ANALYSIS AND EVALUATION of SPACECRAFT BATTERY LIFE TEST DATA

(PHASE 2)

prepared for
GODDARD SPACE FLIGHT CENTER
Naval Ammunition Depot
S-23404 G

QUALITY EVALUATION LABORATORY
NAD CRANE, INDIANA

TABLE OF CONTENTS

APPENDIXES

LIST OF TABLES

LIST OF ILLUSTRATIONS

FIGURE PAGE

ABSTRACT

This report presents the findings from the mathematical/statistical analysis of data generated by life tests on 660 nickel-cadmium spacecraft battery cells. The tests were conducted at NAD Crane beginning in 1963.

Three major objectives of the analysis were to: (1) determine the reliability of methods of predicting the useful life of the cells, (2) determine the statistical meaning of data collected during present acceptance testing and whether the acceptance data can be used in making life predictions, and (3) determine if particular failure characteristics or combinations thereof could be related to specific environmental factors.

Results of the analysis indicate: (1) about 85% accuracy in predicting the useful life of a cell, (2) the addition of acceptance data to the prediction model is of little value, and (3) failure characteristics were found to be highly correlated with specific environmental factors in several instances.

The improved automated data acquisition system to be installed will generate precise data which will yield more accurate predictions from more meaningful test results. Also important is the consideration that the improved data acquisition will permit earlier predictions of cell quality in a period of time known to be nondestructive to cells of reasonable quality.

I. INTRODUCTION

A. GENERAL

This is a summary report on mathematical/statistical analyses of spacecraft battery data conducted by the Naval Ammunition Depot, Crane, Indiana for the National Aeronautics and Space Administration from January 1968 to July 1969. The work was performed in accordance with NASA Defense Purchase Request No. S-23404-G, Amendment No. A-24 of 17 January 1968.

The report deals primarily with three topics:

a. The reliability of NAD Crane's prediction techniques,

b. The relationship of acceptance test parameters to life test data and prediction,

c. The evaluation of failure analysis data.

B. APPROACH

A technique for predicting cell life (failure time) of spacecraft battery cells was outlined in NAD Crane Report QE/C 67-592 of November 1967. The technique was devised and predictions were made for 170 of 660 standard nickel-cadmium cells which were placed on life test at NAD Crane beginning in 1963. This report presents the results of applying the prediction methods to all 660 cells.

Using the techniques of multiple linear regression, possible relationships between failure times of the various cells and the data generated during acceptance testing were investigated.

All NAD Crane failure analysis data were transferred to IBM data cards for subsequent computer processing; failure characteristics or combinations of characteristics were related to specific environmental factors where possible.

C. ORGANIZATION

The following sections of this report give in the order listed: the conclusions which were derived from the data analysis; recommendations based on the conclusions; and a summary of the data analysis performed on each of the topics listed above.

II. CONCLUSIONS

Based on the analysis of the test results, the following conclusions are drawn with regard to:

A. PREDICTION

The average cell-times to selected charge and discharge voltage levels are effective parameters for predicting cell life of spacecraft batteries using a relatively small number of test cycles (300) and all available failure data. Hence, these parameters may be used as bases for a cell screening procedure to assure that higher quality cells will be used in space missions. There were no significant differences in the percentage of correct decisions due to the number of cycles (300, 1000 or 2000) used in making the predictions.

The overall accuracy in predicting cell failures is better when using "time to discharge data" rather than "time to charge" data. However, use of the charge data yielded slightly better results with regard to the percentage of unreliable cells retained when using 300 cycles.

The reliability of cells selected for space missions could be improved substantially (about 7% when 300 cycles of data are available) over the proposed prediction and screening procedure by over-specifying the cell lifetime requirements of the missions. This over-specification would be somewhat more costly since an increased number of good cells would inadvertently be rejected. (See page 15, Section IV).

B. ACCEPTANCE TESTING

The purpose of the acceptance tests conducted by the manufacturer and NAD Crane were to screen battery cells for the life test which was performed subsequently and hence to remove catastrophic or short life failures from the life test group. The Crane acceptance tests, analyzed in this report, accomplished this end and, in addition, allowed a comparison between the acceptance test parameters measured and the eventual failure time of the cell. The latter is an important consideration since the Crane tests include most acceptance test measurements used to qualify cells for spacecraft use.

Parameters measured during acceptance tests (as they are presently being performed) are of little value in predicting the cell life of nickel-cadmium spacecraft batteries since they are not, in general, significantly correlated with the cell failure time. Furthermore, specifications are not generally established and used. If specifications can not be placed on acceptance test parameters and these parameters do not relate significantly to cell life, their value must be seriously questioned and re-evaluated.

A more accurate profile of cell quality could be obtained by increasing the number of cycles for performing acceptance tests. Presently acceptance tests are performed on only three charge-discharge cycles.

C. FAILURE ANALYSIS

Statistical examination of the data showed that it was possible to associate different failure characteristics:

(1) to source of manufacture,

(2) to one another by examining the correlations or rates of simultaneous occurrence,

(3) to propensities to fail under certain ambient temperature levels within manufacturer, and

(4) with deterioration rates across temperature.

For example, the results show that migration of the plate material and separator deterioration are highly correlated (correlation coefficient, r = .95); this result implies that it should not be necessary to distinguish between these characteristics during future failure analysis for battery types of similar design.

The failure characteristics observed and recorded, while informative and useful in correcting manufacturing design and quality control deficiencies, appear to need examination and re-structuring in the light of correlations and information now available. The fact that battery designs were not standard and little was known about the interiors of the battery types subjected to test reduces the amount of meaningful information that may be gleaned from the available failure data.

A proposed Bayesian technique to quantitatively (probabilistically) analyze failure analysis data was derived and is given in this report. (See page 79). Additional information from manufacturers pertaining to battery cell structure and, hopefully, from future sampling of new procurements (so that their initial characteristics could be studied by dissecting the interior) may later be incorporated into a Bayesian model for quantitative analysis.

This technique will systematically review the failure information (stored on magnetic tape and updated when new failures occur) and will give the project engineers a readable computer printout illustrating the cell failure characteristics and their associations with different test conditions and manufacturers.

III. RECOMMENDATIONS

Based on the battery reliability needs for space vehicles and on the data analysis of the cycling test results, it is recommended that:

A. PREDICTION

All spacecraft batteries which now or will in the near future be put on life test be continued until failure or until 10,000 successful cycles have been completed. If it becomes necessary that life testing of certain cells be discontinued at any point prior to failure, these cells should undergo the same examination as failed cells. This would allow a comparison between the characteristics noted in good cells and those noted in cells that have failed.

Voltage and temperature data be collected via the new automated data acquisition system every cycle for the first 500 cycles at two minute intervals. After 500 cycles, less frequent monitoring, such as every five or ten cycles, will be sufficient from a prediction point of view.

Failure times be predicted after 50, 100, and 200 cycles of testing on the new automated data acquisition system using the methods described herein and the results compared with the actual failure times.

Frequent measurements of internal cell pressure be made early in the life of the battery. The frequency of measurement should approach that given above for voltage and temperature if economy permits. Many cells in the Crane life tests have failed because of high internal pressure. Hence, it is logical to conjecture that some empirical relationship, as well as physical, exists between the cell's internal pressure and voltage. It has already been established that the cell's discharge time to 1.25 volts is correlated with failure time. Such a relationship could form the basis for a highly reliable prediction and screening method when combined with present knowledge.

Time to charge and time to discharge profiles and prediction methods be examined for cells of more recent manufacture so that prediction and screening methods might be tailored to any battery type of interest to NASA. Even if such studies should result in conclusions that cell life predictions are consistently high or low for some newer battery types (where the manufacturer has significantly modified construction), then it will still be possible to accurately rank a test group of batteries by quality. In other words, if times to discharge and charge data were determined for a lot of batteries during some pre-use stage, the 50% with the best quality could be accurately segregated from the remainder.

B. ACCEPTANCE TESTING

A complete re-evaluation of present acceptance tests be made by battery experts. In light of possible reliable life prediction techniques, it may be advisable to combine acceptance and prediction tests in order to minimize the early stressing placed on new procurements.

Specifications be established for use with future acceptance tests. Where specifications cannot be established, definite reasons for conducting a particular test should be documented along with the characteristics of interest which the test is designed to reveal.

A list of internal cell characteristics which are desirable or undesirable for extended cell quality be established so that for future procurements a small sample of cells could be dissected and inspected internally for these characteristics. Too many undesirable characteristics should be a criterion for rejecting the cells even if variable measurements are acceptable.

C. FAILURE ANALYSIS

NASA select a working group to review failure analysis results and conclusions from the Crane tests and other related tests and to recommend a newly structured failure analysis scheme for use on dissected cells of new procurement and cells that have failed during the cycling life test. Such a study should examine cause and effect relationships, correlations of cell failure characteristics, etc. and finally list all important known characteristics in categories such as failure modes, and failure mechanisms. Work presently being done by Battelle for NASA Goddard and the Air Force (WPAFB) could help serve as a basis for this approach.

When major expected failure mechanisms are pinpointed and defined, methods should be developed to monitor the characteristics of these mechanisms as the cell degenerates to failure.

The Bayesian failure evaluation technique described in this report be applied to failure analysis data available on existing battery test programs and refined for future use on test results that will be obtained from the NASA accelerated test which is presently in the planning stages.

IV. DATA ANALYSIS AND SUMMARY

A. PREDICTION

1. Discussion

Three methods of predicting cell life have been developed and used with good success. This report compares the three and presents results of their application to the 660 cells.

The three methods used in predicting the cell lives are as follows:

Average Time To Discharge: Assuming the failure times of the cells are log-normally distributed, the failures were predicted using the average time for the cell to discharge to a pre-specified voltage. This average time to discharge ($\bar{t}_i$) was used with the actual failure times to make the predictions. This method is described in detail in Appendix A of this report.

Average Time To Charge: The procedure here is the same as that described in the preceding paragraph except that an average time to charge ($\bar{t}_i'$) to a pre-specified voltage rather than the time to discharge was utilized. The details of this procedure are given in Appendix B.

Linear Regression: This method uses standard regression techniques with the $\bar{t}_i$ as the independent variable and the logarithm of the failure time as the dependent variable. Details of this procedure are given in Appendix C.

Using average time to discharge, a failure time was predicted for each of the 660 nickel-cadmium cells originally put on test (480 in 10-cell packs and 180 in 5-cell packs). Predictions were made based on data available after 300, 1000, and 2000 cycles of life testing.

Using average time to charge, fifteen 10-cell packs were analyzed and predictions based on 300, 1000, and 2000 cycles of life testing were made.

Using linear regression, predictions were made for each of the 660 cells based on the first 1000 cycles of life testing.

This section also includes a brief study on the cell reliability improvement noted by making cell screening requirements greater than the aerospace requirements.

2. Summary

a. Comparison of Prediction Methods

Evaluations and comparisons of the methods are as follows:

(1) Average Time To Discharge

Using the first method and 300, 1000, and 2000 test cycles, a failure time was predicted for each of the 660 nickel-cadmium cells originally put on test. Based on the predicted failure time and a 5000 (10,000) cycle minimum acceptable life (MAL) each cell was classified as good or defective. A cell classified as good would be retained for a 5000 (10,000) cycle mission. A cell classified as defective would be discarded, or used in some lesser capacity.

The predicted failure times were then compared with the actual failure times (where available) to see if a correct decision had been made. Approximately 100 cells could not be evaluated for a 5000 cycle MAL and approximately 150 cells could not be evaluated for a 10,000 cycle MAL. Evaluations could not be made for these 250 cells because testing was discontinued after 6 cell failures in the 10-cell packs and 3 failures in the 5-cell packs. For example, a cell might have a predicted failure time of 15,000 cycles. However, if testing was discontinued after 4,500 cycles, the prediction could not be classified as correct or incorrect.

Predictions on the 5-cell packs resulted in a significantly higher percentage of correct decisions than those on the 10-cell packs as shown below.

No. Test Cycles	MAL	Percentage of Correct Decisions	
		5-Cell Packs	10-Cell Packs
300	5,000	93.4%	84.9%
	10,000	94.2%	85.2%
1000	5,000	97.4%	84.7%
	10,000	94.2%	87.9%
2000	5,000	95.3%	86.9%
	10,000	95.6%	88.0%

Also illustrated in the above table, no significant differences in the percentage of correct decisions were noted between the 5000 cycle MAL and the 10,000 MAL.

No significant differences in the percentage of correct decisions were noted between the results based on the first 300, 1000 or 2000 cycles of life testing.

A more detailed breakdown of these comparisons is given in Table 1.

TABLE 1

PERCENTAGE OF CORRECT AND INCORRECT DECISIONS USING THE AVERAGE TIME TO DISCHARGE ($\bar{t}_1$)

No. Test Cycles	MAL	5 Cell Packs				10 Cell Packs				Total			
		No. Cells	Bad Cells Retained	Good Cells Discarded	Correct Decision	No. Cells	Bad Cells Retained	Good Cells Discarded	Correct Decision	No. Cells	Bad Cells Retained	Good Cells Discarded	Correct Decision
300 Cycles	5000 Cycle MAL	152	6 / 3.9%	4 / 2.6%	142 / 93.4%	404	45 / 11.1%	16 / 4.0%	343 / 84.9%	556	51 / 9.2%	20 / 3.6%	485 / 87.2%
	10,000 Cycle MAL	138	3 / 2.2%	5 / 3.6%	130 / 94.2%	372	35 / 9.4%	20 / 5.4%	317 / 85.2%	510	38 / 7.5%	25 / 4.9%	447 / 87.6%
1000 Cycles	5000 Cycle MAL	152	3 / 2.0%	1 / 0.7%	148 / 97.4%	404	46 / 11.4%	16 / 4.0%	342 / 84.7%	556	49 / 8.8%	17 / 3.1%	490 / 88.1%
	10,000 Cycle MAL	138	3 / 2.2%	5 / 3.6%	130 / 94.2%	372	27 / 7.3%	18 / 4.8%	327 / 87.9%	510	30 / 5.9%	23 / 4.5%	457 / 89.6%
2000 Cycles	5000 Cycle MAL	149	6 / 4.0%	1 / 0.7%	142 / 95.3%	398	41 / 10.3%	11 / 2.8%	346 / 86.9%	547	47 / 8.6%	12 / 2.2%	488 / 89.2%
	10,000 Cycle MAL	135	2 / 1.5%	4 / 3.0%	129 / 95.6%	366	24 / 6.6%	20 / 5.5%	322 / 88.0%	501	26 / 5.2%	24 / 4.8%	451 / 90.0%

The failure time for each cell for which a correct decision was made was then examined to determine the magnitude of the prediction error. The correct decisions were classified according to an error of ≤2000 cycles, >2000 cycles, or not known. In some cases the decision to retain or discard could be made although the magnitude of error could not be determined (usually due to early failures which caused discontinuance of pack testing). These cells were classified "not known." The most prevalent type of error is one which would result in classifying a cell as acceptable for a mission it could not complete. Further study is needed to try to alleviate this problem. These results are shown in Table 2.

(2) Average Time To Charge

The second method was used on fifteen (15) ten-cell packs, and a prediction for failure time was made for each cell. For these particular 15 packs there was a significant difference between the percentage of correct decisions for a 5000 cycle MAL versus a 10,000 cycle MAL using the time to discharge data.

The percentage of correct decisions obtained using the "time to charge" data did not differ significantly from that obtained using the "time to discharge" data and a 5000 cycle MAL. However, the percentage of correct decisions obtained using the "time to charge" data was significantly lower than that obtained using the "time to discharge" data and a 10,000 cycle MAL. The following table summarizes the data for the 15 packs.

	5,000 Cycle MAL			10,000 Cycle MAL		
	Number of Test Cycles			Number of Test Cycles		
Method	300	1000	2000	300	1000	2000
Time to Charge	69.8%	69.1%	66.9%	73.1%	74.8%	73.1%
Time to Discharge	69.8%	71.2%	75.5%	79.8%	84.9%	84.0%

The number of test cycles used did not significantly affect the percentage of correct decisions obtained using the "time to charge" data.

A complete breakdown of the percentage of correct decisions is given in Table 3.

(3) Regression Analysis

The third method used to predict failure times of spacecraft batteries was a linear regression method. In this method the $\bar{t}_1$ (average time to discharge to a specified voltage) was used as the independent variable and the natural logarithm of the failure time as the dependent variable. Failure times were predicted using 1000 test cycles.

TABLE 2

EVALUATION OF PREDICTIONS - TIME TO DISCHARGE METHOD

Test Time	Pack Type	Minimum Acceptable Life (MAL)	No. of Cells Prediction System Would		Total Cells That Could Be Evaluated	Frequency Of Wrong Decisions		Frequency of Correct Decisions When Magnitude of Prediction Error is:		
			Discard	Retain		Retain Bad Cell	Discard Good Cell	≤2000 Cycles	>2000 Cycles	Not Known
300 Cycles	5 Cell	5000 Cycles	80	100	152	6	4	72	7	63
		10,000 Cycles	119	61	138	3	5	74	9	47
	10 Cell	5000 Cycles	196	284	404	45	16	134	47	162
		10,000 Cycles	292	188	372	35	20	142	48	127
1000 Cycles	5 Cell	5000 Cycles	80	100	152	3	1	75	8	65
		10,000 Cycles	119	61	138	3	5	78	6	46
	10 Cell	5000 Cycles	197	283	404	46	16	139	40	163
		10,000 Cycles	291	189	372	27	18	151	48	128
2000 Cycles	5 Cell	5000 Cycles	73	102	149	6	1	71	6	65
		10,000 Cycles	113	62	135	2	4	76	6	47
	10 Cell	5000 Cycles	183	287	398	41	11	148	34	164
		10,000 Cycles	186	284	366	24	20	159	36	127

TABLE 3

COMPARISON OF PREDICTIONS OF 15 SELECTED 10 CELL PACKS USING CHARGE AND DISCHARGE DATA

No. of Test Cycles	Minimum Acceptable Life (MAL)	Type of Data Used	No. Packs Tested	No. Cells For Which Prediction Made	Bad Cells Retained	Good Cells Discarded	Correct Decisions
300 Cycles	5000 Cycles	Charge	15	139	25/18.0%	17/12.2%	97/69.8%
		Discharge	15	139	30/21.6%	12/8.6%	97/69.8%
	10,000 Cycles	Charge	15	119	11/9.2%	21/17.6%	87/73.1%
		Discharge	15	119	14/11.8%	10/8.4%	95/79.8%
1000 Cycles	5000 Cycles	Charge	15	139	26/18.7%	17/12.2%	96/69.1%
		Discharge	15	139	28/20.1%	12/8.6%	99/71.2%
	10,000 Cycles	Charge	15	119	11/9.2%	19/16.0%	89/74.8%
		Discharge	15	119	10/8.4%	8/6.7%	101/84.9%
2000 Cycles	5000 Cycles	Charge	15	139	28/20.1%	18/12.9%	93/66.9%
		Discharge	15	139	25/18.0%	9/6.5%	105/75.5%
	10,000 Cycles	Charge	15	119	14/11.8%	18/15.1%	87/73.1%
		Discharge	15	119	10/8.4%	9/7.6%	100/84.0%

The percentage of correct decisions for a 5000 cycle MAL did not differ significantly from that for a 10,000 cycle MAL.

The 5-cell packs yielded a significantly higher percentage of correct decisions than the 10-cell packs (95.9% versus 88.5%).

A comparison between the first and third prediction methods revealed no significant differences.

These results along with the percentage of correct decisions are given in Table 4.

As with the first method, each cell, for which a prediction was made, was examined to determine the magnitude of the prediction error. Each correct decision was classified according to an error of ≤2000 cycles, >2000 cycles or not known. These results are shown in Table 5.

b. Reliability Improvement Noted by Making Cell Screening Requirements Greater than Aerospace Requirements

It is informative to consider what added reliability is obtained if the required mission time of the batteries is over-specified during the proposed screening process. For example, if NASA would require that cells be screened so that those inserted into space vehicles would last at least 5000 cycles, predictions could be made after the cells were cycled for 300 cycles or less. If the cells with a predicted life of at least 10,000 cycles were screened or selected, then 91.8% of these cells would last at least 5000 cycles. Contrast this with the case where cells with a predicted life of over 5000 cycles were selected for use and the reliability of these cells in completing 5000 cycles would fall to 84.9%. The following table gives the percentage of reliable cells (i.e., the number of cells that survived 5000 cycles by actual test that would have been retained by screening -- divided by the number of cells that would have been retained by screening process) for each category as indicated.

		Number Of Test Cycles Used To Make Predictions		
		300	1000	2000
Cell Predictions	≥5000 Cycles	$\frac{343}{404}$ (84.9%)	$\frac{342}{404}$ (84.7%)	$\frac{346}{398}$ (86.9%)
	≥7500 Cycles	$\frac{190}{212}$ (86.9%)	$\frac{195}{214}$ (91.1%)	$\frac{196}{211}$ (92.8%)
	≥10,000 Cycles	$\frac{169}{184}$ (91.8%)	$\frac{172}{182}$ (94.5%)	$\frac{166}{179}$ (92.7%)

TABLE 4

PERCENTAGE OF CORRECT AND INCORRECT DECISIONS MADE USING THE LINEAR REGRESSION PROCEDURE WITH 1000 TEST CYCLES

	5,000 Cycle MAL				10,000 Cycle MAL			
	No. Cells	Bad Cells Retained	Good Cells Discarded	Correct Decisions	No. Cells	Bad Cells Retained	Good Cells Discarded	Correct Decisions
5 Cell Packs	152	2 / 1.3%	1 / 0.7%	149 / 98.0%	138	4 / 2.9%	5 / 3.6%	129 / 93.5%
10 Cell Packs	404	36 / 8.9%	6 / 1.5%	362 / 89.6%	372	27 / 7.3%	20 / 5.4%	325 / 87.4%

TABLE 5

EVALUATION OF PREDICTIONS - REGRESSION METHOD

Pack Type	Minimum Acceptable Life (MAL)	No. Cells Prediction System Would:		Total Cells That Could Be Evaluated	Frequency of Wrong Decisions		Frequency of Correct Decisions When Magnitude of Prediction Error Is:		
		Discard	Retain		Retain Bad Cell	Discard Good Cell	≤2000 Cycles	>2000 Cycles	Not Known
5 Cell	5,000 Cycles	82	98	152	2	1	78	7	64
	10,000 Cycles	118	62	138	4	5	79	3	47
10 Cell	5,000 Cycles	203	277	404	36	6	161	29	172
	10,000 Cycles	297	183	372	27	20	167	32	126

It is realized that 1000 or 2000 cycles of testing is too long for a screening process, but these portions of the table do illustrate that more voltage information does yield more reliable predictions. Hence, it is logical to assume that more accurate selection of superior cells will be possible with more frequent data monitoring early in the lives of the cells.

The method of over-specifying reliability as given above is effective and could be used to improve the quality of cells for space missions. This method would also be more costly since a larger number of good cells would be rejected. For example, consider the case where cells with a predicted life of over 5000 cycles were selected for use after testing for 300 cycles; only 18 (7.8%) good cells from 230 under consideration would be discarded. But for the case where cells with a predicted life of over 10,000 cycles were selected for use after 300 cycles of testing, 61 (26.5%) good cells would be discarded while 169 would be retained. In summary, use of this method to increase the reliability of units selected or retained for space missions, increases the likelihood that good units will be discarded or used for purposes where the reliability requirements are not so large.

B. ACCEPTANCE TESTING

1. The Data

All spacecraft battery cells received at NAD Crane are subjected to acceptance tests prior to being placed on life test. However, specifications are not placed on the parameters measured for these tests. Only those cells with catastrophic failure and those with test results displaying extreme departure from the usual range of values are excluded from the life test. The tests include measurements on physical dimensions, capacity, cell short, leakage, overcharge, and internal resistance. Since there were no specifications, cells were rejected only if they were leaking badly or completely shorted. A finer breakdown of the acceptance data shows that it included: physical dimensions (height, length, width, weight), capacity (three readings), cell short, leakage (immersion seal and litmus), overcharge (three readings: c/20, c/10, c/5, and internal resistance. These data were readily available for any analysis and were placed on data processing cards for future study. Also included on the cards are: cell serial number, number of pack in which cell is located, location of cell in pack (cell number), average time for a cell to discharge to 1.25 volts using 1000 cycles of life testing, and the actual failure time for cells that failed. Using the acceptance data already available, an attempt was made to relate one or more of these parameters to the failure time of the cell.

2. Summary

An attempt was made to relate the failure time of a cell to one or more of the parameters measured during the acceptance tests for each manufacturer-ampere hour subgroup. A multiple regression technique was used. The purpose of the regression approach was to obtain an equation whereby the failure time of the cell could be accurately predicted using the acceptance data. The regression equation was of the following form.

$$T = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n,$$

where T = failure time of the cell,

α = a constant generated by the regression,

β_i = coefficient of the ith prediction (acceptance) parameter,

X_i = ith prediction parameter,

where $i = 1, 2, 3, \ldots, n$.

The independent variables used in deriving the prediction equation were: capacity (three readings), cell short, overcharge (three readings), internal resistance, and $\bar{t}_i$. The $\bar{t}_i$'s were not a part of the acceptance data, but as was mentioned in Report QE/C 67-592 of November 1967, these appeared to be good predictors of cell life and so were included as one of the independent variables. The dependent variable, of course, was the failure time. Since failure time was the dependent variable, only those cells which were tested to failure were used to develop the model.

A stepwise multiple regression computer program was used to determine what the prediction model (equation) should be. With this program the independent variable which has the greatest simple linear correlation with the dependent variable is entered into the model first. Of the remaining independent variables the one which has the highest first order partial correlation with the dependent variable is entered second.

In all cases, except where the cells were manufactured by Sonotone, the first variable entered into the model was the $\bar{t}_i$. And in each case the simple correlation between the $\bar{t}_i$ and the failure time was relatively high. However, this was expected as it was known that the $\bar{t}_i$ was a good predictor of the failure time. The addition of other variables added little to the model as can be seen in Table 6.

TABLE 6

MULTIPLE REGRESSION CORRELATION COEFFICIENTS

Mfr.	Ampere Hour Rating	Variable Entered	Multiple Correlation Coefficient	Ampere Hour Rating	Variable Entered	Multiple Correlation Coefficient
		$\bar{t}_i$	.615		$\bar{t}_i$	.802
General Electric	3.0	Overcharge (C/10)	.677	12.0	Capacity (3)	.839
		Capacity (1)	.715		Short Test	.865
		Short Test	.727		Overcharge (C/20)	.868
		$\bar{t}_i$	.685		$\bar{t}_i$	.722
Gould	3.0	Internal Resistance	.717	20.0	Overcharge (C/20)	.791
		Capacity (1)	.739		Capacity (2)	.799
		Overcharge (C/20)	.742		Capacity (1)	.804
		$\bar{t}_i$	.730		$\bar{t}_i$	.605
Gulton	6.0	Capacity (3)	.747	20.0	Short Test	.638
		Internal Resistance	.751		Overcharge (C/20)	.650
		Overcharge (C/5)	.752		Internal Resistance	.653
Sonotone	5.0	Capacity (3)	.393			
		Internal Resistance	.503			
		Overcharge (C/10)	.528			
		Capacity (2)	.539			

This indicated that, except for Sonotone, after the $\bar{t}_i$ the other variables are of little value in predicting cell life (failure time).

Table 7 shows the simple correlation coefficient between failure time and $\bar{t}_i$ and also the simple correlation coefficient between failure time and the variable which had the second highest simple correlation. In the case of Sonotone the second value is the largest correlation (although correlated negatively). This indicates which variable would have been first in the model and the correlation between the variable and the failure time had the $\bar{t}_i$ not been included as one of the independent variables.

TABLE 7

SIMPLE CORRELATION COEFFICIENTS

Manufacturer	Ampere-Hour Rating	r ($\bar{t}_1$)	r (second)	Variable
General Electric	3.0	.615	.258	Overcharge (c/20)
General Electric	12.0	.802	.238	Overcharge (c/10)
Gould	3.5	.685	.284	Internal Resistance
Gould	20.0	.722	.445	Overcharge (c/20)
Gulton	6.0	.730	.246	Capacity (2)
Gulton	20.0	.605	.434	Capacity (3)
Sonotone	5.0	.241	-.393	Capacity (3)

Tables 8 through 14 show the simple correlation coefficients between each pair of variables for each manufacturer - ampere hour subgroup. We would normally expect good correlation within the three capacities, and the three overcharges. We also would expect good correlation between the $\bar{t}_1$ and the failure time. This was true in most cases although there were some discrepancies.

