NASA CR-54805
EOS Report 4110-QL-5

HYDROGEN-OXYGEN ELECTROLYTIC REGENERATIVE FUEL CELLS

by

M. Klein and E. Findl

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS3-2781

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ELECTRO-OPTICAL SYSTEMS, INC., Pasadena, California
A Subsidiary of XEROX Corporation

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QUARTERLY REPORT

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17 December 1965

CONTRACT NAS3-2781

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1. INTRODUCTION

This report reviews the progress made on development of a regenerative hydrogen-oxygen fuel cell under NASA Contract 3-2781 during the period of 1 July through 1 October 1965. The program objective is the development of an electrolytically regenerative hydrogen oxygen fuel cell that will be superior in performance to currently available rechargeable batteries. The device under development consists of a cell stack that is utilized as an electrolyzer during charge periods, and as a fuel cell during discharge periods. Integral gas storage tanks are used to contain the hydrogen and oxygen gas generated during charge. Such a device offers advantages in the area of watt hours per lb., high ambient temperature operation, and greater cycle life than that which can be obtained from existing secondary batteries. A two phase program is being conducted. Phase 1 consisted of the design, development and testing of a nominal 75 watt, 44 watt hour, 6 cell unit to demonstrate the feasibility of a multi-cell regenerative device. This phase has been completed. Phase 2 consists of the design and development of a 500 watt 600 watt hour, 34 cell unit of minimum weight for evaluation as a flight prototype.

2. SUMMARY

During this quarter, the 28 volt 600 watt hour, 34 cell unit was electrically and mechanically tested. In addition, 13 single cell tests were made to evaluate electrode-asbestos variations. The 34 cell 500 watt unit demonstrated electrical performance characteristics which well exceeded the nominal design power levels. Power levels to 1300 watts at 25 volts were achieved. Electrode degradation, similar to that shown in single cell tests, was noted upon continued cycling. Capacity tests, using a simulated Voyager Lander power profile, were made and 700 watt hours achieved.

As a result of electrode and asbestos degradation problems uncovered during single and multicell testing, an additional task has been incorporated in the program. This task is essentially to investigate the effects of cycling on asbestos matrices and to evaluate techniques for improving electrode cycle life. The investigation will be carried out in both single and multi-cell test rigs.

3. TECHNICAL DISCUSSION

3.1 Single Cell Tests

Thirteen single cell tests were conducted during this period to evaluate the performance of various electrode structures. The data is summarized in Table 1. Cell number 85 contained EOS standard catalyzed porous nickel plaques as the oxygen and hydrogen electrodes. The asbestos mat was made up of two layers of 0.030" thick material in between which was placed a mercuric oxide reference electrode. The reference electrode consisted of a nickel screen on which mercuric oxide powder was pressed. The screen had a spot welded nickel wire on one end that was fed out the cell through the insulating spacer. The reference electrode was included within the cell to determine which electrode degrades performance due to drying out or flooding of the cell. Figure 1 shows typical performance of the cell. The curves show actual voltage measured between the reference electrode, and the working electrodes. These measurements include IR drop. However,due to the geometric location of the reference electrode, half the IR drop can be considered to be included in the oxygen electrode voltage, and the other half in the hydrogen electrode voltage. Typical total cell impedance was found to be 0.005 ohms. As shown at the end of discharge, a substantial fall-off in performance of the oxygen electrode is encountered. It was necessary to extend the discharge duration beyond our normal 35 minute discharge period to get the extreme effect of oxygen electrode flooding. Figure 2 shows polarization scans as a function of discharge current on the same single cell including the reference electrode. As can be seen on both charge and discharge, the oxygen electrode represents the major polarization loss of total cell performance.

TABLE 1

SUMMARY OF SINGLE CELL TESTS

Cell No.	O_2 Electrode #	O_2 Electrode Catalyst	H_2 Electrode #	H_2 Electrode Catalyst	Mat Thickness and Grade	Mat Dry Wt.	KOH %	KOH Wt. (gms.)	Comments	Results
85	136	20 Mg Pt/cm^2	137	20 Mg.Pt/	2X.030	27	40.3	31	Used HgO Ref. between mat.	Cycled 7 times, obtain individual electrode performance.
86	219	40 Mg.Pt/cm^2	211	"	.060	28	40.3	31	Automatic process oxygen electrode	Showed no improvement in performance
87	219	40 Mg.Pt/cm^2	211	"	.060	27.6	40.3	31	Repeat of cell No. 86	Cycled 16 times. Showed no improvement in performance.
88	Felt Metal	20 Mg.Pt/cm^2	213	"	.060	27	40.3	31	Felt metal oxygen	Cycled 17 times good initial performance.
89	208	"	133	"	2X.030	27.2	40.3	31	Used HgO Ref. between mat	Cycled 45 times Obtain individual electrode performance.
90	Felt Metal	40 Mg.Pt./cm^2	137	"	.060	27	40.3	31	Felt Metal Oxygen	Cycled 11 times poor performance.
91	"	20 Mg.Pt./cm^2	213	"	.060	27.1	40.3	31	Repeat of cell 88	Cycle 39 times. Showed gradual decay in performance.

TABLE 1
SUMMARY OF SINGLE CELL TESTS

Cell No.	O_2 #	Electrode Catalyst	H_2 #	Electrode Catalyst	Mat Thickness and Grade	Mat Dry Wt.	KOH %	KOH Wt. (gms.)	Comments	Results
92		9 Mg Pt/cm^2	215	20 Mg.Pt/cm^2	2 x .030	27	40.3	31	Cyanamid Oxygen electrode with gold plated screen.	Final KOH 26.2% 26.9% 130 cycles Cell should showed gradual degradation in performance.
93		"	213	"	.060	27.5	40.3	31	"	Final KOH 27.8%, 28.4% 38 cycles. Cell showed initial poor performance on charge.
94		20 Mg Pt/cm^2		"	.060	27.1	40.3	31	Bishop platinized oxygen electrode	Final KOH 35.3% 35.6% 21 cycles. Showed initial good performance, but degraded slowly.
95		40 Mg.Pt/cm^2	213	"	.060	26.0	40.3	31	"	Final KOH 29.4%, 48 cycles. Increased catalyst did not improve performance.
96		9 Mg.Pt/cm^2	213	"	.060	27.3	40.3	31	Same electrodes as cell No. 93	Final KOH 29.6% 29.7% Cycled 37 poor initial performance.
97		"	215	"	.060	27.0	40.3	31	Same electrodes as cell No. 92	Final KOH 25.7, 25.8% Cycled 95 times. Initial good performance. Gradual degradation with cycling.

