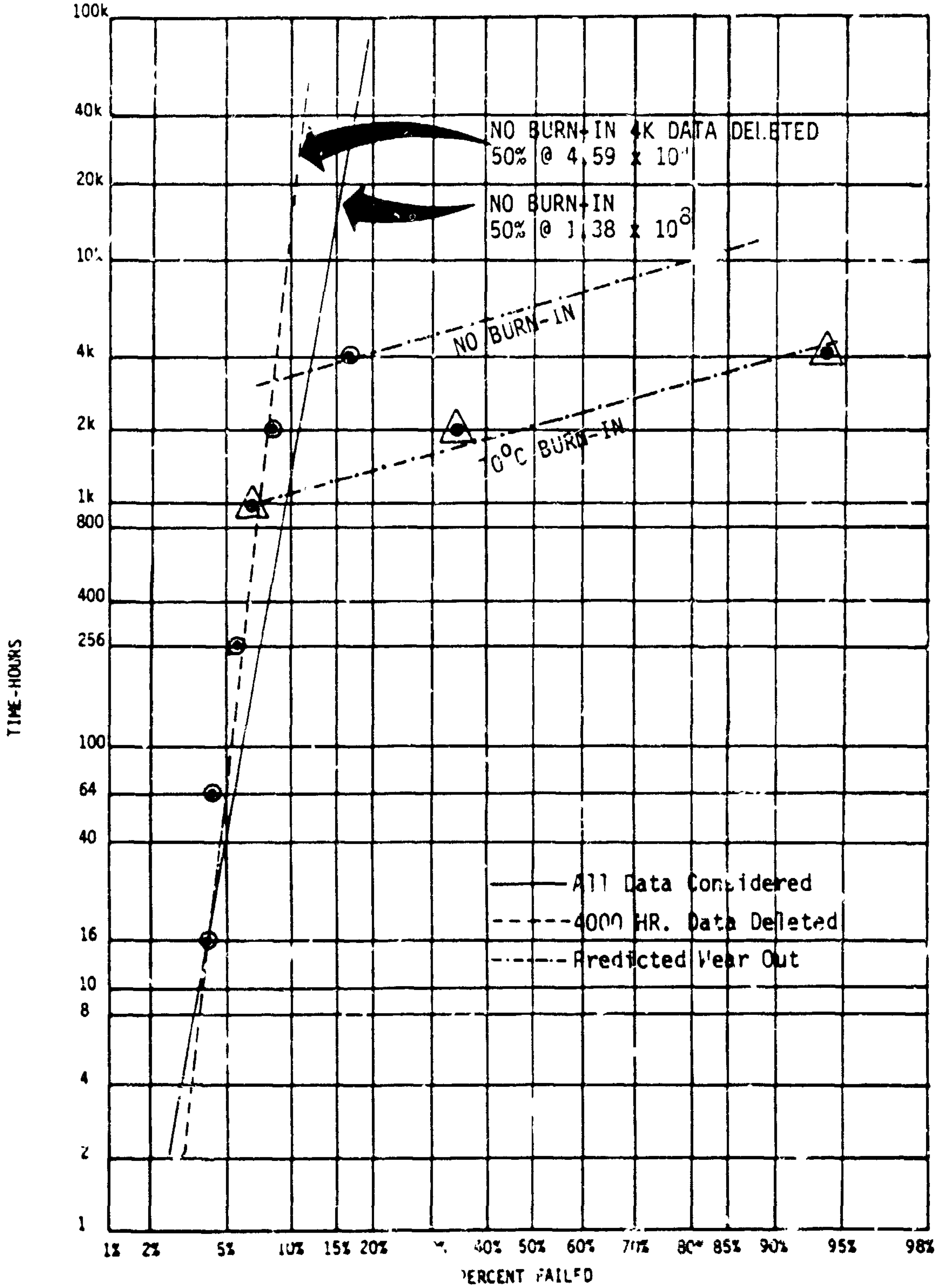

Figure 4-16   MFR B 741 OP AMP 40°C Life Test

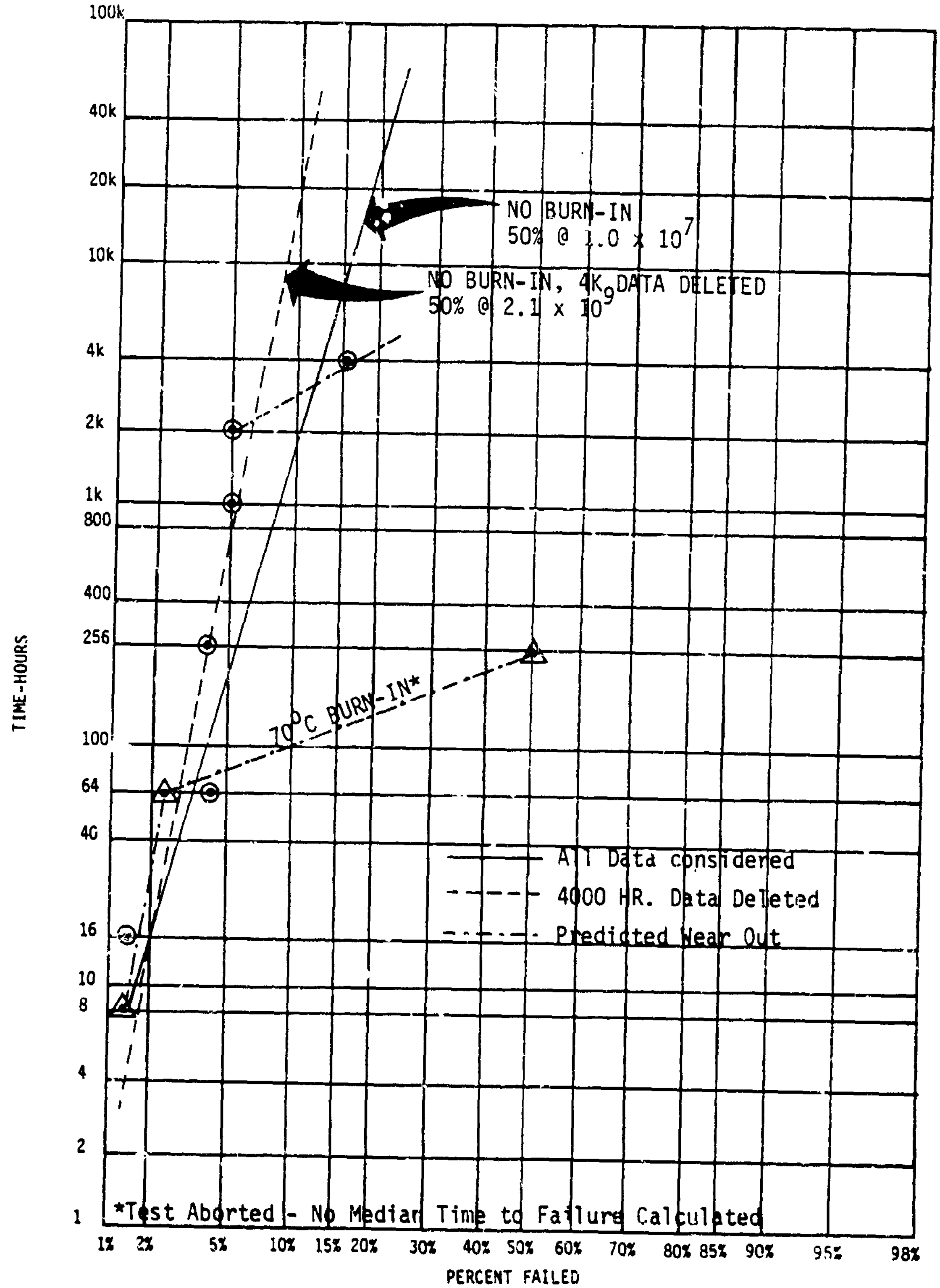

Figure 4-17 MFR B 741 OP AMP 70°C Life Test MR

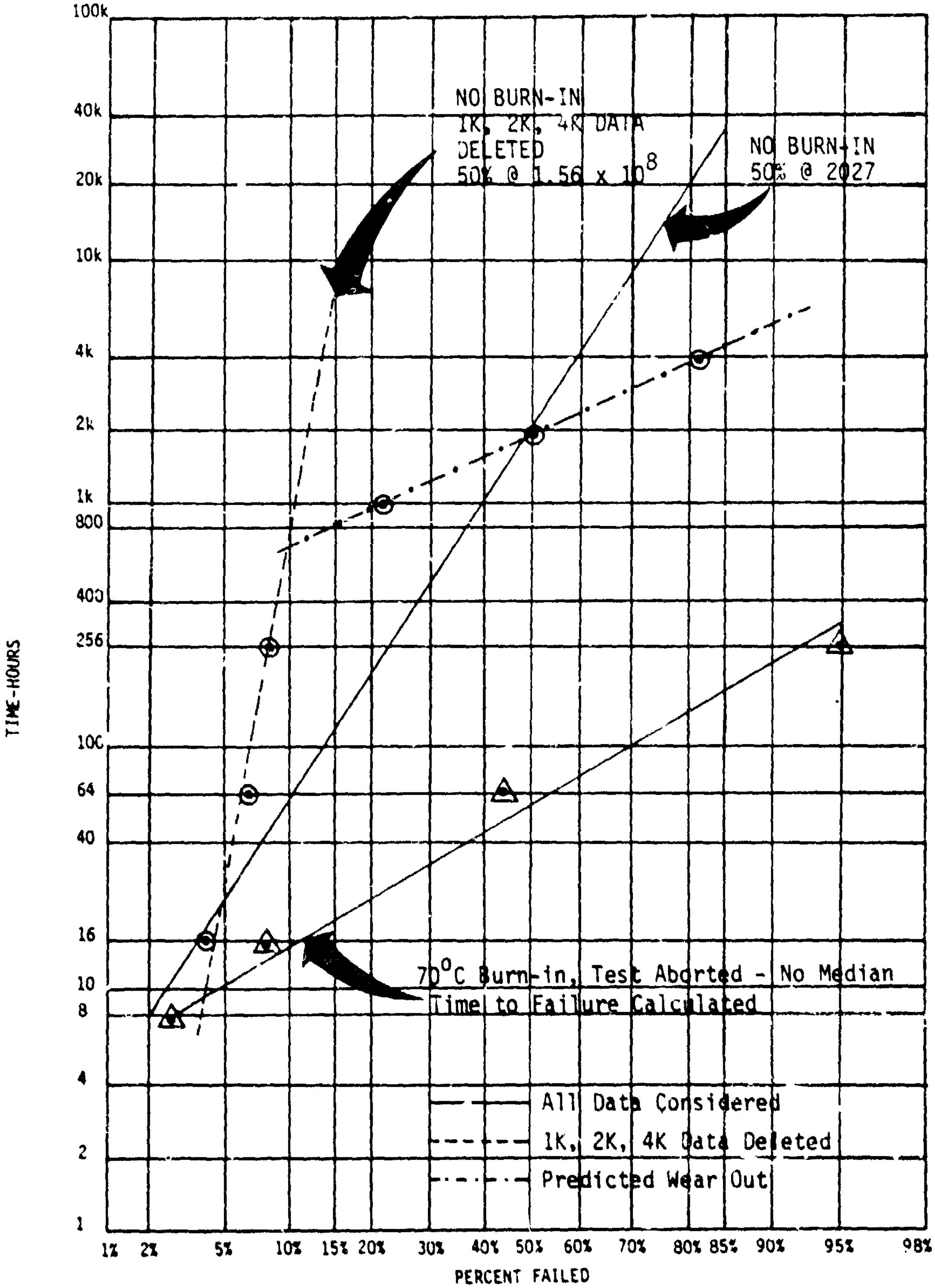

Figure 4-18 MFR B 741 OP AMP 125°C Life Test

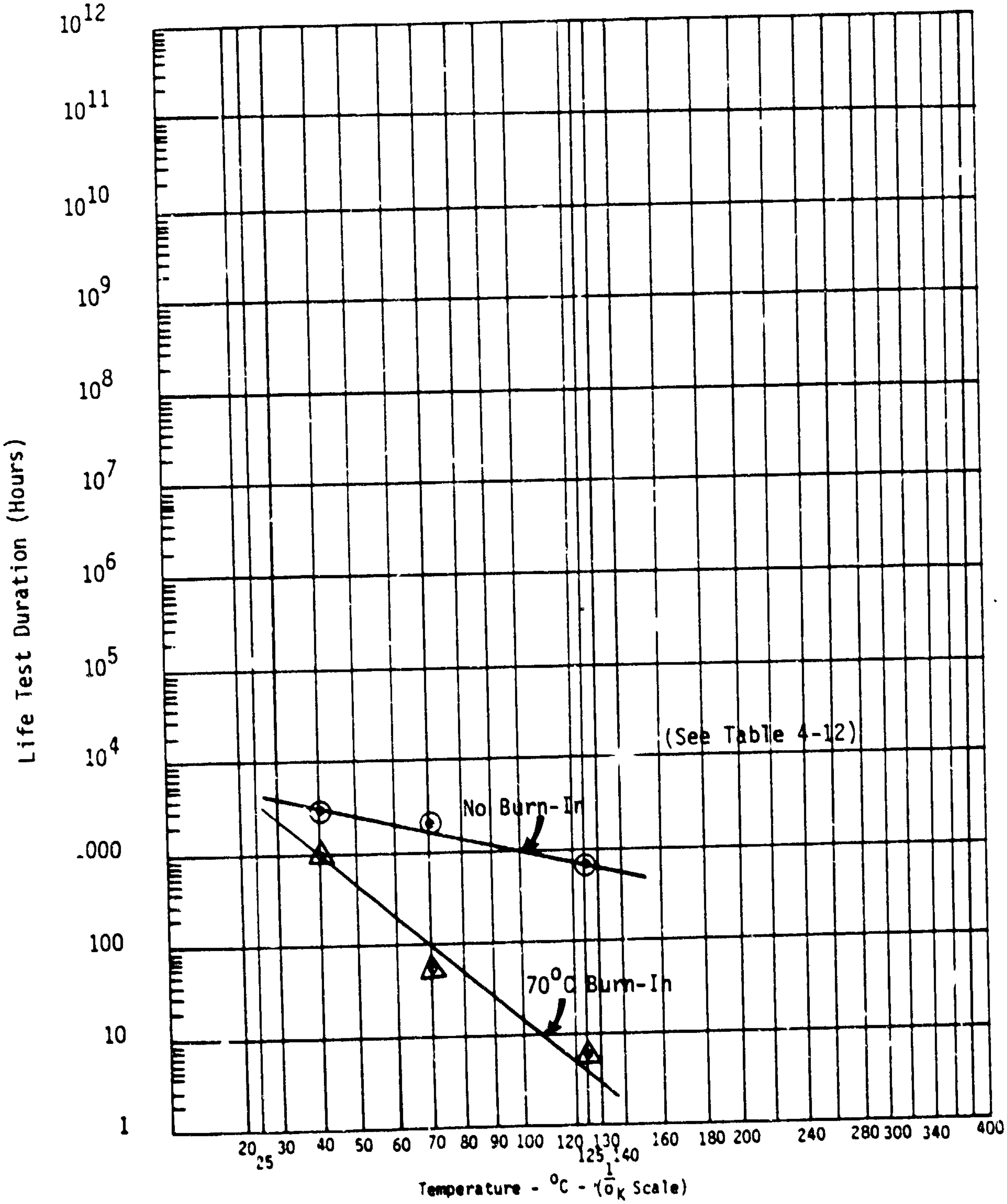

Figure 4-19
Arrhenius Plot of Onset of Wearout For Manufacturer B 741 OP AMPs

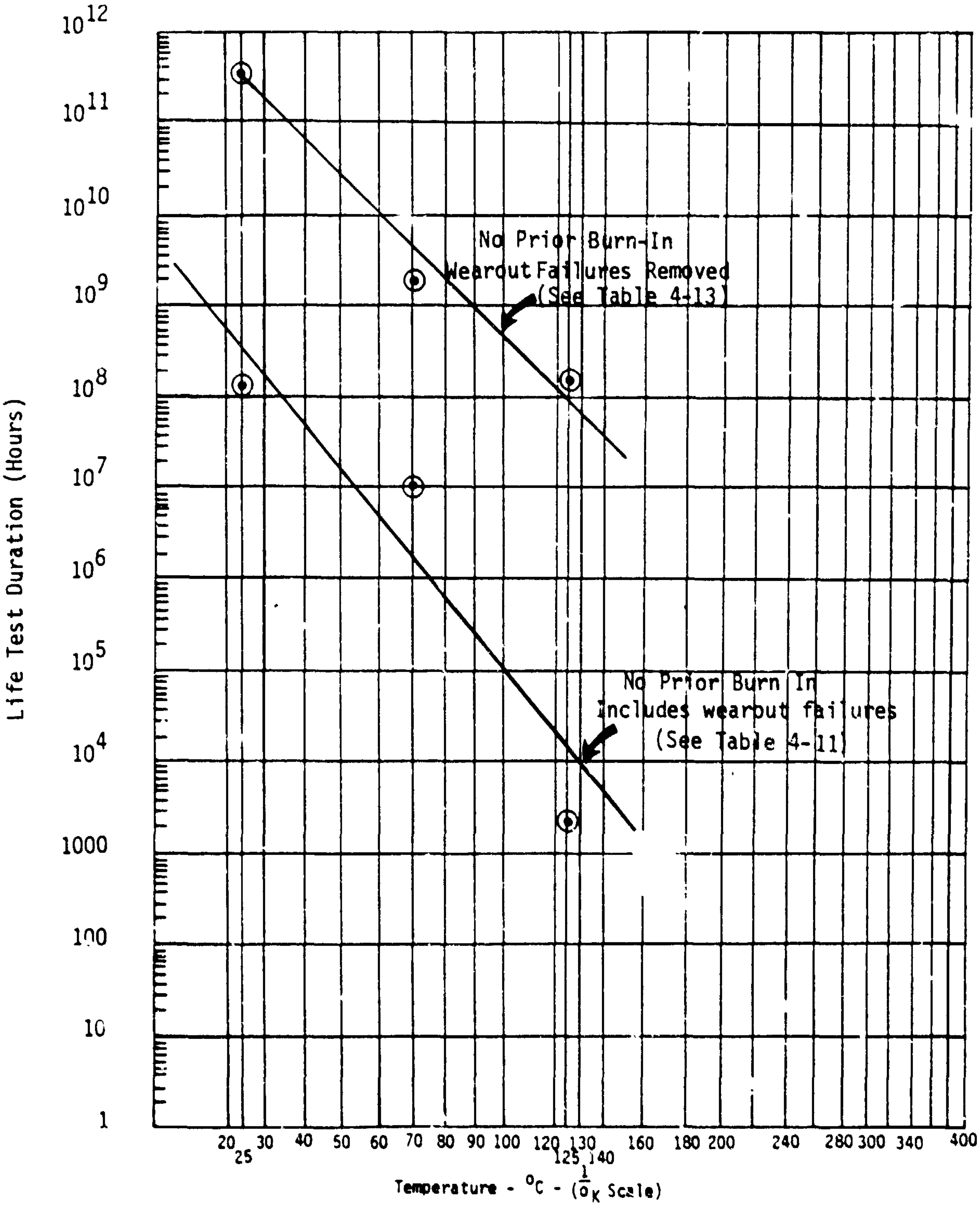

Figure 4-20
Normal Arrhenius Plot of Median Time to Failures For Manufacturer B 741 OP AMP

The overriding conclusion that must be drawn from the results of the life test experiment on the Manufacturer B 741 op amps is that these parts are totally unsuited for use in any high reliability or elevated temperature applications.

4.3.4.2 Manufacturer B Failure Analysis Results for 741 Op Amp—Of the 310 Manufacturer B 741 op amps that failed, one non-catastrophic failure was selected for failure analysis from each of the test cells and life test increments for which the number of failures was 3 or greater for a total of 10 parts. The results of the analysis of these 10 parts was as follows:

o Retest good	8 parts
o Apparent Electrical Overstress	1 part
o Gain Slightly Low	1 part

The retest good parts were found to have failed originally because of slightly out of limit gain values, and upon retest several months later they were found to have gain values within limits. One part did not retest good but was found still to exhibit the marginal gain value which was typical of the other failures. Baking of this part did not affect the test results. The cause of the marginal gain could not be determined.

The part which exhibited electrical overstress was typical of the parts which were felt to have experienced wearout during the life testing. It appears that at some time in the course of life testing, each of the wearout failures went into a high current drain mode in which an internal breakdown occurred from the V+ pin to an adjacent metallization run resulting in excessive supply current flowing.

4.3.5 741 Operational Amplifier (Manufacturer D)

4.3.5.1 Life Test Results—Table 4-14 summarizes the life test results for the Manufacturer D 741 op amps. It was found that there was not an excessive number of failures for this manufacturer.

TABLE 4-14

Life Test Data Summary for Manufacturer D 741 Op Amps

	Cumulative Failures		
	Screen 1 No Burn-In	Screen 2 $70^{o}C$ Burn-In	Screen 3 $125^{o}C$ Burn-In
Life Test at $40^{o}C$	10	5	4
Life Test at $70^{o}C$	7	10	4
Life Test at $125^{o}C$	4	14	13

Although it appears that the $40^{o}C$ life test caused the largest number of failures for the non-burn-in cell, analysis of the log-normal distribution for the three life test cells (tabulated in Table 4-15 and plotted in Figures 4-21 through 4-23) shows that the median time-to-failure for the no-burn-in $40^{o}C$ life test was the longest, as summarized in Table 4-16. In fact, plotting the median time-to-failure for the three no-burn-in life test cells results in a typical Arrhenius curve as shown in Figure 4-24. Unfortunately, the [illegible]-normal distributions for the $70^{o}C$ burn-in and $125^{o}C$ burn-in did not yield [illegible]able Arrhenius curves. In fact, the $125^{o}C$ burn-in curve showed a severe anomaly in that the median time-to-failure at $125^{o}C$ life test was 2-1/2 orders of magnitude better than at $70^{o}C$ life test.

