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D01153

Distr.
LIMITED

ID/WG.62/7
25 May 1970

ORIGINAL: ENGLISH

United Nations Industrial Development Organization

Symposium on Maintenance and Repair in Developing Countries

Duisburg, Federal Republic of Germany, 10-17 November 1970

RELIABILITY AND MAINTAINABILITY CONSIDERATIONS FOR DEVELOPING COUNTRIES INTERESTED IN THE MANUFACTURE OF LOW COST RADIO AND TELEVISION RECEIVERS

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Organised in co-operation with the German Foundation for Developing Countries and the Association of German Machinery Manufacturers (VDMA).

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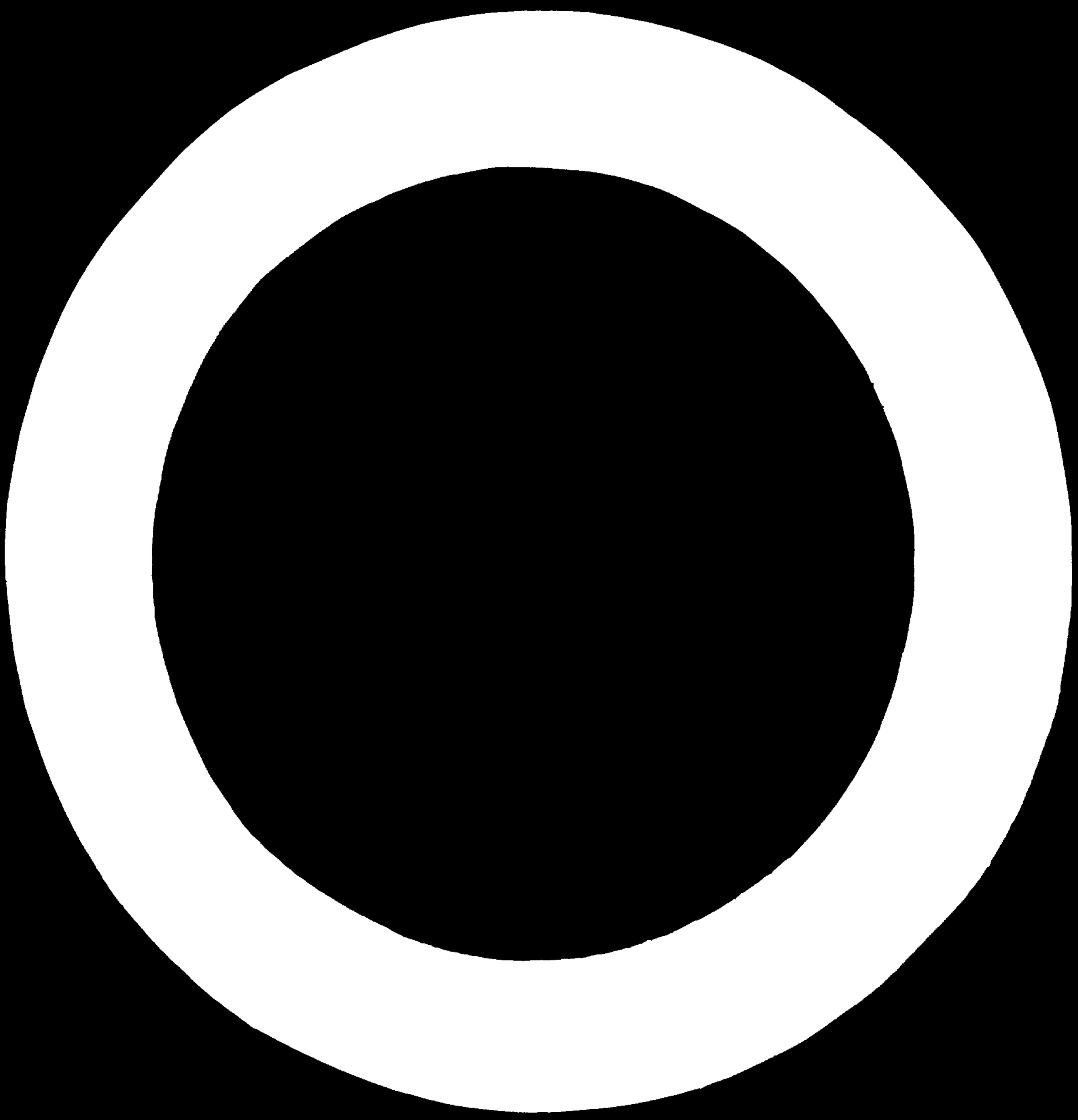


RELIABILITY AND MAINTAINABILITY CONSIDERATIONS FOR DEVELOPING COUNTRIES INTERESTED IN THE MANUFACTURE OF LOW COST RADIO AND TELEVISION RECEIVERS

SECTION I

INTRODUCTION

The developing countries are presently in a difficult position with regard to the reliability and maintainability of low cost radio and television receivers. This is primarily because of three facts:

1. Lack of trained people
2. Need to produce low cost receivers
3. Rapidly advancing technology

The lack of sufficient trained personnel make it imperative that the receivers have long failure free lives. This means that the design must be optimum, the craftsmanship flawless and the parts of high quality. These items tend to raise the cost of receivers and therefore must be carefully balanced against the necessity of producing low cost receivers that can be afforded by the market that this UNIDO program is aimed at, namely the general population of the developing nations.

The problem is further compounded by the rapidly advancing technology from tubes and transistors through complex integrated circuits. Other parts are also changing but not as dramatically. Some changes are to reduce costs and some to improve quality, and some do both. However, in any case changes can affect reliability and maintainability by altering the basic failure mechanisms for the devices.

The problem of selecting the lowest cost parts, design etc. that will do the job is a tough enough problem for developed countries, but for developing countries this task borders on the impossible. In order to succeed in producing the lowest cost radio and television receivers that will do the job, reliability and maintainability principles and practices must be employed.

Some basic areas of reliability and maintainability concerning the manufacture of low cost radio and television receivers along with some suggestions for future courses of action will be covered in the following sections.

SECTION II

BASIC RELIABILITY AND MAINTAINABILITY CONSIDERATIONS

2.1 REQUIRED RELIABILITY

In order to make the proper "trade-off" between original cost of the receiver, the performance that will satisfy most users and the maintenance resources available certain basic calculations must be made.

Perhaps the best place to start is by predicting the reliability of a receiver or receivers that will meet the performance specifications set up by UNIDO or some other acceptable source. This is done by obtaining a list of failure rates for the individual piece parts making up the receiver. Such a list is shown in Table I. The failure rates given are expressed in the probable number of failures for a part type in one million hours of operation. The assumption for the data in Table I is that the parts are of a good commercial quality and the receivers operated in a climate about that of the south temperate or north torrid zones. Adjustments must be made in the failure rates for changes in operating environment and part quality. If no other data is available then predictions can be made with that data supplied in Table I. As more experience is gained with parts and operating conditions more accurate failure rates can be generated. This is an iterative process of predicting, checking the prediction against the receiver performance and using the new failure rates for the next prediction.

TABLE I

Failure Rates of Typical Parts Used for Radio and Television Receivers

Part Type	Failure per 10^6 hours
Capacitors	
Ceramic	1.10
Electrolytic	1.65
Foil, paper or plastic	.25
Mica	.83
Tantalum	1.10
Variable, air	1.63
Electron Tubes	
Cathode Ray (TV PICTURE)	20.00
Receiving	11.00
Inductors	.24
Lamps	
Incandescant	32.00
Neon	11.00
Resistors	
Film	.29
Composition	.17
Wire Wound	1.65
Variable	2.20
Diodes	
Germanium	3.30
Selenium	3.30
Silicon	1.20
Zener	1.65
Transistors	
Germanium	6.60
Silicon	2.80
Switches, per contact set	1.75
Transformers	.34
Speakers	1.72
Integrated Circuits	4.00

An example of a prediction for a hypothetical 7 transistor receiver is shown in Table 2. All of the parts are listed along with the number of times each is used. Then using Table 1 - the expected number of failure for each part type for each million hours of operation is obtained and recorded in column 3. To determine the failure rate for each part type column 2 (the number of times a part is used) is multiplied by column 3 (the failure rate per part type) and the product listed in column 4. The failure rate for the receiver is determined by summing column 4. In this case the expected failure rate for the hypothetical receiver would be 62.55 failures in one million hours of operation.

The usual method of expressing the reliability of a receiver is in terms of "mean time between failures" (MTBF). This is simply the reciprocal of the failure rate, that is, one million hours divided by 62.55 failures per million hours of operation or a 15,987 hour MTBF.

For most receivers this MTBF would be sufficient from the users standpoint. The question of adequately servicing the failed receivers must be investigated. Figure 1 is a graph of expected failures per receiver per year for various MTBF's and various average daily usage. For the above example the average failure per year for an average usage of four hours per day would be .1 failures. If the area being serviced had 100,000 receivers then there would be 10,000 failures not counting receivers damaged by mishandling or accident. Making the further assemption that the average serviceman would be available 250 days a year, then 40 failures a day would be the service load for the area. An experienced man could service one receiver per day and therefore 40 servicemen would be required for the hypothetical case discussed above.

The foregoing illustration serves to show the general techniques used to determine the required reliability of a given receiver for a given set of conditions. Such an analysis serves to show if more

TABLE II

Reliability Prediction for a Hypothetical 7 Transistor Receiver

Part Type	Number used	Failure Rate	Failure Rate Part Type
Capacitors, Electrolytic	4	1.65	6.60
Capacitors, Foil	25	.25	6.25
Capacitors, Mica	4	.83	3.32
Capacitors, Variable Air	1	1.63	1.63
Resistors, Composition	24	.17	4.08
Resistors, Variable	3	2.20	6.60
Coils	3	.24	.72
Diode, Silicon	8	1.20	9.60
Transistors, Silicon	7	2.80	19.60
Speakers	1	1.72	1.72
Transformers	1	.34	.68
Switches (contact sets)	1	1.75	1.75
		TOTAL	62.55

$$MTBF = \frac{10^6}{62.55} = 15{,}987 \text{ hours}$$

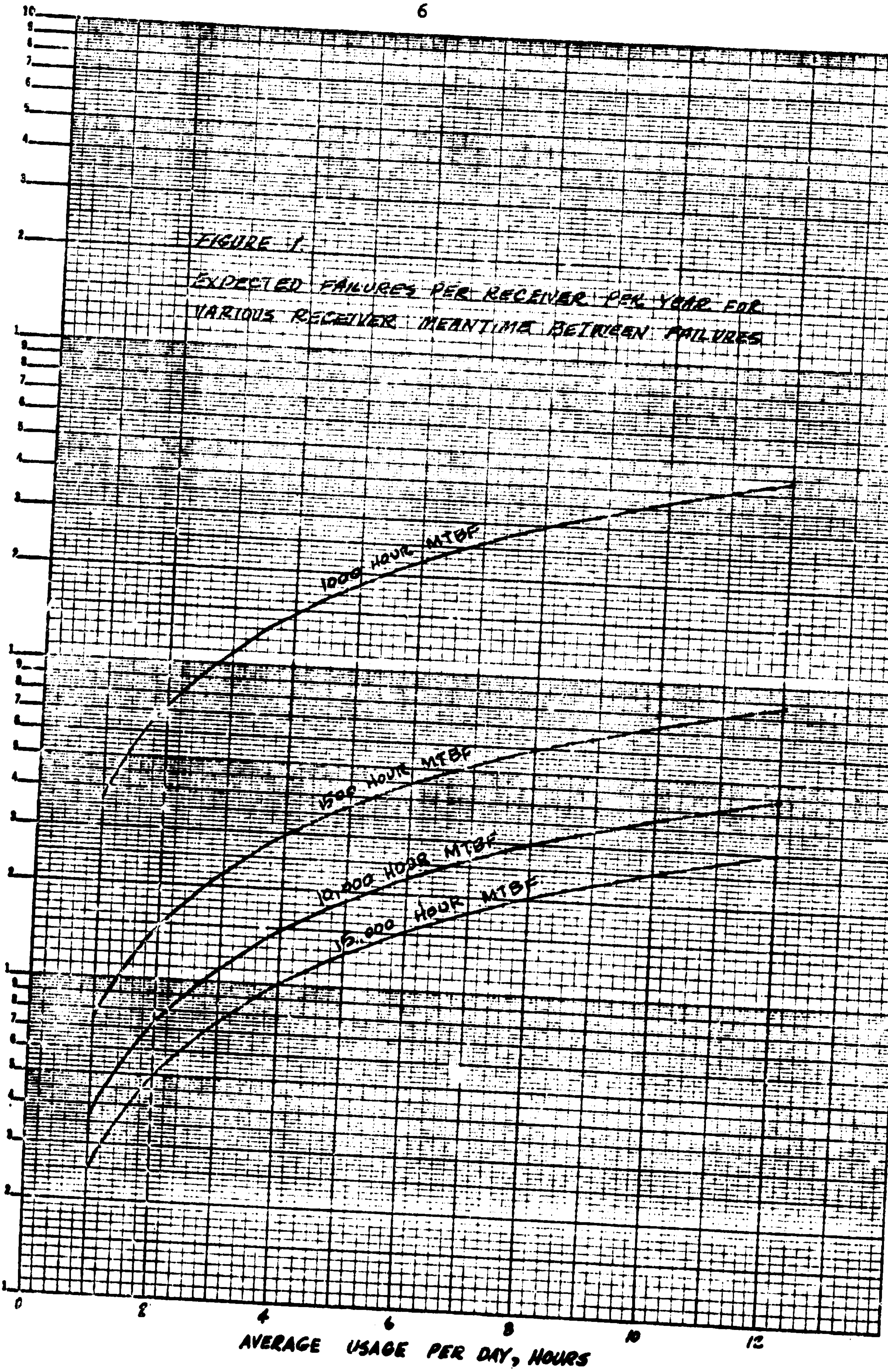


FIGURE 1.
EXPECTED FAILURES PER RECEIVER PER YEAR FOR VARIOUS RECEIVER MEANTIME BETWEEN FAILURES

servicemen or higher quality parts will be needed or if it is possible to lower the quality of some if the parts to decrease the cost and thus make the receiver available to more people.

2.2 REQUIRED MAINTAINABILITY

The two major problems of maintainability for low cost radio and television receivers are:

1. Shortage of adequately trained servicemen
2. Adequate inventory of spare parts

The shortage of trained servicemen was referred to in the previous section on reliability requirements. While good maintenance manuals do aid servicing there appears to be no easy alternative to properly trained servicemen. At present it appears that the trade off of reliability versus servicing must be made in favor of reliability for developing countries in the immediate future.

2.2.1 Method of economically stocking spare part.

A system has been developed whereby unskilled personnel, using simple charts and tables, can select the number of spare parts required to support a given product in a given location.

The detailed method of programming a digital computer to generate the charts and tables is presented below for general background material. Information is generated for various confidence limits, operating times and failure rates. Typical cases are presented for the use of these charts and tables. These include:

1. Selection of minimum spares requirements for a given program.
2. Determination of critical spares after program has been running for some time. Basically this operation is a check on original failure rate assumptions in time to take corrective action before a system is out of service due to the lack of a spare part.
3. Action to be taken if a spare part is determined to be critical.

In the last decade the method of predicting reliability using failure rates of individual piece parts has grown from an experimental toy to a standard tool in systems design and development. Since one step in the prediction of reliability results in establishing the expected failures for a system in a given time period, it would seem logical to tie the spare parts requirements to the same basic method. Therefore, the method outlined below was originated which would make use of component failure-rate data to calculate spare parts list for any given receiver.

In the process of developing the subroutines necessary for overall program, a series of charts were produced which appeared to be useful tools in the solution of certain spare parts problems. These charts are useful, not because of any basically new material, but as a result of the form in which the material is presented. They allow unskilled personnel to prepare a spare parts list, and, after the program has been running for a period of time, to determine which spares are critical.

2.2.2 Computer Program

The charts were developed while generating a subroutine to find the minimum number of spares required to meet some pre-determined confidence level, given the operating time and failure rate of the item in question. The failure times for component parts of relatively complex systems are generally found to be exponentially distributed and, therefore, the Poisson Formula would apply.

$$Pn = \frac{\left(\frac{t}{\bar{T}}\right)^n}{n\,!} \quad e^{-\left(\frac{t}{\bar{T}}\right)}$$

Where Pn = probability of having n failures in time t

$\bar{T}$ = mean-time-between-failures

t = operating time

Since failure rate, as opposed to mean-time-between-failures, is generally easier to handle, we can, by using the equation

$$\text{Failure rate} = \lambda = \frac{1}{\bar{T}}$$

redefine the expression for Pn as follows:

$$Pn = \frac{(\lambda \times t)^n}{n!} e^{-(\lambda \times t)}$$

where as before

Pn = probability of having n failures in time t

t = operating time

and

λ = failure rate

Now define the cumulative probability Pc (r) as the probability of having r or <u>less</u> failure in time t.

$$Pc\ (r) = \sum_{n=0}^{r} Pn$$

Since Pc (r) is the probability of having the number r or less failures of a particular item with a given failure rate during the time interval t, this also becomes the probability of having adequate replacement parts available if at the beginning of the period there were r replacement parts for this particular item in stock. In other words, if a desired cumulative probability is given for a particular item, the number of pieces needed for spares can be determined by summing the values of the individual probabilities of failures until this sum is equal to or greater than the desired cumulative probability. The current working value of n will then be the number of items which must appear as spares at the beginning of some time interval t to ensure the desired part availability. The flow chart shown in Figure 2 and described below was used to generate the data for the charts.

Box 1: Input data to program is entered. λ is the failure rate per million hours, t is the operating time in months Pl, is the desired probability or confidence level for the chart being generated.

