1974

Reliability analysis of the University of Missouri–Rolla Reactor

Jimmy Dale Schottel

RELIABILITY ANALYSIS OF THE

UNIVERSITY OF MISSOURI-ROLLA REACTOR

BY

Jimmy Dale Schottel, 1949-

A THESIS

Presented to the Faculty of the Graduate School of the

UNIVERSITY OF MISSOURI-ROLLA

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN NUCLEAR ENGINEERING

1974

Approved By

_______________ (Advisor) _______________

____

ABSTRACT

The reliability of Nuclear Installations is becoming an important area of research. In this report an approach to reliability analysis was made. The actual failure data was utilized to predict theoretical failure distributions. These distributions were then used to determine future reliability of components, subsystems and system.

ACKNOWLEDGEMENT

The author wishes to thank Dr. D. R. Edwards for his guidance and assistance in the preparation of this work. The author wishes to acknowledge the efforts of Dr. A. E. Bolon and Professor R. V. Wolf for their help in reviewing this report. The author wishes to thank his wife, Nancy, for her assistance in preparing figures and tables utilized as well as her encouragement.

TABLE OF CONTENTS

Page

ABSTRACT ii

ACKNOWLEDGEMENT. iii

TABLE OF CONTENTS. iv

LIST OF ILLUSTRATIONS. vi

LIST OF TABLES vii

I. INTRODUCTION. 1

II. BACKGROUND AND THEORY 2

A. Mathematical Reliability Expressions. 2

1. Break-In Failures 2

2. Random Failures 2

3. Wearout Failures. 4

B. Chi-Squared Goodness-of-Fit Test. 5

III. ANALYSIS. 8

A. Data Collection 8

1. Data Sources. 8

2. Data Collection Criteria. 8

3. Data Accumulation 8

B. Analysis of Data. 9

C. Data Interpretation 11

IV. RESULTS 14

A. Results of Data Analysis. 14

1. Graphical Analysis. 14

2. Chi-Squared Test. 14

B. Results of Data Interpretation. 30

TABLE OF CONTENTS (cont.)

Page

V. RECOMMENDATIONS 43

VI. CONCLUSIONS 46

BIBLIOGRAPHY 47

VITA 48

APPENDICES 49

A. PROGRAM RELIABLE. 49

B. PROGRAM RELIPLOT. 57

C. PROGRAM RELICOMP. 59

D. PROGRAMMING GUIDE 65

LIST OF ILLUSTRATIONS

Figure		Page
1.	FAILURE DISTRIBUTION FOR MAGNET AND POWER SUPPLY.	16
2.	FAILURE DISTRIBUTION FOR SHIM ROD CONTROLS.	17
3.	FAILURE DISTRIBUTION FOR TOTAL SHIM ROD CHANNEL	18
4.	FAILURE DISTRIBUTION FOR STARTUP FISSION CHAMBER.	19
5.	FAILURE DISTRIBUTION FOR STARTUP AMPLIFIER.	20
6.	FAILURE DISTRIBUTION FOR LINEAR PULSE AMPLIFIER	21
7.	FAILURE DISTRIBUTION FOR STARTUP CHANNEL.	22
8.	FAILURE DISTRIBUTION FOR LINEAR POWER CHANNEL	23
9.	FAILURE DISTRIBUTION FOR COMPENSATED ION CHAMBER.	24
10.	FAILURE DISTRIBUTION FOR LOG N & PERIOD AMPLIFIER	25
11.	FAILURE DISTRIBUTION FOR LOG N RECORDER	26
12.	FAILURE DISTRIBUTION FOR PERIOD RECORDER.	27
13.	FAILURE DISTRIBUTION LOG N & PERIOD CHANNEL	28
14.	FAILURE DISTRIBUTION FOR SAFETY AMPLIFIER	29

LIST OF TABLES

Table		Page
I.	Systems, Subsystems and Components to be Analyzed	7
II.	Results of Visual Curve Interpretation	15
III.	Reliability Changes Due to Quality Improvements in the Magnet and Power Supply A, B, or C	31
IV.	Reliability Changes Due to Quality Improvements in the Shim Rod Controls A, B, or C	32
V.	Reliability Changes Due to Quality Improvements in the Startup Fission Chamber	33
VI.	Reliability Changes Due to the Quality Improvements in the Startup Preamplifier	34
VII.	Reliability Changes Due to the Quality Improvements in the Linear Pulse Amplifier	35
VIII.	Reliability Changes Due to the Quality Improvements in the Linear Power Channel	36
IX.	Reliability Changes Due to the Quality Improvements in the Compensated Ion Chamber	37
X.	Reliability Changes Due to the Quality Improvements in the Log N & Period Amplifier	38
XI.	Reliability Changes Due to the Quality Improvements in the Log N Recorder	39
XII.	Reliability Changes Due to the Quality Improvements in the Period Recorder	40

LIST OF TABLES (cont.)

Table Page

XIII. Reliability Changes Due to the Quality Improvements in the Safety Amplifier. 41

XIV. Reliability Changes Due to the Quality Improvements in the Magnet & Power Supply A, B, or C and Shim Rod Controls A, B, or C. 42

I. INTRODUCTION

In this report, the reliability of the University of Missouri-Rolla Reactor is examined. To perform this study, records of components and systems have been studied to verify how they fail and therefore influence the reactor reliability. To better understand the meaning of reliability the following definition by Bazovsky is provided:[1]

> "The reliability of a component is its conditional probability of performing its function within specified performance limits at a given age for the period of time intended and under the operating stress conditions encountered."

The type of distribution which best fits the actual data is examined. The random and wearout distributions are checked for fit to the actual failure curves.

II. BACKGROUND AND THEORY

A. Mathematical Reliability Expressions

In any equipment there are three types of general failure modes. The early "break-in" failures follow a type of exponential distribution. Random or "middle of life" failures follow an exponential distribution. End of life or "wearout" failures are represented by a normal distribution.[1,2,3] The combination of these three distributions form the well-known "bathtub" shaped reliability curve.

1. Break-in Failures

Break-in failures occur when substandard components are inserted into an operating system. In the University of Missouri-Rolla Reactor, which has been in operation for thirteen years, the records do not show any significant indications of this type of failure. This is a result of maintenance of the system with repair not replacement. Therefore, this distribution will not be utilized in this analysis.

2. Random Failures

It is recognized that for most applications the random distribution is the best fit to the actual failure distributions. Garrick and Gekler stated in Nuclear Safety the following:[3]

"During the conversion of experience data to appropriate failure-rate and failure-distribution functions, little statistical support can be found for using a particular distribution function. Examination of the background from which the data are derived, as well as similar practices where statistics are being used for reliability estimates, does suggest that the exponential or random failure distribution is presently the best choice. Specific considerations indicating this choice are the following:

1. In industries using reliability analysis, the exponential distribution is by far the most frequently used because it is commensurate with the quality of the data being utilized and has been shown to be analytically appropriate for complex systems containing many parts with only very weak constraints of the type of life distribution for the parts. ..."

Solid state electrical components, which are not subjected to heat, mechanical vibration or other adverse environmental effects, should exhibit random failures. Random failures for electrical systems should be expected.

In systems with many different components the overall system should exhibit random failure even if the individual components behave in some other manner. An analysis will be performed to investigate this situation.

The relationship for the exponential distribution is:

$$R(t) = R_o e^{-\lambda t}$$

where: R_o is the original number of components at time zero.

λ is the decay constant equal to the reciprical of the mean failure time.

t is time.

R(t) is the remaining number of components at time t. For this analysis the expression

$$R(t)/R_o = e^{-\lambda t}$$

will be utilized as a fraction of remaining components.

3. Wearout Failures

When components are allowed to approach the end of their useful life they exhibit a normal distribution of failures about a mean value. As indicated in two reports by NUS Corporation,[4,5] most statistical analyses of Nuclear Power Systems do not analyze the possibility of wearout failures. An analysis will be performed to verify if any components or systems exhibit this type of failure in this report.

The expression for the normal distribution used in this report is:

$$R(t) = \frac{R_o}{2}\left(1 - \mathrm{erf}\left(\frac{t-M}{\sqrt{2}\sigma}\right)\right)$$

where: R_o is the original number of components.

M is the arithmetic mean time to failure.

σ is the statistical deviation about the mean.

t is time.

R(t) is the number of remaining components at time t.

erf is the error function.

For this analysis the following form of this expression will be utilized:

$$R(t)/R_o = 1/2(1 - \mathrm{erf}(\frac{t-M}{\sqrt{2}\sigma}))$$

as a fraction of remaining components.

B. Chi-Squared Goodness-of-Fit Test

Mack states the chi-squared goodness-of-fit test was developed by Karl Pearson in 1899.[2] Dr. H. A. Wiebe suggested the chi-squared goodness-of-fit test as a method of determining curve fit.[6] In a similar type of report by NUS Corporation[4] the chi-squared goodness-of-fit test was utilized to justify the use of the exponential distribution. The chi-squared goodness-of-fit test has several assets which make it useful for this analysis. In Reliability Engineering the following is stated:[7]

> "1. Chi-square does not require the hypothesized population parameters be completely known in advance.
>
> 2. Chi-square can be partitioned and added.
>
> 3. Chi-square can be applied to discrete populations."

The availability of tables of chi-squared values makes the analysis easier to follow and analyze.

The relationship for the chi-squared goodness-of-fit test is given in Reliability Engineering as:[7]

$$\chi^2 = \sum_{i=1}^{N} \frac{(r_i - n_i p_i)^2}{n_i p_i (1-p_i)}$$

where: r_i is the number of observed frequencies in the i^{th} interval.

n_i is the number of components at time t_i.

$p_i = 1 - R(t_i)/R(t_{i-1})$

where: t_i is the right-hand end point of the i^{th} interval. This relationship will be used in this report as a tool of comparison.[2]

> "The use of the chi-squared test requires that the degrees of freedom (ν) of the critical χ^2 is given by the following rule:
>
> ν = Number of classes - Number of relations between observed and expected frequencies ..."

Thus for the exponential case:

ν is the number of intervals - 1

and for the normal case

ν is the number of intervals - 3.

By using these relations the tables presented in Essentials of Statistics by C. Mack[2] can be used for the purposes of comparison.

Table I. Systems, Subsystems and Components to be Analyzed.

System	Subsystem	Component
Total Shim Rod Channel	Shim Rod Controls	Shim Rod A Controls Shim Rod B Controls Shim Rod C Controls
	Magnets and Power Supplies	Magnet A Magnet B Magnet C
Start-up Channel	--------	Start-up Fission Chamber
		Start-up Preamplifier
		Linear Pulse Amplifier
Linear Power Channel	--------	--------
Log N & Period Channel	--------	Compensated Ion Chamber
		Log N & Period Amplifier
		Log N Recorder
		Period Recorder
Safety Amplifier	--------	--------

III. ANALYSIS

A. Data Collection

1. Data Sources

The University of Missouri-Rolla Reactor Log Book served as the main source of failure data. From initial operation until October of 1968, the Operating Log was the sole source of failure data. After that date until January of 1971, the Reactor Work Log contained supplemental information which was used in data collection.

2. Data Collection Criteria

In order to collect failure data, the following data collection criteria were established. A failure was defined as any discovered malfunction which could keep a system from performing its normal operating functions as intended. A component which indicates weakness during testing is considered a failed component if replacement is necessary.

Table I shows the systems, subsystems, and components chosen for this analysis. These divisions were chosen because of availability of failure data.

3. Data Accumulation

The raw failure data was arranged in chronological order by components or systems, as applicable. The increments of time between these dates were tabulated. These values are the actual values which are used in the analysis. In cases where different subsystems combine into a system the failures for the whole system are treated as if the system were a component. The dates are arranged, in chronological order, then the differences between the dates were tabulated. These actual values of failure times are plotted on Figures 1 through 14.

Using the week as the basic time unit, these values were utilized as input to program RELIABLE (see Appendix A). Program RELIABLE will sort this data in increasing order of time. Program RELIABLE was developed for this analysis.

B. Analysis of Data

The computer program RELIABLE was utilized to establish which of the two theoretical distributions, exponential or normal, approximates the curve of the actual failure points. This program calculated the exponential percentage, normal percentage and the actual percentage of survival chances for the times corresponding to each measured time value.

Program RELIABLE also performs a chi-squared goodness-of-fit test for the actual data versus each of the two theoretical distributions. This test is based upon the analysis presented in References 2 and 7. The chi-squared values are from the relation:[2,7]

$$\chi^2 = \frac{(r_i - n_i p_i)^2}{n_i p_i (1-p_i)}$$

where: r_i is the actual number of failures in interval i.

n_i is the number of components left at the beginning of interval i.

p_i is the conditional probability of failure in the i^{th} interval, given nonfailure in the previous intervals (i-1,i-2,...,1).

That is:

$$p_i = 1 - R(t_i)/R(t_{i-1})$$

where: $R(t_i)$ is the theoretical value of the fraction of components left at the beginning of time interval i. For this analysis:

$$R(t_i) = e^{-\lambda t_i}$$

for the exponential case and

$$R(t_i) = 1/2\mathrm{erfc}\left(\frac{t_i - M}{\sqrt{2}\sigma}\right)$$

for the normal case

where: λ, M and σ are as previously defined and erfc is the complementary error function.

For the purpose of this analysis r_i was arbitrarily set at five for computer analysis. The theoretical failures, $n_i p_i$, were then determined from the corresponding times corresponding to every fifth value by program RELIABLE. These chi-squared values can be added for each component with several points then compared, utilizing the chi-squared values listed in Table A.5 of Reference 2.

The curves developed from the actual distribution, exponential distribution and normal distribution became the final deciding factor upon which of the two theoretical curves more closely approximates the actual values. These curves were obtained from the program RELIPLOT (see Appendix B), which was developed for this study, utilized the output of program RELIABLE as input. These curves are shown in Figures 1 through 14. These plots were performed on the University of Missouri-Rolla Calcomp Plotter.