TABLE 4-16

Median Time-to-Failure for Manufacturer D 741 Op Amps

	Median Time-to-Failure (Hours)		
	Screen 1 (No Burn-In)	Screen 2 ($70^{o}C$ Burn-In)	Screen 3 ($125^{o}C$ Burn-In)
Life Test at $40^{o}C$	2.8×10^{11}	5.2×10^{12}	1.5×10^{16}
Life Test at $70^{o}C$	1.2×10^{9}	3.6×10^{8}	2.8×10^{9}
Life Test at $125^{o}C$	3.6×10^{8}	1.6×10^{7}	7.1×10^{11}

TABLE 4-15 INCREMENTAL FAILURE DISTRIBUTION FOR MANUFACTURER D 741 OP AMPS

LIFE TEST FAILURES

40^oC LIFE TEST INCREMENT (HOURS)	SCREEN 1 (NO BURN-IN)	SCREEN 2 (70^oC BURN-IN)	SCREEN 3 (125^oC BURN-IN)
2	2	1	1
8	0	0	0
16	0	0	0
64	0	0	0
256	0	0	0
1000	0	1	0
2000	6	1	2
4000	2	2	1
TOTAL	10	5	4

70^oC LIFE TEST INCREMENT (HOURS)	SCREEN 1 (NO BURN-IN)	SCREEN 2 (70^oC BURN-IN)	SCREEN 3 (125^oC BURN-IN)
2	2	3	1
8	0	0	0
16	0	0	0
64	1	0	0
256	2	4	3
1000	1	1	0
2000	1	1	0
4000	0	1	0
TOTAL	7	10	4

125^oC LIFE TEST INCREMENT (HOURS)	SCREEN 1 (NO BURN-IN)	SCREEN 2 (70^oC BURN-IN)	SCREEN 3 (125^oC BURN-IN)
2	2	4	5
8	0	1	2
16	0	0	0
64	3	2	0
256	0	2	0
1000	4	2	0
2000	1	3	5
4000	1	0	1
TOTAL	4	14	13

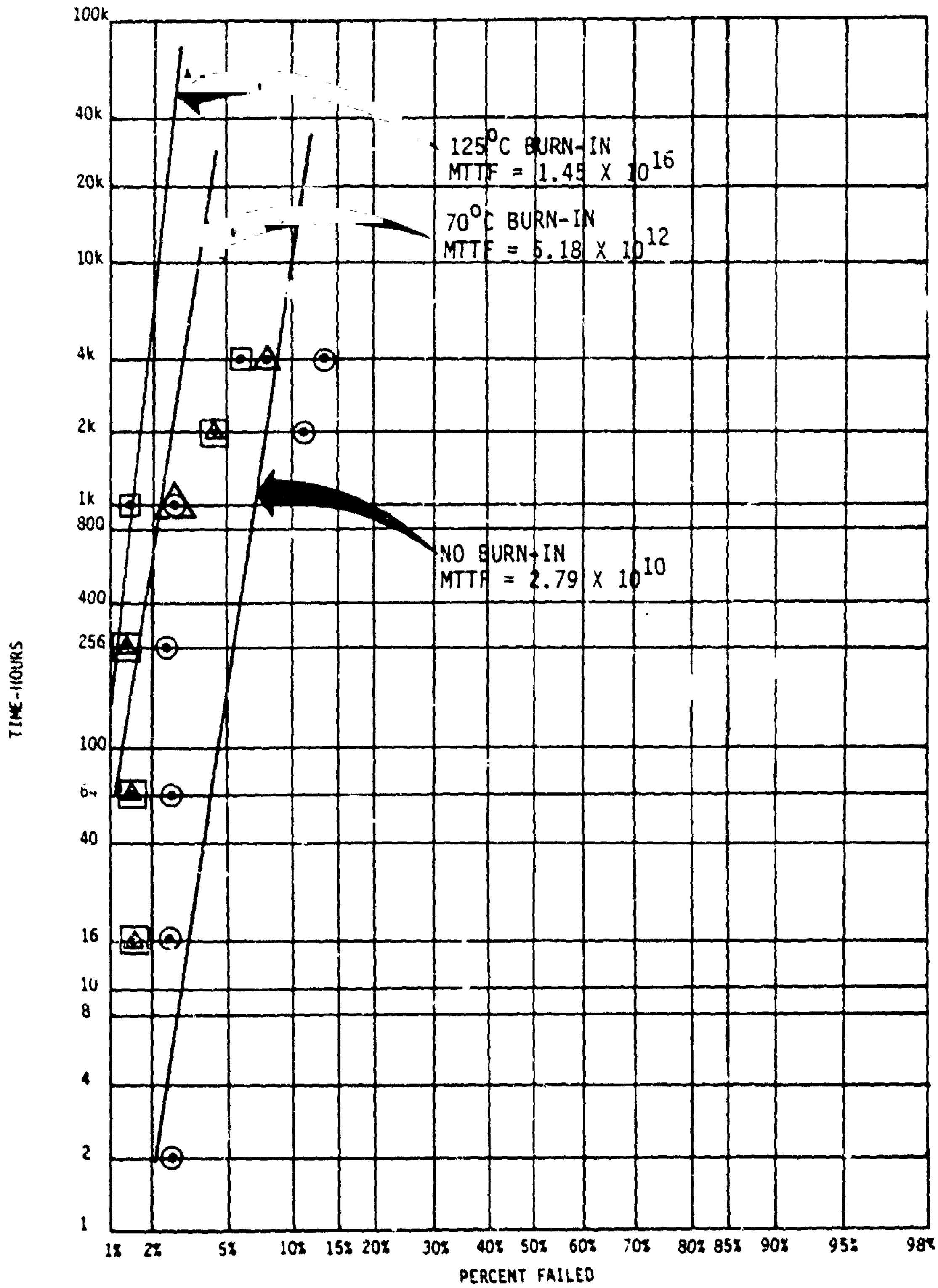

Figure 4-21 MFR.D 741 OP AMP 40°C LIFE TEST

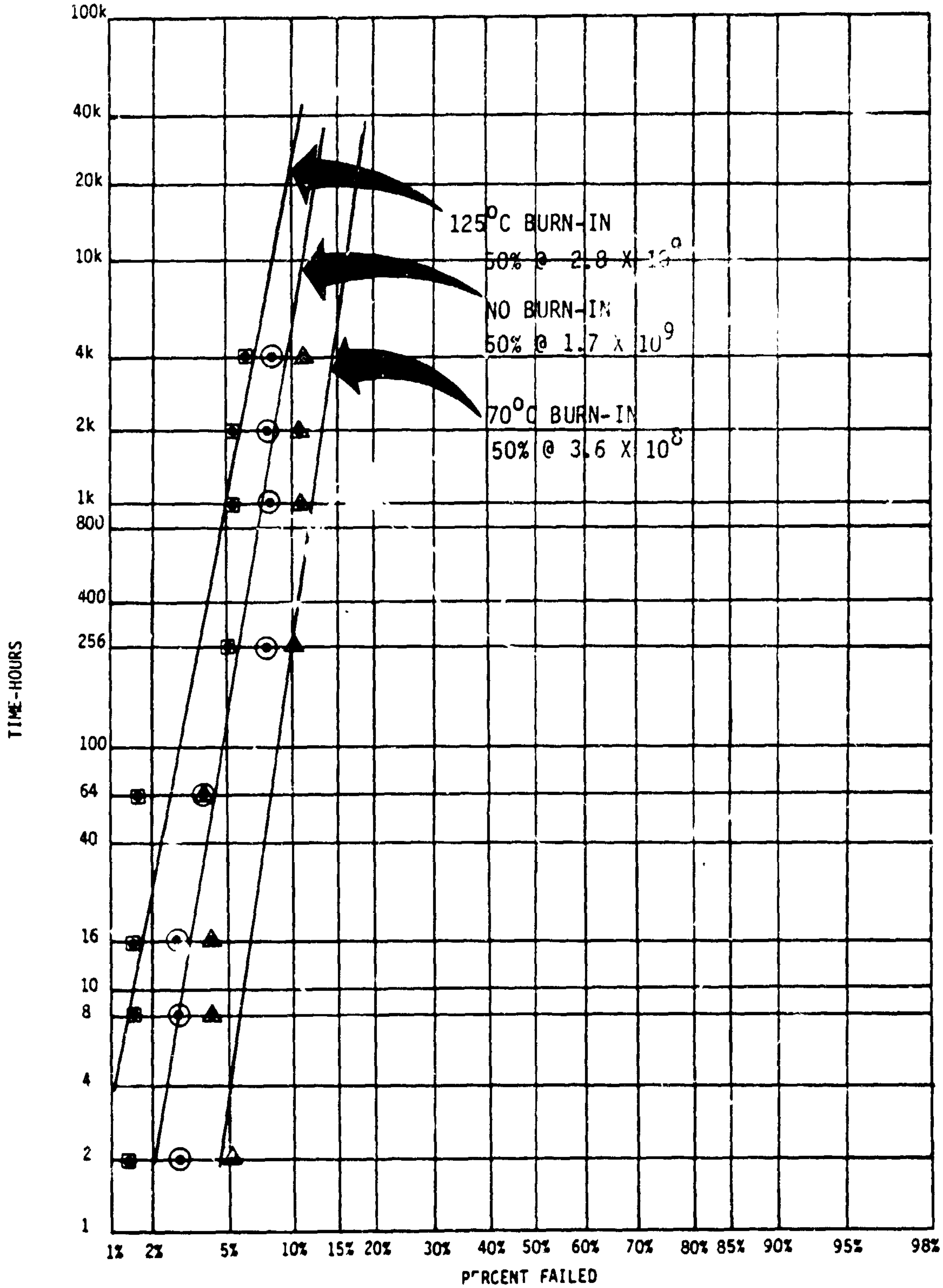

Figure 4-22 MFR.D 741 OP AMP 70°C LIFE TEST

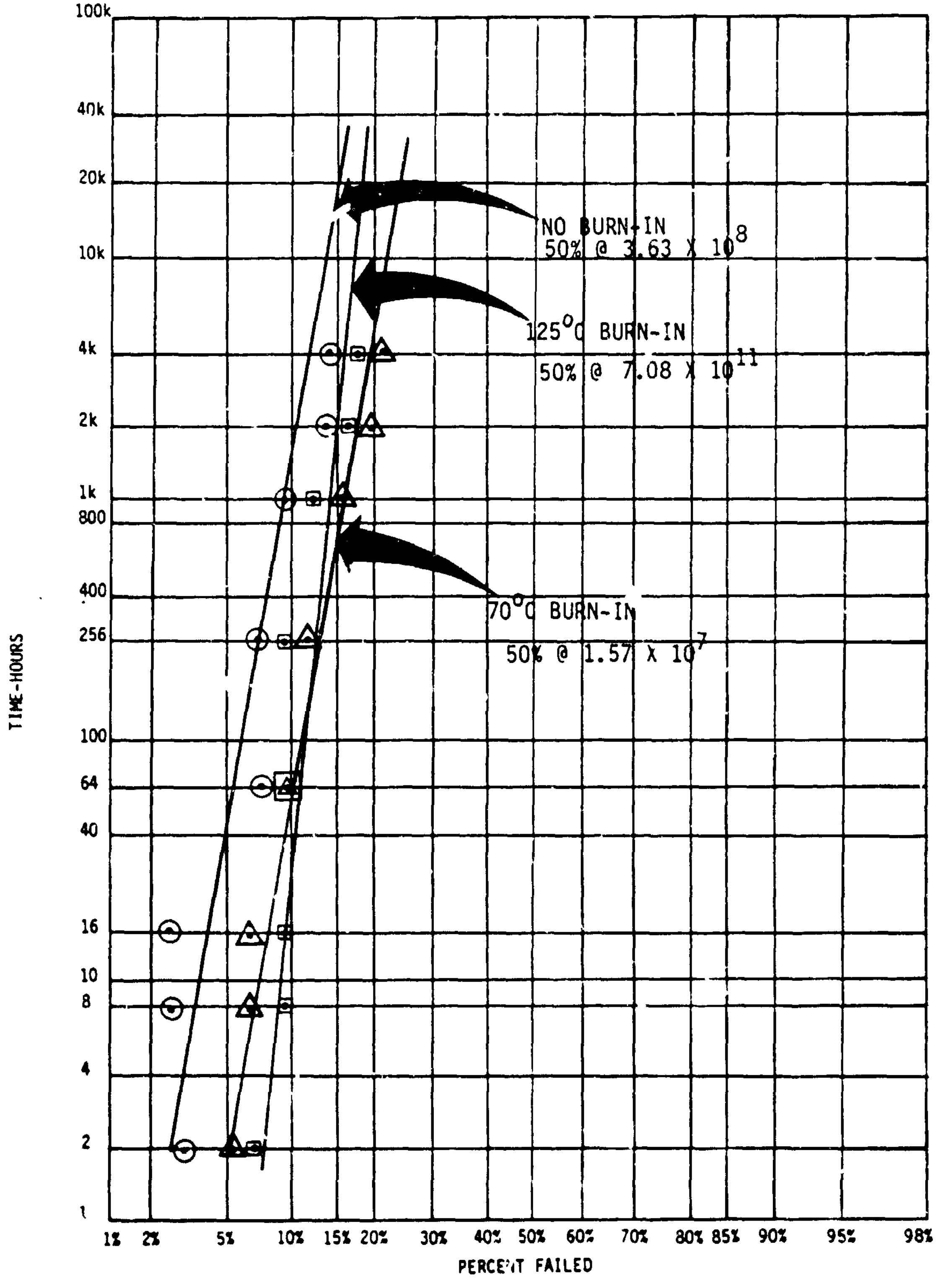

Figure 4-23 MFR.D 741 OP AMP 125°C LIFE TEST

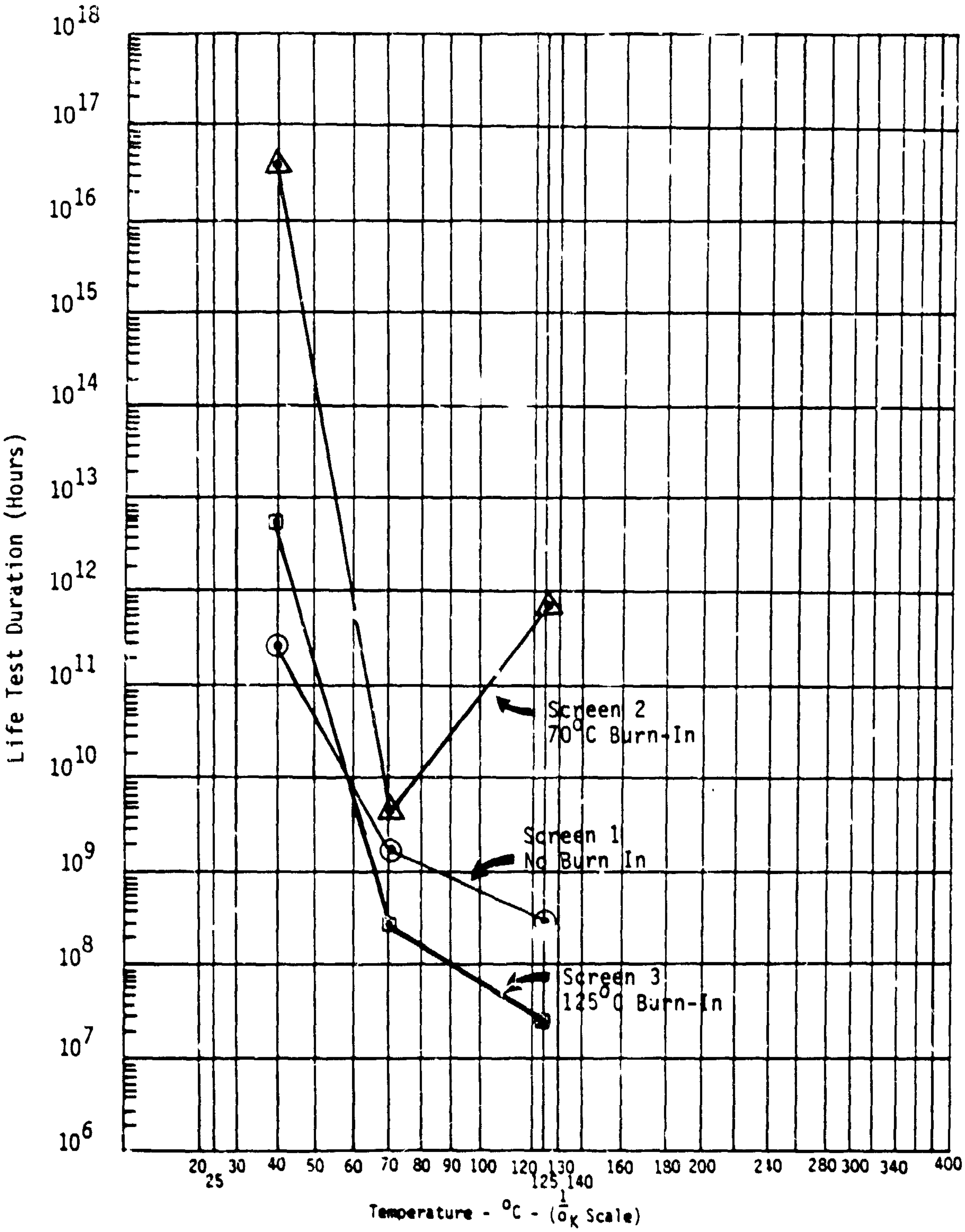

Figure 4-24

Arrhenius Plot of Median Times to Failure For Manufacturer D 741 OP AMPs

None of the log-normal curves for the Manufacturer D 741 op amps show any sign of wear out as occurred with the Manufacturer B 741 op amps. However other anomalies were noted in the log-normal distribution curves. In Figure 4-22, note that the 125°C burn-in parts have the longest median time-to-failure and are distributed nicely to the left of the other test cells. However, the 70°C burn-in cell has the lowest median time to failure and is distributed to the right of the no-burn-in parts.

In Figure 4-23 (125°C life test), it can be seen that the 125°C burn-in parts initially failed at a more rapid rate than the 70°C burn-in or no-burn-in parts, but then as the experiment progressed failed at a slower rate, ending up with a median time-to-failure much greater than the other two cells. Again, however, the no-burn-in cell ended up with a better median time-to- failure than did the 70°C burn-in cell.

The overall conclusion to be drawn from this anomalous data is that burn-in is of little value in improving the longevity of the Manufacturer D 741 op amps.

4.3.5.2 Failure Analysis Results for Manufacturer D 741 Op Amps—Of the 71 Manufacturer D 741-type op amps that failed 10 were selected for failure analysis based on one part from each life test cell and test time increment for which there were 3 or more failures. All of the parts were found to be marginal failures in the first place, having failed for being marginally low in open loop gain or slightly out of limits in common mode rejection ratio. After cleaning the leads of the parts, they all retested good.

4.3.6 2N2222 Transistor (Manufacturer B)

4.3.6.1 Life Test Results—Table 4-17 summarizes the life test results for the Manufacturer B 2N222 transistors. It is interesting to note that a large number of failures occurred in the 40°C life test cell for all three screen conditions: no burn-in, 70°C burn-in and 125°C burn in. Apparently, the low ambient temperature did not provide enough heat to drive off moisture or other impurities, even though the parts were life tested with a collector power dissipation of 250 mW. The thermal resistance of the TO-92 plastic package is 4.8 mW/°C, or 0.21°C/mW. Thus, the internal power dissipation heating would raise the junction temperature (250 mW) X (0.21°C/mw), or 53°C. The net junction temperature for the 40°C life test was therefore 93°C, for the 70°C life test was 123°C, and for the 125°C life test was 178°C. The latter two temperature conditions apparently were high enough to vaporize and drive off any water that could be in the plastic package and thus resulted in far fewer failures for the 70°C and 125°C life test cells.

TABLE 4-17

Life Test Data Summary for Manufacturer B 2N2222 Transistor

	Cumulative Failures		
	Screen 1 No Burn-In	Screen 2 70°C Burn-In	Screen 3 125°C Burn-In
Life Test at 40°C	28	23	24
Life Test at 70°C	9	3	11
Life Test at 125°C	5	6	6

The 40°C life test cells also showed signs of the onset of wear-out at around 2000 hours, since the log-normal distributions (tabulated in Table 4-18 and plotted in Figures 4-25 through 4-27) showed a significant departure from the pattern established in the two hour to 2000 hour time period. The large number of failures that occurred permitted the statistical analysis program to be run and calculate the median times to failure for the three cells. The initial tabulation is shown in Table 4-19. However, because of the onset of wear out after 2000 hours, the calculations were repeated with the 4000 hour data points deleted. This resulted in the tabulation shown in Table 4-20. These data were then plotted on Arrhenius curves as shown in Figure 4-28.

It can be seen that the resultant Arrhenius curves do not make sense, and the data indicate that other factors besides the time-temperature rate relationship are governing the failure distributions. The inconsistency of the data leads to the conclusion that burn-in or the absence of burn-in has little influence in the long term reliability of Manufacturer B plastic encapsulated transistors.