It was necessary to inspect individual readings carefully for unusually high or low values which can affect correlations drastically. For example, two Gulton 20.0 A. H. voltage results of 1.56 volts each at the c/5 overcharge rate were removed from the analysis to obtain the tabled correlations of .791 and .901 with c/20 and c/10 overcharge rates, respectively. All other readings for the three overcharges were in the 1.39 - 1.45 voltage range. With the data for these two cells included in the analysis, the correlations were -.020 and .311 for c/5 correlated with c/20 and c/10, respectively. High positive correlations were expected between the overcharge rates. There were other illogical results in the correlations for which no reasons could be found.

TABLE 8

SIMPLE CORRELATION COEFFICIENTS
GENERAL ELECTRIC 3.0 A. H.

Variable Code

1. Capacity (1)
2. Capacity (2)
3. Capacity (3)
4. Short Test
5. Overcharge, (c/20)
6. Overcharge, (c/10)
7. Overcharge, (c/5)
8. Internal Resistance
9. Time to Discharge ($\overline{t}_1$)
10. Failure Time

Variables

1	2	3	4	5	6	7	8	9	10
1	.316	.586	-.185	.152	-.093	-.104	-.334	.059	-.216
2		.633	-.306	.029	-.220	-.008	-.248	.310	.062
3			-.483	.178	-.213	.046	-.124	.285	-.076
4				-.170	.199	.051	-.023	.004	-.027
5					.594	.241	.170	.052	.258
6						.612	.207	-.240	.128
7							.061	-.149	.059
8								.005	.046
9									.615

Variables

TABLE 9

SIMPLE CORRELATION COEFFICIENTS
GENERAL ELECTRIC 12.0 A. H.

Variable Code

1. Capacity (1)
2. Capacity (2)
3. Capacity (3)
4. Short Test
5. Overcharge (c/20)
6. Overcharge (c/10)
7. Overcharge (c/5)
8. Internal Resistance
9. Time to Discharge ($\overline{t_i}$)
10. Failure Time

Variables

1	2	3	4	5	6	7	8	9	10
1	.450	.366	.097	.157	.283	.608	-.258	.156	-.037
2		-.123	.224	.312	.253	.366	-.052	-.015	.008
3			-.558	-.194	.144	.010	.095	.153	-.118
4				.220	-.294	.197	-.212	-.133	-.149
5					.550	.418	.548	.021	.107
6						.497	.232	.235	.238
7							.063	-.114	-.218
8								-.222	-.100
9									.802

Variables

TABLE 1C

SIMPLE CORRELATION COEFFICIENTS
GOULD 3.5 A. H.

Variable Code

1. Capacity (1)
2. Capacity (2)
3. Capacity (3)
4. Short Test
5. Overcharge (c/20)
6. Overcharge (c/10)
7. Overcharge (c/5)
8. Internal Resistance
9. Time to Discharge ($\overline{t}_1$)
10. Failure Time

Variables

1	2	3	4	5	6	7	8	9	10
1	.807	.551	.417	-.186	-.308	-.117	-.553	.088	.088
	2	.554	.209	-.275	-.381	-.090	-.374	.125	.136
		3	.406	.119	-.079	.035	-.408	-.225	-.266
			4	.217	.073	-.131	-.427	-.206	-.217
				5	.798	.452	.122	-.370	-.169
					6	.611	.202	-.237	-.138
						7	.026	.067	.052
							8	.107	.284
								9	.685

Variables

TABLE 11

SIMPLE CORRELATION COEFFICIENTS
GOULD 20.0 A. H.

Variable Code

1. Capacity (1)
2. Capacity (2)
3. Capacity (3)
4. Short Test
5. Overcharge (c/20)
6. Overcharge (c/10)
7. Overcharge (c/5)
8. Internal Resistance
9. Time to Discharge ($\overline{t_1}$)
10. Failure Time

Variables

1	2	3	4	5	6	7	8	9	10
1	.624	-.029	.345	-.306	-.322	-.117	.501	.086	-.040
	2	.223	.012	-.159	-.125	-.117	.259	.069	-.120
		3	-.237	.578	.675	.587	-.642	.446	.413
			4	-.398	-.456	-.392	.337	.065	-.134
				5	.887	.802	-.655	.176	.445
					6	.887	-.650	.112	.361
						7	-.560	.160	.413
							8	-.276	-.364
								9	.722

Variables

TABLE 12

SIMPLE CORRELATION COEFFICIENTS
GULTON 6.0 A. H.

Variable Code

1. Capacity (1)
2. Capacity (2)
3. Capacity (3)
4. Short Test
5. Overcharge (c/20)
6. Overcharge (c/10)
7. Overcharge (c/5)
8. Internal Resistance
9. Time to Discharge $(\overline{t_1})$
10. Failure Time

Variables

1	2	3	4	5	6	7	8	9	10
1	.152	.385	-.330	.201	.092	.030	.247	-.025	-.091
	2	.429	.025	.183	.291	-.049	.172	.382	.246
		3	-.298	.122	-.023	-.191	.407	.476	.212
			4	.271	.291	-.102	-.026	-.082	-.047
				5	.618	.253	.281	.181	.097
					6	.451	.103	.084	.015
						7	-.059	-.026	-.037
							8	.241	.052
								9	.730

Vatiables

TABLE 13

SIMPLE CORRELATION COEFFICIENTS
GULTON 20.0 A. H.

Variable Code

1. Capacity (1)
2. Capacity (2)
3. Capacity (3)
4. Short Test
5. Overcharge (c/20)
6. Overcharge (c/10)
7. Overcharge (c/5)
8. Internal Resistance
9. Time to Discharge ($\overline{t}_1$)
10. Failure Time

Variables

1	2	3	4	5	6	7	8	9	10
1	.526	.448	-.129	.285	.139	-.159	-.440	.419	.225
	2	.364	-.134	-.042	-.212	-.122	-.395	.614	.420
		3	-.104	-.072	-.158	-.212	.101	.630	.434
			4	.023	.094	.117	-.114	.145	-.113
				5	.918	.791	.136	.018	-.115
					6	.901	.145	-.077	-.156
						7	-.094	-.061	-.093
							8	-.144	-.145
								9	.605

Variables

TABLE 14

SIMPLE CORRELATION COEFFICIENTS
SONOTONE 5.0 A. H.

Variable Code

1. Capacity (1)
2. Capacity (2)
3. Capacity (3)
4. Short Test
5. Overcharge (c/20)
6. Overcharge (c/10)
7. Overcharge (c/5)
8. Internal Resistance
9. Time to Discharge ($\overline{t_1}$)
10. Failure Time

Variables

1	2	3	4	5	6	7	8	9	10
1	.731	.562	-.385	-.116	.229	.233	.058	.008	-.266
2		.847	-.441	-.000	.182	.158	-.008	-.130	-.390
3			-.278	.153	.099	.170	.047	-.165	-.393
4				-.209	-.140	-.257	-.033	.238	.034
5					-.065	.394	.229	-.245	-.052
6						.055	-.031	-.178	-.188
7							-.034	.168	-.014
8								-.246	-.333
9									.241

Variables

C. EVALUATION OF FAILURE ANALYSIS CHARACTERISTICS

1. Failure Analysis Results

As failures occurred in the Crane life test, the failed cells were given a comprehensive internal inspection. Characteristics or observations made by the Crane battery analysts were recorded. The failure analysis observations were categorized under major classifications (i.e., separator deterioration, migration of active material, high internal pressure, depositing, etc.) and then a more descriptive observation was made elaborating on the major classification. For example, if separator deterioration was noted, a further observation would describe whether general decomposition was noted, whether shorting between the plates occurred, and, if so, whether it occurred at the center of the core or on the outermost portion, etc. All failure observations for the standard 660 Ni-Cd cells originally on test are given in Tables 15-18. Tables 19-20 describe failures to date for additional cells placed on test. The frequencies given in the tables represent the number of times a given level of the major classification (i.e., separator deterioration) occurred. All failure analysis information available (by April 1969) has been coded and placed on IBM cards for any subsequent data processing. For a complete listing of failure characteristics for each cell of each pack see Appendix D. For a more detailed description of the failure classifications and levels of each see NAD Crane Report QE/C 69-244, "Cycle Life Test of Secondary Spacecraft Cells" of 7 April 1969.

By condensing Tables 15-18 to give frequencies of the major failure classifications within each manufacturer-ambient temperature combination, as in Table 21, several overall conclusions may be easily derived from the failure information.

(1) All failed cells had an end of charge voltage recorded; hence the frequencies given here are not meaningful. Consult Tables 15-18 to determine the frequency of cells with low, normal or high end of charge voltage.

(2) Cell weight loss is most common in Gould and Gulton cells; a total of 88 failures experienced weight loss and 80 of these were among these manufacturers' cells.

(3) Concave sides are typical only of cells with rectangular construction (Gulton in this case). This deficiency occurs more frequently at the lower temperatures as shown by the table below:

0°C	25°C	40°C
16/28(57.1%)	6/39(15.4%)	4/37(10.8%)

(4) Evidence of weak or inadequate welds are characteristic of Sonotone and Gould cells.

TABLE 15

FREQUENCIES OF FAILURE CHARACTERISTICS AND LEVELS OF EACH-GENERAL ELECTRIC

Capacity Rating		3.0 AMP.-HR.												12.0 AMP.-HR.											
Temperature		0°C				25°C				40°C				0°C				25°C				40°C			
Depth of Discharge		15%		25%		25%		40%		15%		25%		15%		25%		25%		40%		15%		25%	
Orbit Time (Hrs.)		1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0
Pack Number		63A	67A	64A	68A	15A	19A	16A	20A	39A	43A	40A	44A	110A	111A	124A	125A	82A	83A	96A	97A	85A	86A	99A	100A
No. Cells in Each Pack		10	10	10	10	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5	5	5	5	5
Charge Voltage (End of)	Shorted	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3
	Low	0	1	0	1	4	0	3	4	0	1	1	1	0	0	0	0	1	2	3	1	2	1	3	0
	Normal	1	0	0	0	2	1	3	1	3	0	1	1	0	0	1	0	2	0	0	2	1	2	0	0
	High	1	0	0	0	0	0	0	0	3	1	5	2	0	0	1	0	0	0	0	0	0	0	0	0
	Open Circuit	0	0	0	0	0	0	0	0	0	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Weight Loss	Low	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Medium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
Deposits	Around Terminal	1	1	0	0	1	1	0	3	3	0	2	3	0	0	1	0	1	0	0	0	0	1	1	0
	Around Seam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Around Both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
High Pressure	Bulged	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2	0	0	0
	Gas Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
	Both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	3	0	2
Concave Sides	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weak Weld	Tab to Plate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plated Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plated Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loosened Active Material	Present	1	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Extraneous Active Material	Present	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pierced Separator	Grid Wire	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Excess Scoring	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Burned Positive Tab	Present	0	0	0	0	0	0	0	1	5	1	4	1	0	0	0	0	0	0	0	0	0	0	0	0
	Broken	0	0	0	0	0	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Short Separator	Present	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0		0	0	0	0	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceramic Short	One Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Two Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Migration	General	2	1	0	1	3	1	0	3	2	0	0	1	0	0	1	0	1	2	0	2	3	2	2	2
	Sm. Area Penetration	0	0	0	0	0	0	4	0	1	2	0	3	0	0	0	0	0	0	0	0	0	0	1	0
	Shorting Penetration	0	0	0	0	3	0	1	3	0	0	0	1	0	0	1	0	2	0	3	0	0	0	0	0
	Positive Plate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Short Around Tab	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Short Around Scoring	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blisters	Present	1	0	0	0	6	0	0	6	0	0	0	2	0	0	1	0	0	0	0	2	0	0	0	1
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Separator Deterioration	General	2	1	0	1	6	1	0	4	3	3	0	5	0	0	1	0	1	0	0	3	3	0	2	2
	Permitted Short	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	2	2	0	0	0	3	0	1
	Center of Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Permitted Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 16
FREQUENCIES OF FAILURE CHARACTERISTICS AND LEVELS OF EACH–GOULD

Capacity Rating		3.5 AMP.-HR.												20.0 AMP.-HR.											
Temperature		0°C				25°C				40°C				0°C				25°C				40°C			
Depth of Discharge		15%		25%		25%		40%		15%		25%		15%		25%		25%		40%		15%		25%	
Orbit Time (Hrs.)		1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0
Pack Number		51A	55A	52A	56A	3A	7A	4A	8A	27A	31A	28A	32A	84A	80A	98A	94A	104A	105A	118A	119A	112A	108A	126A	122A
No. Cells In Each Pack		10	10	10	10	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5	5	5	5	5
Charge Voltage (End of)	Shorted	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0
	Low	2	0	3	0	1	2	5	4	1	5	4	2	1	0	1	0	3	3	3	1	3	1	3	3
	Normal	0	0	1	0	5	3	1	3	4	0	3	2	0	0	2	1	0	0	0	2	0	0	0	0
	High	0	0	1	0	1	0	0	0	1	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0
	Open Circuit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weight Loss	Low	1	0	0	0	0	3	1	2	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	Medium	0	0	0	0	3	2	1	4	1	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0
	High	0	0	0	0	2	1	2	0	1	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0
Deposits	Around Terminal	2	0	2	0	5	6	5	7	5	5	5	5	0	0	0	0	0	1	0	0	0	0	0	0
	Around Seam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Around Both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
High Pressure	Bulged	0	0	0	0	0	0	2	0	1	0	2	1	0	0	2	0	0	0	0	0	0	0	0	0
	Gas Present	0	0	2	0	0	0	1	0	0	1	0	0	1	0	0	1	3	3	3	2	2	2	3	3
	Both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concave Side	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weak Weld	Tab to Plate	0	0	1	0	2	5	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Case	0	0	0	0	0	0	0	1	1	1	5	2	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Tab to Plate & Case	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plate & Terminal	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loosened Active Material	Present	0	0	3	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Extraneous Active Material	Present	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
	Caused Short	0	0	1	0	1	0	0	0	1	4	0	1	0	0	0	0	0	0	1	0	0	0	0	0
Pierced Separator	Grid Wire	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2	0	2	0	0	0	3	0
	Tab to Plate	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
Excess Scoring	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Burned Positive Tab	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Broken	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Short Separator	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceramic Short	One Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Two Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Migration	General	2	0	5	0	4	1	1	4	1	2	0	0	1	0	2	1	0	2	0	2	0	1	0	3
	Sm. Area Penetration	0	0	0	0	0	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Shorting Penetration	0	0	0	0	0	0	0	0	1	1	2	1	0	0	1	0	0	1	0	0	0	1	0	0
	Positive Plate	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Short Around Tab	0	0	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	Short Around Scoring	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blisters	Present	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	2	1	2	1	3
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Separator Deterioration	General	1	0	5	0	3	6	3	4	3	7	0	0	0	0	2	1	0	2	0	0	0	3	1	2
	Permitted Short	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	3	0	0	0
	Center of Case	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Permitted Short	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 17
FREQUENCIES OF FAILURE CHARACTERISTICS AND LEVELS OF EACH-GULTON

Capacity Rating		6.0 AMP.-HR.												20.0 AMP.-HR.											
Temperature		0°C				25°C				40°C				0°C				25°C				40°C			
Depth of Discharge		15%		25%		25%		40%		15%		25%		15%		25%		25%		40%		15%		25%	
Orbit Time (Hrs.)		1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0
Pack Number		61A	65A	62A	66A	13A	17A	14A	18A	37A	41A	38A	42A	101A	102A	115A	116A	73A	74A	87A	88A	76A	77A	90A	91A
No. Cells In Each Pack		10	10	10	10	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5	5	5	5	5
Charge	Shorted	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	3	3	1	4
Voltage	Low	5	4	3	2	4	4	2	2	3	0	2	3	0	0	0	0	2	1	2	1	0	0	1	0
(End of)	Normal	0	0	0	2	0	0	1	2	2	5	2	2	0	0	1	0	1	2	0	0	0	0	1	0
	High	1	0	1	2	2	2	3	2	1	1	1	1	3	0	2	0	0	0	3	3	0	0	0	0
	Open Circuit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weight	Low	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Loss	Medium	1	0	0	0	0	0	0	1	1	0	3	1	1	0	0	0	1	1	1	0	0	0	0	0
	High	1	0	1	2	2	0	3	1	1	0	0	2	2	0	1	0	1	2	4	3	0	0	0	0
Deposits	Around Terminal	1	1	1	3	1	0	1	1	1	0	1	1	3	0	0	0	1	3	2	2	1	2	0	3
	Around Seam	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	Around Both	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
High	Bulged	4	0	3	5	3	2	3	2	0	0	1	1	2	1	2	1	1	0	3	3	0	1	0	2
Pressure	Gas Present	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	0
Concave	Present	1	1	0	3	0	0	1	1	0	0	0	0	1	0	0	0	2	0	0	0	0	1	0	2
Sides	Caused Short	1	3	0	2	0	0	0	0	0	0	1	0	0	1	3	0	0	1	1	0	0	0	0	0
Weak	Tab to Plate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weld	Tab to Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plate & Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plate & Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loosend Active	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Material	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Extraneous	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Active	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Material																									
Pierced	Grid to Wire	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Separator	Tab to Plate	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Excess	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoring	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Burned	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Positive	Broken	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tab	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Short	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Separator	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceramic	One Terminal	5	0	2	3	4	6	3	5	6	6	4	4	0	0	0	0	1	0	3	1	0	0	1	1
Short	Two Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Migration	General	4	1	1	1	1	1	0	0	1	0	0	1	0	0	0	1	2	1	0	0	0	3	0	2
	Sm. Area Penetration	0	3	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	Shorting Penetration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
	Positive Plate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Short Around Tab	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Short Around Scoring	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blisters	Present	4	4	4	2	4	3	0	1	4	0	0	1	1	0	1	0	2	1	0	0	1	0	1	2
	Caused Short	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Separator	General	2	1	1	0	2	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
Deterioration	Permitted Short	0	2	0	0	0	1	0	0	0	0	0	1	0	0	0	1	2	0	0	0	3	3	1	4
	Center of Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Permitted Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 18
FREQUENCIES OF FAILURE CHARACTERISTICS AND LEVELS OF EACH-SONOTONE

Capacity Rating		5.0 AMP.-HR.											
Temperature		0°C				25°C				40°C			
Depth of Discharge		15%		25%		25%		40%		15%		25%	
Orbit Time (Hrs.)		1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0
Pack Number		49A	53A	50A	54A	1A	5A	2A	6A	25A	29A	26A	30A
No. Cells In Each Pack		10	10	10	10	10	10	10	10	10	10	10	10
Charge Voltage (End of)	Shorted	1	0	0	0	0	0	1	1	0	1	3	2
	Low	1	0	3	1	0	1	2	1	2	1	1	4
	Normal	0	0	0	0	4	1	3	4	3	4	2	0
	High	0	0	0	0	2	1	0	0	1	0	0	0
	Open Circuit	0	0	0	0	0	0	0	0	0	0	0	0
Weight Loss	**Low**	0	0	1	0	0	0	0	0	0	1	0	1
	Medium	0	0	0	0	0	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0	0	0	0	0	0
Deposits	**Around Terminal**	0	0	1	1	4	2	4	0	5	4	2	4
	Around Seam	0	0	0	0	0	0	0	0	0	0	0	0
	Around Both	0	0	0	0	0	0	0	0	0	0	0	0
High Pressure	Bulged	1	0	0	0	0	0	4	1	1	0	3	0
	Gas Present	0	0	0	0	0	1	0	0	0	1	1	0
	Both	0	0	0	0	0	0	0	0	0	0	0	0
Concave Sides	Present	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0
Weak Weld	Tab to Plate	1	0	1	1	3	2	4	3	1	5	3	2
	Tab to Case	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Terminal	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plate & Case	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plate & Terminal	0	0	0	0	0	0	0	0	0	0	0	0
Loosened Active Material	Present	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0
Extraneous Active Material	Present	1	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	1	1	0	0	0
Pierced Separator	Grid Wire	0	0	1	0	0	0	2	2	1	1	1	1
	Tab to Plate	0	0	0	0	0	0	1	0	0	0	0	1
Excess Scoring	Present	0	0	3	0	4	2	3	2	1	3	1	0
	Caused Short	1	0	0	0	1	1	0	1	2	1	1	3
Burned Positive Tab	Present	0	0	0	0	0	0	0	0	0	0	0	0
	Broken	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0
Short Separator	Present	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0
Ceramic Short	One Terminal	0	0	0	0	0	0	0	0	0	0	0	0
	Two Terminal	0	0	0	0	0	0	0	0	0	0	0	0
Migration	General	1	0	3	1	5	3	3	3	3	3	1	2
	Sm. Area Penetration	0	0	0	0	0	0	0	0	1	0	1	0
	Shorting Penetration	0	0	0	0	0	0	0	0	0	0	0	0
	Positive Plate	0	0	0	0	0	0	0	1	0	0	0	0
	Short Around Tab	1	0	0	0	0	0	0	1	0	0	1	2
	Short Around Scoring	0	0	0	0	0	0	0	0	0	1	0	0
Blisters	Present	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0
Separator Deterioration	General	0	0	0	0	0	2	4	1	1	0	5	1
	Permitted Short	0	0	1	1	4	1	0	2	3	3	0	5
	Center of Case	0	0	0	0	1	0	0	0	0	0	0	0
	Center of Case Short	0	0	0	0	0	0	0	0	1	1	0	0

TABLE 19

FREQUENCIES OF FAILURE CHARACTERISTIC AND LEVELS OF EACH FROM NON-STANDARD PACKS

Manufacturer		G. E.	G. E.	G. £.	G. E.	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON
Capacity Rating (Amp. Hr.)		5.0	5.0	5.0	12.0	3.5	3.5	4.0	4.0	4.0	5.0	5.0	5.0	5.0	5.0	5.6	5.6	5.6	5.6	5.6	5.6
Temperature (°C)		25°	40°	40°	40°	-20°	25°	25°	40°	40°	0°	25°	25°	40°	40°	-20°	0°	25°	25°	40°	40°
Depth of Discharge		25%	15%	25%	50%	40%	40%	40%	15%	25%	25%	15%	25%	15%	25%	25%	25%	25%	25%	25%	25%
Orbit Time (Hrs.)		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Pack Number		104B	113A	114A	93A	75D	73C	14B	28B	40B	121A	120A	118B	127A	128A	32B	90C	76B	96C	30B	42B
No. Cells In Each Pack		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Charge Voltage (End of)	Shorted	2	5	3	0	0	0	1	1	1	1	0	1	1	2	0	0	0	0	0	0
	Low	0	0	0	0	1	1	2	1	0	1	0	0	0	0	0	0	0	0	1	1
	Normal	1	0	0	4	0	2	0	1	3	0	0	0	1	0	0	1	2	1	0	2
	High	0	0	0	0	0	0	0	0	0	0	1	2	1	0	1	0	1	2	2	0
	Open Circuit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weight Loss	Low	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3	1
	Medium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	1
	High	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deposits	Around Terminal	2	0	0	4	0	2	0	0	0	1	0	1	1	1	0	1	0	0	0	0
	Around Seam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
	Around Both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	0	3
High Pressure	Bulged	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	Gas Present	2	5	3	0	0	2	1	0	1	0	0	0	1	0	0	0	0	0	2	0
	Both	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Concave Sides	Present	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weak Weld	Tab to Plate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Case	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	2
	Tab to Terminal	0	0	0	0	0	0	2	2	3	0	0	2	1	0	1	0	0	0	1	0
	Tab to Plate & Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plate & Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loosened Active Material	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Extreneous Active Material	Present	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pierced Separator	Grid Wire	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plate	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Excess Scoring	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Burned Positive Tab	Present	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	1
	Broken	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	1
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0
Short Separator	Present	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceramic Short	One Terminal	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0
	Two Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Migration	General	3	0	2	2	1	3	0	3	4	1	1	3	2	1	0	0	0	2	2	3
	Small Area Penetration	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Shorting Penetration	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Positive Plate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Short Around Tab	0	0	1	0	0	0	3	0	0	0	0	0	0	0	1	1	0	1	0	0
	Short Around Scoring	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blisters	Present	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Separator Deterioration	General	0	0	0	4	1	0	0	0	0	1	0	3	0	0	0	1	1	1	3	0
	Permitted Short	3	5	3	0	0	3	3	3	4	0	1	0	3	2	1	0	1	2	0	3
	Center of Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Permitted Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 20

FREQUENCIES OF FAILURE CHARACTERISTICS AND LEVELS OF EACH FROM NON-STANDARD PACKS

Manufacturer		GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	GULTON	SONOTONE	SONOTONE	SONOTONE	SONOTONE	SONOTONE	SONOTONE	SONOTONE	SONOTONE
Capacity Rating (Amp. Hr.)		6.0	6.0	3.0	6.0	12.0	12.0	12.0	12.0	12.0	1.25	1.25	3.0	3.0	3.0	3.0	3.0	5.0	5.0	20.0
Temperature (°C)		0°	40°	25°	25°	0°	0°	25°	40°	40°	-20°	0°	0°	25°	25°	40°	40°	-20°	-20°	25°
Depth of Discharge		40%	40%	40%	50%	25%	40%	25%	15%	25%	25%	60%	25%	25%	40%	15%	25%	25%	40%	40%
Orbit Time (Hrs.)		1.5	1.5	1.5	24.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Pack Number		71A	48B	11A	79A	101B	71B	27B	78A	47B	88D	98B	31B	3B	2B	26B	37B	75C	89B	34B
No. Cells In Each Pack		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	10
Charge Voltage (End of)	Shorted	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3
	Low	0	0	0	1	0	0	0	0	0	0	0	1	3	0	1	0	2	1	0
	Normal	2	5	1	3	0	0	2	2	2	0	1	0	0	2	2	2	0	1	0
	High	2	0	1	0	1	1	1	1	0	1	1	0	0	1	0	1	1	1	0
	Open Circuit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weight Loss	Low	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Medium	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	High	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	3	0	0
Deposits	Around Terminal	2	2	2	1	0	0	0	0	1	0	0	1	0	0	0	0	3	1	0
	Around Seam	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2
	Around Both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
High Pressure	Bulged	1	4	0	0	1	1	1	1	1	0	2	0	0	0	0	0	3	3	0
	Gas Present	1	0	0	2	0	0	1	1	2	0	0	0	1	0	0	0	0	0	0
	Both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Concave Sides	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weak Weld	Tab to Plate	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	3	3	1
	Tab to Case	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plate & Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tab to Plate & Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	0	0	0
Loosened Active Material	Present	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Extraneous Active Material	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pierced Separator	Grid Wire	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Tab to Plate	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Excess Scoring	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	1	2	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	2	0	0
Burned Positive Tab	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Broken	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Short Separator	Present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceramic Short	One Terminal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Two Terminal	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Migration	General	3	3	2	1	1	1	3	2	3	1	2	0	3	1	0	1	3	2	0
	Small Area Penetration	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Shorting Penetration	1	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	Positive Plate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Short Around Tab	0	2	0	0	0	0	0	0	0	0	0	0	0	1	3	2	0	0	0
	Short Around Scoring	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blisters	Present	4	5	3	3	1	0	1	0	0	0	2	0	0	0	0	0	0	0	0
	Caused Short	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Separator Deterioration	General	3	0	2	4	1	0	0	0	0	0	0	0	1	2	0	1	0	1	0
	Permitted Short	0	5	1	0	0	1	3	2	3	0	0	0	2	0	3	2	0	0	0
	Center of Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Permitted Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 21
FREQUENCIES OF OCCURRENCE OF FAILURE CHARACTERISTICS FOR STANDARD NiCd CELLS

Major Failure Modes	Manufacturer												
	General Electric			Gould			Gulton			Sonotone			
	0°C	25°C	40°C	0°C	25°C	40°C	0°C	25°C	40°C	0°C	25°C	40°C	Totals
End of Charge Voltage	6	30	37	13	38	41	28	39	37	6	21	24	320
Weight Loss	2	1	2	1	21	18	10	20	10	1	0	2	88
Deposits	3	7	10	4	24	20	9	11	12	2	10	15	127
High Pressure	2	4	[illegible]	6	14	15	19	17	11	1	6	6	109
Concave Sides	0	0	0	0	0	0	16	6	4	0	0	0	26
Weak Weld	0	0	0	1	12	14	0	0	0	3	12	11	53
Loosened Active Material	1	0	3	3	2	3	0	0	0	0	0	0	12
Extraneous Active Material	0	0	2	3	4	6	0	0	1	1	1	1	19
Pierced Separator	0	1	0	1	5	6	2	0	0	1	5	5	26
Excess Scoring	0	0	0	0	0	0	0	0	0	4	14	12	30
Burned Positive Tab	2	3	17	0	0	0	0	0	0	0	0	0	22
Short Separator	0	0	8	0	0	0	0	0	0	0	0	0	8
Ceramic Short	0	0	0	0	0	0	10	23	22	0	0	0	55
Migration	6	28	20	13	21	17	12	6	12	6	16	15	172
Blisters	2	14	3	0	4	8	18	11	9	0	0	0	69
Separator Deterioration	6	21	22	12	22	22	7	5	16	2	15	20	170
No. Failed Cells	6	30	37	13	38	41	28	39	37	6	21	24	320

(5) Loosened active material which separates from the grid of the positive plate was found only for cells of Gould and G. E.