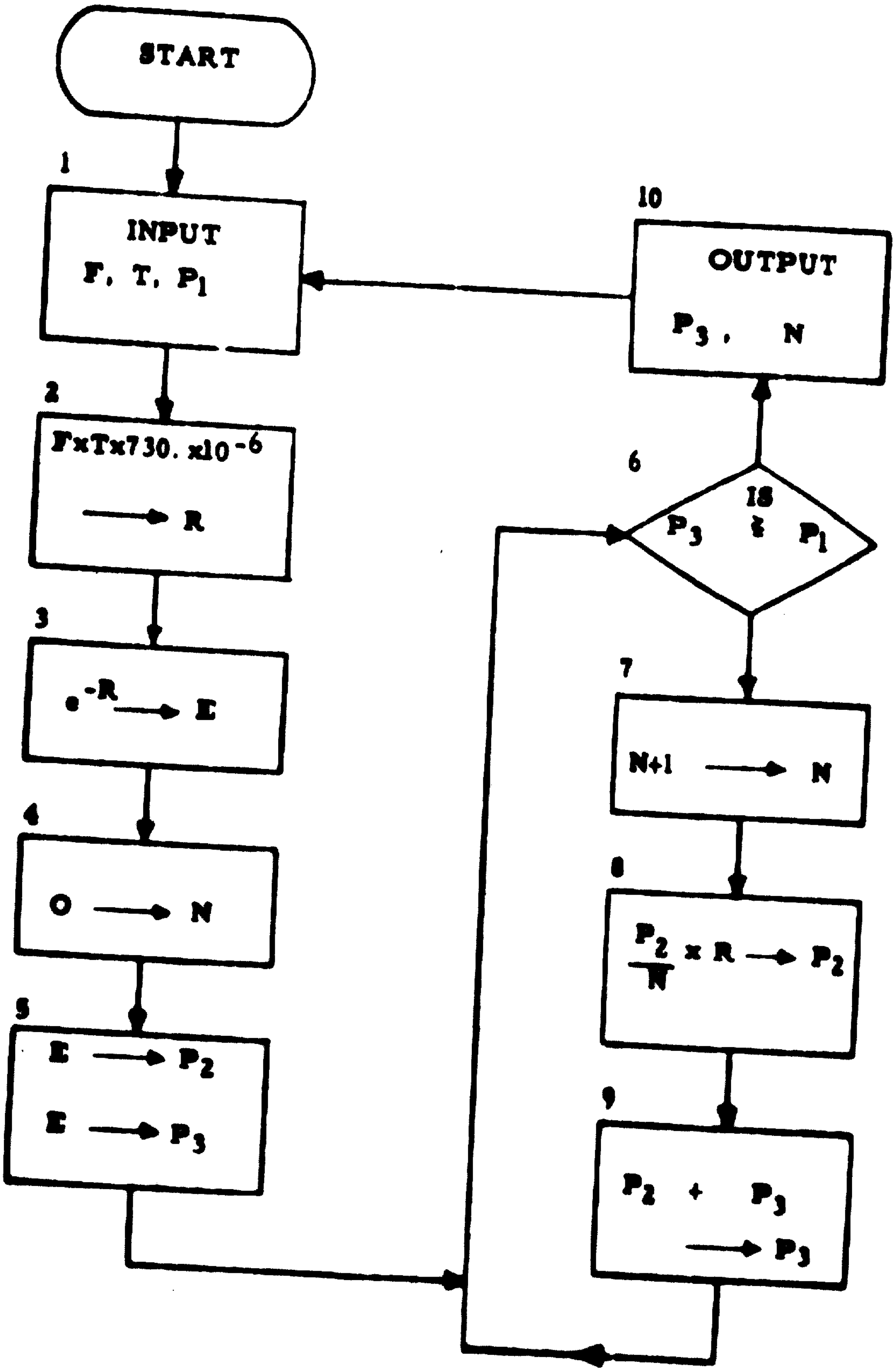


FIGURE 2

PROGRAM FLOW CHART

Box 2: The ratio $\frac{t}{\bar{T}} = \lambda\ t$ is calculated. The constant $730. \times 10^{-6}$ converts time in months to time in hours and adjusts failure rate per million hours to failure rate per hour.

Note: The number of hours per month is taken as 730.

Box 3: The exponential $e^{-(\lambda\ t)}$ is calculated.

Box 4: N, the number of spares required, is initialized to zero.

Box 5: P2, the probability of having N failures, and P3, the probability of having N or less failures, are initizlized to the value of the exponential.

Box 6: If the cumulative probability P3 is greater than or equal to the desired probability, the results are printed. If not, the next iteration is executed.

Box 7: Increment N by one

Box 8: Compute a new value for P2, the probability of having N failures.

Box 9: Compute a new value for P3, the probability of having N or less failures.

Box 10: The probability of having N or less failures, P3 and N are printed.

The only subroutine needed to execute the program is an exponential routine. Since the value of the exponential may fall into a large range, a subroutine, which will maintain sufficient accuracy throughout this range, is required. A suggestion for computing the anti-logarithm is to use a Hastings Approximation[1] for 10^x. The argument is initially multiplied by log e and then divided into an integral and a fractional part. The integral part becomes the characteristic of the result: the fractional portion is evaluated in the polynomial to produce the mantissa. When the argument of the function is positive, the error in the result for an eight digit mantissa does not exceed one in the last digit of the mantissa. When the argument is negative e^x is evaluated as $\frac{1}{e^{|x|}}$ the limit of error is one in the next to last digit of the mantissa because of the additional truncation that may occur when taking the reciprocal.

The following example shows how one point for the 12 month curve of the 99% confidence level was obtained.

__Sample Problem__

Box 1 = 30. Failures/million hours
t = 12 months
P1 = .99 confidence level
Box 2 R = .262800
Box 3 E = .768896
Box 4 N = 0
Box 5 P2 = .768896
P3(0) = .768896

Box 6 P3(0) is not greater than P1
Box 7 N - 1
Box 8 .202066
Box 9 .970962

Box 6 P3(1) is not greater than P1
Box 7 N = 2
Box 8 .026551
Box 9 .997513

Box 6 P3(2) is greater than P1

Box 10 P3(2) = .997513

N = 2

The charts for 50, 75, 90, 95 and 99% confidence levels were plotted and appear in Figures 3 through 7.

2.2.3 Use of Charts to Determine Spares

The charts presented in the preceding section were developed to allow unskilled personnel to perform two basic operations associated with spare parts control. The first operation is used to determine the number of spare parts required to support a program for a specified period of time at a specified level of confidence. The confidence level is the probability that there will be adequate spares for the specified period of time. The second operation is used to determine the critical spares after the program has been running for some time. Both of these operations make use of the failure rates of the parts making up the system.

Table I presents a set of failure rates that has given satisfactory results. However, any set of failure rates (based on constant failure rate assumption) that has proven satisfactory for predicting reliability could be used in conjunction with the spare parts charts.

Certain items may have predictable wearout life which is shorter than the expected operating time of the equipment under consideration. The replacement parts required due to normal wearout should be added to the spares complement determined by using the spare parts charts.

Requirements determined by these charts need not be confined to piece parts. Spares for any item (from piece part to complete system) which has a random failure pattern can be determined using the charts.

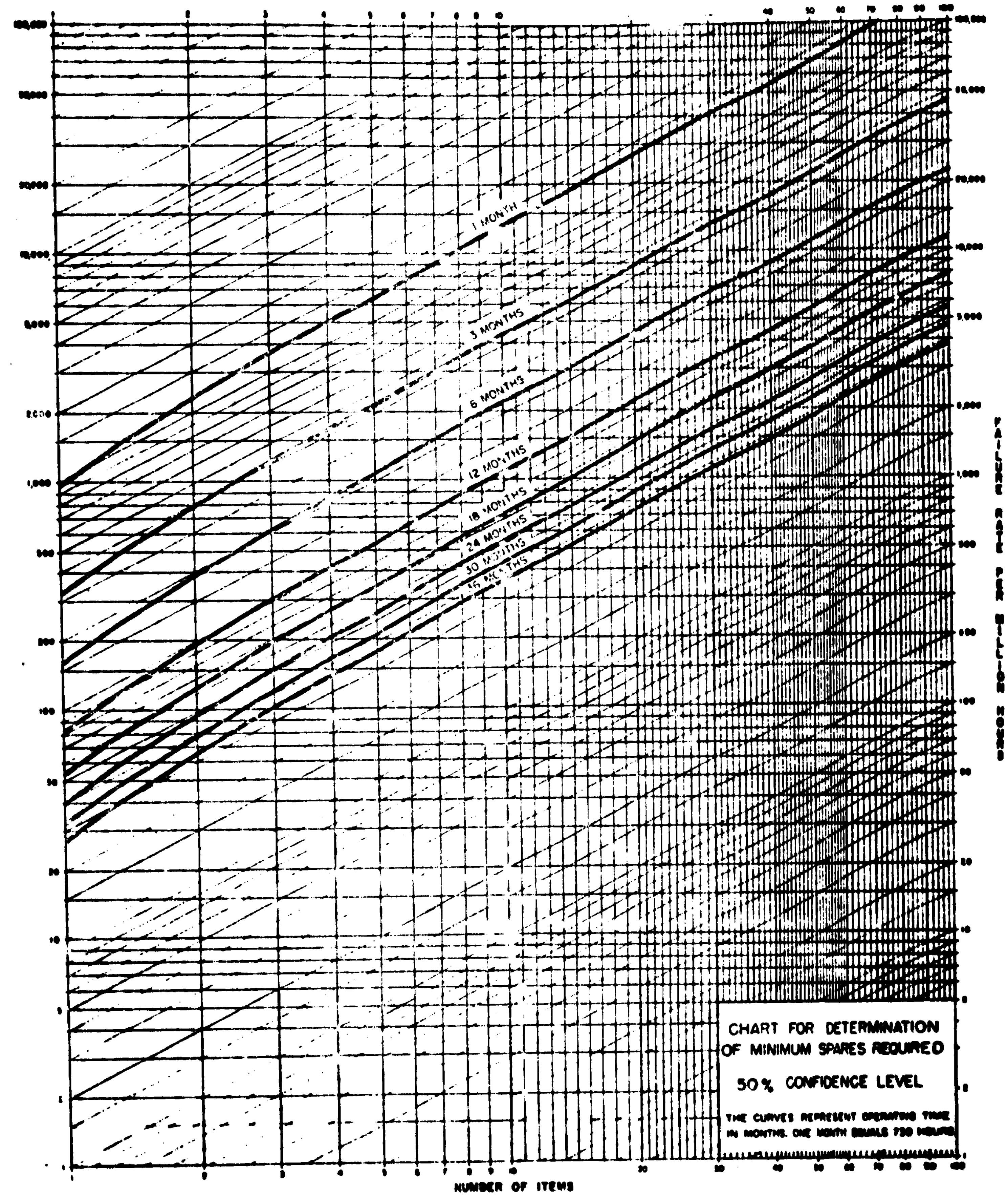
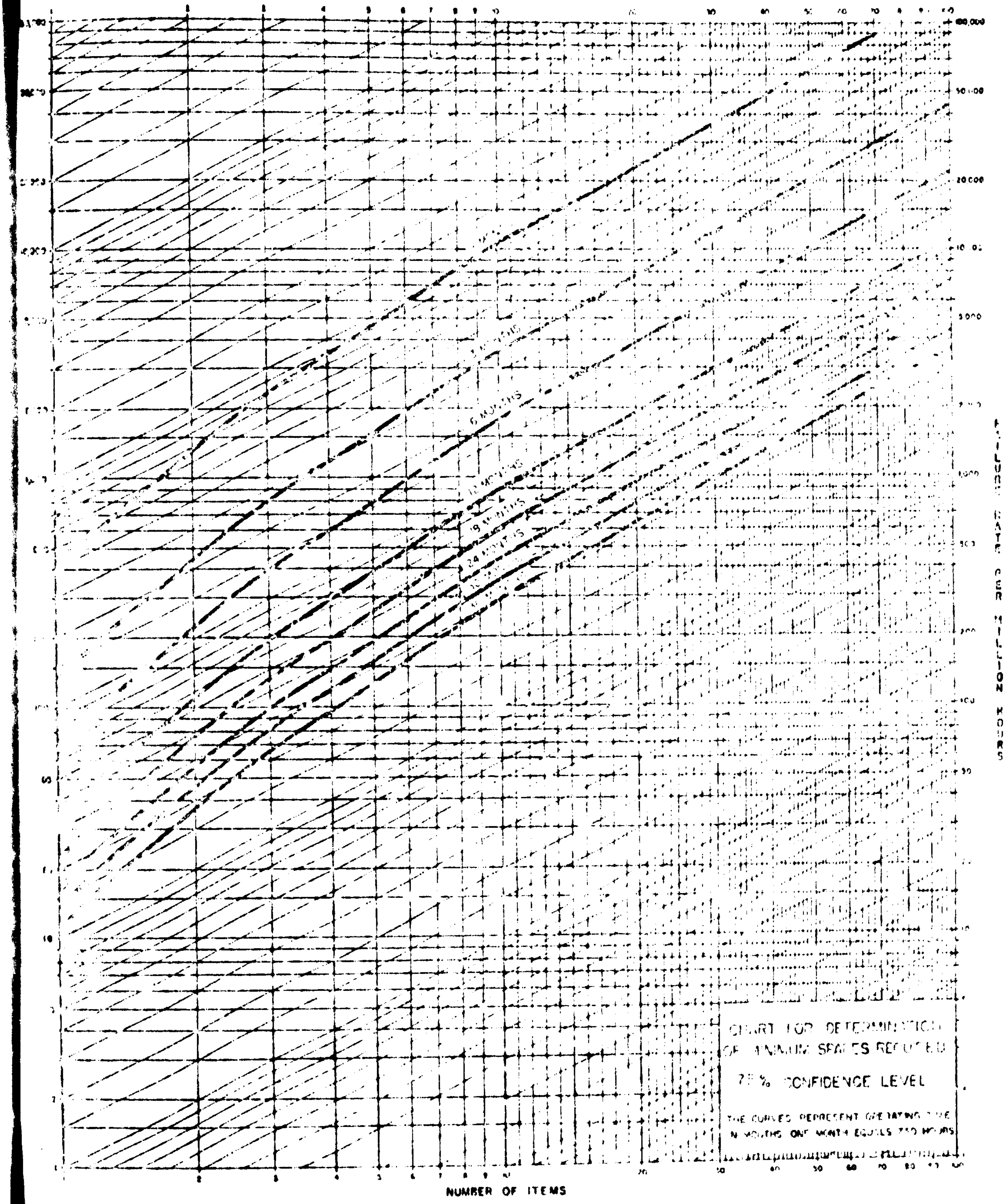

1 MONTH
3 MONTHS
6 MONTHS
12 MONTHS
18 MONTHS
24 MONTHS
30 MONTHS
36 MONTHS
100,000
50,000
20,000
10,000
5,000
2,000
1,000
500
200
100
50
20
10
5
2
1
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
NUMBER OF ITEMS
FAILURE RATE PER MILLION HOURS
CHART FOR DETERMINATION OF MINIMUM SPARES REQUIRED
50% CONFIDENCE LEVEL
THE CURVES REPRESENT OPERATING TIME IN MONTHS. ONE MONTH EQUALS 730 HOURS

FIGURE 3



6 MONTHS
12 MONTHS
18 MONTHS
24 MONTHS
FAILURE RATE PER MILLION HOURS
100,000
50,000
20,000
10,000
5,000
2,000
1,000
500
200
100
50
10
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
NUMBER OF ITEMS
CHART FOR DETERMINATION OF MINIMUM SPARES REQUIRED
75% CONFIDENCE LEVEL
THE CURVES REPRESENT OPERATING TIME IN MONTHS ONE MONTH EQUALS 720 HOURS

FIGURE 4

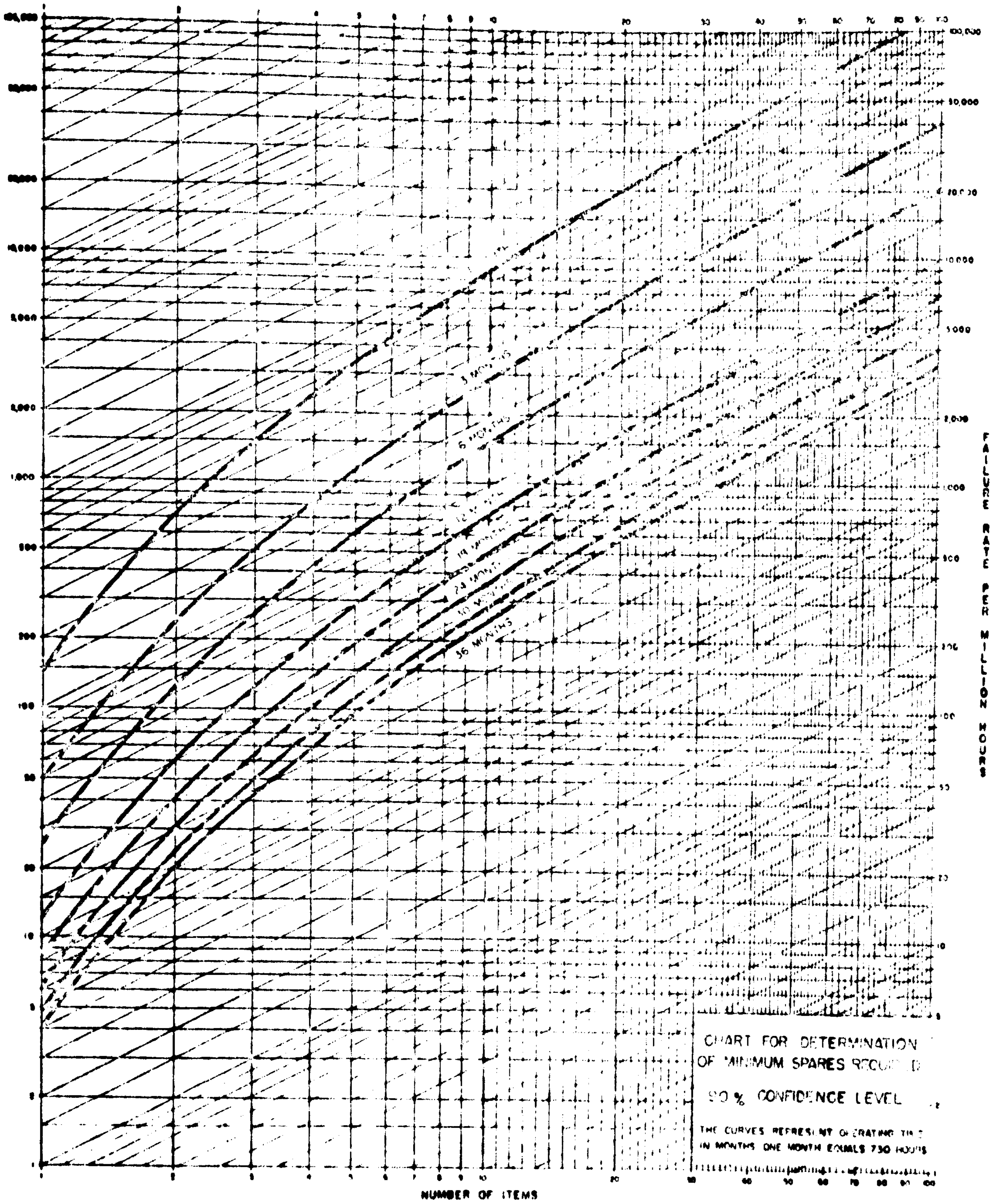


CHART FOR DETERMINATION
OF MINIMUM SPARES REQUIRED
90 % CONFIDENCE LEVEL
THE CURVES REPRESENT OPERATING TIME
IN MONTHS. ONE MONTH EQUALS 730 HOURS
3 MONTHS
6 MONTHS
12 MONTHS
18 MONTHS
24 MONTHS
30 MONTHS
36 MONTHS
NUMBER OF ITEMS
FAILURE RATE PER MILLION HOURS
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
100,000
50,000
20,000
10,000
5,000
2,000
1,000
500
200
100
50
20
10
5
2
1