C. Data Interpretation

Visual interpretation of the curves produced by program RELIPLOT were performed to determine if the actual distribution is approximated better by the exponential or normal distribution. This analysis determined which of the two theoretical distributions should be used in the subsequent reliability analysis.

For the curves which are deemed to be exponential, the value of λ calculated from program RELIABLE was utilized as input for program RELICOMP (see Appendix C). For this routine the value of M, the mean time of failures, is defined as the reciprical of λ. Program RELICOMP will use these values to perform reliability predictions for the exponential components and systems.

The values of λ and σ from program RELIABLE were used as input to program RELICOMP for the curves which fit the normal distribution.

Program RELICOMP will calculate component, subsystem, system and reactor reliabilities for the time periods of one week, one month, three months, six months and one year. For each time period the component reliabilities are multiplied to give the subsystem reliability, the subsystem reliabilities are multiplied to give the system reliability and the system reliabilities are multiplied to give the reactor reliability. These calculations are repeated for each time period.

The effect of increasing component and system quality are interpreted by program RELICOMP. This increase in quality can be accomplished by various means. The quality can be enhanced by changing the original purchase specifications to provide higher standards during fabrication. Preoperational testing of components and systems can help to eliminate potential problem areas which are encountered during the test. Systematic planned surveillance checks would point out potential failures so that repairs can be made to prevent the failure. Scheduled maintenance can replace weakened components and extend the life of components subject to wear. Periodic replacement of components subjected to adverse environmental conditions would reduce the chance of wearout failure.

For this analysis many runs of program RELICOMP were performed. For each subsequent run the value of λ for one component was altered to reflect increased quality and the subsequent change in overall reliability caused by this alteration. For each case the reliabilities of the other components and system are left in their "as found" states. For each component the reliability is multiplied by two and then by five to reflect quality improvements which could be made with reasonable effort. In the case of the Magnets and

Power Supplies (components) and Shim Rod Controls (components) all three components (A, B and C) were changed at the same time because any alterations in the quality of one would affect all three.

IV. RESULTS

A. Results of Data Analysis

1. Graphical Analysis

The results of program RELIPLOT are shown in Figures 1 through 14. From visual inspection Table II was developed. As shown most curves exhibit random failures which are better defined by the exponential distributions. The Shim Rod Controls (subsystem), which are mechanically operated systems, are the only components which exhibit wearout failures better defined by the normal distribution. It must be noted that the graphical distinction on the Shim Rod Controls is not as definitive as on the other curves.

2. Chi-Squared Test

There are three systems or subsystems which have sufficient data to permit valid chi-squared comparisons. The first of these is the Magnets and Power Supplies (subsystem). In this case the χ^2 value for the exponential comparison is 4.5 with 4 degrees of freedom and the χ^2 value for the normal comparison is 17.2 with 2 degrees of freedom. From the tables in Reference 2, it is evident that this test confirms the visual curve interpretation. The second case is the Shim Rod Channel (system). In this case the exponential comparison has a χ^2 value of 3.9 with 6 degrees of freedom and the normal

Table II. Results of Visual Curve Interpretation.

System, Subsystem or Component Name	System, Subsystem or Component	Theoretical Failure Distribution
Magnet and Power Supply	Subsystem	Exponential
Shim Rod Controls	Subsystem	Normal
Total Shim Rod Channel	System	Exponential
Start-up Fission Chamber	Component	Exponential
Start-up Preamplifier	Component	Exponential
Linear Pulse Amplifier	Component	Exponential
Start-up Channel	System	Exponential
Linear Power Channel	System	Exponential
Compensated Ion Chamber	Component	Exponential
Log N & Period Amplifier	Component	Exponential
Log N Recorder	Component	Exponential
Period Recorder	Component	Exponential
Log N & Period Channel	System	Exponential
Safety Amplifier	System	Exponential