TABLE 4-18 INCREMENTAL FAILURE DISTRIBUTION FOR MANUFACTURER B 2N2222 TRANSISTOR

LIFE TEST FAILURES

40°C LIFE TEST INCREMENT (HOURS)	SCREEN 1 (NO BURN-IN)	SCREEN 2 (70°C BURN-IN)	SCREEN 3 (125°C BURN-IN)
2	13	2	7
8	1	0	0
16	0	2	0
64	0	1	5
256	0	0	0
1000	3	0	1
2000	1	0	0
4000	10	18	11
TOTAL	28	23	24

70°C LIFE TEST INCREMENT (HOURS)	SCREEN 1 (NO BURN-IN)	SCREEN 2 (70°C BURN-IN)	SCREEN 3 (125°C BURN-IN)
2	3	0	1
8	0	1	2
16	2	0	0
64	3	0	0
256	0	0	0
1000	0	2	1
2000	0	0	0
4000	1	0	7
TOTAL	9	3	11

125°C LIFE TEST INCREMENT (HOURS)	SCREEN 1 (NO BURN-IN)	SCREEN 2 (70°C BURN-IN)	SCREEN 3 (125°C BURN-IN)
2	1	0	3
8	0	0	1
16	0	1	1
64	1	0	0
256	0	0	0
1000	2	0	1
2000	1	1	0
4000	0	4	0
TOTAL	5	6	6

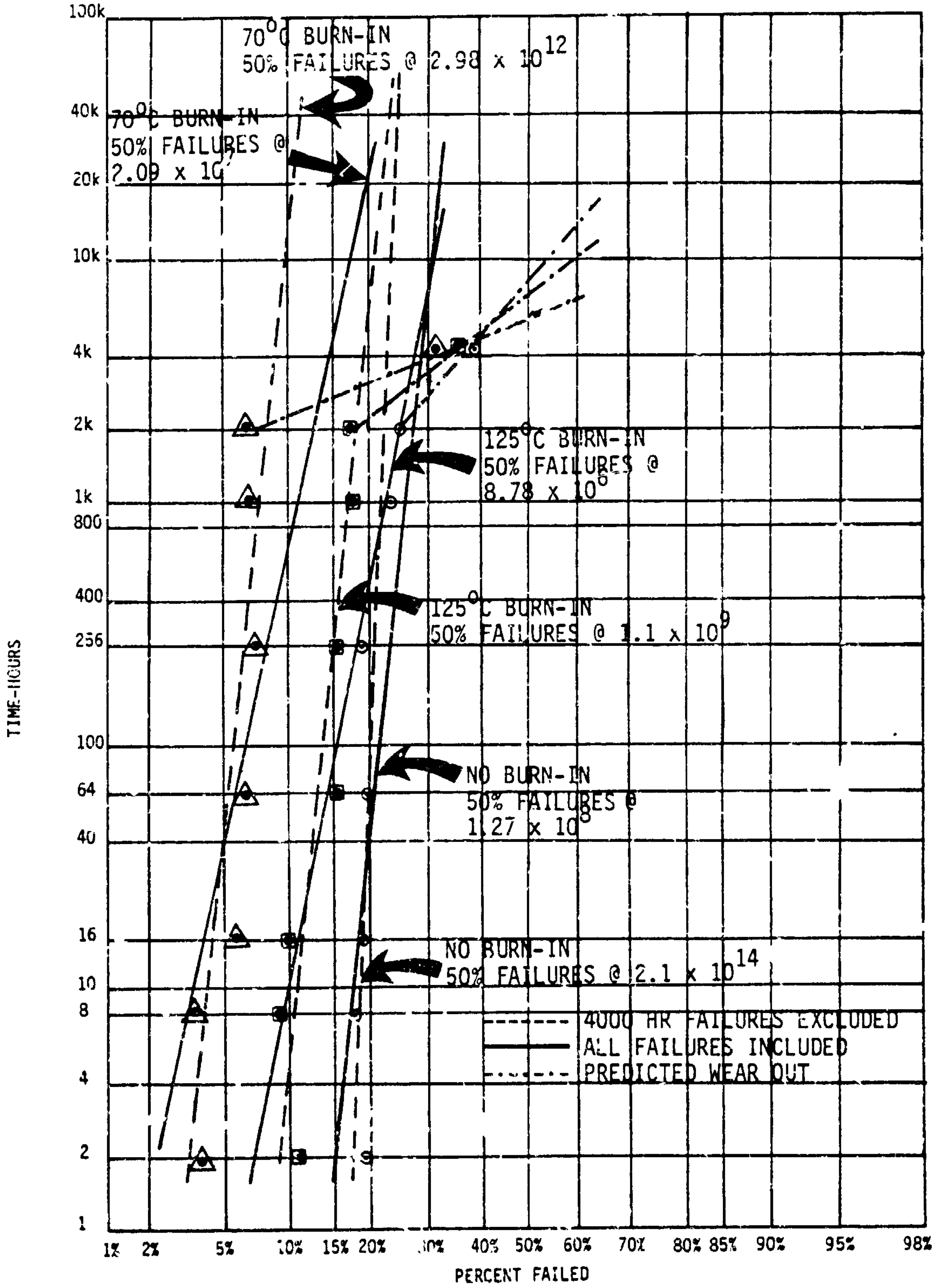

Figure 4-25 MFR B 2N2222 40°C Life Test

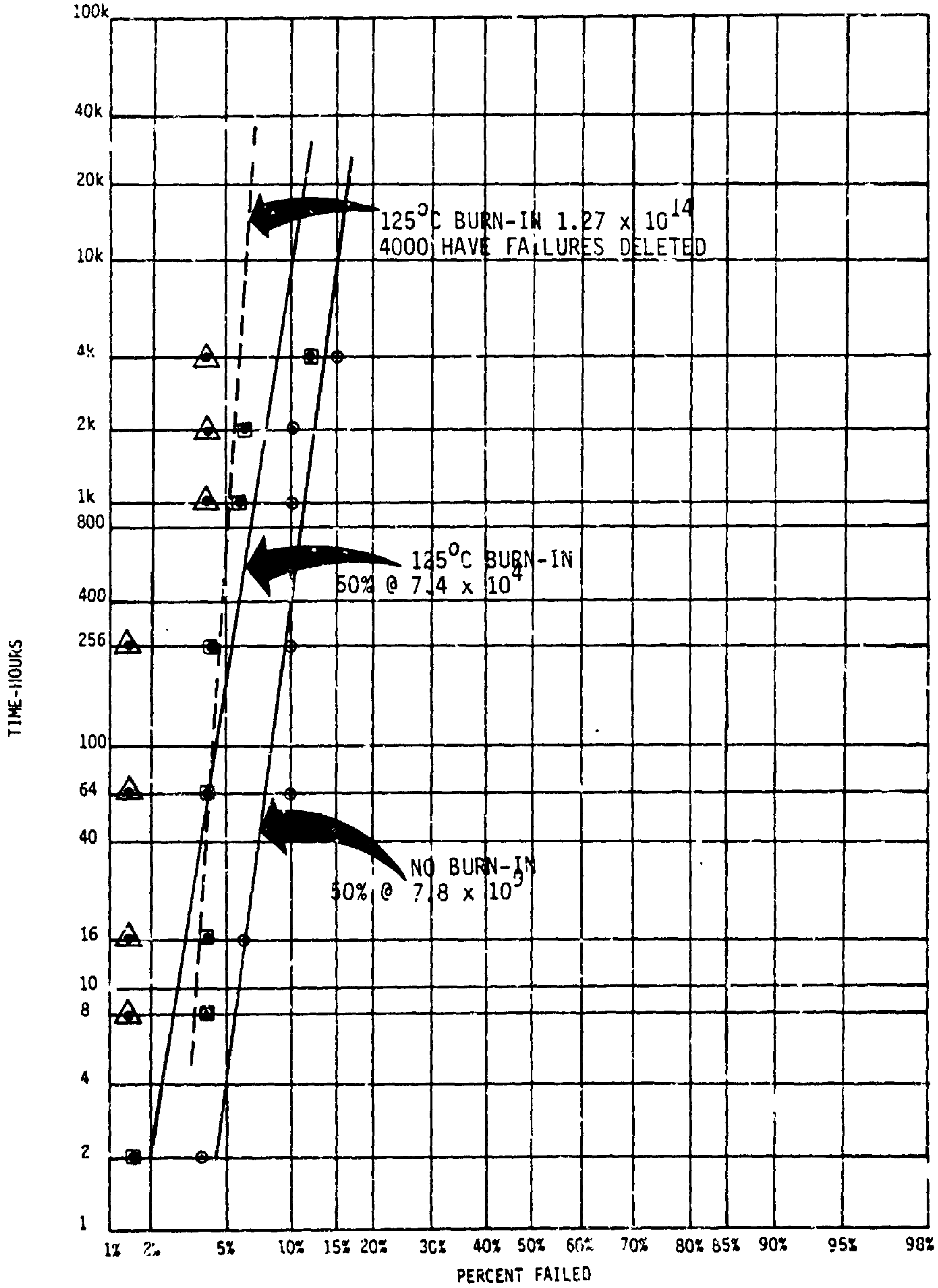

Figure 4-26 MFR B 2N2222 70°C Life Test

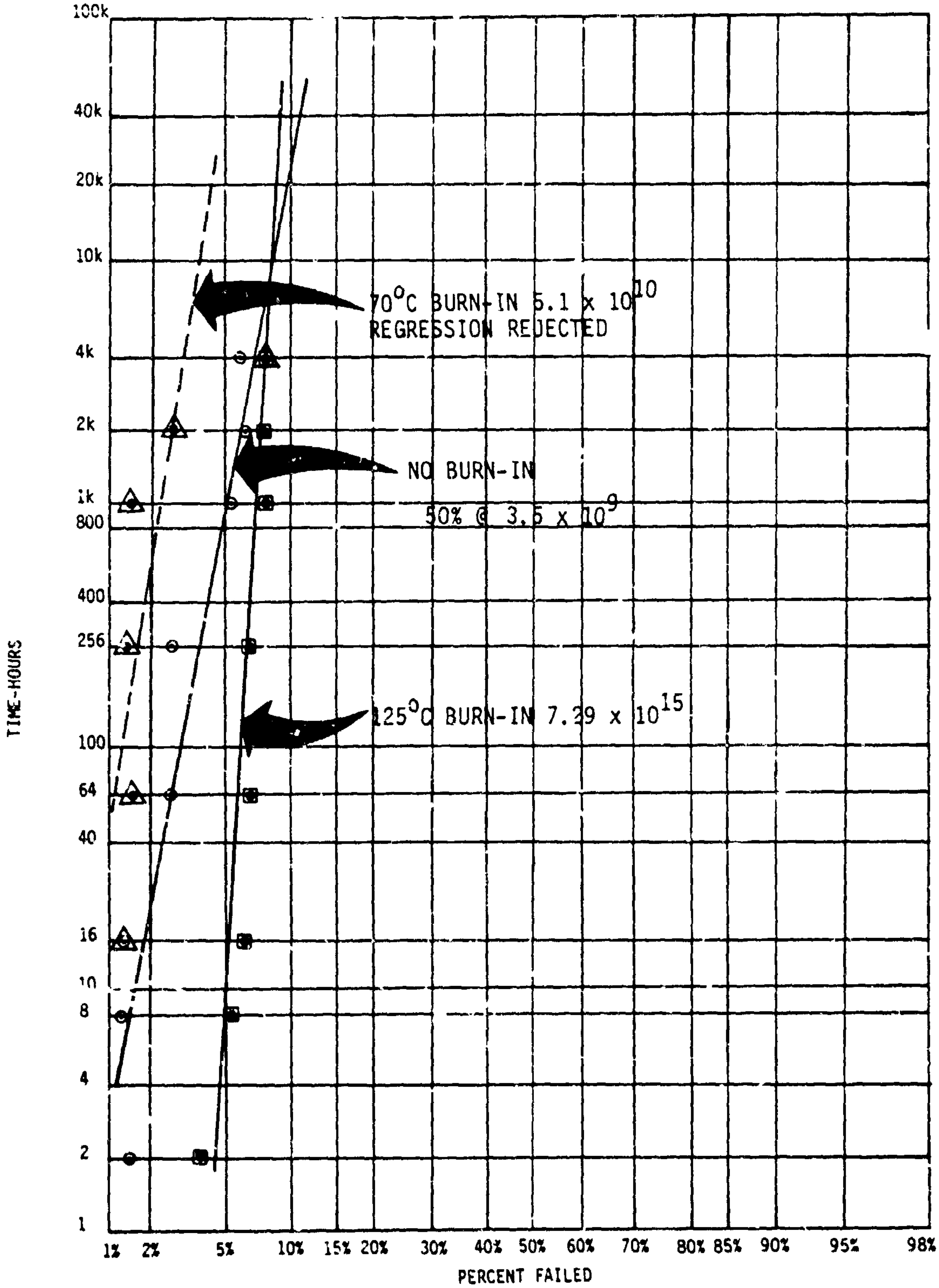

Figure 4-27 MFR B 2N2222 125°C Life Test

TABLE 4-19

Median Time-to-Failure for Manufacturer B 2N2222 Transistor

(Includes 4000 Hour Wear Out Failures)

	Median Time-to-Failure (Hours)		
	Screen 1 (No Burn-In)	Screen 2 (70^oC Burn-In)	Screen 3 (125^oC Burn-In)
Life Test at 40^oC	1.3×10^8	2.1×10^7	8.8×10^6
Life Test at 70^oC	7.8×10^9	*	7.4×10^9
Life Test at 125^oC	3.5×10^9	*	7.3×10^{15}

*Not enough parts failed - regression model rejected.

TABLE 4-20

Median Time-to-Failure for Manufacturer B 2N2222 Transistor

(Deleted 4000 Hour Wear Out Failures)

	Median Time-to-Failure (Hours)		
	Screen 1 (No Burn-In)	Screen 2 (70^oC Burn-In)	Screen 3 (125^oC Burn-In)
Life Test at 40^oC	2.1×10^{14}	3.0×10^{12}	1.1×10^9
Life Test at 70^oC	7.8×10^9	*	1.4×10^{14}
Life Test at 125^oC	3.5×10^9	*	7.3×10^{15}

*Not enough parts failed - regression model rejected.

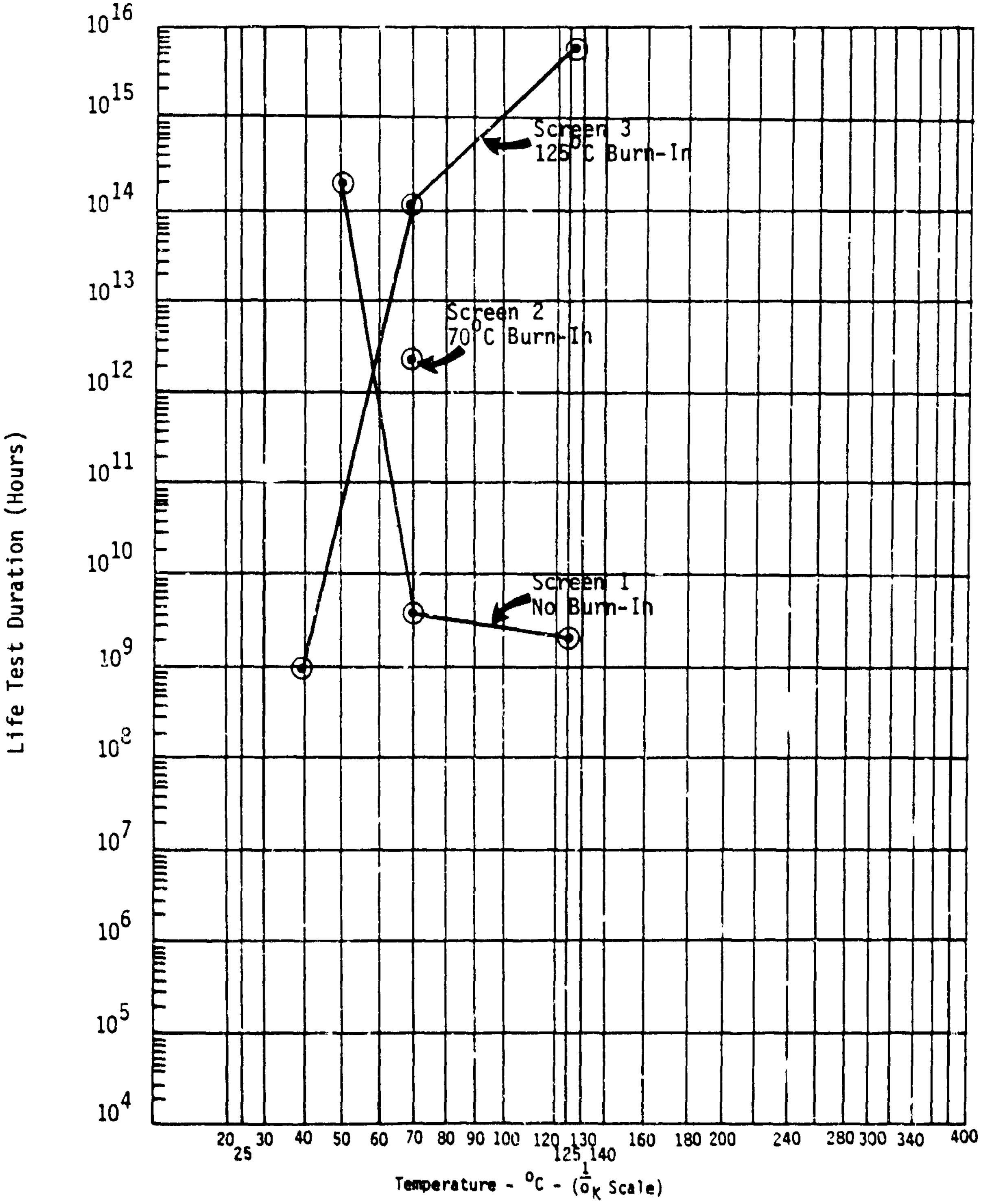

Figure 4-28
Arrhenius Curves For Median Time to Failure For Manufacturer B 2N2222 Transistor (4000 Hour Data Point Excluded)

4.3.6.2 Failure Analysis Results for Manufacturer B Transistor 2N2222—Of the 115 Manufacturer B 2N2222 transistors that failed during life test, 9 were selected for failure analysis, one from each life test cell and time increment for which the number of failures was 3 or more. The breakdown of the failure analysis results is as follows:

- Retest good — 3 parts
- Retest good after baking out (channelling) — 4 parts
- Metal migration — 2 parts

The fact that four parts recovered after being baked at 150°C indicates that there is a surface inversion or channelling failure mechanism at work that results from the presence of the plastic encapsulant. None of the hermetic parts appeared to exhibit this failure mechanism. The other two categories of failures can be attributed to varying degrees of the channelling problem, in that metal migration could occur if the channelling progressed to the point where excessive collector current was drawn, and parts could retest good if the channelling had not progressed very far when the parts were removed from the test group for analysis.

The occurence of channelling indicates a severe problem with the acceptance of this part type in plastic encapsulated form. It appears that the combination of the surface sensitive nature of high gain transistors coupled with the possible contaminants present in the plastic encapsulant represent an unscreenable reliability hazard.

4.3.7 2N2222 Transistor (Manufacturer E)

4.3.7.1 Life Test Results—Table 4-21 summarizes the life test results for the Manufacturer E 2N2222 transistors. The actual distribution of all failures is presented in Table 4-22. It is interesting to note that again the 125°C life test did not cause the largest number of failures. Instead, the 40°C life test and the 70°C life test resulted in the most failures. In addition, the 125°C burn-in screen seemed to degrade the parts such that in each life test cell, the 125°C burn-in (Screen 3) showed the largest number of failures. Both of these results contradict the expected results: it would be expected that 125°C burn-in screening would remove the most failure prone parts, and then 125°C life testing would cause the most failures. Instead, the best performance was turned in by the cell that received no burn-in screen and then was life tested at 125°C.

TABLE 4-21

Life Test Data Summary for Manufacturer E 2N2222 Transistor

	Cumulative Failures		
	Screen 1 No Burn-In	Screen 2 70°C Burn-In	Screen 3 125°C Burn-In
Life Test at 40°C	10	9	12
Life Test at 70°C	7	11	18
Life Test at 125°C	2	5	10

The failure distributions of Table 4-22 were plotted on log-normal distribution curves as shown in Figures 4-29 through 4-31. The data were also subjected to the statistical analysis program to result in the median time-to-failure shown in Table 4-23. Plotting these median times-to-failure resulted in the Arrhenius curves of Figure 4-32. The arrow pointing upward from the 70°C point is intended to indicate that at 125°C the median time-to-failure probably is very large because of the extremely small number of failures that occurred in the 125°C life test.

TABLE 4-23

Median Time-to-Failure for Manufacturer E 2N2222 Transistor

	Median Time-to-Failure (Hours)		
	Screen 1 (No Burn-In)	Screen 2 (70°C Burn-In)	Screen 3 (125°C Burn-In)
Life Test at 40°C	1.2×10^9	5.4×10^8	1.2×10^9
Life Test at 70°C	3.3×10^6	2.6×10^5	1.2×10^9
Life Test at 125°C	**	*1.2×10^9	*9.2×10^5

*Linear Regression Model was rejected

**Only two parts failed - could not predict Median Time-to-Failure

TABLE 4-22 INCREMENTAL FAILURE DISTRIBUTION FOR MANUFACTURER E 2N2222 TRANSISTORS

LIFE TEST FAILURES

40°C LIFE TEST INCREMENT (HOURS)	SCREEN 1 (NO BURN-IN)	SCREEN 2 (70°C BURN-IN)	SCREEN 3 (125°C BURN-IN)
2	1	1	3
8	0	1	1
16	0	1	1
64	1	1	0
256	0	1	3
1000	3	0	2
2000	2	0	0
4000	3	4	2
TOTAL	10	[illegible]	[illegible]
70°C LIFE TEST INCREMENT (HOURS)			
2	0	1	1
8	1	0	1
16	1	5	6
64	0	0	0
256	2	0	0
1000	3	5	7
2000	0	0	3
4000	0	0	0
TOTAL	7	11	18
125°C LIFE TEST INCREMENT (HOURS)			
2	0	0	1
8	0	1	4
16	2	2	3
64	0	0	0
256	0	0	0
1000	0	2	2
2000	0	0	0
4000	0	0	0
TOTAL	2	5	10