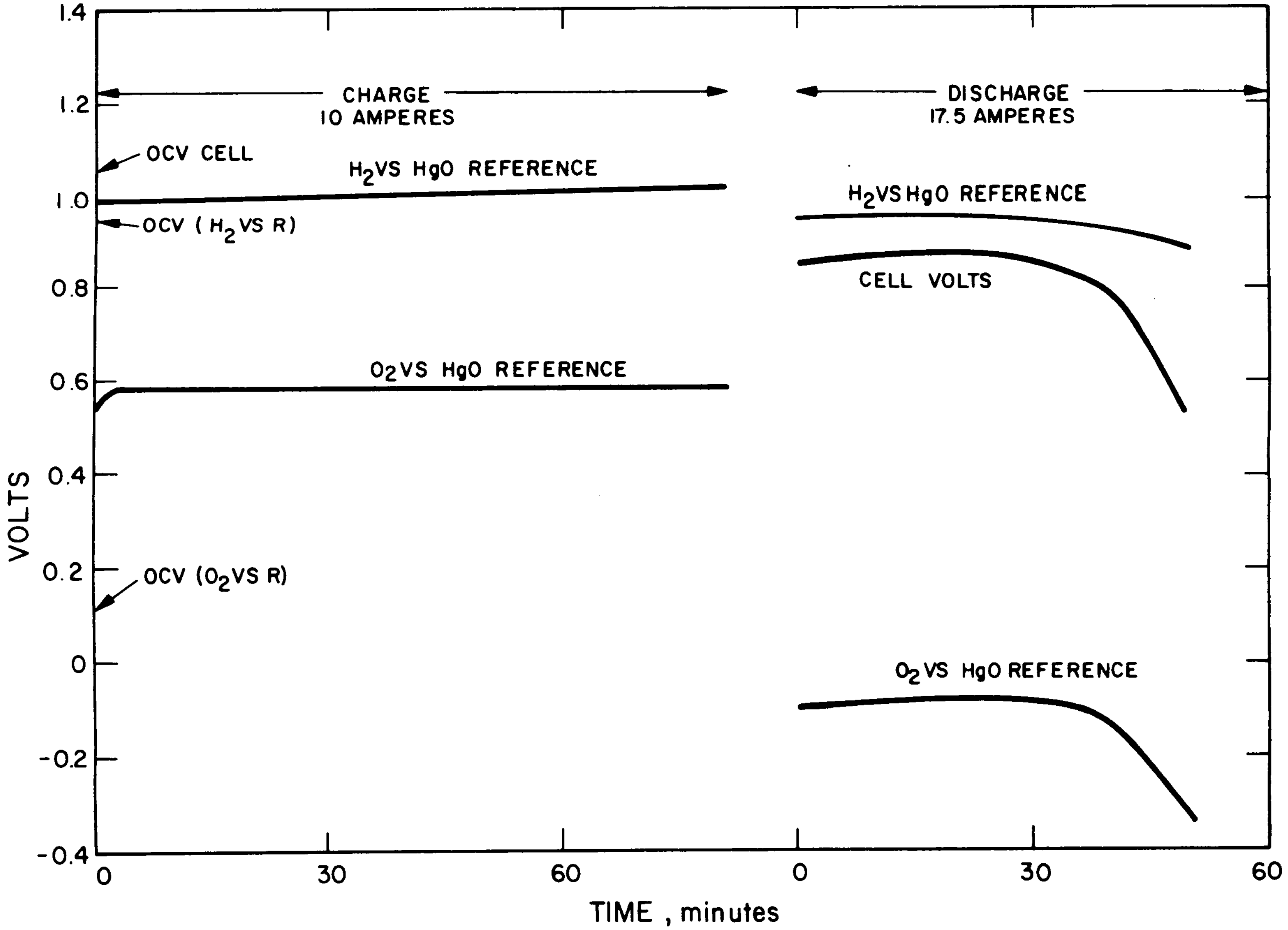

FIG. 1 HALF CELL PERFORMANCE OF REGENERATIVE H_2-O_2 FUEL CELL (Cell No. 85)

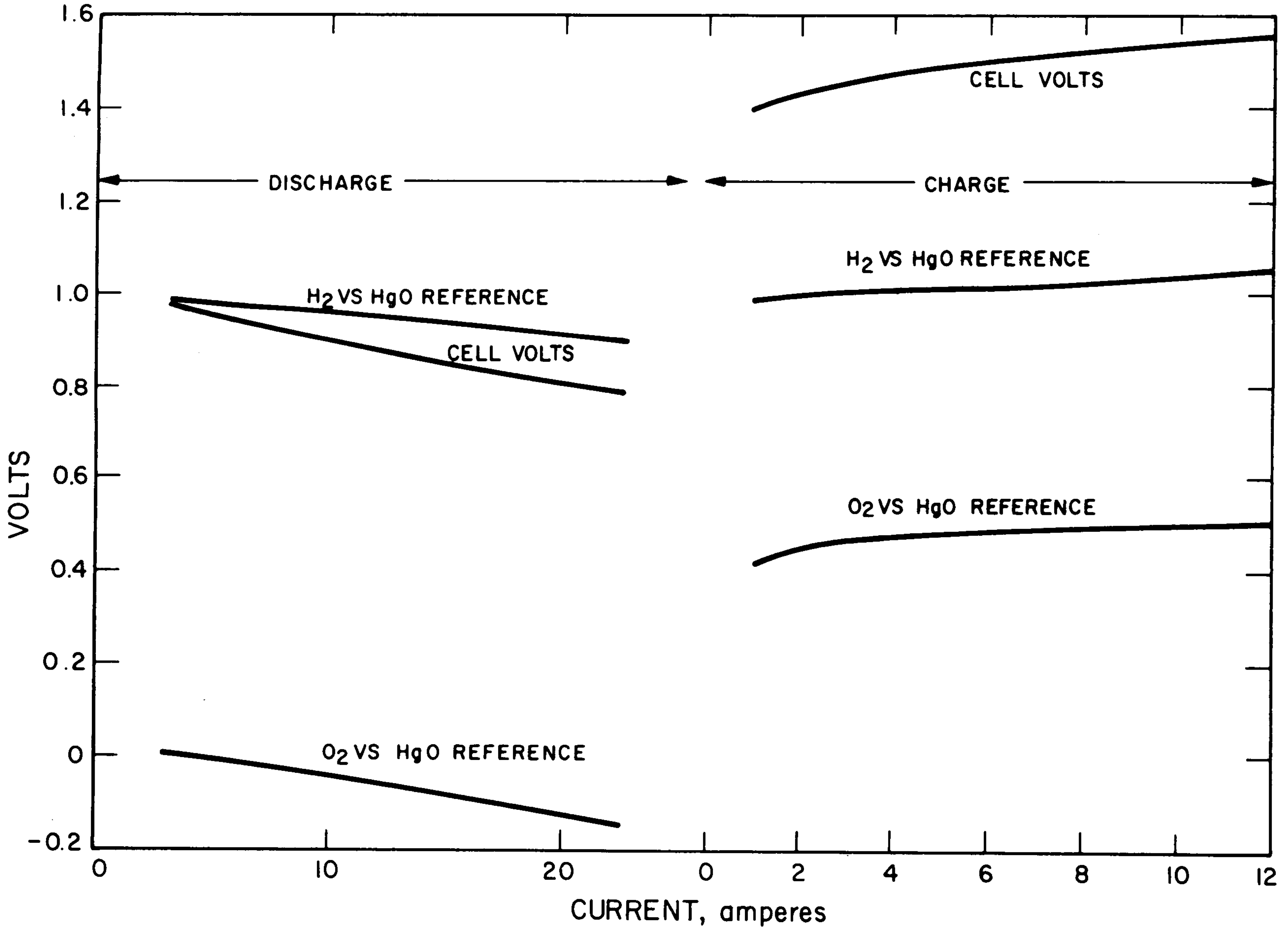

FIG. 2 POLARIZATION SCAN OF H_2-O_2 REGENERATIVE FUEL CELL (Cell No. 85)

Cell number 86 consisted of an oxygen electrode that had been catalyzed with 40 mg. of platinum per sq. cm. by our automatic electrode process. It was hoped this cell would show improved performance due to the increased catalyst loading on the oxygen electrode. However, the electrical performance was no better than obtained with standard 20 mg. platinum per sq. cm. electrodes.

Cell number 87 was a repeat of cell number 86 using the same electrodes that had been washed in distilled water before the reasssembly. This cell also showed no significant improvement of performance as compared to standard 20 mg. platinum per sq. cm. electrodes.

Cell number 88 was a test which included an oxygen electrode of the Huyck felt metal type that had been catalyzed with 20 mg. of platinum per sq. cm. The felt metal employed was material received from NASA that was 0.022" thick, and was designated as 15 percent dense nickel. The substrate was catalyzed in the normal manner by manually recycling a hot solution of chloroplatinic acid through the plaque until 20 mg. per sq. cm. of platinum was picked up by the porous nickel structure. Performance of this cell is shown in Figure 3. The Huyck plaque electrodes performed as well as our standard porous nickel plaque electrodes. Similarly, upon repeated cycling, it showed a gradual degradation of performance, The cell was cycled 17 times, dissassembled, and the electrodes washed.

A new cell was assembled with the washed electrodes plus a new asbestos mat, and was designated cell 91. Initial cell performance was approximately the same level as cell number 88 when the test was stopped. On repeated cycling, the performance gradually degraded. Testing was stopped at the 39th cycle. Figure 3 also shows the performance of the 38th cycle of cell 91.