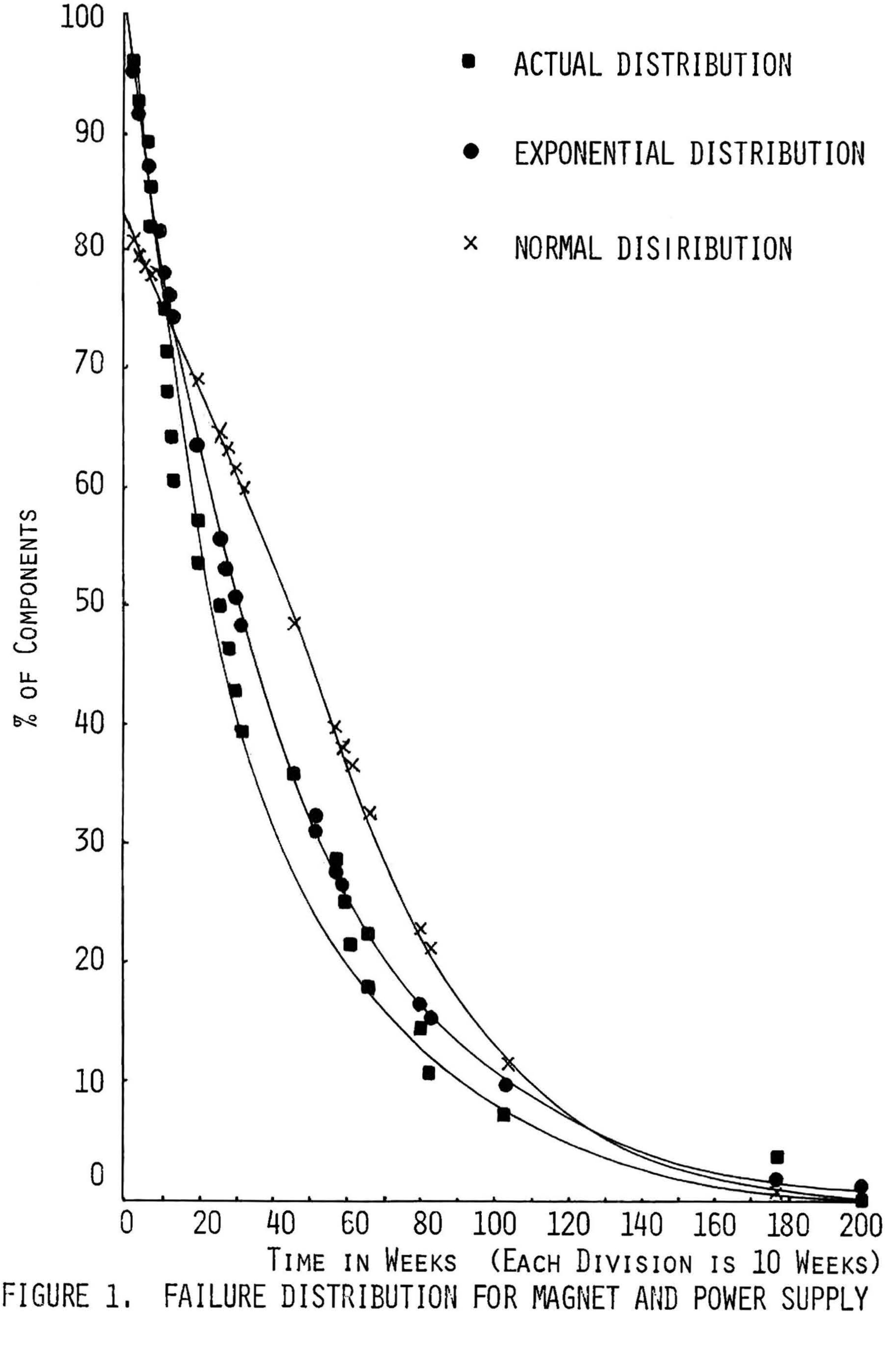

FIGURE 1. FAILURE DISTRIBUTION FOR MAGNET AND POWER SUPPLY

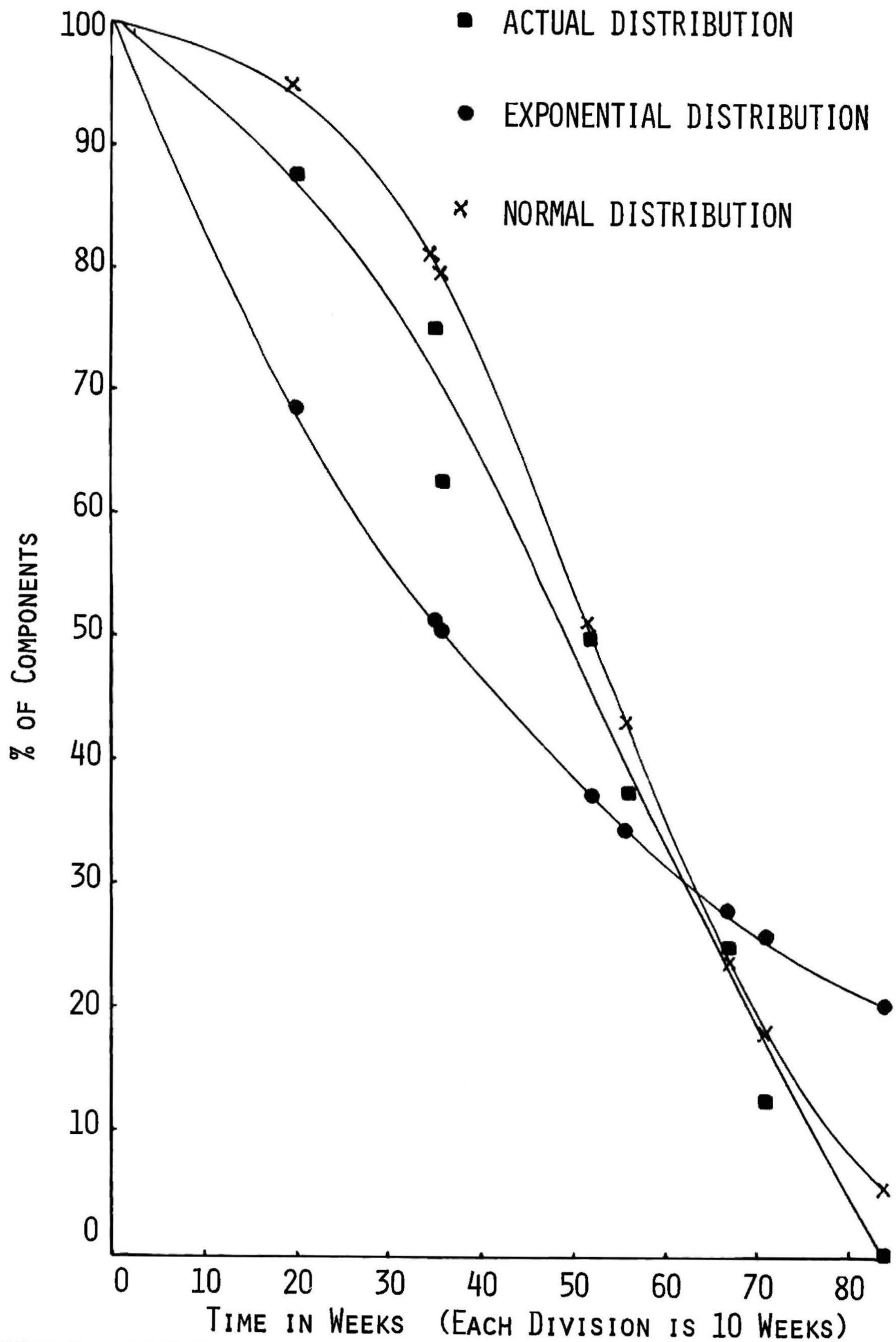

FIGURE 2. FAILURE DISTRIBUTION FOR SHIM ROD CONTROLS

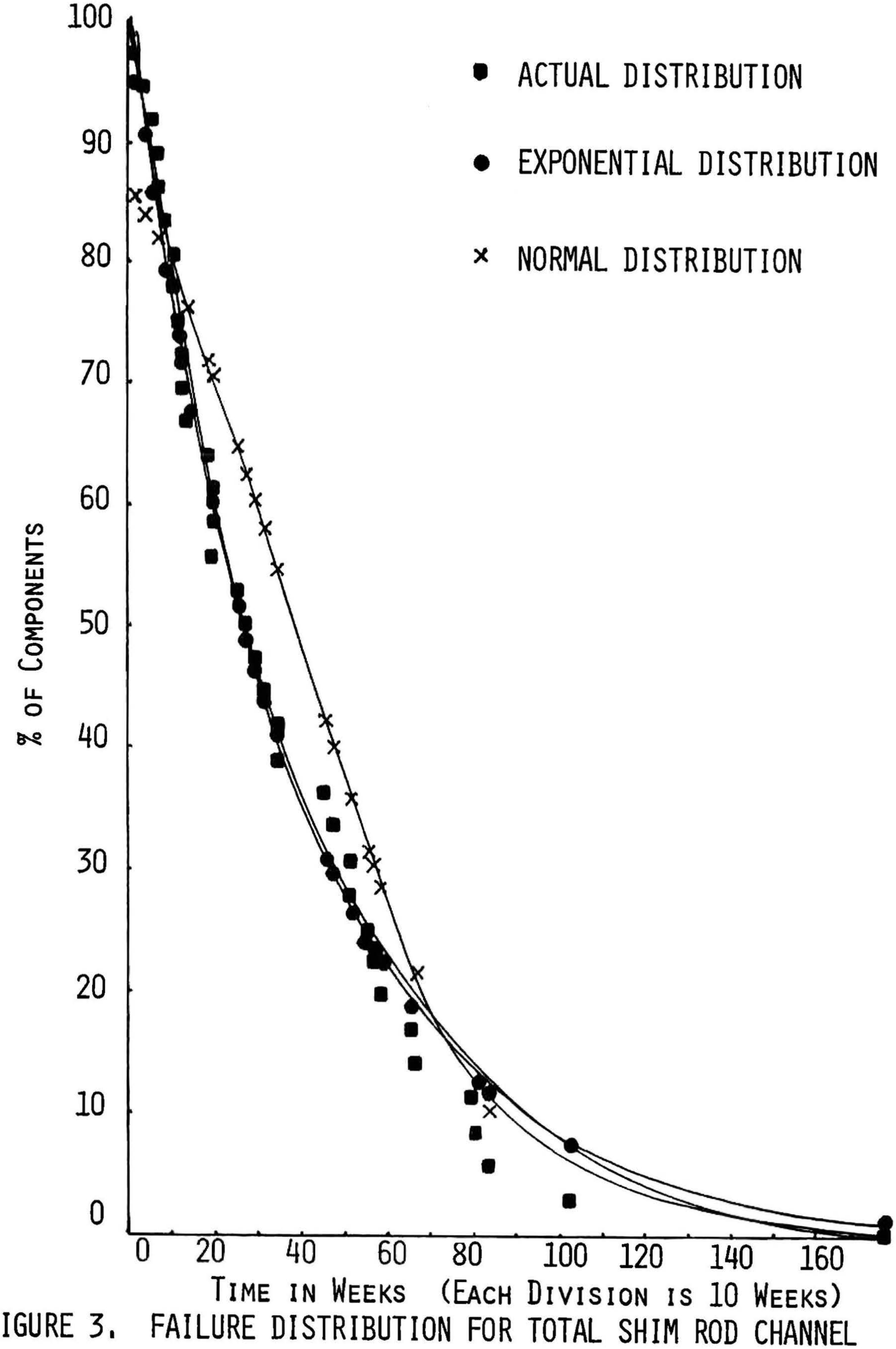

FIGURE 3. FAILURE DISTRIBUTION FOR TOTAL SHIM ROD CHANNEL

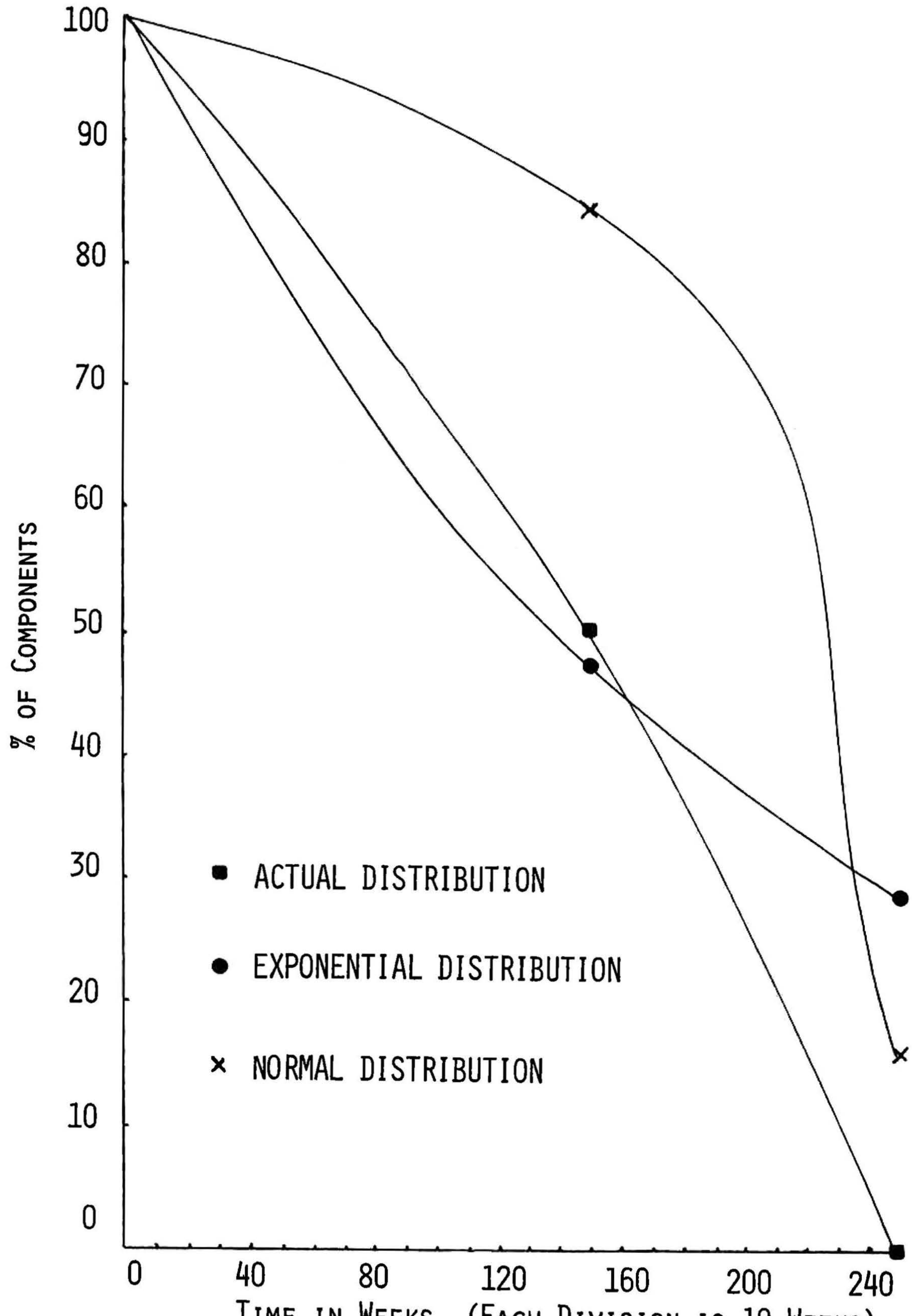

FIGURE 4. FAILURE DISTRIBUTION FOR STARTUP FISSION CHAMBER

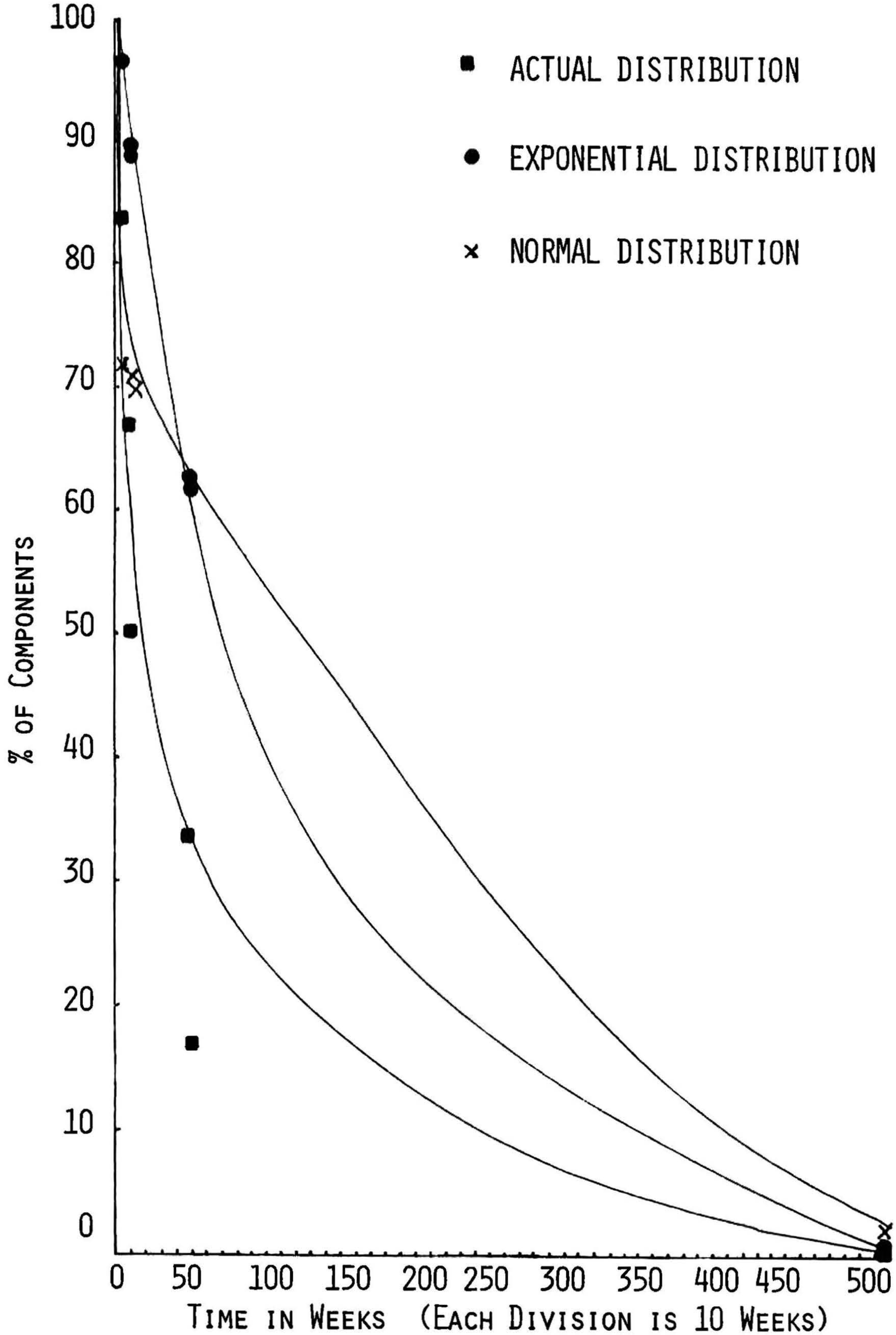

FIGURE 5. FAILURE DISTRIBUTION FOR STARTUP AMPLIFIER

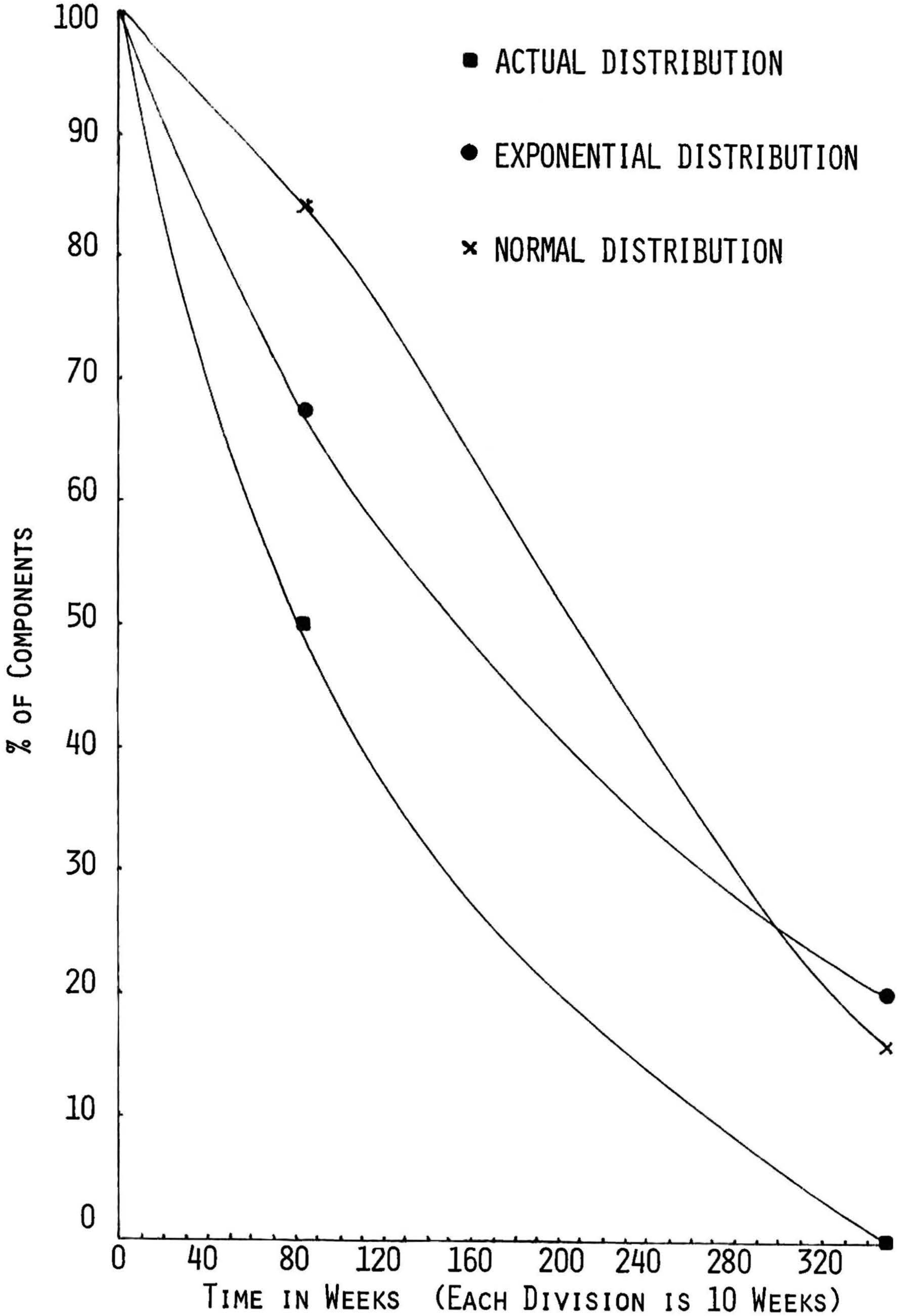

FIGURE 6. FAILURE DISTRIBUTION FOR LINEAR PULSE AMPLIFIER

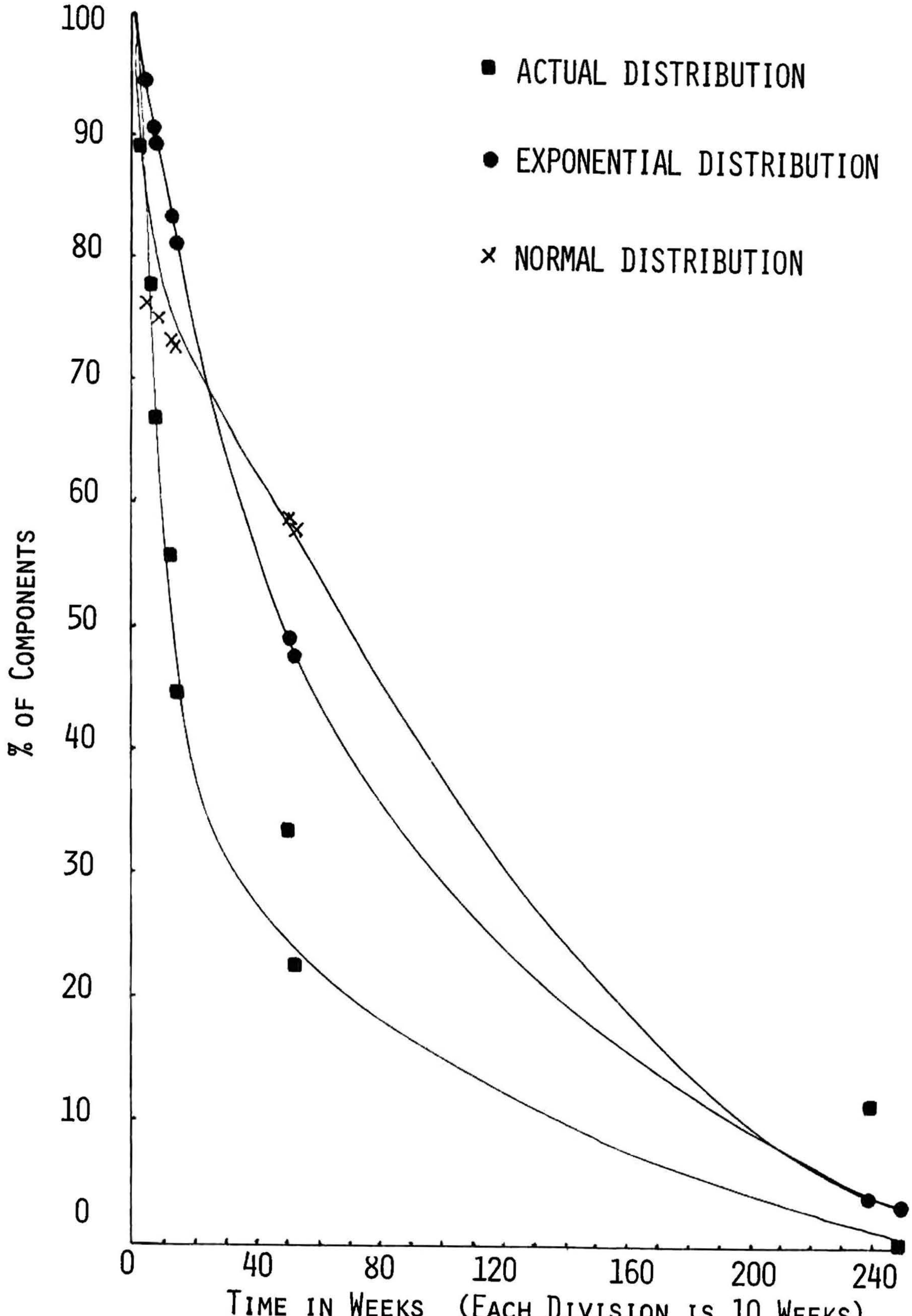

FIGURE 7. FAILURE DISTRIBUTION FOR STARTUP CHANNEL

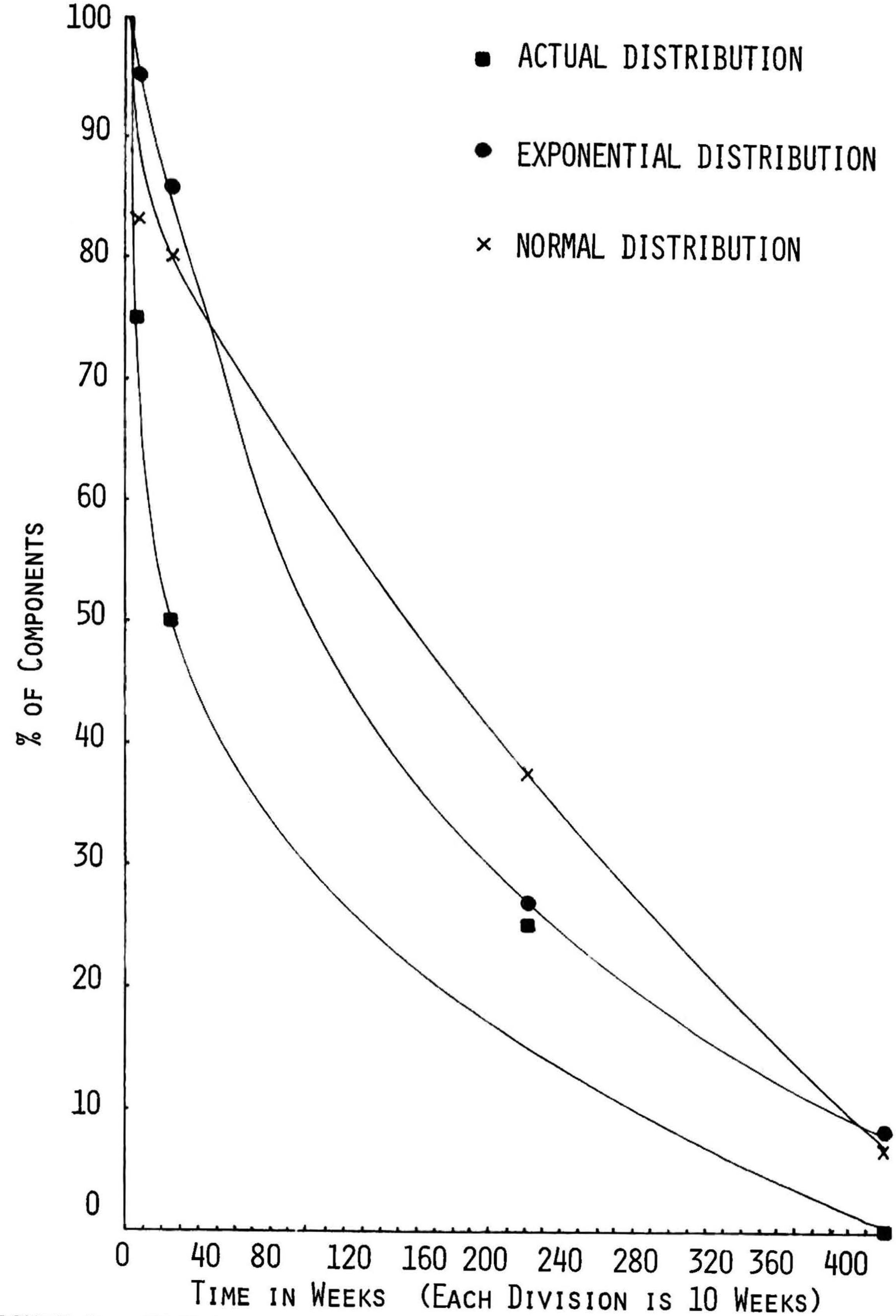

FIGURE 8. FAILURE DISTRIBUTION FOR LINEAR POWER CHANNEL

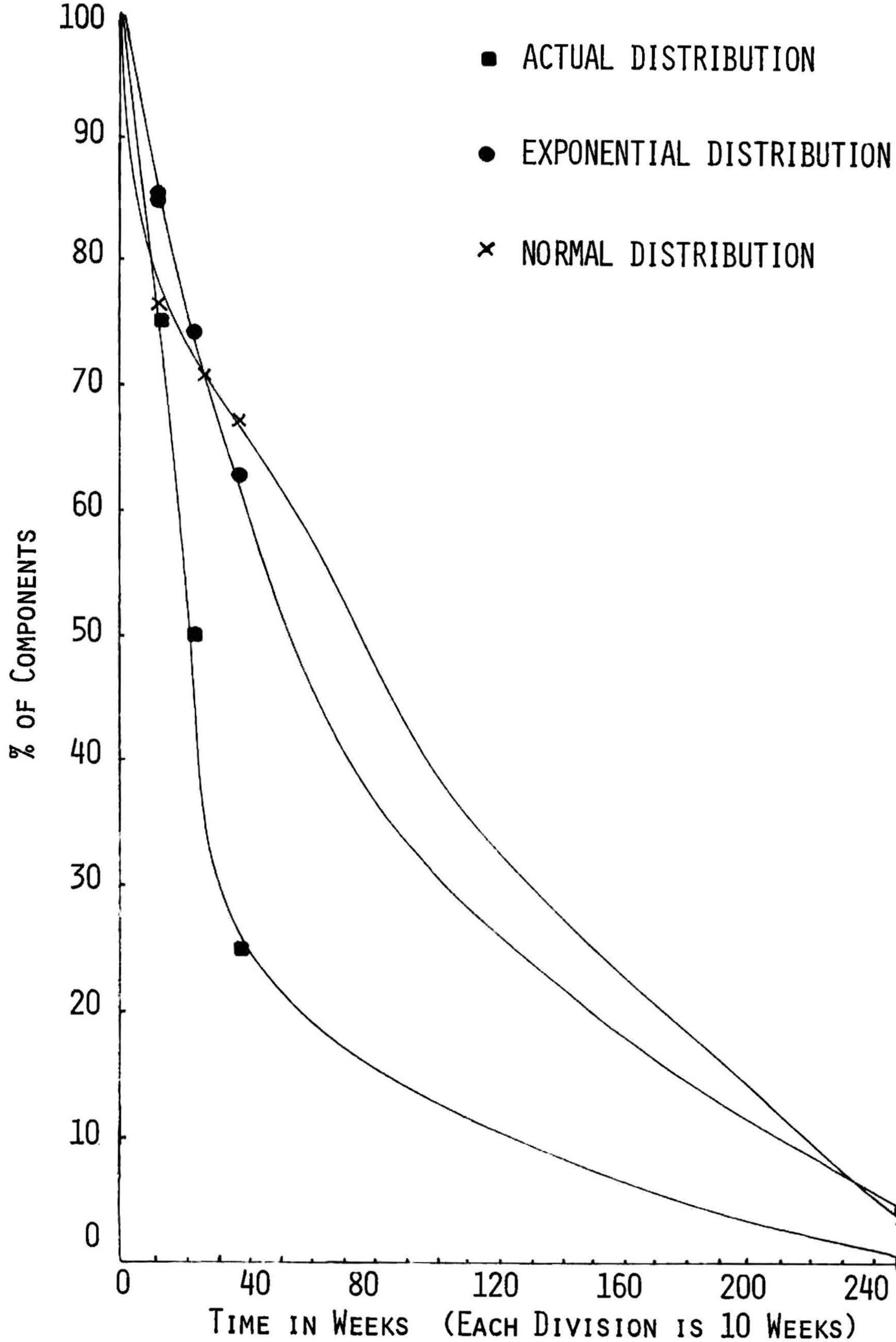

FIGURE 9. FAILURE DISTRIBUTION FOR COMPENSATED ION CHAMBER

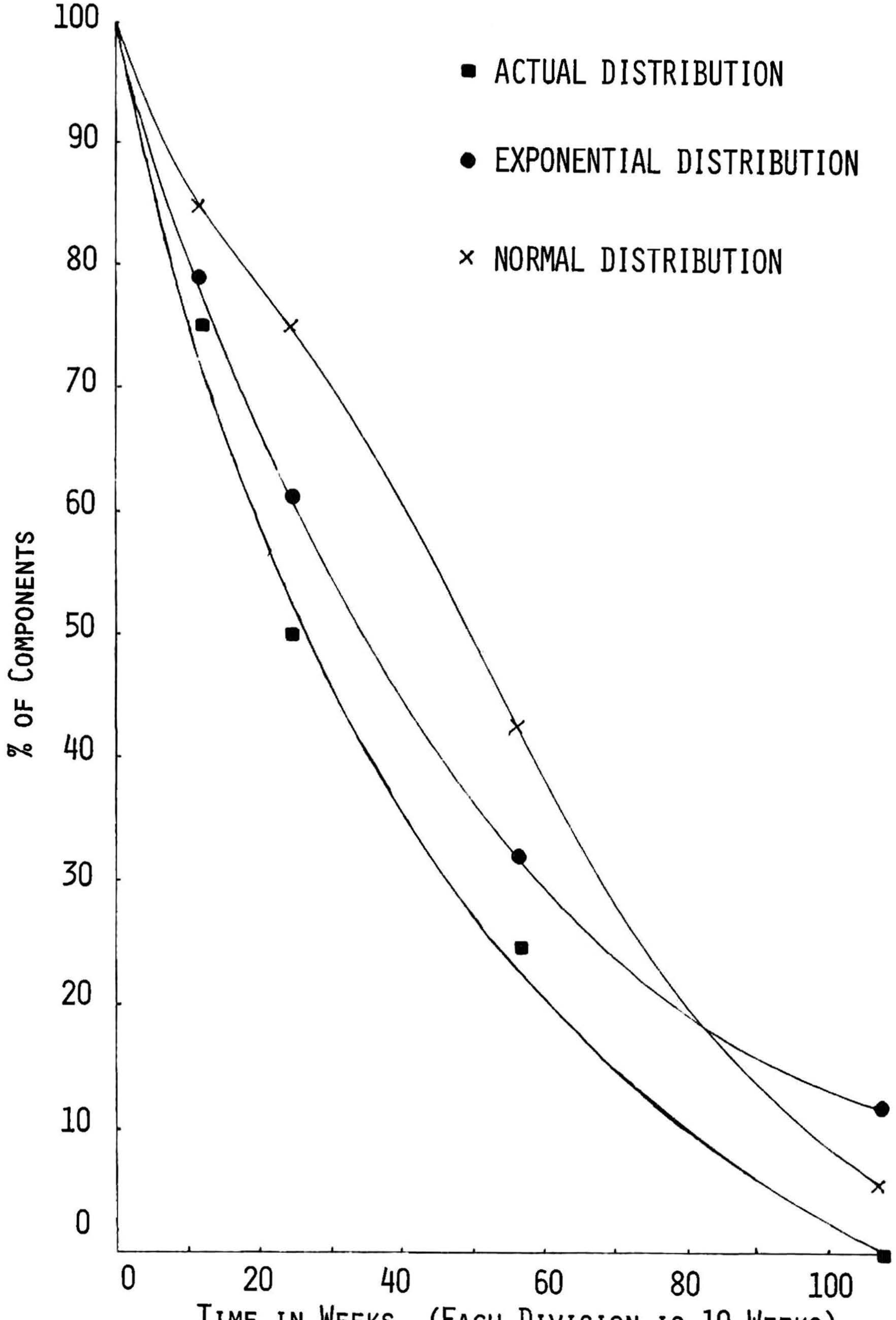

FIGURE 10. FAILURE DISTRIBUTION FOR LOG N & PERIOD AMPLIFIER

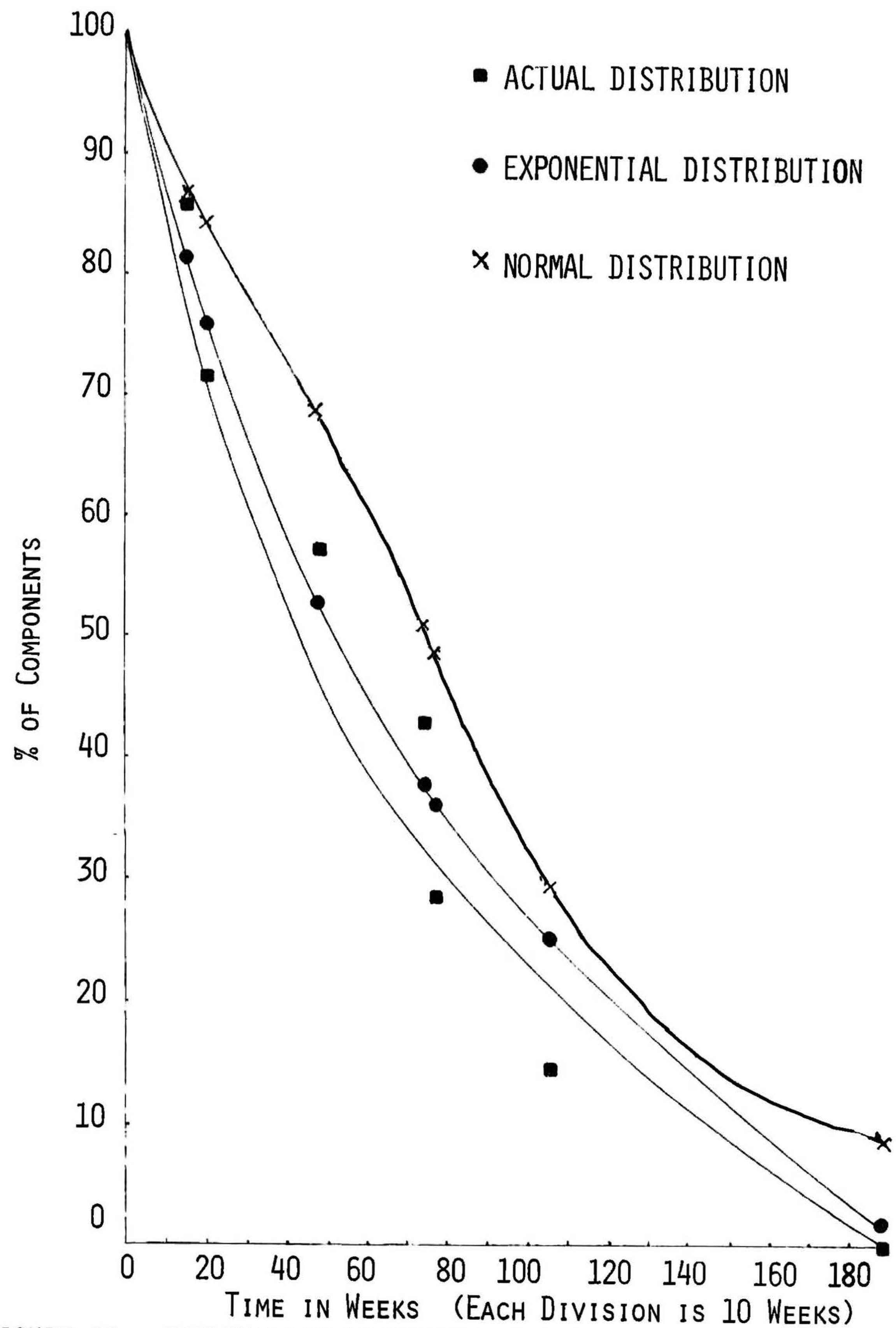

FIGURE 11. FAILURE DISTRIBUTION FOR LOG N RECORDER

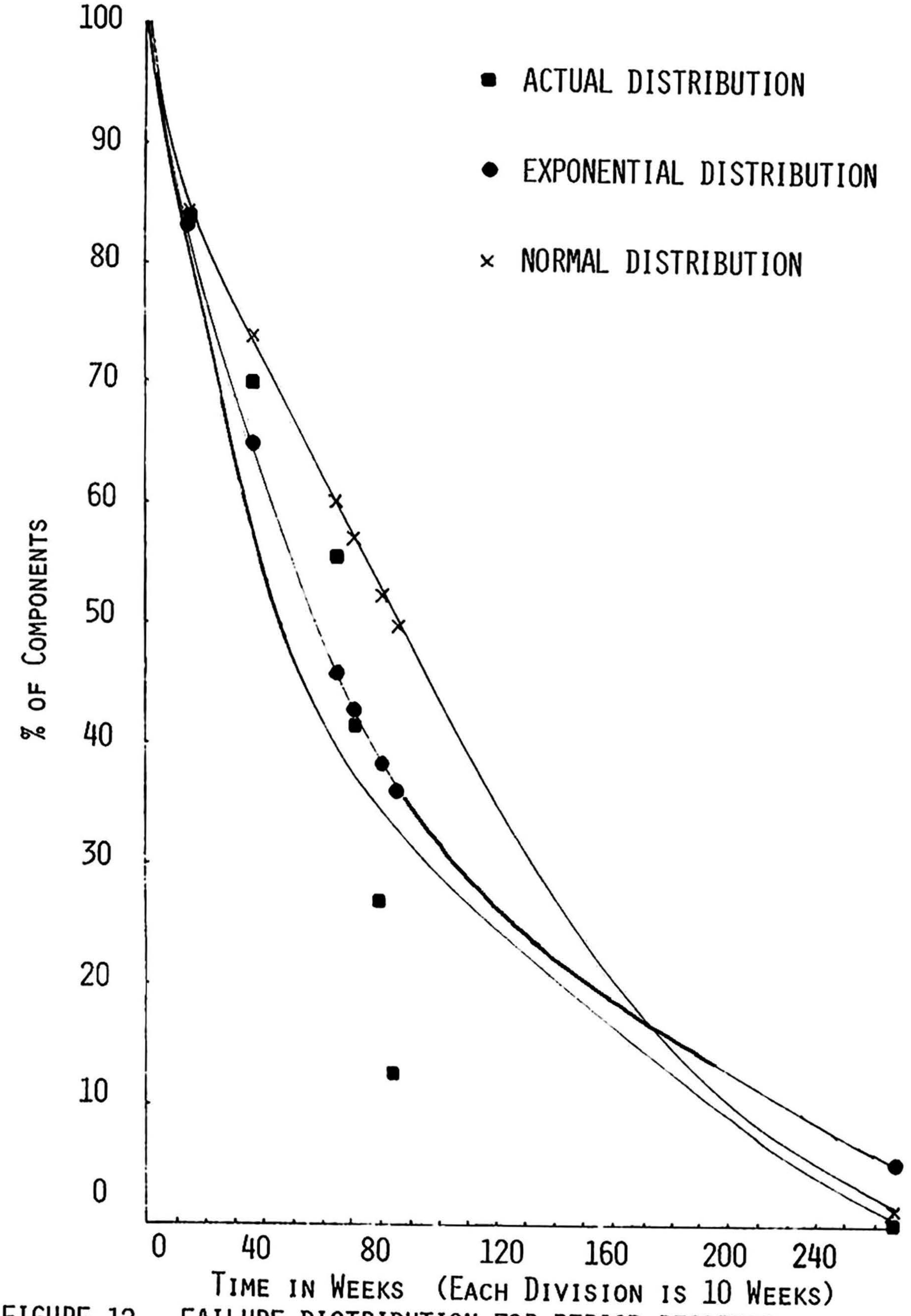

FIGURE 12. FAILURE DISTRIBUTION FOR PERIOD RECORDER

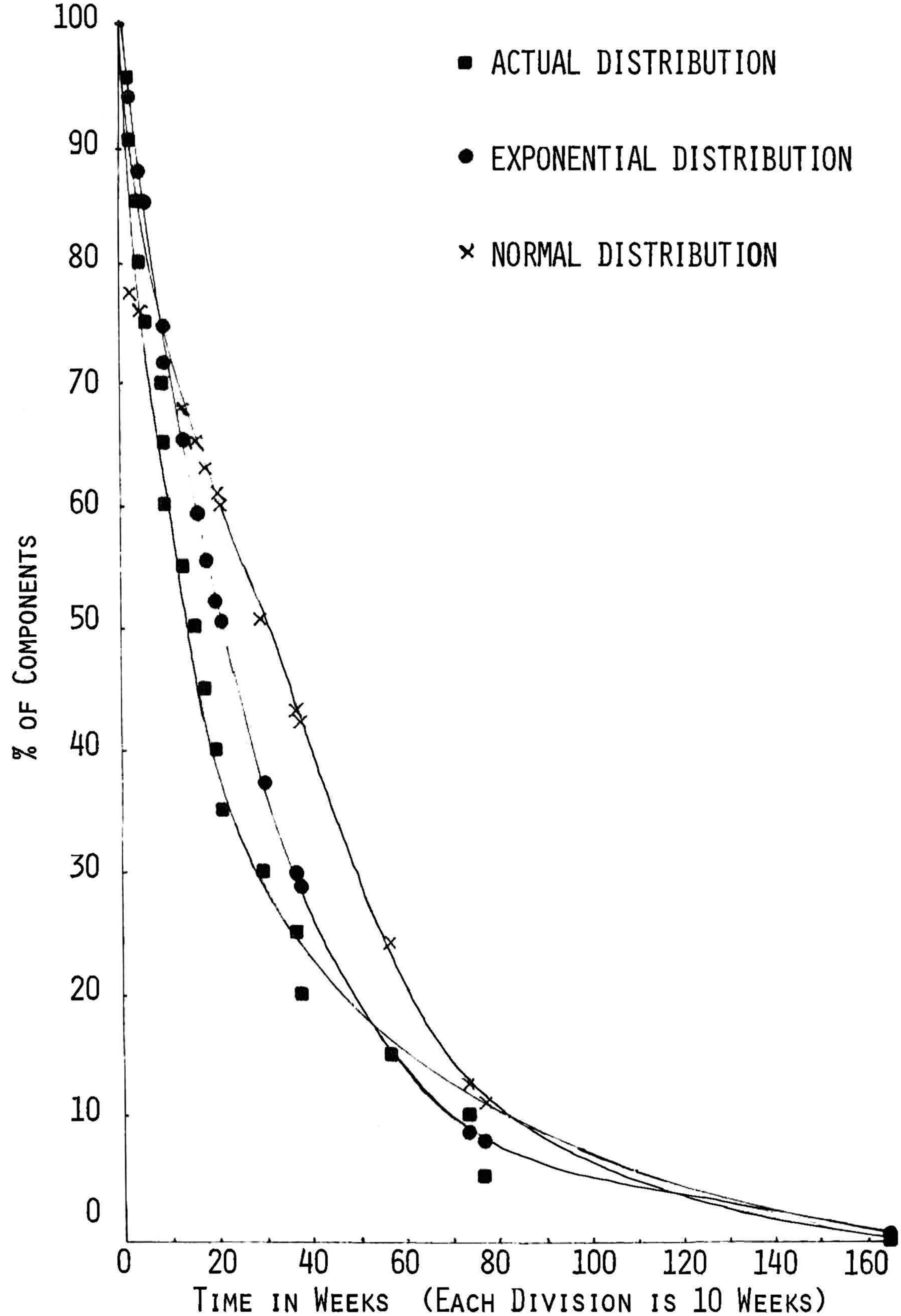

FIGURE 13. FAILURE DISTRIBUTION FOR LOG N & PERIOD CHANNEL

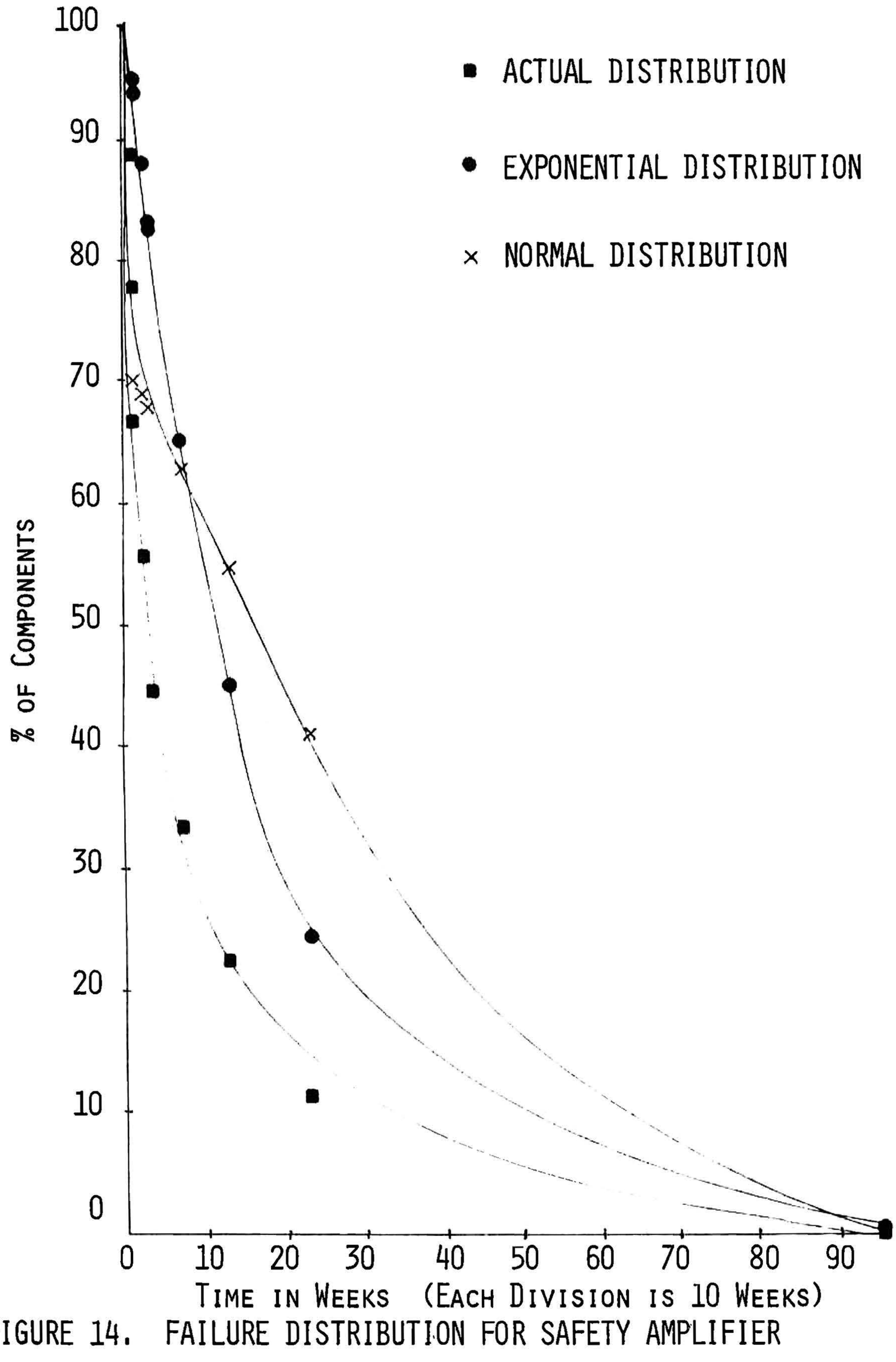

FIGURE 14. FAILURE DISTRIBUTION FOR SAFETY AMPLIFIER

comparison has a χ^2 value of 18.5 with 4 degrees of freedom. This case substantiates the visual curve interpretations. The third case is the Log N & Period Channel (system). In this case the χ^2 value is 11.3 for the exponential case with 3 degrees of freedom and the normal case χ^2 value is greater than 1000 with one degree of freedom. This confirms the visual curve interpretation.

B. Results of Data Interpretation

The reliability predictions from program RELICOMP are tabulated in Tables III through XIV. As seen in these tables, the improved reliability of the Magnets and Power Supplies (components) has a pronounced effect upon the reactor reliability. The same comment can be made about the Shim Rod Controls (components). When both are changed as shown in Table XIV, the effects are evident. These effects are emphasized because when one component is improved the other two components will also be improved. As indicated in Table XIII, the Safety Amplifier (system) has a relatively low reliability. Compared to these mentioned changes the other components and systems do not have significant effects upon the reactor reliability.

Table III. Reliability Changes Due to Quality Improvements in the Magnet and Power Supply A, B, or C.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
As Found Reliability					
Magnet & Power Supply A, B, or C	0.9782	0.9097	0.7513	0.5644	0.3185
Total Shim Rod Channel	0.9344	0.7451	0.4104	0.1459	0.0051