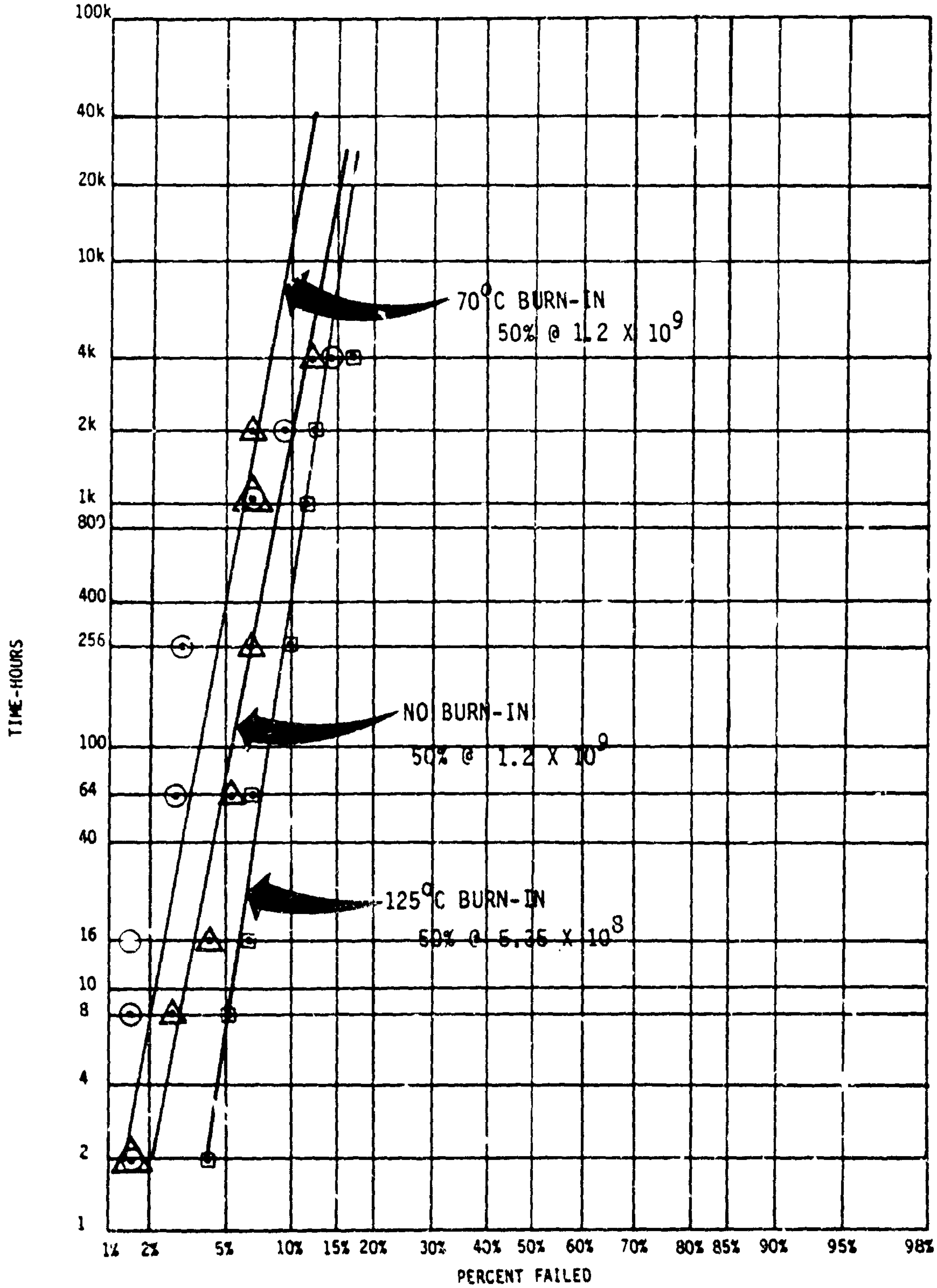

Figure 4-29 MFR.E 2N2222 40°C LIFE TEST

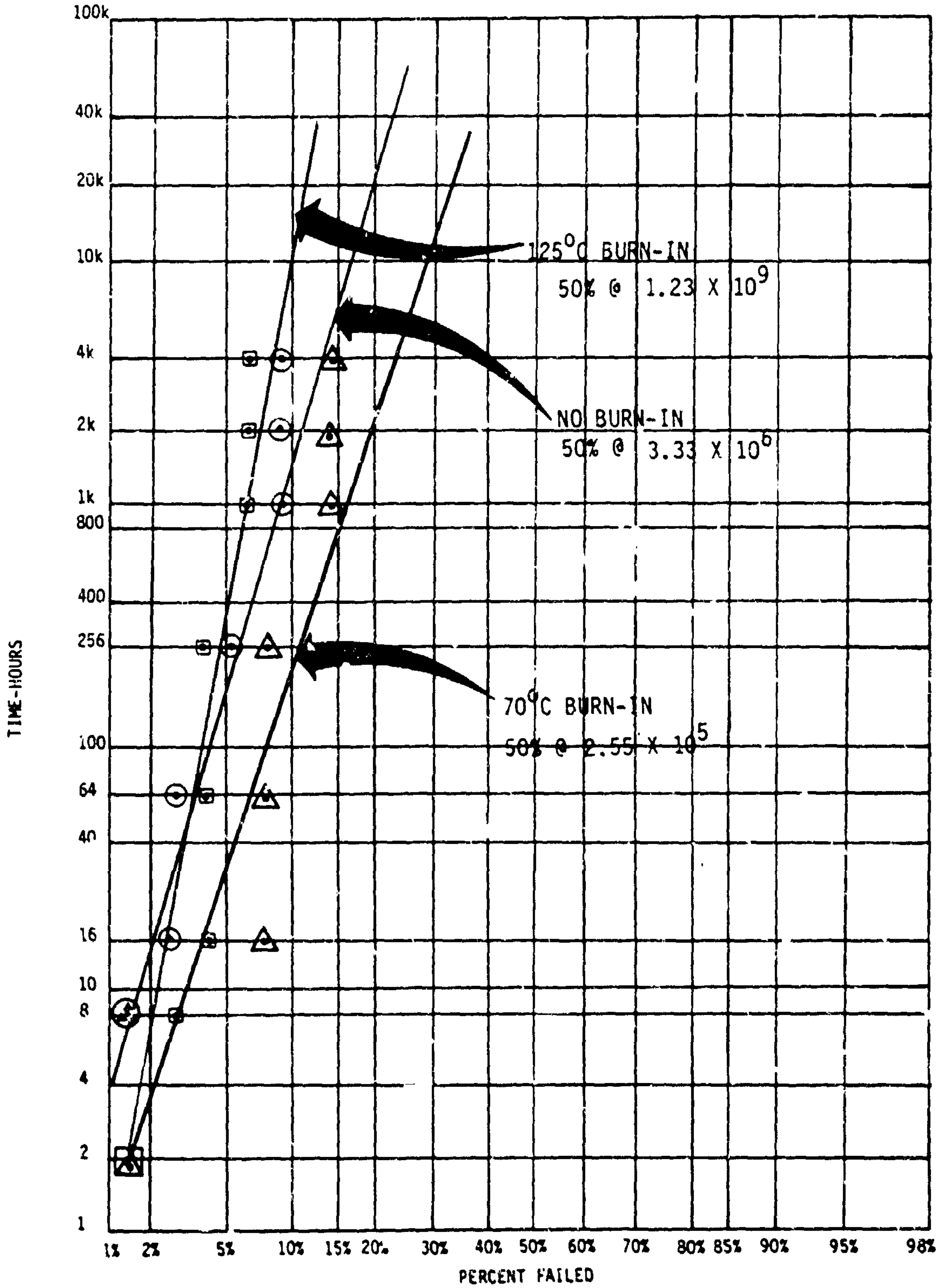

Figure 4-30 ..FR.E 2N2222 70^{0}C LIFE TEST

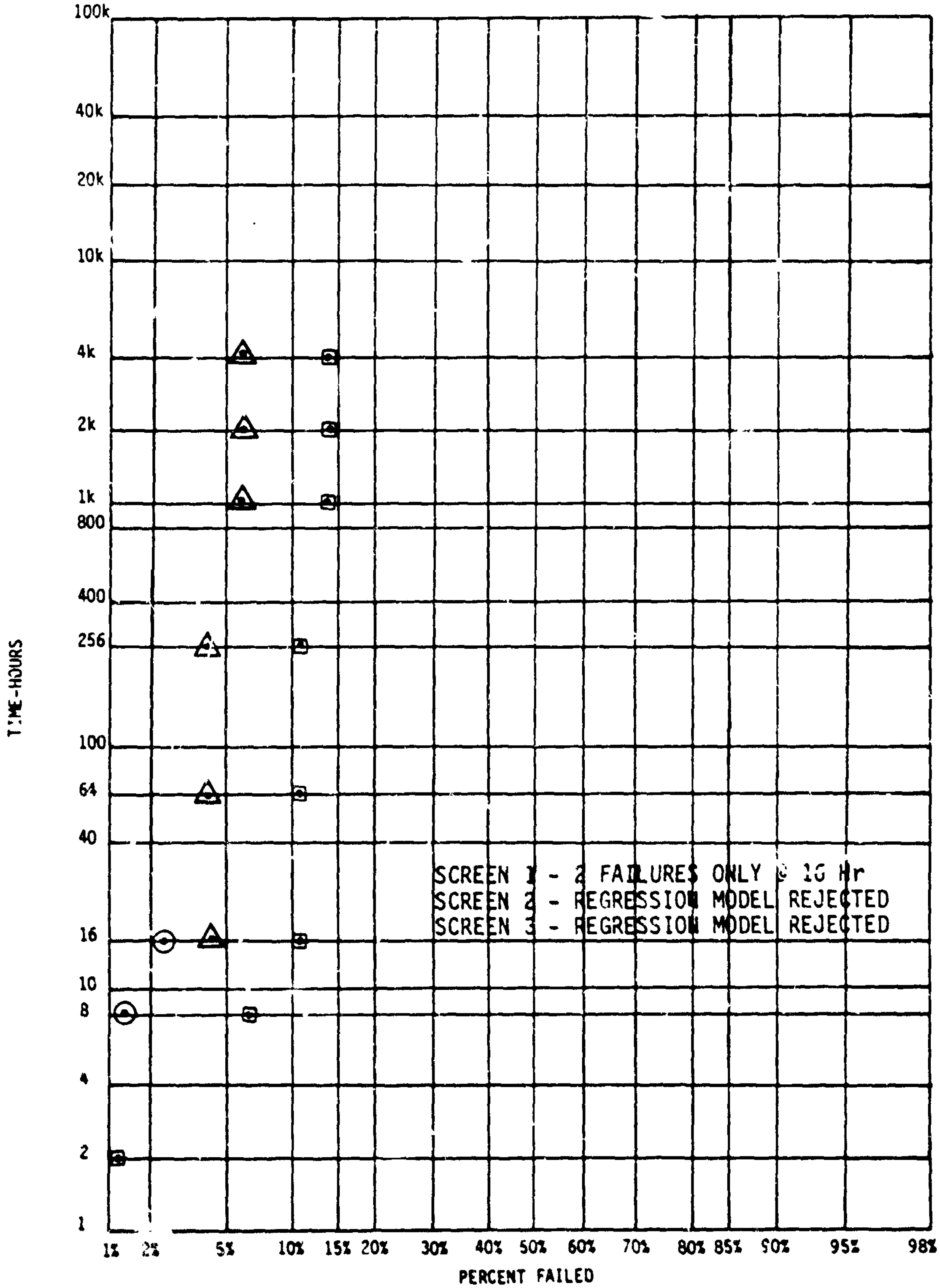

Figure 4-31 MFR.E 2N2222 125°C LIFE TEST

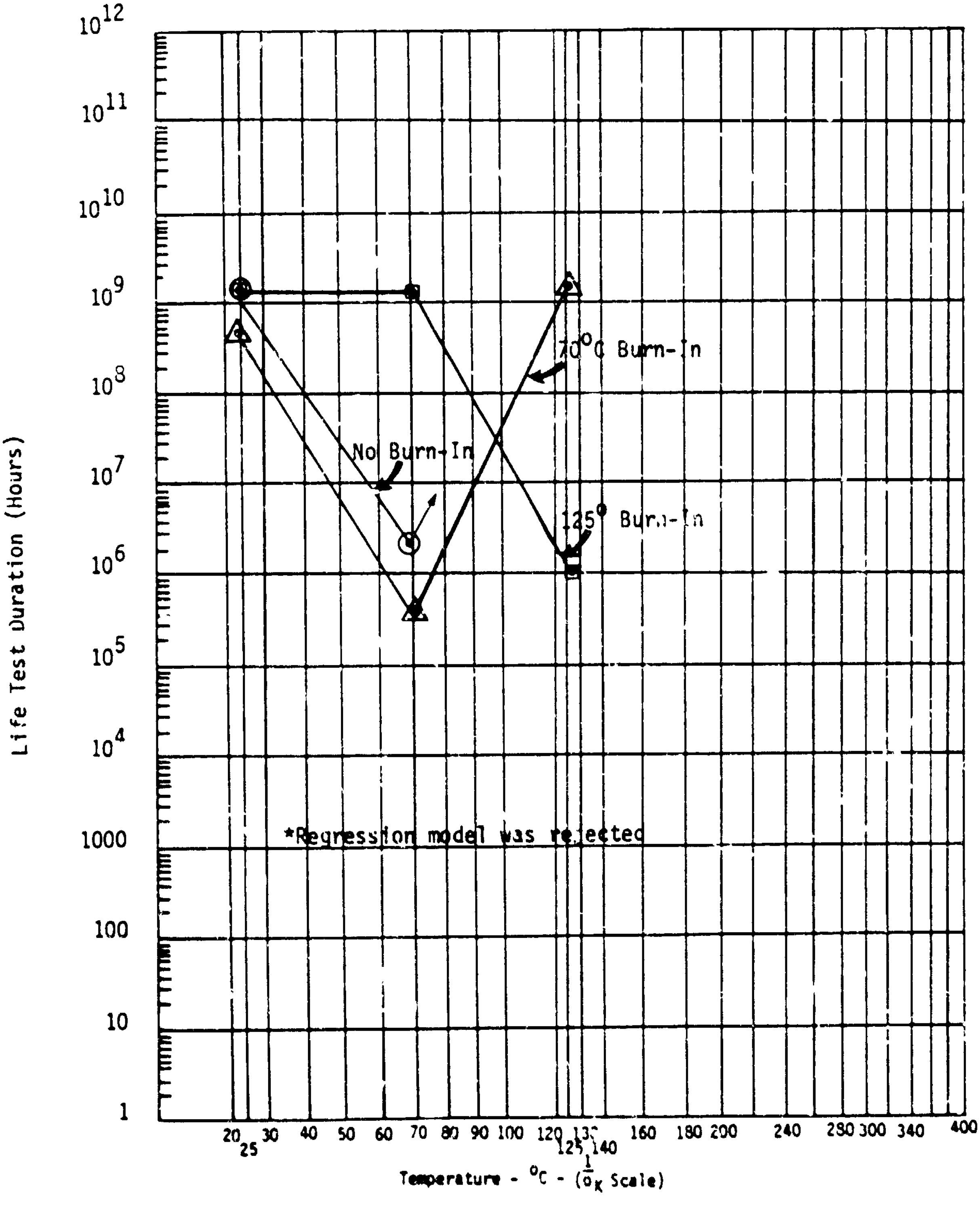

Figure 4-32
Arrhenius Curves of Median Time to Failures For Manfacturer E 2N2222 Transistor

4.3.7.2 Failure Analysis Results for Manufacturer E Transistor 2N2222—Of the 84 Manufacturer E 2N2222 transistors that failed on life test, 13 were selected for failure analysis, one for each of the life test cells and time increments for which the number of failures was 3 or greater. In addition, two hermetically sealed parts that failed at 256 hours and 1000 hours on 40°C life test after being burned-in at 125°C were subjected to failure analysis. The results of the failure analysis were as follows:

	Plastic Encapsulated	Hermetically Sealed
o Retested good after baking at 150°C (channelling)	10 parts	1 part
o Retested good	2 parts	
o Catastrophic failures	1 part	1 part

Again, the occurrence of channelling is indicated by the fact that the parts could be made to recover by being baked at 150°C for several hours up to several hundred hours. This indicates the presence of an instability in the surface that could be possibly triggered by the presence of the plastic encapsulant. However, it was noted that one of the hermetic parts also failed due to channelling, which implies that the surface of the basic silicon die may incorporate a surface contaminant. In any event, it appears that the devices in the plastic encapsulated configuration present an unacceptably high reliability risk which is not possible to ameliorate by screening.

4.4 RESULTS OF SPECIAL TESTS

4.4.1 Flammability

This test was performed on 10 parts of each type and manufacturer to determine the relative proclivity for flammability of the plastic encapsulant of the various device types. It was performed according with MIL-STD-202, Method 111A which calls for application of flame from a propane torch to each part for 15 seconds, with observations made both of the number of seconds required for the parts actually to ignite and the number of seconds for the device flame to extinguish after removal of the torch at the end of the 15 seconds. Table 4-24 summarizes the time onset the flames. It can be seen that there is no significant difference between the different manufacturers' plastic encapsulants, with the possible exception of the Manufacturer C 4069, for which one part did not ignite at all by the end of the 15 seconds.

Table 4-25 summarizes the duration times for the flames after removal of the torch. The most significant finding was that each of the Manufacturer B part types extinguished immediately. This is indicative of the possibility that it would be very difficult to cause these parts to burn up due to part overheating. Yet this very failure mechanism was observed for a number of the Manufacturer B 4069s and 741s. This means that the ignition of the plastic in those cases was due to intense and sustained overheating of the parts.

It is not felt that this flammibility test was a useful discriminator between part types in terms of an evaluation or qualification test that could be applied to parts being considered for use in a program. The differences are not that significant and the meaning of the results in terms of ultimate device reliabilty is not clear.

Table 4-24 Flammability Test Measurements

Time to Onset of Flames (seconds)

	Mfr A 74LS194	Mfr B 4069	Mfr C 4069	Mfr B 741	Mfr D 741	Mfr B 2N2222	Mfr E 2N2222
Maximum	7	8	15	12	11	6	10
Average	6	6.5	11.2	8.9	8.2	4.3	8.4
Minimum	4	5	10	7	6	3	7

Table 4-25 Flammability Extinguishing Measurements

Duration of Flames After Removal of Torch (seconds)

	Mfr A 74LS194	Mfr B 4069	Mfr C 4069	Mfr B 741	Mfr D 741	Mfr B 2N2222	Mfr E 2N2222
Maximum	6	0	6	1	3	0	3
Average	3.5	0	2.5	0.1	0.5	0	1.3
Minimum	0	0	0	0	0	0	0

C-2

4.4.2 Humidity

This test was performed with the parts simply biased at +5 volts and placed in the humidity chamber which was held at 85^{o}C and 85% relative humidity. 30 parts from each manufacturer and part type were tested, with electrical measurements made at time increments of 2, 8, 64, 256 and 1000 hours. Table 4-26 summarizes the failures that occured. It can be seen that again the bipolar LSTTL devices seemed to be impervious to the environmental stress, but surprisingly this was true of the Manufacturer D 741 op amps also.

A second interesting result was that both manufacturers' versions of the 2N2222 transistor showed a large number of failures. Over half of the parts from both Manufacturer B and E 2N2222 transistors failed the humidity test.

The failures were nearly all due to increase in the collector leakage current from the normal maximum of 10 nA to a range of leakage currents of several hundred manoamperes. These "failed" leakage currents are still exceptionally small, but are indicative of the presence of contaminants on the surface of the silicon die. There was no evidence of corrosion caused by the humidity environment.

A humidity test such as was performed on this program has been postulated as being useful in evaluation of plastic encapsulated products from several manufacturers of the same part as an indication of relative merit of the competing manufacturer's products. The results of the tests performed here did not show a clear advantage of any manufacturer over any other. However this may merely indicate that there was no manufcturers that were seriously deficient in this sample. The only clear cut conclusion to be drawn is that either the Manufacturer A plastic encapsulant is of very high integrity, or that the bipolar TTL technology is very insensitive to the presence of contaminents around the silicon die. In any case, humidity testing caused no failures in the Manufacturer A 74LS194 TTL parts.

Table 4-26 Humidity Life Test Results

	Number of Failures at Life Test Increment						
	Mfr A	Mfr B	Mfr C	Mfr B	Mfr D	Mfr B	Mfr E
Operating Life Test Hours	74LS194	4069	4069	741	741	2N2222	2N2222
2	0	0	2	3	0	0	0
8	0	0	0	0	0	6	1
16	0	1	1	0	0	9	1
64	0	0	1	0	0	2	2
256	0	2	0	0	0	2	3
1000	0	1	1	0	1	0	14
Total	0	4	5	3	1	19	21

Note: Initial cell size was 30 parts

4.4.3 Autoclave

This test was also performed with the parts simply biased at +5 volts while placed in the autoclave chamber at 120°C and 15 psig of steam. 30 parts from each manufacturer and part type were tested, with electrical measurements made at time increments of 1, 4, 16, 32, 64 and 96 hours. Table 4-27 summarizes the results.

Here also, the Manufacturer A 74LS194 device showed almost no sensitivity to the contamination that was possibly introduced by the autoclave test. Only one part failed. Nearly all of the 2N2222 transistors from both manufacturers failed the autoclave test, but it was found that the failures could be baked out such that the parts recovered. This indicates that the failures were due to increase of the collector-to-base leakage current Icbo beyond the allowable limit. It appeared that there was no incidence of corrosion of the internal leads caused by the exposure to humidity.

For the CMOS parts and linear parts, a large number of the parts failed but recovered after baking. This again indicates that the failures were due to leakage paths across low leakage junctions, rather than corrosion of the aluminum mealization.

The autoclave test did prove to be capable of generating failures in a manner that could be used as an evaluation tool for plastic encapsulated semiconductors, even though the differences between the manufacturers was not significant. The way that such a test would be implemented would be to compare the results for several different manufacturers and determine if any one manufacturer exhibited signicantly larger numbers of failures than the other manufacturer's parts.

Table 4-27 Humidity Test Lead Failures
Number of Failures at Life Test Increment

	Mfr A	Mfr B	Mfr C	Mfr B	Mfr D	Mfr B	Mfr E
	74LS194	4069	4069	741	741	2N2222	2N2222
Operations Life Test Hours							
1	1	0	0	1	0	11	3
4	0	0	0	0	0	1	0
16	0	0	1	0	0	14	12
32	0	1	1	0	1	1	14
64	0	6	3	5	4	1	1
96	0	11	4	2	6	0	-
Total	1	18	9	8	11	28	30

Note: Initial cell size was 30 parts

Another interesting observation that was made as a result of the autoclave tests was that for four of the seven part types, the autoclave environment caused the external leads to become brittle, resulting in breakage of the leads and inability to measure the parts electrically. This failure mechanism was analyzed extensively in the previous accelerated stress test contract when it occurred for Manufacturer A parts and was found to be caused by the cracking of the nickel plating on the leads which allowed the moisture to attack the kovar leads, causing embrittlement. Figure 4-28 summarizes the part types for which this problem occurred.

Table 4-28

Occurrence of Broken Leads During Autoclave

Operations Life Test Hours	Mfr A 74LS194	Mfr B 4069	Mfr C 4069	Mfr B 741	Mfr D 741	Mfr B 2N2222	Mfr E 2N2222
1	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0
64	9	0	0	0	4	0	0
96	2	1	1	0	0	0	0
Total	11	1	1	0	4	0	0

The Manufacturer A parts are again seen to be the most susceptible to this problem. All of the failures occurred near the end of the test when the parts had been inserted and removed from the life test sockets and electrical test sockets a number of times. It is felt that this normal but repeated handling combined with the severe moisture stress imposed by the autoclave test resulted in the penetration of the corrosion-inducing moisture into the external leads. These failures were not counted in the basic autoclave test results of Table 4-27 because they are not felt to be related to the plastic encapsulant.

4.4.4 High Temperature Storage

Three test cells were formed for each of the CMOS part types from Manufacturer A and Manufacturer B, to determine if there was any benefit in baking plastic encapsulated parts prior to use to drive out any intrinsic moisture imbedded in the plastic. The three test cells were as follows:

- Screen 4: Bake at 125°C for 125 hours
- Screen 5: Bake at 175°C for 125 hours
- Screen 6: Bake at 125°C for 50 hours.

Following bake, the parts were subjected to 40^{o}C operating life test for 1000 hours with electrical measurements made at 4, 16, 64, 256 and 1000 hour increments. The operating life tests were identical to the 40^{o}C life tests performed following Screens 1, 2 and 3. It can be seen that Screen 6 is the least severe of the screens and Screen 5 is most severe.

Table 4-29 summarizes the results of the high temperature storage test on the Manufacturer B 4069 parts and Table 4-30 summarizes the test results on the Manufacturer C 4069 parts.

It can be seen that the Screen 5 parts suffered the largest number of failures for both part types. Failure analysis of the failures from all of the cells indicates that the failures are caused by channeling as evidenced by the fact that the failed parts recover after being baked at 125^{o}C. It thus appears that the initial bake of the parts did not remove the source of the contamination that causes channelling, but instead drove it even deeper into the plastic encapsulant or semiconductor surface. It is not known if this contaminant is water or some other derivative of the plastic encapsulation process.

It appears that the more benign bake screen of Screens 4 and 6 did not result in as many life test failures. In fact, none of the Manufcturer C 4069 parts failed on 40^{o}C life test after being baked for just 50 hours at 125^{o}C. It is not known if this is a statistical anomaly or if this indicates that this might be a valid screen for plastic encapsulated semiconductors. The important observation should be that even with the rather good results that the high temperature storage screen appeared to generate, the number of life test failures is still unacceptably large as compared to the number of failures that would be expected for hermetically sealed parts, with the implication that the failure mechanism that generates the failures in plastic encapsulated parts is basically unscreenable.

Table 4-29 Manufacturer B 4069 High Temperature Storage Life Test Results

40°C Operating Life Test Hours	Screen 4 Bake 125 Hrs @ 125°C	Screen 5 Bake 125 Hrs @ 175°C	Screen 6 Bake 50 Hrs @ 125°C
0	0	0	0
4	1	1	0
16	0	0	0
64	0	0	0
256	0	3	0
1000	2	5	4
Total	3	9	4

Table 4-30 Manufacturer C 4069 High Temperature Storage Life Test Results

40°C Operating Life Test Hours	Screen 4 Bake 125 Hrs @ 125°C	Screen 5 Bake 125 Hrs @ 175°C	Screen 6 Bake 50 Hrs @ 125°C
0	0	0	0
4	0	1	0
16	0	1	0
64	0	0	0
256	0	1	0
1000	2	2	0
Total	2	5	0

5.0 PROCUREMENT AND APPLICATION CONSIDERATIONS

5.1 DESIGN APPLICATION AND PROCESSING CONSTRAINTS

Although plastic encapsulated semiconductors are apparently used with success in commercial application in industry, their use in NASA space application would appear to be fraught with problems and reliability hazards. Any design application for which the use of plastic encapsulated semiconductors is contemplated should be analyzed to determine if such usage would be feasible in the face of the intense parts engineering and supplier monitoring that would have to be performed to ensure a suitably high integrity product.