Cell number 89 was a repeat of the test 85 which included a reference electrode and the results obtained were similar as to performance obtained.

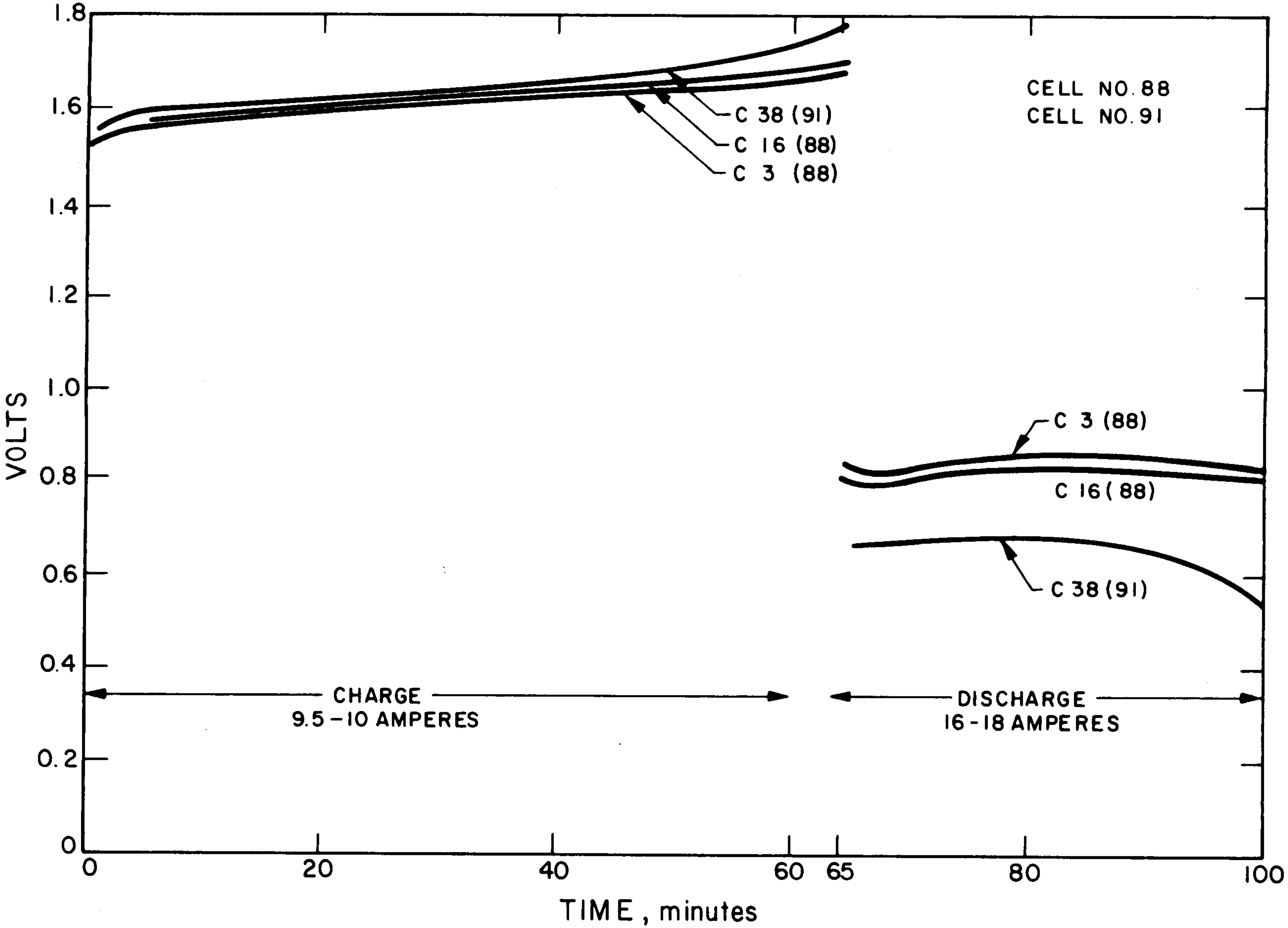

FIG. 3 PERFORMANCE OF FELT METAL ELECTRODES

Cell number 90 consisted of a felt metal electrode which had been catalyzed to 40 mg. of platinum per sq. cm. However, the heavy loading and the process used resulted in a considerable degradation of the fiber structure. Performance of this cell was worse than the 20 mg. per sq. cm. platinum loading.

Cells number 92 and 93 were assembled utilizing oxygen electrodes purchased from the American Cyanamid Corporation. These were the standard AB-4 type containing 9 milligrams of platinum per square centimeter, with the exception that the nickel substrate screen had been gold plated to minimize oxidation and corrosion. Cell number 92 contained two 0.030" asbestos mats and was cycled 130 times on the standard 65 minute charge, 35 minute discharge test cycle. Figure 4 shows voltage performance of the cell at various cycles. As can be seen there was a gradual increase of the charging voltage, and a decrease in the discharge voltage as the cycling continued. The final electrolyte concentration within the asbestos mat was found to be between 26.2 and 26.9 percent. Examination of the cell components after the cell was disassembled revealed no obvious changes in the electrodes. The gold plating on the nickel subscreen, wherever visible, looked impervious and firmly attached to the screen.

Cell number 93 was similar to 92 with the exception that one layer of 0.060" asbestos was used and cycled only 38 times. This cell showed good discharge performance (0.80-0.84 volts at 100 ma/cm^2), but the voltage during charge rose very rapidly to values as high as 2.0 volts. As cycling continued, the voltage on charge got progressively higher, and the discharge voltage fell off rapidly towards the end of discharge. The test was therefore discontinued. KOH concentration in the mat was found to be 27.8, and 28.4 percent on two samples extracted from the asbestos mat.

