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Acceptance Tests and Manufacturer Relationships for 20 Ampere-Hour Sealed Nickel-Cadmium Cells Using Discharge Parameters

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ACCEPTANCE TESTS AND MANUFACTURER RELATIONSHIPS FOR 20 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS USING DISCHARGE PARAMETERS

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SUMMARY

The results of eight acceptance tests were evaluated for their ability to discriminate between manufacturers of nickel-cadmium cells. The results of these acceptance tests were also used to compare cells from each manufacturer for reproducibility of the manufacturing process. The eight acceptance tests used were the amphere-hour capacities from three capacity tests; a charge retention test; a charge efficiency test; two overcharge tests and the voltage from an internal short test.

The data base consisted of 146 twenty amphere-hour cells from five manufacturers. The five manufacturers were: Eagle-Picher (26 cells); General Electric (30 cells); Saft America (50 cells); Yardney Electric (28 cells); and Energy Research Corp. (12 cells). The Saft American cells consisted of two lots, one of 30 cells from a standard cell test and the other 20 cells from a lot supplied to the Lewis Research Center.

Five nonparametric procedures were used to evaluate the eight acceptance tests for differences between manufacturers and reproducibility of each manufacturer. The five procedures are:

1. Mann-Whitney test of equal medians
2. Variance ratio weighting
3. Karhunen-Loeve transformation
4. Nearest Neighbor selection
5. Clustering analysis.

Mann-Whitney Test

Using this procedure each acceptance test's median value for each manufacturer was compared to the median values of every other manufacturer. Although significant differences were found between the median values of some of the acceptance tests and manufacturers, there was no apparent relationship that could be used to separate the cells by manufacturer.

Variance Ratio Weighting

This procedure evaluates the individual importance of each acceptance test for separation of cells by manufacturers. This is done by obtaining the ratio of the variation between manufacturers to the variation of the manufacturer for all manufacturers and acceptance tests.

It was found that sufficient variation between manufacturers existed for five of the acceptance tests. The five tests are:

1. Capacity Test #2
2. Capacity Test #3
3. Charge Efficiency Test
4. Overcharge Test at 0° C
5. Internal Short Test

The remaining three tests were found to be of minor value for separation by manufacturer.

Karhunen-Loeve Transformation

This procedure creates new variables (acceptance tests) that are linear combinations of the original variables in such a way as to maintain the maximum information in the first new variable and decreasing amounts in the remaining new variables. The new variables are linearly independent and are ordered according to decreasing importance.

The results of this procedure on the variance ratio weighted data showed that 93 percent of the difference between manufacturers can be obtained from three new variables. The acceptance tests with the largest impact on separation were:

1. Overcharge Test at 0° C.
2. Charge Efficiency Test
3. Internal Short Test

Nearest Neighbor Selection

This procedure selects the ten nearest neighbors of each data point which is a composite of all the acceptance tests. The manufacturer to which that data point belongs is calculated using a weighting factor in which the nearest neighbor has the largest weight.

It was found that all but two of the cells had as their closest neighbors, cells from the same manufacturer. The two cells were one from Eagle-Picher and one from Saft America, from the standard cell test lot. The one Eagle-Picher cell was classified as belonging to the Yardney group and the one Saft America cell was classified as belonging to the Saft America Lewis Research Center lot.

Clustering Analysis

This procedure compared each cell to each other using a composite of all the acceptance tests. The pair of cells most like each other are then compared to the other pairs. This pair-wise comparison is continued until all the cells are the same. The relative scale used for grouping cells was 1.0 to 0 with 1.0 representing cells that have identical acceptance test results and 0 for cells that are totally different.

It was found that all of the General Electric cells were grouped together at a level of 0.96; all the Eagle-Picher cells (except for the cell not classified correctly by the nearest neighbor procedure) were grouped together at a level of 0.87; Yardney Electric cells formed two groups, at levels of 0.91 and 0.88; Saft American cells formed two groups at levels of 0.92 and 0.86. The 0.92 level group was comprised of eight cells from the standard cell test, the 0.86 level group was comprised of cells from the remaining standard cell lot and the Lewis Research Center lot. This indicates that there is less variation between manufacturing lots than between manufacturing processes.

INTRODUCTION

Batteries constructed by different manufacturers are known to differ, but the quantitative difference between manufacturers is unknown. One of the problems of evaluating different manufacturers is that life cycling data, which is the most prevalent, is available for small samples sizes. Where the number of cells from the same manufacturing lot is large the cells are life cycled using different test conditions. However, it is possible to evaluate acceptance test data which is run using the same test conditions. This type of data is available for different manufacturers and the same manufacturing lot.

This report will examine the acceptance test data of 146 cells from five manufacturers of nickel-cadmium cells. These five manufacturers are known to use different construction techniques. Data for four of the manufacturers (Eagle-Picher Industries, General Electric Company, Saft America Inc., Yardney Electric Division) were obtained from "Initial Evaluation Tests of 20.0 Ampere-hour Sealed Nickel-Cadmium Cells Manufactured for NASA's Standard Cell Program," (ref. 1). Data for the other manufacturer Energy Research Corp. and an additional set of cells from Saft America Inc. were obtained from "Life Cycling of 30 Nickel-Cadmium Cells".*

The data will be evaluated for differences between manufacturers and variations between cells from each manufacturer.

All cells were supplied as nominal 20 ampere-hour sealed nickel-cadmium cells from a single batch. All cells were tested using the same methods by the Naval Weapons Support Center at Crane, Indiana.

ACCEPTANCE TEST PROCEDURE

Eight acceptance tests (ref. 1) are normally used to screen Ni-Cd cells prior to placing them on cycle life testing. These tests are:

I Phenolphthalein Leak Tests:

1. This test is a determination of the condition of the welds and ceramic seals on receipt of the cells and following the last discharge of the cells (Cycle 8).

2. The cells were initially checked with a one-half of one percent phenolphthalein solution applied with a cotton swab and then placed in a vacuum chamber and exposed to a vacuum of 40 microns of mercury or less for 24 hours. Upon removal they were rechecked for leaks and then received a final check following test completion. The requirement is no red or pink discoloration which indicates a leak.

II Capacity Test:

1. The capacity test is a determination of the cells' capacity at the c/2 discharge rate to 0.75 volt per cell, where c is the manufacturer's rated capacity. This type discharge follows all charges of this evaluation test.

*(Unpublished data) Harkness, J. D.: Life Cycling of 30 Nickel-Cadmium Cells. NASA Order C-29233-B. Exhibit B, 1979.

2. The charges for the capacity tests are as follows:

a. c/20, rate 48 hours, room ambient (RA), temp. cycle 0, with a test limit of 1.52 volts or pressure of 100 psia;

b. c/10, 24 hours, RA, temp. cycle 1, with a test limit of 1.52 volts or 100 psia pressure and a requirement of maximum voltage (1.48) or pressure (65 psia);

c. c/10, 24 hours, 20° C, cycle 2, with the same limits and requirements as the charge of cycle 1.

III Internal Resistance:

1. Measurements are taken across the cell terminals 0.5 hour before the end-of-charge (EOC) on cycle 1; and 1 and 2 hours after the start-of-discharge of cycle 2. These measurements were made with a Hewlett-Packard milliohmmeter (Model 4328A).

IV Special Charge Retention Test, 20° C:

1. This test is to establish the capacity retention of each cell following a 7-day open-circuit stand in a charge mode.

2. The cells are charged at c/10 for 24 hours with the same limits and requirements as the charge of cycle 1. They then stand on open-circuit for 7 days, with the requirement that the open-circuit voltage of each cell, following this period, is within ±5 millivolts of the average cell voltage. The cells are then discharged and 80 percent capacity out of that obtained in cycle 3 is required.

V Internal Short Test:

1. This test is a means of detecting slight shorting conditions which may exist because of imperfections in the insulating materials, or damage to element in handling or assembly.

2. Following completion of the charge retention test capacity discharge, the cells are shunted with a 0.5-ohm, 3-watt resistor for 16 hours. At the end of 16 hours the resistors are removed and the cells stand on open-circuit voltage (OCV) for 24 hours. A minimum voltage of 1.15 is required at the end of 24 hours.

VI Charge Efficiency Test, 20° C:

1. This test is a measurement of the cells' charge efficiency when charged at a low current rate.

2. The cells are charged at c/40 for 20 hours with a test limit of 1.52 volts or 100 psia pressure. They are then discharged and the requirement is that the minimum capacity out equals 55 percent of capacity in during the preceding charge.

VII Overcharge Test:

A. Overcharge Test 1, 0° C:

1. The purpose of this test is to determine the degree to which the cells will maintain a balanced voltage, and to determine the cells' capability to be overcharged without overcharging the negative electrode.

2. The cells are charged at c/20 for 60 hours. The test limits are cell voltages of 1.56 or greater for a continuous time period of 2 hours or pressures of 100 psia. The requirement is a voltage of 1.520 or a pressure of 65 psia. The cells are then discharged and 85 percent capacity out of that obtained in cycle 3 is required.

B. Overcharge Test 2, 35° C:

1. This test is a measurement of the cells' capacity at a higher temperature when compared to its capacity at 20° C. This test also determines the cells' capability of reaching a point of pressure equilibrium; oxygen recombination at the negative plate at the same rate it is being generated at the positive plate.