FIGURE 5

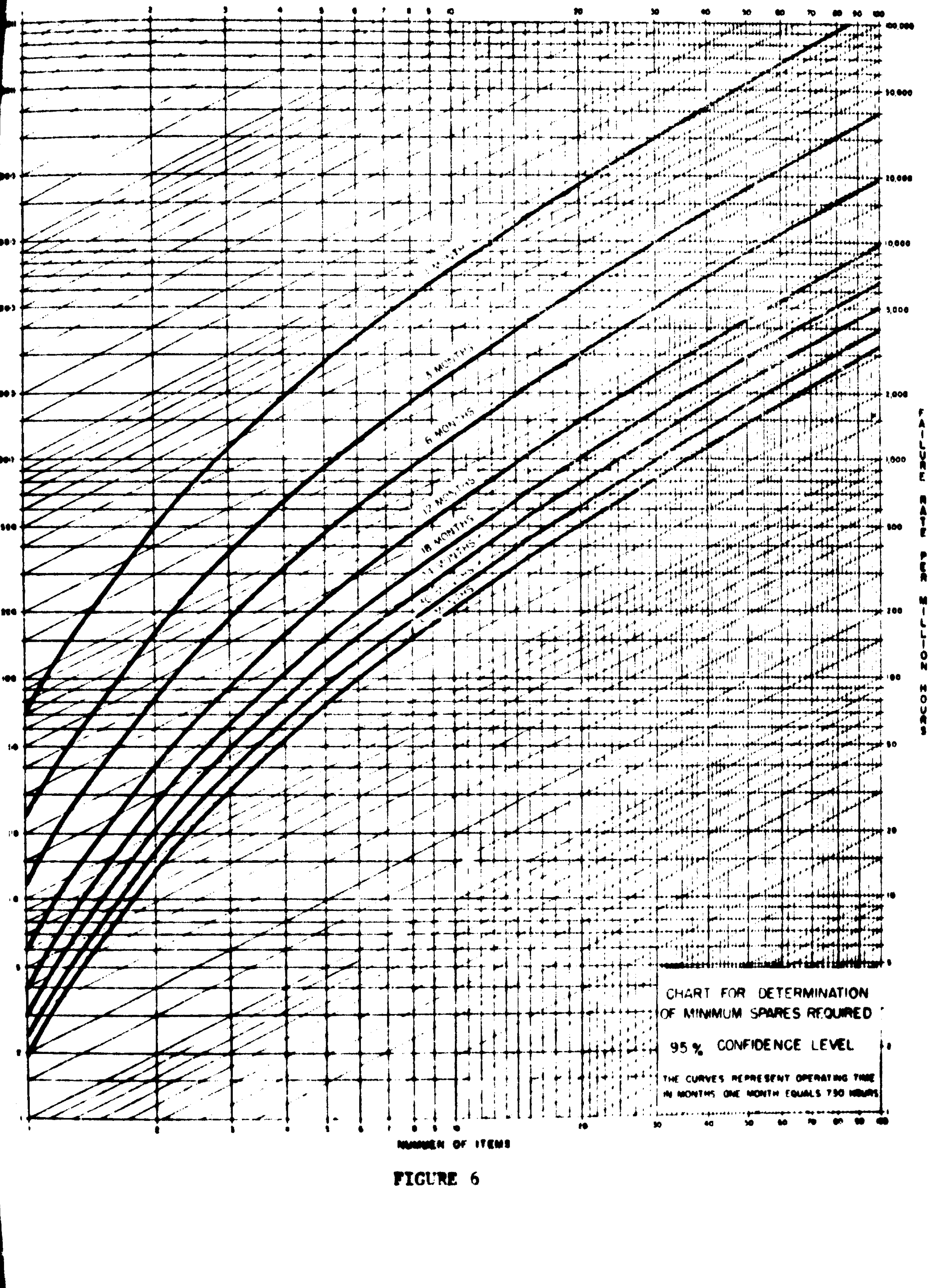

1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
100,000
50,000
20,000
10,000
5,000
2,000
1,000
500
200
100
50
20
10
5
2
1
FAILURE RATE PER MILLION HOURS
NUMBER OF ITEMS
3 MONTHS
6 MONTHS
12 MONTHS
18 MONTHS
24 MONTHS
CHART FOR DETERMINATION OF MINIMUM SPARES REQUIRED
95 % CONFIDENCE LEVEL
THE CURVES REPRESENT OPERATING TIME IN MONTHS ONE MONTH EQUALS 750 HOURS

FIGURE 6

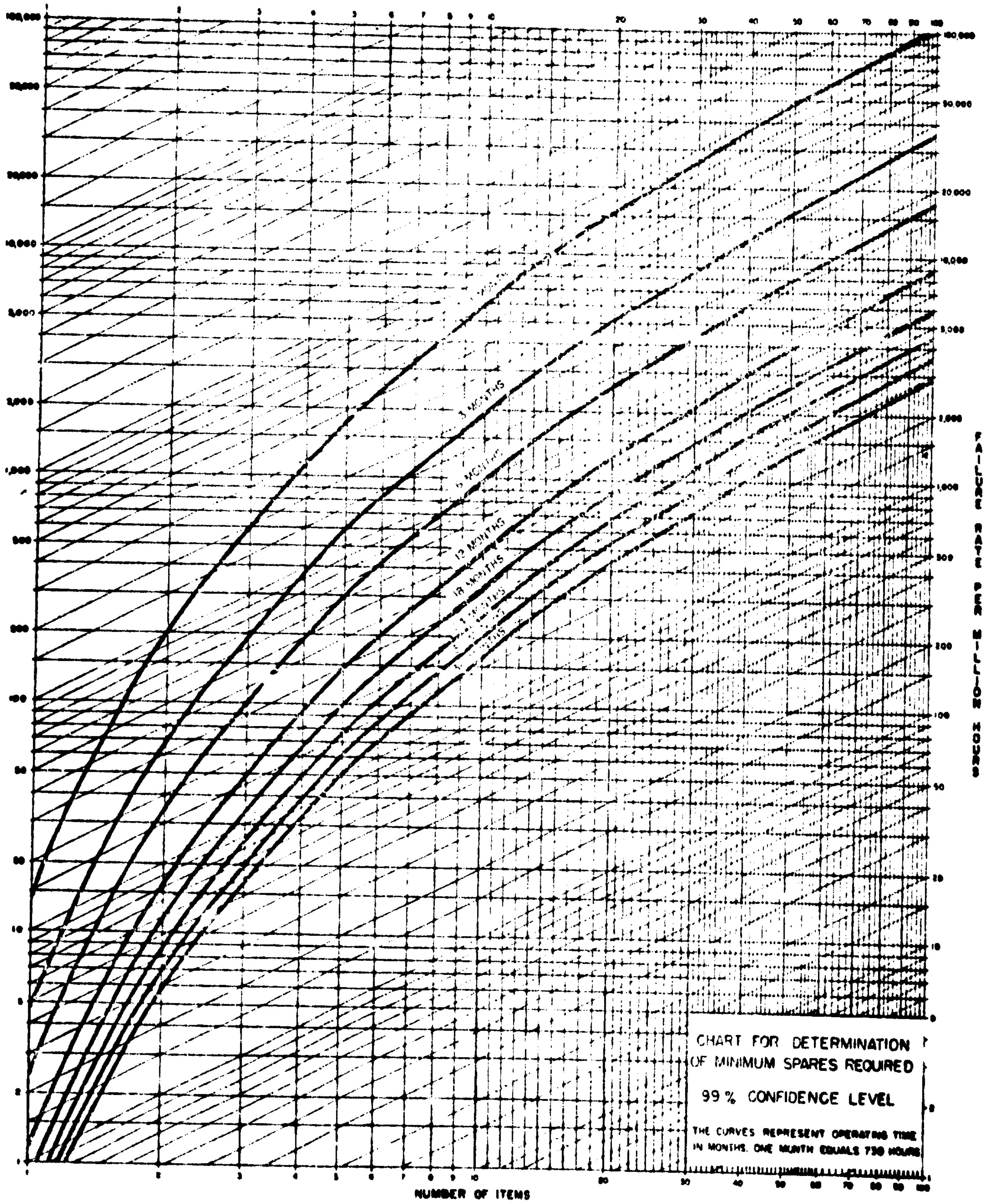


FIGURE 7

The basic procedure for determing the spares required is as follows:

Step I Determine the applicable failure rate for the part, component, assembly, etc., under consideration (See Table I)

Step II Determine the number of times the part (component, assembly, etc.) is used in equipment to be serviced by the supply point, i.e., the number of times the item is used in a system times the number of systems serviced by the supply point.

Step III Enter the left-hand side of the chart at the value determined in Step 1.

Step IV Move up the sloped line until it intersects the vertical line determined in Step II. This determines the total failure rate for the items for a particular supply point.

Step V Move horizontally to the curve of operating time for the item. Operating time is determined by multiplying the length of the program (calendar time) by the fraction of the time the equipment is turned on.

Step VI Move down to the abscissa to determine the number of spares required.

The basic procedure for determining the critical spares after the program has been running for some time is as follows:

Step I Locate the point on the chart at which the original spare quota was determined i.e., the intersection of the operating time curve and the spare parts initially required.

Step II Move horizontally to the left until the curve of expected operating time remaining in the program is reached.

Step III Move down to the abscissa to determine the minimum spares which should still be in stock for the applicable confidence level.

Step IV Compare the number in stock with that determined in Step III. If the number in stock is less than that determined in Step III, then the item is in a critical condition.

After a spare has been established as critical, the problem arises as to what action should be taken. For a spare to be in a critical condition either the original estimate of failure rate was too low or the parts are being used up faster than expected due to statistical variations associated with the random failure process. The original failure rate assigned to the part is usually based on a considerable amount of past history and therefore the hypothesis that the original failure rate is correct should not be rejected unless there is substantial evidence to reject the hypothesis.

If the number of failures occuring in the time interval in question is such that there is less than a 10% chance that the true failure rate could be as low as estimated, then it would seem reasonable to recalculate a new failure rate for that part and increase the spares accordingly. This means that one time out of every ten we would be ordering more parts than necessary to support the program at the original confidence level. Based on the foregoing discussion the following procedure can be established for action to be taken if a spare is determined to be in a critical state:

1. Enter the 90% confidence level chart at the original failure rate and move up the sloped line to the intersection of the vertical line representing the number of times the item is used in equipment serviced by the supply point. Move horizontally to the operating curve determined by the operating time of the equipment from the beginning of the program to the time of the stock check.

2. Move down to the abscissa to determine maximum number of spares that could be used in the time interval before the failure rate for that part should be recalculated.

3. If the number actually used is less than the number determined in Step 2, then go back to Step III of "the basic procedure for determining the critical spares after the program has been running for some time" to determine the number of spares required to support the program at the proper confidence level.

4. Order the difference between the number actually left in stock and the number determined in Step 3.

5. If the number actually used is <u>more</u> than the number determined in Step 2 then a new failure rate should be calculated using the following formula:

$$\lambda_n = \frac{N \times 10^6}{nt_o}$$

Where λ_n = new failure rate

N = number of spares used in the time interval from beginning of program to time stock is checked

n = number of times the part is used in equipment serviced by the supply point

t_o = time interval in hours (assume 730 hours in a month)

6. Using the new failure rate and the operating time left in the program, determine the number of spares required to support the program at the proper confidence level. (Use "the basic procedure for determining the spares required")

7. Order the difference between the number actually left in stock and the number determined in Step 6.

2.2.4 Examples of Spare Part Requirement Calculations

The following three examples are presented to show several typical cases for the use of the spare parts charts.

1. Selection of minimum requirements for a given program in which all spares are ordered at the start of the program.

2. Determination of critical spares after the program has been running for some time.

3. Action to be taken in the case of critical spares.

Example I

Assume a television receiver repair facility wanted to have enough spares on board to service 50 television receivers for a three year period. The requirement was established that there be a 95% assurance that at least one spare of each part would be available, at the end of the three year period. The operational duty cycle for the receivers was set at an average of 8 hours a day (or twelve months out of thirty-six) for each receiver.

For this example the problem is to determine the number of spare picture tubes required to satisfy the requirements stated above.

The first step is to locate the proper failure rate for picture tubes. Table I lists this as twenty. Next select the chart for 95% confidence level and enter the chart on the left hand side at a failure rate of twenty. Move up the slanted line until it intersects the vertical line marked 50 (the number of receivers to be serviced at the repair point). This will determine the total failure rate for the 50 picture tubes. Now move horizontally (in this case to the left) until the operation time curve for twelve months is reached and then down to the abscissa to determine the number of spares required. In this case the abscissa is intersected between seventeen and eighteen so eighteen picture tubes are required.

Example II

The service manager in charge of supplies in the first example must know if any spare parts are in a critical situation in time to procure new spares before the supply is exhausted. In other words he should have a method for reviewing his stock at any point in the program and quickly selecting those items which are in a critical state. For this example let us assume that the program in Example I has been running for eighteen months and has eighteen months left to run. This would mean that there is an average of six months of operation time left for each receiver. The problem is to determine if enough picture tubes are in stock to safely complete the three year period without re-ordering. In this case we enter the chart at the intersection of the initial operating time curve (twelve months) and the spares in stock at the beginning of the program (eighteen). Now move horizontally to the left until the six month operation time curve is intersected. Then move down to the abscissa to determine the minimum number of spares which should be in stock for a given confidence level to complete the program without re-order. In this case, there should be at least eleven picture tubes in stock. If there are more than eleven tubes in stock, then the spares situation is not critical. If there are less than eleven tubes in stock, the action to be taken would hinge on the number of spares used in the first eighteen months of calendar time, and six months of operating time.

Example III

Assume that 12 cathode ray tubes had been used in the first half of the program described in examples I and II. This means that only 6 remained in stock, and the spares are in a critical condition.

To determine if the failure rate of 20 for the cathode ray tube should be recalculated, the 90% confidence chart is entered at 20. Move up the sloped line until the vertical line for 50 units is intersected. Next move horizontally to the operating time curve for 6 months (for the actual calendar time for 18 months) and then down to the abscissa to determine the number which would not be exceeded more than 10% of the time if 20 were the true failure rate. In this case, the number is seven. Since twelve tubes were used, the failure rate should be recalculated as follows:

$$\lambda_n = \frac{N \times 10^6}{n t_e} = \frac{12 \times 10^6}{50 \times 6 \times 730} = 55$$

With a new failure rate of 55 for 6 months operating time left in the program the spares required for a 95% confidence level is 23 (determined following basic procedure for determining the spares required as in example I). Since there are still 6 tubes in stock, 17 tubes will have to be ordered.

2.3 COMPONENT CONSTRUCTION AND PRIME FAILURE MODES

In order to make the proper "trade-offs" between reliability, maintainability and cost of low cost receivers the construction and predominant failure modes of the parts making up the receiver should be understood. It is beyond the scope of this paper to compile such a list for all or even most of the parts that would be used in low cost radio and television receivers. To point out some of the type of information that should be compiled, film resistors and semiconductors will be used as examples. Other information on component construction and failure modes is discussed in the next section on failure analysis.

2.3.1 Film Resistor Contruction and Failure Modes

The construction of metal-film resistors consists of metal or metal-oxide deposited on a refractory base. For high-resistance values, a spiral groove is grounded in the film to increase the effective path of resistance. The usual metal-film resistor involves metals such as platinum, paladium, rhodium and alloys such as nickel-chromium, etc. These films are deposited on a ceramic substrate by evaporation in a vacuum. Terminations are made with conducting bands fired on the ends of the core. The specific resistance of the metal film may be much greater than the resistance of the bulk material.

The metal-oxide film resistors use a tin oxide film bonded to a glass core at red heat. The expansion coefficients of the materials are matched. The films are rugged so these resistors are less susceptible to mechanical damage than carbon-film resistors.

Irreversible changes in film resistors result from overheating, humidity or mechanical damage. The increase in specific resistance of thin film of metal is thought to be due to the fact that conductivity is essentially determined by the mean free path of the electrons in the metal. A silver film, less than 400 angstroms thick, will not give consistent conductivity and a film less that 45 angstroms thick, will not give consistent conductivity and a film less than 45 angstroms thick does not conduct at all. Bulk characteristics are achieved only at a thickness of 3,000 angstroms. The temperature coefficient of resistance is very low for the metal-films.

Changes in resistance values occur over long periods of time and are not detected in the usual 1,000-hour life test. However, core defects and hot spots in the film due to uneven deposition or thin spot due to film chipping during spiraling are quickly found by using a short-term overload test.

Table III lists the major failures encountered in a testing program on precision metal-film resistors.

The test results show that incoming inspection ranks high for these resistors as uncovering a number of defects. Difficulties are also noted for the type of encapsulation used, since 1.7 per cent fail the humidity test. Some manufacturing defects are also indicated by the 1.4 per cent failures in the overload test. Mechanical environments apparentlv are not a problem for these resistors. In addition to the resistance degradation failures at incoming inspection, test results also show 0.9 per cent of the specimens inspected failed the insulation resistance, 3.4 percent failed the noise test, and 0.25 per cent failed because of open circuits. Another major reported failure mode was 17 per cent of the specimens lacking acceptable insulation resistance after humidity exposure.

TABLE III

METAL-FILM PRECISION RESISTOR FAILURES RANKED BY TYPE OF TEST

(Per Cent of Sample Failing)

Quality Tests -	
Incoming Inspection	1.9
Humidity	1.7
Overload	1.4
Vibration	0.7
Acceleration	0
Shock	0
Soldering	0
Performance Tests -	
Temperature Coefficient	14.4
125°C Life	5.2
Temperature Immersion	2.0
70°C Life	1.2
Thermal Shock	0
High Temperature	0
Low Temperature	0
60°C. 100°C, 175°C and 200°C Life	0

By analysing the test results of Table III, it is found that these devices experienced the most failures during the temperature coefficient test (14.4%), followed by the failures occuring during 125°C life tests (5.2%). The large number of failures for the temperature-coefficient tests may be due in part to the stringent specification requirements (0.005 per cent resistance change per degree centigrade in this particular instance). However, these requirements are reasonable since the metal-film resistor is often considered in applications requiring excellent temperature-coefficient properties. No additional failure modes were investigated.

Two examples of metal-film resistor characteristics are shown on Figures 8 and 9. Figure 8 represents the performance of 25 samples of 30K-ohm, 1/8 watt metal-film resistors. They were stabilized for 24 hours at 125°C before the initial data were taken. The conditions for the test were 125°C and full rated load. One failure was recorded which occurred because of a loose termination between the lead and the ceramic rod due to insufficient epoxy cement (talon construction described below).

During the test, the median deviation from initial was as much as 1.25 per cent, but for 5000 hours the median deviation was zero. The distribution range for 80 per cent of the sample, was ±0.5 per cent.

Figure 9 shows the end results of a 14,000 hour load-life on tin-oxide metal-film resistors, but these particular samples were rated at 1/2 watt and 10K-ohm. The 75 samples were subjected to 100 per cent load at 60°C. It can be seen that 80 per cent of the sample had deviations from initial between +0.8 and -0.25 per cent at the end of 14,000 hours of exposure. The total excursion for the median was approximately ±0.15 per cent. Similar resistors of different ohmic values had a continued decrease in resistance value by the end of the test in contrast to the upswing shown for the 10,000 ohm units.