Any device type which employs surface related structures such as are found in linear microcircuits, high voltage or high gain transistors, and low leakage current low dissipation device types such as CMOS and FET devices is expected to present severe reliability problems upon application to NASA designs. The only possible device type for which there might be reasonable success in use of plastic encapsulated devices would be the high-power-dissipation bipolar TTL-technology devices (such as LSTTL, TTL and ALSTTL) and other bipolar digital devices. It does not appear that the reliability of CMOS or linear device types could be controlled satisfactorily by exercising parts engineering or device processing constraints, even if the manufacturers of plastic encapsulated devices would allow these constraints to be applied to them.

5.2 QUALIFICATION TEST CONSIDERATIONS

It would be desirable for users of plastic encapsulated semiconductors to be able to perform qualification testing on samples of devices they are planning to use and be able to derive useful reliability information from the qualification tests. However it appears that there are no significant tests that can be performed as qualification tests that would shed light on the relative merit of any given lot of plastic encapsulated semiconductors.

While parts can be made to fail by the application of humidity and pressure cooker (autoclave) tests, the meaning of the failures observed cannot be discerned, other than that at a gross level the tests are likely to identify production lots of parts that are significantly worse than other lots. Thus it appears that lot qualification of plastic encapsulated semiconductors cannot be used as a means of assuring the reliability of the devices, and manufacturer line or in-process qualification cannot be considered in the atmosphere of the high volume, low cost production characteristics of the plastic encapsulated semiconductor technology.

5.3 SCREENING TEST CONSIDERATIONS

The results of this program indicate that the failure mechanisms of plastic encapsulated semiconductors are unscreenable by any of the well-known or low cost screens available to parts control engineers. The failures that occur with surface sensitive device types appear to be log-normally distributed with a low sigma, such that throughout the duration of operation of a system bearing plastic encapsulated semiconductor, failures would be continuing to occur at a unacceptably high rate. For the device types which are not surface sensitive (such as bipolar LSTTL devices), there does not seem to be any advantage to conventional screens such as burn-in. The use of electrical measurement of parameters and functional performance at two temperatures does serve to weed out "parts that never worked", but this is the only screen that would be of value.

6.0 RECOMMENDATIONS

6.1 APPLICABILITY OF PLASTIC ENCAPSULATED SEMICONDUCTORS TO SPACE APPLICATIONS

The results of this program indicate that with the possible exception of bipolar digital devices, plastic encapsulated semiconductors are not applicable to space application or to other applications where even a minimal degree of reliability assurance is desired. The low cost of plastic encapsulated semiconductors is more than offset by the high cost of screening and parts engineering that would be required to provide adequate reliability assurance, and even then the reliability would probably not be adequate for other than the most undemanding system applications such as ground equipment in an environmentally controlled application.

6.2 ADDITIONAL STUDY AND EVALUATION AREAS

A recent technological development has provided an alternative to the use of CMOS for low power drain system design. This is the integrated injection logic (IIL) technology which offers extremely low power dissipation in a bipolar technology. Little is known about the reliability of the IIL technology in either hermetic or plastic encapsulated versions.

One of the problems with IIL is that there are no large families of device types for system design available in IIL. Most of the emphasis in IIL has been in the custom VLSI area, although there are several standard VLSI designs (microprocessors, etc) on the market.

It is recommended that the problems of plastic encapsulated CMOS be given an alternative solution: use of IIL technology. This would require that an accelerated stress test be performed to evaluate the screenability of IIL in plastic encapsulated form. A program similar to this Phase 2 program should be initiated on examples of IIL in custom VLSI and standard VLSI form, to determine the suitability of this technology for use in space application.

APPENDIX A

STATISTICAL ANALYSIS PROGRAM

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INTRODUCTION

The linear regression program described herein is used for the statistical analysis of life test failure data of parts from the NASA contract "Development of Design, Qualification, Screening, and Application Requirements for Plastic Encapsulated Solid-State Devices for Space Applications".

Two objectives are met in this program. The first is to calculate a measure of the variance of the data. This measure gives the user some idea about the quality of the data. The second objective is to calculate the 50% failure point in hours. This 50% point is calculated by converting the data into a linear relationship, finding the equation of the best fit line through the data, and finally using this equation for the solution.

The life test data is converted into a linear relationship by calculating the log of the hour increment, and by calculating the probit of the cummulative failure percentage. A probit is a linear measure on the normal cummulative distribution function.

In addition to these objectives, the program also calculates a confidence interval for the parameters of the line and allows the user to find the probit value and confidence interval for any hour value.

The following sections of this document briefly describe simple linear regression and detail the program and how it is used.

SIMPLE LINEAR REGRESSION

This section briefly describes simple linear regression and the equations used in this program.

There are many occasions where one variable in a process linearly depends on another variable. The variable which is controlled is called the independent variable, x in this case, while the other is obviously the dependent variable, y. If different values of x_i are used to determine values of y_i then a scatter diagram of figure 1 may be plotted which shows the linear relationship.

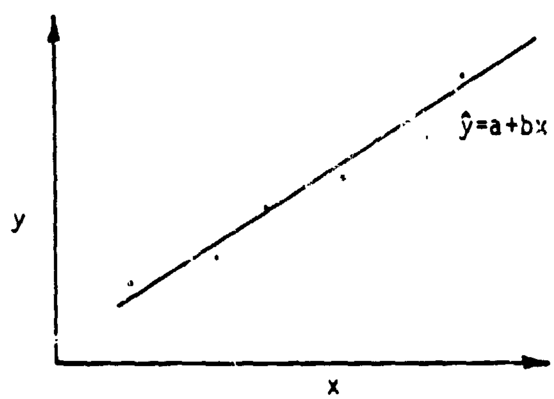


FIGURE 1 Scatter Diagram

If more data is taken for the same values of x_i then it would be expected that the y_i values would vary. That is, for each x_i there exists many

$(y_{i1} \ldots\ldots y_{ij})$ where these y's may be thought of as a random variable. This may be represented by figure 2 where the density of y_i, $f(y_i)$, is plotted for a few x_i.

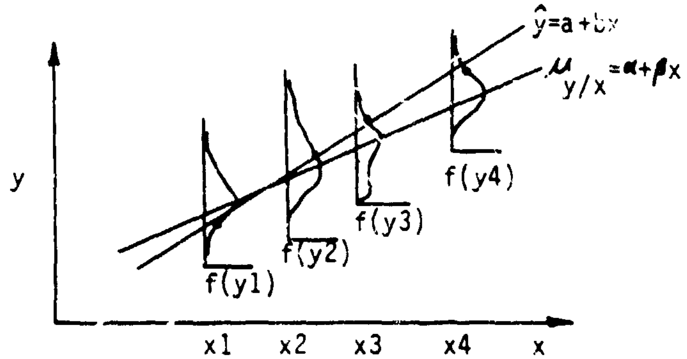


FIGURE 2 True Linear Relationship vs. Estimation

The line through the mean of each $f(y_i)$ can be expressed as in figure 2. In some sense this is the true line for the data. The line

$$\hat{y}=a+bx \tag{1}$$

is therefore an estimate of the line.

$$\mu_{y/x}=\alpha+\beta x \tag{2}$$

If a minimum sum of squared error criterion is used then the following equations provide an estimation of the constants a and b.

$$b=\frac{n\sum_{i=1}^{n} x_i y_i - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \tag{3}$$

$$a=\bar{y}-b\bar{x} \tag{4}$$

where n= # data points
$\bar{x}$= mean of x data
$\bar{y}$= mean of y data

Since a and b are normally distributed random variables then confidence intervals around α and β may be found using the T statistic.

$$b - \frac{t_{\alpha/2}\, s}{\sqrt{S_{xx}}} < \beta < b + \frac{t_{\alpha/2}\, s}{\sqrt{S_{xx}}} \tag{5}$$

where:

$$s = \sqrt{\frac{S_{yy} - bS_{xy}}{n - 2}} \tag{6}$$

$$S_{xx} = \sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n} \tag{7}$$

$$S_{yy} = \sum_{i=1}^{n} y_i^2 - \frac{\left(\sum_{i=1}^{n} y_i\right)^2}{n} \tag{8}$$

$$S_{xy} = \sum_{i=1}^{n} x_i y_i - \frac{\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n} \tag{9}$$

$t_{\alpha/2}$ has n-2 degrees of freedom

and

$$a - \frac{t_{/2}\, s\sqrt{\sum_{i=1}^{n} x_i^2}}{\sqrt{n\, S_{xx}}} < \alpha < a + \frac{t_{/2}\, s\sqrt{\sum_{i=1}^{n} x_i^2}}{\sqrt{n\, S_{xx}}} \tag{10}$$

If a certain $x=x_0$ is known and it is desired to find a confidence interval of $\hat{y}_0$ then again the T statistic may be used.

$$\hat{y}_0 - t_{\alpha/2}\, s\sqrt{\frac{1}{n} + \frac{(x_0 - x)^2}{S_{xx}}} < \mu_{y/x_0} < \hat{y}_0 + t_{\alpha/2}\, s\sqrt{\frac{1}{n} + \frac{(x_0 - x)^2}{S_{xx}}} \tag{11}$$

Finally it is often desirable to have a measure fo the variance of the data. Using the F statistic, a measure may be calculated in order to test the null hypothesis, H_0, that the data did not reflect sufficient evidence to support the model postulated.

$$f = \frac{b\, S_{xy}}{s^2} \qquad (12)$$

The comparison is then made:

IF $f > f\,(1, n-2)$ THEN REJECT H_0 AT THE LEVEL OF SIGNIFICANCE

ELSE ACCEPT H_0

where $f\,(\nu_1, \nu_2)$

ν_1 = 1 degree of freedom

ν_2 = n-2 degrees of freedom

These are the necessary equations to compute the results of the program.

THE PROGRAM

Since this section includes a listing as well as a flow chart of the program, a verbal explanation of the program will not be presented.

Instead a step by step description of how to use the program will be offered. Text printed on the Fluke 1720A Controller will be typed in capitals while responses will be typed in small letters. Comments will be set off by parenthesis. A sample of the printed output will also be shown. The data presented to the program is from the 4069 life test of the previously cited NASA contract.

EXAMPLE:

ENTER PART TYPE: 4069

ENTER SCREEN #: 1

ENTER LIFE TEST: 125

ENTER # OF POINTS (>2 AND<50) 6
(6 points for data to 1000hrs, 8 points to 4000hrs)

ENTER ALPHA FOR CONFIDENCE INTERVAL .05
(for 95% confidence interval enter alpha=1-.95)

ENTER T OF.025 FOR 4 DEGREES OF FREEDOM 2.776
(see figure 3. find alpha column in figure for .025 and row
for , # degrees of freedom, of 4. intersection gives T=2.776)

ENTER # PARTS IN SCREEN 75
(this should be # of parts accounted for at the end of
life testing)

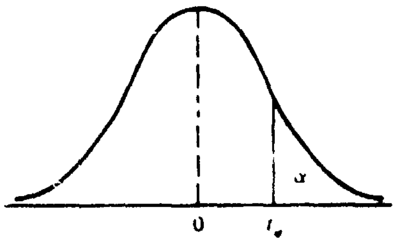
```
ENTER X(1) 2
( life test increment in hours)

ENTER Y(1) 3

ENTER X(2) 8

ENTER Y(2) 1

ENTER X(3) 16

ENTER Y(3) 0

ENTER X(4) 64

ENTER Y(4) 4

ENTER X(5) 256

ENTER Y(5) 5

ENTER X(6) 1001

ENTER Y(6) 25

DO YOU WISH TO CHANGE A VALUE (Y OR N) y

CHANGE X y

ENTER I 6

ENTER X(I) 1000

CHANGE Y y

ENTER I 6

ENTER Y(I) 4

DO YOU WISH TO CHANGE A VALUE (Y OR N) n

DO YOU WISH TO FIND AN INTERVAL FOR SOME MEAN OF Y/XO y

IS THIS TO BE A  .95 INTERVAL y

ENTER XO VALUE 50

DO YOU WANT THE LOG(X) y

ENTER F OF ALPHA FOR(1,4) DEGREES OF FREEDOM 7.71
```

(see figures 4-7. find figure for alpha=.05. find γ_1 column=1 and γ_2 row=4 intersection gives f=7.71, for 8 data points γ_2 row=6)

```
END OF PROGRAM
```

The resulting program output is shown in figure 8.

Table V†
Critical Values of the t Distribution

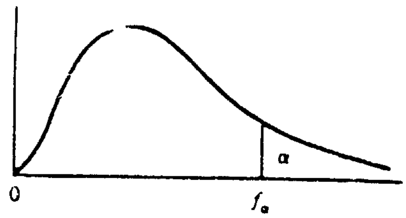


ν	α 0.10	0.05	0.025	0.01	0.005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.169
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.787
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.313	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
inf.	1.282	1.645	1.960	2.326	2.576

† From Table IV of R. A. Fisher, *Statistical Methods for Research Workers*, published by Oliver & Boyd, Edinburgh, by permission of the author and publishers.

FIGURE 3

Table VII† Critical Values of the F Distribution



$f_{0.05}(\nu_1, \nu_2)$

ν_2	ν_1 = 1	2	3	4	5	6	7	8	9
1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88

† Reproduced from Table 18 of *Biometrika Tables for Statisticians*, Vol. I, by permission of E. S. Pearson and the Biometrika Trustees.

FIGURE 4

Table VII Critical Values of the *F* Distribution (*continued*)

$f_{0.05}(\nu_1, \nu_2)$

ν_2	ν_1: 10	12	15	20	24	30	40	60	120	∞
1	241.9	243.9	245.9	248.0	249.1	250.1	251.1	252.2	253.3	254.3
2	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.78
23	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81	1.76
24	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
26	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
27	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
28	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
29	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
30	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
60	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35	1.25
∞	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

517

FIGURE 5

Table VII Critical Values of the F Distribution *(continued)*

$f_{0.01}(\nu_1, \nu_2)$

ν_2 \ ν_1	1	2	3	4	5	6	7	8	9
1	4052	4999.5	5403	5625	5764	5859	5928	5981	6022
2	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39
3	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35
4	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66
5	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16
6	13.75	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98
7	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72
8	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91
9	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35
10	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19
14	8.86	6.51	5.56	5.04	4.69	4.46	4.28	4.14	4.03
15	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78
17	8.40	6.11	5.18	4.67	4.34	4.10	3.93	3.79	3.68
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60
19	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40
22	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35
23	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26
25	7.77	5.57	4.68	4.18	3.85	3.63	3.46	3.32	3.22
26	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18
27	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15
28	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12
29	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	[illegible]	3.07
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72
120	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.56
∞	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41

FIGURE 6

Table VII Critical Values of the F Distribution (*continued*)

$f_{0.01}(\nu_1, \nu_2)$

ν_2	ν_1									
	10	12	15	20	24	30	40	60	120	∞
1	6056	6106	6157	6209	6235	6261	6287	6313	6339	6366
2	99.40	99.42	99.43	99.45	99.46	99.47	99.47	99.48	99.49	99.50
3	27.23	27.05	26.87	26.69	26.60	26.50	26.41	26.32	26.22	26.13
4	14.55	14.37	14.20	14.02	13.93	13.84	13.75	13.65	13.56	13.46
5	10.05	9.89	9.72	9.55	9.47	9.38	9.29	9.20	9.11	9.02
6	7.87	7.72	7.56	7.40	7.31	7.23	7.14	7.06	6.97	6.88
7	6.62	6.47	6.31	6.16	6.07	5.99	5.91	5.82	5.74	5.65
8	5.81	5.67	5.52	5.36	5.28	5.20	5.12	5.03	4.95	4.86
9	5.26	5.11	4.96	4.81	4.73	4.65	4.57	4.48	4.40	4.31
10	4.85	4.71	4.56	4.41	4.33	4.25	4.17	4.08	4.00	3.91
11	4.54	4.40	4.25	4.10	4.02	3.94	3.86	3.78	3.69	3.60
12	4.30	4.16	4.01	3.86	3.78	3.70	3.62	3.54	3.45	3.36
13	4.10	3.96	3.82	3.66	3.59	3.51	3.43	3.34	3.25	3.17
14	3.94	3.80	3.66	3.51	3.43	3.35	3.27	3.18	3.09	3.00
15	3.80	3.67	3.52	3.37	3.29	3.21	3.13	3.05	2.96	2.87
16	3.69	3.55	3.41	3.26	3.18	3.10	3.02	2.93	2.84	2.75
17	3.59	3.46	3.31	3.16	3.08	3.00	2.92	2.83	2.75	2.65
18	3.51	3.37	3.23	3.08	3.00	2.92	2.84	2.75	2.66	2.57
19	3.43	3.30	3.15	3.00	2.92	2.84	2.76	2.67	2.58	2.49
20	3.37	3.23	3.09	2.94	2.86	2.78	2.69	2.61	2.52	2.42
21	3.31	3.17	3.03	2.88	2.80	2.72	2.64	2.55	2.46	2.36
22	3.26	3.12	2.98	2.83	2.75	2.67	2.58	2.50	2.40	2.31
23	3.21	3.07	2.93	2.78	2.70	2.62	2.54	2.45	2.35	2.26
24	3.17	3.03	2.89	2.74	2.66	2.58	2.49	2.40	2.31	2.21
25	3.13	2.99	2.85	2.70	2.62	2.54	2.45	2.36	2.27	2.17
26	3.09	2.96	2.81	2.66	2.58	2.50	2.42	2.33	2.23	2.13
27	3.06	2.93	2.78	2.63	2.55	2.47	2.38	2.29	2.20	2.10
28	3.03	2.90	2.75	2.60	2.52	2.44	2.35	2.26	2.17	2.06
29	3.00	2.87	2.73	2.57	2.49	2.41	2.33	2.23	2.14	2.03
30	2.98	2.84	2.70	2.55	2.47	2.39	2.30	2.21	2.11	2.01
40	2.80	2.66	2.52	2.37	2.29	2.20	2.11	2.02	1.92	1.80
60	2.63	2.50	2.35	2.20	2.12	2.03	1.94	1.84	1.73	1.60
120	2.47	2.34	2.19	2.03	1.95	1.86	1.76	1.66	1.53	1.38
∞	2.32	2.18	2.04	1.88	1.79	1.70	1.59	1.47	1.32	1.00

FIGURE 7

ORIGINAL PAGE IS
OF POOR QUALITY

```
PART TYPE:MFR C 4069
SCREEN:NO BURN IN
LIFE TEST:125 DEG C

FAILURE DATA:

HOURS= 2       FAILURES= 3    CUM. FAIL.= 3    % CUM. FAIL.= 4
HOURS= 8       FAILURES= 1    CUM. FAIL.= 4    % CUM. FAIL.= 5.333333
HOURS= 16      FAILURES= 0    CUM. FAIL.= 4    % CUM. FAIL.= 5.333333
HOURS= 64      FAILURES= 4    CUM. FAIL.= 8    % CUM. FAIL.= 10.66667
HOURS= 256     FAILURES= 5    CUM. FAIL.= 13   % CUM. FAIL.= 17.33333
HOURS= 1000    FAILURES= 4    CUM. FAIL.= 17   % CUM. FAIL.= 22.66667

SAMPLE SIZE= 75

LOG(HOURS) 0.30103        PROBIT(%FAILURES)= 3.24713
LOG(HOURS) 0.90309        PROBIT(%FAILURES)= 3.38562
LOG(HOURS) 1.20412        PROBIT(%FAILURES)= 3.38562
LOG(HOURS) 1.80618        PROBIT(%FAILURES)= 3.75392
LOG(HOURS) 2.40824        PROBIT(%FAILURES)= 4.05761
LOG(HOURS) 3.00000        PROBIT(%FAILURES)= 4.24906


RESULTS FOR 0.95 CONFIDENCE INTERVAL WITH 4 DEGREES OF FREEDOM
AND T OF 0.025 = 2.76

REGRESSION CONSTANT ESTIMATES:
A= 3.036079
B= 0.401394

THE 0.95 CONFIDENCE INTERVAL FOR B IS:
                 0.2955178 <BETA< 0.5072702

THE 0.95 CONFIDENCE INTERVAL FOR A IS:
                 2.840767 <ALPHA< 3.231392


ESTIMATE OF Y GIVEN X:

T OF 0.025 = 2.76
X= 50
LOG(X)= 1.69897
Y ESTIMATE= 3.718036

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
                  3.441806 <MEAN OF Y/XO< 3.994266 PROBITS


50% OF FAILURES OCCUR AT 78117.34 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
                  4.111257 <MEAN OF Y/XO< 5.788743 PROBITS


ANALYSIS OF VARIANCE:

F= [illegible]9872 IS GREATER THAN F OF ALPHA(1, 4 )= 7.71
THEREFORE REJECT H0 - DO NOT REJECT THE REGRESSION MODEL
```