(6) The occurrence of extraneous active material is primarily attributed to Gould since there were only 6 instances, of the total 19, where cells of other manufacturers displayed this deficiency.

(7) Pierced separator occurrences are attributed mostly to Sonotone and Gould as 23 of the observed 26 cases were for these manufacturers.

(8) The presence of excess scoring alludes only to the Sonotone cells.

(9) Burned positive tabs occur only for G. E. cells (more specifically G. E. 3.0 A. H.); 17 of the 22 instances of burned positive tabs occurred at 40°C.

(10) Shorted separators occur only in G. E. cells; all eight occurrences were noted at 40°C. The occurrence of this characteristic is always associated with the burned positive tab. But the burned tab does not necessarily result in the separator short.

(11) Ceramic shorts or shorting across the ceramic insulator at the terminal is a characteristic of Gulton cells only and occur in a higher percentage of failures at the higher ambient temperatures.

(12) Only Sonotone cells exhibited an absence of blisters. This deficiency was noted in a significantly higher proportion of failures at the lower temperatures for G. E. and Gulton. This trend was reversed for Gould cells (see the following table for fractions and percents).

	0°C	25°C	40°C
G. E.	2/6(33.3%)	14/30(46.7%)	3/37(8.1%)
Gulton	18/28(64.3%)	11/39(28.2%)	9/37(24.3%)
Gould	0/13(0.0%)	4/38(10.5%)	8/41(19.5%)

2. Correlation or Frequency of Occurrence of One Failure Characteristic with Another

A major aspect of failure analysis is determining when and under what conditions specified failure characteristics occur. This information is essential so that problem areas may be defined and designers and suppliers of batteries may avoid such deficiencies in future productions. Other major aspects which should be given more emphasis are (i) the establishment of cause and effect relationships between failure characteristics and (ii) the periodic establishment of a more meaningful list of cell failure characteristics to adhere to during failure analysis. In order that correlations (or rates of joint occurrence) might be quickly determined between any two failure characteristics for any manufacturer and for any tested level of temperature, depth of discharge or orbit time, Tables 22-33 have been constructed.

Codes representing each of the 15 major failure characteristics have been used in these tables. Code 1 has been omitted from these tables since every cell had an end of charge voltage of some sort. The list of codes are defined as follows:

1 - End of Charge Voltage (either low or high)
2 - Cell Weight Loss
3 - Deposits on (+) and/or (-) Terminals
4 - High Pressure
5 - Concave Sides
6 - Weak Weld
7 - Loosened Active Material from Grid of (+) Plate
8 - Extraneous Active Material
9 - Pierced Separator
10 - Excess Scoring
11 - Burned Positive Tabs
12 - Shorted Separator
13 - Ceramic Short
14 - Migration of (+) and/or (-) Plate Material
15 - Blistering on (+) Plate
16 - Separator Deterioration

These tables make it possible to quickly determine the frequency of occurrence of each major failure characteristic alone and with other characteristics. Use of the plastic overlay, page 36, allows one to compare the rate of occurrence at a given stress level or manufacturer to the overall rate for all standard Ni-Cd cells. Placing the overlay above any of Tables 22 thru 33 displays the fraction of simultaneous occurrence for any two major failure characteristics. Using Table 24 (manufacturer--Gulton), for example, we observe that high pressure (4) occurs jointly with ceramic shorts (13) sixteen times. However, this is not a high correlation since ceramic shorts occurred with a total frequency of 55 for Gulton cells. Use of the overlay reveals that over all manufacturers the frequencies are still 16 and 55 so the data verifies the absence of ceramic shorts in other manufacturers.

Numerous conclusions may be drawn by examination of the tables and overlay. Some of these are as follows:

(1) From Table 22 we can see that shorted separators (12) always occur with burned positive tabs (11) and G. E. cells.

(2) From Table 28 we further see that shorted separators (12) always occurred under 40°C ambient temperature.

(3) Tables 22 (G. E.) and 23 (Gould) show that in the 12 instances where loosened active material (7) was found separator deterioration (16) had occurred 11 times (91.7%).

NASA - FAILURE ANALYSIS
ALL NI-CD DATA

Failure Characteristics

	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	67	28	12	20	4	4	1	3	2	0	14	37	10	39
3		32	12	32	8	7	8	15	7	2	8	75	18	81
4			13	10	1	6	12	6	0	0	16	55	33	55
5				0	0	0	1	0	0	0	6	13	13	9
6					1	5	6	15	0	0	0	35	0	37
7						1	1	0	0	0	0	9	3	11
8							2	1	1	0	0	6	0	9
9								3	0	0	0	8	5	12
10									0	0	0	25	0	26
11										8	0	8	1	9
12											0	1	0	1
13												12	21	10
14													45	134
15														42
88	126	109	26	53	12	19	26	30	22	8	55	171	69	169

TABLE 22
GENERAL ELECTRIC (73 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	0	2	0	0	0	0	0	0	2	0	0	4	1	5
3		2	0	0	3	0	0	0	7	2	0	13	7	14
4			0	0	0	0	0	0	0	0	0	12	3	14
5				0	0	0	0	0	0	0	0	0	0	0
6					0	0	0	0	0	0	0	0	0	0
7						0	0	0	0	0	0	3	2	3
8							0	0	1	0	0	1	0	0
9								0	0	0	0	1	0	1
10									0	0	0	0	0	0
11										8	0	8	1	9
12											0	1	0	1
13												0	0	0
14													17	44
15														19

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
5	19	14	0	0	4	2	1	0	22	8	0	33	17	48

Number of Occurrences for Each Failure Code

TABLE 23
GOULD (92 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	40	5	0	19	4	4	1	0	0	0	0	22	0	25
3		6	0	21	5	5	1	0	0	0	0	29	0	32
4			0	2	1	6	9	0	0	0	0	16	9	18
5				0	0	0	0	0	0	0	0	0	0	0
6					1	4	1	0	0	0	0	17	0	16
7						1	1	0	0	0	0	6	1	8
8							1	0	0	0	0	5	0	8
9								0	0	0	0	2	3	4
10									0	0	0	0	0	0
11										0	0	0	0	0
12											0	0	0	0
13												0	0	0
14													9	41
15														8

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	48	35	0	27	8	11	13	0	0	0	0	51	12	56

Number of Occurrences for Each Failure Code

TABLE 24
GULTON (104 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	21	21	12	0	0	0	0	0	0	0	14	8	9	7
3		17	12	0	0	1	1	0	0	0	8	14	11	11
4			13	0	0	0	1	0	0	0	16	17	21	13
5				0	0	0	1	0	0	0	6	13	13	9
6					0	0	0	0	0	0	0	0	0	0
7						0	0	0	0	0	0	0	0	0
8							0	0	0	0	0	0	0	1
9								0	0	0	0	1	2	1
10									0	0	0	0	0	0
11										0	0	0	0	0
12											0	0	0	0
13												12	21	10
14													19	21
15														15

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	32	47	26	0	0	1	2	0	0	0	55	30	38	28

Number of Occurrences for Each Failure Code

TABLE 25
SONOTONE (51 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	3	0	0	1	0	0	0	3	0	0	0	3	0	2
3		7	0	11	0	1	6	15	0	0	0	19	0	21
4			0	8	0	0	2	6	0	0	0	10	0	10
5				0	0	0	0	0	0	0	0	0	0	0
6					0	1	5	15	0	0	0	18	0	21
7						0	0	0	0	0	0	0	0	0
8							1	1	0	0	0	1	0	0
9								3	0	0	0	4	0	6
10									0	0	0	25	0	26
11										0	0	0	0	0
12											0	0	0	0
13												0	0	0
14													0	28
15														0

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3	27	13	0	26	0	3	11	30	0	0	0	37	0	27

Number of Occurrences for Each Failure Code

TABLE 26
0°C (53 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	10	8	7	0	0	0	0	1	1	0	2	7	6	5
3		8	5	2	1	1	1	1	2	0	1	13	6	9
4			10	1	0	2	2	0	0	0	8	17	15	9
5				0	0	0	1	0	0	0	4	8	10	5
6					0	0	0	1	0	0	0	4	0	3
7						1	0	0	0	0	0	4	1	4
8							0	1	0	0	0	4	0	3
9								1	0	0	0	3	2	2
10									0	0	0	4	0	1
11										0	0	2	0	2
12											0	0	0	0
13												5	7	1
14													11	26
15														7

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
14	18	28	16	4	4	4	4	4	2	0	10	37	20	27

Number of Occurrences for Each Failure Code

TABLE 27
25°C (128 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	31	15	5	11	2	1	1	0	0	0	4	17	2	16
3		13	4	15	2	1	3	6	1	0	2	31	7	31
4			1	4	0	2	6	3	0	0	6	15	7	16
5				0	0	0	0	0	0	0	2	2	1	1
6					1	1	5	9	0	0	0	15	0	19
7						0	0	0	0	0	0	2	0	2
8							2	0	0	0	0	0	0	1
9								1	0	0	0	3	0	3
10									0	0	0	12	0	14
11										0	0	2	1	2
12											0	0	0	0
13												4	9	4
14													22	51
15														20

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
42	51	41	6	24	2	5	11	14	3	0	23	70	29	62

Number of Occurrences for Each Failure Code

TABLE 28
40°C (139 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	26	5	0	9	2	3	0	2	1	0	8	13	2	18
3		11	3	15	5	5	4	8	4	2	5	31	5	38
4			2	5	1	2	4	3	0	0	2	23	11	30
5				0	0	0	0	0	0	0	0	3	2	3
6					0	4	1	5	0	0	0	16	0	15
7						0	1	0	0	0	0	3	2	5
8							0	0	1	0	0	2	0	5
9								0	0	0	0	2	3	7
10									0	0	0	9	0	11
11										8	0	4	0	5
12											0	1	0	1
13												3	5	5
14													12	57
15														15

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
32	57	40	4	25	6	10	11	12	17	8	22	64	20	80

Number of Occurrences for Each Failure Code

TABLE 29
DEPTH OF DISCHARGE-15% (89 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	17	4	3	6	2	2	0	1	2	0	4	11	3	17
3		6	4	9	2	4	3	5	5	2	1	21	3	28
4			4	3	1	2	3	2	0	0	4	19	9	19
5				0	0	0	1	0	0	0	1	7	6	6
6					0	3	1	3	0	0	0	11	0	10
7						0	1	0	0	0	0	2	2	4
8							0	1	0	0	0	3	0	5
9								0	0	0	0	3	3	4
10									0	0	0	7	0	7
11										5	0	6	0	7
12											0	1	0	1
13												4	8	3
14													11	43
15														11

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
22	36	29	9	13	4	8	6	8	13	5	17	49	18	58

Number of Occurrences for Each Failure Code

TABLE 30
DEPTH OF DISCHARGE-25% (161 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	34	12	6	10	2	1	1	2	0	0	6	21	7	16
3		15	6	17	6	2	3	9	2	0	6	43	11	36
4			8	5	0	3	5	2	0	0	9	29	21	30
5				0	0	0	0	0	0	0	4	6	7	3
6					1	1	1	8	0	0	0	19	0	19
7						1	0	0	0	0	0	7	1	7
8							1	0	1	0	0	3	0	3
9								2	0	0	0	3	2	6
10									0	0	0	13	0	13
11										3	0	1	0	1
12											0	0	0	0
13												8	12	7
14													25	73
15														23

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
43	64	55	14	29	8	8	13	16	7	3	26	90	40	86

Number of Occurrences for Each Failure Code

TABLE 31
DEPTH OF DISCHARGE-40% (70 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	16	12	3	4	0	1	0	0	0	0	4	5	0	6
3		11	2	6	0	1	2	1	0	0	1	11	4	14
4			1	2	0	1	4	2	0	0	3	7	3	6
5				0	0	0	0	0	0	0	1	0	0	0
6					0	1	4	4	0	0	0	5	0	8
7						0	0	0	0	0	0	0	0	0
8							1	0	0	0	0	0	0	1
9								1	0	0	0	2	0	2
10									0	0	0	5	0	6
11										0	0	1	1	1
12											0	0	0	0
13												0	1	0
14													9	18
15														8

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
23	26	26	3	11	0	3	7	6	2	0	12	32	11	25

Number of Occurrences for Each Failure Code

TABLE 32
ORBIT TIME-1.5 HRS. (177 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	31	18	7	4	2	1	1	1	2	0	9	15	6	17
3		18	5	12	4	4	4	8	5	2	4	31	6	33
4			5	6	0	4	10	3	0	0	10	25	16	27
5				0	0	0	0	0	0	0	2	3	5	3
6					0	0	4	7	0	0	0	12	0	13
7						1	0	0	0	0	0	4	1	6
8							1	1	1	0	0	3	0	4
9								2	0	0	0	4	3	9
10									0	0	0	13	0	13
11										5	0	3	0	3
12											0	0	0	0
13												7	15	7
14													19	60
15														20

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
48	62	63	11	22	7	12	19	17	12	5	29	83	35	82

Number of Occurrences for Each Failure Code

TABLE 33
ORBIT TIME-3.0 HRS. (143 CELL FAILURES)
COMBINATION FREQUENCIES OF CHARACTERISTICS OCCURRING JOINTLY

Failure Characteristic	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	26	10	5	16	2	3	0	2	0	0	5	22	4	22
3		14	7	20	4	3	4	7	2	0	4	44	12	48
4			8	4	1	2	2	3	0	0	6	30	17	23
5				0	0	0	1	0	0	0	4	10	8	6
6					1	5	2	8	0	0	0	23	0	26
7						0	1	0	0	0	0	5	2	5
8							1	0	0	0	0	3	0	5
9								1	0	0	0	4	2	3
10									0	0	0	12	0	13
11										3	0	5	1	6
12											0	1	0	1
13												5	6	3
14													26	74
15														22

Failure Characteristic Code

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	64	46	15	31	5	7	7	13	10	3	26	88	34	87

Number of Occurrences for Each Failure Code

(4) Table 25 (Sonotone) shows that when <u>excess scoring</u> (10) occurs, <u>migration</u> (14) also occurs 83.3% (25 of 30) of the time.

(5) Table 25 also shows that <u>separator deterioration</u> (16) occurs with <u>excess scoring</u> (10) 86.6% (26 of 30) of the time.

(6) The previous items imply a correlation between <u>migration</u> (14) and <u>separator deterioration</u> (16); summing across all manufacturers shows that separator deterioration occurred with migration during 78.4% (134 of 171) of the cases where migration occurred. Separator deterioration occurred 169 times. The correlation coefficient between these two characteristics is very high at .951 and implies that it is not really necessary to refer to both characteristics during failure analysis.

A computer program has been written for the Honeywell 2200 to determine the frequency of cell failure involving each of the various possible combinations of failure characteristics (up to four at a time). For example, the frequency of failure characteristic A and the combinations AB, ABC, and ABCD for any specified set of test conditions may be readily obtained for failure characteristic codes A, B, C, and D. Figure 1 is a sample of the computer output with the frequencies indicated for only a sampling of the possible combinations of numerical codes 2, 3, ... , 17. For instance, the 3rd combination listed, 2-3-4-0 (weight loss-depositing-high pressure) is a triple combination. The frequency, 5, indicates that these three characteristics occurred in combination in five of the cells that failed at 40°C.

This computer program will also sum frequencies for the possible combinations of failure characteristics when the various levels of the characteristics are included. For example, if the major failure characteristic is weight loss, the levels are low, medium and high. If deposits occurred, the levels would be deposits around the terminal, around the seam or both. See Tables 15-20 or Appendix D for a complete listing of the failure characteristic breakdowns.

3. <u>Failure Time Dependency on Failure Characteristic</u>

It has been noted that some failure characteristics tend to occur in certain time intervals when tested under certain conditions. For example blistering of the positive plates never occurred on G. E. cells until after about 4,000 cycles for the 3.0 hour orbit time and after 8,000 cycles for the 1.5 hour orbit time.

Graphs (Figures 2-23) showing the cell degradation rates by ambient temperature (cell life is plotted vs temperature) are given for each manufacturer, orbit time and failure characteristic combination where at least two points were available for plotting.

Figure 1

COMBINATION FREQUENCIES OF FAILURE CHARACTERISTICS (UP TO FOUR CODES PER COMBINATION)

Failure Characteristic Combination Codes	Number of Occurrences
2- 3- 4- 16	1
2- 3- 4- 17	5
2- 3- 4- 0	5
2- 3- 6- 8	3
2- 3- 6- 10	1
2- 3- 6- 14	6
2- 3- 6- 16	6
2- 3- 6- 17	9
2- 3- 6- 0	9
2- 3- 7- 16	2
2- 3- 7- 17	2
2- 3- 7- 0	2
2- 3- 8- 14	1
2- 3- 8- 16	2
2- 3- 8- 17	3
2- 3- 8- 0	3
2- 3- 10- 14	2
2- 3- 10- 16	2
2- 3- 10- 17	2
2- 3- 10- 0	2
2- 3- 13- 14	2
2- 3- 13- 15	1
2- 3- 13- 16	2
2- 3- 13- 17	4
2- 3- 13- 0	4
2- 3- 14- 15	1
2- 3- 14- 16	11
2- 3- 14- 17	12
2- 3- 14- 0	12
2- 3- 15- 16	1
2- 3- 15- 17	1
2- 3- 15- 0	1
2- 3- 16- 17	16
2- 3- 16- 0	16
2- 3- 17- 0	26
2- 3- 0- 0	26
2- 4- 13- 17	1
2- 4- 13- 0	1
2- 4- 16- 17	1
2- 4- 16- 0	1
2- 4- 17- 0	5
2- 4- 0- 0	5
2- 6- 8- 14	1
2- 6- 8- 16	2
2- 6- 8- 17	3
2- 6- 8- 0	3
2- 6- 10- 14	1
2- 6- 10- 16	1
2- 6- 10- 17	1
2- 6- 10- 0	1
2- 6- 14- 16	5
2- 6- 14- 17	6
2- 6- 14- 0	6
2- 6- 16- 17	6
2- 6- 16- 0	6
2- 6- 17- 0	9
2- 6- 0- 0	9
2- 7- 16- 17	2
2- 7- 16- 0	2
2- 7- 17- 0	2
2- 7- 0- 0	2
2- 8- 14- 16	1

All graphs utilize data for only 25% depth of discharge since this is the only rate represented at all three temperatures (0°, 25° and 40°C). Two lines were drawn for each failure characteristic; one line represents the data available for all failure characteristics combined and the other represents the data available for cases where the specified characteristic is involved. The line representing all the characteristics ignores any individual consideration of the characteristics and thus reflects the average temperature effect on the cycle life of the cells. By comparing the slopes and relative positions of the two lines for each failure characteristic, failure characteristics that cause the cells to fail more rapidly at specific temperatures or at all temperatures may be detected. This method, however, does not totally solve the problem if important interactions among the failure characteristics are existent.

These lines were determined from either two or three points (or averages per temperature). The points are determined from calculated averages using all the cell failure times available at each temperature. Then the averages were used to determine the best linear or straight line fit by linear regression. Thus the actual averages do not usually fall exactly on the lines. These actual averages are indicated by "o" for the overall case and by "x" for the case of the individual characteristic. No plots were made for end of charge voltage or for other characteristics where failure times were available at only one temperature.

For illustrative purposes consider Figure 2 for manufacturer General Electric, 1.5 hour orbit time, and the failure characteristic, deposits on the terminals. The failure times and means for each temperature are given as follows:

0°C	25°C		40°C	
13,218	5,164	10,382	2,073	3,841
25,786	7,527	10,463	2,182	3,841
	8,065	10,624	2,182	4,835
	8,254	10,878	2,446	6,059
	8,714	13,149	2,461	6,059
	10,123		2,509	8,273
	10,382		2,509	
$\bar{x}$ = 19,502	$\bar{x}$ = 9,477		$\bar{x}$ = 3,790	

The equation of best linear fit for these three averages is L(cycle life) = 19,450 - 394 T (Temperature). Substituting temperatures back into L = 19,450 - 394 T yields the following cycle life estimates:

L (for 0°C) = 19,450 cycles
L (for 25°C) = 9,600 clcles
L (for 40°C) = 3,690 cycles

Plotting these three values yields the line of Figure 2 and it is readily seen that the actual means at each temperature are very close to the estimated values.

To obtain the other line for the deposits graphs of Figure 2, we use only the failure times (expressed in cycles) that involved depositing as a deficiency.

0°C	25°C	40°C
13,218	8,714	2,182
	10,463	2,182
	10,878	2,509
	13,149	2,509
		3,841
		3,841
$x = 13,218$	$\bar{x} = 10,800$	$\bar{x} = 2,844$

From these points we get the equation L = 14,210 - 243 T which estimates the points at each temperature to be:

L (0°C) = 14,210 cycles
L (25°C) = 8,135 cycles
L (40°C) = 4,510 cycles

Here it is seen that the equation does not fit so well as before (The location of these means are indicated on the graphs by "x" to give one an indication whether the fit is good or poor).

Tables 34-37 give the mean and range for each combination of manufacturer, orbit time, failure characteristic and temperature where at least one failure time was available (all combinations included 25% depth of discharge only).

Some of the observations that may be made from inspection of the plots and their slopes are as follows:

(1) General Electric, 1.5 hour orbit time (Figures 2-3)

The graphs show that cells with the characteristics of weight loss, deposits and blistering have lower average failure times at 0°C than do all failed cells with any set of failure characteristics. High pressure and blistering failures exhibit comparably higher average failure times at 40°C.

(2) General Electric, 3.0 hour orbit time (Figures 4-5)

The linear fit to the failure time averages for these graphs is not good.