Requests for samples and data were made of several suppliers of metal-film resistors. Test Data and samples were received from

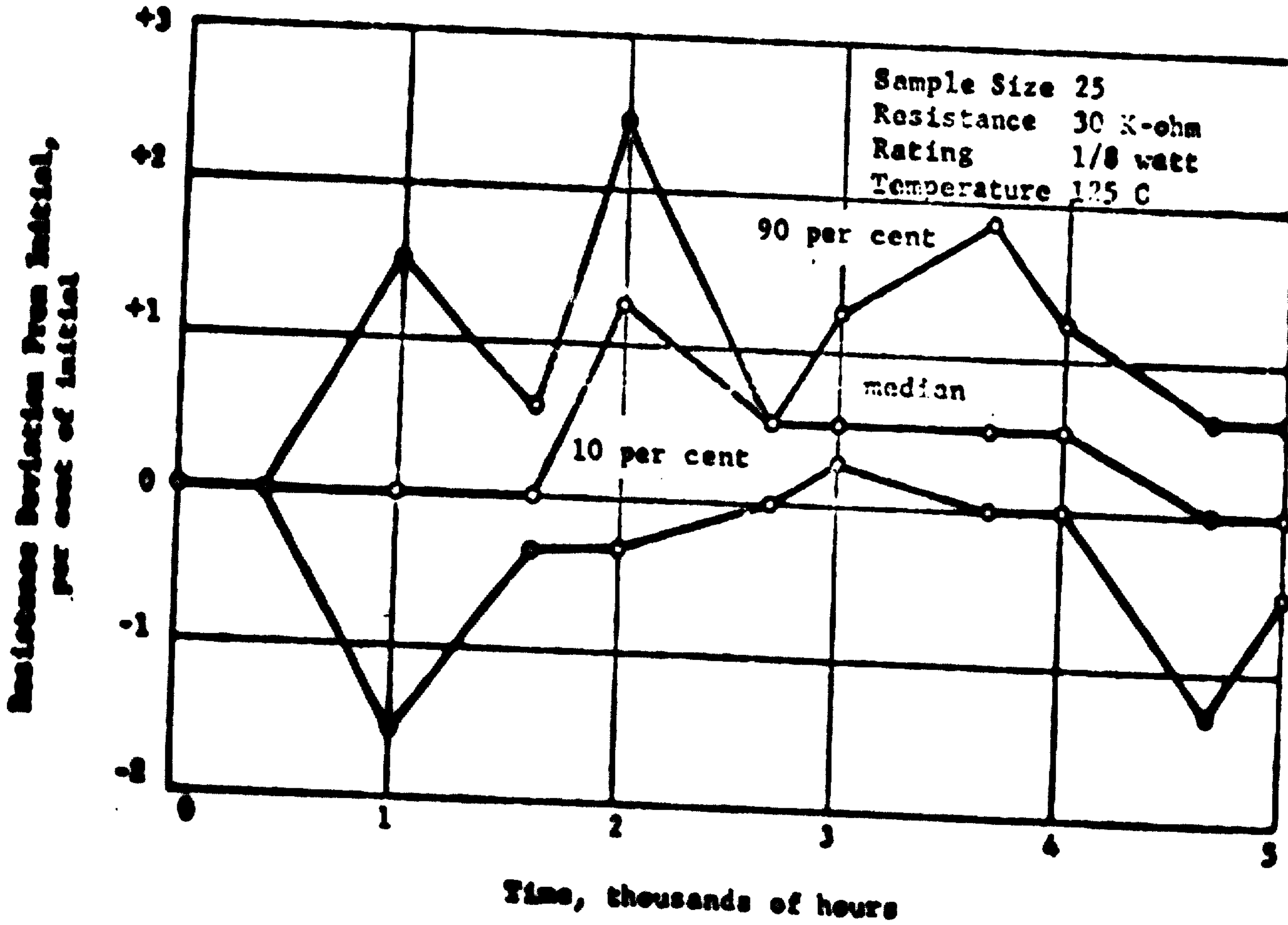


FIGURE 8 LIFE CHARACTERISTICS OF METAL-FILM RESISTORS

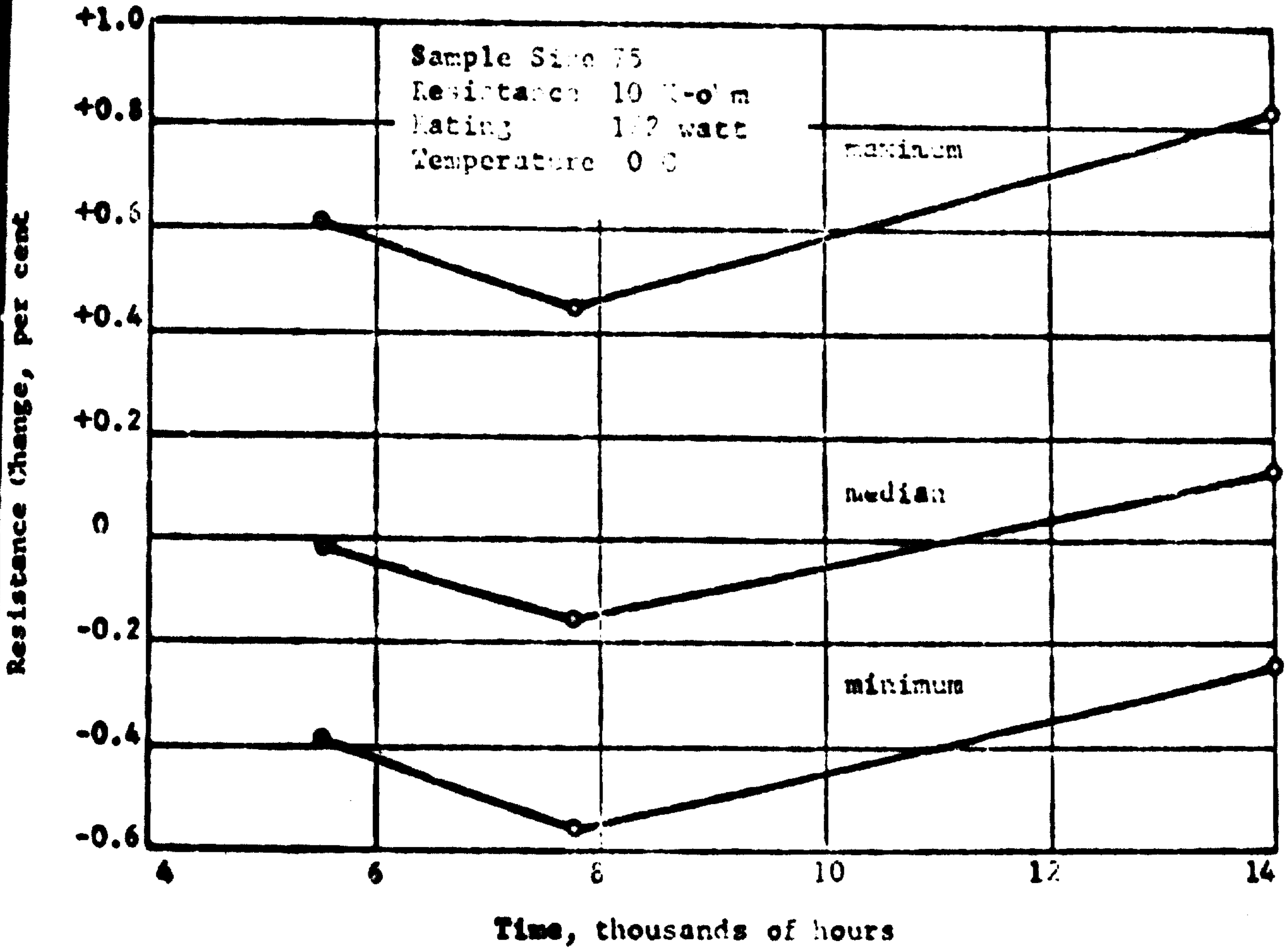


FIGURE 9 LIFE CHARACTERISTICS OF METAL-FILM RESISTORS (tin oxide)

International Resistance Company for the talon and cap and lead type Metal-Film Resistors. These samples were opened and subjected to microscopic observations.

After examining both types of resistors (see Figures 10 and 11), it was determined that the cap and lead construction presently used by IRC is much more reliable than the talon type of construction. The talon assembly method holds the substrate loosely with an epoxy conductive cement and solder. Conductive epoxy cements are difficult to control during manufacturing and have a time-temperature degredation characteristic. This makes them unsuitable for high reliability applications. An attempt was made by the manufacturer to utilize screening tests to weed out defective talon units. Although screening did assist, they could not meet high reliability requirements. The cap and lead construction not only is held by solder and epoxy cement, but the end cap is press fitted to the outside diameter of the substrate. This type of construction has proven to be useful for high reliability applications and is only slightly higher in cost than talon type units.

2.3.2 Prime Failure Modes of Semiconductors

Table IV is a comprehensive ten page table of failure modes in silicon transistors and integrated circuits. At first a list such as this leads one to believe that the only product coming off the lines are failures. In fact, most of these modes do not exist in any one device manufactured. The compilation serves two useful purposes: First to aid in failure analysis of malfunctioning devices and, second to develop economical and realistic screening tests.

2.4 FAILURE ANALYSIS, REPORTING AND FEEDBACK

For some unexplained reason, failures are rarely analyzed in depth and even more rarely, systematically catalogued. It seems logical that if most of the product performs satisfactorily, then there should be a reason for the piece of equipment, popularly referred to as "a lemon", to behave so differently. Most causes

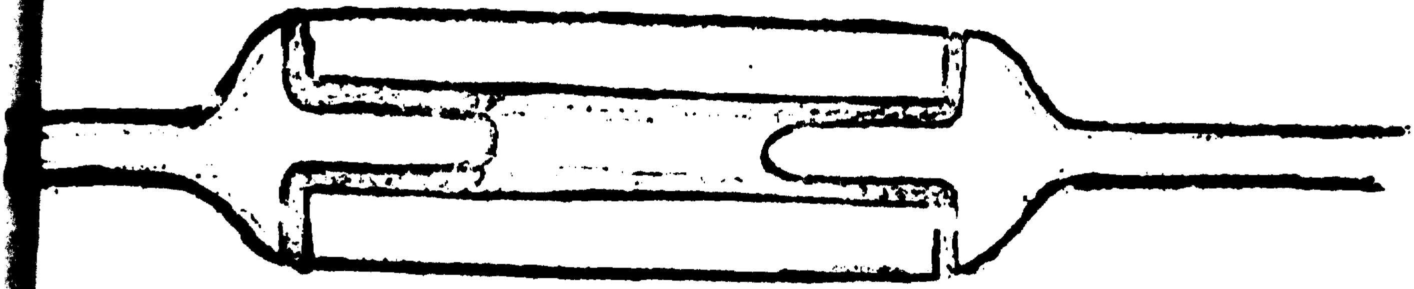


FIGURE 10
CROSS SECTION OF A FILM RESISTOR
USING TALON CONSTRUCTION

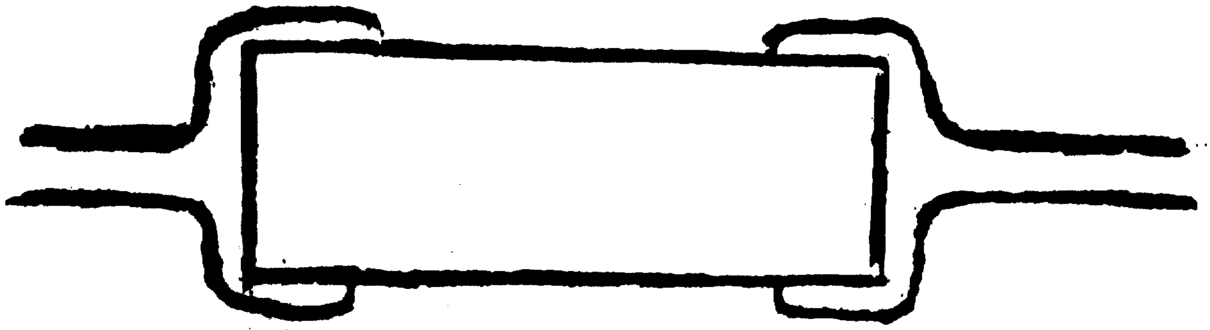


FIGURE 11
CROSS SECTION OF A FILM RESISTOR
USING CAP AND LEAD CONSTRUCTION

Failure Modes of Originally Good
Silicon Transistors or Integrated Circuits
Which Might Be Observed During Life and Environmental Testing

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Technique
1.0 Open No Continuity	1.1 Die off Header	Dynamic Testing, Thermal Fatigue	Die Lifting	Cleaning of header, die or preform; header plating, die down temp.	Microscope examination.
	1.2 Cracked Die	Dynamic Testing, Thermal Fatigue	Crack in die extending thru the isolation and/or deposited leads	Header not flat, lead bond pressure or impact, ultrasonic cleaning, scribing, void under die	Microscopic examination, use of preferential etch; crack is visible
	1.3 Bonds 1.3.1 Off Clean				
	1.3.1.1 - Intermetallic Phase Formation	Dynamic Testing, Thermal Fatigue, High Temperature Storage	Bond Lifting	Eutectic formation, metallization properties, bonding jig temperatures, wire properties.	Microscopic examination - bond comes off clean leaving traces of wire material on the bonding pad.
	1.3.1.2 - Bad Metal Surface	Dynamic Testing, Thermal Fatigue -	Bond Lifting	Washing of subassemblies, wire properties, insufficient metal, eutectic formation.	Microscopic examination - bond comes off bonding pad clean. Pad metal under bond sometimes of a lighter color than remaining pad material.
	1.3.2 Broken at Heel or Ball	Dynamic Testing, Thermal Fatigue	Work hardening of Lead Wire	Wire properties, mishandling of unit. Capillary condition.	Microscopic examination - wire is broken at heel of wedgebond or immediately above ball bond.

TABLE IV

Failure Modes of Originally Good
Silicon Transistors or Integrated Circuits
Which Might Be Observed During Life and Environmental Testing

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Technique
1.0 Open No Continuity (Cont)	1.3.3 Broken within the Bond	Dynamic Testing, Thermal Fatigue	Bond Lifting	Wire properties, capillary configuration, bonding jig temperatures operator error, excess pressure on bonding jig.	Microscopic exam. - wire broken within the bond leaving traces of wired material (wedge bond) or a donut shaped wire material on the bonding pad (capillary bond).
	1.3.4 Off, Lifting Pad Material	Dynamic Testing, Thermal Fatigue	Bond Off	Metallizing, cleanliness, alloy time, alloying temperature.	Microscopic examinatioh - pad material removed from under bond.
	1.3.5 Off, Lifting Silicon and Pad Material	Dynamic Testing, Thermal Fatigue	Bond Off	Excess pressure on lead bonding jig, header height, variation, bonding jig temperatures, excessive capillary impact pressure.	Microscopic examination - Silicon is removed from the bonding area.
	1.3.6 Discontinuity of deposited metal				
	1.3.6.1 Lack of Metal	Operating/ Storage Life	Lack of Metal Deposition	Insufficient metal deposition, scratches caused by mishandling, operator error, metal properties.	Microscopic examination reveals a break in the metal, thereby resulting in the loss of continuity.
	1.3.6.2 Intermetallic Phase Formation	Operating/ Storage Life	Intermetallic Phase Formation	Insufficient metal deposition, scratches due to mishandling. Exposure to excessive temperature.	Microscopic examination - break in metal lead due to intermetallic phase formation.

TABLE IV

Failure Modes of Originally Good
Silicon Transistors or Integrated Circuits
Which Might Be Observed During Life and Environmental Testing

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomena Involved	Possible Production Fault Causing Defect	Failure Analysis Technique
1.0 Open No Continuity (Cont)	1.3.6.3 Bad Metal	Operating/ Storage Life	Blistered Metal	Metal properties, Alloy Temperature, Alloy Time, Metallizing, Cleanliness	Microscopic examination - break in metal due to blistering.
	1.4 Weld(s)				
	1.4.1 Off Clean	Dynamic Testing, Thermal Fatigue	Weld Off	Cleaning of subassemblies, welding jig voltage, wire properties, welding jig pressures	Microscopic examination - weld comes off clean or leaves traces of wire material on the post.
	1.4.2 Broken at Heel	Dynamic Testing, Thermal Fatigue	Work hardening of lead wire	Wire properties, mishandling of unit, welding electrode shape.	Microscopic examination - wire is broken at the heel of the weld.
	1.5 Wire Broken in Span	Dynamic Testing, Thermal Fatigue	Work hardening of lead wire	Wire properties, mishandling of unit.	Microscopic examination - wire is broken in that portion which is not associated with bonding and welding stresses.
	1.6 Electrical Overload	Excess Power or Current	Fused Lead, electrical path may be visible under the oxide.	Test equipment or misuse.	Microscopic examination - lead wire fused in span. Bond may be melted. Discontinuity of printed circuit material - material may be melted.
2.0 I_L (Current leakage) and I_{LR}	2.1 Excessive Current Leakage				
	2.1.1 Surface Contamination	High Temperature, Storage or Operating	Imperfect oxide protection, contamination on junction.	Improper washing subassemblies, improper vacuum baking, improp. masking, scratches due to handling, pinholes in oxide under metal.	Microscopic exam.- look for contam. particles, if none visible, isolate defective area. Remove all metal, look for pinholes in oxide under metal. Light wash of die with HF, retest for improvement.

TABLE IV

[illegible] of Originally [illegible]
Silicon Transistors or Integrated Circuits
Which Might Be Observed During Life and Environmental Tests

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Technique
2.0 I_L (Current leakage) and I_{LR} (Cont)	2.1.2 Internal Contamination	High Temperature, Storage or Operating	Contamination internal to the device.	Unknown	Light wash of defective area of die with HF, retest indicates no improvement.
	2.1.3 Hermetic Seal	"	Bad hermetic seal & imperfect Oxide protection.	Bad final seal, bad glass to metal seal, improper leak test, improper handling.	Radiflo test and further analysis as outlined in 2.1.1
	2.1.4 Crack	High Temperature, Storage or Operating, Dynamic	Conduction thru a flow in the silicon, usually a crack.	Header not flat, lead bond pressure or impact, ultrasonic cleaning, scribing, cracked die, void under die.	Diode may "switch" from high voltage low current to lower voltage high current. Microscopic examination, use of preferential etch, crack is visible.
	2.1.5 Break in Isolation	"	Conduction thru a break in the isolation.	Masking defect, improper isolation diffusion	Microscopic examination - break in isolation visible. Section for verification.
	2.1.6 External Contamination	"	Contamination external to device.	Washing of subassemblies, improper handling, dirty work area, poor workmanship.	External wash with HF improves the unit.
	2.1.6.1 - Surface Contamination (Header)	"	Contamination external to device but inside can.	Washing of subassemblies, improper handling, dirty work area, poor workmanship.	After uncapping the device, examine the glass around the posts (eyelets) for foreign material bridging from the header to the post. Remove the welds at the post and check the insulation resistance of the header. Leakage can be eliminated with HF wash of [illegible].