2. The cells are charged at c/10 for 24 hours with a test limit of 1.52 volts or 100 psia pressure and a requirement of 1.45 volts or 65 psia pressure. The cells are then discharged with a requirement that capacity out equals 55 percent capacity out as obtained in cycle 3.

VIII Pressure Versus Capacity Test:

1. The purpose of this test is to determine the capacity to a pressure and the pressure decay during charge and open-circuit stand respectively.

2. Each cell is charged at c/2 to either a pressure of 20 psia or a voltage of 1.550. Recordings are taken on each cell when it reaches 5, 10, 15 and 20 psia pressure. The cells then stand OCV for 1 hour with 30-minute recordings and then are discharged, shorted out and leak tested.

TEST RESULTS SELECTED FOR DATA ANALYSIS

Eight tests were selected as being the most likely to characterize the cells. The acceptance tests chosen were:

1. Capacity Test #1
2. Capacity Test #2
3. Capacity Test #3
4. Special Charge Retention Test
5. Charge Efficiency Test
6. Overcharge Test #1 at 0° C
7. Overcharge Test #2 at 35° C
8. Internal Short Test

The measured quantity of the first seven acceptance tests was the ampere-hour delivered on discharge. For the Internal Short Test the open-circuit-voltage after 24 hours of stand was used.

CELL SELECTION FOR DATA ANALYSIS

Four cells which failed the initial phenolphthalein leak test (acceptance test I) and four cells which had open circuit voltages less than 1.0 volts after 24 hours of open circuit stand (acceptance test V) were excluded from the group submitted by the Energy Research Corp.

Two cells from the group submitted by the Yardney Electric Division were also deleted from data analysis because they also had voltages of less than 1.0 volts after 24 hours of open circuit stand. All other cells under consideration passed all the acceptance tests. Table I lists all the cells and acceptance test results used.

RESULTS AND DISCUSSION

With the number of cells (~30) from each manufacturer it was possible to check the results of each acceptance test for conformity to a normal distribution. It was found that some manufacturers and/or acceptance tests were normal but not all. Since parametric tests require random samples from a normally distributed population or at least from a known distribution non-parametric tests were used to evaluate the data.

Test of Median Values

If manufacturers produced cells that are the same then it would be expected that the acceptance test of those cells from various manufacturers would yield the same results. A non-parametric test was chosen to determine if the median values between manufacturers were the same, at a 95 percent confidence level, for each acceptance test.

The Mann-Whitney Test was selected because the only assumption needed is that the populations sampled are continuous, and in actual practice even the violation of this assumption is not serious (ref. 2). The Mann-Whitney Test was performed on all pair-wise combinations of the manufacturers for all the acceptance tests. It is known that cycle life is a function of depth-of-discharge and where the median capacity of the capacity tests were arranged into a descending order the following order was obtained:

> Eagle Picher, Yardney Electric, General Electric, Saft America (standard cell lot), Saft America (LeRC lot) and Energy Research Corp. If these capacity tests were chosen as a criterion for judging cells, Eagle Picher would be the best; however, life testing of these cells under identical conditions have shown Eagle Picher to have an average (4 cells) cycle life of 4,687 cycles, while General Electric had an average (4 cells) cycle life of 11,897 cycles. Yardney and Saft America (standard cell lot) are still on test and have completed 5,985 and 7,534 cycles, respectively.

Pattern Recognition

No readily discernible relationship exists between manufacturers and/or median values of the acceptance tests. In order to search for a relationship, non-parametric pattern recognition programs were employed.

Variance Weighting

In order to determine which acceptance tests would most effectively differentiate between manufacturers, a variance weighting was used. This weighting uses the ratio of the interclass variance to the interclass variance, i.e., the ratio of the between manufacturer variance to the within manufacturer variance. If the variance between manufacturers is equal to the variance within manufacturer a unity weighting factor is obtained and separation would be unlikely (ref. 3).

Table II lists the geometrical average of the variance ratios for all pair-wise combinations of manufacturers for each acceptance test.

The charge efficiency and Overcharge Test #1 show the largest variance weight between manufacturers; however, there are a number of other acceptance tests that have significant variance weights that cannot be discounted.

Vector Analysis

A Karhunen-Loeve transformation of the variance weighted data creates new variables as orthoginal linear combinations of the variance weighted acceptance test data (ref. 4).

As a result of this transformation the first new variable contains the greatest amount of variance between manufacturers and each successive new variable contains the next greatest amount of the residual variance. Table III shows the result of this transformation. Ninety-three percent of the variance can be accounted for in the first three new variables. The largest eigenvector component of the first new variable (accounting for 69.3 percent of the variance) is associated with the Overcharge Test #1, the next largest new variable (accounting for 15 percent of the residual variance) has its largest eigenvector component associated with the Charge Efficiency Test, and the third largest new variable (accounting for 8.3 percent of the residual variance) has its largest eigenvector component associated with the Internal Short Test.

Figures 1 and 2 are plots of the first three Karhunen-Loeve transformations. Figure 1, a plot of the first two new variables from the Karhunen-Loeve transformation show that three groups can easily be identified:

Group 1	continuing Eagle Picher (EP) and Yardney (YRD) cells
Group 2	containing General Electric (GE) and the two lots of Saft America (SFT1 & SFT2)
Group 3	Energy Research Corp. (ERC)

Figure 2 is a plot of the first and third new variables from the Karhunen-Loeve transformations. This combination shows three groupings.

Group 1	containing only Eagle Picher (EP) cells
Group 2	containing General Electric (GE) the two lots of Saft American (SFT1 & SFT2), and Yardney (YRD) cells.
Group 3	containing only Energy Research Corporation (ERC) cells.

By combining the information in figures 1 and 2, i.e., a three dimensional plot, it is possible to visualize the data as consisting of four (4) groups.

Group 1	containing only Eagle Picher (EP) cells
Group 2	containing General Electric (GE) and both lots of Saft America (SFT1 & SFT2) cells
Group 3	containing only Yardney (YRD)
Group 4	containing only Energy Research Corporation (ERC)

Nearest Neighbor

The nearest neighbor algorithm (refs. 3 and 5) selects the ten nearest neighbors of each data point in n space (n = number of acceptance tests) and calculates the group to which each data point belongs using a weighing factor in which the nearest neighbor has the largest weight and the tenth nearest neighbor the least weight. Table IV is the result of grouping the data using the eight acceptance tests. Group 1 (Eagle Picher cells) and Group 3 (Saft America-standard cell lot) each has one data point incorrectly classified. The one Eagle Picher cell had all ten neighbors in group 4 (Yardney cells) and the one Saft American (standard cell lot) cell had as its eighth nearest neighbors Saft American (LeRC lot) cells.

Clustering Analysis

A hierarchical clustering (sometimes referred to as Q-mode clustering (ref. 6) which produces a dendrogram which connects groups of cells at levels of similarity starting with pairs of cells. The cells are grouped with equal weight regardless of the size of the group from which the cell comes.

The result of this clustering is shown in figure 3. The fine structure from which figure 3 was derived can be seen in figure 4. All of the General Electric cells are grouped together at a level of similarity of 0.96 (where identity is equal to 1.0). All of the Eagle-Picher cells except for cell #85 (which was not classified correctly by the nearest neighbor algorithm) are grouped together at a level of similarity of 0.87. Yardney Electric cells form two groups, one of 8 cells having a similarity of 0.91 and the other 20 cells having a similarity of 0.88. These two Yardney Electric groups are similar at a level of 0.71. Saft America cells form two groups, one of 8 cells, all from the standard cell lot; having a similarity of 0.92 and the other 42 cells having a similarity of 0.86. These two Saft America groups are similar at a level of 0.78. All of the Energy Research cells are grouped together at a similarity of 0.65.

The level of similarity of each manufacturer gives an indication of the data spread of a composite of all eight acceptance tests relative to the other manufacturers. The level of similarity for the five manufacturers of cells investigated are:

1.	General Electric	0.96
2.	Eagle Picher	0.87
3.	Saft American	0.78
4.	Yardney Electric	0.71
5.	Energy Research Corp.	0.65

CONCLUSIONS

The non-normality of acceptance tests results may be a result of the parent population of electrochemical cells not being normal or more likely the distributions observed is the result of culling of cells by the manufacturer.

Median values of the acceptance tests did not have a discernible relationship between manufacturers, but pattern recognition techniques of the eight acceptance tests for the five manufacturers provided a means of separating the cells. The differences are attributed to manufacturer/ construction techniques because the two lots of Saft America cells overlapped and the manufacturers are known to use different construction techniques.

Using the Karhunen-Loeve transformation on the variance ratio weighed data, it was found that 93 percent of the difference between manufacturer could be accounted for by using three new variables which are made up of three linear combinations of the eight acceptance tests. The largest single contributor to each of the three new variables are:

1. Overcharge at 0° C
2. Charge Efficiency
3. Internal Short (24 hr)

These three new variables can separate the cells into four groups which are:

1. Eagle-Picher
2. Yardney Electric
3. Energy Research
4. General Electric and Saft American

This separation shows that the differences between manufacturers is greater than the difference between cells of the manufacturers.

To test the ability of predicting cell construction and/or manufacturer from the acceptance test the Nearest Neighbor algorithm was used. This algorithm measures the distance between cells in n-space and compares it to its neighboring cells. The result of this procedure showed that all but two cells were grouped together. These two exceptions are:

1. One cell from the Eagle-Picher group was located closest to the Yardney group
2. One cell from the Saft American standard cell lot was located closest to the Saft American Lewis Research lot.