Figure 8 Sample Program Output

```
5 !                            ***********************************
10 !                           **                               **
15 !                           **   LINEAR REGRESSION PROGRAM   **
20 !                           **                               **
25 !                           ***********************************
30 !
35 ! WRITTEN BY: FRANK MOORE  ORG:2-3622   PH:3-9434
40 ! LAST UPDATE: JULY 7,1981
45 !
50 ! THIS PROGRAM IS WRITTEN TO PROVIDE SIMPLE LINEAR REGRESSION
55 ! ANALYSIS FOR USER DEFINED DATA. OPTIONS EXIST TO ANALYZE
60 ! PARTS SCREENING LIFE TEST DATA. THESE OPTIONS CONSIST OF MAKING
65 ! THE DATA LINEAR BY COMPUTING THE LOG OF THE LIFE TEST HOURS
70 ! INCREMENT AND THE PROBIT (SEE PROGRAM DOCUMENTATION) OF THE
HE LINEAR REGRESSION
80 ! CONSTANTS, THIS PROGRAM COMPUTES THE POINT AT WHICH 50% OF THE
ANCE OF THE DATA. A MORE
90 ! DETAILED DESCRIPTION OF THE PROGRAM CAN BE FOUND IN THE PROGRAM
95 ! DOCUMENTATION.
100 !
105 ! CONSTANTS AND VARIABLES DEFINITIONS
110 !
115 ! A=LINEAR REGRESSION ESTIMATE        A$=PART TYPE
120 ! B=LINEAR REGRESSION ESTIMATE        B$=SCREEN #
125 ! C=SUM X(I)                          C$=LIFE TEST
130 ! D=SUM Y(I)                          D1=PROBIT INTERCEPT
)Y(I)                    F=SUM X(I)^2, VALUE OF F FOR DATA
140 ! F1=LOG DECISION FLAG, F OF ALPHA   F2=PROBIT DECISION FLAG
145 !     STATISTIC                       G=SUM Y(I)^2
150 ! I,J=COUNTERS                        K1=SAMPLE SIZE
155 ! L=SLOPE FOR INTERPOLATION           M=LOWER CONFIDENCE BOUND
160 ! N=# OF DATA POINTS                  N$=DECISION VARIABLE
165 ! P=UPPER CONFIDENCE BOUND            P1=PRINT FLAG
170 ! Q=ALPHA                             S=ESTIMATE OF SIGMA
175 ! S1=SXX                              S2=SYY
180 ! S3=SXY                              T=T OF ALPHA/2 STATISTIC
185 ! T1=SUM OF FAILURES, PROBIT          T2=PROBIT INTERPOLATION POINT
190 !     INTERPOLATION POINT             X=ARBITRARY X VALUE
195 ! X(50)=X VALUE ARRAY                 Y=RESULT OF X
200 ! Y(50)=Y VALUE ARRAY                 Y$=DECISION VARIABLE
205 ! Z(47)=% VALUES FOR PROBIT
210 !        CONVERSION
215 !
220 DIM X(50),Y(50)
225 P1=1
226 !
230 ! TO PRINT TO SCREEN OR PRINTER
231 !
235 OPEN "KB0:" AS NEW FILE 1%
240 OPEN "KB1:" AS NEW FILE 2%
245 PRINT "PRINTED RESULTS (Y OR N)";
250 INPUT Y$
255 IF Y$="Y" THEN GOTO 270
260 IF Y$="N" THEN GOTO 280
265 GOTO 245
270 P1=2
271 !
275 ! PART DATA
276 !
280 PRINT "ENTER PART TYPE:";
285 INPUT A$
290 PRINT "ENTER SCREEN #:";
295 INPUT B$
```

```
300 PRINT "ENTER LIFE TEST:";
305 INPUT C$
306 '
310 ! INPUT DATA FOR PROGRAM
311 '
315 PRINT "ENTER # OF POINTS (2<AND<50)";
320 INPUT N
325 PRINT "ENTER ALPHA FOR CONFIDENCE INTERVAL";
330 INPUT Q
335 PRINT "ENTER T OF";Q/2;"FOR";N-2;"DEGREES OF FREEDOM";
340 INPUT T
342 PRINT "ENTER # PARTS IN SCREEN";
343 INPUT K1
344 PRINT "WARNING:PROGRAM WILL NOT ESTIMATE VERTICAL LINES (ALL FAILS IN
345 PRINT "ENTER DATA FROM 1ST NON-ZERO INCR.  MODIFY # POINTS & T OF ALPH
346 FOR I=1 TO N
350 PRINT "ENTER LIFE TEST HOURS X(";I;")";
355 INPUT X(I)
360 PRINT "ENTER # OF FAILURES Y(";I;")";
365 INPUT Y(I)
370 NEXT I
371 '
375 ' KEYSTROKE ERROR CORRECTION
376 !
380 PRINT "DO YOU WISH TO CHANGE A VALUE (Y OR N)";
385 INPUT Y$
390 IF Y$="Y" THEN GOSUB 2015
HEN GOTO 410
400 GOTO 380
401 '
405 ' DISPLAY PART DATA
406 '
410 PRINT #P1,"PART TYPE:";A$
415 PRINT #P1,"SCREEN:";B$
420 PRINT #P1,"LIFE TEST:";C$
425 PRINT #P1,
477 PRINT #P1,
478 PRINT #P1,"FAILURE DATA:"
479 PRINT #P1,
506 '
510 ' MODIFY NASA DATA FOR STRAIGHT LINE
511 '
520 GOSUB 3020
550 PRINT #P1,
551 '
555 ' PRINT # PARTS IN SCREEN
556 !
560 PRINT #P1,"SAMPLE SIZE=";K1
561 '
565 ' PRINT MODIFIED FAILURE DATA
566 '
567 PRINT #P1,
570 FOR I=1 TO N
575 X(I)=LOG(X(I))                                        'FOR LOG DATA
580 NEXT I
590 FOR I=1 TO N
595 PRINT #P1,"LOG(HOURS)";
600 PRINT #P1,USING "S#.#####",X(I);
605 PRINT #P1,"            PROBIT(%FAILURES)=";
610 PRINT #P1,USING "S#.#####",Y(I)
615 NEXT I
616 '
620 ' SET UP SUMMING CONSTANTS
```

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OF POOR QUALITY

```
621 '
625 C=0
630 D=0
635 E=0
640 F=0
645 G=0
646 '
650 ' CALCULATE SUMS NEEDED LATER
651 '
655 FOR I=1 TO N
660 C=C+X(I)                                    ' SUM OF X(I)
665 D=D+Y(I)                                    ' SUM OF Y(I)
670 E=E+X(I)*Y(I)                               ! SUM OF X(I)Y(I)
675 F=F+X(I)^2                                  ' SUM OF X(I)^2
680 G=G+Y(I)^2                                  ' SUM OF Y(I)^2
685 NEXT I
690 ' PRINT CONFIDENCE INTEVAL VALUES
691 '
695 PRINT #P1,
700 PRINT #P1,
705 PRINT #P1,"RESULTS FOR";1-Q;"CONFIDENCE INTERVAL WITH";N-2;"DEGREES";
710 PRINT #P1," OF FREEDOM"
715 PRINT #P1,"AND T OF";Q/2;"=";T
720 PRINT #P1,
721 '
725 ! CALCULATE AND PRINT REGRESSION CONSTANTS A AND B
726 '
730 PRINT #P1,"REGRESSION CONSTANT ESTIMATES:"
735 B=((N*E)-(C*D))/((N*F)-C^2)                   COMPUTE B
740 A=(D/N)-B*(C/N)                             ' COMPUTE A
745 PRINT #P1,"A=";A
750 PRINT #P1,"B=";B
751 '
755 ' CALCULATE COVARIANCE AND VARIANCE ESTIMATES
756 '
760 S1=F-(C^2/N)                                ' SXX
765 S2=G-(D^2/N)                                ' SYY
C*D)/N)                              ' SXY
775 S=SQR((S2-(B*S3))/(N-2))                    ' ESTIMATE OF SIG
776 !
780 ' CALCULATE AND PRINT A AND B CONFIDENCE INTERVALS
781 !
785 M=B-((T*S)/S1^.5)
790 P=B+((T*S)/S1^.5)
795 PRINT #P1,
800 PRINT #P1,"THE";1-Q;"CONFIDENCE INTERVAL FOR B IS:"
805 PRINT #P1,"                ";M;"<BETA<";P
810 M=A-((T*S*(F^.5))/(N*S1)^.5)
815 P=A+((T*S*(F^.5))/(N*S1)^.5)
820 PRINT #P1,
825 PRINT #P1,"THE";1-Q;"CONFIDENCE INTERVAL FOR A IS:"
 PRINT #P1,"                ";M;"<ALPHA<";P
835 '
840 ' CALCULATE Y GIVEN SOME X
841 '
845 PRINT "DO YOU WISH TO FIND AN INTERVAL FOR SOME MEAN OF Y/X0";
850 INPUT Y$
855 IF Y$="Y" THEN GOTO 870
860 IF Y$="N" THEN GOTO 1035
865 GOTO 845
870 PRINT "IS THIS TO BE A";1-Q;"INTERVAL";
875 INPUT Y$
880 IF Y$="Y" THEN GOTO 920
```

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```
885 IF Y$="N" THEN GOTO 900
890 GOTO 870
891 '
895 ' CHANGE T OF ALPHA?
896 '
900 PRINT "ENTER NEW ALPHA";
905 INPUT Q
910 PRINT "ENTER T OF ALPHA/2";
915 INPUT T
920 PRINT "ENTER X0 VALUE";
925 INPUT X
926 '
930 ' PROVISION FOR NASA [illegible] TO TAKE LOG OF X
931 '
935 PRINT "DO YOU WANT [illegible] LOG(X)";
940 INPUT Y$
945 IF Y$="Y" THEN GOTO [illegible]
950 IF Y$="N" THEN GOTO 970
955 GOTO 935
960 X=LOG(X)
961 '
965 ' CALCULATE AND OUTPUT RESULTS
966 '
970 PRINT #P1,
975 PRINT #P1,
980 PRINT #P1,"ESTIMATE OF Y GIVEN X:"
985 PRINT #P1,
990 PRINT #P1,"T OF";Q/2;"=";T
991 '
995 ' DETERMINE Y FROM REGRESSION LINE
996 '
1000 Y=A+B*X
1005 PRINT #P1,"X=";10^X
1010 PRINT #P1,"LOG(X)=";X
1015 PRINT #P1,"Y ESTIMATE=";Y
1016 '
1020 ' GO DETERMINE CONFIDENCE IN Y
1021
1025 GOSUB 4020
1026 GOTO 345
1027 '
1030 ' DETERMINE X WHERE 50% OF PARTS FAIL
1031
1035 X=(5-A)/B
1040 PRINT #P1,
1045 PRINT #P1,
1050 PRINT #P1,"50% OF FAILURES OCCUR AT";10^X;"HOURS"
1055 Y=5
1056
1060 ' GO DETERMINE CONFIDENCE IN RESULTING Y
1061 '
1065 GOSUB 4020
1066 '
1070 ' GET F VALUE TO TEST DATA VARIANCE
1071
1075 PRINT "ENTER F OF ALPHA FOR(1,";N-2;") DEGREES OF FREEDOM";
1080 INPUT F1
1085 PRINT
1086
1090 ' CALCULATE F OF DATA TO COMPARE TO F1
1091
1095 F=(B*[illegible])
1100 PRINT #P1,
```

```
1105 PRINT #P1,
1110 PRINT #P1,"ANALYSIS OF VARIANCE""
1115 PRINT #P1,
1116 '
1120 '  MAKE COMPARISON
1121 '
1125 IF F>F1 THEN GOTO 1145
1130 PRINT #P1,"F=";F;" IS LESS THAN F OF ALPHA(1,";N-2;")=";F1
1135 PRINT #P1,"THEREFORE ACCEPT HO - REJECT THE REGRESSION MODEL"
1140 GOTO 1155
1145 PRINT #P1,"F=";F;" IS GREATER THAN F OF ALPHA(1,";N-2;")=";F1
1150 PRINT #P1,"THEREFORE REJECT HO - DO NOT REJECT THE REGRESSION MODEL"
1155 PRINT "END OF PROGRAM"
1156 '
1160 '  CLOSE PRINT FILES
1161 '
1165 CLOSE 1%
1170 CLOSE 2%
1175 END
2000 '
2005 '                ** SUBROUTINE TO CHANGE DATA **
2010 '
2015 PRINT "CHANGE X";
2020 INPUT N$
2025 IF N$="Y" THEN GOTO 2045
2030 IF N$="N" THEN GOTO 2070
2035 GOTO 2015
2036 '
2040 '  FIND OUT WHICH X TO CHANGE
2041 '
2045 PRINT "ENTER I";
2050 INPUT I
2051 '
2055 '  CHANGE IT
2056 '
2060 PRINT "ENTER X(I)";
2065 INPUT X(I)
2070 PRINT "CHANGE Y";
2075 INPUT N$
2080 IF N$="Y" THEN GOTO 2100
2085 IF N$="N" THEN GOTO 2125
2090 GOTO 2070
2091 '
2095 '  FIND OUT WHICH Y VALUE TO CHANGE
2096 '
2100 PRINT "ENTER I";
2105 INPUT I
2106 '
2110 '  CHANGE IT
2111 '
2115 PRINT "ENTER Y(I)";
2120 INPUT Y(I)
2125 RETURN
3000 '
3005 '                ** SUBROUTINE TO INTERPOLATE PROBITS **
3010 '
3015 '  % VALUES
3016 '
3020 DIM Z(47)
3025 Z(1)=.0107
3030 Z(2)=.0139
3035 Z(3)=.0179
3040 Z(4)=.0228
```

```
3045 Z(5)=.0287
3050 Z(6)=.0359
3055 Z(7)=.0446
3060 Z(8)=.0548
3065 Z(9)=.0668
3070 Z(10)=.0808
3075 Z(11)=.0968
3080 Z(12)=.1151
3085 Z(13)=.1357
3090 Z(14)=.1587
3095 Z(15)=.1841
3100 Z(16)=.2119
3105 Z(17)=.2420
3110 Z(18)=.2743
3115 Z(19)=.3085
3120 Z(20)=.3446
3125 Z(21)=.3821
3130 Z(22)=.4207
3135 Z(23)=.4602
3140 Z(24)=.5000
3141 !
3145 ! CALCULATE OTHER HALF OF TABLE
3146 !
3150 FOR I=25 TO 47
3155 Z(I)=1-Z(48-I)
3160 NEXT I
3165 T1=0
3181 !
3185 ! COMPUTE % FAILURES AT EACH INCREMENT
3186 !
3190 FOR I=1 TO N
3195 T1=Y(I)+T1
3200 Q5=T1/K1
"CUM. FAIL.=";T1;
3202 PRINT #P1,TAB(47);"% CUM. FAIL.=";Q5*100
3203 Y(I)=Q5
3205 NEXT I
3210 I=1
3215 J=1
3216 !
3220 ! SEARCH % VALUES IN TABLE TO FIND TWO VALUES FOR
3225 ! INTERPOLATION
3226 !
3230 IF Y(I)<Z(1) THEN GOTO 3260
3235 IF Y(I)<Z(J) THEN GOTO 3275
3240 J=J+1
3241 !
3245 ! DONE WITH TABLE?
3246 !
3250 IF J<=47 THEN GOTO 3230
3251 !
3255 ! FOR VALUES OUTSIDE TABLE RANGE
3256 !
3260 PRINT "Y(";I;") OUT OF PROBIT RANGE"
3265 GOTO 3340
3266 !
3270 ! COMPUTE PROBIT VALUES TO ACCOMPANY % VALUES FROM TABLE
3271 !
3275 T2=(J*.1)+2.6
3280 T1=((J-1)*.1)+2.6
3281 !
3285 ! FIND SLOPE OF INTERPOLATION LINE
3286 !
```

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```
3290 L=(T2-T1)/(Z(J)-Z(J-1))
3291 !
3295 ! FIND INTERCEPT
3296 !
3300 D1=T1-(L*Z(J-1))
3301 !
3305 ! FIND PROBIT VALUE
3306 !
3310 Y(I)=L*Y(I)+D1
3315 I=I+1
3316 !
3320 ! FINISHED WITH ALL Y'S?
3321 !
3325 IF I<=N THEN GOTO 3215
3330 RETURN
3331 !
3335 ! IN CASE OF ERROR CLOSE PRINT FILES
3336 !
3340 CLOSE 1%
3345 CLOSE 2%
3350 END
4000 !
4005 !                    ** SUBROUTINE TO FIND CONFIDENCE **
4010 !                              INTERVAL FOR Y
4015 !
4020 ! COMPUTE UPPER AND LOWER BOUNDS
4021 !
4025 M=Y-(T*S*(1+(1/N)+(((X-C/N)^2)/S1)))
4030 P=Y+(T*S*(1+(1/N)+(((X-C/N)^2)/S1)))
4031 !
4035 ! PRINT RESULTS
4036 !
4040 PRINT #P1,
4045 PRINT #P1,"THE";1-Q;"CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:"
4050 PRINT #P1,"                 ";M;"<MEAN OF Y/XO<";P;"PROBITS"
 #P1,
4060 RETURN
```

APPENDIX B

STATISTICAL ANALYSIS COMPUTER PRINTOUTS OF LIFE TEST LOG-NORMAL DISTRIBUTIONS

PRECEDING PAGE BLANK NOT FILMED

PART TYPE: MFR. B 4069
SCREEN:1 - NO BURN IN
LIFE TEST:40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 8	FAILURES= 2	CUM. FAIL.= 5	% CUM. FAIL.= 6.66667
HOURS= 16	FAILURES= 2	CUM. FAIL.= 7	% CUM. FAIL.= 9.33333
HOURS= 64	FAILURES= 10	CUM. FAIL.= 17	% CUM. FAIL.= 22.66667
HOURS= 256	FAILURES= 1	CUM. FAIL.= 18	% CUM. FAIL.= 24
HOURS= 1000	FAILURES= 3	CUM. FAIL.= 21	% CUM. FAIL.= 28
HOURS= 2000	FAILURES= 3	CUM. FAIL.= 24	% CUM. FAIL.= 32
HOURS= 4000	FAILURES= 10	CUM. FAIL.= 34	% CUM. FAIL.= 45.33333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 10995.29 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.484138 <MEAN OF Y/XO< 5.515862 PROBITS

ANALYSIS OF VARIANCE:

F= 108.0835 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

ORIGINAL PAGE IS
OF POOR QUALITY

PART TYPE: MFR. B 4069
SCREEN: 2 - 70 DEG C BURN IN
LIFE TEST: 40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 13	CUM. FAIL.= 13	% CUM. FAIL.= 17.33333
HOURS= 8	FAILURES= 1	CUM. FAIL.= 14	% CUM. FAIL.= 18.66667
HOURS= 16	FAILURES= 4	CUM. FAIL.= 18	% CUM. FAIL.= 24
HOURS= 64	FAILURES= 0	CUM. FAIL.= 18	% CUM. FAIL.= 24
HOURS= 256	FAILURES= 3	CUM. FAIL.= 21	% CUM. FAIL.= 28
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 21	% CUM. FAIL.= 28
HOURS= 2000	FAILURES= 3	CUM. FAIL.= 24	% CUM. FAIL.= 32
HOURS= 4000	FAILURES= 14	CUM. FAIL.= 38	% CUM. FAIL.= 50.66667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 75849.9 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.2669 <MEAN OF Y/XO< 5.7331 PROBITS

ANALYSIS OF VARIANCE:

F= 19.16555 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE:MFR. B 4069
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 7	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 8	FAILURES= 0	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 16	FAILURES= 0	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 64	FAILURES= 0	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 256	FAILURES= 2	CUM. FAIL.= 9	% CUM. FAIL.= 12
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 9	% CUM. FAIL.= 12
HOURS= 2000	FAILURES= 6	CUM. FAIL.= 15	% CUM. FAIL.= 20
HOURS= 4000	FAILURES= 2	CUM. FAIL.= 17	% CUM. FAIL.= 22.66667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.1409715E+10 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/X0 IS:
3.052571 <MEAN OF Y/X0< 6.947429 PROBITS

ANALYSIS OF VARIANCE:

F= 15.66381 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

ORIGINAL PAGE IS OF POOR QUALITY

PART TYPE: MFR. B 4069
SCREEN: 1 - NO BURN IN
LIFE TEST: 70 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 4	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 4	FAILURES= 1	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 16	FAILURES= 1	CUM. FAIL.= 6	% CUM. FAIL.= 8
HOURS= 64	FAILURES= [illegible]	CUM. FAIL.= 9	% CUM. FAIL.= 12
HOURS= 256	FAILURES= 2	CUM. FAIL.= 11	% CUM. FAIL.= 14.66667
HOURS= 1000	FAILURES= 43	CUM. FAIL.= 54	% CUM. FAIL.= 72
HOURS= 2000	FAILURES= 2	CUM. FAIL.= 56	% CUM. FAIL.= 74.66667
HOURS= 4000	FAILURES= 3	CUM. FAIL.= 59	% CUM. FAIL.= 78.66666

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 605.3017 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
3.754885 <MEAN OF Y/XO< 6.245115 PROBITS

ANALYSIS OF VARIANCE:

F= 36.55207 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. B 4069
SCREEN: 2 - 70 DEG C BURN IN
LIFE TEST: 70 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 14	CUM. FAIL.= 14	% CUM. FAIL.= 18.66667
HOURS= 8	FAILURES= 0	CUM. FAIL.= 14	% CUM. FAIL.= 18.66667
HOURS= 16	FAILURES= 0	CUM. FAIL.= 14	% CUM. FAIL.= 18.66667
HOURS= 64	FAILURES= 21	CUM. FAIL.= 35	% CUM. FAIL.= 46.66667
HOURS= 256	FAILURES= 3	CUM. FAIL.= 38	% CUM. FAIL.= 50.66667
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 38	% CUM. FAIL.= 50.66667
HOURS= 2000	FAILURES= 1	CUM. FAIL.= 39	% CUM. FAIL.= 52
HOURS= 4000	FAILURES= 8	CUM. FAIL.= 47	% CUM. FAIL.= 62.66667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 653.4605 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.413523 <MEAN OF Y/XO< 5.586477 PROBITS

ANALYSIS OF VARIANCE:

F= 37.78726 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. B 4069
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:70 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 8	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 16	FAILURES= 1	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 64	FAILURES= 3	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
M. FAIL.= 12	% CUM. FAIL.= 16		
HOURS= 1000	FAILURES= 6	CUM. FAIL.= 18	% CUM. FAIL.= 24
HOURS= 2000	FAILURES= 3	CUM. FAIL.= 21	% CUM. FAIL.= 28
HOURS= 4000	FAILURES= 11	CUM. FAIL.= 32	% CUM. FAIL.= 42.66667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 27765.75 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.555573 <MEAN OF Y/XO< 5.444427 PROBITS

ANALYSIS OF VARIANCE:

F= 177.2985 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

ORIGINAL PAGE IS OF POOR QUALITY

PART TYPE: **MFR. B 4069**
SCREEN: 1 - NO BURN IN
LIFE TEST: 125 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 4	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 8	FAILURES= 2	CUM. FAIL.= 6	% CUM. FAIL.= 8
HOURS= 16	FAILURES= 0	CUM. FAIL.= 6	% CUM. FAIL.= 8
HOURS= 64	FAILURES= 3	CUM. FAIL.= 9	% CUM. FAIL.= 12
HOURS= 256	FAILURES= 36	CUM. FAIL.= 45	% CUM. FAIL.= 60
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 45	% CUM. FAIL.= 60
HOURS= 2000	FAILURES= 4	CUM. FAIL.= 49	% CUM. FAIL.= 65.33333
HOURS= 4000	FAILURES= 9	CUM. FAIL.= 58	% CUM. FAIL.= 77.33333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 495.4287 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.105295 <MEAN OF Y/XO< 5.894705 PROBITS

ANALYSIS OF VARIANCE:

F= 63.32523 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. B 4069**
SCREEN:2 - 70 DEG C BURN IN
LIFE TEST:125 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 12	CUM. FAIL.= 12	% CUM. FAIL.= 16
HOURS= 8	FAILURES= 0	CUM. FAIL.= 12	% CUM. FAIL.= 16
HOURS= 16	FAILURES= 12	CUM. FAIL.= 24	% CUM. FAIL.= 32
HOURS= 64	FAILURES= 5	CUM. FAIL.= 29	% CUM. FAIL.= 38.66667
HOURS= 256	FAILURES= 8	CUM. FAIL.= 37	% CUM. FAIL.= 49.33333
HOURS= 1000	FAILURES= 4	CUM. FAIL.= 41	% CUM. FAIL.= 54.66667
HOURS= 2000	FAILURES= 2	CUM. FAIL.= 43	% CUM. FAIL.= 57.33333
HOURS= 4000	FAILURES= 8	CUM. FAIL.= 51	% CUM. FAIL.= 68

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 431.4323 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.617801 <MEAN OF Y/XO< 5.382199 PROBITS

ANALYSIS OF VARIANCE:

F= 106.635 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. B 4069
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:125 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 46	CUM. FAIL.= 46	% CUM. FAIL.= 61.33333
HOURS= 8	FAILURES= 0	CUM. FAIL.= 46	% CUM. FAIL.= 61.33333
HOURS= 16	FAILURES= 6	CUM. FAIL.= 52	% CUM. FAIL.= 69.33333
HOURS= 64	FAILURES= 10	CUM. FAIL.= 62	% CUM. FAIL.= 82.66667
HOURS= 256	FAILURES= 10	CUM. FAIL.= 72	% CUM. FAIL.= 96

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 1.81639 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
3.666272 <MEAN OF Y/XO< 6.333728 PROBITS

ANALYSIS OF VARIANCE:

F= 20.09286 IS GREATER THAN F OF ALPHA(1, 3)= 10.13
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. C 4069
SCREEN:1 NO BURN IN
LIFE TEST:40 DEG C

FAILURE DATA:

HOURS= 256	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 1000	FAILURES= 1	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 2000	FAILURES= 1	CUM. FAIL.= 3	% CUM. FAIL.= 4

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 5327106 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
-4.316704 <MEAN OF Y/XO< 14.3167 PROBITS

ANALYSIS OF VARIANCE:

F= 274.8725 IS GREATER THAN F OF ALPHA(1, 1)= 161.4
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. C 4069
SCREEN: 2 - 70 DEG C BURN IN
LIFE TEST: 40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 8	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 64	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 256	FAILURES= 4	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 2000	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 4000	FAILURES= 1	CUM. FAIL.= 6	% CUM. FAIL.= 8

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.1659067E+09 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
2.894391 <MEAN OF Y/XO< 7.105609 PROBITS

ANALYSIS OF VARIANCE:

F= 29.1328 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. C 4069
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 8	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 16	FAILURES= 2	CUM. FAIL.= 6	% CUM. FAIL.= 8
HOURS= 64	FAILURES= 1	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 256	FAILURES= 1	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 1000	FAILURES= 3	CUM. FAIL.= 11	% CUM. FAIL.= 14.66667
HOURS= 2000	FAILURES= 4	CUM. FAIL.= 15	% CUM. FAIL.= 20
HOURS= 4000	FAILURES= 2	CUM. FAIL.= 17	% CUM. FAIL.= 22.66667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 2549885 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.489834 <MEAN OF Y/XO< 5.510166 PROBITS

ANALYSIS OF VARIANCE:

F= 171.6581 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. C 4069
SCREEN:2 - 70 DEG C BURN IN
LIFE TEST:70 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 8	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 16	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 64	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333

% CUM. FAIL.= 8

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.1644756E+12 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
-4.510406 <MEAN OF Y/XO< 14.51041 PROBITS

ANALYSIS OF VARIANCE:

F= 12.09641 IS GREATER THAN F OF ALPHA(1, 3)= 10.13
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. C 4069
SCREEN: 3 - 125 DEG C BURN IN
LIFE TEST: 70 DEG C

FAILURE DATA:

HOURS= 256	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 1000	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 2000	FAILURES= 0	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 4000	FAILURES= 1	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.2388573E+12 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
-7.653863 <MEAN OF Y/XO< 17.65386 PROBITS

ANALYSIS OF VARIANCE:

F= 27.6256 IS GREATER THAN F OF ALPHA(1, 2)= 18.51
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. C 4069
SCREEN: 1 - NO BURN IN
LIFE TEST: 125 DEG C

FAILURE DATA.