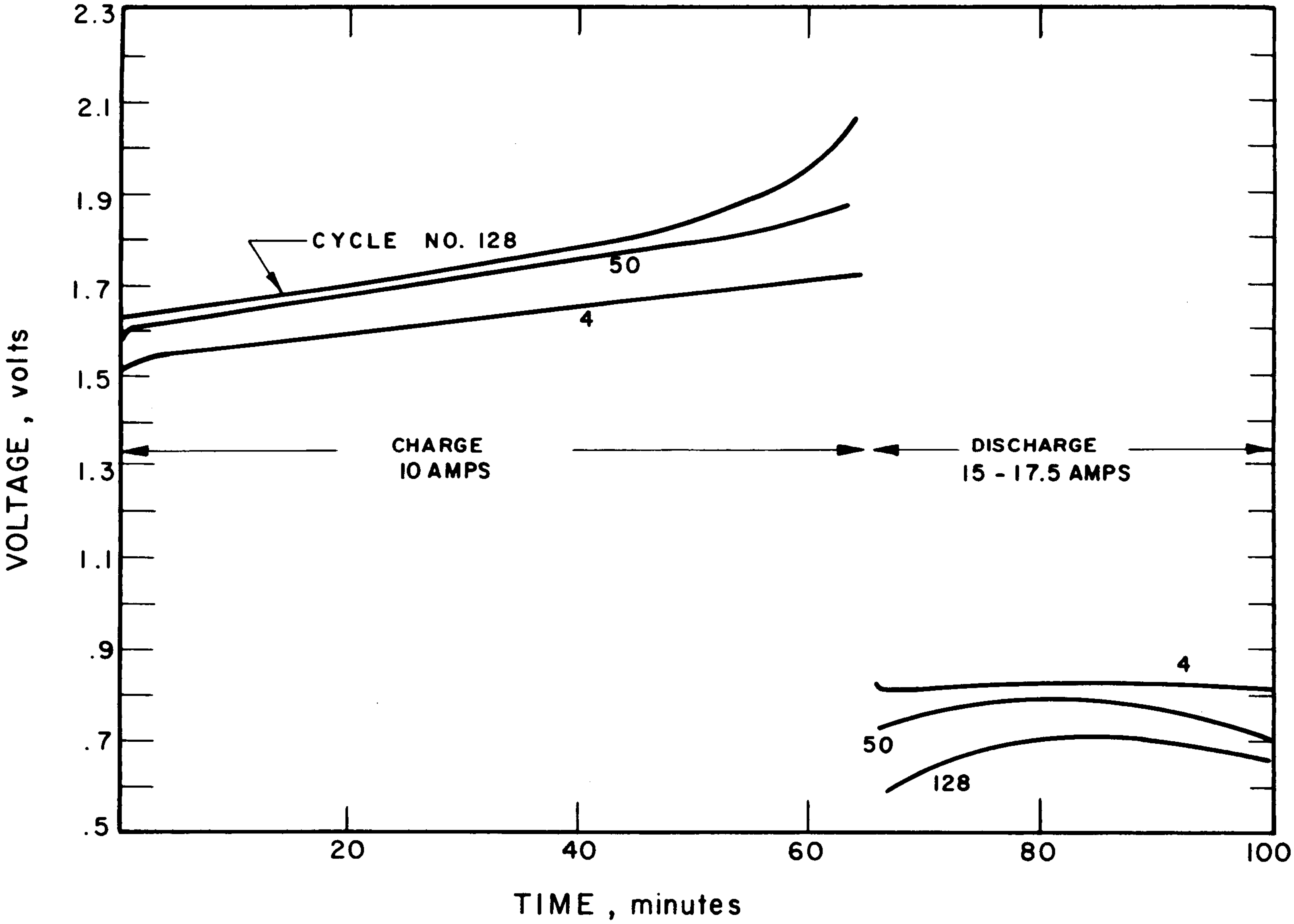

FIG. 4 CYCLING PERFORMANCE OF CELL NO. 92

Cell number 94 consisted of an oxygen electrode that had been platinized to 20 mg. of platinum per sq. cm. by a proprietary process of the Bishop Company. The substrate of these electrodes consisted of porous sintered carbonyl nickel plaques of the type used in standard EOS electrodes. This cell was cycled 21 times. The initial performance of the cell was good, discharge voltage being approximately 0.82 volts (100 ma/cm^2) and charge voltage approximately 1.6--1.75 volts (55 ma/cm^2). However, as the cycling continued a gradual increase in the charging voltage, and a decrease in the discharge voltage accompanied with a substantial fall-off in discharge voltage at the end of discharge was observed.

Cell number 95 consisted of an oxygen electrode that had been platinized by the Bishop Company to 40 mg. of platinum per sq. cm. This cell also exhibited good initial performance, and showed a gradual degradation of both charge and discharge voltage. However, the increased catalyst loading of the electrode did not improve performance above that obtained with the 20 mg. platinum per sq. cm. loading as used in cell number 94.

Cell numbers 96 and 97 were repeats of cells 92 and 93, utilizing the same electrodes with fresh asbestos mats. Before the test,each of the electrodes was washed with hot distilled water and dried. Performance obtained with cell 96 was similar to that obtained with cell number 93, i.e., the charge voltage would rise rapidly to levels as high as 2.2 volts. Discharge performance was low, ranging between 0.5 and 0.7 volts. The cell was cycled 37 times. Cell number 97 showed good initial performance, but gradually degraded with cycling. Voltage performance at various cycles is shown in Figure 5. The final KOH concentration in the mat was found to be 25.7 percent.

Test results, using American Cyanamid electrodes, indicate that performance degradation can occur even though nickel is not present in the electrochemical reaction zone. Since these electrodes can

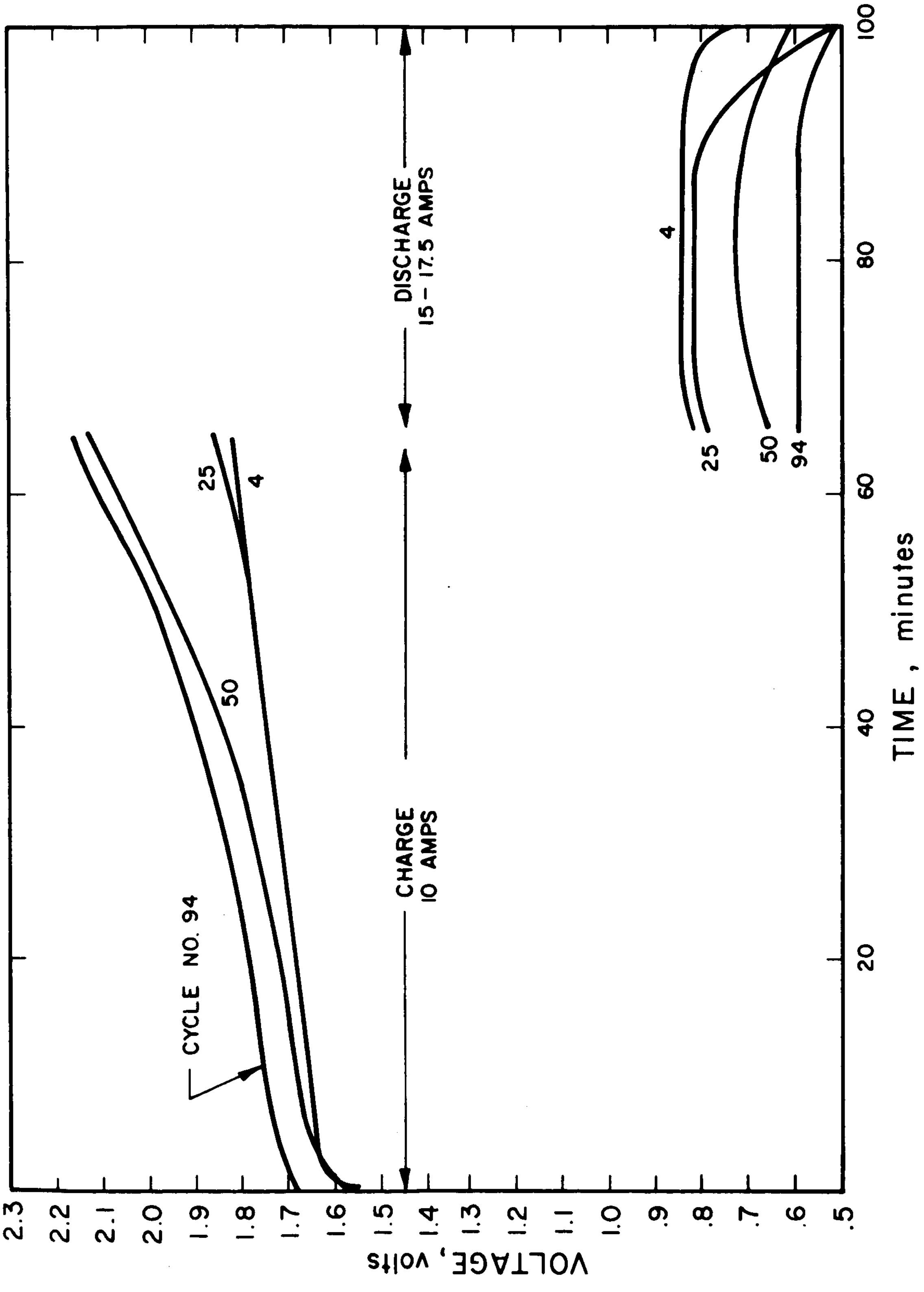

FIG. 5 CYCLING PERFORMANCE OF CELL NO. 97

apparently be rejuvenated by a simple washing process, this indicates that either the asbestos/electrolyte interface is the cause of performance degradation, or some water soluble catalyst poison is formed which is removed by washing. Since KOH is lost during cycling, the initial premise appears to be more likely. This KOH loss factor is definitely accelerated by cyclical operation and indications are that increasing temperature also accelerates the loss. This loss factor will be investigated in depth in the near future.

3.2 Multicell Testing

During the report period, the new insulator separators fabricated from glass epoxy sheet were received, and a 34 series cell, 500 watt prototype was assembled incorporating these separators. Platinized porous nickel plaque electrodes of the standard EOS type were utilized. The intent of the assembly was to use existing hardware to check out the mechanical, thermal and electrochemical characteristics of the 500 watt design, and to debug the readout instrumentation. This unit, designated cell number 1002-34, incorporated stainless steel gas tanks.