TABLE IV

Failure Modes of Originally Good

Silicon Transistors or Integrated Circuits
Which Might Be Observed During Life and Environmental Testing

Problem From Curve Tracer Anal. (External)	**Defect Causing Failure (Internal)**	**Stress Most Likely As Cause**	**Phenomenon Involved**	**Possible Production Fault Causing Defect**	**Failure Analysis Technique**
2.0 I_L (Current leakage) and I_{LR} (Cont)	2.1.6.2 - Internal Contamination (Header	High Temperature, Storage or Operating, Dynamic	Insulation Resistance of header too low	Header manufacturing problem, Inadequate incoming inspection, faulty inspection limits, operator error.	**No improvement after HF wash.**
	2.2 Low Breakdown Reverse Biased Diode	High Temperature, Storage or Operating, Dynamic	Change in resistivity of junction.	Conductive particle on junction	**Isolate defective area. Remove all metal.** Retest for improvement. Removal of several layers of oxide may be necessary to remove the contaminant.
	2.3 Loose Foreign Material (Intermittent short)	High Temperature, Storage or Operating, Dynamic	Audible sound detected in device.	**Improper cleaning, poor workmanship.**	Audible sound detected in device. Uncap by grinding off the flange. Microscope examination of particle to determine if conductive or not. Retest device on curve tracer; if no improvement, proceed as per 2.1.
	2.4 High Apparent Saturation Current.				
	2.4.1 Inversion layer to Har Breakdown	High Temperature Storage or Operating.	**Surface state Change**	**Surface ionization, or change separation, other unknown.**	**Trace displays current conduction at low voltage, resistance and hard breakdown at higher voltage. Uncapping causes inversion layer to disappear.**
	2.4.2 Inversion layer to Har Breakdown	"	Surface state Change	**Unknown**	Inversion layer remains after uncapping; can be eliminated by removal of metal and/or oxide.

TABLE IV

Failure Modes of Originally Good Silicon Transistors or Integrated Circuits Which Might Be Observed During Life and Environmental Testing

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Technique
2.0 I_L (Current leakage) and I_{LK} (Cont)	2.4.3 Inversion layer to Hard Breakdown	High Temperature Storage or Operating	Surface state change	Unknown	Inversion layer remains after uncapping and after metal and oxide removal.
	2.5 High Apparent Saturation Current				
	2.5.1 Inversion Layer to Soft Breakdown	High Temperature Storage or Operating	Surface state change	Unknown	Trace displays current conduction at low voltage, resistance, and soft breakdown at higher voltage. Uncapping causes inversion layer to disappear.
	2.5.2 Inversion Layer to Soft Breakdown	"	Surface state Change	Unknown	Inversion layer remains after uncapping; can be eliminated by removal of metal and/or oxide.
	2.5.3 "	"	"	"	Inversion layer remains after uncapping and after metal and oxide removal.
	2.6 Shorted Diode				
	2.6.1 Shorted Diode	Test Equipment or Thermal Runaway	Excessive current or power causing melting of bond or metallized paths	Test equipment, thermal runaway, operation error.	Curve tracer indicates a short. Microscopic examination shows definite evidence of electrical overload.

TABLE IV

Failure Modes of Originally Good
Silicon Transistors or Integrated Circuits
Which Might Be Observed During Life and Environmental Testing

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Technique
2.0 I_R (Current leakage) and I_{LR} (Cont)	2.6.2 Crack in Die	High Temperature Storage or Operating Dynamic	Conduction thru a flow in the silicon, usually a crack.	Scribing, pressures, header not flat, bonding pressure or impact, ultrasonic cleaning, void under die.	Microscopic examination reveals cracked die; or use of preferential etch, crack is visible.
	2.6.3 Loose Foreign Material	High Temperature Storage, Operating, Dynamic	Intermittent short and audible sound detected in device.	Washing subassemblies, dirty work area, impure preform, poor header plating, poor workmanship	Curve trace displays intermittent short. Audible sound detected with silicon particle detector. Uncap device at the flange - conductive particle visible.
	2.6.4 Holes in Oxide under metal.	High Temperature Storage, Operating	Insufficient Oxide Protection.	Faulty masking, scratches improper oxide removal, operator error.	Holes in oxide under the metal visible after removal of metal with NaOH. Verify by probing the transistors or resistors in question.
3.0 I_A (Current available) and/or V(Sat) Change to Higher Value	3.1 High Resistance				
	3.1.1 Surface	High Temperature Storage or Operating	Metal Surface	Metal properties, metallized cleanliness or thickness, alloy time, alloy temp., cleanliness after scribing.	Sectioning reveals resistive area between bond and the metallized pad.
	3.1.2 Bond Attach	"	Bond Attach	Lead bond temperature, tool pressure, tool configuration, dirty bonding surface, wire properties, operator error.	Sectioning reveals some separation between the bonding material and the pad material. Voids due to intermetallic phase formation will also be visible.
	3.1.3 Weld	"	Resistive Weld	Cleaning of subassemblies welding tip temperatures, wire properties.	Rewelding of leads to posts increases I_A.

TABLE IV

Failure Modes of Originally Good
Silicon Transistors or Integrated Circuits
Which Might Be Observed During Life and Environmental Testing

Problem From Curve Tracer Anal. (External)	**Defect Causing Failure (Internal)**	**Stress Most Likely As Cause**	Phenomenon Involved	Possible Production Fault Causing Defect	**Failure Analysis Technique**
3.0 I_A (Current available) and/or V(Sat) Change to Higher Value (Cont)	3.1.4 Intermetallic Phase Formation	High Temperature Storage or Operating	Resistance due to Intermetallic Phase formation.	High temperature, metallize cleanliness, thickness, alloy time, alloy temperature, insufficient metal deposition.	Microscopic examination reveals near break in metal due to excessive intermetallic phase formation near bonds. Probing of metal next to intermetallic phase formation improves V(Sat).
	3.1.5 Lack of Metal	"	Lack of metal deposition.	Metal thickness, scratches due to mishandling, excessive metal removal, operator error.	Microscopic examination reveals lack of metal. With probe contacts, probe for decrease in SAT around defective area.
	3.1.6 **Change in Resistor Value**	"	**Value of resistor increased.**	Insufficient oxide removal, masking, wrong type etchant, operator error.	Microscopic examination - after metal removal, resistor display little or no cutouts in the oxide for metal contact.
	3.1.7 **Internal Crack**	"	Crack in Silicon	High temperature, bonding pressures or impact. Header not flat, ultrasonic cleaning, scribing, cracked die, void under die.	Sectioning reveals fracture in silicon.
	3.1.8 **Butt Welded** Lead to Header	"	**Butt Weld**	Header manufacturing problem, inadequate incoming inspection, faulty inspection limits, operator error.	Use of another lead clipped on to header decreases SAT. Verify by sectioning through butt weld.
3.0 I_A (Current available) V_{BE}(Sat) Only	3.2 **Base to Emitter Resistance Up**				

TABLE IV

Failure Modes of Originally Good
Silicon Transistors or Integrated Circuits
Which Might Be Observed During Life and Environmental Testing

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Technique
3.0 I_A (Current available) $V_{BE}(Sat)$ Only (Cont)	3.2.1 Surface	High Temperature Storage or Operating	Metal Surface	Metallize cleanliness or thickness, alloy time, alloy temp., cleanliness after scribing.	Probing of metallized path adjacent to the bond in question reveals a decrease in $V_{BE}(Sat)$. Section thru the bond followed by examination on a metallograph.
	3.2.2 Bond Attach (Emitter and/or Base)	"	Bond Attach	Bond jig temperature, tool pressure, tool configuration, misplaced bond, operator error.	Probing of metallized path adjacent to the bond in question improves $V_{BE}(Sat)$. Sectioning reveals separations between the bond material and pad material.
	3.2.3 Weld Attach (Emitter and/or Base)	"	Weld Attach	Cleaning of subassemblies Welder manfunction, electrode configuration, wire properties, operator error.	Reweld welds and check for decrease in SAT. Further check as per 3.2.2 and 3.2.1
	3.2.4 Intermetallic Phase Formation	"	Intermetallic Phase Formation	High temperature, insufficient metal, bonding pressure.	Microscopic examination reveals near-break in metal due to intermetallic phase formation. Probing of metal near intermetallic phase formation decreases $V_{BE}(Sat)$.
	3.2.5 Lack of Metal	"	Lack of Metal Deposition	Metal thickness, scratches due to mishandling, excessive metal removal, operator error.	Microscopic examination reveals lack of metal. Probing reduces $V_{BE}(Sat)$.
	3.2.6 Change in Resistor Value	"	Value of Resistor Increased	Insufficient oxide removal, masking, wrong type etchant, operator	Microscopic examination - after metal removal, resistor displays little or no cutouts in the oxide for metal contact.

TABLE IV

Failure Modes of Originally Good
Silicon Transistors or Integrated Circuits
Which Might Be Observed During Life and Environmental Testing

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Technique
3.0 I_A (Current available) V_{EB}(Sat) Only (Cont)	3.2.7 **Internal Crack**	High Temperature Storage or Operating, **Dynamic**.	**Crack in Silicon**	High temperature bonding pressure or impact; header not flat, ultrasonic cleaning, scribing, cracked die, void under die.	**Sectioning reveals fracture in silicon.**
	3.2.8 Butt Welded Lead to Header	"	**Butt Weld**	Header manufacturing problem, inadequate incoming inspection, faulty inspection limits, operator	Use of another lead clipped on to header decreases SAT. Verify by sectioning thru butt weld.
4.0 h_{FE}	**4.1** **Soft EB Diode** (Surface)	"	**Contaminated** Surface	Scratches, foreign material, insufficient oxide protection, operator error	Proceed as per Para. 2.1.1
	4.2 Increased V(Sat)	"	**Emitter/Collector resistance u.**	See "V(Sat)"	Examine the test data to determine the relationship between SAT readings and h_{FE}. Proceed as per Section 3.1 and the appropriate failure mode exhibited.
	4.3 **Carrier Recombination Velocity**	"	Migration of metal atoms, charge in surface state. Other unknown	**Unknown**	Curve tracer shows hard EB Breakdown. Microscopic examination - no cause for failure visible after metal and/or oxide removal after locating defective area. Sectioning inconclusive.
	4.4 **Short and/or Partial** Shorted Diode	"	See 2.6 "Shorted Diode"	**See 2.6 "Shorted Diode"**	Proceed according to the failure mode exhibited under Section 2.6 "Shorted Diode."

TABLE IV

for the different behavior fall into the following three general categories:

1. A marginal problem where parts coming from the tails of normal product distribution combine to cause malfunctions.
2. A "sport" problem where a part or parts fall well outside of normal product distribution.
3. An environmental problem where the equipment is stressed (intentionally or unintentionally) beyond the design limit.

The problem then, is to perform failure analysis adequate to determine the category of failure and allow feedback of corrective action on an economical basis. The key to the solution of this problem is that well-controlled processes result in homogeneous population of the product produced. This fact is useful in failure analysis techniques anywhere in the production cycle from early design to field use.

2.4.1 Specific Program

Probably the most effective area in which failure analysis effort should be concentrated is in the manufacturing test area. This is because of the large number of equipments tested and the relatively accurate failure information obtainable at this point in the manufacturing cycle. This, in turn, allows for meaningful application of statistical techniques. Also, the early feedback to designers at this stage minimizes continuous "in-plant" repairs, reduces warranty problems and results in more staisfied customers.

The step-by-step method evolved for handling part removals during manufacturing test is briefly as follows:

<u>Step 1.</u> All parts removed from an equipment type are placed in a box. The high priority items discussed in Step 5 should be segregated by individual compartments for closer surveillance.

<u>Step 2.</u> The parts are checked daily to see if any patterns not previously noted are beginning. This simple check has greatly reduced

the amount of rework by minimizing the number of units exhibiting a new symptom. The parts are collected from the manufacturing area once a week by taking the box with the week's removed parts and replacing it with an empty one. This allows for efficient handling of the parts using two boxes per manufacturing test location.

Step 3. Obtain the production records for the week the parts were collected. Using this and a parts list the total number of parts tested for that period can be established.

Step 4. Calculate the percent removal for each of the parts. This kind of an operation lends itself to computer operation.

Step 5. Determine the 12 parts that have the highest removal rate.

Step 6. Assign priorities to the 12 problem areas selected in Step 5. This priority assignment is based on many things such as, cost of part, cost of replacement, ease of solution of the problem, technical improvement of product, history of field complaints, etc., but the guiding rule is to give highest priority to that problem which, when solved, will result in the greatest overall economic gain.

The above six steps have resulted in a rather objective means of determining where to place the effort. Experience has led us to the conclusion that only the top three priorities should be worked on at a time, unless an inevitable delay is reached on any of the first three problems. Three seems to be enough to keep things moving at a brisk pace while still allowing enough time to really understand the problem so that it need be solved only once.

Once the three top priority problems are selected, the following process for investigating the problem has been evolved (this process is also useful for the investigation of parts removed for any reason, i.e., field removals, special test, etc.). First, all parts in the "top three" category that have been removed from equipment are put through incoming inspection. If the parts fail, an autopsy is performed on a few parts to determine general construction, the actual point of failure, and a possible cause. From this analysis a hypothesis as to the failure mechanism is formulated. Then several more failed parts are checked to see if the hypothesis still appears valid or should be modified.

After a reasonable hypothesis has been established, a sample of new parts is drawn out of stores. Careful quantitative measurements are taken on the sample lot. This is useful in attempting to correlate specific parameter variations to the problem at hand. The measurements need not be confined to the purchase specification, but must not be destructive. If possible, they should be kept as simple as is feasible since these measurements may well form the basis of a screening test or a requirement on a purchase specification. When the parts have been measured, they should be tested in an attempt to reproduce the same failure experienced in the equipment.

If at this point the hypothesis appears to be wrong, a new one must be proposed and the process repeated. Once the hypothesis gains the status of an acceptable theory, then action is almost always quite clear. If the part is at fault, screening, followed by better vendor control or possibly a new vendor, is called for. If the theory points to a faulty manufacturing process, backtracking through the line until the offending process or operator is located is the action called for. Finally, if it appears that neither the part nor the manufacturing is at fault, the problem is referred back to engineering. When this is the case, it is surprising how often the solution results in a more reliable design at a lower overall cost.

If the parts still pass incoming inspection, the approach is slightly different. Engineering is usually called in immediately since they will almost invariable inherit a problem of this type. The first step for parts passing incoming inspection is to take quantitative data on various parameters to determine if any trend exists. In some cases the solution is as simple as picking a new center value for a parameter. Parts at or near one end of the limit condition do not necessarily call for a simple pulling in of one end of the specification. It is possible that overstressing the parts, either in manufacturing or normal operation of the equipment, could cause a shift or nominal value to either extreme. Parts requiring matching quite often show up in removal as parts on both ends of the distribution curve with very few parts in the middle of the distribution.

In general, if removals still pass incoming inspection, the problem is to find that parameter which was not properly specified in the inspection procedures. Care must be taken so that the cost of increased inspection is not more than the cost of locating and removing the defective part. Although I am sure that one could devise such a situation, I have never run into a case where, if the percent removals were greater than 1%, a suitable, economical incoming test could not be devised.

2.4.2 Determination of Top Priority Items

Figure 12 shows the form used for determining the priority of the top twelve problems. The first five columns (part, cost, number used, number removed and % removed) are self explanatory. The sixth column, "total cost", is determined by adding the cost of isolating and correcting a malfunction (a conservative figure of $3.00 per part was used for this example) to the cost of the part (column 2) and multiplying by the number of parts removed (column 4). The total cost represents the maximum savings that can be realized for the quantity of equipment involved if that part were never removed again. Since the goal, for economic reasons, has been set at reducing removals of a particular part to less than one percent, column seven (savings for 1% removal) indicates the minimum savings that could be realized for the quantity of equipment involved, if the 1% goal were attained. Practically, the actual saving lies between the dollar values shown

PRIORITY EVALUATION CHART

PART	COST	NO. USED	NO. REMOVED	% REMOVED	*TOTAL COST	SAVINGS FOR 1% REMOVAL	"BREAK-EVEN" INCREASED PART COST
A	$ .38	286	127	44.0	$ 429.26	$ 419.61	$ 1.47
B	2.11	215	31	14.4	158.41	147.42	.68
C	1.23	1090	61	5.6	258.03	211.92	.19
D	1.96	1446	86	5.9	426.56	355.24	.24
E	2.95	1408	142	10.0	844.90	775.20	.55
F	.90	585	58	9.9	226.20	203.38	.34
G	.95	4569	194	4.2	766.30	585.82	.12
H	.65	1031	84	8.0	306.60	269.21	.26
I	1.25	3804	146	3.8	620.50	458.83	.12
J	1.11	1085	50	4.6	205.50	160.91	.14
K	1.50	1980	183	9.2	823.50	734.40	.37
L	1.75	560	53	9.4	251.75	225.15	.40
TOTAL		(18,059)	(1215)	6.7	($5,317.51)	($4,547.09)	

* Total cost includes the cost of the part plus $3.00 labor per part.

FIGURE 12

in column six and column seven. The figures in column seven are determined by taking 1% of the number of parts used (1% of column 3) and multiplying the part cost plus the cost of isolating and correcting the malfunction and subtracting it from the dollars in column six. Column eight ("Break-Even" increased part cost) shows the increased cost that could be incurred, per part, if the removal rate were lowered to 1%. The "Break-Even" increased part cost is determined by dividing the savings for 1% removal (column 7) by the number of parts used (column 3).

For the example shown in Figure 12, the top three priority items would probably be parts E, K and G in that order. However, when a "break-even" increased part cost is as high as item A, it is adviaable to take a look at that item to see if a higher quality part could solve the high removal rate problem quickly.

2.4.3 Failure Analysis Case Histories

Once an item is isolated for further investigation a comprehensive evaluation program should be initiated. Perhaps the best way to illustrate this is with some case histories.