To determine the relative variation of the cells in each group a hierarchial clustering was performed using the eight acceptance tests. This algorithm selects cells in a pair-wise procedure that are most similar, based on their n-space distance. This procedure of comparing pairs is continued until at some level all cells are the same.

The manufacturers were found to have different similarities and are:

1.	General Electric	0.97
2.	Eagle-Picher	0.87
3.	Saft American	0.78
4.	Yardney Electric	0.71
5.	Energy Research Corp.	0.65

This algorithm can also depict abnormal cells in that their similarity will be much less than the others of the group. Such a cell was found in the Eagle Picher group. Cell number 85 had a similarity value of less than 0.5. This algorithm could be used in selecting cells to build a balanced battery with a known level of similarity.

It was shown by use of pattern recognition techniques that:

1. Manufacturers and/or cell construction can be detected from acceptance tests.
2. Differences between individual cells from the same manufacturers or between manufacturers can be detected from acceptance tests.

These comparisons were made using the capacities delivered as the characterization parameter. It would be interesting to include values for charging characteristics to see if they also can be used to characterize manufacturer and/or construction differences. This would allow a characterization and detection of abnormal cell behavior based on the charge regime.

REFERENCES

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TABLE 1
ACCEPTANCE TESTS

----MANUFACTURER---- NAME	SERIAL NO.	CAPACITY TEST #1	#2	#3	CHARGE RETENTION AMP.-HR.	CHARGE EFFICIENCY AMP.-HR.	OVER CHARGE 0 C AMP.-HR.	35 C	INTERNAL SHORT VOLTS
EAGLE-PICHER	75	25.8	25.2	24.7	22.7	5.8	23.8	19.5	1.247
EAGLE-PICHER	76	26.0	24.8	24.7	22.3	5.8	24.2	21.6	1.246
EAGLE-PICHER	78	26.0	25.2	24.7	23.1	6.1	21.7	22.8	1.248
EAGLE-PICHER	79	26.0	25.6	25.1	23.1	6.1	24.2	23.6	1.248
EAGLE-PICHER	80	26.1	25.3	24.2	22.5	6.4	23.2	20.9	1.249
EAGLE-PICHER	81	26.5	25.9	25.0	22.9	6.4	23.6	20.5	1.250
EAGLE-PICHER	82	26.5	25.9	25.4	23.3	6.4	23.2	22.1	1.247
EAGLE-PICHER	83	26.1	25.3	25.0	22.9	6.4	23.6	21.7	1.246
EAGLE-PICHER	84	25.7	24.9	25.2	22.5	6.4	22.4	20.9	1.251
EAGLE-PICHER	85	25.3	24.4	23.5	22.7	6.1	22.6	23.2	1.247
EAGLE-PICHER	87	25.3	24.8	23.9	22.7	5.8	23.4	23.2	1.247
EAGLE-PICHER	88	25.3	24.8	23.9	22.7	6.1	22.6	23.2	1.250
EAGLE-PICHER	89	26.0	25.2	24.7	23.1	6.1	23.4	22.4	1.245
EAGLE-PICHER	90	25.3	24.4	23.9	22.7	6.1	22.6	22.8	1.246
EAGLE-PICHER	91	25.6	24.8	24.3	22.7	6.1	23.4	22.8	1.246
EAGLE-PICHER	92	26.5	25.7	25.0	22.9	6.4	23.2	21.7	1.244
EAGLE-PICHER	93	26.1	24.9	23.8	22.5	6.4	22.8	20.9	1.250
EAGLE-PICHER	94	25.7	24.5	23.8	22.5	6.4	23.6	19.7	1.246
EAGLE-PICHER	95	26.5	25.7	24.7	22.9	6.4	23.6	21.3	1.243
EAGLE-PICHER	96	26.1	24.9	24.2	22.5	6.4	23.2	20.1	1.246
EAGLE-PICHER	97	25.6	24.7	24.6	22.8	5.7	23.3	15.2	1.248

TABLE 1.-CONTINUED ACCEPTANCE TESTS

----MANUFACTURER---- NAME	SERIAL NO.	CAPACITY TEST #1	#2	#3 AMP.-HR.	CHARGE RETENTION AMP.-HR.	CHARGE EFFICIENCY AMP.-HR.	OVER CHARGE 0 C AMP.-HR.	35 C	INTERNAL SHORT VOLTS
EAGLE-PICHER	98	26.4	25.5	25.4	22.8	5.9	24.1	18.8	1.247
EAGLE-PICHER	99	25.6	24.7	24.6	22.8	6.0	23.7	19.2	1.246
EAGLE-PICHER	100	26.0	25.1	24.6	22.8	5.9	24.1	16.0	1.246
EAGLE-PICHER	101	26.0	25.5	25.8	23.6	5.9	24.1	19.2	1.246
EAGLE-PICHER	102	26.0	25.9	25.8	23.6	6.0	23.3	20.2	1.247
GENERAL ELEC.	5	24.5	23.0	22.1	20.2	7.1	22.1	23.9	1.247
GENERAL ELEC.	6	24.9	23.8	23.3	21.0	6.7	24.1	25.1	1.241
GENERAL ELEC.	7	24.6	23.1	22.6	20.6	7.0	23.8	24.5	1.242
GENERAL ELEC.	8	24.2	23.1	22.6	20.6	7.0	23.8	24.1	1.242
GENERAL ELEC.	9	24.5	23.4	22.9	20.6	7.1	24.1	25.1	1.245
GENERAL ELEC.	10	24.5	23.4	22.9	21.0	6.7	24.1	25.1	1.241
GENERAL ELEC.	18	24.5	23.0	22.1	20.2	7.1	22.1	24.7	1.248
GENERAL ELEC.	19	24.5	23.4	22.9	20.6	6.7	23.7	24.7	1.244
GENERAL ELEC.	21	24.5	23.0	22.1	20.2	7.1	22.1	23.9	1.250
GENERAL ELEC.	22	24.5	23.8	23.3	21.0	6.8	24.1	25.0	1.240
GENERAL ELEC.	25	24.5	23.5	22.9	20.6	6.4	24.1	25.0	1.241
GENERAL ELEC.	26	24.6	23.5	22.6	20.6	7.0	23.8	24.1	1.241
GENERAL ELEC.	32	24.5	23.5	22.9	20.6	6.8	23.7	25.0	1.244
GENERAL ELEC.	33	24.5	23.5	22.9	20.6	6.8	22.5	24.6	1.245
GENERAL ELEC.	35	25.0	23.5	23.0	21.0	7.0	24.2	23.7	1.242
GENERAL ELEC.	37	25.0	23.5	23.0	20.6	7.0	23.8	23.7	1.243
GENERAL ELEC.	38	24.5	23.1	22.5	20.2	6.8	22.1	24.6	1.247
GENERAL ELEC.	39	24.9	23.5	23.3	20.6	6.8	24.1	25.4	1.244

TABLE 1.-CONTINUED ACCEPTANCE TESTS

----MANUFACT. NAME	RER---- SERIAL NO.	CAPACITY TEST #1 AMP.-HR.	#2 AMP.-HR.	#3 AMP.-HR.	CHARGE RETENTION AMP.-HR.	CHARGE EFFICIENCY AMP.-HR.	OVER CHARGE 0 C AMP.-HR.	35 C AMP.-HR.	INTERNAL SHORT VOLTS
GENERAL ELEC.	40	24.5	23.1	22.9	20.2	6.8	22.1	24.6	1.246
GENERAL ELEC.	41	25.0	23.5	23.0	20.6	7.0	24.2	23.7	1.241
GENERAL ELEC.	42	25.0	23.5	23.0	21.0	7.0	24.2	23.7	1.244
GENERAL ELEC.	43	25.0	23.5	23.0	20.6	7.0	23.8	23.7	1.243
GENERAL ELEC.	48	24.2	23.5	22.6	20.6	6.6	24.2	24.9	1.242
GENERAL ELEC.	49	24.6	23.5	23.0	20.6	6.6	23.8	24.9	1.243
GENERAL ELEC.	53	24.5	22.7	22.9	20.6	6.8	22.1	24.2	1.242
GENERAL ELEC.	54	24.5	23.4	22.9	21.0	6.7	23.7	23.9	1.242
GENERAL ELEC.	55	24.9	23.5	23.3	21.0	6.8	24.5	24.6	1.240
GENERAL ELEC.	57	24.9	23.4	22.5	20.6	7.1	23.7	24.3	1.244
GENERAL ELEC.	60	24.9	23.8	23.3	21.0	6.8	23.7	24.6	1.241
GENERAL ELEC.	61	24.5	23.4	22.5	20.6	6.7	23.7	24.7	1.244
SAFT AMERICA	719	23.8	23.0	22.5	20.5	7.4	23.1	21.2	1.213
SAFT AMERICA	722	23.8	23.4	22.5	20.5	7.4	23.5	21.2	1.215
SAFT AMERICA	725	25.0	24.1	23.9	22.3	7.0	24.7	21.4	1.214
SAFT AMERICA	726	24.7	22.9	23.1	21.5	7.0	23.9	23.0	1.219
SAFT AMERICA	728	25.0	24.1	23.9	21.9	7.0	24.3	23.0	1.220
SAFT AMERICA	729	24.6	23.8	24.0	21.7	7.4	24.7	21.6	1.213
SAFT AMERICA	2653	23.5	22.5	22.3	20.3	7.0	23.5	21.8	1.218
SAFT AMERICA	2654	24.7	24.1	23.5	21.5	7.0	24.3	22.2	1.219
SAFT AMERICA	2655	24.7	23.8	22.8	20.4	7.5	22.9	18.3	1.228
SAFT AMERICA	2656	25.0	23.3	23.5	21.5	7.0	24.3	21.8	1.224
SAFT AMERICA	2657	24.7	23.3	23.1	21.1	7.0	23.9	21.8	1.226