Figure 2

GENERAL ELECTRIC-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 2-4

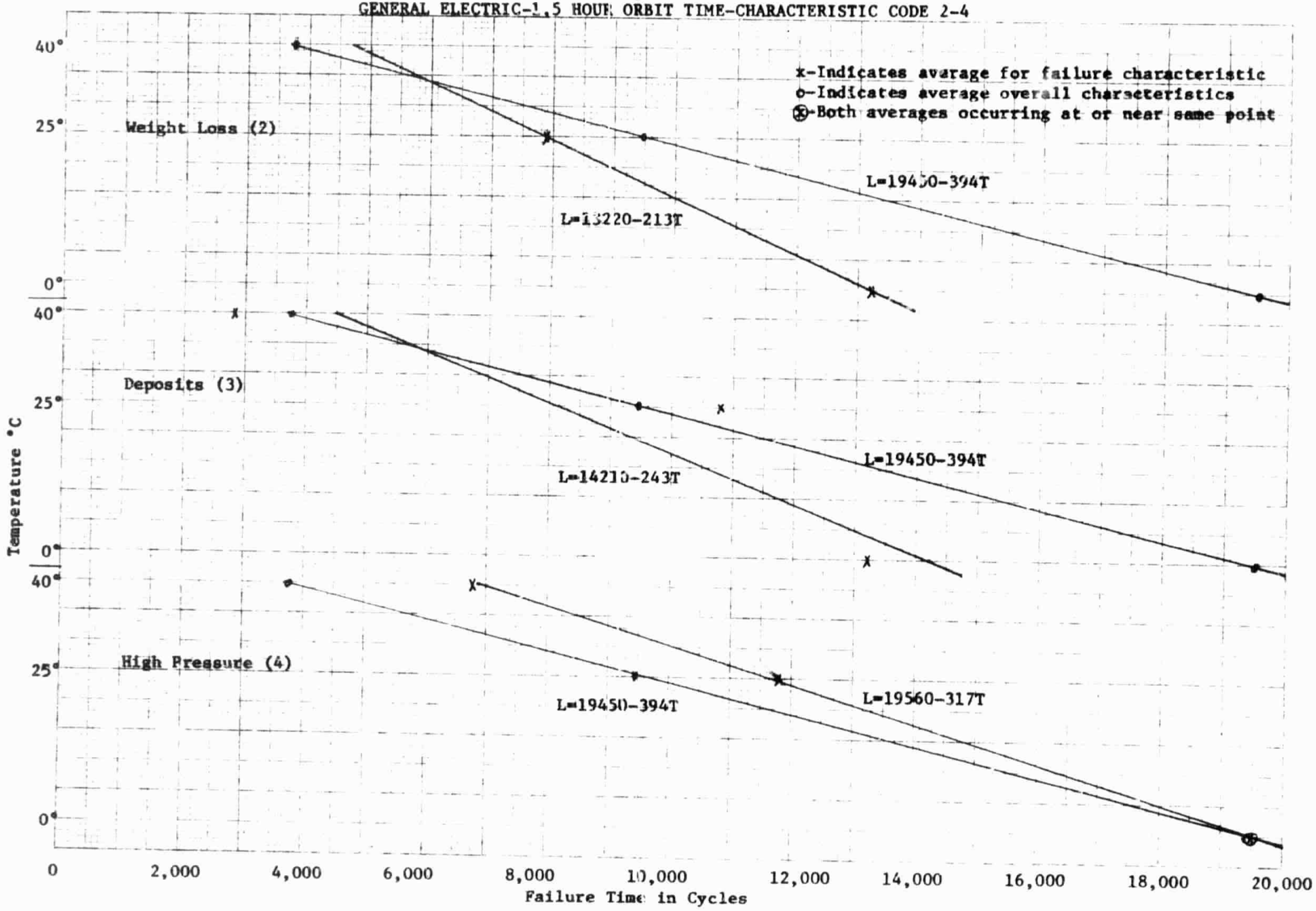


Figure 3

GENERAL ELECTRIC-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 14-16

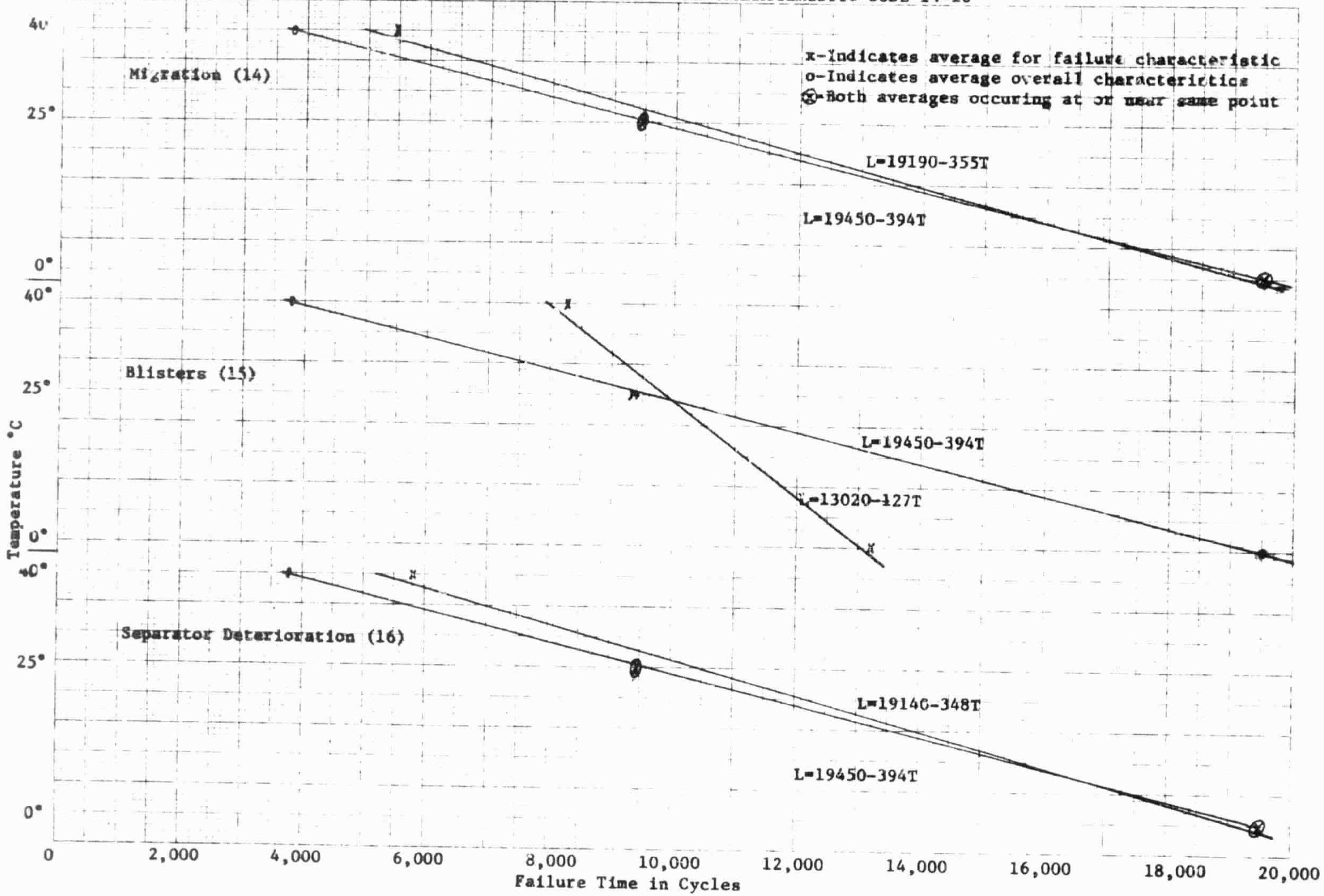


Figure 4

GENERAL ELECTRIC-3.0 HOUR ORBIT TIME-CHARACTERISTIC CODE 3, 11, 14

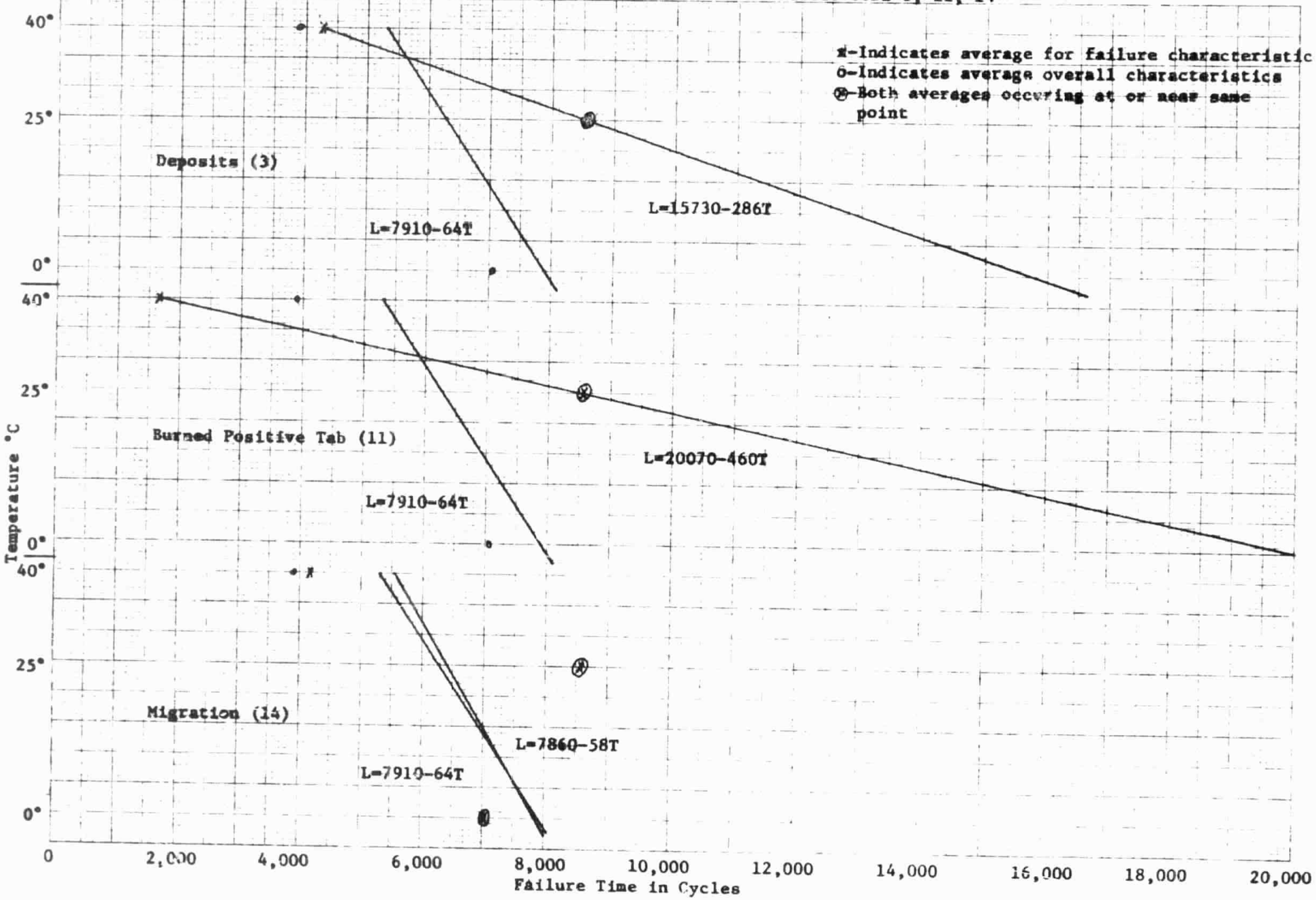


Figure 5
GENERAL ELECTRIC-3.0 HOUR ORBIT TIME-CHARACTERISTIC CODE 16

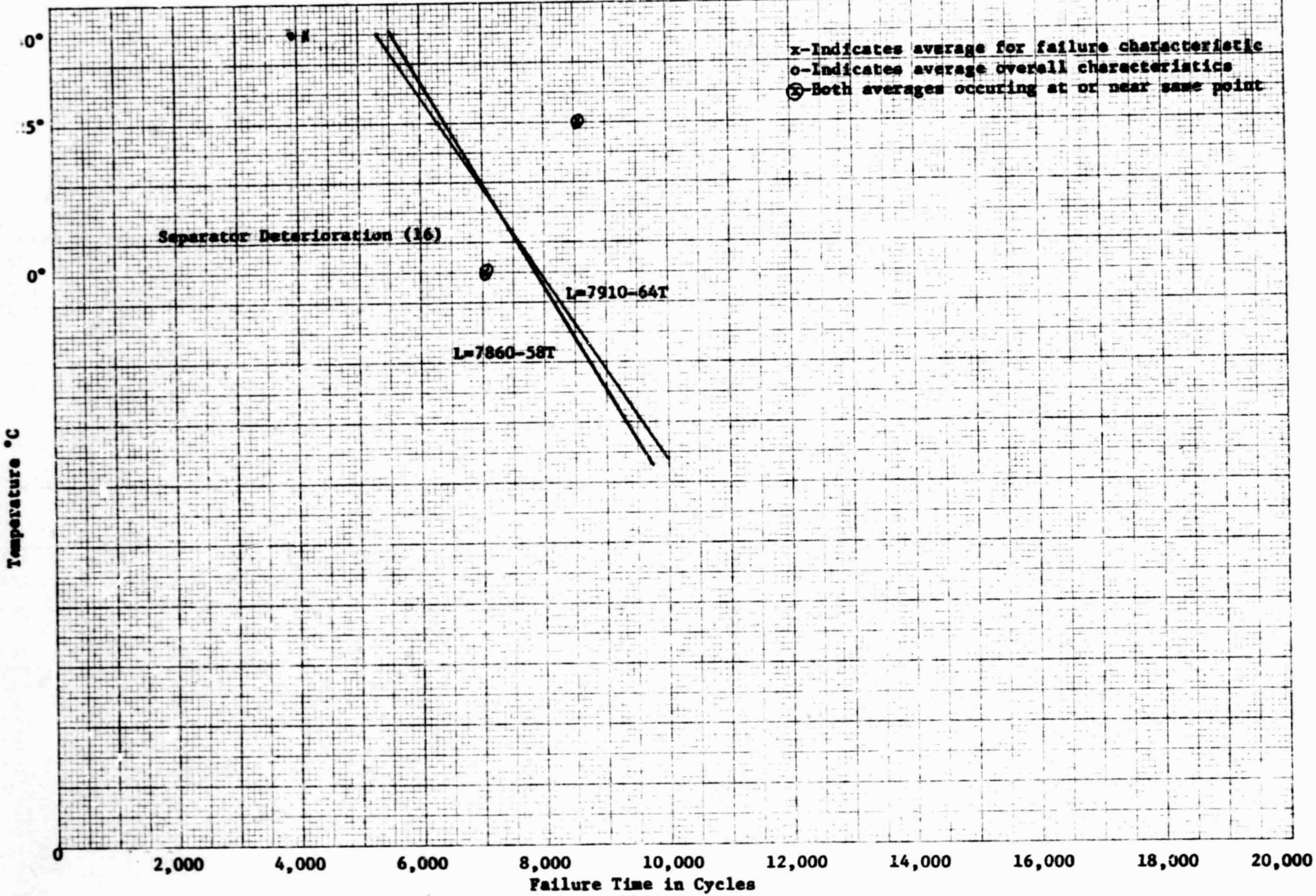


Figure 6
GOULD-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 2-4

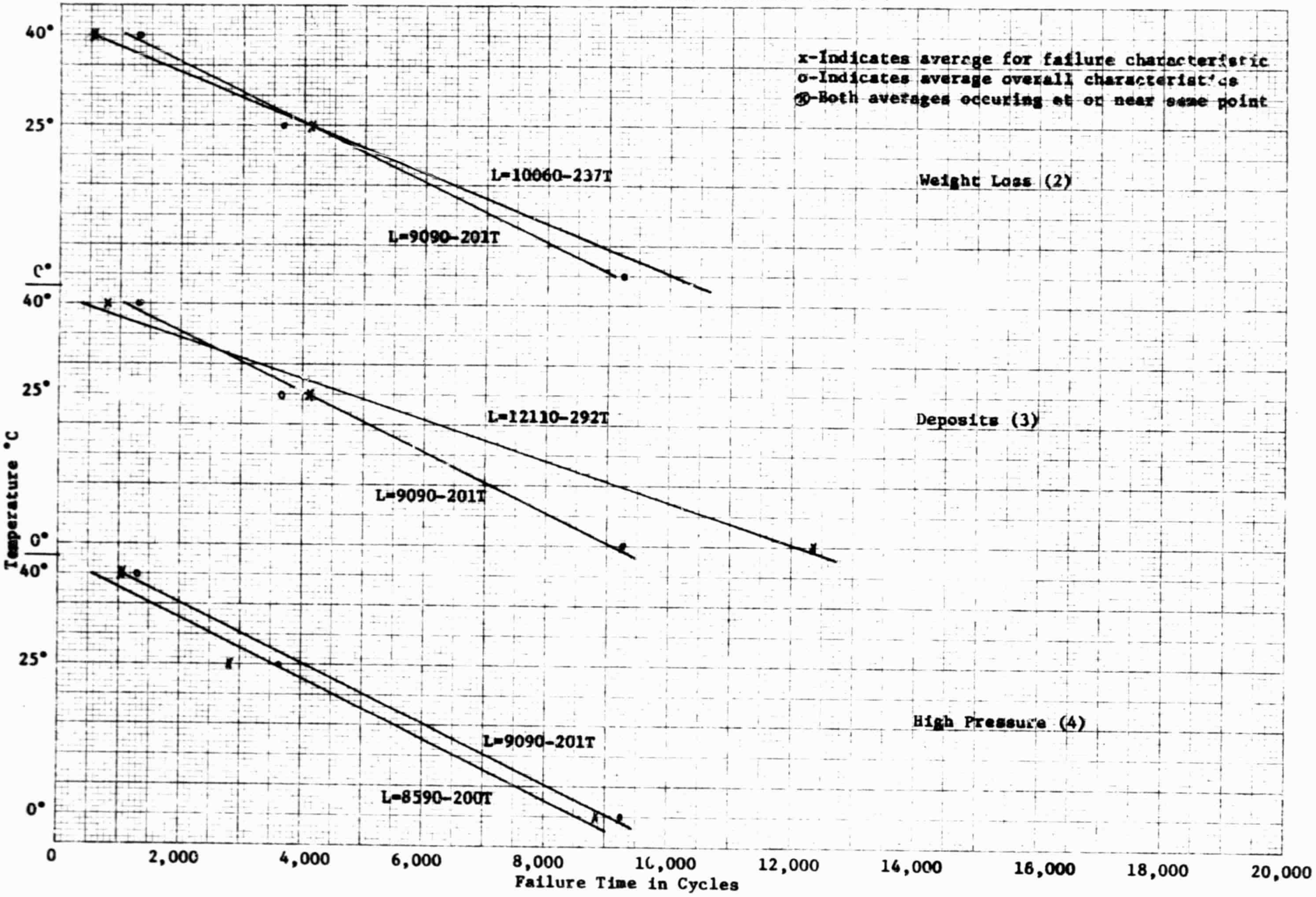


Figure 7
GOULD-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 6, 8, 9

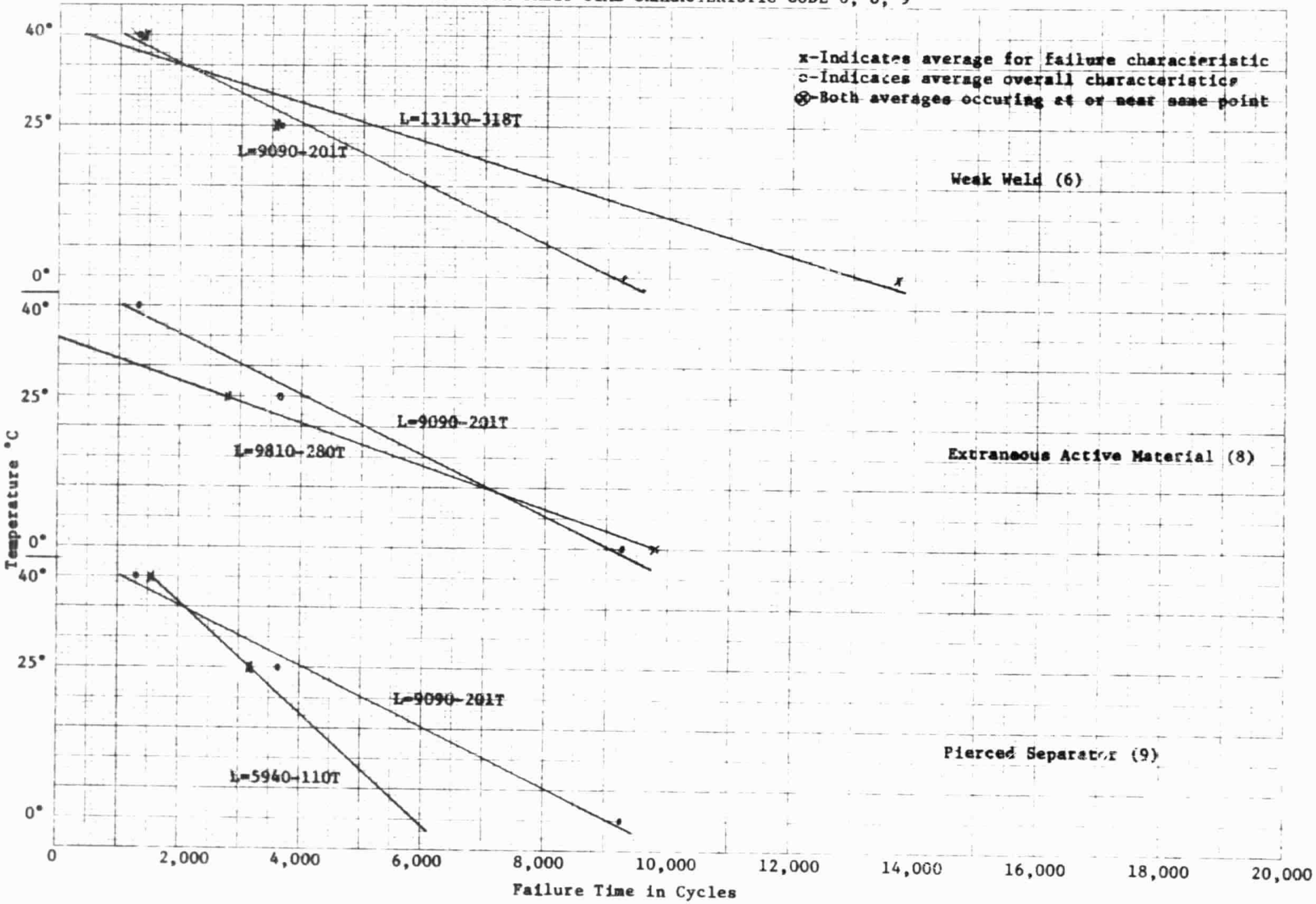


Figure 8
GOULD-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 14-16

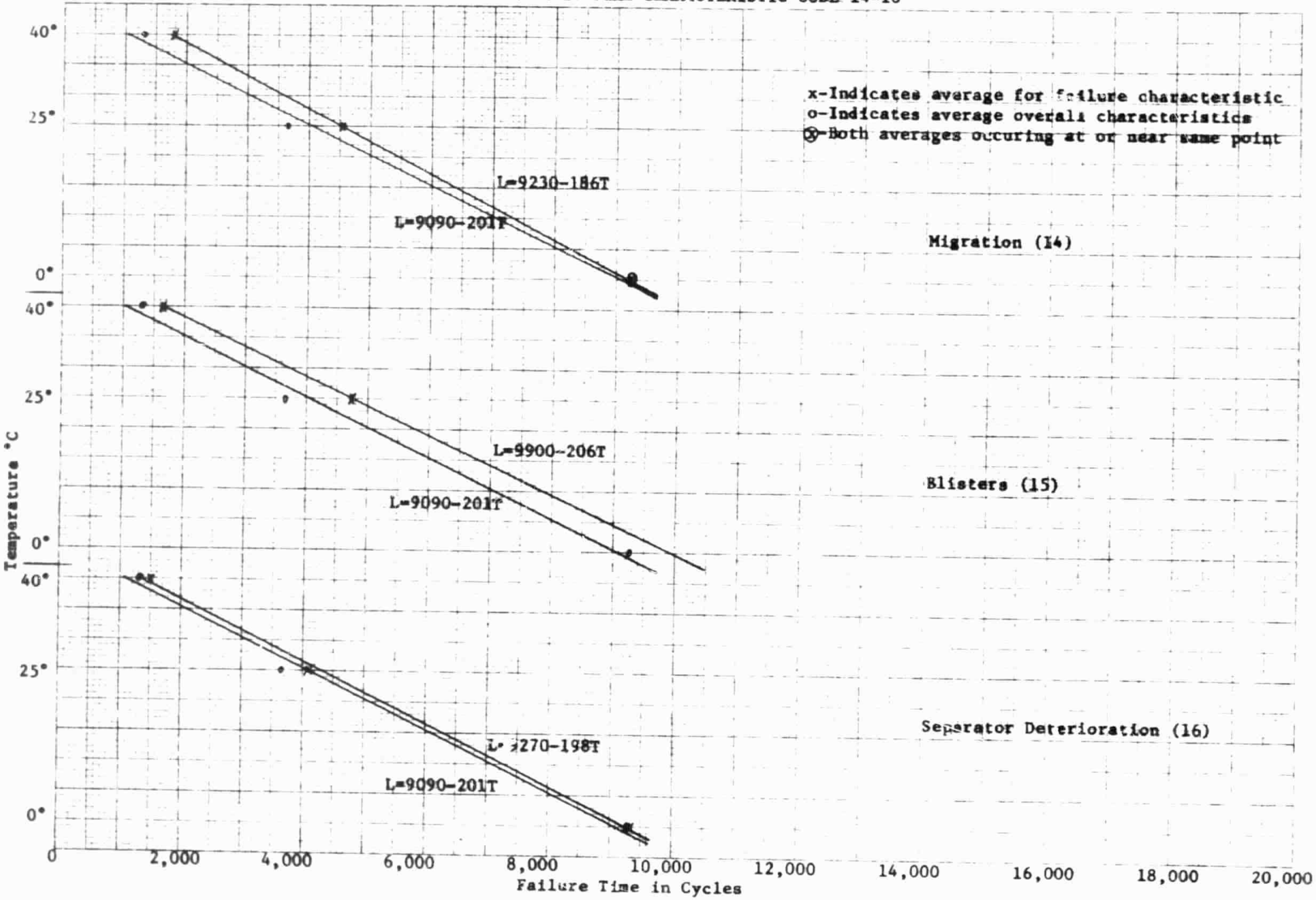


Figure 9
GOULD-3.0 HOUR ORBIT TIME-CHARACTERISTIC CODE 2-4

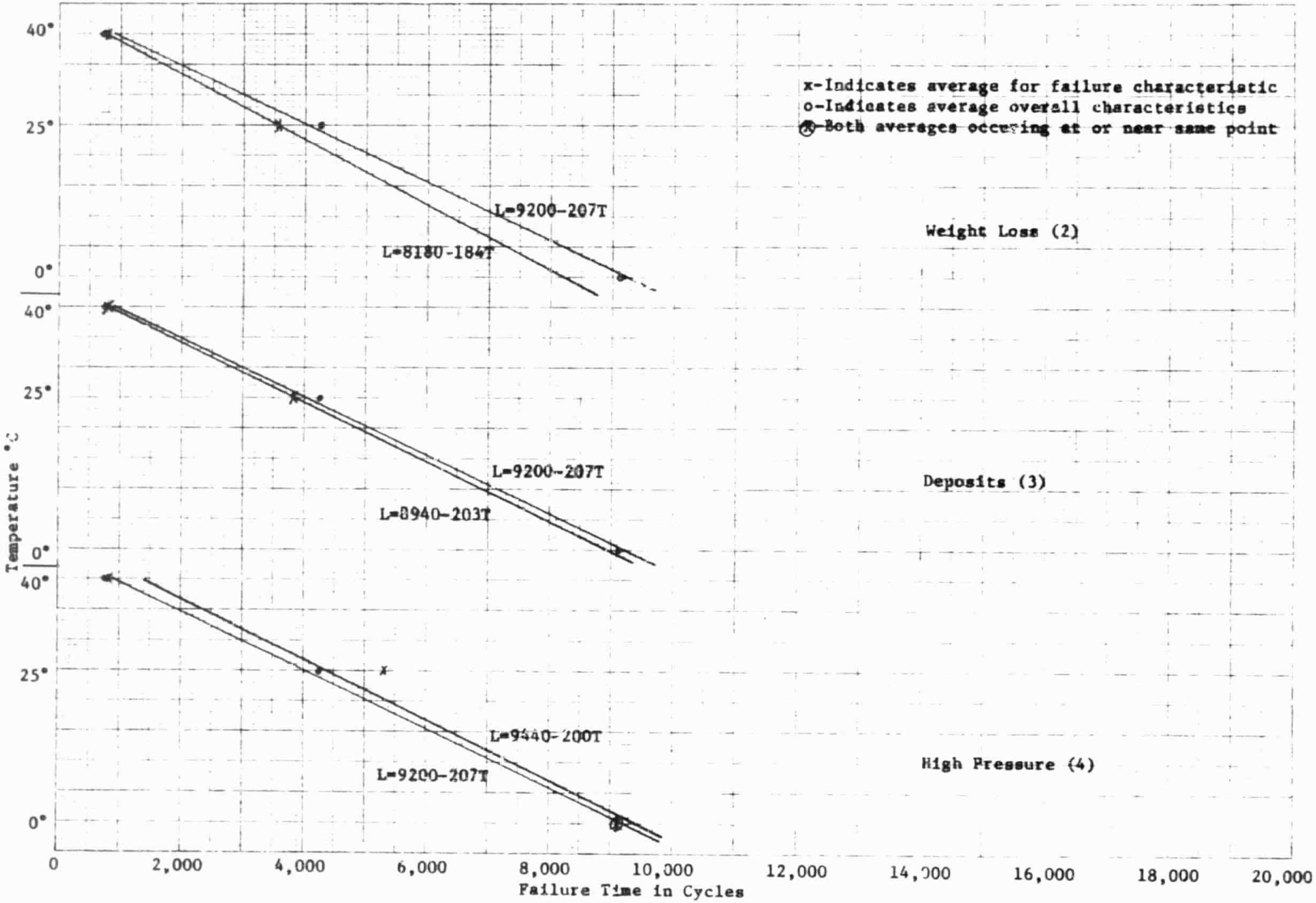


Figure 10
GOULD-3.0 HOUR ORBIT TIME-CHARACTERISTIC CODE 6, 8, 14

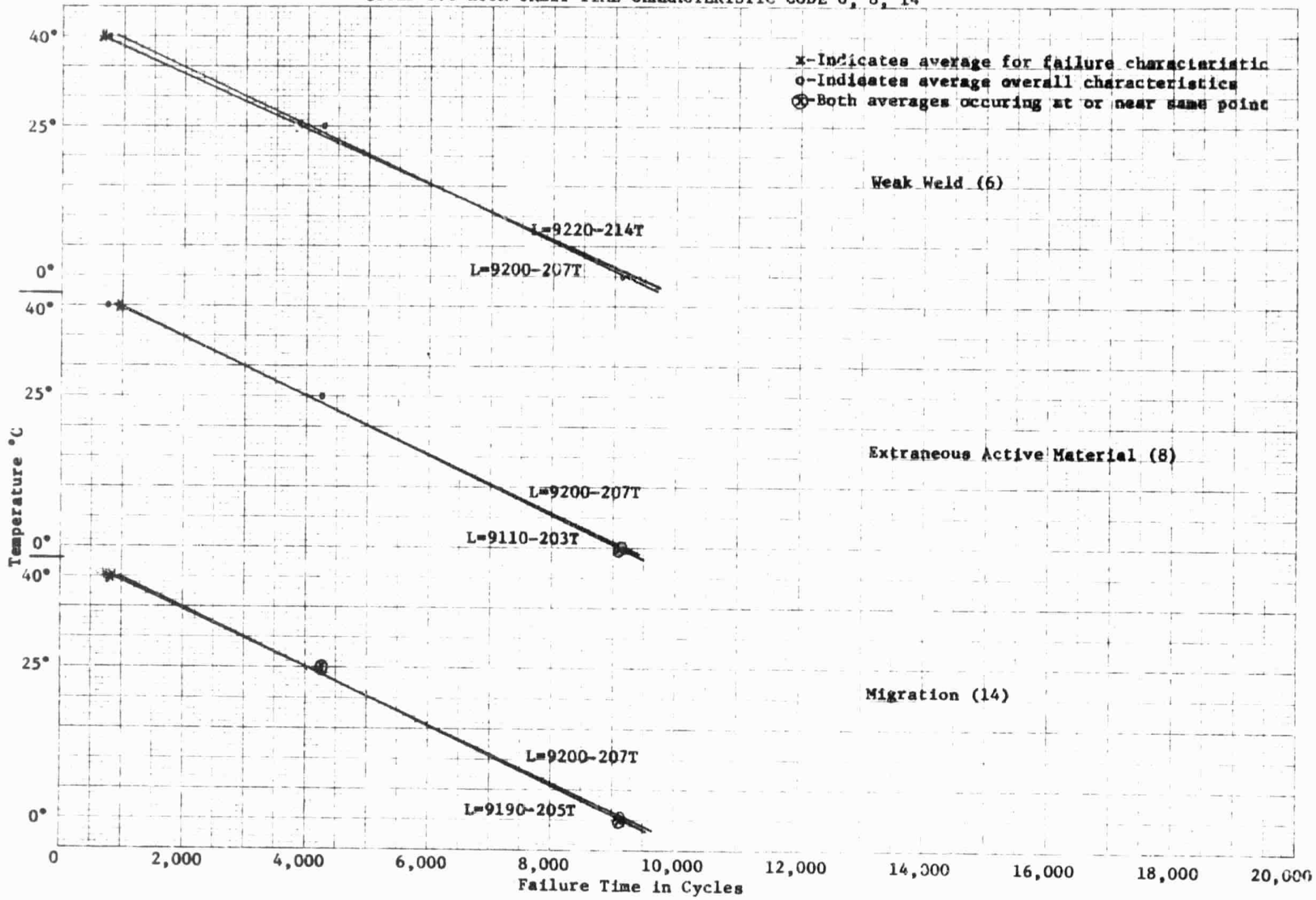


Figure 11
GOULD-3.0 HOUR ORBIT TIME-CHARACTERISTIC CODE 15, 16

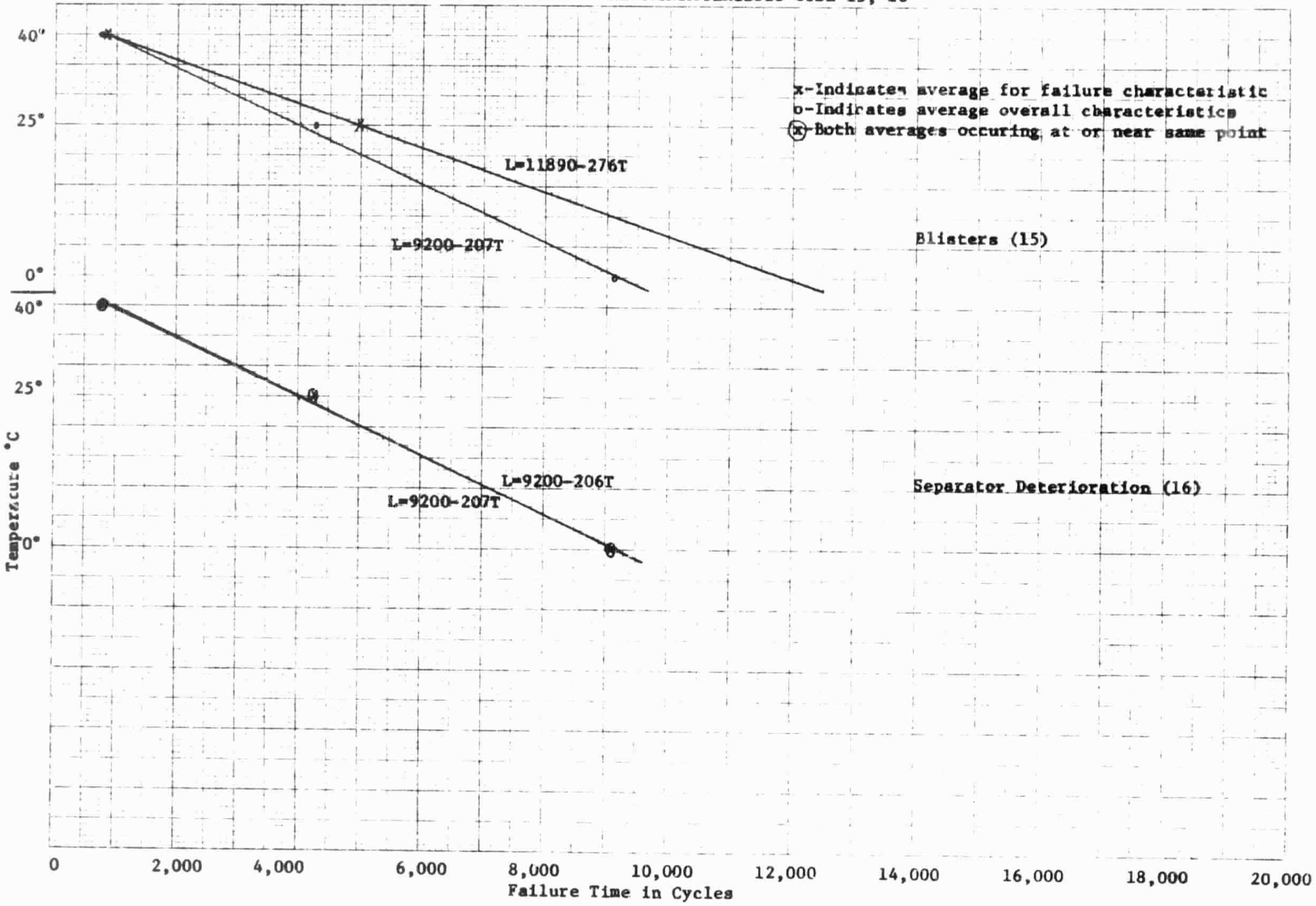


Figure 12
GULTON-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 2-4

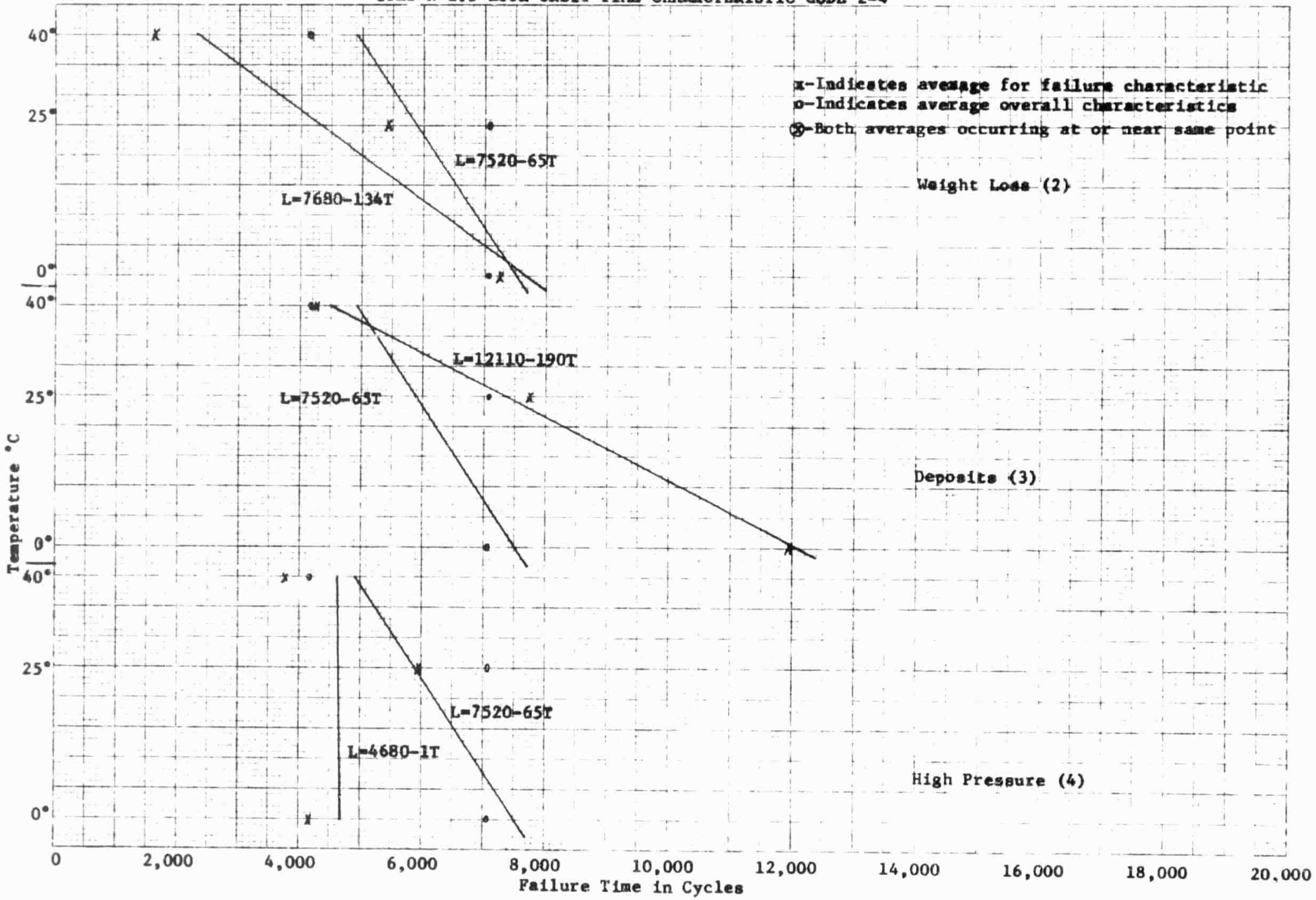


Figure 13
GULTON-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 5, 6, 9

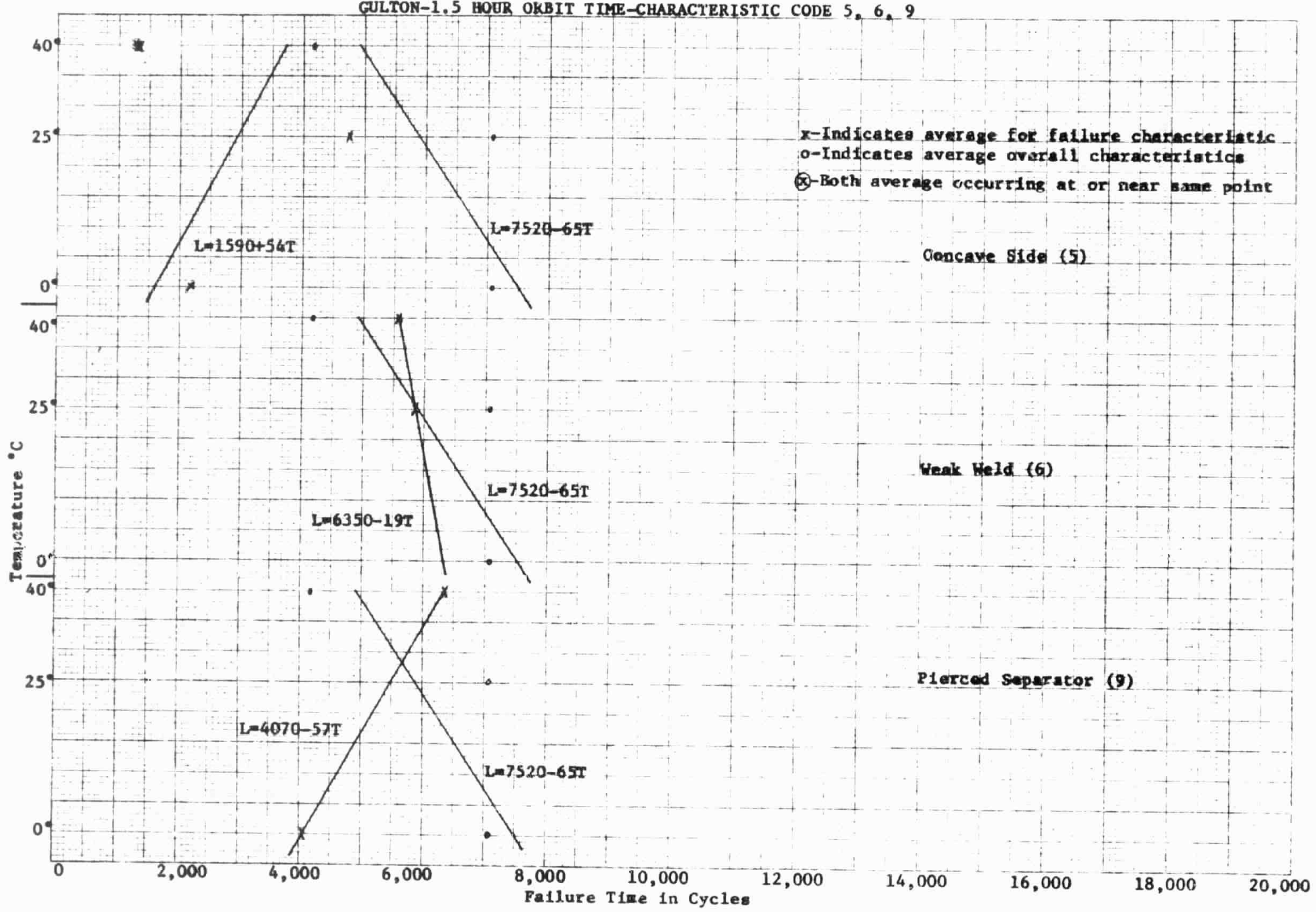


Figure 14
GULTON-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 11, 13, 14