The cell was placed in the test chamber, and put on standard cycle, 65 minutes charge at 10 amps, and 35 minutes discharge at a nominal current of 17.5 amps. The cell performed satisfactorily during the initial cycles. However, during the 7th and 8th cycles a wiggle in the cell voltage was observed. In the middle of the 8th discharge, an internal short developed. It was later found that the short was between the positive terminal bus and the negative tank wall at the insulated feed through connector.

During cycling, substantial temperature gradients ($\approx 40^{\circ}C$) were encountered between the cell stack and the end of the hydrogen tank where the feed through was located. Typical temperatures during discharge were $110^{\circ}C$ at the H_2 end of the cell stack and approximately 70° at the tank end. This temperature gradient apparently caused condensation of moisture in the cool end of the tank. The condensed water apparently caused arcing at the copper bus resulting in a metallic short from the bus to the grounded feed through connector. Figure 6 shows data for saturation pressure of KOH solutions vs. temperature and concentration. It shows that approximately 30°C temperature differences can be tolerated without exceeding the saturation pressure of the 40 percent KOH solution and water, and therefore avoiding condensation. However, since all the heat is generated by the cell stack, and the stainless steel tank is a poor conductor, the rate of heat transfer was such that the end of the hydrogen tank did not heat up sufficiently during discharge.

Figure 7 shows typical voltage performance of the unit during its initial cycles. Since the performance of the cell stack was quite good when the short developed, the tanks were disassembled and a new insulated feed through was installed. Asbestos insulation was wrapped around the hydrogen end of the tank in an attempt to keep the end hot enough to prevent additional condensation. The unit was subsequently cycled through the 26th discharge. During the second cycling period, a degradation in discharge voltage was observed similar to that recorded in previous single and 6 cell tests. The discharge voltage during the initial and end portions of discharge was 10-20 percent lower than at the mid point. This performance data is also shown in Figure 7. Large temperature gradients were again observed between the cell stack and the hydrogen tank end, and it was assumed that additional condensation within the unit was occurring due to this temperature gradient. Considering the gradual degradation of performance and the substantial temperature gradient encountered, it was decided to discontinue the test and make modifications on the unit to eliminate the temperature problem.

Examination of the disassembled unit showed all aspects of the internal components in good condition, and did reveal that additional condensation had taken place in the end of the hydrogen tank.