2.4.3.1 Case I - High Voltage Capacitor Selection

The field had been narrowed down to three possible suppliers of a certain capacitor. All three were being sold to the same specification, and there was no price differential. It was decided to check breakdown voltage distribution for each of the three capacitors. Figure 13 shows the distribution for each supplier as a function of the specified breakdown voltage. It is obvious that, if the test were a valid one, supplier C would be the best. A sample of each type was assembled into equipments. The test, in fact, supported the contention that supplier C was superior. The equipment was run for 100 hours and supplier A had about 25% failures; supplier B had no

DISTRIBUTION OF CAPACITOR BREAKDOWN VOLTAGES FOR THREE DIFFERENT MANUFACTURERS FOR THE SAME COMMERCIAL SPECIFICATION

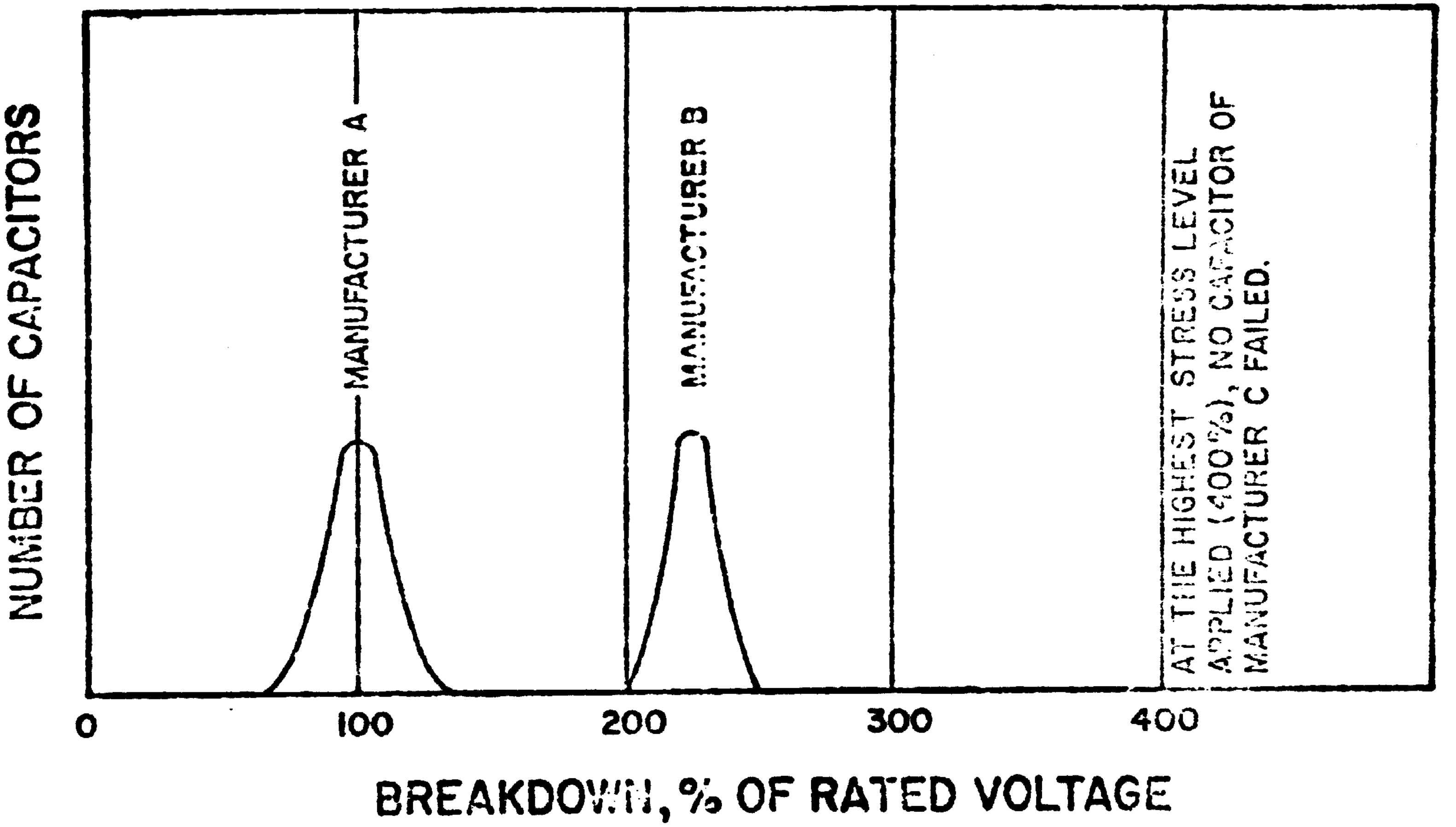


FIGURE 13

failures in test but about a 3% failure rate on incoming inspection. Supplier C had no failures in incoming or during the test. Over 4000 of supplier C's capacitors have been assembled into equipment with no known failures to date.

An analysis of the three types of capacitors showed that supplier C had better winding techniques than either of the other suppliers. The failures could always be traced to a crease in the foil that caused excessive voltage gradients.

This is a simple example of differences between suppliers. The most significant thing about the investigation is that the decision was made, based on the data in Figure 13, in one afternoon of testing.

2.4.3.2 Case II - Radio Noise Screening of Deposited Carbon Resistors

The technique of screening resistors by means of noise analysis 2,3 has progressed to the point where it is included in many purchase specifications. Before embarking on a program of noise analysis of resistors it would be well to study the referenced material. Generally speaking, there are two types of noise -- that expected due to such things as thermal noise, normal processing and fabrication, size, shape, and the bulk noise of the resistive material, and unexpected noise due to such things as high current density areas (see Figure 14) or loose end caps. The expected noise level on one type of resistor may well be above the unexpected noise level of an unreliable resistor of another type.

In the case discussed below there was a removal rate of approximately 25% on a certain carbon film resistor. All resistors removed from the end product showed higher resistance values than the specification called for. The resistor had a conformal epoxy coating and therefore it was decided that a plastic sleeving was to be put over the resistor for protection. A review of the manufacturing process

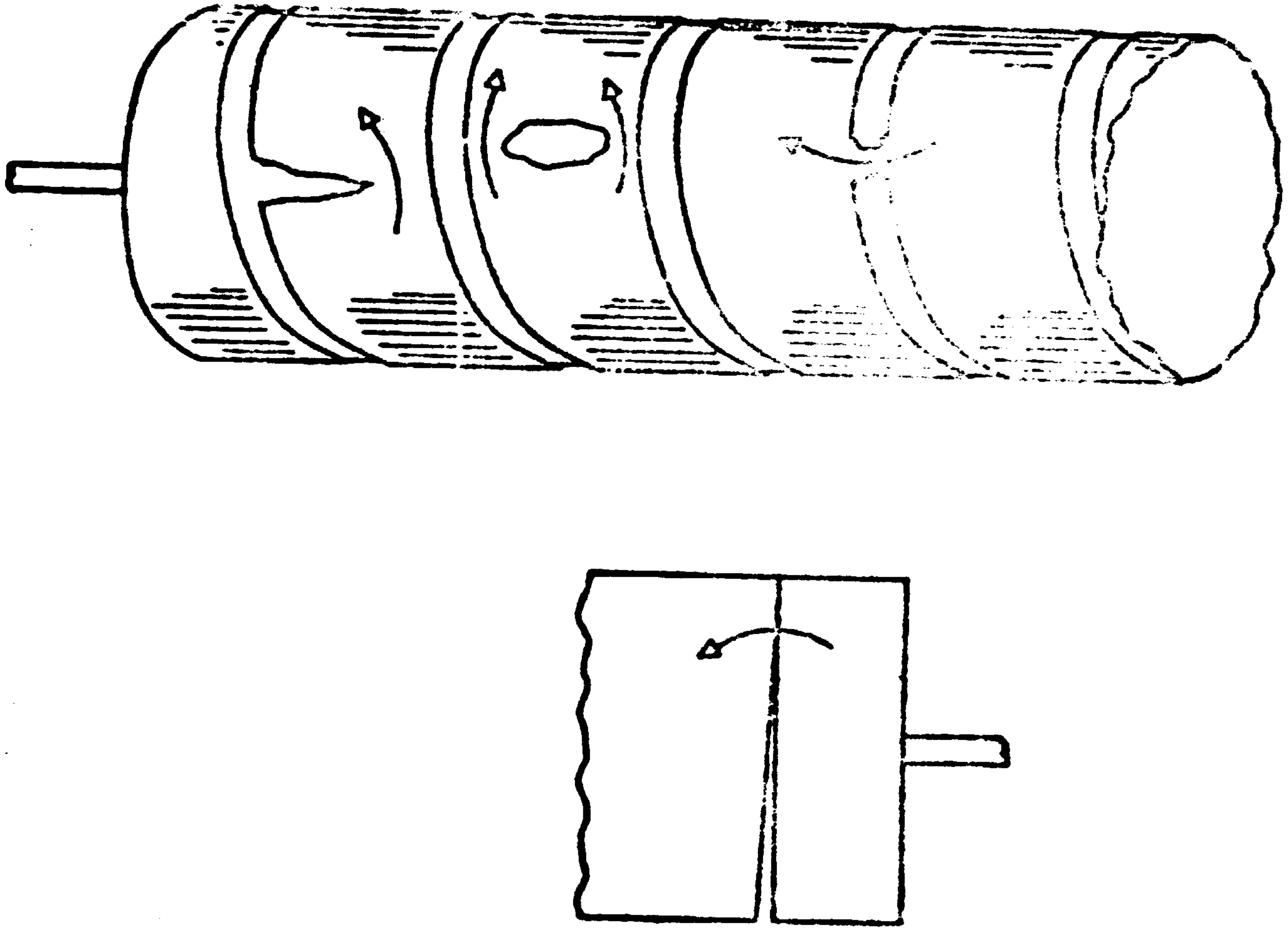


FIGURE 14

HIGH CURRENT DENSITY AREAS
OF FILM RESISTORS

revealed that the lubricant used to slide the plastic sleeve on the resistor would also dissolve the epoxy coating. Therefore, the hypothesis was established that some of the lubricant was trapped under the plastic coating which in turn created hot spots in the resistors and caused the resistors to fail.

To check this hypothesis two sets of resistors were made up. One set used the epoxy dissolving lubricant to apply the protective sleeving and the other set used no lubricant at all. Sure enough, about 25% of the first set failed but, alas, so did about 25% of the second set.

A new hypothesis was required. About this time we were fortuate enough to have available a Quan Tech model 327 diode noise analyzer. Nineteen resistors were tested on the noise analyzer. It was noted that there were significant differences in the noise level of some of the resistors. Because of power supply limitation, only six resistors could be run under simulated circuit conditions. The six resistors selected for test had the following noise readings:

RESISTOR NUMBER	NOISE, mv.	ARBITRARY NOISE MAGNITUDE
6	0.8 erratic	8
11	0.13	1
13	1.2	> 9
17	0.55	5
18	0.25	2
19	0.18	1

Figure 15 shows the percent change in resistance for the first 80 hours of operation. The correlation between noise measurements and resistor performance was 100%. What is also significant is that no difference could be detected (even using careful microscopic inspection) between those resistors that failed in equipment and those that failed as part of the controlled test.

As a result of this small sample testing, a radio noise screening test for these resistors was instituted. A lot of 375 resistors was screened to determine the noise distribution of the resistors. This distribution is shown in Figure 16. The resistors were grouped into arbitrary noise magnitude levels. Each level was 0.1 mv wide. Based on the test results illustrated in Figure 15, all resistors having a noise magnitude of 2 or more were rejected. As a final control, three resistors in the lowest rejectable noise level (noise magnitude 2) were color coded and deliberately put into equipment. All three failed during manufacturing test. Figure 17 shows that the screening test reduced the removal rate from about 25% down to about 1%. Subsequent investigations tend to show that the removal rate could be further reduced by subjecting the resistors to elevated humidity prior to testing.

The final outcome of this problem was a vendor study of similar resistors. The study resulted in obtaining a better resistor at a lower cost. Also, the new resistor selected was the same size but the rating was such that in the circuit the resistor was only operating at about 25% of its rating instead of 67%.

2.4.3.3 Case III - Noise Analysis of Zener Diodes

The removal rate of IN721A diodes in two equipments was excessively high. One case (manufacturer A) was for excessive noise in the circuit and the other case (manufacturer B) was because of erratic behavior of a precision oscillator. All of these diodes that were removed passed incoming inspection and, indeed, met all the requirements for IN721A zener diodes.

One group of diodes was obtained from manufacturer A and a second group from manufacturer B. Also, a third manufacturer, C, was investigated at the same time. The black painted coating was scraped off one diode from each manufacturer. The differences in