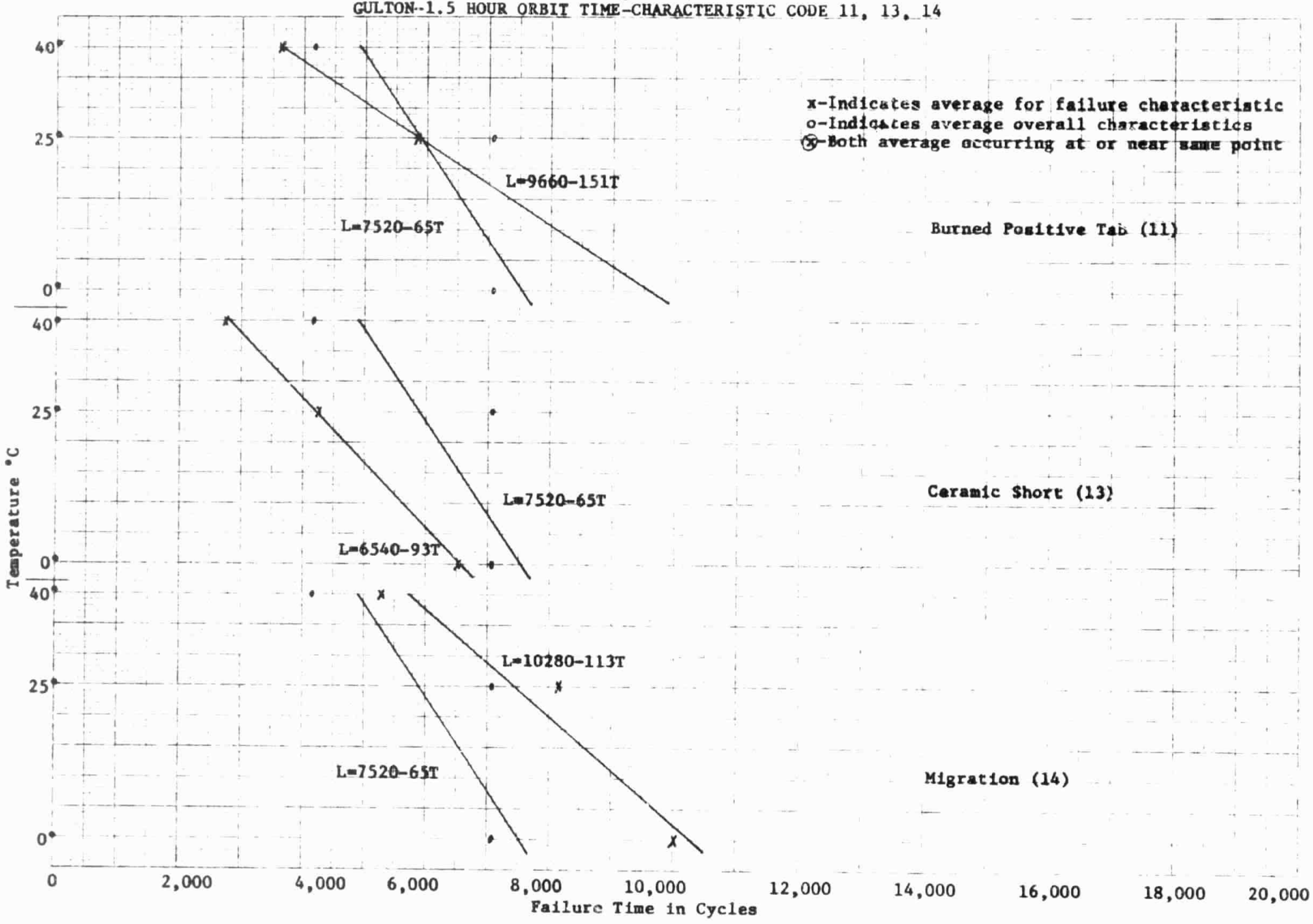


Figure 15
GULTON-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 15, 16

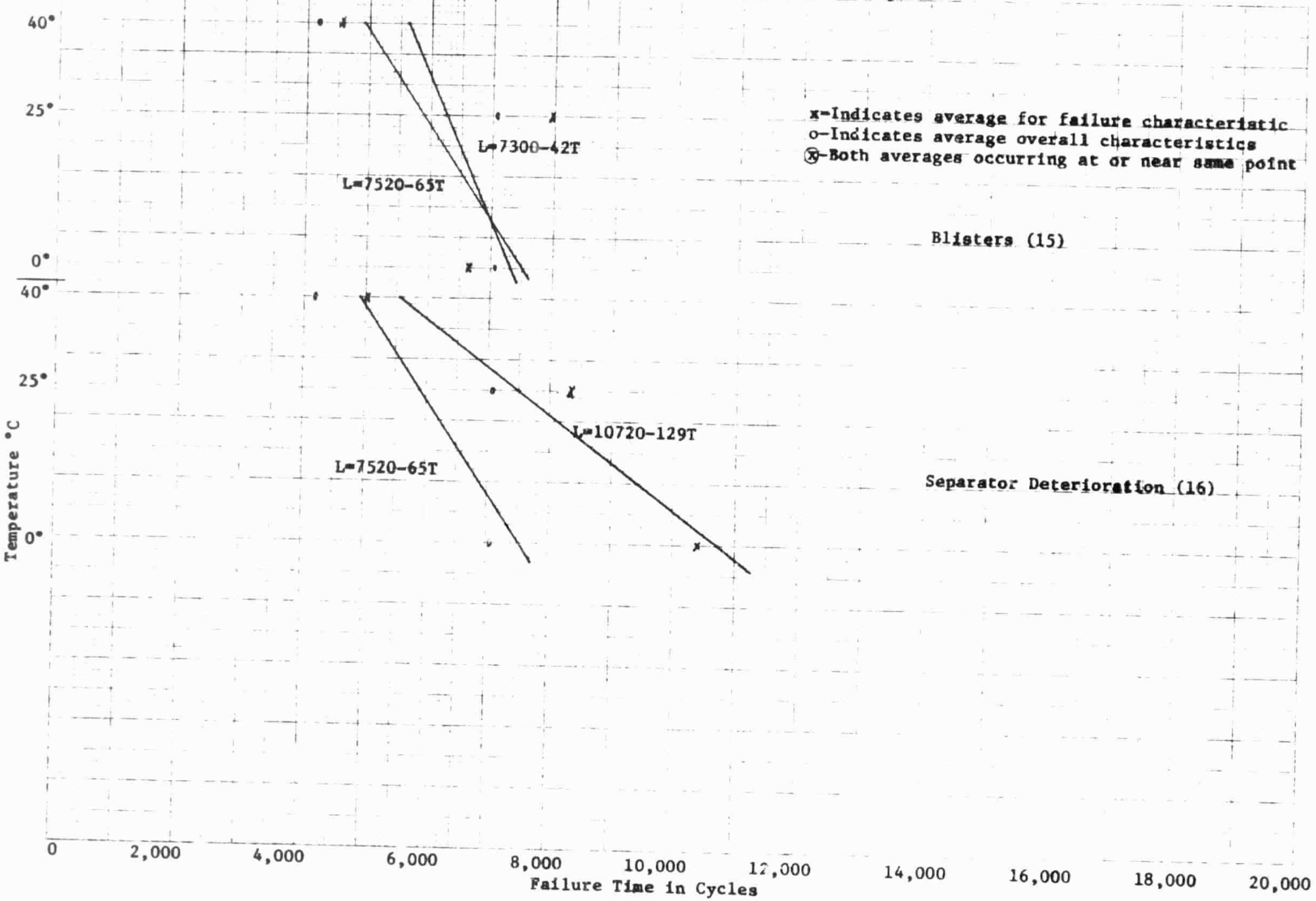


Figure 10

GULTON-3.0 HOUR ORBIT TIME-CHARACTERISTIC CODE 2-4

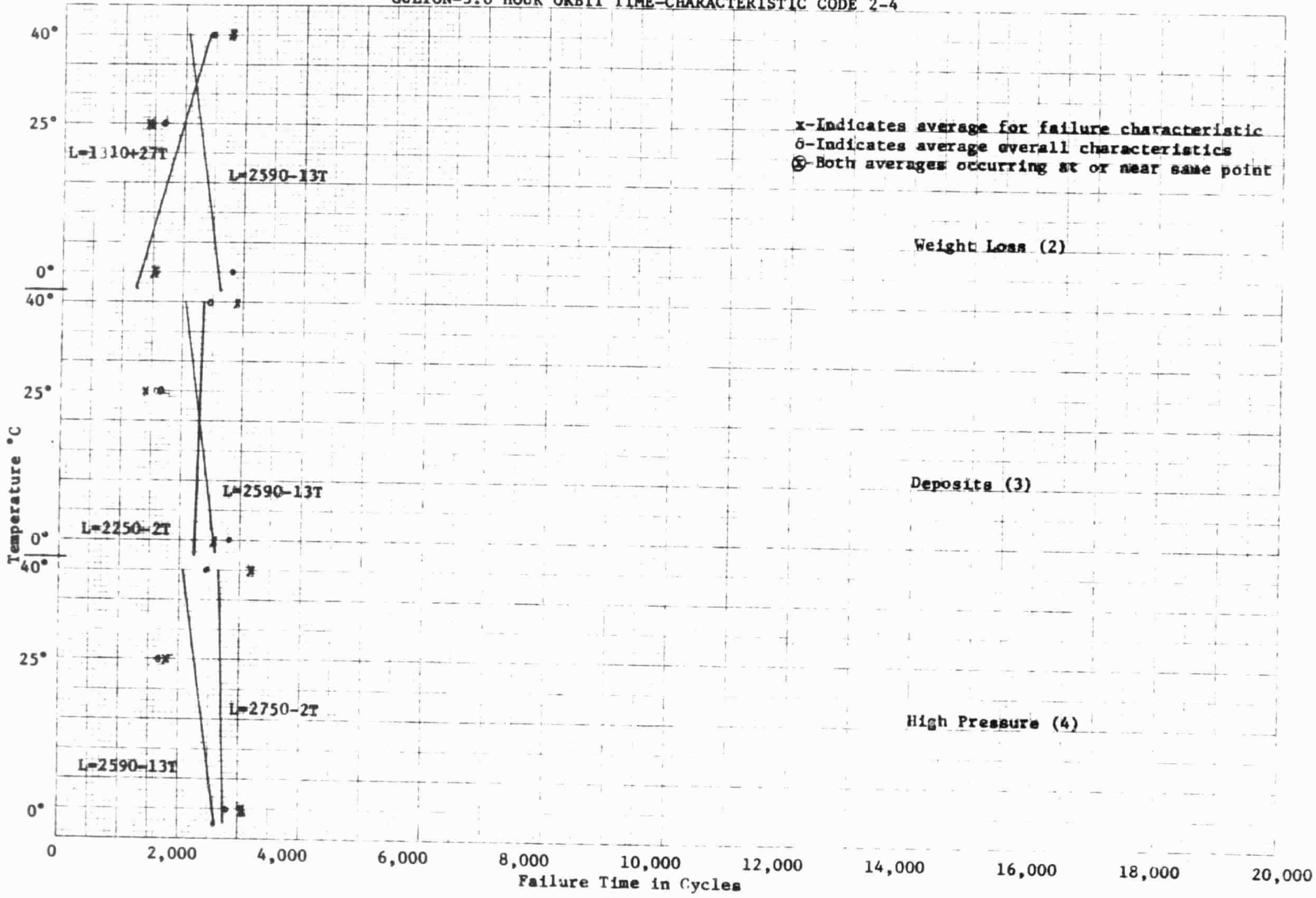


Figure 17
GULTON-3.0 HOUR ORBIT TIME-CHARACTERISTIC CODE 5, 13, 14

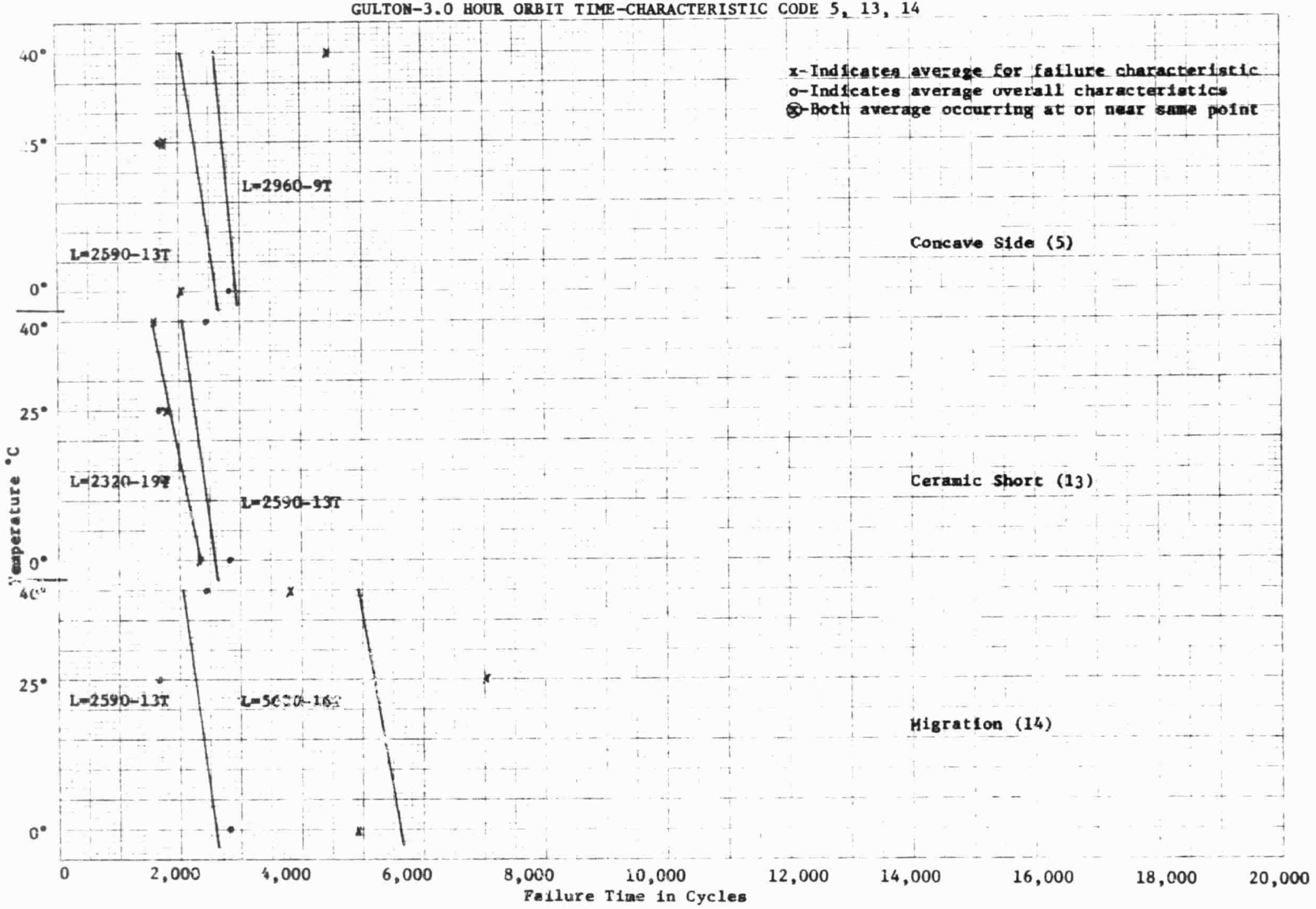


Figure 18

GULTON-3.0 HOUR ORBIT TIME-CHARACTERISTIC CODE 15, 16

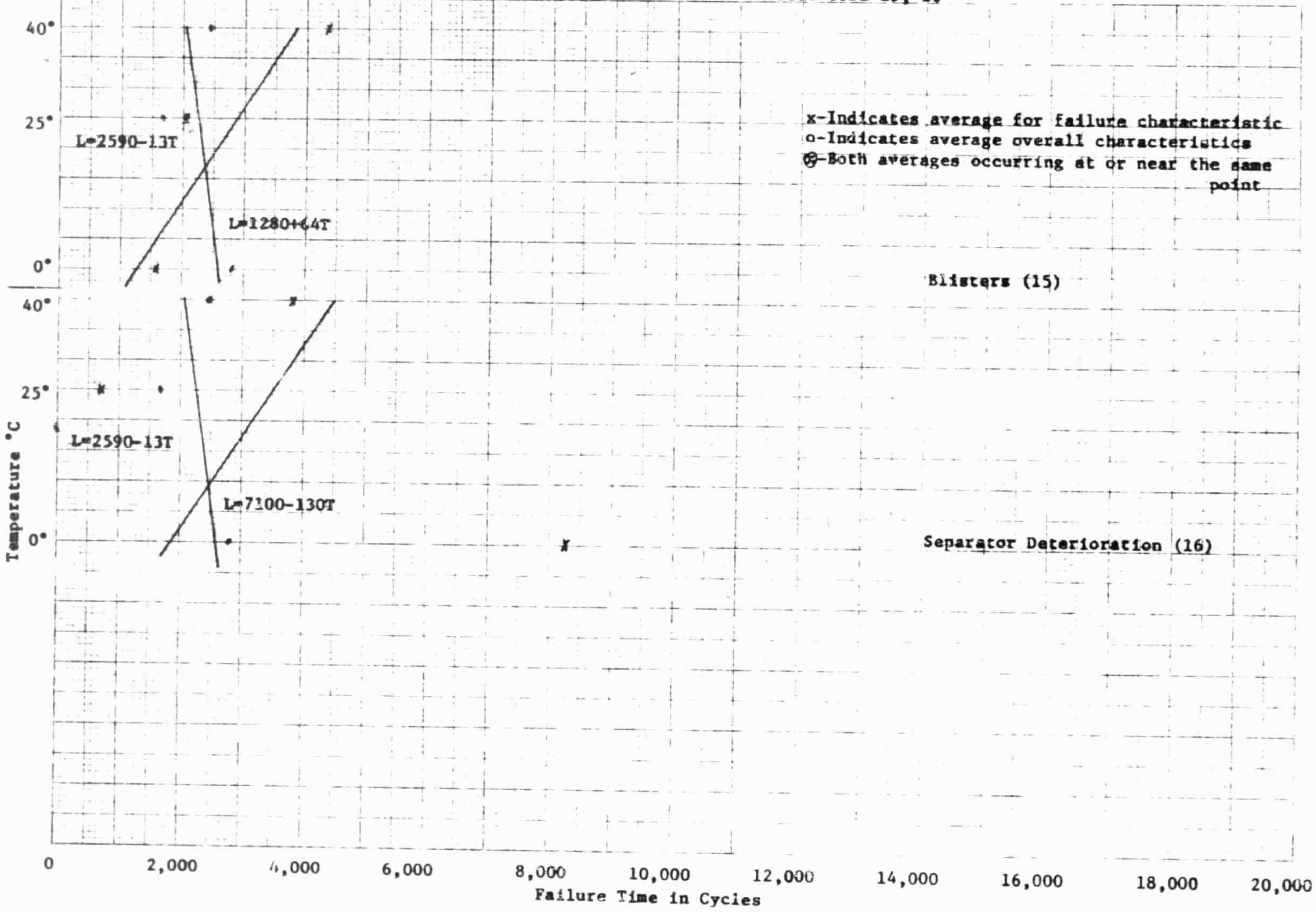


Figure 19

SONOTONE-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 3, 4, 6

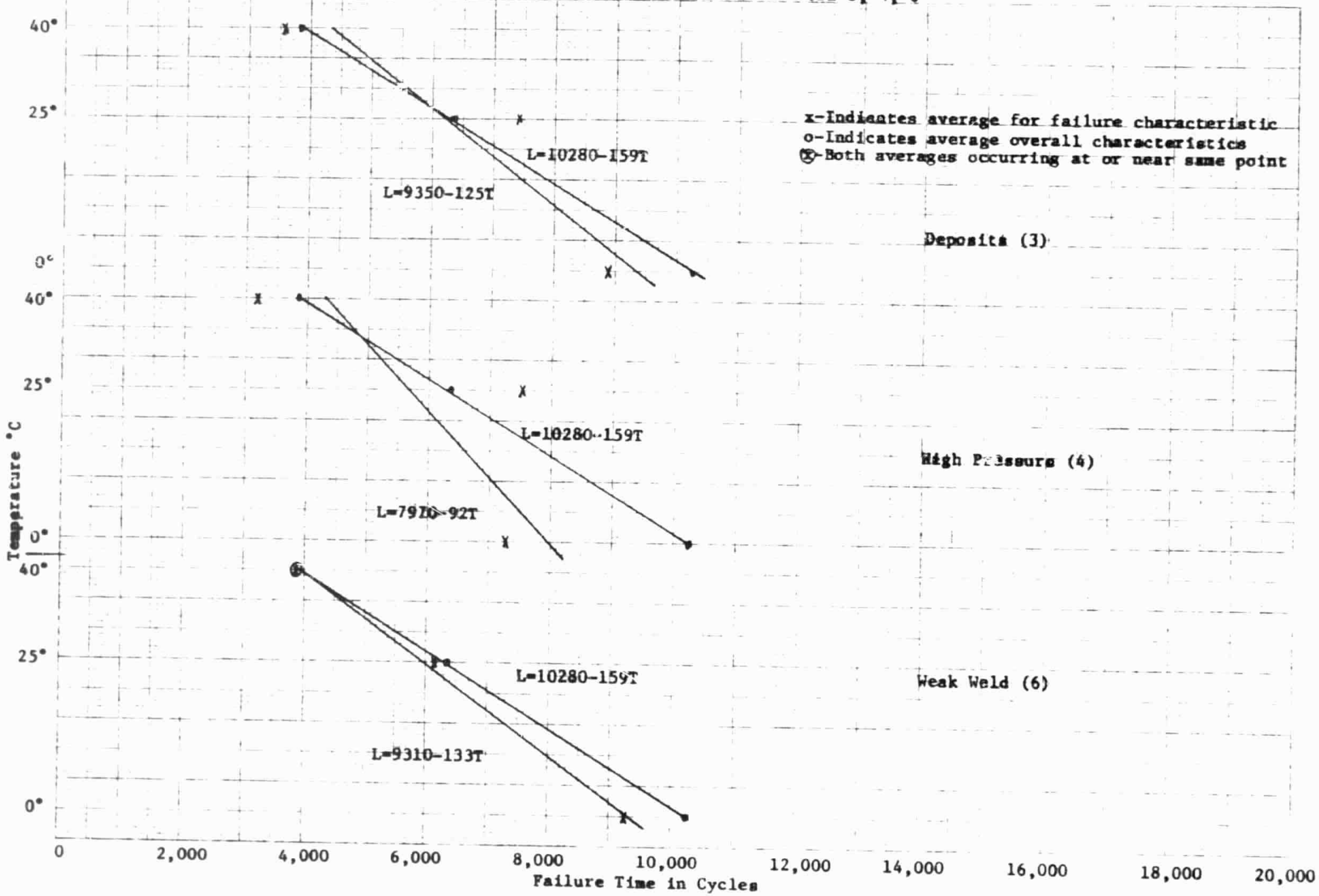


Figure 20

SONOTONE-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 9, 10, 13

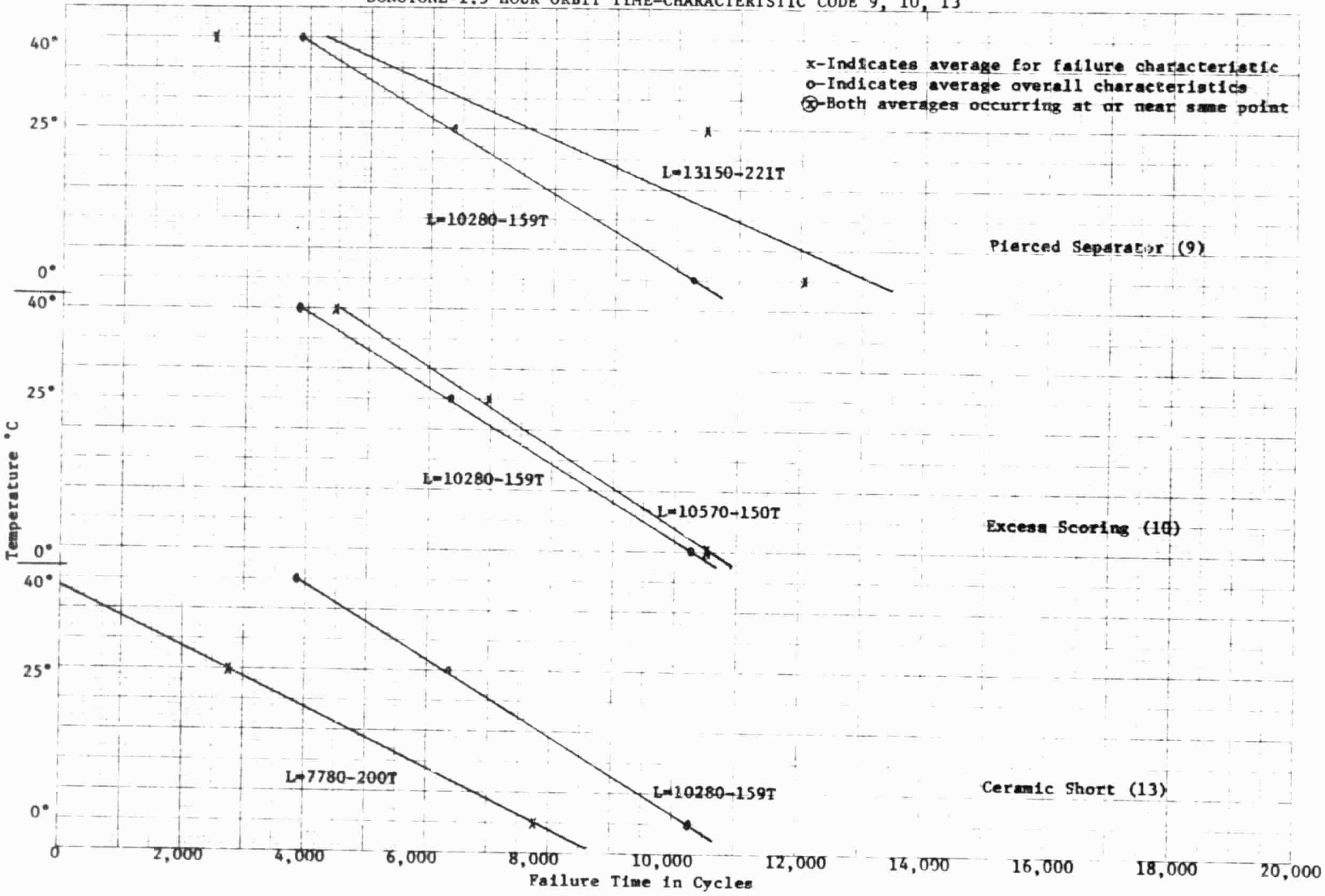


Figure 21
SONOTONE-1.5 HOUR ORBIT TIME-CHARACTERISTIC CODE 14-16

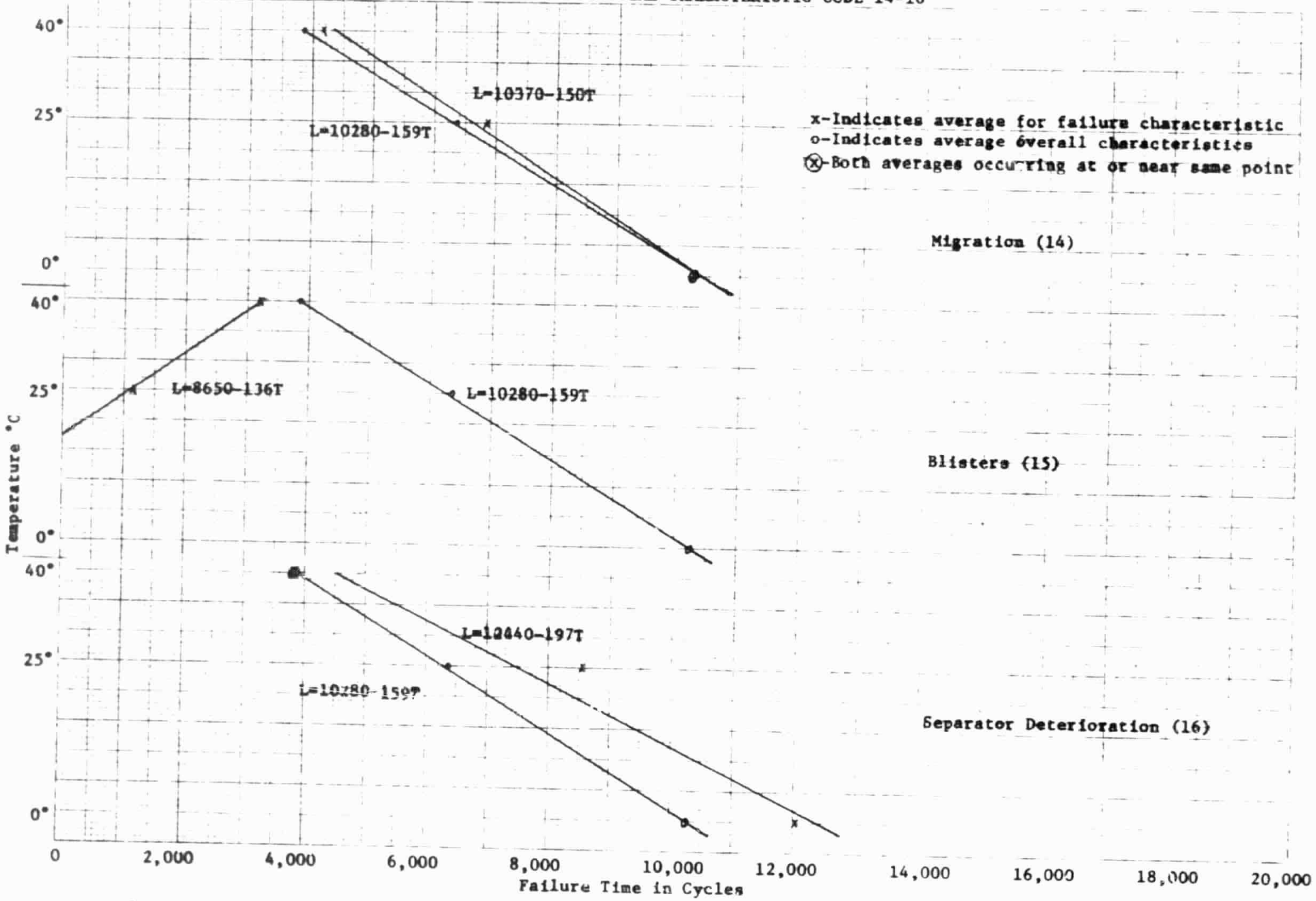


Figure 22
SONOTONE-3.0 HOUR ORBIT TIME-CHARACTERISTIC CODE 3, 6, 10

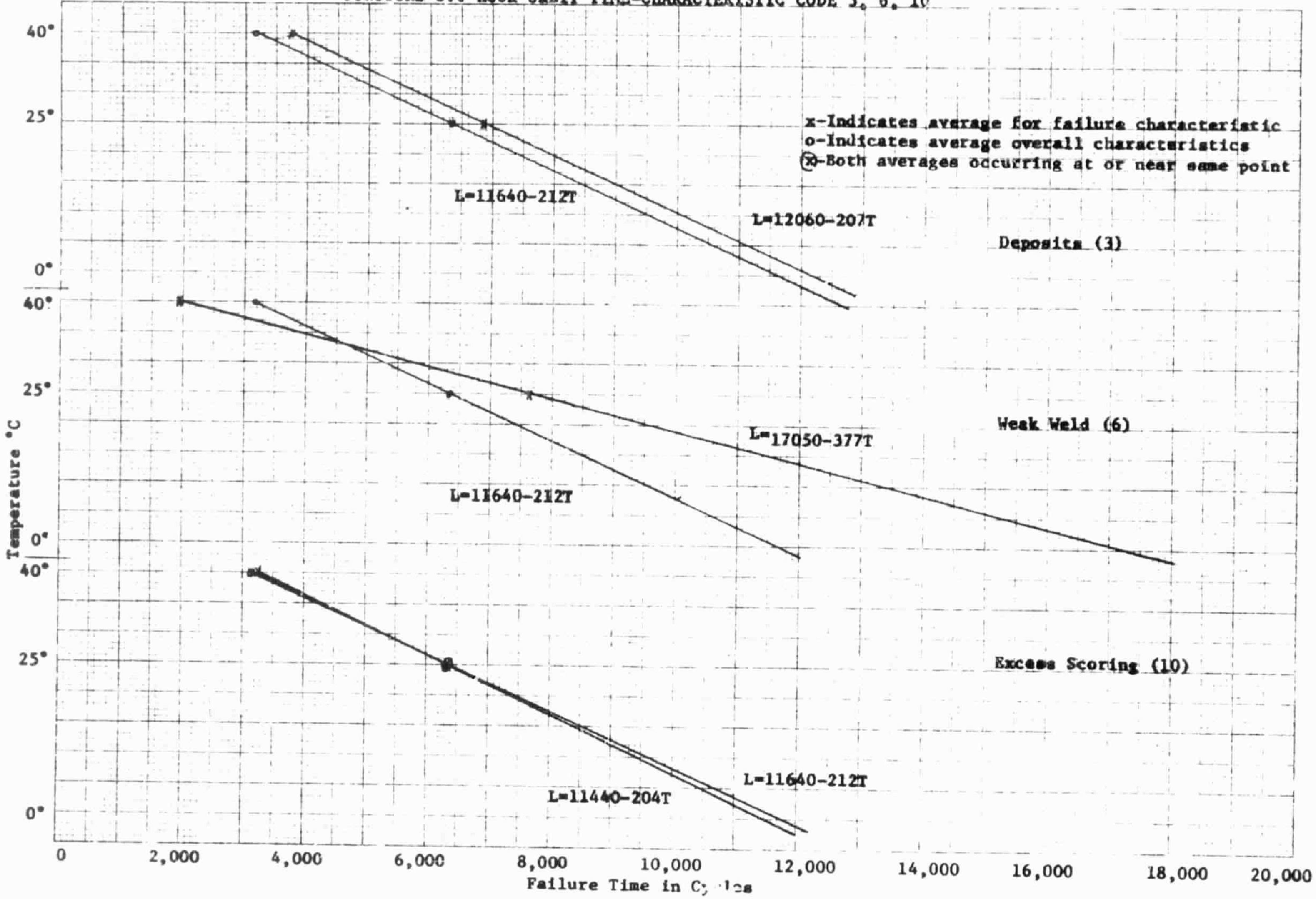


Figure 23
SONOTONE-3.0 HOUR ORBIT TIME-CHARACTERISTIC CODE 14, 16

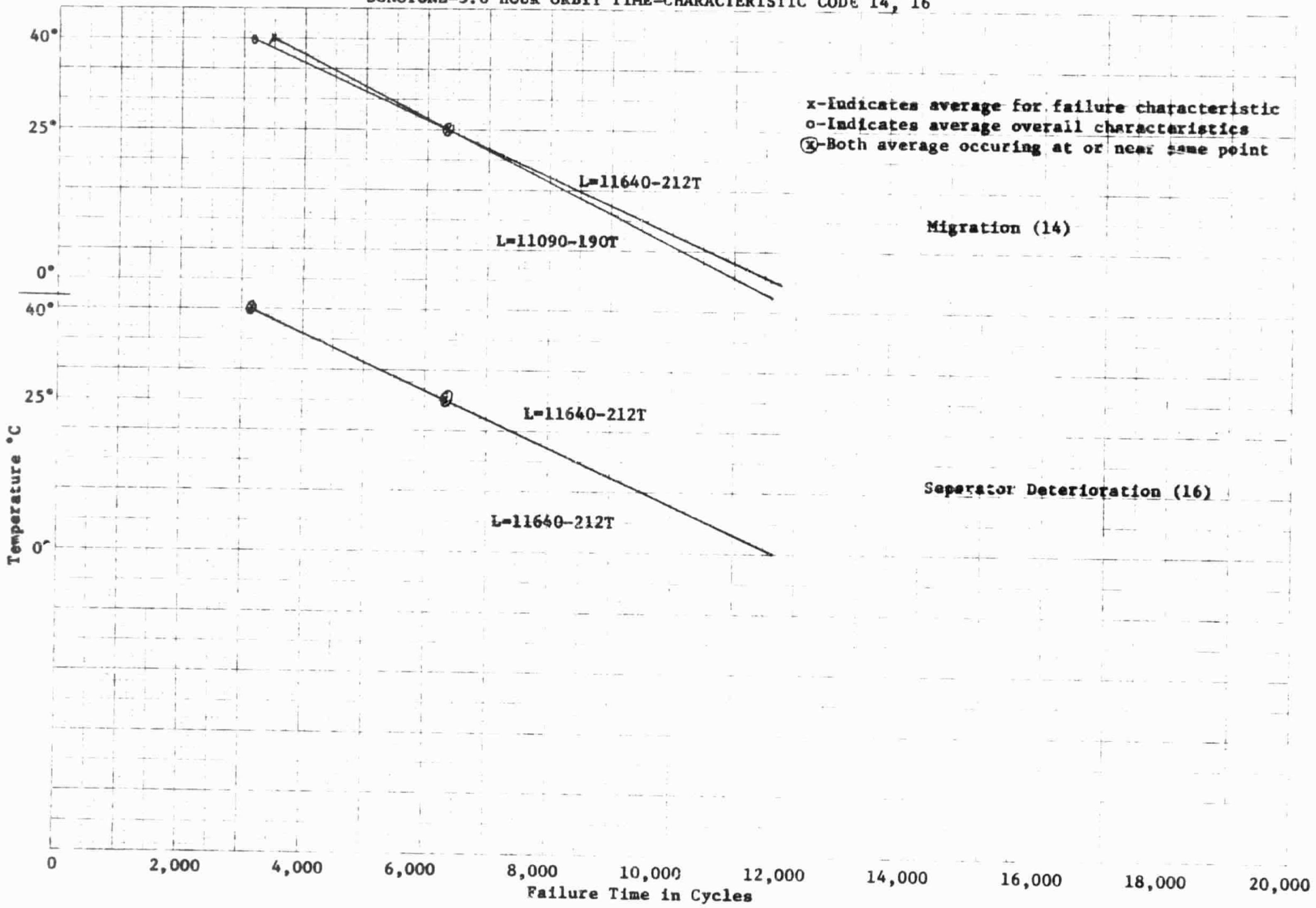


TABLE 34-GENERAL ELECTRIC
MEAN FAILURE TIMES AND RANGE OF FAILURES FOR MANUFACTURER-ORBIT TIME COMBINATIONS

		ORBIT TIME 1.5			ORBIT TIME 3.0		
Failure Characteristic	Ambient Temperature	Number of Failures	Mean Failure Time (Cycles)	Range of Failures (Cycles)	Number of Failures	Mean Failure Time (Cycles)	Range of Failures (Cycles)
Overall	0°	2	19502	13218-25786	1	7054	7054
	25°	12	9477	5164-13149	1	8572	8572
	40°	13	3790	2073- 8273	9	3906	1672- 4424
2	0°	1	13218	13218	0	-	-
	25°	2	7844	5164-10624	0	-	-
	40°	0	-	-	0	-	-
3	0°	1	13218	13218	0	-	-
	25°	4	10801	8714-13149	1	8572	8572
	40°	3	2844	2182- 3841	2	4276	3854- 4487
4	0°	2	19502	13218-25786	0	-	-
	25°	2	11806	10463-13149	0	-	-
	40°	3	6797	6[illegible]9- 8273	2	4264	4170- 4358
5	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
6	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
7	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	1	2182	2182	2	4487	4487- 4487
8	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	2	2454	2446- 2461	0	-	-
9	0°	0	-	-	0	-	-
	25°	2	10338	7537-13149	0	-	-
	40°	0	-	-	0	-	-
10	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
11	0°	0	-	-	0	-	-
	25°	0	-	-	1	8572	8572
	40°	5	2344	2073- 2509	1	1672	1672
12	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	3	2255	2073- 2509	0	-	-
13	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
14	0°	2	19502	13218-25786	1	7054	7054
	25°	12	9478	5164-13149	1	8572	8572
	40°	5	5485	3841- 8273	7	4187	3848- 4487
15	0°	1	13218	13218	0	-	-
	25°	6	9320	8065-10382	0	-	-
	40°	1	8273	8273	3	4168	3848- 4170
16	0°	2	19502	13218-25786	1	7054	7054
	25°	12	9478	5164-13149	1	8572	8572
	40°	5	5813	3841- 8273	8	4185	3848- 4487

TABLE 35—GOULD
MEAN FAILURE TIMES AND RANGE OF FAILURES FOR MANUFACTURER-ORBIT TIME COMBINATIONS

Failure Characteristic	Ambient Temperature	ORBIT TIME 1.5 Number of Failures	Mean Failure Time (Cycles)	Range of Failures (Cyles)	ORBIT TIME 3.0 Number of Failures	Mean Failure Time (Cycles)	Range of Failures (Cycles)
Overall	0°	9	9246	3556-13730	1	9110	9110
	25°	10	3663	2672- 4751	10	4268	3007- 5690
	40°	13	1303	408- 1811	9	749	138- 983
2	0°	0	-	-	0	-	-
	25°	5	4122	3090- 4751	6	3569	3007- 4173
	40°	4	539	408- 860	5	304	495- 974
3	0°	2	12362	10994-13730	0	-	-
	25°	5	4122	3090- 4751	7	3856	3007- 5580
	40°	[illegible]	809	408- 1811	5	804	495- 974
4	0°	4	8871	7858-10641	1	9110	9110
	25°	3	2826	2672- 2980	4	5317	4306- 5690
	40°	5	1064	484- 1569	4	865	801- 983
5	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
6	0°	1	13730	13730	0	-	-
	25°	2	3586	3090- 4081	6	3870	3007- 5690
	40°	5	1427	408- 1811	3	662	138- 974
7	0°	3	10147	9724-10994	0	-	-
	25°	0	-	-	2	3507	3130- 3884
	40°	0	-	-	0	-	-
8	0°	2	9807	8619-10994	1	9110	9110
	25°	2	2806	2785- 2826	0	-	-
	40°	0	-	-	1	974	974
9	0°	0	-	-	0	-	-
	25°	3	3193	2672- 4081	0	-	-
	40°	4	1541	1273- 1811	0	-	-
10	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
11	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
12	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
13	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
14	0°	9	9246	3556-13730	1	9110	9110