TABLE 1.-CONTINUED ACCEPTANCE TESTS

----MANUFACTURER---- NAME	SERIAL NO.	CAPACITY TEST #1 #2 #3 AMP.-HR.	CHARGE RETENTION AMP.-HR.	CHARGE EFFICIENCY AMP.-HR.	OVER CHARGE 0 C AMP.-HR.	35 C	INTERNAL SHORT VOLTS
SAFT AMERICA	2658	23.9 22.5 22.3	20.3	7.0	22.7	21.0	1.225
SAFT AMERICA	2660	22.5 23.0 22.8	20.4	7.5	22.9	18.7	1.229
SAFT AMERICA	2662	24.3 23.7 23.5	21.5	7.0	23.9	22.2	1.224
SAFT AMERICA	2663	23.1 22.5 21.9	19.9	7.0	23.1	21.4	1.223
SAFT AMERICA	2666	24.9 23.8 22.9	21.3	7.0	23.9	20.8	1.228
SAFT AMERICA	2667	24.2 23.0 22.5	20.9	7.0	23.1	20.0	1.226
SAFT AMERICA	2668	23.5 22.6 22.1	20.1	7.0	22.7	20.0	1.222
SAFT AMERICA	2669	23.3 22.6 22.4	20.0	7.1	22.9	18.7	1.228
SAFT AMERICA	2670	24.2 23.4 22.9	20.5	7.0	23.5	20.0	1.227
SAFT AMERICA	2671	24.6 23.8 22.9	21.3	7.0	24.3	20.8	1.225
SAFT AMERICA	2673	24.9 23.4 22.9	20.9	7.0	23.9	20.0	1.229
SAFT AMERICA	2674	24.2 23.4 22.9	20.9	7.0	23.5	20.0	1.227
SAFT AMERICA	2675	22.9 22.2 22.0	19.6	7.1	22.5	18.3	1.225
SAFT AMERICA	2676	24.3 23.4 22.8	20.4	7.5	23.7	19.1	1.226
SAFT AMERICA	2677	24.7 23.8 23.5	20.8	7.5	24.1	19.1	1.225
SAFT AMERICA	2680	22.6 22.2 21.6	19.6	7.1	22.5	18.3	1.225
SAFT AMERICA	2681	24.7 23.4 23.1	20.8	7.5	23.7	19.1	1.227
SAFT AMERICA	2685	24.1 23.0 21.6	20.0	7.5	22.9	18.7	1.229
SAFT AMERICA	2700	22.5 23.0 22.8	20.4	7.5	22.9	19.1	1.227
YARDNEY ELEC.	1	27.3 24.9 24.5	23.2	6.6	27.5	23.2	1.183
YARDNEY ELEC.	3	26.9 24.9 24.0	23.2	6.6	26.3	22.8	1.178
YARDNEY ELEC.	8	25.7 23.3 23.2	22.0	5.8	25.9	22.8	1.203
YARDNEY ELEC.	12	26.5 23.3 22.8	21.6	5.8	25.5	22.4	1.198

TABLE 1.-CONTINUED ACCEPTANCE TESTS

----MANUFACT.RER---- NAME	SERIAL NO.	CAPACITY TEST #1	#2	#3	CHARGE RETENTION	CHARGE EFFICIENCY	OVER CHARGE 0 C	35 C	INTERNAL SHORT VOLTS
		AMP.-HR.			AMP.-HR.	AMP.-HR.	AMP.-HR.		
YARDNEY ELEC.	14	26.2	24.0	23.7	21.1	6.0	25.8	23.3	1.188
YARDNEY ELEC.	16	27.3	24.5	24.5	22.6	6.6	27.1	23.2	1.178
YARDNEY ELEC.	21	27.3	24.9	24.5	22.8	6.2	26.7	23.6	1.184
YARDNEY ELEC.	22	26.9	24.5	24.5	23.2	6.2	27.1	23.2	1.182
YARDNEY ELEC.	24	26.6	24.4	23.2	20.7	6.0	26.6	23.3	1.192
YARDNEY ELEC.	26	26.6	24.7	23.7	21.1	6.4	27.0	23.3	1.180
YARDNEY ELEC.	28	27.8	25.1	24.5	21.5	6.4	27.8	24.1	1.179
YARDNEY ELEC.	30	25.0	23.6	23.2	20.7	6.0	27.0	22.9	1.190
YARDNEY ELEC.	34	27.4	25.9	25.3	22.3	6.8	28.6	23.3	1.162
YARDNEY ELEC.	35	26.6	25.1	24.5	21.5	6.8	27.0	23.3	1.172
YARDNEY ELEC.	37	26.6	24.7	24.1	21.1	6.4	26.3	23.3	1.181
YARDNEY ELEC.	42	27.8	24.7	24.1	21.5	6.4	27.4	23.3	1.189
YARDNEY ELEC.	43	25.9	23.1	23.3	21.5	5.5	25.5	22.5	1.205
YARDNEY ELEC.	44	26.9	24.9	24.5	23.2	6.2	26.7	23.2	1.191
YARDNEY ELEC.	46	27.5	23.9	24.5	22.7	5.9	27.1	22.9	1.200
YARDNEY ELEC.	51	27.5	25.2	25.2	23.1	6.3	27.1	23.3	1.177
YARDNEY ELEC.	52	27.3	24.5	24.5	23.2	5.8	27.5	23.6	1.191
YARDNEY ELEC.	53	25.5	23.1	23.3	20.3	5.5	25.5	22.9	1.200
YARDNEY ELEC.	56	26.3	24.8	25.2	22.7	6.3	26.7	22.9	1.190
YARDNEY ELEC.	60	25.7	23.3	22.8	22.0	5.8	25.5	22.8	1.199
YARDNEY ELEC.	61	27.5	24.8	24.9	22.7	5.9	26.3	22.9	1.197
YARDNEY ELEC.	70	26.7	23.9	24.1	21.9	5.9	26.3	23.3	1.193
YARDNEY ELEC.	71	27.1	24.8	24.9	22.7	6.3	25.9	22.9	1.194

TABLE 1.-CONTINUED ACCEPTANCE TESTS

----MANUFACT. NAME	RER---- SERIAL NO.	CAPACITY TEST #1 #2 #3 AMP.-HR.	CHARGE RETENTION AMP.-HR.	CHARGE EFFICIENCY AMP.-HR.	OVER CHARGE 0 C AMP.-HR.	35 C	INTERNAL SHORT VOLTS
YARDNEY ELEC.	76	26.7 24.4 24.5	22.3	5.9	26.3	23.3	1.192
ENERGY RES.	1	22.7 19.8 19.3	17.5	3.5	14.2	22.0	1.175
ENERGY RES.	2	23.6 20.1 20.0	18.3	3.4	14.2	22.3	1.168
ENERGY RES.	3	23.9 20.6 20.7	18.1	3.4	13.8	20.9	1.141
ENERGY RES.	4	21.4 19.9 18.1	15.9	2.2	12.3	20.2	1.079
ENERGY RES.	7	23.9 21.0 20.7	18.4	3.5	14.1	20.8	1.163
ENERGY RES.	8	23.9 20.7 20.0	18.0	3.5	13.1	22.8	1.163
ENERGY RES.	9	23.9 20.8 19.7	16.4	3.3	11.7	20.1	1.074
ENERGY RES.	10	23.9 20.8 19.7	17.6	3.5	12.7	20.1	1.175
ENERGY RES.	15	23.5 20.4 19.7	10.2	3.5	10.5	20.1	1.152
ENERGY RES.	16	23.7 20.7 19.7	17.8	3.5	12.7	20.5	1.173
ENERGY RES.	17	23.7 20.7 19.7	17.6	3.5	12.7	20.5	1.175
ENERGY RES.	18	23.6 20.7 19.4	18.2	3.5	12.9	20.4	1.153
SAFT AMERICA	2735	23.5 22.7 22.0	19.6	7.2	21.1	19.1	1.220
SAFT AMERICA	2735	23.1 22.7 22.5	19.6	7.2	21.1	18.7	1.214
SAFT AMERICA	2737	23.5 23.1 22.5	20.0	7.2	21.1	19.1	1.224
SAFT AMERICA	2738	22.7 22.3 22.1	19.3	7.2	21.1	19.1	1.218
SAFT AMERICA	2739	23.9 23.1 22.9	20.4	7.2	21.1	18.7	1.219
SAFT AMERICA	2740	23.9 23.1 22.5	20.4	7.2	21.1	18.7	1.219
SAFT AMERICA	2741	25.3 23.1 22.5	19.6	7.2	21.1	18.7	1.216
SAFT AMERICA	2742	25.3 23.1 22.5	20.0	7.2	21.1	18.3	1.217
SAFT AMERICA	2743	25.3 23.1 22.5	19.7	7.2	21.1	18.7	1.218
SAFT AMERICA	2744	25.3 22.7 22.1	19.7	7.2	21.1	18.7	1.219