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
Reliability Times Two					
Magnet & Power Supply A, B, or C	0.9891	0.9538	0.8668	0.7513	0.5644
Total Shim Rod Channel	0.9552	0.8196	0.5463	0.2585	0.0160
Reactor	0.8305	0.4505	0.0897	0.0070	0.0000
Reliability Times Five					
Magnet & Power Supply A, B, or C	0.9960	0.9829	0.9493	0.9012	0.8122
Total Shim Rod Channel	0.9686	0.8698	0.6553	0.3720	0.0331
Reactor	0.8429	0.4785	0.1076	0.0100	0.0000

Table IV. Reliability Changes Due to Quality Improvements in the Shim Rod Controls A, B, or C.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
As Found Reliability					
Shim Rod Controls A, B, or C	0.9951	0.9922	0.9764	0.9088	0.5126
Total Shim Rod Channel	0.9344	0.7451	0.4104	0.1459	0.0051
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
Reliability Times Two					
Shim Rod Controls A, B, or C	1.0000	1.0000	1.0000	1.0000	0.9985
Total Shim Rod Channel	0.9484	0.7962	0.5021	0.2521	0.0633
Reactor	0.8253	0.4380	0.0824	0.0068	0.0000
Reliability Times Five					
Shim Rod Controls A, B, or C	1.0000	1.0000	1.0000	1.0000	1.0000
Total Shim Rod Channel	0.9541	0.8170	0.5428	0.2946	0.0868
Reactor	0.8420	0.4494	0.8910	0.0079	0.0001

Table V. Reliability Changes Due to Quality Improvements in the Startup Fission Chamber.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
As Found Reliability					
Startup Fission Chamber	0.9950	0.9787	0.9371	0.8781	0.7711
Startup Channel	0.9822	0.9255	0.7914	0.6263	0.3922
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
Reliability Times Two					
Startup Fission Chamber	0.9980	0.9914	0.9743	0.9493	0.9012
Startup Channel	0.9851	0.9375	0.8228	0.6771	0.4584
Reactor	0.8156	0.4152	0.0700	0.0042	0.0000
Reliability Times Five					
Startup Fission Chamber	0.9990	0.9957	0.9871	0.9743	0.9493
Startup Channel	0.9861	0.9416	0.8336	0.6949	0.4829
Reactor	0.8164	0.4170	0.0710	0.0044	0.0000

Table VI. Reliability Changes Due to the Quality Improvements in the Startup Preamplfier.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
As Found Reliability					
Startup Preamplifier	0.9910	0.9620	0.8896	0.7914	0.6263
Startup Channel	0.9822	0.9255	0.7914	0.6263	0.3922
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
Reliability Times Two					
Startup Preamplifier	0.9960	0.9829	0.9493	0.9012	0.8122
Startup Channel	0.9871	0.9456	0.8445	0.7132	0.5086
Reactor	0.8172	0.4188	0.0719	0.0045	0.0000
Reliability Times Five					
Startup Preamplifier	0.9900	0.9957	0.9871	0.9743	0.9493
Startup Channel	0.9900	0.9579	0.8781	0.7711	0.5945
Reactor	0.8196	0.4242	0.0747	0.0048	0.0000

Table VII. Reliability Changes Due to the Quality Improvements in the Linear Pulse Amplifier.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
<u>As Found Reliability</u>					
Linear Pulse Amplifier	0.9960	0.9829	0.9493	0.9012	0.8122
Startup Channel	0.9822	0.9255	0.7914	0.6263	0.3922