	25°	4	4548	4289- 4751	10	4268	3007- 5690
	40°	1	1811	1811	5	852	800- 983
15	0°	0	-	-	0	-	-
	25°	1	4751	4731	2	4998	4306- 5690
	40°	2	1660	1509- 1811	3	862	801- 963
16	0°	8	9356	3556-13730	1	9110	9110
	25°	4	4105	2980- 4751	10	4268	3007- 5690
	40°	1	1509	1509	3	801	800- 801

TABLE 36—GULTON
MEAN FAILURE TIMES AND RANGE OF FAILURES FOR MANUFACTURER-ORBIT TIME COMBINATIONS

		ORBIT TIME 1.5			ORBIT TIME 3.0		
Failure Characteristics	Ambient Temperature	Number of Failures	Mean Failurs Time (Cycles)	Range of Failures (Cyles)	Number of Failures	Mean Failure Time (Cycles)	Range of Failures (Cycles)
Overall	0°	14	7074	2107-16325	7	2812	1045- 8274
	25°	24	7084	308-15711	9	1675	721- 2885
	40°	34	4177	37-10360	10	2434	96- 4480
2	0°	6	7269	2107-14863	3	1528	1045- 2122
	25°	10	5439	308-15711	3	1413	1184- 1754
	40°	9	1630	114- 3795	4	2775	484- 4133
3	0°	5	11970	2995-16325	3	2591	1237- 4414
	25°	11	7734	308-15711	3	1413	1184- 1754
	40°	11	4271	187- 6537	7	2920	382- 4480
4	0°	7	4187	2203- 8590	6	3085	1045- 8274
	25°	6	5966	308-14250	2	1803	721- 2885
	40°	11	3795	1196- 7900	4	3207	484- 4480
5	0°	3	2200	2107- 2291	5	2034	1045- 4414
	25°	2	4770	1776- 7763	1	1754	1754
	40°	1	1333	1333	1	4480	4480
6	0°	0	-	-	0	-	-
	25°	4	5867	2743- 8108	0	-	-
	40°	9	5598	1195-10360	0	-	-
7	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
8	0°	1	10830	10830	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
9	0°	1	4066	4066	0	-	-
	25°	0	-	-	0	-	-
	40°	1	6345	6345	0	-	-
10	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
11	0°	0	-	-	0	-	-
	25°	7	5808	2025- 9791	0	-	-
	40°	7	3623	1196- 5766	0	-	-
12	0°	1	10803	10803	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
13	0°	2	6516	441- 8590	3	2335	1173- 4414
	25°	5	4287	2969- 7763	6	1807	721- 2885
	40°	9	2780	37- 5888	5	1598	96- 4133
14	0°	7	10018	3202-16325	3	4937	2122- 8274
	25°	15	8149	2743-15711	3	7028	1754-16881
	40°	23	5303	1195-10360	6	3827	2862- 4480
15	0°	9	6655	2203-14863	3	1592	1237- 2122
	25°	10	7991	2969-15711	4	2052	1184- 2885
	40°	10	4555	2824- 5766	3	4364	4133- 4480
16	0°	6	10400	4066-14863	1	8274	8274
	25°	18	8345	2025-10592	1	721	721
	40°	27	5034	1195-10360	6	3827	2862- 4480

TABLE 37-SONOTONE
MEAN FAILURE TIMES AND RANGE OF FAILURES FOR MANUFACTURER-ORBIT TIME COMBINATIONS

		ORBIT TIME 1.5			ORBIT TIME 3.0		
Failure Characteristic	Ambient Temperature	Number of Failures	Mean Failure Time (Cycles)	Range of Failures (Cycles)	Number of Failures	Mean Failure Time (Cycles)	Range of Failures (Cycles)
Overall	0°	7	10262	5788-15294	0	-	-
	25°	15	6340	1136-11745	3	6338	3771- 9971
	40°	12	3865	2487- 5625	6	3160	855- 4141
2	0°	2	11137	8774-13500	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	1	3684	3684
3	0°	5	8894	5788-13500	0	-	-
	25°	7	7446	2773-11745	2	6871	3771- 9971
	40°	5	3596	2993- 4388	4	3759	3068- 4141
4	0°	2	7281	5788- 8774	0	-	-
	25°	2	7531	3742-11319	1	5272	5272
	40°	5	3146	2902- 3625	0	-	-
5	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
6	0°	5	9253	5788-15294	0	-	-
	25°	6	6128	2342-11745	2	7622	5272- 9971
	40°	7	3860	2902- 5625	2	1962	855- 3068
7	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
8	0°	0	-	-	0	-	-
	25°	1	1179	1179	0	-	-
	40°	0	-	-	0	-	-
9	0°	1	12069	12069	0	-	-
	25°	2	10489	9658-11319	0	-	-
	40°	1	2487	2487	2	3605	3068- 4141
10	0°	6	10510	5788-15294	0	-	-
	25°	8	6989	2342-11745	3	6338	3771- 9971
	40°	7	4450	2993- 5625	3	3273	3068- 3684
11	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	2	4388	4388	0	-	-
12	0°	0	-	-	0	-	-
	25°	0	-	-	0	-	-
	40°	0	-	-	0	-	-
13	0°	3	7779	5788- 8774	0	-	-
	25°	1	2773	2773	0	-	-
	40°	0	-	-	0	-	-
14	0°	7	10262	5788-15294	0	-	-
	25°	13	6885	1136-11745	3	6338	3771- 9971
	40°	9	4172	2902- 5625	4	3490	3068- 4141
15	0°	0	-	-	0	-	-
	25°	1	1179	1179	0	-	-
	40°	1	3216	3216	0	-	-
16	0°	2	12034	8774-15294	0	-	-
	25°	10	8584	2342-11745	3	6338	3771- 9971
	40°	10	3864	2487- 5625	6	3160	855- 4141

(3) Gould, 1.5 hour orbit time (Figures 6-8)

Depositing and weak weld type failures have higher averages at 0°C. Cells with pierced separators were indicated to have lower failure times at 0°C by extrapolation from the plot, but no actual failure times were recorded for this characteristic.