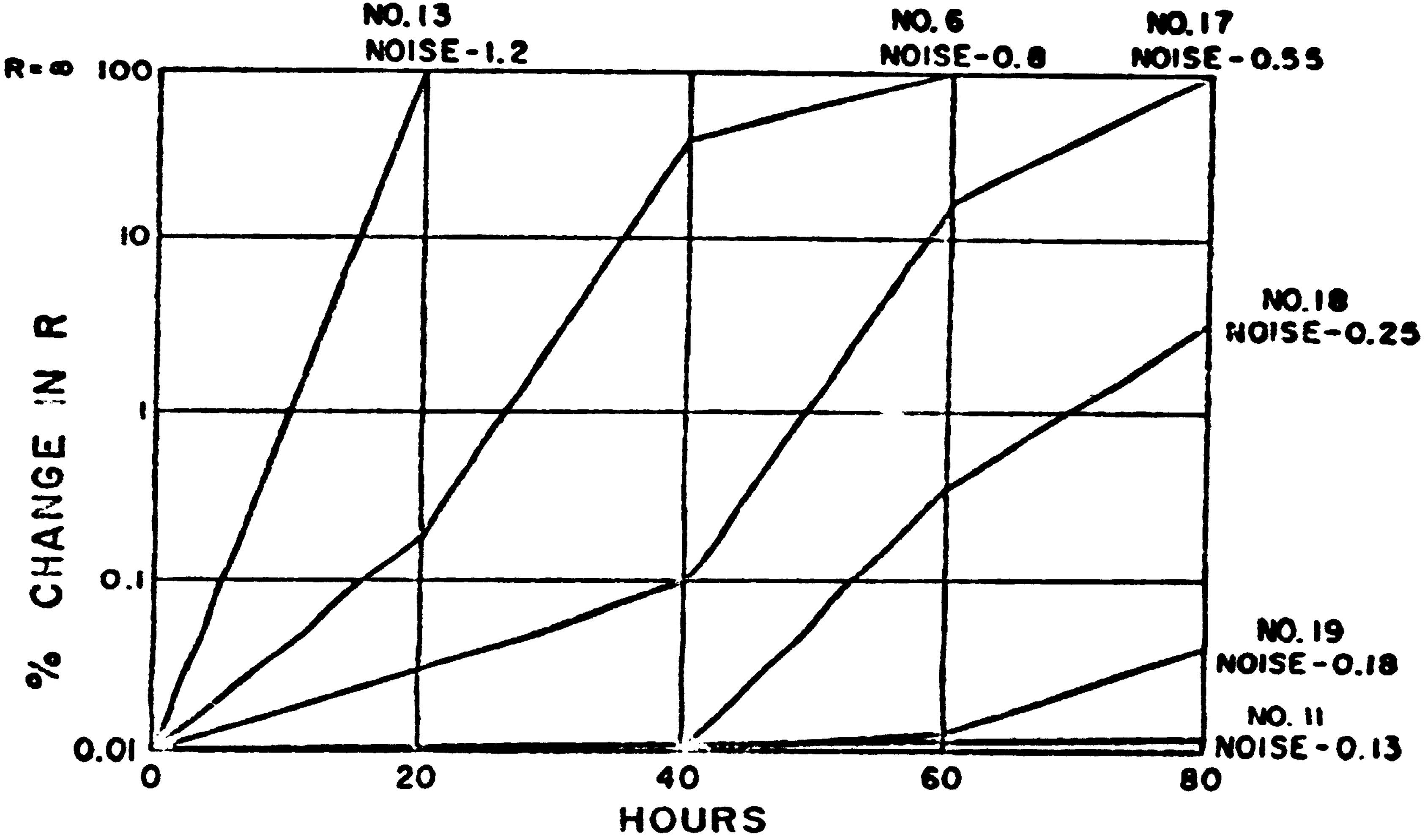


FIGURE 15

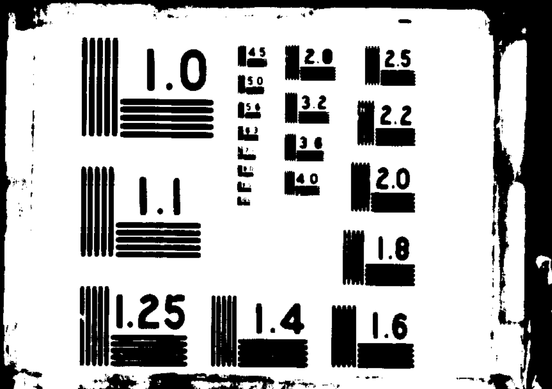
BURN IN OF 6 SELECTED SAMPLES

→

74.10.9

2 OF 2

01153



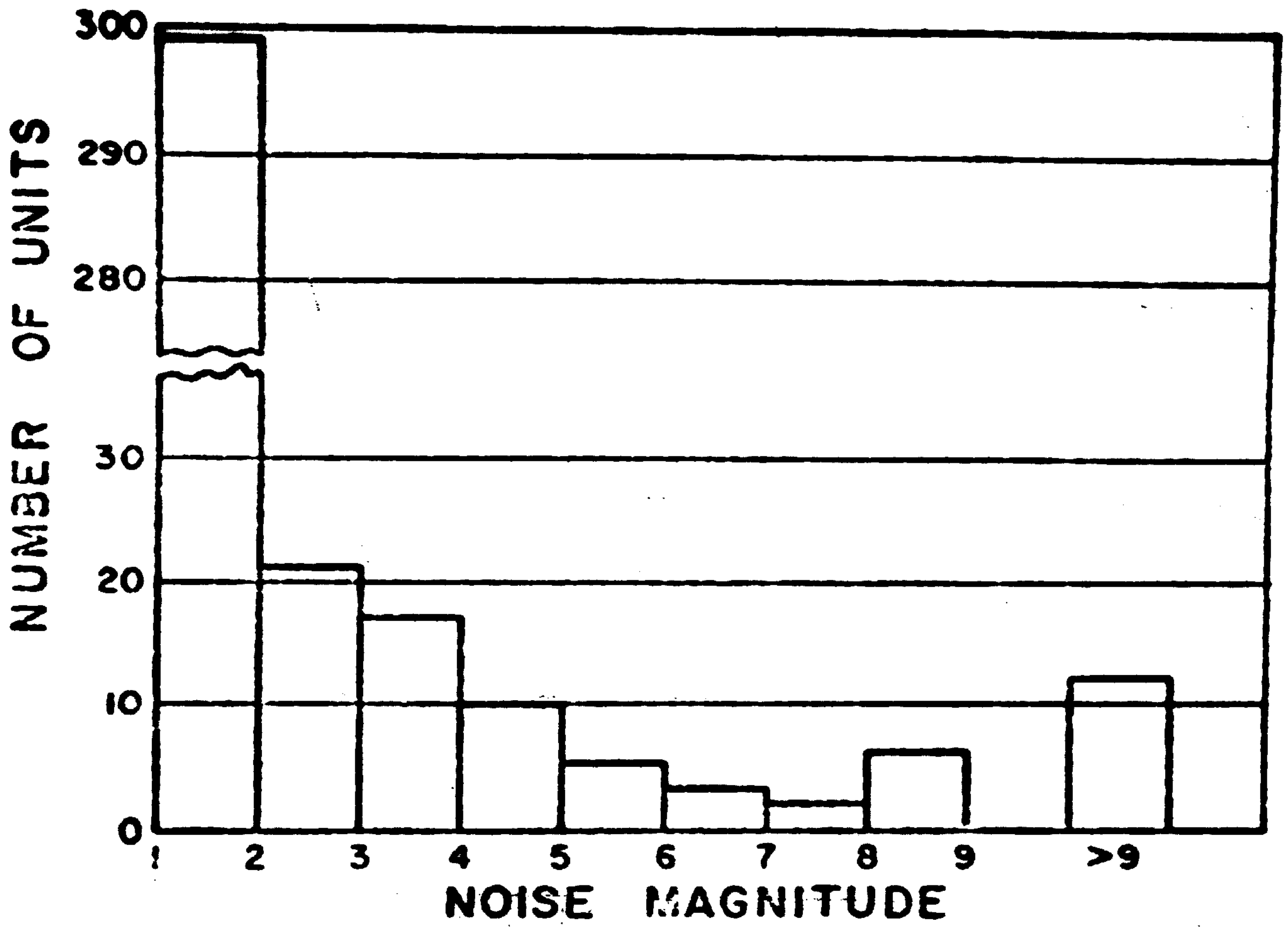


FIGURE 16

NOISE HISTOGRAM OF CARBON FILM RESISTORS

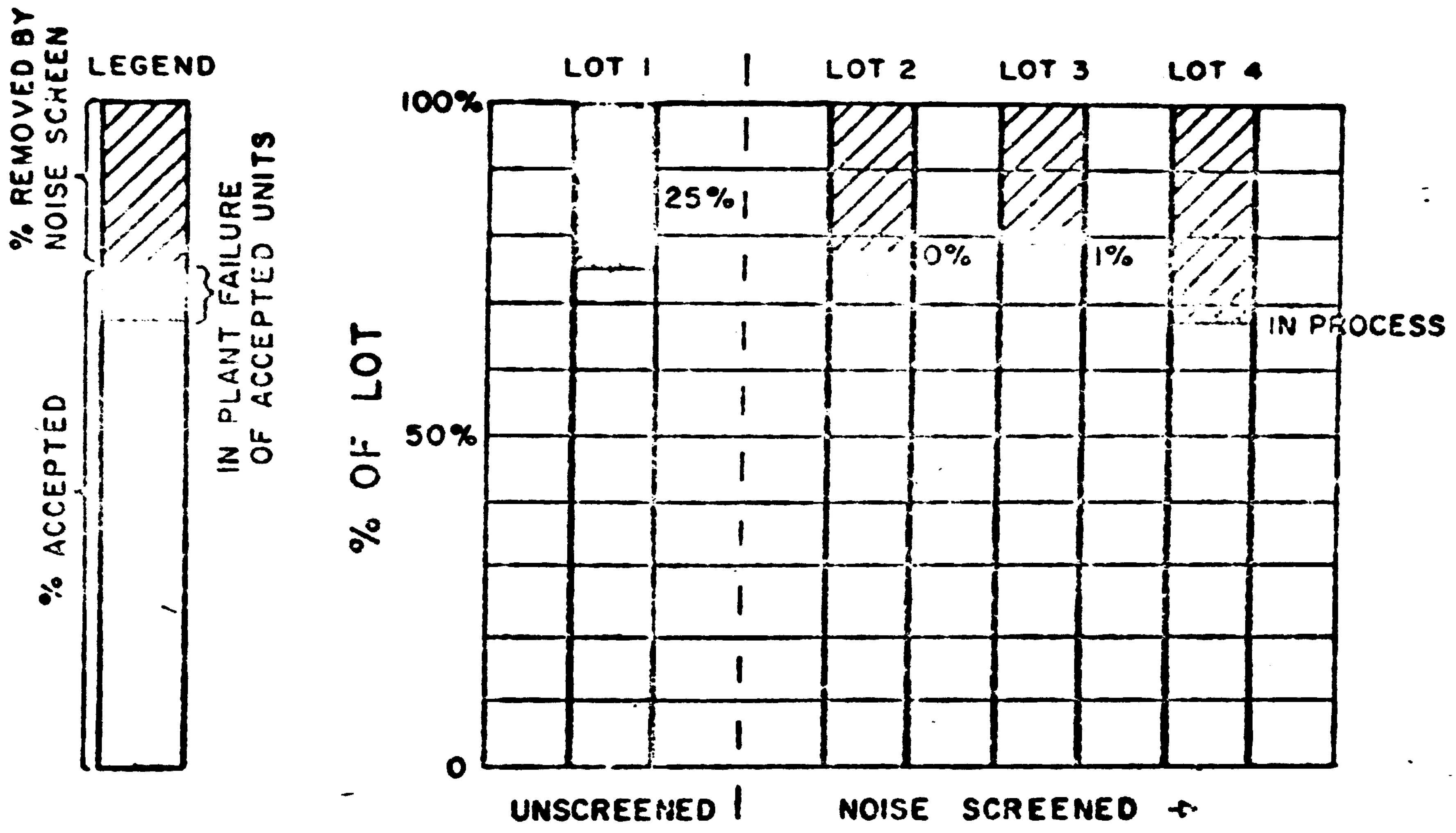


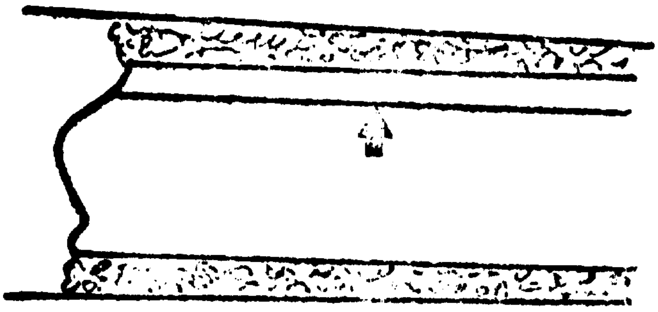
FIGURE 17

IN PLANT HISTORY OF CARBON FILM RESISTORS physical construction between the three diodes were obvious even without a microscope. The diodes were ported in clear epoxy and sectioned. Then the samples were etched to bring out the diode junctions and a picture of the junction area was taken at 100X magnification. Drawings made from these pictures for diode manufacturers A, B and C are shown in Figure 18. The arrows denote the junction.

The differences between the diodes were not limited to physical construction alone. There were also significant differences in the basic processes in making the diodes. Manufacturer A used a diffused junction with boron as the P dopant. and phosphorous as the N+ dopant. Manufacturer B used an etched alloy technique for making the junction with aluminum silicon eutectic as the P dopant. Manufacturer C, as did Manufacturer A. used boron as the P dopant and phosphorous as the N+ dopant, but used a planar method for producing the junction. Manufacturer C also used a process which caused the zener breakdown to occur in the internal portion of the junction rather than at the surface. .

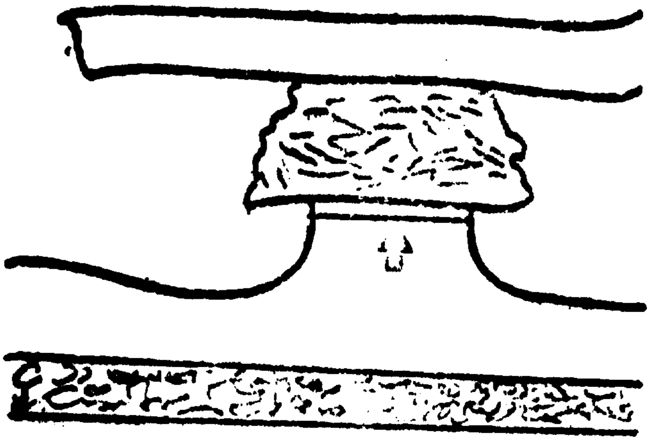
The differences mentioned above also resulted in electrical differences not covered in the IN721A specification but, nevertheless, important to the two circuit applications under investigation.

Five diodes from each manufacturer were selected at random. The noise levels for about the first 250 µa of conduction were viewed on an oscilloscope. The standard diffused silicon wafers' characteristics (manufacturer A) exhibited high noise, multistate breakdown (resulting in junction hot spots) and a large dissimilarity between the 5 diodes. The alloy-type junction (manufacturer B) produces the following characteristics: a high noise level in two diodes, multistating, and non-uniformity of the diode noise characteristics. The characteristic of a planar zener diode (manufacturer C) were designed for bulk breakdown. These diodes have low noise, no multistating and relatively good uniformity.



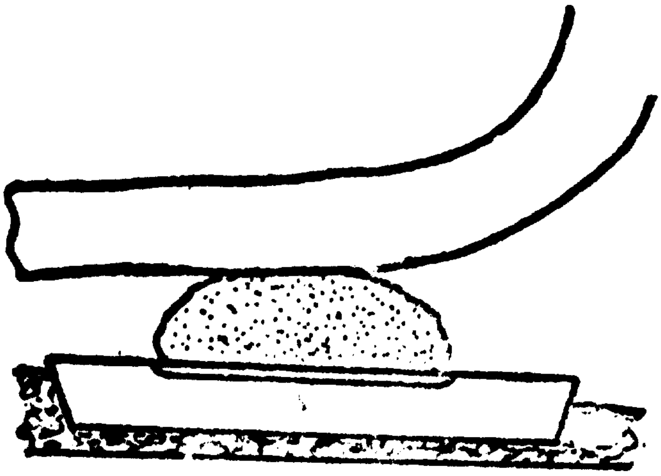
-a-

IN721A Zener Diode - Diffused Junction (boron for P dopant)



-b-

IN721A Zener Diode - Etched Alloy Junction (aluminum silicon eutectic as the P dopant)



-c-

IN721A Zener Diode - Planar Diffused (doped for internal breakdown)

FIGURE 18

ETCHED DIODE SECTIONS
SHOWING JUNCTIONS
100X MAGNIFICATION

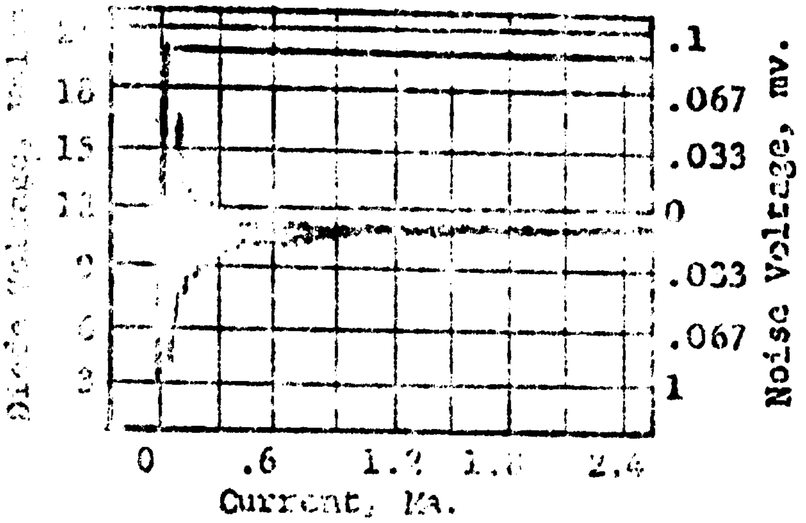
Figure 19 shows the E-I characteristics and the noise voltages generated at diode breakdown for a representative sample from each manufacturer out to 2.4 milliamps of conduction. From this series of pictures it is obvious that supplier C had the least noisy diodes for operation in the malfunctioning circuit where the current range was from 0.5 mils to 1.5 mils. The present theory for this phenomenon is that the junction designed for internal breakdown did not have surface problems which would cause multiple breakdowns of the junction.

The noise characteristics alone did not solve the second diode problem of unstable oscillator performance. Four diodes were selected at random from each of the 3 suppliers. The zener current vs the dynamic impedance was plotted using the diode noise analyzer and an oscilloscope. Figure 20 shows these plots for the 12 diodes. Here again the differences can be traced to the lack of surface problems with supplier C.

Both diode problems were solved by using diodes made by manufacturer C. The cost per diode from manufacturer C was slightly higher than A and B. However, the cost per useful diode after incoming inspection was considerable lower for manufacturer C since about a third of the other diodes would not have been usable in finished equipment.

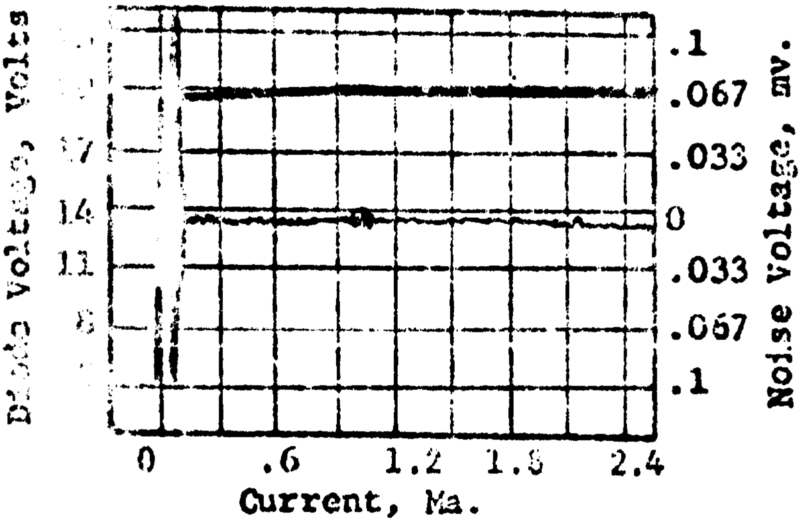
2.4.3.4 Commercial Physics of Failure Laboratory

The first step into the world of failed-part analysis is usually taken with apprehension. Most people lack the knowledge of component construction and, therefore, there is great reluctance to look inside a component. However, those who have entered the field would urge every apprehensive person to start dissecting components for a useful education. It isn't until knowledge gained of possible failure modes caused by various construction techniques that real gains are made in commercial reliability programs. The understanding of components is equally useful whether the problem is one of vendor selection, devising a screening test, or studying a failed component.



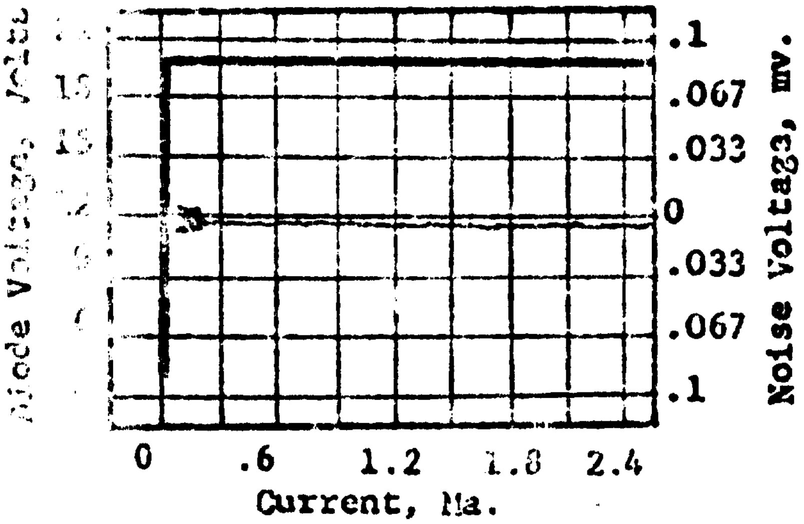
a

Diffused Junction
E-I Characteristics
and
Noise VS Current



b

Alloy Junction
E-I Characteristics
and
Noise VS Current

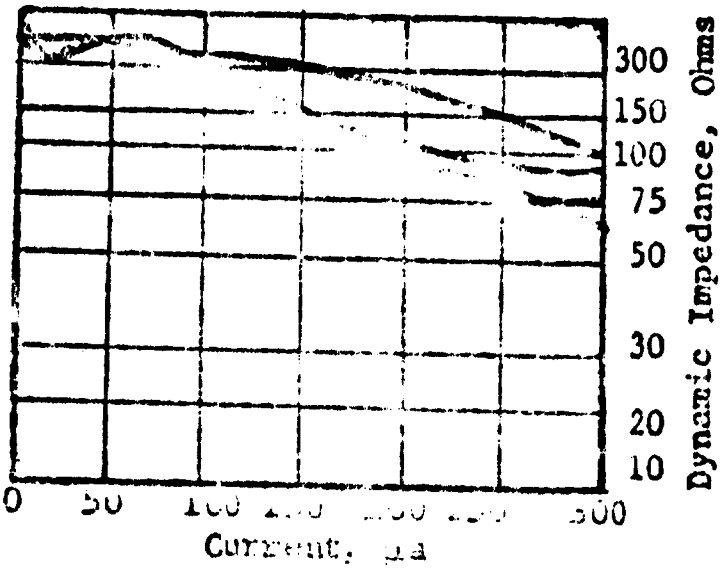


c

Planar Junction
E-I Characteristics
and
Noise VS Current

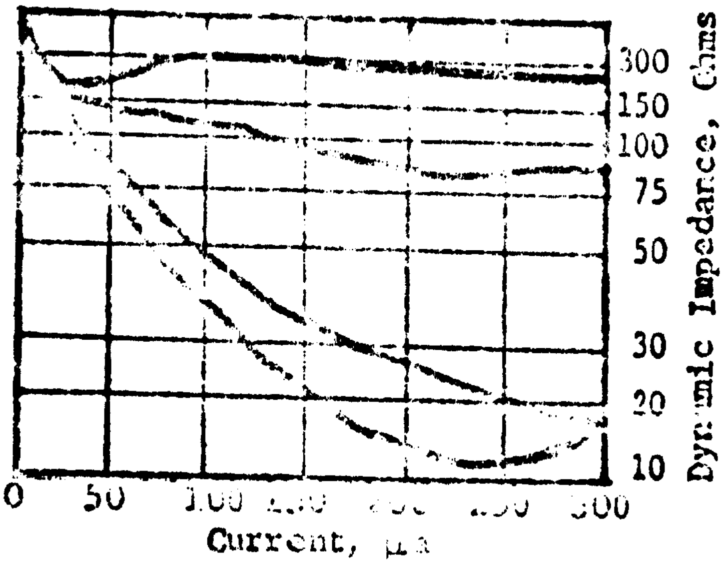
FIGURE 19

Medium Conduction
E-I and Noise Characteristics of IN721A
Diodes from Three Different Manufacturers



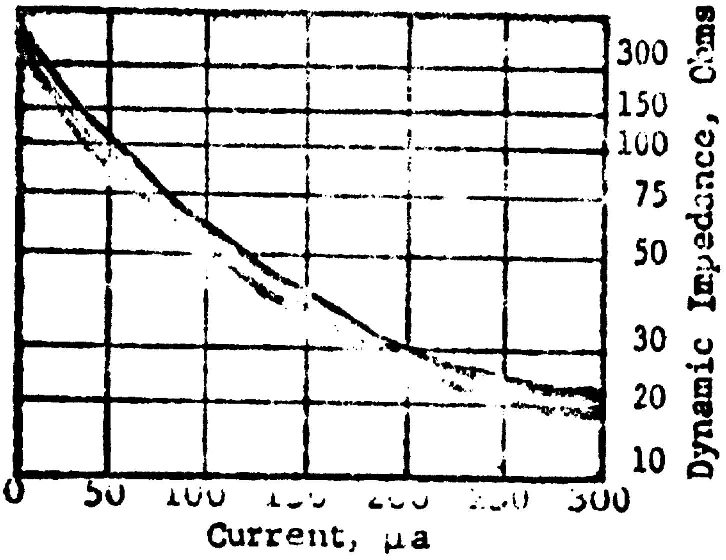
a

**Diffused Junction
Dynamic Impedance
VS
Current**



b

**Alloy Junction
Dynamic Impedance
VS
Current**



c

**Planar Junction
Dynamic Impedance
VS
Current**

FIGURE 20

Dynamic Impedance Characteristics of IN721A Diodes from Three Different Manufacturers

The purpose of a commercial physics of failure laboratory is not for basic research on components, but primarily to gather enough information to make intelligent decisions. The component manufacturer probably knows more about his product than anyone else. Therefore, if enough detailed information is gathered on a specific problem to carry on an intelligent conversation with the manufacturer, he will usually meet you more than halfway in arriving at a sensible solution. However, before a supplier can help, he must be given more to work on than -- "Your components aren't any good - they keep failing."