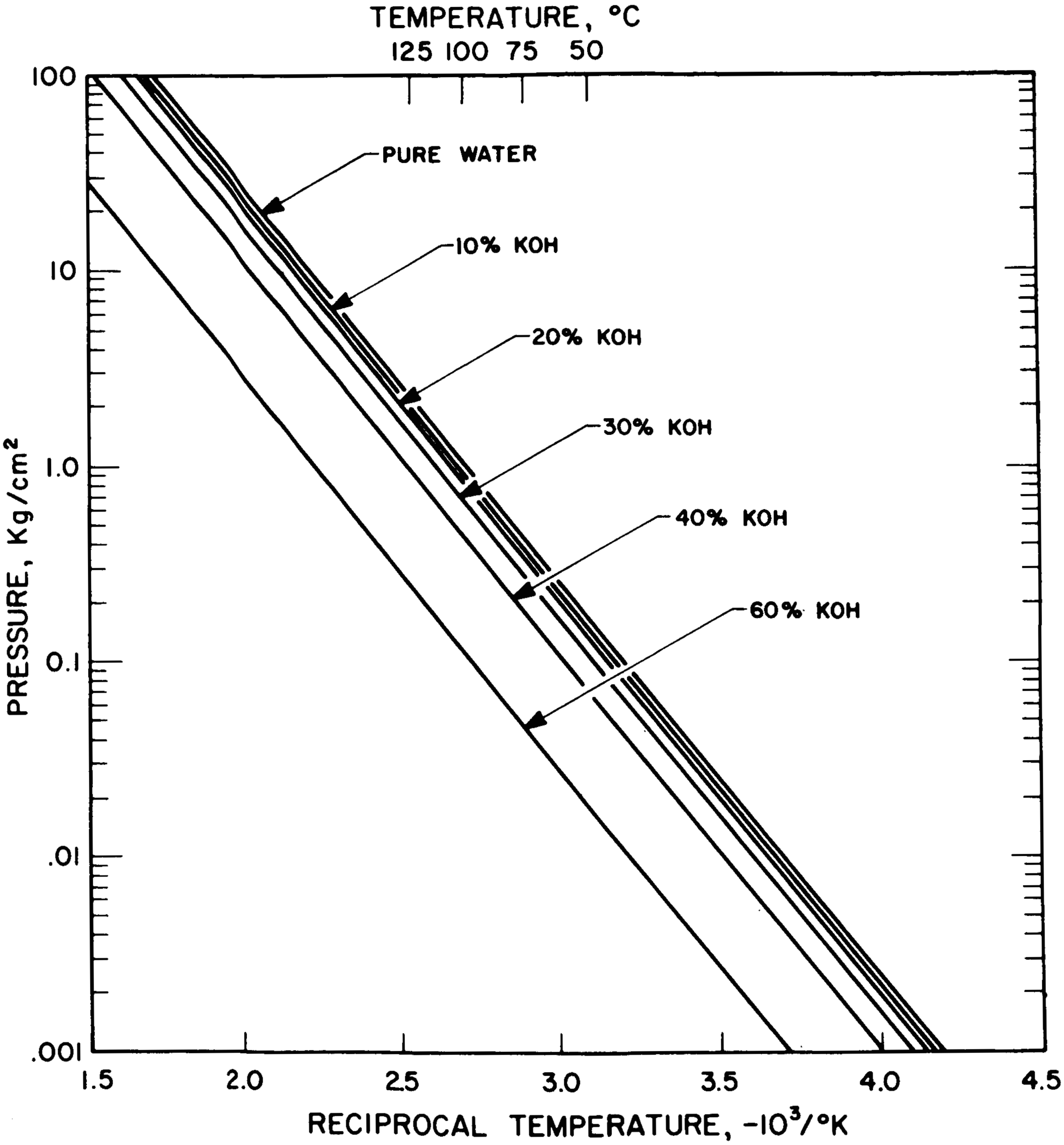

FIG. 6 SATURATION PRESSURE OF KOH SOLUTIONS VS TEMPERATURE AND CONCENTRATION

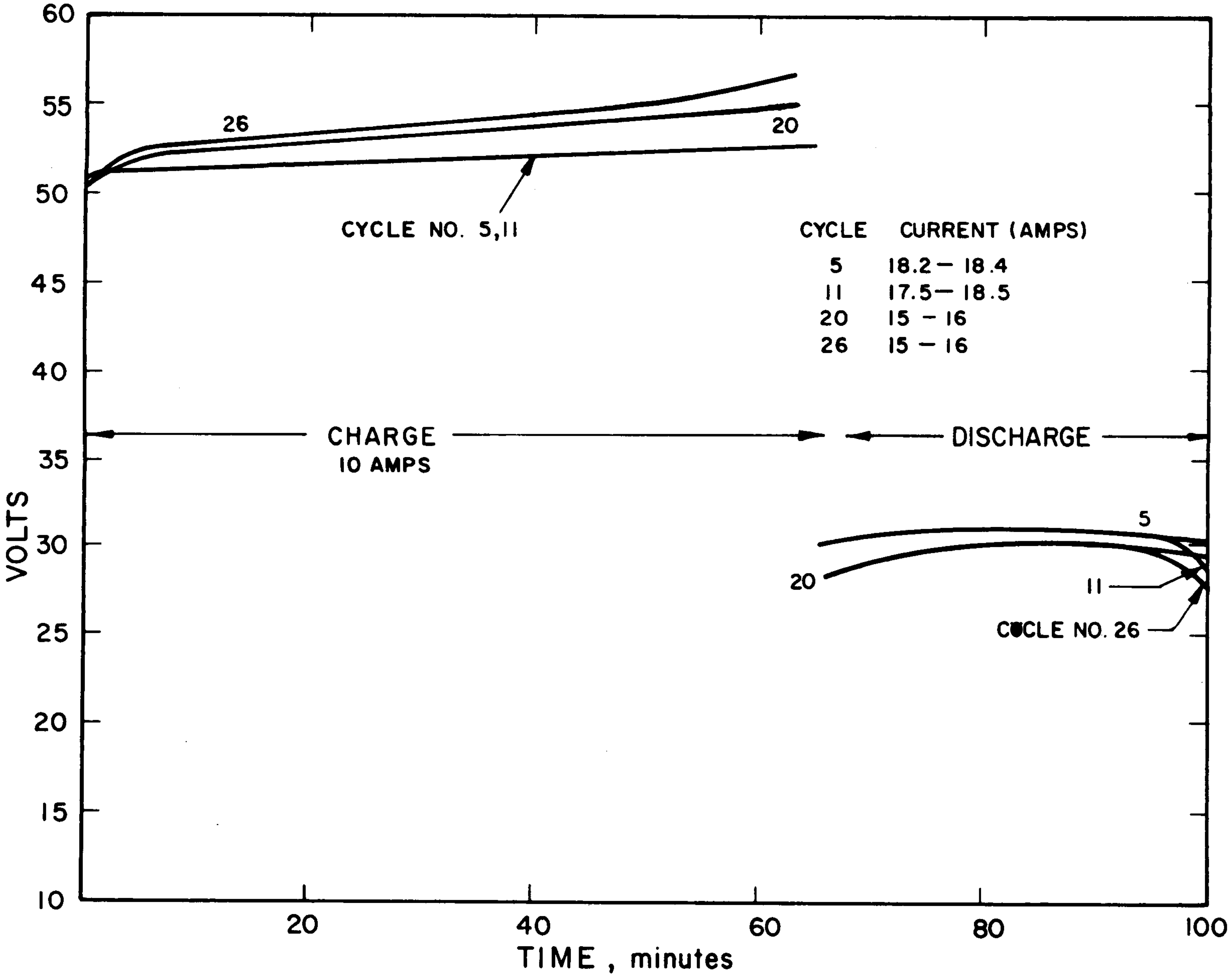

FIG. 7 CYCLING PERFORMANCE OF 500 WATT REGENERATIVE HYDROGEN-OXYGEN FUEL CELL S/N 1002-34

To determine overload capabilities of the unit during the 12th discharge, voltage vs. current data was obtained, and is presented in Figure 8. This showed considerable overload capabilities with minimal polarizations. This data was also utilized in plotting power vs current data which is presented in Figure 9. Line resistance between the cell and the load bank limited the maximum current drawn to ≈ 50 amps. It is believed that powers to ≈ 2000 watts could have been achieved with larger size power lines. (We are presently using No. 8 wire)

These tests of the 500 watt unit showed that the mechanical design, including compensating bellows, tank volumes, etc. was proper, and that the unit is capable of running continously in excess of 500 watts, and has an overload capability > 2.5 times nominal. Temperature gradient and condensation problem encountered can be attributed primarily to the poor thermal conductivity of the stainless steel tank used. It is believed that an aluminum tank, such as will be used in the final design, would have eliminated the problem.

To study the above difficulties, and to obtain additional test information from the unit, the unit was rebuilt and designated serial number 1003-34. This unit contained the same electrodes that were used in the previous unit, except that the bi-polar plates were reversed, i.e., the old oxygen electrodes became the hydrogen electrodes, and the old hydrogen electrodes became the oxygen electrodes. Previous experience from single cell tests has shown that the degradation in performance occurs on the oxygen electrode, and by reversing the electrodes, recovery and good performance can be obtained. The following changes were also made in the new assembly and test set up.