(4) Gould, 3.0 hour orbit time (Figures 9-11)

Cells with blistering were indicated to have higher failure times at 0°C, but again no failure times occurred at this temperature.

(5) Gulton, 1.5 hour orbit time (Figures 12-15)

Cells with weight loss had lower averages at 40°C. Cells with deposits, migration and separator deterioration have higher averages at 0°C. High pressure, concave sides, and pierced separater characteristics have lower averages at 0°C. In general, the means do not show a good linear fit for the Gulton data.

(6) Gulton, 3.0 hour orbit time (Figures 16-18)

Cells with migration have higher averages across all temperature levels. Those with separator deterioration failures had a much higher average at 0°C.

(7) Sonotone, 1.5 hour orbit time (Figures 19-21)

High pressure cells have lower values at 0°C. Pierced separator cells have higher averages at 0°C and 25°C. The occurrence of ceramic shorts yields lower averages at 0°C and 25°C while blisters exhibit lower averages at 25°C; lower values for blisters at 0°C are indicated but no such failures had occurred.

(8) Sonotone, 3.0 hour orbit time (Figures 22-23)

No differences between failure characteristic plots and the overall plots were noted. However, a difference was indicated at 0°C for weak welds, but no actual failures occurred.

4. A Proposed Bayesian Approach to Evaluation of Failure Analysis Results

a. Discussion

In many real-life situations it is desirable to quantify the likelihood or probability of an occurrence when the available information surrounding the occurrence deals mostly with effects noted previously. If information prior to the occurrence is so lacking that the occurrence can not be prepared for or prevented, then it is certainly useful to be able to identify when it occurs and act accordingly. In the real world the identification or diagnosis is not always a sure thing, hence decision-making assistance is needed. Use of Bayesian techniques is one way to attain this assistance in the form of probabilities. The method proposed here is similar to that used in the medical area where, with symptoms known, Bayes Theorem is used to diagnose diseases. However, the application here is battery cells and the symptoms are failure characteristics and levels of failure characteristics.

b. An Example

A total of 20 battery cell failures resulted from tests conducted under two different environments, E_1 and E_2. The following table shows the failure symptoms or characteristics, S_1, S_2, and S_3, and the levels of each. For example, S_2 might be concerned with weight loss and and the levels might be no weight loss (0), low (1), medium (2) or high (3) weight loss. S_3 might represent separator deterioration and the levels could describe whether general decomposition was noted, whether shorting between the plates occurred, etc.

Symptoms	Level of Symptom	E_1 $f(E_1) = 8$	E_2 $f(E_2) = 12$
S_1	0	5	2
	1	3	0
	2	0	10
S_2	0	0	6
	1	2	0
	2	2	0
	3	4	6
S_3	0	0	4
	1	1	2
	2	0	4
	3	2	0
	4	5	2

To systematically study the failure characteristics and their associations to test environment, a Bayesian approach shows possibilities. Suppose one is asked to compute the probability that one of the 20 cells with a failure symptom set, $S = S_1 = 2, S_2 = 0, S_3 = 3$, failed under environmental conditions E_1; $P[E_1|S]$. If we ignore, for the moment, the fact that we can easily determine the true failure environment, the best answer would depend upon the history of failure characteristics for the 20 cells.

To compute $P[E_1|S]$ we resort to Bayes Equation,

$$P[E_1|S] = \frac{P[E_1]P[S|E_1]}{\sum_{i=1}^{2} P[E_i]P[S|E_i]}$$

The prior probabilities are easily determined from inspection of the table:

$$P[E_1] = 8/20 \text{ and } P[E_2] = 12/20$$

However, $P[S|E_1] = P[S_1=2,\ S_2=0,\ S_3=3|E_1]$

$= P[S_1=2|E_1]P[S_2=0|E_1]P[S_3=3|E_1]$, assuming that symptoms are independent.

We now use an extension of Laplace's Rule,

$$P = \frac{m_o + m}{n_o + n},$$ to compute the necessary probabilities.

This method combines the prior estimate, $P = \frac{m_o}{n_o}$, with the historical data or sample MLE, $P = \frac{m}{n}$, and is preferred to the usual maximum likelihood estimate (MLE) since it (1) yields a reasonable compromise between the extremes of the prior and the maximum likelihood estimate, and (2) yields desirable non-zero probabilities as opposed to frequent maximum likelihood probabilities of zero.

Then $P[S_1 = 2|E_1] = \frac{1+0}{3+8} = \frac{1}{11}$

where n_o = # levels of S_1
m = # failures in E_1 that exhibited symptom level 2 in S_1
n = # failures in E_1

Similarly, $P[S_2 = 0|E_1] = \frac{1+0}{4+8} = \frac{1}{12}$

and $P[S_3 = 3|E_1] = \frac{1+2}{5+8} = \frac{3}{13}$

Then
$$P[S|E_1] = P[S_1 = 2|E_1]P[S_2 = 0|E_1]P[S_3 = 3|E_1] = \left(\frac{1}{11}\right)\left(\frac{1}{12}\right)\left(\frac{3}{13}\right)$$

and similarly,
$$P[S|E_2] = P[S_1 = 2|E_2]P[S_2 = 0|E_2]P[S_3 = 3|E_2] = \left(\frac{1+10}{3+12}\right)\left(\frac{1+6}{4+12}\right)\left(\frac{1+0}{5+12}\right) = \left(\frac{11}{15}\right)\left(\frac{7}{16}\right)\left(\frac{1}{17}\right)$$

Now substituting back into Bayes Equation,

$$P[E_1|S] = \frac{\left(\frac{8}{20}\right)\left(\frac{1}{11}\cdot\frac{1}{12}\cdot\frac{3}{13}\right)}{\left(\frac{8}{20}\right)\left(\frac{1}{11}\cdot\frac{1}{12}\cdot\frac{3}{13}\right)+\left(\frac{12}{20}\right)\left(\frac{11}{15}\cdot\frac{7}{16}\cdot\frac{1}{17}\right)}$$

we finally obtain:

$$P[E_1|S] = .051644 \qquad P[E_2|S] = .948356.$$

c. Summary

So we are quite confident that the failure with symptoms, S = [2, 0, 3] did fail under test conditions E_2 and not E_1 since the probability is .948, the risk of being wrong is approximately five percent. By putting many different failure characteristics or symptom sets through a computer program written for this purpose, we can systematically:

(1) determine which failure analysis information is inconsistent or misleading,

(2) determine the associations of failure mechanisms with stress levels, and

(3) determine to some extent which failure mechanisms and characteristics remain unchanged for varying stress levels.

This method, or any method, will require that the listing of failure characteristics be meaningful and that the data recording is done in a consistent fashion (i.e., with definitions basically unchanged for a specified life test). The method also requires that significantly high correlations do not exist between failure characteristics. Computer programs are available whereby one may determine inter-correlations and segregate the data accordingly.

APPENDIX A

Procedure For Prediction of Cell Failure Time Using Time To Discharge

The following procedures were used for each pack:

1. The $\bar{t}_i$ represents the average time for the ith cell of a pack to discharge to 1.25 volts. The voltage was arbitrarily chosen and other values may yield varying degrees of success.

2. The $\bar{t}_i$'s for the cells of a pack were assumed to be normally distributed and the mean and variance of the pack were estimated as follows:

$$\hat{\mu}_t = \frac{\sum_{i=1}^{n} \bar{t}_i}{n} \qquad \hat{\sigma}_t^{2} = \frac{\sum_{i=1}^{n} (\bar{t}_i - \hat{\mu}_t)^2}{n-1}$$

3. Since the actual failure times of several of the packs were distributed approximately lognormal (i.e., the logarithms of the failure times tend to give a normal distribution), the logarithms of the actual failure times (T_i's) were obtained. Where the number of failure times were sufficient, a mean ($\hat{\mu}_{F.T.}$) and variance ($\hat{\sigma}^2_{F.T.}$) were estimated from the natural logarithms of the actual failure times:

$$\hat{\mu}_{F.T.} = \frac{\sum_{i=1}^{n} (\ln T_i)}{n} \qquad \hat{\sigma}_{F.T.} = \frac{\sum_{i=1}^{n} (\ln F.T. - \hat{\mu}_{F.T.})^2}{n-1}$$

In instances where the number of failure times were insufficient for estimates of μ and σ^2, conservative estimates were made.

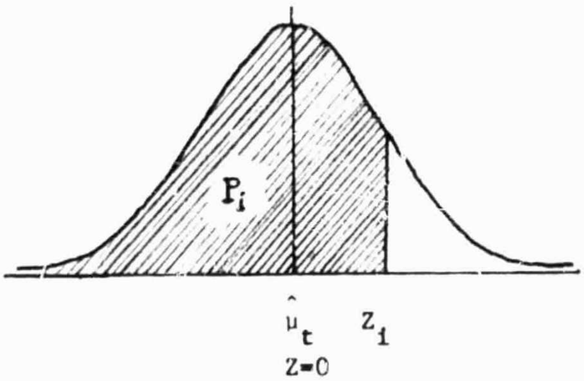
4. Now for any calculated $\bar{t}_i$ the number of standard normal deviates from the mean could be determined from the distribution of discharge times and mapped to the failure time distribution. The number of standard normal deviates (Z_i) is found by

$$Z_i = \frac{\bar{t}_i - \hat{\mu}_t}{\hat{\sigma}_t}$$

and the cumulative probability or area under the normal curve (P_i) for the ith battery is given by

$$P_i = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z_i} e^{-x^2/2} \, dx$$

Area Under The Normal Curve



5. After determining each of the Z_i, they were mapped to the failure time distributions. From this mapping a predicted failure time was obtained such that the cumulative probabilities or areas on each distribution were equal. That is, let $P_i\ (\bar{t}_i) = P_i\ (\ln T_i)$ and $Z_i\ (\bar{t}_i) = Z_i\ (\ln T_i)$. The Z_i then was used to determine a unique $\ln T_i$ for each $\bar{t}_i$ and hence, a unique T_i, the predicted or estimated failure time for the ith cell having an average time to discharge of $\bar{t}_i$.

$$Z_i = \frac{\text{Est } \ln T_i - \hat{\mu}_{F.T.}}{\hat{\sigma}_{F.T.}}$$

$$\text{Est. } \ln T_i = Z_i\ \hat{\sigma}_{F.T.} + \hat{\mu}_{F.T.}$$

$$\text{Est. } T_i = \text{antilog } (Z_i\ \hat{\sigma}_{F.T.} + \hat{\mu}_{F.T.})$$

APPENDIX B

Procedures For Prediction Of Cell Failure Time Using Time To Charge

The following procedures were used for the packs evaluated.

1. The $\bar{t}_i'$ represents the average time for the ith cell of a pack to charge to 1.35 volts.

2. The predictions for each cell were then made following the procedures of Appendix A but with $\bar{t}_i'$ substituted for $\bar{t}_i$.

APPENDIX C

Procedures For Prediction Of Cell Failure Time Using Linear Regression

A linear regression analysis in conjunction with the time to discharge was used to make predictions of cell failures.

1. The $\bar{t}_i$ represents the average time for the ith cell of a pack to discharge to 1.25 volts.

2. A simple linear regression equation was generated using the natural logarithm of the available failure times as the dependent variable and the $\bar{t}_i$ as the independent variable.

$$\ln FT_i = \alpha + \beta \bar{t}_i$$

3. The $\bar{t}_i$'s for all cells of the pack were then substituted into the regression equation and a failure time was estimated for each cell.

$$\text{Est. } \ln F.T._i = \alpha + \beta \bar{t}_i$$

$$\text{Est. } F.T._i = \text{antilog } (\alpha + \beta \bar{t}_i)$$

APPENDIX D

Failure Analysis Results-NAD Crane Life Cycling Program

Numerical codes were developed for the NASA-NAD Crane Failure Analysis Program so that data processing facilities could be used for analysis of the data. Following are (1) coding sheets with individual cell information and (2) computer output sheets identifying each failed cell, listing failure characteristics and cycle failure time, and indicating the test conditions (orbit time, temperature, and depth of discharge) for any cell that has failed.

CODING FOR DATA PROCESSING ON NASA--NAD CRANE FAILURE ANALYSIS PROGRAM (APRIL 1969)

NOMENCLATURE	CODES	COLUMN
Pack Number	xxxA	1-4
Manufacturer	xx 01 - General Electric 02 - Gould 03 - Gulton 04 - Sonotone 05 - Yardney 06 - Delco 07 - C & D 08 - NIFE	5-6
Rated Capacity	xxx.xx (Capacity indicated by actual numerical rating--decimal assumed after 9th column)	7-11
Depth of Discharge	xx 01 - 15% 02 - 25% 03 - 40% 04 - 50% 05 - 60% 06 - 20% 07 - 10% 08 - 16% 09 - 27% 10 - 30% 11 - 31% 12 - 42% 13 - 43% 14 - 75%	12-13
Orbit Time	xx 01 - 1.5 hrs. 02 - 3.0 hrs. 03 - 8.0 hrs. 04 -24.0 hrs.	14-15
Ambient Temperature	xx 01 - -20°C 02 - 0°C 03 - 25°C 04 - 40°C 05 - 50°C 06 - 0°/40°C (stepped from 0° to 40° every 48 hrs.)	16-17
Cycles Completed	xxxxx (Give actual number of cycles completed)	18-22
Position in Pack	xx	23-24
Shape	xx 01 - Round or cylindrical (Unless specified as Nimbus) 02 - Rectangular 03 - Nimbus	25-26

FAILURE MODES

Charge Voltage	01xx 01 - Shorted 02 - Low 03 - Normal 04 - High 05 - Open Circuit
Weight Loss	02xx 01 - Low 02 - Medium (Rated capacity ±50% Rated) 03 - High
Deposits	03xx 01 - Around Terminal 02 - Around Seam 03 - Around Both
High Pressure	04xx 01 - Bulged 02 - Gas Present 03 - Both
Concave Side	05xx 01 - Present 02 - Caused Short
Weak Weld	06xx 01 - Tab to Plate 02 - Tab to Case 03 - Tab to Terminal 04 - Tab to Plate & Case 05 - Tab to Plate & Terminal
Loosened Active Material	07xx 01 - Present 02 - Caused Short
Extraneous Active Material	08xx 01 - Present 02 - Caused Short
Pierced Separator	09xx 01 - Grid Wire 02 - Tab to Plate 03 - Foreign Pieces of Metal
Excess Scoring	10xx 01 - Present 02 - Caused Short

Burned Positive Tab

11xx
01 - Present
02 - Broken
03 - Caused Short

Short Separator

12xx
01 - Present
02 - Caused Short

Ceramic Short

13xx
01 - One Terminal
02 - Two Terminal

Migration

14xx
01 - General
02 - Small Area Penetration
03 - Shorting Penetration
04 - Positive Plate
05 - Short Around Tab
06 - Short Around Scoring
07 - General with Shorting

Blisters

15xx
01 - Present
02 - Caused Short

Separator Deterioration

16xx
01 - General
02 - Permitted Short
03 - Center of Case
04 - Permitted Short

Weight Loss

17xx
xx - Amount of Loss in Grams if measurable
(Usually in the Range of 1 - 27 gms)