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
<u>Reliability Times Two</u>					
Linear Pulse Amplifier	0.9980	0.9914	0.9743	0.9493	0.9012
Startup Channel	0.9841	0.9335	0.8122	0.6597	0.4352
Reactor	0.8147	0.4134	0.0691	0.0041	0.0000
<u>Reliability Times Five</u>					
Linear Pulse Amplifier	0.9991	0.9961	0.9884	0.9769	0.9543
Startup Channel	0.9852	0.9379	0.8239	0.6788	0.4608
Reactor	0.8156	0.4153	0.0701	0.0043	0.0000

Table VIII. Reliability Changes Due to the Quality Improvements in the Linear Power Channel.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
As Found Reliability					
Linear Power Channel	0.9950	0.9787	0.9371	0.8781	0.7711
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
Reliability Times Two					
Linear Power Channel	0.9980	0.9914	0.9743	0.9493	0.9012
Reactor	0.8156	0.4152	0.0700	0.0042	0.0000
Reliability Times Five					
Linear Power Channel	0.9990	0.9957	0.9871	0.9743	0.9493
Reactor	0.8164	0.4170	0.0710	0.0044	0.0000

Table IX. Reliability Changes Due to the Quality Improvements in the Compensated Ion Chamber.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
As Found Reliability					
Compensated Ion Chamber	0.9881	0.9497	0.8556	0.7320	0.5358
Log N & Period Channel	0.9465	0.7894	0.4892	0.2393	0.0573
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
Reliability Times Two					
Compensated Ion Chamber	0.9940	0.9745	0.9250	0.8556	0.7320
Log N & Period Channel	0.9522	0.8100	0.5289	0.2797	0.0782
Reactor	0.8180	0.4206	0.0728	0.0046	0.0000
Reliability Times Five					
Compensated Ion Chamber	0.9980	0.9914	0.9743	0.9493	0.9012
Log N & Period Channel	0.9560	0.8241	0.5571	0.3104	0.0963
Reactor	0.8213	0.4279	0.0767	0.0051	0.0000

Table X. Reliability Changes Due to the Quality Improvements in the Log N & Period Amplifier.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
As Found Reliability					
Log N & Period Amplifier	0.9812	0.9215	0.7811	0.6102	0.3723
Log N & Period Channel	0.9465	0.7894	0.4892	0.2393	0.0573
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
Reliability Times Two					
Log N & Period Amplifier	0.9910	0.9620	0.8896	0.7914	0.6263
Log N & Period Channel	0.9560	0.8241	0.5571	0.3104	0.0963
Reactor	0.8213	0.4279	0.0767	0.0051	0.0000
Reliability Times Five					
Log N & Period Amplifier	0.9970	0.9872	0.9618	0.9250	0.8556
Log N & Period Channel	0.9618	0.8456	0.6023	0.3628	0.1316
Reactor	0.8263	0.4390	0.0829	0.0060	0.0000

Table XI. Reliability Changes Due to the Quality Improvements in the Log N Recorder.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
As Found Reliability					
Log N Recorder	0.9871	0.9456	0.8445	0.7132	0.5086
Log N & Period Channel	0.9465	0.7892	0.4892	0.2393	0.0573
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
Reliability Times Two					
Log N Recorder	0.9440	0.9745	0.9250	0.8556	0.7320