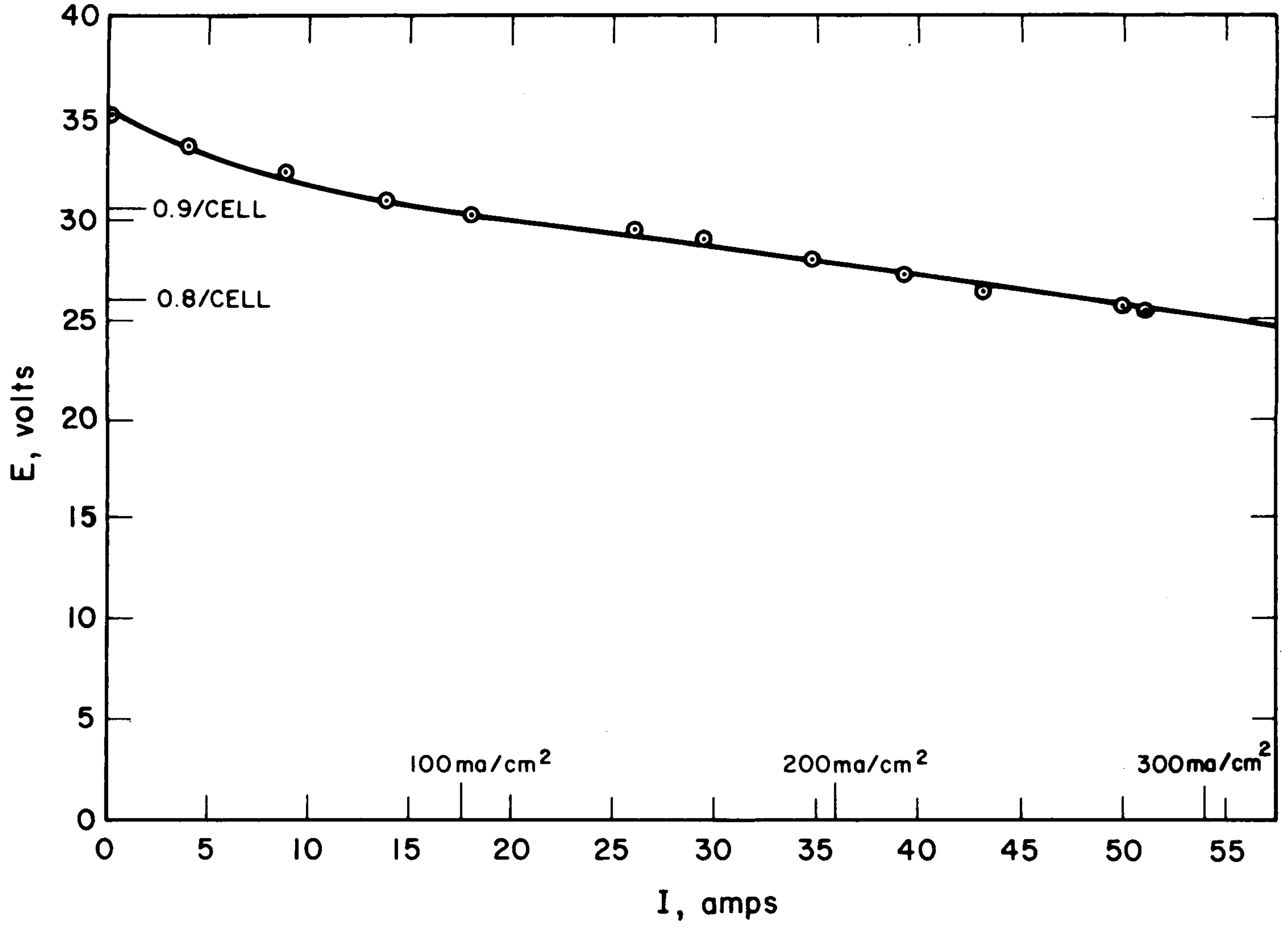

FIG. 8 VOLTAGE VS CURRENT DATA FOR 500 WATT REGENERATIVE HYDROGEN-OXYGEN FUEL CELL S/N 1002-34

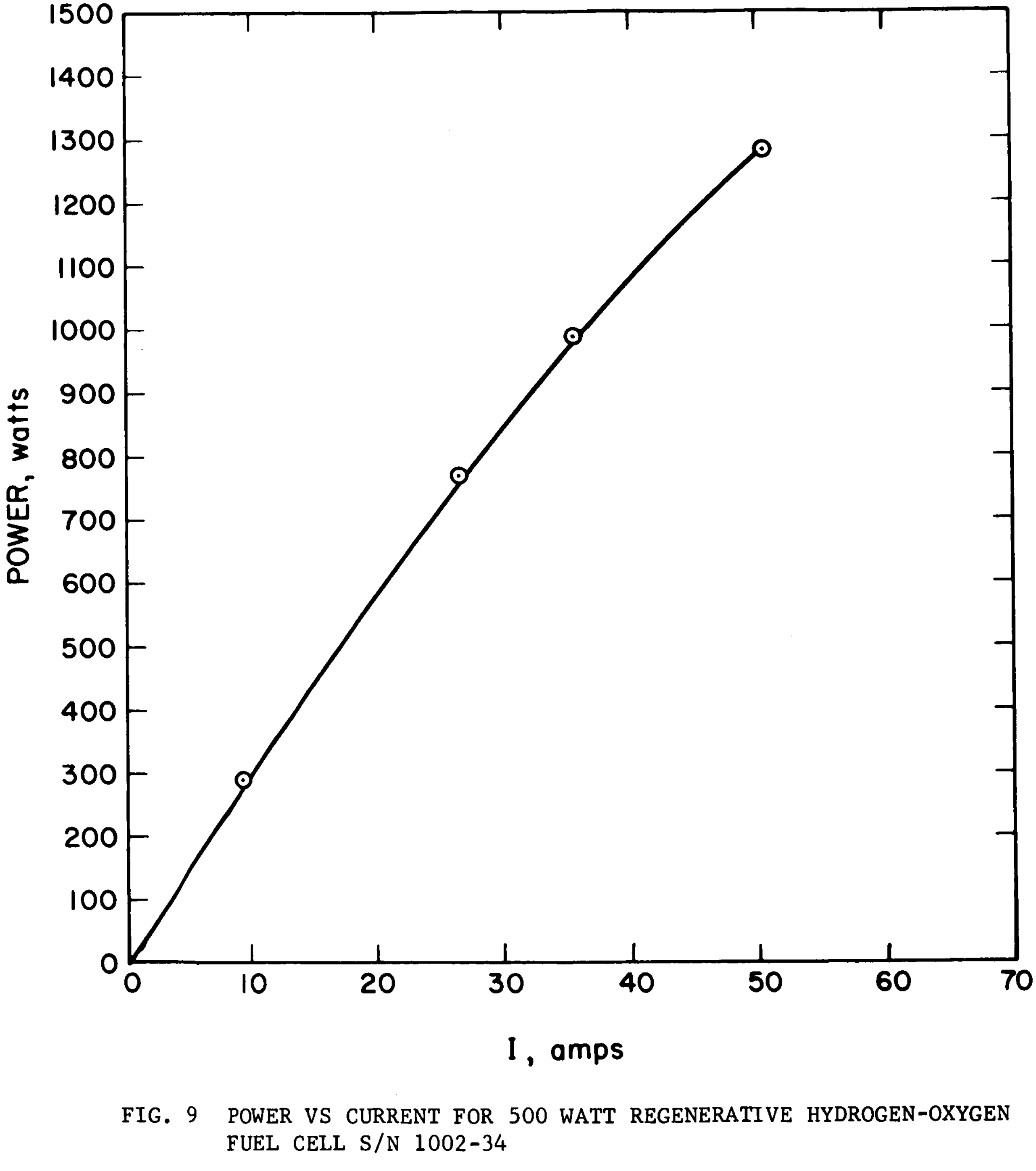

FIG. 9 POWER VS CURRENT FOR 500 WATT REGENERATIVE HYDROGEN-OXYGEN FUEL CELL S/N 1002-34

1. An electrical heating band was placed on the end of the hydrogen gas tank. The heater was connected to a Variac for controlling of the temperature of the H_2 end tank to prevent large gradients and water condensation.

2. The new asbestos mats were impregnated with 50 percent potassium hydroxide to decrease vapor pressure, and further reduce possibilities of condensation within the gas tanks.

3. The previous unit contained a five mil strip of teflon wrapped around the fuel cell stack to prevent vibration shorting of the stack to the walls of the hydrogen tank. This continouos strip was replaced by bands of glass tape that were placed logitudinally down the stack. This change was incorporated to improve the conduction of heat (generated within the stack during discharge) to the outer walls of the hydrogen tank.

4. The internal thermocouple that is connected to the hydrogen end plate was electrically insulated from that plate by means of a mica washer. This thermocouple had caused an instrumentation problem due to being at the cell stack potential. By insulating the couple, the problem was eliminated.

5. To further reduce the temperature gradient of the unit, the entire assembly was inverted such that the hydrogen end was up and the oxygen end was down. It had been observed in the previous test that substantial temperature gradients due to poor circulation existed within the test chamber that was being used to control ambient temperature.

The 34 cell unit was placed in the oven, flushed, and cycled 3 times to check out instrumentation and temperature gradients. The unit was allowed to sit overnight at open circuit, and the following morning a continuous 72 hour cycling test was initiated. The test regime consisted of the standard 100 minute cycle, 65 minutes charge, and 35 minutes discharge. During the cycling a gradual degradation in discharge voltage was observed. This degradation was similar to performance previously observed, and could be attributed to the gradual oxidation of the porous nickel substrate used on the oxygen electrode.

The purpose of the test was not to obtain long term life data since this type of degradation was predictable from previous data. However, since these types of electrodes were available, it was deemed desirable to assemble the unit and run the electrical tests to determine if any other difficulties or deficiencies would become apparent. Aside from the gradual voltage decay, the unit performed satisfactorily. The temperature gradient problem was considerably reduced, and typical gradients between stack and the oxygen tank end, which now exhibited the lowest temperature, was 80-100°C.

Figure 10 shows performance of various cycles throughout the test period. At the completion of the 72 hour test, the unit was allowed to sit at open circuit for approximately the 3 hours, and then a new test was started at a slow rate of charge and discharge. This test consisted of a charge of 4 amps to 500 psi, and then a discharge for 1 hour at 200 watts, and the remainder of the discharge at 50 watts to exhaustion. The test was conducted to see the effects of a slow cycle. Performance is shown in Figure 11. On this slow charge discharge test regime, the unit was capable of delivering in excess of 700 watt hours.