Computer Printout Of Failure Analysis Results

```
Pack Number / Manufacturer / Capacity Rating / Depth Of Discharge / Orbit Time / Temperature / Failure Time / Pack Position / Shape / Failure Characteristics And Levels / Number of Characteristics Per Cell

1A  04  5.0 020103  2995  4 01 0104 0301 1401                                3
1A  04  5.0 020103  4423  1 01 0104 0601 1001 1603                           4
1A  04  5.0 020103  7782  6 01 0103 0301 1002 1401 1602                      5
1A  04  5.0 020103 11361  5 01 0103 0301 1001 1401 1602                      5
1A  04  5.0 020103 11745  3 01 0103 0601 1001 1401 1602                      5
1A  04  5.0 020103 11745 10 01 0103 0301 0601 1001 1401 1602                 6
2A  04  5.0 030103  3155 10 01 0101 0301 0401 0601 0901                      5
2A  04  5.0 030103  3992  5 01 0103 0301 0401 1401                           4
2A  04  5.0 030103  4411  2 01 0102 0601 1001 1601                           4
2A  04  5.0 030103  5262  6 01 0103 0301 0401 0601 0902 1601                 6
2A  04  5.0 030103  5262  7 01 0102 0601 0901 1001 1401 1601                 6
2A  04  5.0 030103  6671  1 01 0103 0301 0401 1001 1401 1601                 6
2B  04  3.0 030103  1272  3 01 0104                                          1
2B  04  3.0 030103  5113  4 01 0103 0605 1001 1407 1601                      5
2B  04  3.0 030103  5399  5 01 0103 0601 1002 1401 1601                      5
3A  02  3.5 020103  2785  5 01 0104 0802                                     2
3A  02  3.5 020103  3090  2 01 0102 0202 0301 0601 1702                      5
3A  02  3.5 020103  4081  9 01 0103 0202 0301 0601 0902 1702                 6
3A  02  3.5 020103  4289  6 01 0103 0203 0301 1401 1601 1703                 6
3A  02  3.5 020103  4401  7 01 0103 0203 0301 1401 1601 1702                 6
3A  02  3.5 020103  4751  4 01 0103 1401 1501 1601                           4
3A  02  3.5 020103  4751 10 01 0103 0202 0301 1401 1702                      5
3B  04  3.0 020103  9658  2 01 0102 0901 1401 1601                           4
3B  04  3.0 020103 11319  1 01 0102 0402 0902 1401 1602                      5
3B  04  3.0 020103 11726  4 01 0102 0302 1401 1602                           4
4A  02  3.5 030103  1609  7 01 0102 0203 0301 0401 1703                      5
4A  02  3.5 030103  1827  8 01 0102 0203 0301 0401 1703                      5
4A  02  3.5 030103  2110  1 01 0102 0402 1603                                3
4A  02  3.5 030103  2954  6 01 0102 0201 0301 1401 1601 1701                 6
4A  02  3.5 030103  3029  3 01 0103 0301 1601                                3
4A  02  3.5 030103  3164 10 01 0102 0202 0301 0801 1601 1702                 6
5A  04  5.0 020203  3771  2 01 0104 0301 1002 1401 1601                      5
5A  04  5.0 020203  5272  3 01 0103 0402 0601 1001 1401 1601                 6
5A  04  5.0 020203  9971  1 01 0102 0301 0601 1001 1401 1602                 6
6A  04  5.0 030203  1069  8 01 0103 1401                                     2
6A  04  5.0 030203  1136 10 01 0102 0901 1404                                3
6A  04  5.0 030203  1161  4 01 0101 0601 0802 0701                           4
6A  04  5.0 030203  3798  9 01 0103 0401 1001 1401 1602                      5
6A  04  5.0 030203  4608  7 01 0103 0601 1002 1405 1601                      5
6A  04  5.0 030203  5211  6 01 0103 0601 1001 1401 1602                      5
7A  02  3.5 020203  3007  2 01 0102 0203 0301 0601 1401 1601 1703            7
7A  02  3.5 020203  3130  1 01 0103 0201 0301 0601 0701 1402 1601 1701       8
7A  02  3.5 020203  3483  6 01 0102 0202 0301 0601 1402 1601 1702            7
7A  02  3.5 020203  3736  5 01 0101 0201 0301 0601 1402 1601 1701            7
7A  02  3.5 020203  3884  7 01 0103 0202 0301 0701 1402 1601 1702            7
7A  02  3.5 020203  4173  3 01 0103 0201 0301 0601 1402 1601 1701            7
8A  02  3.5 030203  1346  6 01 0102 0201 0301 1401 1702                      5
8A  02  3.5 030203  1704  8 01 0103 0202 0301 0604 1702                      5
8A  02  3.5 030203  1985  1 01 0103 0301 1401 1601                           4
8A  02  3.5 030203  2494  2 01 0102 0202 0301 0601 1401 1601 1702            7
8A  02  3.5 030203  1985 10 01 0103 0202 0301 0601 1403 1702                 6
8A  02  3.5 030203  2138  7 01 0102 0201 0301 0602 1401 1601 1701            7
8A  02  3.5 030203  2494  9 01 0102 0202 0301 1404 1601 1702                 6
11A 03  6.0 030103  2255  3 02 0103 0201 1302 1501 1601 1701                 6
11A 03  6.0 030103  7743  1 02 0101 0301 1401 1501 1602                      5
11A 03  6.0 030103  7743  2 02 0104 0301 1401 1501 1601                      5
13A 03  6.0 020103   308  1 02 0104 0203 0301 0401 1712                      5
13A 03  6.0 020103   502 10 02 0104 0203 0401 1710                           4
```

```
13A 03   6.0 020103   2969  5 02 0102 1301 1501                                    3
13A 03   6.0 020103   3084  7 02 0102 1301 1501                                    3
13A 03   6.0 020103   3598  4 02 0102 1301 1501 1601                               4
13A 03   6.0 020103   4021  2 02 0102 0401 1301 1401 1501 1601                     6
14A 03   6.0 030103    262  4 02 0104 0203 0401 1712                               4
14A 03   6.0 030103    262  5 02 0102 0203 0301 0401 0501 1706                     6
14A 03   6.0 030103    450  1 02 0104 0203 0401 1702                               4
14A 03   6.0 030103   1113  2 02 0104 1301                                         2
14A 03   6.0 030103   1618  3 02 0102 1301                                         2
14A 03   6.0 030103   2086  7 02 0103 1301                                         2
14B 03   4.0 030103   7564  3 02 0101 0402 0501 0603 1407 1602                     6
14B 03   4.0 030103   8474  1 02 0102 0403 0603 1407 1501 1602                     6
14B 03   4.0 030103   8474  5 02 0102 0403 1407 1501 1602                          5
14D 04   5.0 020103   1136  1 02 0104 1403                                         2
14D 04   5.0 020103   1179  4 02 0103                                              1
14D 04   5.0 020103   1179  5 02 0104 0802 1401 1502                               4
15A 01   3.0 020103   8065  7 01 0102 1401 1501 1601                               4
15A 01   3.0 020103   8254  8 01 0102 1401 1501 1601                               4
15A 01   3.0 020103   8714  5 01 0103 0301 1401 1501 1601                          5
15A 01   3.0 020103  10123 10 01 0103 1403 1501 1601                               4
15A 01   3.0 020103  10382  4 01 0102 1403 1501 1601                               4
15A 01   3.0 020103  10382  9 01 0102 1403 1501 1601                               4
16A 01   3.0 030103   3985  7 01 0103 1103                                         2
16A 01   3.0 030103   4473  6 01 0103 1402                                         2
16A 01   3.0 030103   4741  1 01 0103 1402                                         2
16A 01   3.0 030103   4917  5 01 0102 1402                                         2
16A 01   3.0 030103   4917 10 01 0102 1402                                         2
16A 01   3.0 030103   5013  4 01 0102 1403                                         2
17A 03   6.0 020203   1698 10 02 0102 1301 1401 1501                               4
17A 03   6.0 020203    721  3 02 0104 0401 1301 1602                               4
17A 03   6.0 020203    721  5 02 0104 1301                                         2
17A 03   6.0 020203   2375  1 02 0102 1301                                         2
17A 03   6.0 020203   2449  2 02 0102 1301 1402 1501                               4
17A 03   6.0 020203   2885  9 02 0102 0401 1301 1501                               4
18A 03   6.0 030203    365  6 02 0103 0202 0501 1301 1703                          5
18A 03   6.0 030203    608  3 02 0103 0203 0301 0401 1705                          5
18A 03   6.0 030203    643  7 02 0104 0401 1301                                    3
18A 03   6.0 030203    643  9 02 0104 1301                                         2
18A 03   6.0 030203   1145  5 02 0102 1301                                         2
18A 03   6.0 030203   1550  1 02 0102 1301 1501                                    3
18B 03   6.0 030103   5364  2 02 0102 1302 1402 1501 1601                          5
18B 03   6.0 030103   7577  3 02 0103 1401 1501 1601                               4
18B 03   6.0 030103   7577  4 02 0103 1401 1501 1601                               4
19A 01   3.0 020203   8572  1 01 0103 0301 1103 1411 1601                          5
20A 01   3.0 030203   3704  5 01 0102 1401 1501 1601                               4
20A 01   3.0 030203   4485  2 01 0102 1101 1403 1501 1601                          5
20A 01   3.0 030203   4485  6 01 0102 0301 1403 1501 1601                          5
20A 01   3.0 030203   4889  3 01 0101 0301 1403 1501 1601                          5
20A 01   3.0 030203   5410  4 01 0103 0301 1401 1501 1602                          5
20A 01   3.0 030203   5410  9 01 0102 1401 1501 1602                               4
23A 03   6.0 020103  10338  5 02 0101 0301 1407 1502 1602                          5
23A 03   6.0 020103  15711  1 02 0103 0301 1401 1501 1602                          5
23A 03   6.0 020103  15711  4 02 0103 0201 0301 1407 1502 1602 1703                7
25A 04   5.0 010104   6348  5 01 0104 1002 1402 1604                               4
25A 04   5.0 010104   7052  4 01 0103 0301 0401 1002 1401 1602                     6
25A 04   5.0 010104   7758  1 01 0102 0301 1001 1401 1602                          5
25A 04   5.0 010104   9070  3 01 0103 0301 0901 1602                               4
25A 04   5.0 010104   9220  6 01 0103 0301 0802                                    3
25A 04   5.0 010104   9328  2 01 0102 0301 0601 1401 1601                          5
26A 04   5.0 020104   2487  1 01 0101 0901 1601                                    3
26A 04   5.0 020104   2902  9 01 0101 0402 0601 1405 1601                          5
26A 04   5.0 020104   2993  6 01 0103 0301 0401 0601 1401 1601                     6
26A 04   5.0 020104   2993  7 01 0103 0301 0401 0601 1001 1601                     6
26A 04   5.0 020104   3344  3 01 0101 1002                                         2
26A 04   5.0 020104   3625  4 01 0102 0401 1402 1601                               4
26B 04   3.0 010104   5959  3 01 0103 0605 1001 1407 1602                          5
26B 04   3.0 010104   6289  1 01 0102 0302 0605 1001 1407 1602                     6
26B 04   3.0 010104   6289  5 01 0103 0701 1001 1407 1602                          5
27A 02   3.5 010104   2901  3 01 0102 0201 0301 0701 1601 1702                     6
27A 02   3.5 010104   2901  8 01 0103 0203 0301 0701 1604 1704                     6
27A 02   3.5 010104   2908  7 01 0103 0401 0802                                    3
27A 02   3.5 010104   3270 10 01 0103 0202 0301 0602 1403 1603 1702                7
27A 02   3.5 010104   4102  9 01 0104 0201 0301 1405 1601 1701                     6
27A 02   3.5 010104   4485  2 01 0103 0301 1401 1601                               4
27B 03  12.0 020103  10592  3 02 0104 0401 1401 1501 1602                          5
27B 03  12.0 020103  14250  2 02 0103 1401 1602                                    3
27B 03  12.0 020103  14250  5 02 0103 0402 1401 1602                               4
28A 02   3.5 020104    484  7 01 0103 0202 0301 0401 1702                          5
28A 02   3.5 020104    484  8 01 0103 0202 0301 0401 1702                          5
28A 02   3.5 020104    860  5 01 0104 0203 0301 1704                               4
28A 02   3.5 020104   1293 10 01 0104 0602                                         2
28A 02   3.5 020104   1811  1 01 0102 0901                                         2
28A 02   3.5 020104   1811  3 01 0104 0602                                         2
28A 02   3.5 020104   1811  4 01 0102 1405 1501                                    3
```

```
28A 02  3.5 020104  1811  6 01 0102 0602 1403                               3
28A 02  3.5 020104  1811  9 01 0102 0301 0602 1403                          4
28A 02  3.5 020104   408  2 01 0103 0202 0301 0602 1702                     5
28B 03  4.0 010104 17021  1 02 0103 0401 0603 1401 1602                     5
28B 03  4.0 010104 20227  3 02 0102 0403 0603 1401 1602                     5
28B 03  4.0 010104 20227  4 02 0101 0403 1401 1602                          4
29A 04  5.0 010204  1418  1 01 0101 0601 1406                               3
29A 04  5.0 010204  4340  8 01 0103 0301 1002 1602                          4
29A 04  5.0 010204  4835  7 01 0102 0301 0601 0901                          4
29A 04  5.0 010204  4964  9 01 0103 0402 0601 1001 1401 1602                6
29A 04  5.0 010204  5581  5 01 0103 0301 0601 1001 1401 1602                6
29A 04  5.0 010204  5975  6 01 0103 0201 0301 0601 1001 1401 1604 1703      8
30A 04  5.0 020204   855  7 01 0101 0601 1602                               3
30A 04  5.0 020204  3068  4 01 0102 0601 1002 1405 1602                     5
30A 04  5.0 020204  3068  9 01 0102 0301 0901 1002 1405 1601                6
30A 04  5.0 020204  3684  8 01 0102 0201 0301 1002 1401 1602 1701           7
30A 04  5.0 020204  4141  1 01 0101 0301 0902 1602                          4
30A 04  5.0 020204  4141 10 01 0102 0301 1401 1602                          4
30B 03  5.6 020104  1195  5 01 0102 0201 0302 0603 1401 1601 1702           7
30B 03  5.6 020104  1196  3 01 0104 0201 0402 1102 1601 1702                6
30B 03  5.6 020104  1275  1 01 0104 0201 0402 1103 1401 1601 1701           7
31A 02  3.5 010204  1500  9 01 0102 0203 0301 1601 1707                     5
31A 02  3.5 010204  1500 10 01 0102 0201 0301 0601 1403 1601 1702           7
31A 02  3.5 010204  1696  2 01 0104 0802 1601                               3
31A 02  3.5 010204  2411  3 01 0102 0202 0301 0601 0802 1401 1601 1702      8
31A 02  3.5 010204  2477  8 01 0104 0202 0301 0602 1402 1601 1702           7
31A 02  3.5 010204  2517  1 01 0102 0202 0301 0601 0802 1601 1702           7
31A 02  3.5 010204  2517  6 01 0102 0402 0605 0802 1401 1601                6
31B 04  3.0 020102  7636  5 01 0102 0301 0601 1002 1403                     5
32A 02  3.5 020204   800  1 01 0102 0203 0301 1403 1604 1703                6
32A 02  3.5 020204   875  4 01 0102 0202 0301 0602 1405 1702                6
32A 02  3.5 020204   875  7 01 0101 0203 0301 0401 1704                     5
32A 02  3.5 020204   974  9 01 0104 0201 0301 0604 0802 1701                6
32A 02  3.5 020204   138  6 01 0103 0602                                    2
32A 02  3.5 020204   495  3 01 0103 0201 0301 1702                          4
32B 03  5.6 020101 13846  2 01 0104 0303 0603 1101 1407 1602                6
34B 04 20.0 030103   512  8 02 0101 0403 0601                               3
34B 04 20.0 030103   877  2 02 0101 0302 0403                               3
34B 04 20.0 030103   877  3 02 0101 0302 0403                               3
35A 03  6.0 010104 11471  4 02 0103 0301 0403 1401 1501 1601                6
35A 03  6.0 010104 12224  5 02 0103 0402 1401 1602                          4
35A 03  6.0 010104 12511  2 02 0103 0301 0403 1401 1501 1601                6
37A 03  6.0 010104  1566  8 02 0102 0203 1301 1710                          4
37A 03  6.0 010104  2819  4 02 0102 1301 1501                               3
37A 03  6.0 010104  2991 10 02 0103 1301 1501                               3
37A 03  6.0 010104  4897  7 02 0103 0201 1301 1501 1601 1701                6
37A 03  6.0 010104  6064  6 02 0104 0301 1301 1401 1501 1601                6
37A 03  6.0 010104   238  3 02 0102 0202 1301 1704                          4
37B 04  3.0 020104  4903  5 01 0104 0605 1001 1401 1601                     5
37B 04  3.0 020104  5510  2 01 0103 1001 1407 1602                          4
37B 04  3.0 020104  5625  4 01 0103 0605 1001 1407 1602                     5
38A 03  6.0 020104   187  9 02 0103 0202 0301 1301 1704                     5
38A 03  6.0 020104   225  3 02 0104 0202 1704                               3
38A 03  6.0 020104  1333  5 02 0103 0502                                    2
38A 03  6.0 020104  1377  2 02 0102 0401 1301                               3
38A 03  6.0 020104    37  8 02 0101 1301                                    2
38A 03  6.0 020104   114  6 02 0102 0202 1301 1704                          4
38B 03  6.0 020104  5184  2 02 0102 0301 1101 1302 1401 1501 1601           7
38B 03  6.0 020104  4350  5 02 0102 0402 1101 1401 1502 1602                6
38B 03  6.0 020104  5766  4 02 0103 1101 1301 1401 1501 1601                6
39A 01  3.0 010104  2083  6 01 0104 0301 1101 1202                          4
39A 01  3.0 010104  2532  7 01 0104 1101                                    2
39A 01  3.0 010104  7213  1 01 0103 0301 1101 1401 1601                     5
39A 01  3.0 010104  8109  5 01 0103 0203 1101 1401 1601 1704                6
39A 01  3.0 010104  8109  8 01 0103 1402 1601                               3
39A 01  3.0 010104   779  2 01 0104 0301 1101 1202                          4
40A 01  3.0 020104  2073  3 01 0104 1101 1202                               3
40A 01  3.0 020104  2182  7 01 0104 1102 1202                               3
40A 01  3.0 020104  2182  8 01 0103 0301 0701                               3
40A 01  3.0 020104  2446  5 01 0104 0801 1101                               3
40A 01  3.0 020104  2461 10 01 0104 0801                                    2
40A 01  3.0 020104  2509  2 01 0104 0301 1101                               3
40A 01  3.0 020104  2509  6 01 0102 1101 1202                               3
40B 03  4.0 020104  7900  4 02 0101 0402 0603 1401 1602                     5
40B 03  4.0 020104 10360  2 02 0103 0603 1401 1602                          4
40B 03  4.0 020104 10360  3 02 0103 0603 1401 1602                          4
40B 03  4.0 020104 10360  5 02 0103 1401 1602                               3
41A 03  6.0 010204   649  9 02 0104 1301                                    2
41A 03  6.0 010204  1062  6 02 0103 1301                                    2
41A 03  6.0 010204  1132  2 02 0103 1301                                    2
41A 03  6.0 010204  1157  7 02 0103 1301                                    2
41A 03  6.0 010204  1157  8 02 0103 1301                                    2
41A 03  6.0 010204  1689  3 02 0103 1301                                    2
42A 03  6.0 020204    96  8 02 0103 1301                                    2
```

```
42A 03  6.0 020204   342  7 02 0102 0302                                             2
42A 03  6.0 020204   416  9 02 0104 1301                                             2
42A 03  6.0 020204   484  1 02 0102 0202 0302 0401 1301 1703                         6
42A 03  6.0 020204  3619  6 02 0103 0203 0303 1402 1601 1708                         6
42A 03  6.0 020204  4133  4 02 0102 0203 0301 1301 1401 1501 1602 1709               8
42B 03  5.6 020104  3625  3 01 0103 0201 0303 0602 1401 1602 1702                    7
42B 03  5.6 020104  3795  5 01 0103 0202 0303 0602 1102 1401 1602 1705               8
42B 03  5.6 020104  3798  2 01 0102 0303 1101 1401 1602                              5
43A 01  3.0 010204  1182  4 01 0102 1101 1202                                        3
43A 01  3.0 010204  1515  3 01 0104 1102 1202                                        3
43A 01  3.0 010204  1911  6 01 0105 1102                                             2
43A 01  3.0 010204  2298  9 01 0105 1102 1201 1402 1601                              5
43A 01  3.0 010204  2515  7 01 0105 1102 1601                                        3
43A 01  3.0 010204  2656 10 01 0105 1102 1402 1601                                   4
44A 01  3.0 020204  1672  6 01 0105 1101                                             2
44A 01  3.0 020204  3848  8 01 0104 1402 1501 1601                                   4
44A 01  3.0 020204  3854  1 01 0101 0301 1402 1601                                   4
44A 01  3.0 020204  3854  3 01 0103 1401 1601                                        3
44A 01  3.0 020204  4487  2 01 0104 0301 0701 1402 1501 1601                         6
44A 01  3.0 020204  4487 10 01 0102 0301 0701 1403 1601                              5
47A 03  6.0 020104  6200  5 02 0101 0301 0402 1401 1501 1602                         6
47A 03  6.0 020104  5223  2 02 0101 0301 0601 1401 1501 1602                         6
47A 03  6.0 020104  5502  1 02 0101 0601 1401 1501 1602                              5
47B 03 12.0 020104  5463  2 02 0101 0402 1401 1602                                   4
47B 03 12.0 020104  5801  3 02 0103 0402 1401 1602                                   4
47B 03 12.0 020104  6537  1 02 0103 0301 0401 1401 1602                              5
48B 03  6.0 030106  3669  1 02 0103 1401 1501 1602                                   4
48B 03  6.0 030106  6139  4 02 0103 0302 0401 0602 0802 1407 1501 1602               8
48B 03  6.0 030106  6156  2 02 0103 0301 0401 1401 1501 1602                         6
48B 03  6.0 030106  6156  3 02 0103 0301 0401 0602 1401 1501 1602                    7
48B 03  6.0 030106  6156  5 02 0103 0401 1407 1501 1602                              5
49A 04  5.0 010102  2010  9 01 0102 0401 0601 1405                                   4
49A 04  5.0 010102 10073  3 01 0101 0801 1002 1401                                   4
50A 04  5.0 020102 12069  5 01 0102 0901 1001 1401                                   4
50A 04  5.0 020102 13500  3 01 0102 0201 0301 1001 1408 1701                         6
50A 04  5.0 020102 15294  4 01 0102 0601 1001 1401 1602                              5
51A 02  3.5 010102 17373  4    0102 0301 1401 1601                                   4
51A 02  3.5 010102 14738 10 01 0102 0201 0301 1408 1604 1701                         6
52A 02  3.5 020102  7858  8 01 0102 0402 1401 1601                                   4
52A 02  3.5 020102  8367 10 01 0103 0402 1407                                        3
52A 02  3.5 020102  9724  7 01 0104 0701 1401 1601                                   4
52A 02  3.5 020102  9724  9 01 0102 0701 1401 1601                                   4
52A 02  3.5 020102 10994  3 01 0101 0301 0701 0802 1401 1601                         6
52A 02  3.5 020102 13730  2 01 0102 0301 0601 1408 1601                              5
54A 04  5.0 020202 11331  3    0102 0301 0601 1401 1602                              5
59A 03  6.0 020102  3202  3 02 0103 0201 0403 1401 1701                              5
59A 03  6.0 020102 14863  2 02 0102 0202 0301 1401 1501 1601 1703                    7
59A 03  6.0 020102 14863  5 02 0103 0201 0301 1401 1501 1601 1702                    7
61A 03  6.0 010102  2762  5 02 0102 1301                                             2
61A 03  6.0 010102  4094  4 02 0102 0401 1301 1401 1501                              5
61A 03  6.0 010102  4285 10 02 0102 0401 1301 1401 1601                              5
61A 03  6.0 010102  4413  6 02 0102 0401 1301 1501                                   4
61A 03  6.0 010102  9760  3 02 0102 0202 0401 0501 1301 1401 1501 1601 1703          9
61A 03  6.0 010102 10146  1 02 0104 0203 0301 0502 1401 1601 1706                    7
62A 03  6.0 020102  2995 10 02 0104 0203 0301 0401 1501 1707                         6
62A 03  6.0 020102  4066  4  2 0102 0902 1501 1601                                   4
62A 03  6.0 020102  4441  5 02 0102 0401 1301 1501                                   4
62A 03  6.0 020102  8590  7 02 0102 0401 1301 1401 1501                              5
63A 01  3.0 010102 14917  6 01 0103 0701 1408 1501 1601                              5
63A 01  3.0 010102 20126  4 01 0104 0201 0301 1103 1401 1601 1701                    7
65A 03  6.0 010202  5012  4 02 0102 0301 0402 0501 0902 1401 1501                    7
65A 03  6.0 010202  5706  6 02 0102 0502 1402 1501 1601                              5
65A 03  6.0 010202  6186  8 02 0102 0502 1402 1501 1602                              5
65A 03  6.0 010202  9431  5    0102 0502 1402 1501 1602                              5
66A 03  6.0 020202  1045  6 02 0104 0203 0401 0502 1705                              5
66A 03  6.0 020202  1173  8 02 0102 0501 1301                                        3
66A 03  6.0 020202  1237  5 02 0104 0301 0401 1502                                   4
66A 03  6.0 020202  1417  3 02 0103 0201 0401 0501 1301 1501 1702                    7
66A 03  6.0 020202  2122  7 02 0102 0203 0301 0401 0501 1401 1501 1708               8
66A 03  6.0 020202  4414  4 02 0103 0301 0401 0502 1301 1402                         6
67A 01  3.0 010202  9980  3 01 0102 0301 1103 1401 1601                              5
68A 01  3.0 020202  7054  9 01 0102 1401 1601                                        3
71A 03  6.0 030102  2993  5 02 0104 0202 0301 0401 0602 1403 1501 1709               8
71A 03  6.0 030102  5070  4 02 0104 0202 1401 1501 1601 1706                         6
71A 03  6.0 030102  5753  1 02 0103 0202 0301 0402 1401 1501 1601 1704               8
71A 03  6.0 030102  5753  3 02 0103 1401 1501 1601                                   4
71B 03 12.0 030102  9991  2 02 0104 0401 1401 1602                                   4
73A 03 20.0 020103  1776  3 02 0103 0203 0501 1724                                   4
73A 03 20.0 020103  6120  1 02 0102 0202 0401 1401 1501 1602 1713                    7
73A 03 20.0 020103  7763  4 02 0102 0301 0501 1301 1401 1501 1602                    7
73B 04  5.0 020103  2342  2 01 0103 0603 1001 1401 1601                              5
73B 04  5.0 020103  2773  1 01 0104 0301 0603 1001 1301 1408                         6
73B 04  5.0 020103  3742  5 01 0103 0301 0401 0603 1002 1401 1601                    7
73C 03  3.5 030103  8940  3 01 0102 0301 1401 1602                                   4
```

```
73C 03  3.5 030103  9406  2 01 0103 0402 1401 1602                              4
73C 03  3.5 030103  9978  1 01 0103 0301 0402 1401 1602                         5
74A 03 20.0 020203  1184  4 02 0102 0202 0301 1501 1714                         5
74A 03 20.0 020203  1302  3 02 0103 0203 0301 1722                              4
74A 03 20.0 020203  1754  2 02 0103 0203 0301 0502 1401 1718                    6
75C 04  5.0 020101   353  1 01 0104 0203 0301 0401 0601 1001 1401 1705          8
75C 04  5.0 020101  1448  3 01 0102 0203 0301 0401 0601 1002 1401 1704          8
75C 04  5.0 020101  1601  4 01 0102 0203 0301 0401 0601 1002 1401 1706          8
75D 03  3.5 030101  3625  2 01 0102 0401 1401 1601                              4
76A 03 20.0 010104  7697  2 02 0101 0301 0802 1602                              4
76A 03 20.0 010104  7698  4 02 0101 0403 1403 1602                              4
76A 03 20.0 010104  9348  3 02 0101 0403 1403 1501 1602                         5
76B 03  5.6 020103  2025  2 01 0104 0302 1103 1601                              4
76B 03  5.6 020103  6637  5 01 0103 0202 0303 1602 1703                         5
76B 03  5.6 020103 11158  4 01 0103                                             1
77A 03 20.0 010204  5510  2 02 0101 0301 0501 1401 1602                         5
77A 03 20.0 010204  5684  1 02 0101 0403 1401 1602                              4
77A 03 20.0 010204  6012  4 02 0101 0301 0401 1401 1602                         5
78A 03 12.0 010104  1307  4 02 0104                                             1
78A 03 12.0 010104 10426  3 02 0103 0401 1401 1602                              4
78A 03 12.0 010104 11081  2 02 0103 0402 1401 1502 1602                         5
79A 03  6.0 040403   149  1 02 0103 0301 0402 1302 1401 1601                    6
79A 03  6.0 040403   164  3 02 0102 0402 1302 1402 1501 1601                    6
79A 03  6.0 040403   545  2 02 0103 1403 1501 1601                              4
79A 03  6.0 040403   545  4 02 0103 1403 1501 1601                              4
82A 01 12.0 020103  7527  2 02 0102 0902 1401 1601                              4
82A 01 12.0 020103 10624  5 02 0103 0203 1403 1602 1708                         5
82A 01 12.0 020103 10878  1 02 0103 0301 1403 1602                              1
83A 01 12.  020203 12822  4 02 0102 0402 1401 1602                              4
83A 01 12.  020203 12316  3 02 0102 0403 1401 1602                              4
84A 02 20.0 010102 17040  5 02 0102 0402 0901 1401 1602                         5
85A 01 12.0 010104  8888  4 02 0102 0401 1401 1601                              4
85A 01 12.0 010104  8947  3 02 0102 0401 1401 1601                              4
85A 01 12.0 010104  9710  2 02 0103 0402 1401 1601                              4
86A 01 12.0 010204 10661  4    0102 0403 1401 1602                              4
86A 01 12.0 010204  8998  3 02 0103 0201 0301 0403 1602 1702                    6
86A 01 12.0 010204 10575  5 02 0103 0403 1401 1602                              4
87A 03 20.0 030103   164  1 02 0104 0202 0401 1708                              4
87A 03 20.0 030103   208  2 02 0104 0203 1301 1727                              4
87A 03 20.0 030103   627  3 02 0104 0203 0301 0401 1301 1716                    6
87A 03 20.0 030103   627  4 02 0102 0203 0301 0502 1722                         5
87A 03 20.0 030103   627  5 02 0102 0203 0401 1301 1718                         5
87B 04  5.0 030103   948  2 01 0103 0201 0301 0401 0601 0802 1001 1301 1401 1701 10
87B 04  5.0 030103  1513  3 01 0103 0301 0401 0601 1001 1401 1602               7
87B 04  5.0 030103  2302  1 01 0103 0201 0301 0401 0601 1001 1301 1401          8
87B 04  5.0 030103  2392  4 01 0103 0301 0601 1001 1408                         5
88A 03 20.0 030203   151  1 02 0104 0203 0301 0401 1725                         5
88A 03 20.0 030203   151  2 02 0104 0203 0301 0401 1725                         5
88A 03 20.0 030203   358  3 02 0104 0203 0401 1716                              4
88A 03 20.0 030203   358  5 02 0102 1301                                        2
88D 03  1.25020101  1897  5 02 0104 0203 0701 1401 1502 1703                    6
89B 04  5.0 030101   111  5 01 0103 0401 0601 1001 1401                         5
89B 04  5.0 030101   495  3 01 0104 0201 0301 0401 0601 1401 1601 1701          8
89B 04  5.0 030101  1530  4 01 0102 0401 0601 1001                              4
90A 03 20.0 020104  2824  4 02 0102 0403 1602                                   3
90A 03 20.0 020104  2824  5 02 0103 0403 1501                                   3
90A 03 20.0 020104  4045  3 02 0101 1301 1601                                   3
90B 03 12.0 020104  3060  4 02 0102 0201 1403 1501 1602 1702                    6
90B 03 12.0 020104  3318  3 02 0101 1403 1501 1602                              4
90B 03 12.0 020104  5124  5 02 0102 1403 1501 1602                              4
90C 03  5.6 020102 16325  5 01 0103 0301 1407 1601                              4
91A 03 20.0 020204  2862  4 02 0101 0201 0301 1301 1401 1602 1707               7
91A 03 20.0 020204  3385  3 02 0101 0401 1401 1602                              4
91A 03 20.0 020204  4480  1 02 0101 0301 0402 0501 1403 1501 1602               7
91A 03 20.0 020204  4480  2 02 0101 0301 0401 0501 1403 1501 1602               7
92A 04  5.0 020102  5788  5 01 0104 0301 0401 0601 1001 1301 1401               7
92A 04  5.0 020102  8774  3 01 0103 0201 0301 0401 0601 1301 1401 1701          8
92A 04  5.0 020102  8774  4 01 0102 0301 0601 1002 1301 1401 1602               7
93A 01 12.0 040104   349  1 02 0103 0301 1403 1601                              4
93A 01 12.0 040104   349  3 02 0103 0301 1401 1601                              4
93A 01 12.0 040104   349  4 02 0103 0301 1402 1601                              4
93A 01 12.0 040104   349  5 02 0103 0301 1401 1601                              4
94A 02 20.0 020202  9110  3 02 0103 0402 0801 1408 1601                         5
96A 01 12.0 030103  4020  4 02 0102 1403                                        2
96A 01 12.0 030103  3822  3 02 0102 1403                                        2
96A 01 12.0 030103  4020  2 02 0102 1403                                        2
96B 03 12.0 030103  8036  4 02 0103 0801 1403 1501 1602                         5
96B 03 12.0 030103  8152  2 02 0101 0201 0401 1501 1602                         5
96B 03 12.0 030103  8152  3 02 0102 0301 0401 1401 1602                         5
96C 03  5.6 020103  2743  1 01 0104 0202 0302 0602 1102 1401 1602 1704          9
96C 03  5.6 020103  5934  2 01 0104 0202 0303 1101 1401 1601 1706               7
96C 03  5.6 020103  9791  3 01 0103 0202 0303 1101 1407 1602 1704               7
97A 01 12.0 030203  3894  2 02 0102 0303 1501 1601                              4
97A 01 12.0 030203  3946  3 02 0103 0403 1401 1501 1601                         5
```

```
 97A 01 12.0 030203  5002 4 02 0103 0401 1401 1601                              4
 98A 02 20.0 020102  3556 5 02 0102 1401 1601                                   1
 98A 02 20.0 020102  8619 1 02 0103 0401 0801 1403 1601                         5
 98A 02 20.0 020102 10641 4 02 0103 0401 1401 1602                              4
 98B 03  1.25050102  5033 5 02 0104 0401 1401 1501                              4
 98B 03  1.25050102  5513 4 02 0103 0401 1401 1501                              4
 98B 03  1.25050102 12247 2 02 1003                                             1
 99A 01 12.0 020104  3841 2 02 0102 1401 1601                                   3
 99A 01 12.0 020104  3841 3 02 0102 0301 1402                                   3
 99A 01 12.0 020104  4835 1 02 0102 1401 1601                                   3
 99B 04  5.0 020104  3216 4 01 0103 0301 0401 0603 1401 1501 1602               7
 99B 04  5.0 020104  4388 3 01 0101 0301 0601 1001 1101 1401 1601               7
 99B 04  5.0 020104  4388 5 01 0102 0301 1001 1101 1401                         5
100A 01 12.0 020204  4170 3 02 0101 0403 1501 1602                              4
100A 01 12.0 020204  4358 2 02 0101 0403 1401 1601                              4
100A 01 12.0 020204  4424 1 02 0101 1401 1601                                   3
101B 03 12.0 020102  5586 4 02 0104 0203 0401 1401 1501 1601                    6
101A 03 20.0 010102  3111 2 02 0104 0203 0301 0401 1725                         5
101A 03 20.0 010102  3111 5 02 0104 0203 0301 1720                              4
101A 03 20.0 010102  3629 4 02 0104 0202 0301 0401 0501 1501 1713               7
102A 03 20.0 010202   135 2 02 0101 0401 0502                                   3
104A 02 20.0 020103  2672 1 02 0102 0402 0901                                   3
104A 02 20.0 020103  2826 5 02 0102 0402 0801 0901                              4
104A 02 20.0 020103  2980 3 02 0102 0402 1602                                   3
104B 01  5.0 020103  5164 4 03 0101 0201 1407 1602 1702                         5
104B 01  5.0 020103 10463 3 03 0103 0301 0402 1407 1602                         5
104B 01  5.0 020103 13149 1 03 0101 0301 0402 0902 1401 1602                    6
105A 02 20.0 020203  4306 1 02 0102 0402 1403 1501 1601                         5
105A 02 20.0 020203  5580 3 02 0102 0301 0402 1401 1602                         5
105A 02 20.0 020203  5690 4 02 0102 0402 0603 1401 1601                         5
108A 02 20.0 010204  4273 3 01 0101 0402 0701 0902 1401 1501 1601               7
108A 02 20.0 010204  3796 4 02 0102 1403 1601                                   3
108A 02 20.0 010204  4003 2 01 0101 0402 1501 1601                              4
112A 02 20.0 010104  5005 1 02 0102 0402 1602                                   3
112A 02 20.0 010104  5005 2 02 0102 0402 1602                                   3
112A 02 20.0 010104  5213 5 02 0102 0902 1501 1602                              4
113A 01  5.0 010104  4998 1 02 0101 0402 1101 1602                              4
113A 01  5.0 010104  4998 2 02 0101 0402 1101 1602                              4
113A 01  5.0 010104  4998 3 02 0101 0402 1101 1602                              4
113A 01  5.0 010104  4998 4 02 0101 0402 1602                                   3
113A 01  5.0 010104  4998 5 02 0101 0402 1602                                   3
114A 01  5.0 020104  6059 3 02 0101 0402 1401 1602                              4
114A 01  5.0 020104  6059 5 02 0101 0402 1401 1602                              4
114A 01  5.0 020104  8273 2 02 0101 0402 1407 1502 1602                         5
115A 03 20.0 020102  2107 3 02 0103 0203 0502 1727                              4
115A 03 20.0 020102  2203 2 02 0104 0401 0502 1501                              4
115A 03 20.0 020102  2291 4 02 0104 0401 0502 1502                              4
116A 03 20.0 020202  8274 3    0101 0401 1401 1602                              4
118A 02 20.0 030103  1747 2 02 0102 0402 0901                                   3
118A 02 20.0 030103  1963 4 02 0102 0402 0901                                   3
118A 02 20.0 030103  2937 5 02 0102 0402 0802                                   3
118B 03  5.0 020103  4863 2 02 0101 0201 0602 1103 1401 1601 1702               7
118B 03  5.0 020103  7755 4 02 0104 0603 1102 1401 1601                         5
118B 03  5.0 020103  8108 5 02 0104 0301 0603 1102 1401 1601                    6
119A 02 20.0 030203   222 5 02 0102                                             1
119A 02 20.0 030203  1793 2 02 0103 0402 1401 1501                              4
119A 02 20.0 030203  1793 3 02 0103 0402 1401 1501                              4
120A 03  5.0 010103  9310 2 02 0104 1401 1602                                   3
121A 03  5.0 020102  6694 1 02 0102 1401 1601                                   3
121A 03  5.0 020102 10603 4 02 0101 0301 0801 1201                              4
122A 02 20.0 020204   801 2 02 0102 0402 1401 1501 1601                         5
122A 02 20.0 020204   801 3 02 0102 0402 1401 1501 1601                         5
122A 02 20.0 020204   983 5 02 0102 0402 1401 1501                              4
124A 01 12.0 020102 25786 5    0104 0403 1401 1602                              3
124A 01 12.0 020102 13218 3 02 0103 0203 0301 0401 1403 1501 1601 1708          8
126A 02 20.0 020104  1509 4 02 0102 0402 0901 1501 1601                         5
126A 02 20.0 020104  1569 5 02 0102 0402 0901                                   3
126A 02 20.0 020104  1273 3 02 0102 0402 0901                                   3
127A 03  5.0 010104  7218 2 02 0104 0902 1401 1602                              4
127A 03  5.0 010104  7649 1 02 0101 0603 1301 1602                              4
127A 03  5.0 010104 10638 4 02 0103 0301 0402 1301 1401 1602                    6
128A 03  5.0 020104  2422 3 02 0101 0602 1301 1401 1602                         5
128A 03  5.0 020104  5888 2 02 0101 0301 1301 1602                              4
9999       .

***END OF FILE ON UNIT 0002
```