Log N & Period Channel	0.9531	0.8135	0.5358	0.2871	0.0824
Reactor	0.8188	0.4224	0.0738	0.0047	0.0000
Reliability Times Five					
Log N Recorder	0.9980	0.9914	0.9743	0.9493	0.9012
Log N & Period Channel	0.9570	0.8276	0.5644	0.3185	0.1015
Reactor	0.8222	0.4297	0.0777	0.0052	0.0000

Table XII. Reliability Changes Due to the Quality Improvements in the Period Recorder.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
<u>As Found Reliability</u>					
Period Recorder	0.9891	0.9538	0.8668	0.7513	0.5644
Log N & Period Channel	0.9465	0.7894	0.4892	0.2393	0.0573
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
<u>Reliability Times Two</u>					
Period Recorder	0.9950	0.9787	0.9371	0.8781	0.7711
Log N & Period Channel	0.9522	0.8100	0.5289	0.2797	0.0782
Reactor	0.8181	0.4206	0.0728	0.0046	0.0000
<u>Reliability Times Five</u>					
Period Recorder	0.9980	0.9914	0.9743	0.9493	0.9012
Log N & Period Channel	0.9550	0.8205	0.5499	0.3024	0.0914
Reactor	0.8205	0.4260	0.0757	0.0050	0.0000

Table XIII. Reliability Changes Due to the Quality Improvements in the Safety Amplifier.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
As Found Reliability					
Safety Amplifier	0.9408	0.7693	0.4525	0.2047	0.0419
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
Reliability Times Two					
Safety Amplifier	0.9704	0.8790	0.6771	0.4584	0.2101
Reactor	0.8387	0.4683	0.1008	0.0088	0.0000
Reliability Times Five					
Safety Amplifier	0.9881	0.9497	0.8556	0.7320	0.5358
Reactor	0.8540	0.5060	0.1274	0.0141	0.0000

Table XIV. Reliability Changes Due to the Quality Improvements in the Magnet & Power Supply A, B, or C and Shim Rod Controls A, B, or C.

Period of Time	1 Week	1 Month	3 Months	6 Months	1 Year
As Found Reliability					
Magnet & Power Supply A, B, or C	0.9782	0.9097	0.7513	0.5644	0.3185
Shim Rod Controls A, B, or C	0.9951	0.9222	0.9764	0.9088	0.5126
Total Shim Rod Channel	0.9344	0.7451	0.4104	0.1459	0.0051
Reactor	0.8132	0.4098	0.0674	0.0039	0.0000
Reliability Times Two					
Magnet & Power Supply A, B, or C	0.9891	0.9538	0.8668	0.7513	0.5644
Shim Rod Controls A, B, or C	1.0000	1.0000	1.0000	1.0000	0.9985
Total Shim Rod Channel	0.9695	0.8752	0.6683	0.4466	0.1986
Reactor	0.8437	0.4814	0.1097	0.0120	0.0001
Reliability Times Five					
Magnet & Power Supply A, B, or C	0.9960	0.9829	0.9493	0.9012	0.8122
Shim Rod Controls A, B, or C	1.0000	1.0000	1.0000	1.0000	1.0000
Total Shim Rod Channel	0.9891	0.9538	0.8668	0.7513	0.5644
Reactor	0.8608	0.5247	0.1423	0.0202	0.0004

V. RECOMMENDATIONS

In order to develop a operating program which increases the reliability of any operating system, it is essential that an adequate data collection system must be developed. This data collection system must provide information which could be utilized to establish surveillance schedules, equipment replacement, and system maintenance routines.