TABLE 1.-CONTINUED ACCEPTANCE TESTS

----MANUFACTURER---- NAME	SERIAL NO.	CAPACITY TEST #1	#2	#3 AMP.-HR.	CHARGE RETENTION AMP.-HR.	CHARGE EFFICIENCY AMP.-HR.	OVER CHARGE 0 C AMP.-HR.	35 C	INTERNAL SHORT VOLTS
SAFT AMERICA	2745	23.7	22.4	22.7	20.6	7.4	22.0	20.2	1.180
SAFT AMERICA	2746	22.9	22.0	21.9	20.2	7.0	21.6	19.8	1.190
SAFT AMERICA	2747	24.1	22.8	22.3	21.0	7.4	21.6	20.2	1.184
SAFT AMERICA	2748	23.7	22.4	22.3	21.0	7.0	22.0	20.2	1.183
SAFT AMERICA	2749	22.9	22.0	21.9	20.2	7.0	21.2	19.5	1.183
SAFT AMERICA	2750	24.1	22.4	22.3	21.0	7.0	22.0	20.2	1.180
SAFT AMERICA	2751	23.3	22.4	22.3	20.6	7.0	21.6	20.2	1.179
SAFT AMERICA	2752	24.1	22.4	22.3	21.0	7.4	21.6	20.2	1.183
SAFT AMERICA	2753	23.7	22.8	22.3	20.6	7.4	21.6	19.8	1.178
SAFT AMERICA	2755	22.9	22.0	21.9	20.2	7.0	21.6	19.8	1.187

TABLE II

GEOMETRICAL AVERAGE OF THE VARIANCE RATIOS FOR ALL PAIRS OF MANUFACTURERS

Acceptance Test	Variance
Capacity Test #1	2.706
Capacity Test #2	7.708
Capacity Test #3	6.025
Special Charge Retention	4.041
Charge Efficiency	10.46
Overcharge Test #1 ($0^{o}C$)	13.49
Overcharge Test #2 ($35^{o}C$)	3.956
Internal Short Test	6.940

TABLE III

KARHUNEN-LOEVE TRANSFORMATION OF VARIANCE WEIGHTED DATA

New variable	Eigenvalue	Info preserved		Capacity test 1	Capacity test 2	Capacity test 3	Charge retention	Charge efficiency	Over 0^{o}	Charge 35^{o}	Internal short
		Each	Total								
1	3.289E 02	69.3	69.3	-7.366E-02	-3.570E-01	-2.854E-01	-1.827E-01	-4.341E-01	-7.162E-01	-5.570E-02	-2.188E-01
2	7.355E 01	15.5	84.8	-1.955E-01	-3.492E-01	-2.669E-01	-1.570E-01	7.825E-01	-2.066E-01	-1.249E-01	2.707E-01
3	3.926E 01	8.3	93.0	-3.962E-02	-3.574E-01	-2.124E-01	-1.252E-01	1.281E-01	4.494E-01	7.197E-02	-7.657E-01
4	1.891E 01	4.0	97.0	1.395E-02	3.080E-01	2.579E-01	1.257E-01	2.146E-01	-2.369E-01	-7.435E-01	-4.095E-01
5	7.010E 00	1.5	98.5	1.839E-01	3.703E-01	1.435E-01	-3.681E-02	3.607E-01	-4.144E-01	6.240E-01	-3.404E-01
6	3.008E 00	0.6	99.1	1.153E-01	3.397E-01	-1.043E-01	-9.083E-01	-4.852E-02	1.134E-01	-1.296E-01	5.916E-02
7	2.669E 00	0.6	99.7	9.357E-01	-1.387E-01	-2.590E-01	1.157E-01	6.275E-02	-1.814E-03	-1.282E-01	6.662E-02
8	1.409E 00	0.3	100.0	-1.788E-01	5.062E-01	-7.982E-01	2.662E-01	-2.042E-02	4.032E-02	-2.700E-02	-3.143E-02

TABLE IV

NEAREST NEIGHBOR ANALYSIS

		Calculated					
		1	2	3	4	5	6
	1	25	0	0	1	0	0
T	2	0	30	0	0	0	0
R	3	0	0	29	0	0	1
U	4	0	0	0	28	0	0
E	5	0	0	0	0	12	0
	6	0	0	0	0	0	20

1 = Eagle Picher
2 = General Electric
3 = Saft American (Std. cell lot)
4 = Yardney
5 = Energy Research Corp.
6 = Saft American (LeRC lot)