HOURS= 2	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 8	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 16	FAILURES= 0	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 64	FAILURES= 4	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 256	FAILURES= 5	CUM. FAIL.= 13	% CUM. FAIL.= 17.33333
HOURS= 1000	FAILURES= 4	CUM. FAIL.= 17	% CUM. FAIL.= 22.66667
HOURS= 2000	FAILURES= 1	CUM. FAIL.= 18	% CUM. FAIL.= 24

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 105057.8 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.486964 <MEAN OF Y/XO< 5.513036 PROBITS

ANALYSIS OF VARIANCE:

F= 175.6419 IS GREATER THAN F OF ALPHA(1, 5)= 6.61
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. C 4069**
SCREEN: 2 - 70 DEG C BURN IN
LIFE TEST: 125 DEG C

FAILURE DATA:

HOURS= 8	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 1	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 64	FAILURES= 2	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 256	FAILURES= 7	CUM. FAIL.= 11	% CUM. FAIL.= 14.66667
HOURS= 1000	FAILURES= 5	CUM. FAIL.= 16	% CUM. FAIL.= 21.33333
HOURS= 2000	FAILURES= 9	CUM. FAIL.= 25	% CUM. FAIL.= 33.33333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 9581.721 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.591604 <MEAN OF Y/XO< 5.408396 PROBITS

ANALYSIS OF VARIANCE:

F= 406.3059 IS GREATER THAN F OF ALPHA(1, 4)= 7.71
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. C 4069**
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:125 DEG C

FAILURE DATA:

HOURS= 8	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 1	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 64	FAILURES= 0	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 256	FAILURES= 10	CUM. FAIL.= 12	% CUM. FAIL.= 16
HOURS= 1000	FAILURES= 2	CUM. FAIL.= 14	% CUM. FAIL.= 18.66667
HOURS= 2000	FAILURES= 1	CUM. FAIL.= 15	% CUM. FAIL.= 20
HOURS= 4000	FAILURES= 2	CUM. FAIL.= 17	% CUM. FAIL.= 22.66667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 49491.57 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
3.952482 <MEAN OF Y/XO< 6.047518 PROBITS

ANALYSIS OF VARIANCE:

F= 52.50274 IS GREATER THAN F OF ALPHA(1, 5)= 6.61
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. D 741**
SCREEN: 1 - NO BURN IN
LIFE TEST: 40 DEG C

FAILURE DATA:

HOURS= 2 FAILURES= 2 CUM. FAIL.= 2 % CUM. FAIL.= 2.666667
HOURS= 8 FAILURES= 0 CUM. FAIL.= 2 % CUM. FAIL.= 2.666667
HOURS= 16 FAILURES= 0 CUM. FAIL.= 2 % CUM. FAIL.= 2.666667
HOURS= 64 FAILURES= 0 CUM. FAIL.= 2 % CUM. FAIL.= 2.666667
M. FAIL.= 2 % CUM. FAIL.= 2.666667
HOURS= 1000 FAILURES= 0 CUM. FAIL.= 2 % CUM. FAIL.= 2.666667
HOURS= 2000 FAILURES= 6 CUM. FAIL.= 8 % CUM. FAIL.= 10.66667
HOURS= 4000 FAILURES= 2 CUM. FAIL.= 10 % CUM. FAIL.= 13.33333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.2789069E+11 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
-0.2380276 <MEAN OF Y/X < 10.23803 PROBITS

ANALYSIS OF VARIANCE:

F= 6.217214 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. D 741
SCREEN:2 - 70 DEG C BURN IN
LIFE TEST:40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 8	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 64	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 256	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 1000	FAILURES= 1	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 2000	FAILURES= 1	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 4000	FAILURES= 2	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.5177957E+13 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
-0.7886196E-01 <MEAN OF Y/XO< 10.07886 PROBITS

ANALYSIS OF VARIANCE:

F= 13.00401 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
EL

PART TYPE: MFR. D 741
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 8	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 64	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 256	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 2000	FAILURES= 2	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 4000	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.1448615E+17 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
-4.597028 <MEAN OF Y/XO< 14.59703 PROBITS

ANALYSIS OF VARIANCE:

F= 6.180262 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. D 741**
SCREEN:1 - NO BURN IN
LIFE TEST:70 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 2	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 8	FAILURES= 0	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 16	FAILURES= 0	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 64	FAILURES= 1	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 256	FAILURES= 2	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 1000	FAILURES= 1	CUM. FAIL.= 6	% CUM. FAIL.= 8

% CUM. FAIL.= 9.333333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.1169475E+10 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
3.379212 <MEAN OF Y/XO< 6.670788 PROBITS

ANALYSIS OF VARIANCE:

F= 67.52799 IS GREATER THAN F OF ALPHA(1, 5)= 6.61
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. D 741
SCREEN:2 - 70 DEG C BURN IN
LIFE TEST:70 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 8	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 16	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 64	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 256	FAILURES= 4	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 1000	FAILURES= 1	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 2000	FAILURES= 1	CUM. FAIL.= 9	% CUM. FAIL.= 12
HOURS= 4000	FAILURES= 1	CUM. FAIL.= 10	% CUM. FAIL.= 13.33333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.3629153E+09 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
3.546716 <MEAN OF Y/XO< 6.453284 PROBITS

ANALYSIS OF VARIANCE:

F= 41.85142 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. D 741**
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:70 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 8	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 64	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 256	FAILURES= 3	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 2000	FAILURES= 0	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 4000	FAILURES= 1	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.2785381E+10 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
2.634375 <MEAN OF Y/XO< 7.365625 PROBITS

ANALYSIS OF VARIANCE:

F= 30.38031 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. D 741**
SCREEN: 1 - NO BURN IN
LIFE TEST: 125 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 2	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 8	FAILURES= 0	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 16	FAILURES= 0	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 64	FAILURES= 3	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 256	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 1000	FAILURES= 4	CUM. FAIL.= 9	% CUM. FAIL.= 12
HOURS= 2000	FAILURES= 1	CUM. FAIL.= 10	% CUM. FAIL.= 13.33333
HOURS= 4000	FAILURES= 1	CUM. FAIL.= 11	% CUM. FAIL.= 14.66667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.1027198E+08 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.111978 <MEAN OF Y/XO< 5.888022 PROBITS

ANALYSIS OF VARIANCE:

F= 90.74352 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. D 741**
SCREEN:2 - 70 DEG C BURN IN
LIFE TEST:125 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 4	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 8	FAILURES= 1	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 16	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 64	FAILURES= 2	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
M. FAIL.= 9	% CUM. FAIL.= 12		
HOURS= 1000	FAILURES= 2	CUM. FAIL.= 11	% CUM. FAIL.= 14.66667
HOURS= 2000	FAILURES= 3	CUM. FAIL.= 14	% CUM. FAIL.= 18.66667
HOURS= 4000	FAILURES= 1	CUM. FAIL.= 15	% CUM. FAIL.= 20

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.1567998E+08 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.605846 <MEAN OF Y/XO< 5.394154 PROBITS

ANALYSIS OF VARIANCE:

F= 314.6314 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. D 741**
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:125 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 5	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 8	FAILURES= 2	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 16	FAILURES= 0	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 64	FAILURES= 0	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 256	FAILURES= 0	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 2000	FAILURES= 5	CUM. FAIL.= 12	% CUM. FAIL.= 16
HOURS= 4000	FAILURES= 1	CUM. FAIL.= 13	% CUM. FAIL.= 17.33333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.7079793E+12 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
2.000471 <MEAN OF Y/XO< 7.999529 PROBITS

ANALYSIS OF VARIANCE:

F= 12.40021 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. B 741**
SCREEN: 1 - NO BURN IN
LIFE TEST: 40DEG C

FAILURE DATA:

HOURS= 16	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 64	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 256	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 1000	FAILURES= 1	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 2000	FAILURES= 1	CUM. FAIL.= 6	% CUM. FAIL.= 8
HOURS= 4000	FAILURES= 6	CUM. FAIL.= 12	% CUM. FAIL.= 16

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.137502E+09 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
1.343378 <MEAN OF Y/XO< 8.656622 PROBITS

ANALYSIS OF VARIANCE:

F= 12.82717 IS GREATER THAN F OF ALPHA(1, 4)= 7.71
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. B 741**
SCREEN: 1 - NO BURN IN
LIFE TEST: 70 DEG C

FAILURE DATA:

HOURS= 16	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 64	FAILURES= 2	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 256	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 1000	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 2000	FAILURES= 0	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 4000	FAILURES= 8	CUM. FAIL.= 12	% CUM. FAIL.= 16

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.1001815E+08 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
1.548785 <MEAN OF Y/XO< 8.451215 PROBITS

ANALYSIS OF VARIANCE:

F= 12.92958 IS GREATER THAN F OF ALPHA(1, 4)= 7.71
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. B 741**
SCREEN:1 - NO BURN IN
LIFE TEST:125 DEG C

FAILURE DATA:

HOURS= 16	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 64	FAILURES= 2	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 256	FAILURES= 1	CUM. FAIL.= 6	% CUM. FAIL.= 8
HOURS= 1000	FAILURES= 10	CUM. FAIL.= 16	% CUM. FAIL.= 21.33333
HOURS= 2000	FAILURES= 22	CUM. FAIL.= 38	% CUM. FAIL.= 50.66667
HOURS= 4000	FAILURES= 23	CUM. FAIL.= 61	% CUM. FAIL.= 81.33333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 2027.921 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
3.220149 <MEAN OF Y/XO< 6.779851 PROBITS

ANALYSIS OF VARIANCE:

F= 17.71264 IS GREATER THAN F OF ALPHA(1, 4)= 7.71
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. B 2N2222
SCREEN:1 NO BURN IN
LIFE TEST:40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 13	CUM. FAIL.= 13	% CUM. FAIL.= 17.33333
HOURS= 8	FAILURES= 1	CUM. FAIL.= 14	% CUM. FAIL.= 18.66667
HOURS= 16	FAILURES= 0	CUM. FAIL.= 14	% CUM. FAIL.= 18.66667
HOURS= 64	FAILURES= 0	CUM. FAIL.= 14	% CUM. FAIL.= 18.66667
HOURS= 256	FAILURES= 0	CUM. FAIL.= 14	% CUM. FAIL.= 18.66667
HOURS= 1000	FAILURES= 3	CUM. FAIL.= 17	% CUM. FAIL.= 22.66667
HOURS= 2000	FAILURES= 1	CUM. FAIL.= 18	% CUM. FAIL.= 24
HOURS= 4000	FAILURES= 10	CUM. FAIL.= 28	% CUM. FAIL.= 37.33333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.1274257E+09 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
3.380649 <MEAN OF Y/XO< 6.619351 PROBITS

ANALYSIS OF VARIANCE:

F= 8.735123 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. B 2N2222
SCREEN: 2 - 70 DEG C BURN IN
LIFE TEST: 40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 2	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 8	FAILURES= 0	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 16	FAILURES= 2	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 64	FAILURES= 1	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 256	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 2000	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 4000	FAILURES= 18	CUM. FAIL.= 23	% CUM. FAIL.= 30.66667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.2094584E+08 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
2.141132 <MEAN OF Y/XO< 7.858868 PROBITS

ANALYSIS OF VARIANCE:

F= 8.949981 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. B 2N2222
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 7	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 8	FAILURES= 0	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 16	FAILURES= 0	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 64	FAILURES= 5	CUM. FAIL.= 12	% CUM. FAIL.= 16
HOURS= 256	FAILURES= 0	CUM. FAIL.= 12	% CUM. FAIL.= 16
HOURS= 1000	FAILURES= 1	CUM. FAIL.= 13	% CUM. FAIL.= 17.33333
HOURS= 2000	FAILURES= 0	CUM. FAIL.= 13	% CUM. FAIL.= 17.33333
HOURS= 4000	FAILURES= 11	CUM. FAIL.= 24	% CUM. FAIL.= 32

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 8781970 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
3.760194 <MEAN OF Y/XO< 6.239806 FRUBITS

ANALYSIS OF VARIANCE:

F= 21.56617 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. B 2N2222
SCREEN: 1 NO BURN IN
LIFE TEST: 70 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 8	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 16	FAILURES= 2	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 64	FAILURES= 3	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 256	FAILURES= 0	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 2000	FAILURES= 0	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 4000	FAILURES= 1	CUM. FAIL.= 9	% CUM. FAIL.= 12

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.7810345E+10 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
2.963839 <MEAN OF Y/XO< 7.036161 PROBITS

ANALYSIS OF VARIANCE:

F= 23.90478 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. B 2N2222**
SCREEN:2 - 70 DEG BURN IN
LIFE TEST:70 DEG C

FAILURE DATA:

HOURS= 8	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 64	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 256	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 1000	FAILURES= 2	CUM. FAIL.= 3	% CUM. FAIL.= 4

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.5407762E+14 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
-20.18233 <MEAN OF Y/XO< 30.18233 PROBITS

ANALYSIS OF VARIANCE:

F= 3.618488 IS LESS THAN F OF ALPHA(1, 3)= 10.13
THEREFORE REJECT THE REGRESSION MODEL

PART TYPE: **MFR. B 2N2222**
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:70 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 8	FAILURES= 2	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 16	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 64	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 256	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 1000	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 2000	FAILURES= 0	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 4000	FAILURES= 7	CUM. FAIL.= 11	% CUM. FAIL.= 14.66667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.7399464E+10 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
1.536661 <MEAN OF Y/XO< 8.463339 PROBITS

ANALYSIS OF VARIANCE:

F= 12.0436 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. B 2N2222
SCREEN: 1 NO BURN IN
LIFE TEST: 125 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 8	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 64	FAILURES= 1	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 256	FAILURES= 0	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 1000	FAILURES= 2	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 2000	FAILURES= 1	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.350724E+10 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
2.6104 <MEAN OF Y/XO< 7.3896 PROBITS

ANALYSIS OF VARIANCE:

F= 45.69831 IS GREATER THAN F OF ALPHA(1, 5)= 6.61
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. B 2N2222
SCREEN:2 - 70 DEG C BURN IN
LIFE TEST:125 DEG C

FAILURE DATA:

HOURS= 16	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 64	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 256	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 2000	FAILURES= 1	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 4000	FAILURES= 4	CUM. FAIL.= 6	% CUM. FAIL.= 8

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.5076186E+11 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
-7.192048 <MEAN OF Y/XO< 17.19205 PROBITS

ANALYSIS OF VARIANCE:

F= 3.870924 IS LESS THAN F OF ALPHA(1, 4)= 7.71
THEREFORE REJECT THE REGRESSION MODEL

PART TYPE: MFR. B 2N2222
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:125 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 8	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 16	FAILURES= 1	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 64	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 256	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 1000	FAILURES= 1	CUM. FAIL.= 6	% CU FAIL.= 8

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.7293213E+16 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
-2.032947 <MEAN OF Y/XO< 12.03295 PROBITS

ANALYSIS OF VARIANCE:

F= 16.06927 IS GREATER THAN F OF ALPHA(1, 4)= 7.71
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. E 2N2222
SCREEN:1 - NO BURN IN
LIFE TEST:40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 8	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 64	FAILURES= 1	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 256	FAILURES= 0	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 1000	FAILURES= 3	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 2000	FAILURES= 2	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333
HOURS= 4000	FAILURES= 3	CUM. FAIL.= 10	% CUM. FAIL.= 13.33333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.2032666E+08 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/X0 IS:
3.541602 <MEAN OF Y/X0< 6.458398 PROBITS

ANALYSIS OF VARIANCE:

F= 49.86748 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. E 2N2222**
SCREEN:2 - 70 DEG C BURN IN
LIFE TEST:40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 8	FAILURES= 1	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 16	FAILURES= 1	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 64	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 256	FAILURES= 1	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 1000	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 2000	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 4000	FAILURES= 4	CUM. FAIL.= 9	% CUM. FAIL.= 12

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.5353193E+09 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
3.412396 <MEAN OF Y/XO< 6.587604 PROBITS

ANALYSIS OF VARIANCE:

F= 44.70009 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. E 2N2222**
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:40 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 3	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 8	FAILURES= 1	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 16	FAILURES= 1	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 64	FAILURES= 0	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 256	FAILURES= 3	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 1000	FAILURES= 2	CUM. FAIL.= 10	% CUM. FAIL.= 13.33333
HOURS= 2000	FAILURES= 0	CUM. FAIL.= 10	% CUM. FAIL.= 13.33333
HOURS= 4000	FAILURES= 2	CUM. FAIL.= 12	% CUM. FAIL.= 16

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.1198341E+09 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
4.45624 <MEAN OF Y/XO< 5.54376 PROBITS

ANALYSIS OF VARIANCE:

F= 229.0105 IS GREATER THAN F OF ALPHA(1, 6)= 5.99
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. E 2N2222**
SCREEN: 1 - NO BURN IN
LIFE TEST: 70 DEG C

FAILURE DATA:

HOURS= 8	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 1	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 64	FAILURES= 0	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 256	FAILURES= 2	CUM. FAIL.= 4	% CUM. FAIL.= 5.333333
HOURS= 1000	FAILURES= 3	CUM. FAIL.= 7	% CUM. FAIL.= 9.333333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 3331946 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
2.218255 <MEAN OF Y/XO< 7.781745 PROBITS

ANALYSIS OF VARIANCE:

F= 42.4155 IS GREATER THAN F OF ALPHA(1, 3)= 10.13
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. E 2N2222
SCREEN:2 - 70 DEG C BURN IN
LIFE TEST:70 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 8	FAILURES= 0	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 5	CUM. FAIL.= 6	% CUM. FAIL.= 8
HOURS= 64	FAILURES= 0	CUM. FAIL.= 6	% CUM. FAIL.= 8
HOURS= 256	FAILURES= 0	CUM. FAIL.= 6	% CUM. FAIL.= 8
HOURS= 1000	FAILURES= 5	CUM. FAIL.= 11	% CUM. FAIL.= 14.66667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 255329.8 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
2.050675 <MEAN OF Y/XO< 7.949325 PROBITS

ANALYSIS OF VARIANCE:

F= 13.2205 IS GREATER THAN F OF ALPHA(1, 4)= 7.71
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: MFR. E 2N2222
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:70 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 8	FAILURES= 1	CUM. FAIL.= 2	% CUM. FAIL.= 2.666667
HOURS= 16	FAILURES= 6	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 64	FAILURES= 0	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 256	FAILURES= 0	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 1000	FAILURES= 7	CUM. FAIL.= 15	% CUM. FAIL.= 20
HOURS= 2000	FAILURES= 3	CUM. FAIL.= 18	% CUM. FAIL.= 24

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 63443.04 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
3.677836 <MEAN OF Y/XO< 6.322164 PROBITS

ANALYSIS OF VARIANCE:

F= 31.44068 IS GREATER THAN F OF ALPHA(1, 5)= 6.61
THEREFORE DO NOT REJECT THE REGRESSION MODEL

PART TYPE: **MFR. E 2N2222**
SCREEN:2 - 70 DEG C BURN IN
LIFE TEST:125 DEG C

FAILURE DATA:

HOURS= 8	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 16	FAILURES= 2	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 64	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 256	FAILURES= 0	CUM. FAIL.= 3	% CUM. FAIL.= 4
HOURS= 1000	FAILURES= 2	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 0.1230537E+10 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/XO IS:
-5.321065 <MEAN OF Y/XO< 15.32106 PROBITS

ANALYSIS OF VARIANCE:

F= 6.185773 IS LESS THAN F OF ALPHA(1, 3)= 10.13
THEREFORE REJECT THE REGRESSION MODEL

PART TYPE: MFR. E 2N2222
SCREEN:3 - 125 DEG C BURN IN
LIFE TEST:125 DEG C

FAILURE DATA:

HOURS= 2	FAILURES= 1	CUM. FAIL.= 1	% CUM. FAIL.= 1.333333
HOURS= 8	FAILURES= 4	CUM. FAIL.= 5	% CUM. FAIL.= 6.666667
HOURS= 16	FAILURES= 3	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 64	FAILURES= 0	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 256	FAILURES= 0	CUM. FAIL.= 8	% CUM. FAIL.= 10.66667
HOURS= 1000	FAILURES= 2	CUM. FAIL.= 10	% CUM. FAIL.= 13.33333

SAMPLE SIZE= 75

50% OF FAILURES OCCUR AT 923042.8 HOURS

THE 0.95 CONFIDENCE INTERVAL FOR THE MEAN OF Y/X0 IS:
1.250765 <MEAN OF Y/X0< 8.749235 PROBITS

ANALYSIS OF VARIANCE:

F= 7.273718 IS LESS THAN F OF ALPHA(1, 4)= 7.71
THEREFORE REJECT THE REGRESSION MODEL

APPENDIX C

DETAILED FAILURE ANALYSIS RESULTS

C.1 LIFE TEST FAILURES

C.1.1 74LS194 (MANUFACTURER A)

Six parts submitted to failure analysis. All retested good.