First in the development of a data collection system is a well-planned equipment numbering system. This system must be clear and concise. It must be designed to fit possible future additions. The following is a suggested numbering form:

a.xxx.yyy.zzz

where: a is the unit designation code

xxx is the system code

yyy is the subsystem code

zzz is the component code

The indicated number of digits should be flexible within reasonable limits (generally less than five digits). The above system will allow for additions or removals to the listing without altering other component designations. This system will fit a computer analysis.

The digital computer can become a very useful tool in the collection and interpretation of reliability data. To handle the data, a program is needed to sort and store data for equipment history files. These files are vital to the proper operation, repair and maintenance of the equipment.

Current regulations in industrial nuclear installations demand that more information must be contained in equipment history files. These files can eliminate the great loss of equipment hisotry when an employee terminates employment, that is, the history will be written down, not carried in someone's memory. Typical data to be contained in this file is as follows:

1. Component Identification - This includes the number code and the system, subsystem or component name.

2. Manufacturer - This should indicate the supplier identification and manufacturing location.

3. Quality Requirements - This should include vendor purchasing specifications and customer reference standards, testing requirements and storage conditions for the components.

4. Dates - The dates of purchase, installation, repair and removal should be indicated for each specific system, subsystem or component.

5. Surveillance - This should contain the dates and results of surveillance tests upon the system, subsystem or component.

6. Operating Conditions and Abnormalities - This section should describe any abnormal operating condition which could become a factor in the failure of the component. Adverse environmental conditions encountered should be listed here.

As with any system, controls must be established to insure that collection and interpretation of data is performed as scheduled. This will require a procedure to implement this plan. The output of this history file program can be placed on magnetic tape or card decks to be utilized as input in later runs.

After implementation of these suggestions and sufficient time to permit data accumulation, the analysis performed in this report should be performed again. Such an analysis should provide better reliability predictions than were possible in this report.

The type of analysis presented in this report could be expanded to cover larger plants such as the University of Missouri Research Reactor Facility located in Columbia, Missouri. This facility operates approximately 100 hours per week, so the reliability is extremely important. This type of analysis could provide guidance for future efforts to increase reliability.

The reliability of low reliability systems, subsystems or components can be increased to improve the reactor reliability. Detailed pretesting procedures could help to limit magnet failures. This test could involve tests in pressurized tanks to test for leakage. Shim Rod Controls can be improved by scheduled replacements of switches which are shown to be reaching wearout failure. A detailed surveillance procedure should be implemented to determine the problem areas which must be corrected.

To properly implement the findings of this report, a cost-benefit analysis should be performed. This analysis could determine the most economical alternative to improve reliability. Decisions must be made to replace or repair low reliability systems, subsystems or components. In-plant procedures for surveillance, maintenance and modification could be better determined through the use of this analysis.

VI. CONCLUSIONS

In most cases examined, failure curves appear to follow a random occurrence as defined by the exponential distribution. This indicates that in multicomponent systems random failure distribution can usually be assumed. The normal distribution approximated the actual failure data in only one case, the Shim Rod Controls (components).

There are three reliability problem areas which are identified in this report. These are the Magnet and Power Supplies, Shim Rod Controls and the Safety Amplifier. Increasing the quality of these will increase the overall reactor reliability. As shown in Tables III through XIV, the increased benefit of increasing reliability of these individual components, subsystems or systems by a factor of five is not significantly more beneficial than increasing the reliability by a factor of two.

An overall reliability analysis upon an operating system can be performed without detailed individual component failure information. Problem areas can be determined and remedial actions can be suggested and implemented from information which is obtained from operating records.

BIBLIOGRAPHY

1. Bazovsky, Igor. Reliability Theory and Practice. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1961, pp. 33, 74.

2. Mack, C. Essentials of Statistics for Scientists and Technologists. New York: Plenum Press, 1967, pp. 95-98, 156.

3. Garrick, B. J. and Gekler, W. C. "Reliability Analysis of Engineered Safeguards," Nuclear Safety, Volume 8, Number 5, (Sept.-Oct. 1967), pp. 470-9.

4. Stone, John T., Rudy, George C., Negin, Charles A., and Lurf, Gunther. SM-1A Protection System Review, NUS-504. For U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia. By NUS Corporation, Washington, D. C., Nov. 1968.

5. Stone, John T., Rudy, George C., Negin, Charles A., and Born, Urs. MH-1A Protection System Review, NUS-616. For U. S. Army Mobility Equipment Research and Development Center. Fort Belvoir, Virginia. By NUS Corporation, Washington, D. C., Nov. 1969.

6. Wiebe, Henry A. Personal conversation, Dec. 1973.

7. Von Alven, William H. (ed.), ARINC Research Corporation. Reliability Engineering. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1964, pp. 170-172.

VITA

Jimmy Dale Schottel was born on May 22, 1949 in Whitesville, Missouri. After completing primary and secondary education at King City R-I School District, he attended the University of Missouri-Rolla from September of 1967 until December of 1970 when he received the degree of Bachelor of Science in Metallurgical Engineering with a Nuclear Engineering Option.

He was employed as a Nuclear Engineer at Dresden Nuclear Power Station by Commonwealth Edison Company from January of 1971 until May of 1972. He then was employed as a Quality Assurance Specialist at Cooper Nuclear Station by Nebraska Public Power District from June of 1972 until August of 1973 when he entered the University of Missouri-Rolla as a Graduate Student in Nuclear Engineering.

Mr. Schottel is a member of the American Nuclear Society. He is married to the former Nancy Marie Boyd of Rosendale, Missouri.

APPENDIX A

PROGRAM RELIABLE

Operating Guide for this program is in Appendix D.

```
C      THE FOLLOWING CONTROL CHARECTORS WERE USED IN THIS PROGRAM
C      5 FOR READ; 6 FOR PRINT; 7 FOR PUNCH
C      THIS PROGRAM WILL COMPARE EXPONENTIAL, NORMAL AND ACTUAL VALUES
C      FOR THE FAILURE CURVES
C      OUTPUT IS PROVIDED ON BOTH PRINT AND PUNCH
C      THE PUNCH OUTPUT CAN BE USED ON A PLOT ROUTINE FOR GRAPHICAL
C      INTERPRETATION
C      THE MAIN PROGRAM READS INPUT,PROVIDES OUTPUT,CALCULATES VALUES OF
C      LAMBA AND THE ACTUAL FRACTION FOR A TIME T.
C      THE MAIN PROGRAM ALSO PROVIDES FOR JOB FLOW CONTROL
      DIMENSION X1(20),X2(20),X3(20),X4(20),X5(20),X6(20),X7(20),X8(20)
      DIMENSION NTIMES(20),TIMES(20,50),ALAMBA(20),FRAC(1000),FRACX(1000
     $),FRACN(1000),CHIX(1000),CHIN(1000),STIME(1000),TI(1000),TIME(50)
      READ(5,100) NSYS
  100 FORMAT( I3)
      DO 1000 III=1,NSYS
      READ(5,110) NSUB
  110 FORMAT( I3)
      READ(5,120) XA,XB,XC,XD,XE,XF,XG,XH
  120 FORMAT( 8A4)
      DO 1010 II=1,NSUB
      READ(5,130) X1(II),X2(II),X3(II),X4(II),X5(II),X6(II),X7(II),X8(II
     $)
  130 FORMAT( 8A4)
      READ(5,129) NTIMES(II)
  129 FORMAT( I3)
      SUM=0
      NTIME=NTIMES(II)
      DO 1020 K1=1,NTIME
      READ(5,140) TIMES(II,K1)
  140 FORMAT( F9.2)
      SUMN=SUM+TIMES(II,K1)
      SUM=SUMN
 1020 CONTINUE
```

```
      BTIME=NTIMES(II)
      ALAMBA(II)=BTIME/SUM
      DO 1011 I=1,NTIME
      TI(I)=TIMES(II,I)
 1011 CONTINUE
      CALL SORT(NTIME,TI)
      DO 1012 I=1,NTIME
      TIMES(II,I)=TI(I)
 1012 CONTINUE
      DO 1013 I2=1,NTIME
      A2=I2
      ATIME=NTIME
      FRAC(I2)=100*(1-A2/ATIME)
 1013 CONTINUE
      CALL COMEXP(NTIME,ALAMBA(II),FRACX,TI,CHIX)
      CALL COMNOR(NTIME,ALAMBA(II),FRACN,TI,CHIN,SIGMA)
      WRITE(7,2150) X1(II),X2(II),X3(II),X4(II),X5(II),X6(II),X7(II),X8(
     $II)
 2150 FORMAT( 8A4)
      WRITE(6,150) X1(II),X2(II),X3(II),X4(II),X5(II),X6(II),X7(II),X8(I
     $I)
  150 FORMAT('1',T15,8A4,//)
      WRITE(7,2151) NTIMES(II)
 2151 FORMAT( I3)
      WRITE(6,1151) ALAMBA(II),SIGMA
```

```
1151 FORMAT( ' LAMBA=',F6.4,6X,' SIGMA=',F10.6,//)
     WRITE(6,151)
 151 FORMAT(' TIME',T10,'%ACTUAL',T20'%EXPONENTIAL',T35,'CHI SQ',T50,'%
    $NORMAL',T65,'CHI SQ',//)
     DO 1032 L=1,NTIME
     TIME(L)=TIMES(II,L)
1032 CONTINUE
     ICT=0
     DO 1030 L=1,NTIME
     IB=ICT
     ICT=IB+1
     IF(ICT.NE.5) GO TO 98
     WRITE(6,161) TIME(L),FRAC(L),FRACX(L),CHIX(L),FRACN(L),CHIN(L)
     WRITE(7,161) TIME(L),FRAC(L),FRACX(L),CHIX(L),FRACN(L),CHIN(L)
 161 FORMAT( 2X,F5.1,T10,F5.2,T20,F5.2,T35,F8.4,T50,F5.2,T65,F8.4)
     ICT=0
     GO TO 1030
  98 WRITE(6,160) TIME(L),FRAC(L),FRACX(L),FRACN(L)
     WRITE(7,160) TIME(L),FRAC(L),FRACX(L),FRACN(L)
 160 FORMAT( 2X,F5.1,T10,F5.2,T20,F5.2,T50,F5.2)
1030 CONTINUE
1010 CONTINUE
     ICOUNT=0
     SUM=0
     DO 1040 LI=1,NSUB
     NTIME=NTIMES(LI)
     DO 1041 LK=1,NTIME
     IC=ICOUNT+1
     ICOUNT=IC
     SUMN=SUM+TIMES(LI,LK)
     SUM=SUMN
     STIME(IC)=TIMES(LI,LK)
1041 CONTINUE
1040 CONTINUE
     AC=IC
     ALAM=AC/SUM
```

```
      CALL SORT(IC,STIME)
      CALL COMEXP(IC,ALAM,FRACX,STIME,CHIX)
      CALL COMNOR(IC,ALAM,FRACN,STIME,CHIN,SIGMA)
      DO 1071 I3=1,IC
      A3=I3
      FRAC(I3)=100*(1-A3/AC)
 1071 CONTINUE
      WRITE(6,150) XA,XB,XC,XD,XE,XF,XG,XH
      WRITE(7,2150) XA,XB,XC,XD,XE,XF,XG,XH
      WRITE(6,1151) ALAM,SIGMA
      WRITE(6,151)
      WRITE(7,2151) IC
      ICT=0
      DO 1060 L=1,IC
      IB=ICT
      ICT=IB+1
      IF(ICT.NE.5) GO TO 99
      WRITE(6,161) STIME(L),FRAC(L),FRACX(L),CHIX(L),FRACN(L),CHIN(L)
      WRITE(7,161) STIME(L),FRAC(L),FRACX(L),CHIX(L),FRACN(L),CHIN(L)
      ICT=0
      GO TO 1060
   99 WRITE(6,160) STIME(L),FRAC(L),FRACX(L),FRACN(L)
      WRITE(7,160) STIME(L),FRAC(L),FRACX(L),FRACN(L)
 1060 CONTINUE
 1000 CONTINUE
      STOP
      END
```

```
      SUBROUTINE COMNOR(NTIME,AL,FRACN,TIMES,CHIN,SIGMA)
C     SUBPROGRAM COMNOR CALCULATES THE NORMAL FRACTION VALUES FOR TIME T
C     THEN IT COMPARES THIS VALUE TO THE ACTUAL VALUE
C     SIGMA IS ALSO CALCULATED HERE
      DIMENSION FRACN(1000),TIMES(1000),CHIN(1000)
      DIMENSION ANI(1000),PI(1000)
      TOT1=0
      DO 1 I=1,NTIME
      TOT=(TIMES(I)-1/AL)**2+TOT1
      TOT1=TOT
    1 CONTINUE
      SIGMA=(TOT/NTIME)**0.5
      DO 2 I=1,NTIME
      FRACN(I)=100*(0.5-0.5*ERF((TIMES(I)-1/AL)/(SIGMA*1.41421)))
    2 CONTINUE
      ATIME=NTIME
      AN5=ATIME
      PI5=1-FRACN(5)/100
      CHIN(5)=((5-AN5*PI5)**2)/(AN5*PI5*(1-PI5))
      IF(NTIME.LT.10) GO TO 15
      DO 3 I=10,NTIME,5
      ATIME=NTIME
      ANI(I)=FRACN(I-5)*ATIME/100
      PI(I)=1-FRACN(I)/FRACN(I-5)
      X=ABS(1-FRACN(I)/FRACN(I-5))
      IF(X.LT.1.E-8) GO TO 13
      CHIN(I)=((5-ANI(I)*PI(I))**2)/((ANI(I)*PI(I))*(1-PI(I)))
      GO TO 3
   13 CHIN(I)=1.E9
    3 CONTINUE
   15 RETURN
      END
```

```
      SUBROUTINE COMEXP(NTIME,AL,FRACX,TIMES,CHIX)
C     SUBROUTINE COMEXP PERFORMS THE SAME FUNCTIONS FOR THE EXPONENTIAL
C     DISTRIBUTION AS COMNOR DOES FOR THE NORMAL DISTRIBUTION
      DIMENSION FRACX(1000),TIMES(1000),CHIX(1000)
      DIMENSION ANI(1000),PI(1000)
      DO 1 I=1,NTIME
      FRACX(I)=100*EXP(-AL*TIMES(I))
    1 CONTINUE
      ATIME=NTIME
      AN5=ATIME
      PI5=1-FRACX(5)/100
      CHIX(5)=((5-AN5*PI5)**2)/(AN5*PI5*(1-PI5))
      IF(NTIME.LT.10) GO TO 15
      DO 5 I=10,NTIME,5
      ATIME=NTIME
      ANI(I)=FRACX(I-5)*ATIME/100
      PI(I)=1-FRACX(I)/FRACX(I-5)
      X=ABS(1-FRACX(I)/FRACX(I-5))
      IF(X.LT.1.E-8) GO TO 13
      CHIX(I)=((5-ANI(I)*PI(I))**2)/((ANI(I)*PI(I))*(1-PI(I)))
      GO TO 5
   13 CHIX(I)=1.E9
    5 CONTINUE
   15 RETURN
      END
```

```
      SUBROUTINE SORT(N,T)
C     SUBROUTINE SORT IS A SIMPLE SORTING ROUTINE
      DIMENSION T(1000)
      DO 3 K1=1,N
      DO 1 J=1,N
      N1=N-1
      DO 2 K=1,N1
      IF(T(J).LT.T(K)) GO TO 100
      GO TO 2
  100 T1=T(J)
      T2=T(K)
      T(K)=T1
      T(J)=T2
    2 CONTINUE
    1 CONTINUE
    3 CONTINUE
      RETURN
      END
```