KARHUNEN-LOEVE TRANSFORMATION OF VARIANCE WEIGHTED DATA

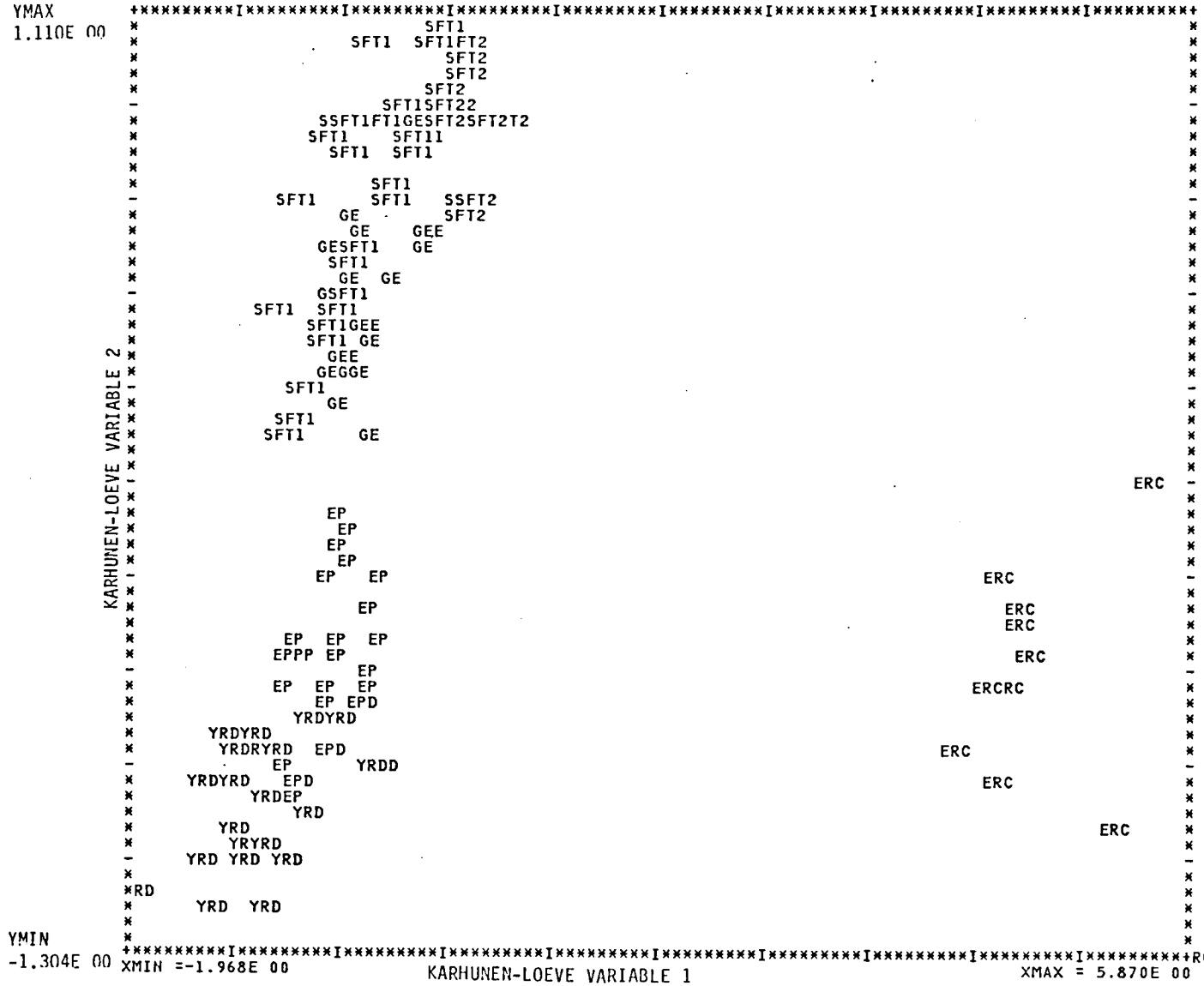

FIGURE 1

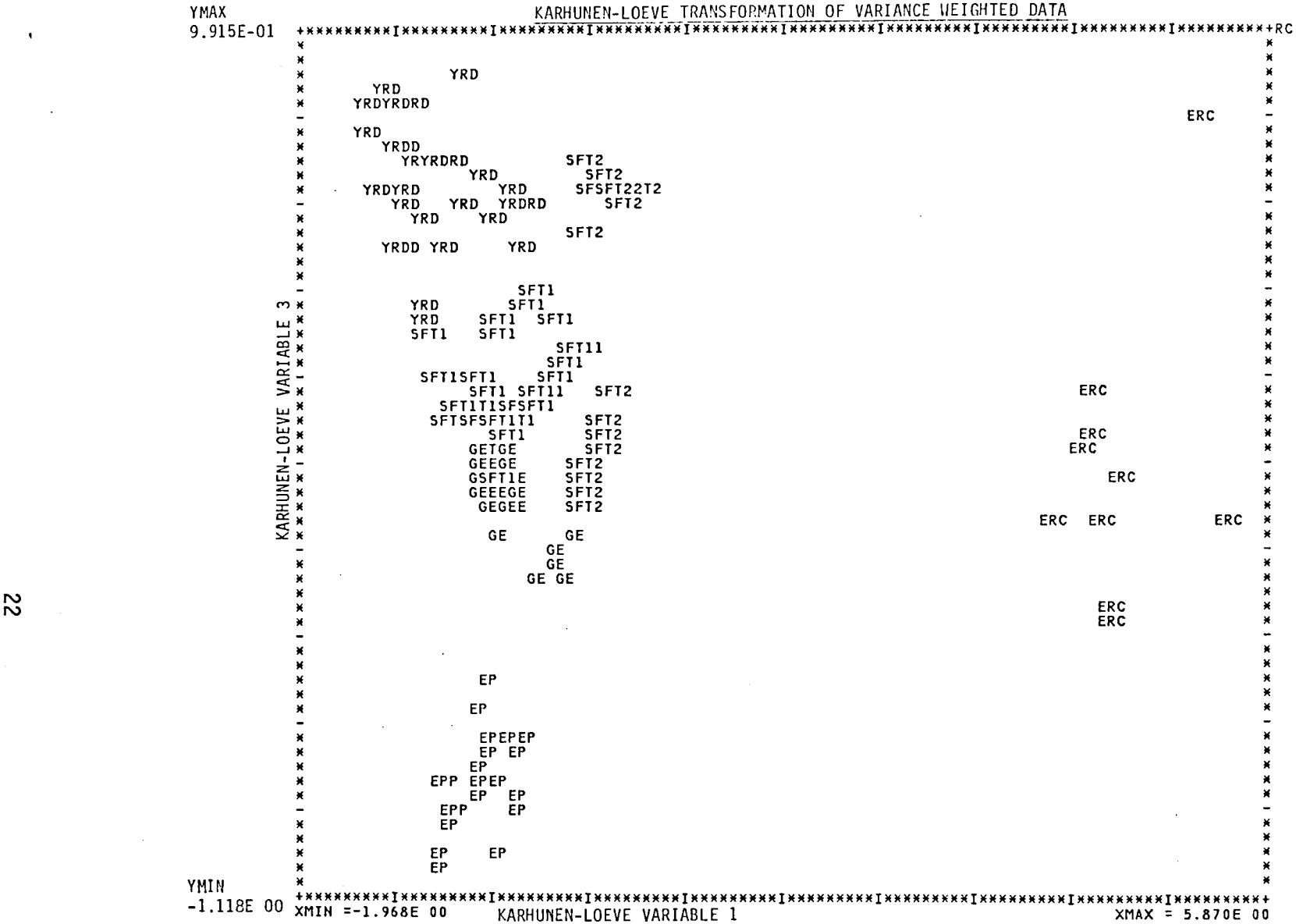
KARHUNEN-LOEVE TRANSFORMATION OF VARIANCE WEIGHTED DATA
YMAX
9.915E-01
YMIN
-1.118E 00
XMIN =-1.968E 00
KARHUNEN-LOEVE VARIABLE 1
XMAX = 5.870E 00
KARHUNEN-LOEVE VARIABLE 3

FIGURE 2

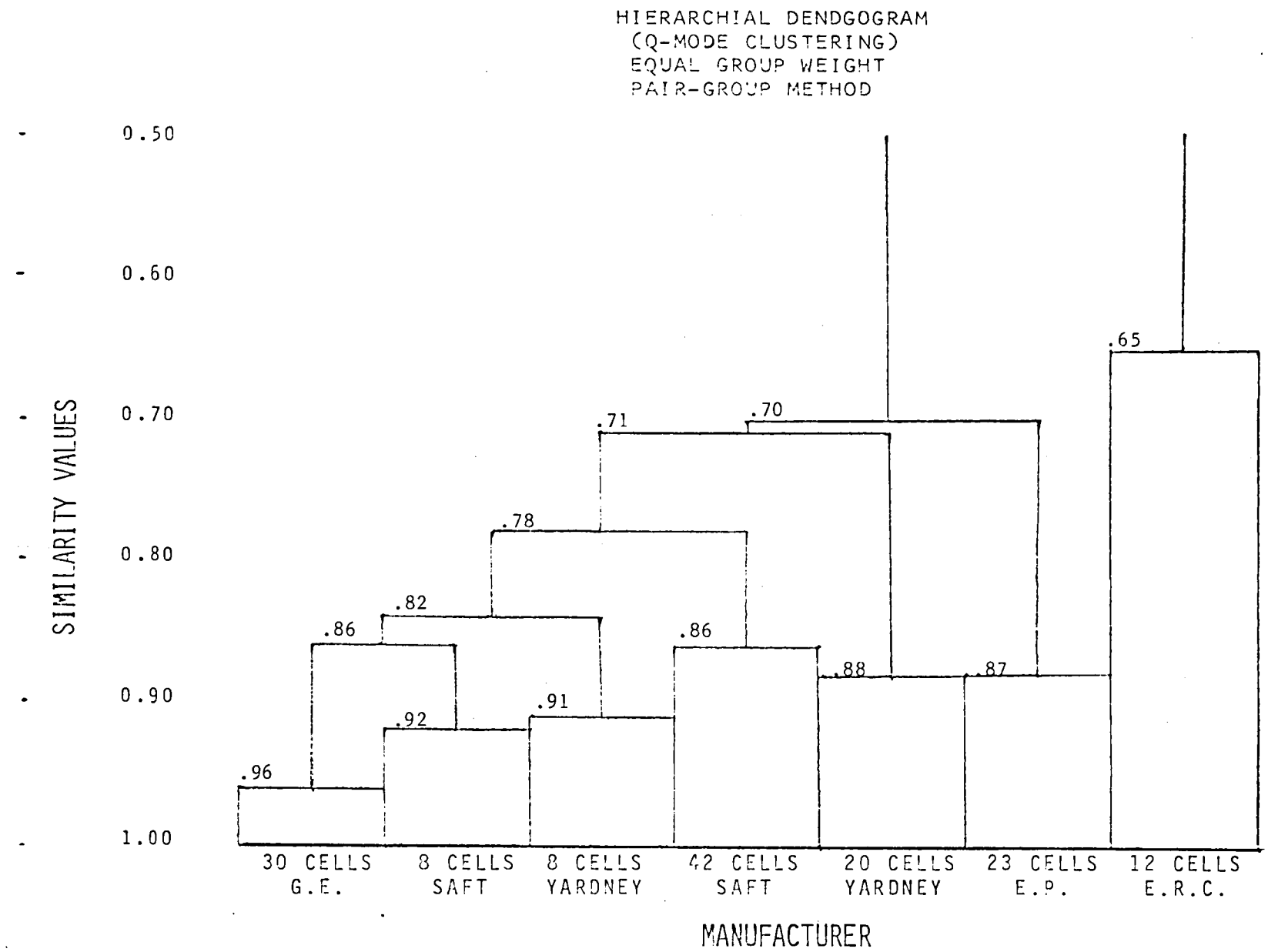
HIERARCHIAL DENDGOGRAM
(Q-MODE CLUSTERING)
EQUAL GROUP WEIGHT
PAIR-GROUP METHOD
SIMILARITY VALUES
0.50
0.60
0.70
0.80
0.90
1.00
.96
.86
.92
.82
.91
.78
.86
.71
.88
.70
.87
.65
30 CELLS G.E.
8 CELLS SAFT
8 CELLS YARDNEY
42 CELLS SAFT
20 CELLS YARDNEY
23 CELLS E.P.
12 CELLS E.R.C.
MANUFACTURER