TABLE C-1 Summary of 74LS194 Failure Analysis Results

	Screen 1 No Burn-in	Screen 2 70°C Burn-in	Screen 3 125°C Burn-in
40° Life Test		4000 Hours: Retest Good	4000 Hours: Retest Good 4000 Hours: Propagation delay, could not find cause.
70°C Life Test		8 Hours: Retest Good	
125°C Life Test	2 Hours: Retest Good		2000 Hours: Retest Good

C.1.2 CMOS 4069 (Manufacturer B)

Total Number of Failures	416	
Number of Failures Analyzed	17	See Table C-2
o Open Metal - Ground or VCC	11	See Figure C-1
o Channelling	4	
o Kirkendall Voiding	1	See Figure C-2
o Plastic Burned	1	See Figure C-3

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TABLE C-2 Summary of Manufacturer B CMOS 4069 Failure Analysis Results

	Screen 1 No Burn-in	Screen 2 70°C Burn-in	Screen 3 125°C Burn-in
40°C Life Test	64 Hours: Ground Metal Burned Open (Figure C-1) 4000 Hours: Channelling	2 Hours: Ground and VCC Metal Burned Open 4000 Hours: Ground Metal Burned Open	4000 Hours: Package Cracked Open. All leads vaporized (Figure C-3)
70°C Life Test	1000 Hours: Channelling	2 Hours: Ground Metal Burned Open 64 Hours: VCC Wire Burned Open 4000 Hours Ground Metal Burned Open	4000 Hours: Ground Metal Burned Open
125°C Life Test	64 Hours: Channelling 256 Hours: Kirkendall Voiding on VCC (Figure C-2) 1000 Hours: Channelling 4000 Hours: Ground Metal Burned Open	2 Hours: Ground Metal Burned Open 16 Hours: Ground Metal Burned Open 4000 Hours: Ground & VCC Metal Burned Open	

375X

Figure C-1   CMOS 4069 (Mfr. B) Typical Burned Ground Metallization Failure

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Figure C-2   CMOS 4069 (Mfr. B) Kirkendall Voiding Failure

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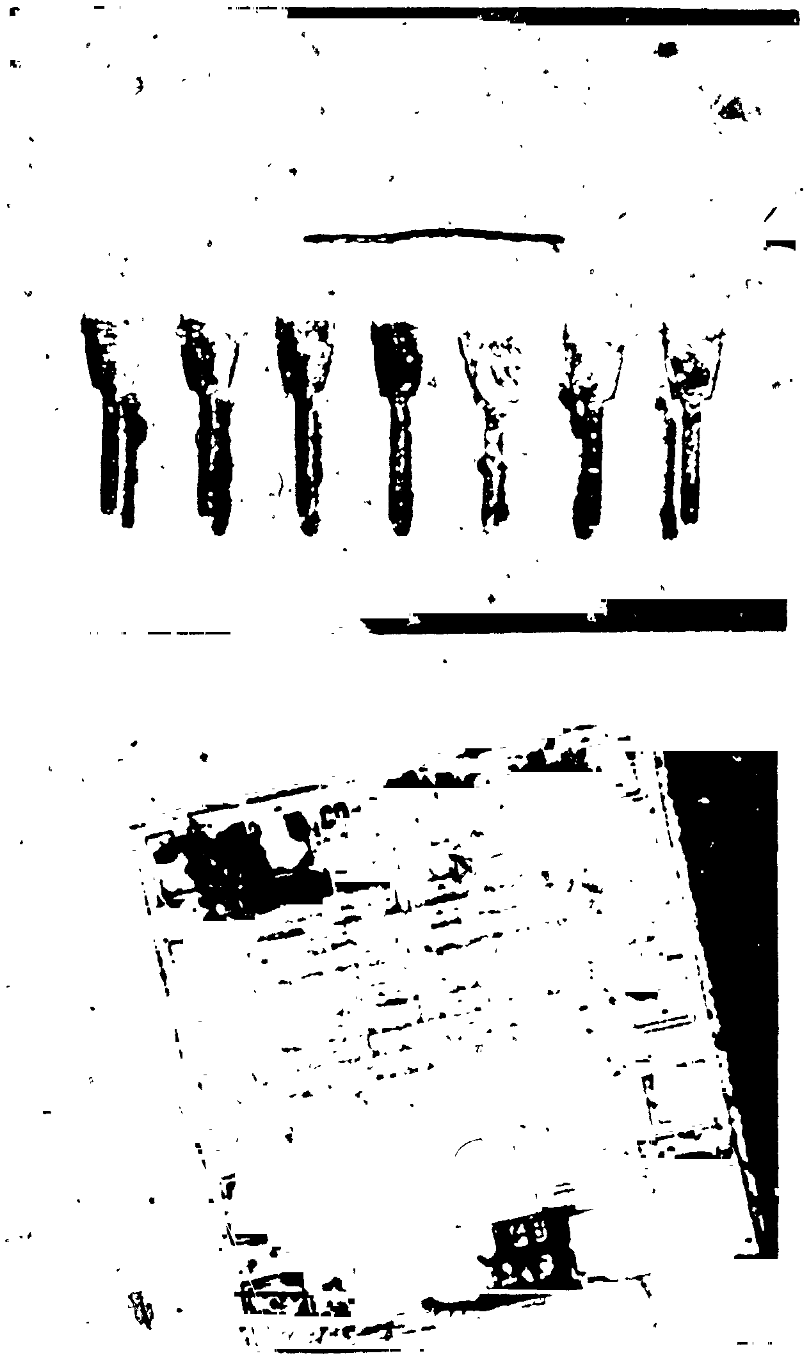

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75X

Figure C-3 CMOS 4069 (Mfr. B) Cracked Package, Leads Vaporized

C.1.3 CMOS 4069 (Manufacturer C)

Total Number of Failures	101	
Number Analyzed	9	(See Table C-3)
o Open Metal-Ground or VCC	4	(See Figure C-4)
o Channelling	4	
o Burned Package	1	

TABLE C-3 Summary of CMOS 4069 (Manufacturer C) Failure Analysis Results

	Screen 1 No Burn-in	Screen 2 70°C Burn-in	Screen 3 125°C Burn-in
40°C Life Test		256 Hours: Channelling	2 Hours: VCC Metal Burned Open 1000 Hours: Channelling 2000 Hours: Ground and VCC Metal Migration (Figures C-5, C-6)
70°C Life Test	2000 Hours: Channelling		
125°C Life Test	256 Hours: Channelling	256 Hours: 2 Gate Inputs Open 1000 Hours: VCC Metal Burned Open (Figure C-4) 2000 Hours: Plastic Burned	

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Figure C-4 CMOS 4069 (Mfr C) Typical Burned Vcc Metallization Failure

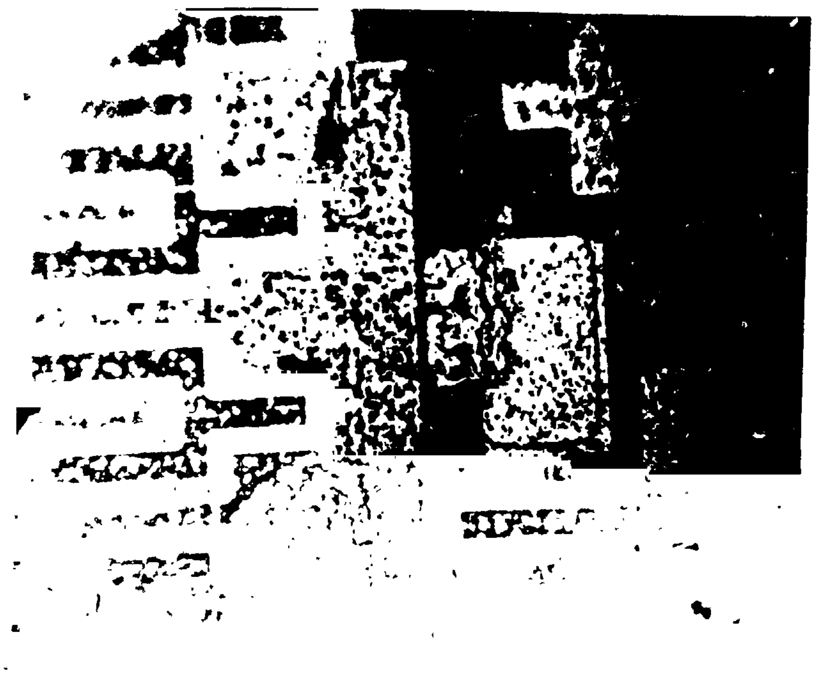

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Figure C-5 CMOS 4069(Mfr C) Metal Migration Failure Near Ground Lead

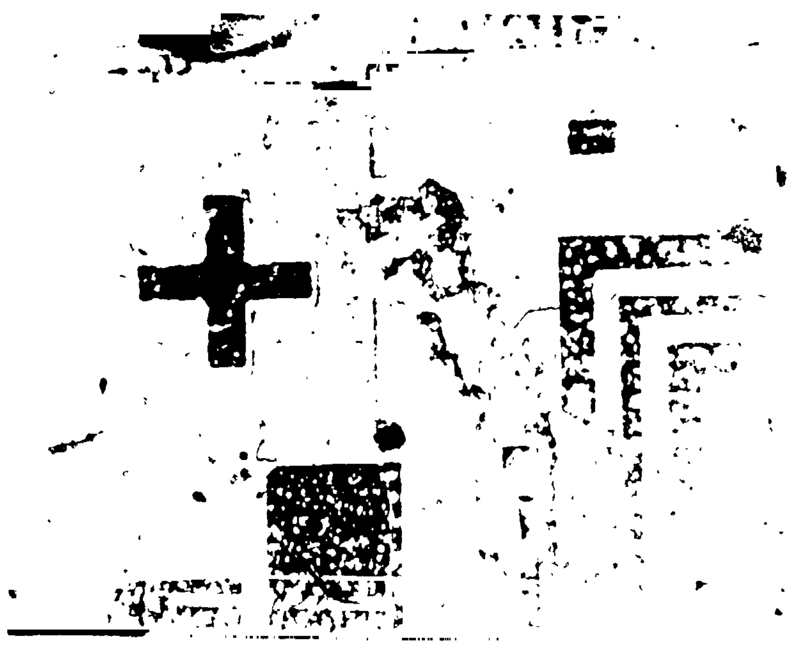

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Figure C-6 CMOS 4069 (Mfr. C) Metal Migration Near Vcc Lead

C.1.4 Linear 741 Op Amp (Mfr. B)

Total Number of Failures	310	
Number Analyzed	9	(See Table C-3)
o Retest good after cleaning leads	8	
o Burned Metal on V+	1	(See Figure C-7)

TABLE C-4 Summary of 741 Op Amp (Manufacturer B) Failure Analysis Results

	Screen 1 No Burn-in	Screen 2 70°C Burn-in
40°C Life Test	16 Hours: Retest Good	1000 Hours: Retest Good, but Marginal Open Loop Gain 2000 Hours: Retest Good, but Marginal Open Loop Gain
70°C Life Test	64 Hours: V+ Metal Burned Open (Figure C-7)	256 Hours: Retest Good, but Marginal Offset Voltage
125°C Life Test	16 Hours: Open Loop Gain Slightly Below Limit 1000 Hours: Retest Good 2000 Hours: Retest Good	64 Hours: Retest Good

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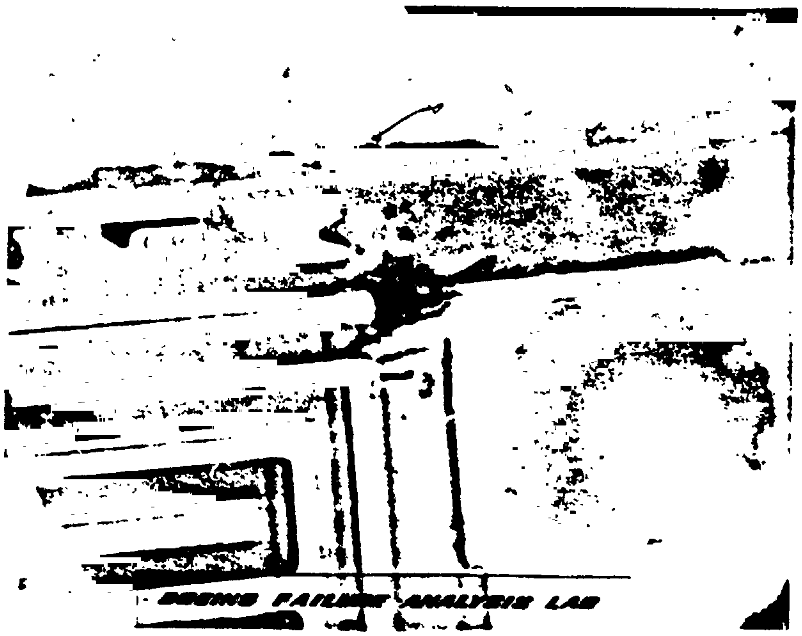

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Figure C-7 Linear 741 Op Amp (MFR. B) Burned V_{cc} Metallization Failure

C.1.5 Linear 741 Op Amp (Mfr. D)

Total Number of Failures	71
Number Analyzed	10
o Retest good	10

TABLE C-5 Summary of 741 Op Amp (Manufacturer D) Failure Analysis Results

	Screen 1 No Burn-In	Screen 2 70^oC Burn-In	Screen 3 125^oC Burn-In
40^o Life Test	2000 Hours: Retest Good		
70^oC Life Test		2 Hours: Retest Good 256 Hours Retest Good	256 Hours: Retest Good
125^oC Life Test	64 Hours: Retest Good 1000 Hours: Retest Good	2 Hours: Retest Good 2000 Hours: Retest Good	2 Hours: Retest Good 2000 Hours: Retest Good

C.1.6 2N2222 Transistor (Manufacturer B)

Number Failed	115
Number Analyzed	9
o Retest good	3
o Channelling	4
o Metal Migration	1 Plastic (Figure C-8) 1 Hermetic (Figure C-9)

TABLE C-6 Summary of 2N2222 Transistor (Manufacturer B) Failure Analysis Results

	Screen 1 No Burn-In	Screen 2 70°C Burn-In	Screen 3 125°C Burn-In
40° Life Test	2 Hours: Retest Good 1000 Hours: Channelling		64 Hours: Channelling
70°C Life Test	2 Hours: Retest Good 64 Hours Channelling		1000 Hours: Channelling
125°C Life Test	1000 Hours: Retest Good	2000 Hours: Gold Migration along metallization Hermetic Part (Figure C-9)	2 Hours: Metal Migration Burned Metallization NearEmitter Bond (Figure C-8)

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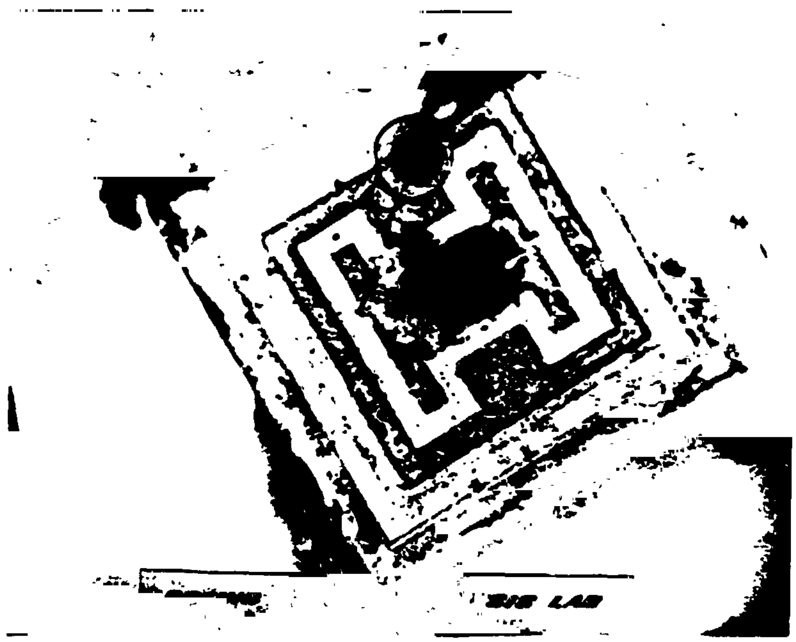

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Figure C-8   2N2222 Transistor (Mfr. B) Metal Migration and Burned Metal

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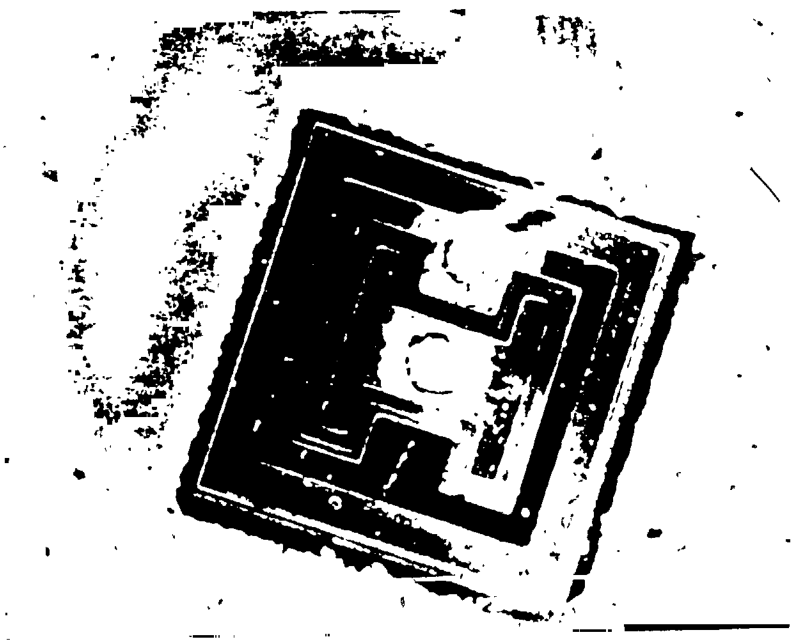

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Figure C-9 2N2222 Transistor (Mfr. B - Hermetic Part) Metal Migration Failure

C.1.7 2N2222 Transistor (Manufacturer E)

Total Number of Failures		115
Number of Failures Analyzed		13 Plastic
		2 Hermetic
o	Channelling	10 Plastic
		1 Hermetic
o	Retest good	2 Plastic
o	Catastrophic	1 Plastic (Figure C-10)
		1 Hermetic (Figure C-11)

TABLE C-7 Summary of 2N2222 Transistor (Manufac⁴ ımer E) Failure Analys s Results

	Screen 1 No Burn-In	Screen 2 70°C Burn-In	Screen 3 125°C Burn-In
40°C Life Test	1000 Hours: Channelling	256 Hours: Channelling	2 Hours: Channelling 256 Hours (Hermetic) Channelling 1000 Hours: (Hermetic) Catastrophic (Figure C-11)
70°C Life Test	1000 Hours: Channelling	16 Hours Channelling 1000 Hours Retest Good	16 Hours: Channelling 1000 Hours: Channelling 2000 Hours: Catastrophic (Figure C-10)
125°C Life Test	16 Hours: Retest Good	1000 Hours: Channelling	8 Hours: Channelling 16 Hours: Channelling

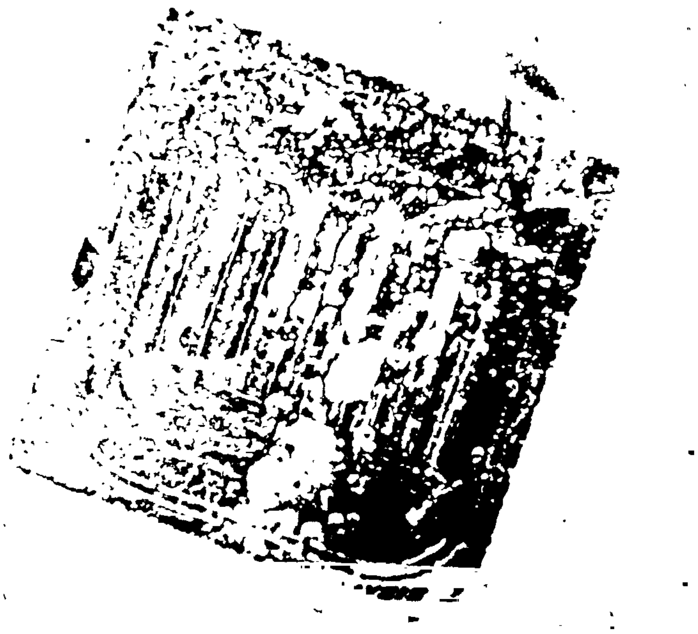

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Figure C-10 2N2222 Transistor (Mfr. E) Catastrophic Failure

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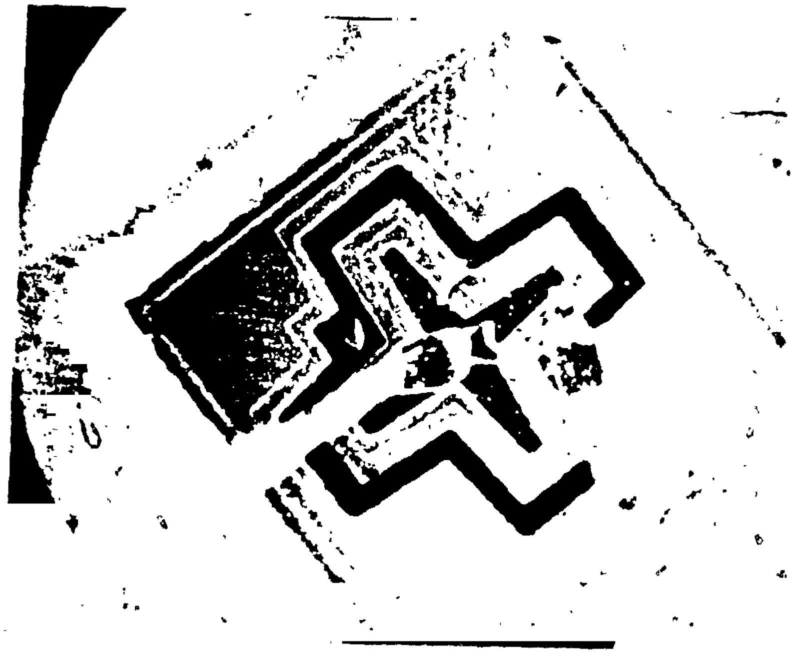

150X

Figure C-11 2N2222 Transistor (Mfr. E - Hermetic Part). 2 Megohm Base-Emitter Short