APPENDIX B

PROGRAM RELIPLOT

Operating Guide for this program is in Appendix D.

```
C       THIS PROGRAM USES THE PUNCHED OUTPUT FROM PROGRAM RELIABLE
C       THIS PROGRAM WILL PLOT THE NORMAL, EXPONENTIAL AND THE ACTUAL
C       FAILURE CURVES VERSUS TIME
        DIMENSION X(8),TIME(50),FRAC(50),FRACX(50),FRACN(50)
C       N IS THE NUMBER OF GRAPHS
        READ(5,100) N
  100   FORMAT(I3)
        CALL PENPOS ('SCHOTTEL',8,0)
        DO 1000 I=1,N
        READ(5,101) X(1),X(2),X(3),X(4),X(5),X(6),X(7),X(8)
  101   FORMAT(8A4)
        READ(5,100) L
        DO 10 J=1,L
        READ(5,102) TIME(J),FRAC(J),FRACX(J),FRACN(J)
  102   FORMAT(2X,F5.1,T10,F5.2,T20,F5.2,T50,F5.2)
   10   CONTINUE
        CALL NEWPLT (2.0,2.0,8.5)
        CALL ORIGIN (0.0,0.0)
        CALL XSCALE (0.0,TIME(L),5.0)
        CALL YSCALE (0.0,100.0,8.0)
        CALL XAXIS (10.0)
        CALL YAXIS (10.0)
        CALL XYPLT (TIME,FRAC,L,2,0)
        CALL XYPLT (TIME,FRACX,L,2,11)
        CALL XYPLT (TIME,FRACN,L,2,4)
        CALL SYM (2.0,6.0,0.105,X,0.0,32)
        CALL SYM (2.0,5.5,0.105,0,0.0,-1)
        CALL SYM (2.3,5.5,0.105,'ACTUAL',0.0,6)
        CALL SYM (2.0,5.0,0.105,11,0.0,-1)
        CALL SYM (2.3,5.0,0.105,'EXPONENTIAL',0.0,11)
        CALL ENDPLT
 1000   CONTINUE
        CALL LSTPLT
        STOP
        END
```

APPENDIX C

PROGRAM RELICOMP

Operating Guide for this program is in Appendix D.

```
C     THIS PROGRAM CALCULATES RELIABILITY FOR VARIOUS TIME PERIODS
      DIMENSION NEX(30),X1(10),X2(10),X3(10),X4(10),X5(10),X6(10),X7(10)
     $,X8(10),AMBA(30,10),SIGMA(30,10),NCO(30)
C     NYS IS THE NUMBER OF GROUPS TO BE ANALYZED
      READ(5,100) NSY
  100 FORMAT(I2)
      PT1W=1
      PT1M=1.0
      PT3M=1.0
      PTSA=1.0
      PTYR=1.0
      DO 1 I=1,NSY
C     NOW I WILL READ THE GROUP NAME
      READ(5,101) XA,XB,XC,XD,XE,XF,XG,XH
  101 FORMAT(8A4)
C     NEX IS THE NUMBER OF EXPONENTIALLY BEHAVING COMPONENTS IN THE LOT
      READ(5,100) NEX(I)
      NE=NEX(I)
      IF(NE.EQ.0) GO TO 98
      DO 2 J=1,NE
      READ(5,101) X1(J),X2(J),X3(J),X4(J),X5(J),X6(J),X7(J),X8(J)
      WRITE(6,101) X1(J),X2(J),X3(J),X4(J),X5(J),X6(J),X7(J),X8(J)
C     AMBA IS LAMBA
      READ(5,102) AMBA(I,J)
  102 FORMAT(F6.4)
      A=AMBA(I,J)
      WRITE(6,223) A
  223 FORMAT( ' LAMBA=',F6.4)
```

```
C      P1W IS THE PROBABILITY OF SURVIVING FOR ONE WEEK
C      P1M IS THE PROBABILITY OF SURVIVING FOR ONE MONTH
C      P3M IS THE PROBABILITY OF SURVIVING FOR THREE MONTHS
C      PSA IS THE PROBABILITY OF SURVIVING FOR ONE HALF YEAR
C      PYR IS THE PROBABILITY OF SURVIVING FOR ONE YEAR
       P1W=EXP(-A)
       P1M=EXP(-4.3*A)
       P3M=EXP(-13*A)
       PSA=EXP(-26*A)
       PYR=EXP(-52*A)
       WRITE(6,103) P1W,P1M,P3M,PSA,PYR
   103 FORMAT( 6X,' THE PROBABILITY OF SURVIVAL IS AS INDICATED',/,T6,'ON
      $E WEEK',T21,'ONE MONTH',T36,'THREE MONTHS',T51,'HALF YEAR',T66,'ON
      $E YEAR',/,T8,F6.4,T23,F6.4,T38,F6.4,T53,F6.4,T68,F6.4,//)
     2 CONTINUE
       GO TO 99
    98 NE=1
    99 CONTINUE
C      NCO IS THE NUMBER OF NORMAL BEHAVING COMPONENTS IN THE LOT
       READ(5,100) NCO(I)
       NC=NCO(I)
       IF(NC.EQ.0) GO TO 96
       NB=NC+NE-1
       DO 3 J=NE,NB
       READ(5,101) X1(J),X2(J),X3(J),X4(J),X5(J),X6(J),X7(J),X8(J)
       WRITE(6,101) X1(J),X2(J),X3(J),X4(J),X5(J),X6(J),X7(J),X8(J)
       READ(5,104) AMBA(I,J),SIGMA(I,J)
   104 FORMAT(F6.4,T10,F7.4)
       A=1/AMBA(I,J)
       S=SIGMA(I,J)
       WRITE(6,204) AMBA(I,J),S
```

```
  204 FORMAT( ' LAMBA=',F6.4,'        SIGMA=',F7.4)
      P1W=0.5-0.5*ERF((1-A)/(1.414*S))
      P1M=0.5-0.5*ERF((4.3-A)/(1.414*S))
      P3M=0.5-0.5*ERF((13-A)/(1.414*S))
      PSA=0.5-0.5*ERF((26-A)/(1.414*S))
      PYR=0.5-0.5*ERF((52-A)/(1.414*S))
      WRITE(6,103) P1W,P1M,P3M,PSA,PYR
    3 CONTINUE
   96 CONTINUE
C     NOW TO CALCULATE THE PROBABILITY FOR THE GROUP
      NE=NEX(I)
      PR1W=1.0
      PR1M=1.0
      PR3M=1.0
      PRSA=1.0
      PRYR=1.0
      IF(NE.EQ.0) GO TO 90
      DO 5 J=1,NE
      A=AMBA(I,J)
      P1W=PR1W*EXP(-A)
      PR1W=P1W
      P1M=PR1M*EXP(-4.3*A)
      PP1M=P1M
      P3M=PR3M*EXP(-13*A)
      PR3M=P3M
      PSA=PRSA*EXP(-26*A)
      PRSA=PSA
      PYR=PRYR*EXP(-52*A)
      PRYR=PYR
    5 CONTINUE
      GO TO 93
   90 NE=1
   93 CONTINUE
```

```
      NC=NCO(I)
      IF(NC.EQ.0) GO TO 89
      NB=NC+NE-1
      DO 6 J=NE,NB
      A=1/AMBA(I,J)
      S=SIGMA(I,J)
      P1W=PR1W*(0.5-0.5*ERF((1-A)/(1.414*S)))
      PT1W=P1W
      P1M=PR1M*(0.5-0.5*ERF((4.3-A)/(1.414*S)))
      PR1M=P1M
      P3M=PR3M*(0.5-0.5*ERF((13-A)/(1.414*S)))
      PR3M=P3M
      PSA=PRSA*(0.5-0.5*ERF((26-A)/(1.414*S)))
      PRSA=PSA
      PYR=PRYR*(0.5-0.5*ERF((52-A)/(1.414*S)))
      PRYR=PYR
    6 CONTINUE
   89 CONTINUE
      WRITE(6,101) XA,XB,XC,XD,XE,XF,XG,XH
      WRITE(6,103) P1W,P1M,P3M,PSA,PYR
      PT1WA=PT1W*P1W
PT1W=PT1WA
      PT1MA=PT1M*P1M
      PT1M=PT1MA
      PT3MA=PT3M*P3M
      PT3M=PT3MA
```

```
      PTSAA=PTSA*PSA
      PTSA=PTSAA
      PTYRA=PTYR*PYR
      PTYR=PTYRA
    1 CONTINUE
      WRITE(6,106)
  106 FORMAT( ' THE TOTAL REACTOR RELIABILITY')
      WRITE(6,103) PT1W,PT1M,PT3M,PTSA,PTYR
      STOP
      END
```

APPENDIX D

PROGRAMMING GUIDE

Program RELIABLE

Description

Program RELIABLE is a Fortran program which will help to determine whether an actual failure distribution is exponential or normal. The program calculates the reciprical of the mean failure time and the statistical deviation of the points from the mean. Also, chi-squared values are calculated for the actual distribution versus each of the two theoretical distributions.

Operating Instructions

The unit of time is left to the discretion of the individual user, but the same basic time unit must be used throughout. The input on cards is arranged as follows:

1. The first card contains the total number of systems to be analyzed (NSYS). This number is to be an integer in a field of three spaces.

2. The next card contains the total number of subsystems or components in the system (NSUB). This number is an integer in a field of three spaces.

3. The next card contains the system name (XA through XH) as alphabetic characters in Spaces 1 through 32. If the components or subsystems are not equal and separate parts a message stating "disregard" should be punched here.

4. The next card contains the subsystem or component name (X1(II) through X8(II)) as alphabetic characters in Spaces 1 through 32.

5. The next card contains the number of failure times (NTIMES(II)) for the component or subsystem.

6. The next cards contain the failure times for the component or subsystem. These are read as F9.2 with one value per card on NTIMES(II) number of cards.

7. Steps 4 through 6 are repeated for each subsystem or component in the systems.

8. Steps 2 through 7 are repeated for each system.

The output is both printed and punched. The punched cards are utilized as input for program RELIPLOT.

Program RELIPLOT

Description

Program RELIPLOT utilizes the punched output from program RELIABLE to give graphical interpretation of the comparisons between the actual failure distribution and the two theoretical distributions.

Operating Instructions

The input to program RELIPLOT is generated in program RELIABLE. Minor corrections to the input are required as follows:

1. All cards beginning with the statement "disregard" to the next valid component, subsystem or system name should be removed.

2. The first input card should contain an integer in a field of three spaces telling how many cards containing system, subsystem or component names are in the input deck.

3. The source deck card

"CALL PENPOS ('SCHOTTEL',8,0)"

should be modified to reflect the user's name and the Number 8 should be changed to reflect the number of letters in the user's name.

Program RELICOMP

Description

Program RELICOMP calculates the reliability of the components, subsystems, systems and reactor for various time periods. (For this program the time unit of week must be used) By slightly modifying the input, this program will give the user the reliability effects of changing quality.

Operating Instructions

The input to program RELICOMP should be arranged as follows:

1. Card one should contain the number of systems as an integer in a two space field.

2. Card two should contain the name of the system analyzed. This is alphabetic in Spaces 1 through 32.

3. Card three is an integer in a two space field which tells how many exponential components in the system.

4. The next card is the component name. This is alphabetic in Spaces 1 through 32.

5. The next card is a real number containing the value of lambda. It is input as F6.4.

6. Steps 4 and 5 are repeated for each exponential component in the system.

7. The next card should contain the number of normally behaving components in the system. This is an integer in a field of two spaces.

8. If the number in Step 7 is zero disregard this step. Otherwise this card will contain the name of the component. This is alphabetic in Spaces 1 through 32.

9. If the number in Step 7 is not zero, this card will contain the values for lambda and sigma, with lambda as F6.4 and sigma starting in Space 10 as F7.4.

10. Steps 8 and 9 should be repeated for each normal component in the system.

11. Steps 2 through 10 are repeated for each system.