FIGURE 3

HIERARCHICAL DENDROGRAM PLOT

EQUAL GROUP WEIGHT PAIR-GROUP METHOD OF CLUSTERING

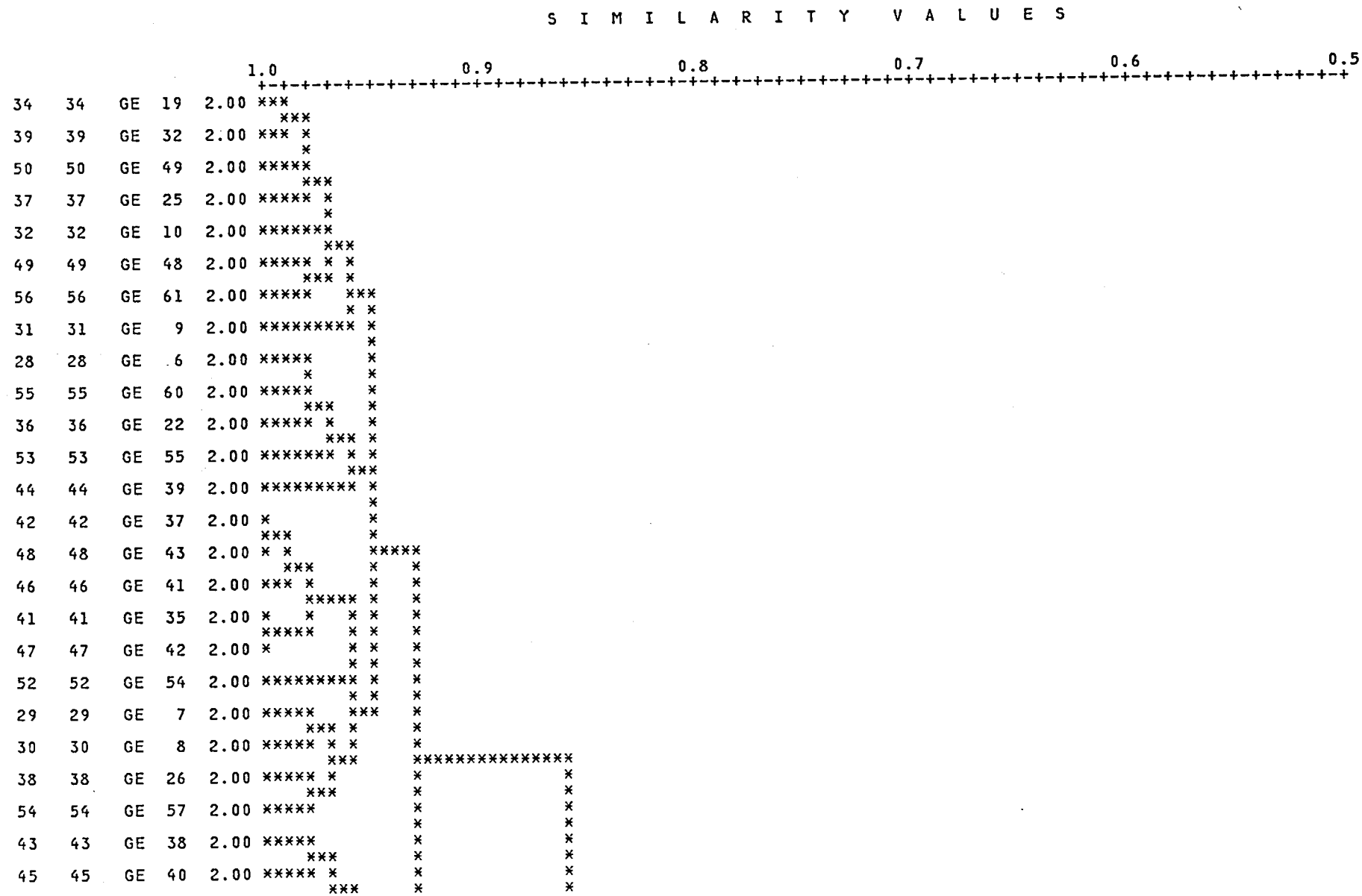

FIGURE 4

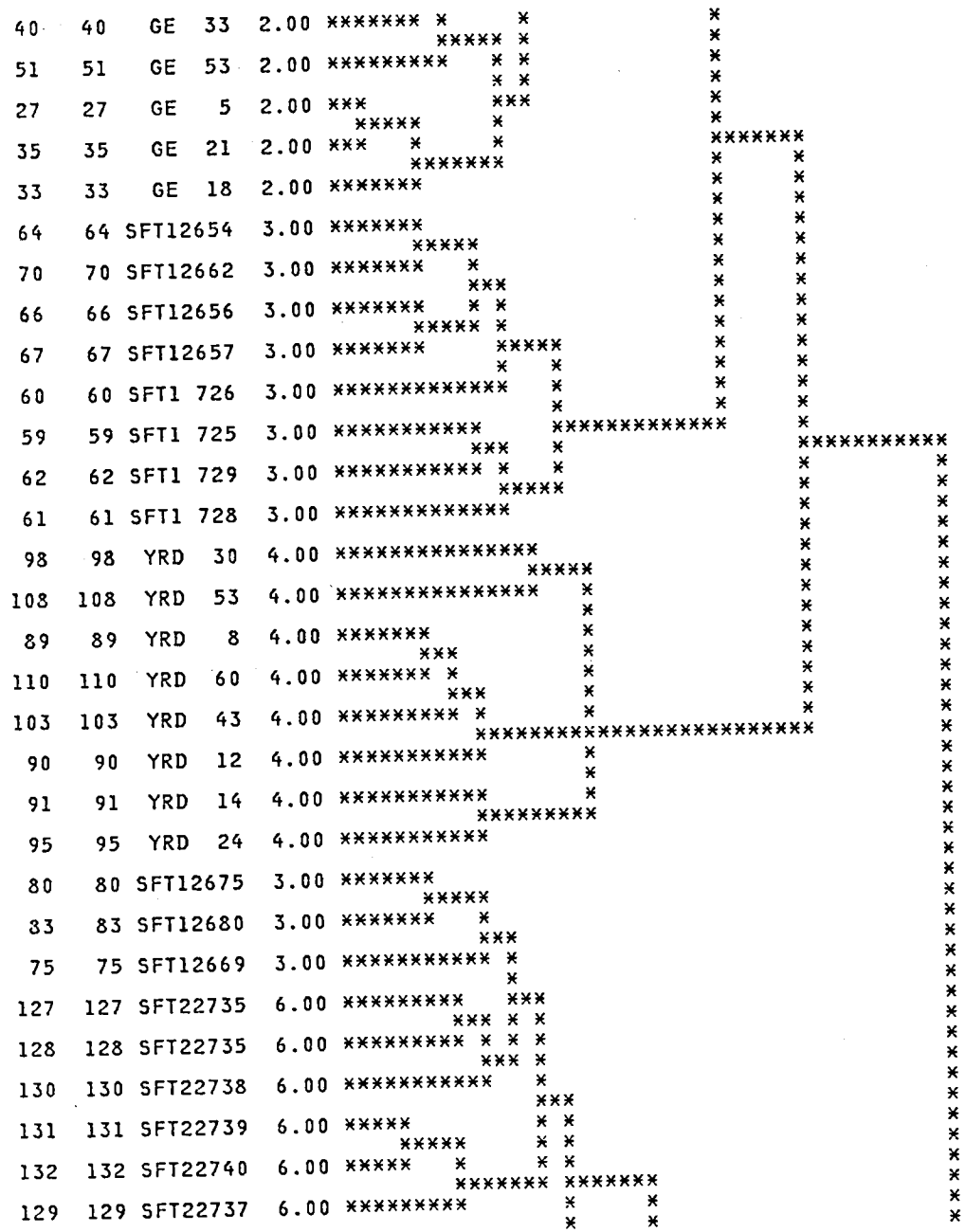

FIGURE 4. - Continued.

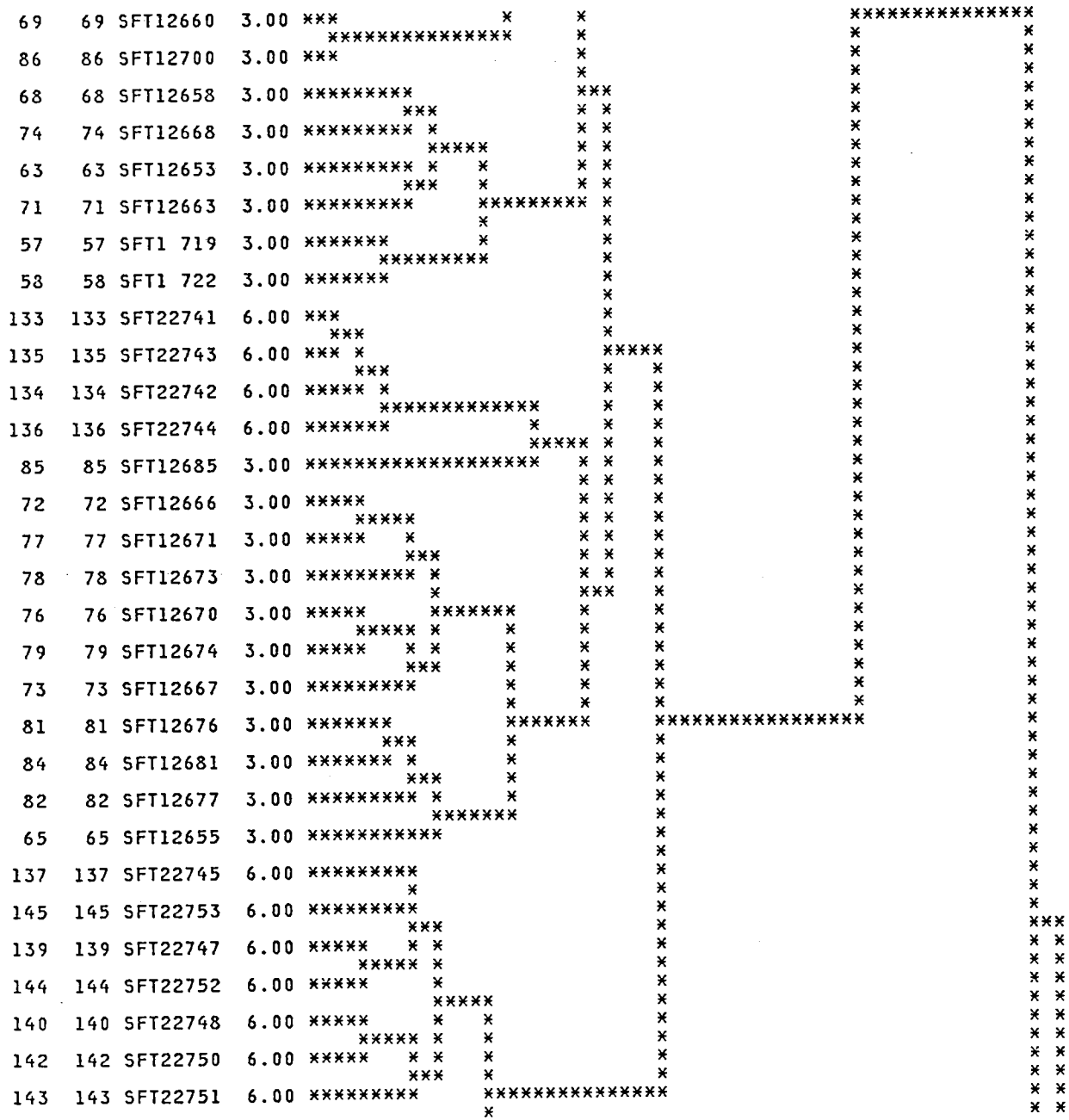

FIGURE 4. - Continued.