Summing up, the main functions of the commercial physics of a failure laboratory are:

1. vendor selection and liaison
2. rapid isolation of design, manufacturing, or field problems
3. design of economical screening tests to allow orderly production to continue

The gamut of problems that could arise is exceedingly large. In addition to the three cases cited above, ten more representative problems are outlined in Table V.

From the ten foregoing examples it is obvious that detailed failure analysis can lead down many trails. It does not, however, required an elaborate laboratory to produce cost savings and increase equipment reliability. For example, periodic testing of liquid solder fluxes, cleaning solutions, etc., by using litmus and silver chromate paper to detect acidity and chlorine problems can be carried out for pennies. Example ten above was solved in about two hours using less than one cent's worth of silver chromate paper. If this problem had not been detected and corrected rapidly, thousands of dollars of rework could have been wasted on this item.

Along with simple, rapid, low cost chemical testing equipment, a basic laboratory consists of:

Metallurgical microscope

TABLE V

TEN REPRESENTATIVE PROBLEMS SOLVED BY COMMERCIAL PHYSICS OF FAILURE LABORATORY

PROBLEM	CAUSE	CURE
1. Corrosion on coax delay line.	Excess catalyst in foam epoxy reacted with copper braid.	Changed to foam using a catalyst that did not affect delay line.
2. Sticking of tuning slug in polystyrene body of a variable capacitor.	Soldering temperature caused polystyrene to deform when tuning slug was not entirely within body of capacitor.	Tuning slugs were turned into body before soldering.
3. Shorting of ceramic disc capacitors.	Silver migration.	Changed to better capacitor.
4. Ceramic trimmer capacitors would not turn.	Improper curing process of epoxy moisture proofing -- epoxy only hardened after capacitor had passed incoming inspection.	Capacitors were returned to supplier for replacement parts.
5. Shorted wrap and fill capacitors.	Damaged by soldering aids and irons.	Cautioned workers and added fiber glass tape wrap on capacitors.

TABLE V

PROBLEM	CAUSE	CURE
6. Shorted zener diodes (glass envelope).	Flaking of gold epoxy paste in diode.	Changed to manufacturers not using epoxy paste in diode construction.
7. Shorted zener diodes (metal stud).	Excessive torque used in tightening diodes to chasis caused piercing of mica insulating washers.	Used torque wrench to install diodes.
8. Arcing of high voltage transformer.	Removal of special coating during a cleaning process.	Changed cleaning process.
9. Shorting of some vacuum diodes in a power supply.	Occasional motorboating of an amplifier in another package.	Eliminated an unnecessary capacitor in the amplifier.
10. Low resistance in switch assembly.	Use of unauthorized flux containing chloride.	Continuous education and surveillance is required to minimize this type of problem. Total elimination appears impossible as long as there are people soldering.

Two eyepieces - 4X and 10X
Four objectives - 1.5X, 5X, 10X, 40X
Leitz IPSO microscope-to-camera adaptor
35mm camera back
Vertical illuminator
Microscope lamp
Quan-Tech Model 327 Diode Noise Analyzer
Sears lapidary kit (for preparing samples)
Small oven

In conjunction with normal incoming inspection facilities, the above equipment is all that has been necessary to solve every problem encountered to date. The only major piece (over $200) of equipment purchased for the failure analysis laboratory has been the diode noise analyzer mentioned before. The usefulness of the noise analyzer has not been fully explored as yet, but the amount saved to date has already paid for the equipment several times over. By making only minor modifications in the diode analyzer it has been possible to investigate not only diodes but also transistors and field effect transistors. Of course, resistors and certain types of capacitors can be investigated without modifying the analyzer. I do not want to leave the impression that all problems can be solved through the use of the noise analyzer, but our experience has been that, when carefully used to determine statistically significant differences between parts made by the same process, and the reasons for these differences determined, the noise analyzer can aid significantly in improving a product in the areas of reliability and over-all cost. Probably the biggest advantage of the noise analysis approach is that it offers a good, rapid, non-destructive method of screening out defective components.

Don't underestimate the value of the camera. At first Polaroid was tried, but since then, all pictures have been taken on 35mm Kodacolor X. The cost per print — Polaroid black and white vs Kodacolor X — is about the same. The advantages of using Kodacolor are:

1. Good reproducible color prints are available for reports
2. High-quality slides can be made from the color negative
3. The film appears to have a wide latitude

The major disadvantage of Kodacolor is the time required for processing. At first it was thought that this would be a serious limitation. Because of the wide range of exposures which will yield useful pictures, the number of retakes required has been insignificant.

2.5 COMPONENT SCREENING

The subject of screening parts is a complex and controversial subject. The amount of part screening should be based on the results of the failure modes and effects analysis and the results of analysis on all failed parts. In this manner the screening tests, if required, can be done in the most efficient manner. The screening of integrated circuits no doubt affords the most topical example for detailed discussion.

Integrated circuits are today in about the same situation that transistors were a decade ago. The glamour has worn off, corners are being cut, marginal suppliers have moved into the field to fill the large demands, and even reputable suppliers have several grades of circuits using the same chip design. The pendulum has begun to swing away from the perfection aura that integrated circuits had. People now are beginning to realize that it takes more than the name "integrated circuit" to build highly reliable equipment.

Every time a new device appears on the market the pendulum swings back and forth until all the myths and philosophies are tested and the device is an established item. One of the most common attitudes leading to unreliable parts is, "These parts are just as good as the top grade parts; they probable come off the same production line, and they save me about 25%". The parts probably did come off the same production line, as rejects, perhaps, or they could have been made by a supplier, much like the equipment manufacturer, who bought his raw material on the basis of a trade name and a 25% discount.

There has been much evidence that integrated circuits, properly specified, screened, and handled do, in fact, produce equipments that far surpass the reliability of equipment built using discrete components. There also has been much evidence that equipment built using integrated circuits, without screening, plastic encapsulated, and using "commercial grade" have had lower reliability than the electromechanical devices they were supposed to replace.

The question then becomes how does a prospective buyer or manufacturer of equipment find his way through the maze of conflicting reports. A good way of starting is to understand the basic failure modes of integrated circuits. The comprehensive ten page Table IV shows possible failure modes for integrated circuits.

By sampling a few circuits from various manufacturers and using such techniques as step-stress testing it is possible to find which failure modes are most prevalent from a given manufacturer. With this information available, economical screening methods can be developed to keep bad parts from being assembled into the receivers.

The previous example has been devoted to integrated circuit screening. This is not the only area where efficient screening procedures are useful. The following example concerning the screening of solid tantalum capacitors is a good illustration of an efficient approach to parts screening.

A study of the failure modes of solid tantalum capacitors revealed that better than 90% of the failures were due to breakdown of the tantalum pentoxide dielectric. The next step was to screen the capacitors using some form of power "burn-in". This was effective in removing the weaker capacitors from the lot. However, the process was relatively time consuming and costly. A detailed study of the failure mechanisms revealed that thin spots in the dielectric caused the capacitors to short. Further investigation showed that a simple dissipation measurement at a low (less than 1 volt) DC bias and 60 cps was as effective as the long time power burn-in. Now effective screening can be done in minutes for pennies instead of in hours for dollars.

In general, screening of parts is at a higher level earlier in the program. However, if the results of the screening tests are not closely followed the testing will become inefficient. By carefully analyzing the parts failing the screening tests, more and more efficient testing can be used. Of even greater importance than the better screening techniques, is the information that is available to institute corrective action so that the total product reliability is significantly improved.

2.6 SPECIFICATION FOR PURCHASE ITEMS

The foregoing sections discussed many of the pieces of information required to write a good specification in terms of quality and reliability. For example, if the predicted reliability of a receiver has plenty of margin for a particular requirement, then items specified for that receiver can be purchased from reputable suppliers without any extra screening or testing. Also, the prediction indicates what purchased components or subassemblies contribute the most toward unreliability. Then by knowing the construction and failure modes for a particular item, economical and efficient screening or aging procedures can be added to the general part specification.

2.6.1 Assembled Subassemblies

The more complex subassemblies should probably have an MTBF specified together with a means for determining if the requirement is met, the environment in which the MTBF applies, and the penalties for not meeting the specification. The mean-time-to-repair (MTTR) should also be specified along with the skill level and equipment required to meet the specified MTTR.

The use of 100 hour failure free operation before an assembled item can be accepted is generally a sound investment. Other relatively low cost acceptance testing that has proven effective is thermal cycling, low amplitude single frequency vibration, and simple low level mechanical shock. The thermal cycling usually consists of several cycles moving equipment from a chamber at elevated temperature to one at low temperature. The low frequency vibration is usually done at a nonresonant frequency between 20 and 60 cycles per second at about a 2g. level. The mechanical shock is done at a level low enough not to cause damage to a good piece of equipment but high enough to cause weak equipment to fail. The purpose of all of these tests on assembled items is to remove early failures caused by substandard parts and poor workmanship.

2.6.2 Component Parts

The underlying basis to writing cost effective specifications is that parts made by one same process should have smooth, rather tight, continuous distributions of any measurable characteristic. Another important item to keep in mind is that in order to stay in business a product must be made today with existing components. The problem then is to select the best component from about a half dozen available manufacturers. The solution of this problem is attained by finding differences in component characteristics, both between manufacturers and within a sample from a given manufacturer, and then determining the reasons for the differences.

Once the technical problem of what causes the differences between components is determined, the choice of what part to use becomes one of economics. Some of the costs which must be considered in making a final selection are:

initial cost of part
replacement costs (both in plant and in warranty)
cost of screening
salvage costs for parts not passing screening
gain or loss in sales due to improved or degraded performance

By understanding the failure mechanisms and devising simple, low-cost acceptance criteria using physics-of-failure studies, reduction in the overall cost can be attained while improving performance. The technique of writing tougher specification often does not solve the problem while it almost always increases the cost. This situation is compounded by an apparent law which does not allow for the removal of a requirement once it has been established. There are cases where expensive screening tests were continued for over a year after a design change eliminated the need for such screening.

The reason usually given for not removing an obsolete requirement is that, "the person who established it must have thought it was necessary so why take a chance?" Therefore, before any requirement is added to a specification, a report giving the specific need for the requirement should be referenced in the specification.

The International Electrotechnical Commission whose headquarters are located at 1 Varembé Street, Geneva, Switzerland has a technical committee (TC-56) that is charged with the responsibility of handling international reliability problems. Two publications that would be of interest to developing countries are:

1. Publication 319

   First Edition 1969

   "Presentation of Reliability Data on Electronic Components (or Parts)"
2. Publication 300

   First Edition 1969

   "Managerial Aspects of Reliability"

3.0 POSSIBLE AREAS FOR UNIDO ASSISTANCE

The following discussion covers various areas where UNIDO's assistance could be useful. No attempt is made to list the items in order of importance.

3.1 COMPILE, PUBLISH, AND DISTRIBUTE RELIABILITY AND MAINTAINABILITY HANDBOOK

Although there are many books on reliability and maintainability most of these are compiled for use in highly complex military or space exploration programs where reliability is generally more important than cost. A handbook for the use by developing countries in connection with the production of low cost radio and television receivers should concentrate on information that would allow the manufacture of the lowest cost item that will do the job.

With UNIDO's aid a useful handbook featuring such items, various part construction and the reasons for these differences, failure modes, and hints on writing efficient, economical specifications, could be compiled. Once such a handbook is compiled it should be published through the auspices of UNIDO and then distributed to the developing countries cooperating with UNIDO in producing low cost radio and television receivers.

3.2 INTERCHANGE OF INFORMATION

UNIDO could provide the much needed and important communication information channel between developed and developing countries. One method of accomplishing this is to compile a list of specialists from developed countries in the field of reliability and maintainability who could aid developing countries with their particular problem. Also a clearing house could be set up to which developing countries would apply for help in certain chronic problem areas. Through UNIDO at least a first contact with a specialist could be established.

Problems from various developing countries could be catalogued and progress on these problems could be disseminated to all the developing countries on a quarterly or semi-annual basis. This could help each of the countries from having to solve the same problem over and over again.

3.3 REGIONAL TESTING AND ANALYSIS FACILITIES

It would be most beneficial for each country to do as much of their own testing and analysis as possible. However, for economical reasons and lack of trained personnel, start up problems do present difficulties for developing countries. Therefore, if UNIDO could establish some Regional testing and analysis facilities the result could prove extremely rewarding. Such a facility would train people from the developing countries in the basics of failure analysis and aid in establishing rudimentary failure analysis laboratories in each country.

Another important function that could be performed by a regional facility would be to act as a clearing house for mutual problems. It is not unlikely that many of the countries in a given region would have similar failure patterns of components due to environments peculiar to a region. By having regional facilities, the inefficiencies of solving the same problem many times could be avoided.

A regional facility could also perform testing and evaluation of new parts in a more economical fashion than each individual country.

4.0 SUMMARY AND RECOMMENDATIONS FOR FUTURE ACTION

This paper has outline many of the items that should be considered in order to produce reliable, low cost radio and television receivers. The items discussed include:

1. Reliability Requirements
2. Reliability Prediction
3. Maintainability Consideration
4. Spare Parts Stocking
5. Component Construction
6. Failure Analysis
7. Component Screening
8. Specifications for Purchased Items

It is recommended that under UNIDO direction, the program outlined in this paper be expanded into a useful handbook on reliability and maintainability for developing countries. This could be accomplished by an "Ad Hoc" group selected by UNIDO from both developed and developing countries.

Other items that should be covered by an "Ad Hoc" group would be:

1. Study the feasibility of having regional test and analysis facilities.
2. Cooperate with the reliability group (TC-56) of the Electrotechnical Commission.
3. Compile a list of specialists in the field that could aid developing countries.
4. Recommend that best method of establishing two way communications between developed and developing countries concerning reliability and maintainability.

In order to maximize the success of the UNIDO program on the manufacture of low cost radio and television receivers, modern reliability and maintainability disciplines must be adequately considered. The same discipline that assured a safe trip to the moon and back should aid substantially in maximizing the number of properly functioning receivers in developing countries.

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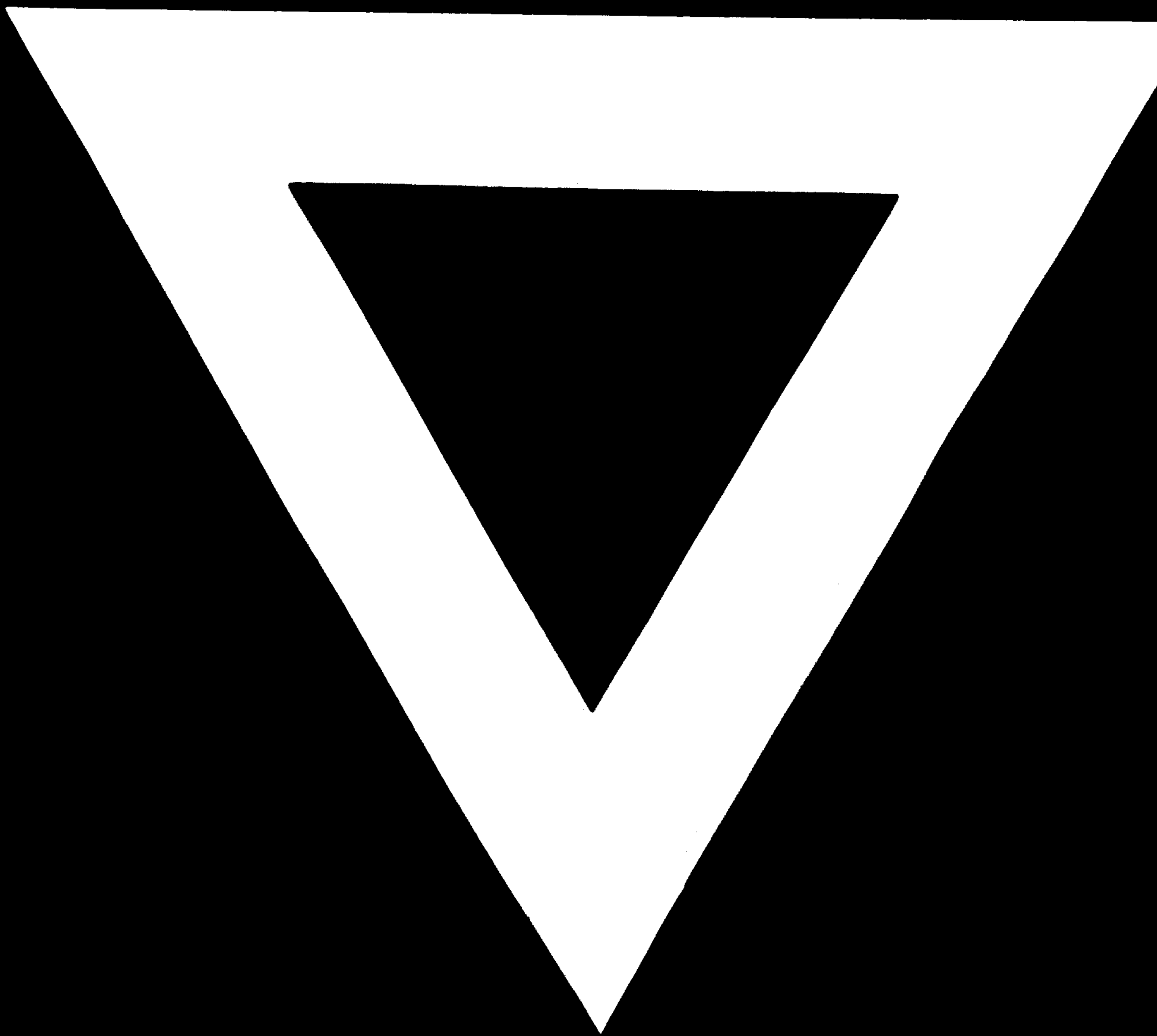

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