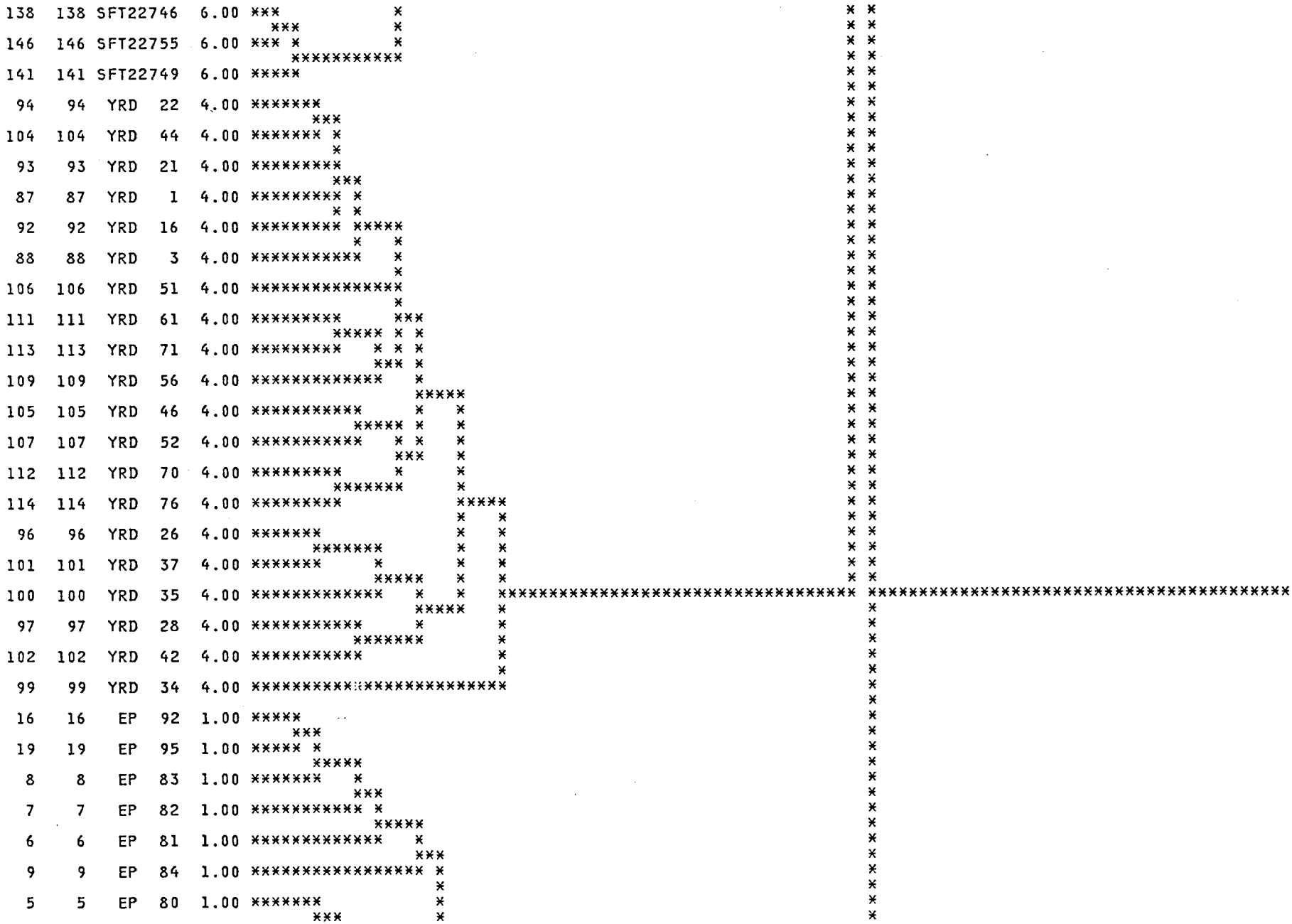

FIGURE 4. - Continued.

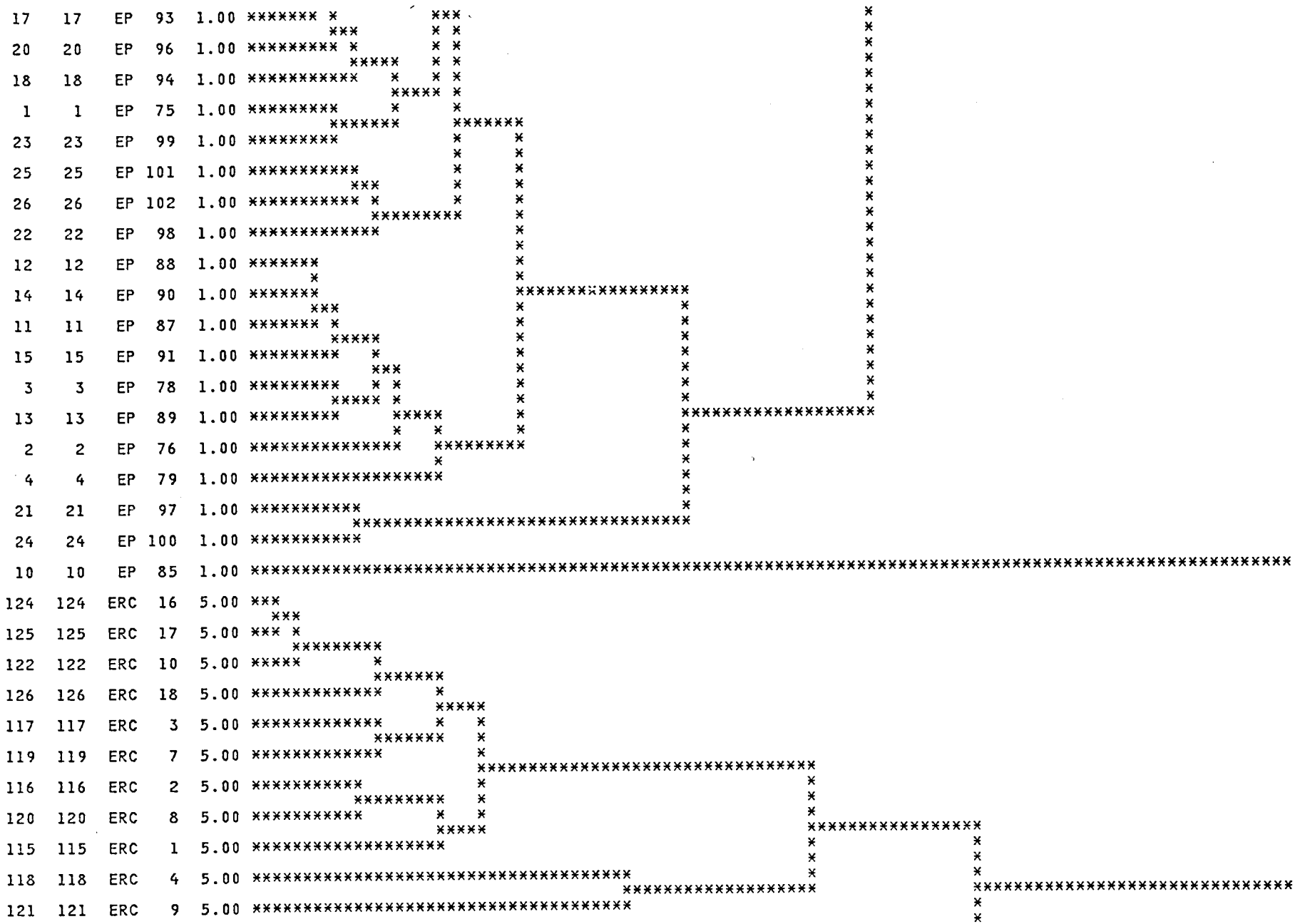

FIGURE 4. - Continued.

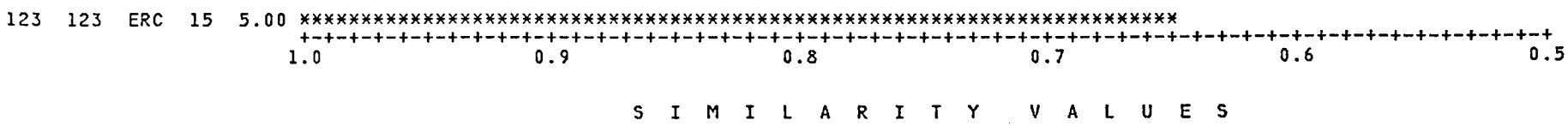

FIGURE 4. - Concluded.

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16. Abstract

One hundred and forty-six 20 ampere-hour sealed nickel-cadmium cells from five manufacturers were evaluating, using pattern recognition techniques. Differences between cells from different manufacturers were detected using simple preliminary tests which do not require life testing and do not reduce the expected life of the cells. Differences between individual cells were also detected, using these same tests, allowing a comparison of variability of cell construction by and between manufacturers.

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