CYCLE NO.	DISCHARGE CURRENT	DISCHARGE PRESSURE RANGE
6	17 - 17.5	310 - 120
25	16.5 - 17	385 - 195
47	15 - 16	380 - 205

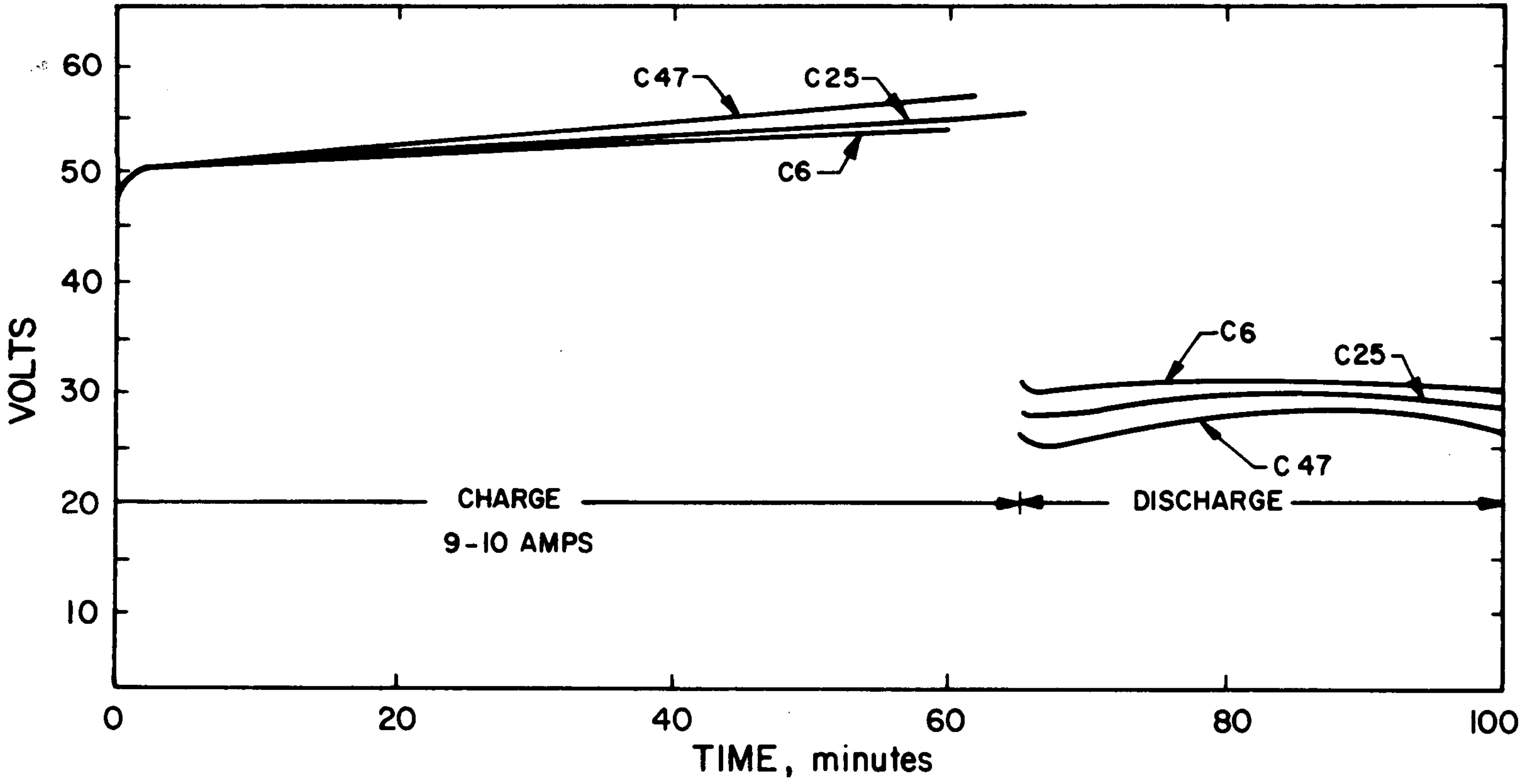

FIG. 10 CYCLING PERFORMANCE OF 500 WATT REGENERATIVE FUEL CELL S/N 1003-34

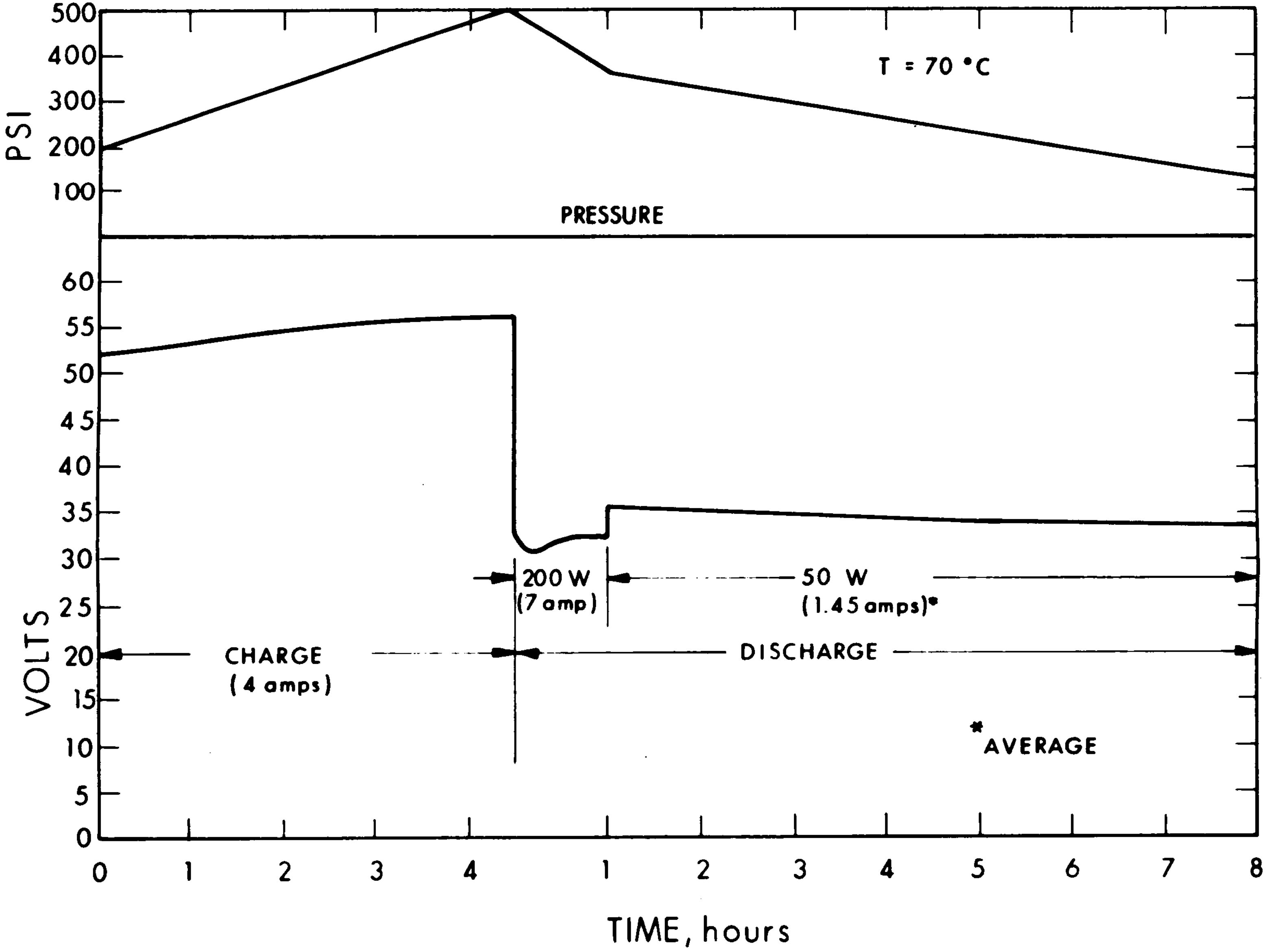

FIG. 11 34 CELL PERFORMANCE FOR 600 WATT HOUR DISCHARGE AS PER JPL SPEC GMP-50-136-DSN-A

After completion of this test, the unit was put back on the 100 minute cycle, 35 minutes discharge, 65 minutes charge. However, due to the degradation in performance that was observed during the 72 hour test, the load levels were reduced, and the charge was conducted at 4 amps, and the discharge at approximately the 200 watt level. At this load level, the unit was cycled continuously unattended for 48 additional cycles. During that period, there was a slight, almost negligible decrease in the discharge voltage. This performance can be seen in Figure 12.

At the start of the 95th charge, recorded data shows a substantial drop in the internal pressure of the unit and in the operating voltage. The differential pressure was off scale during this period, and then dropped to 0 differential. Examination of cycle data showed that substantial differential pressures were rapidly built up at the start of each charge, and gradually reduced as the charge proceeded. This magnitude of the differential pressure apparently increased gradually as cycling proceeded. The differential was due to an excess hydrogen pressure, causing the bellows to reach its fully extended position. Recorded temperature data during the drop-off in pressure point showed a substantial rise in internal temperature of the unit.

Due to this difficulty, the test was stopped, the unit disassembled and examined. Examination of the internal components revealed that the excessive differential pressure had resulted in the splitting of one of the welded seams on the bellows. This resulted in gas mixing and chemically recombination in the oxygen compartment. The hydrogen compartment was perfectly clean while the 0_2 tank and external surfaces of the bellows were oxidized. In addition, the oxygen tank, directly opposite the rip in the bellows, exhibited a highly heated zone indicating that this was the point of high temperature recombination.

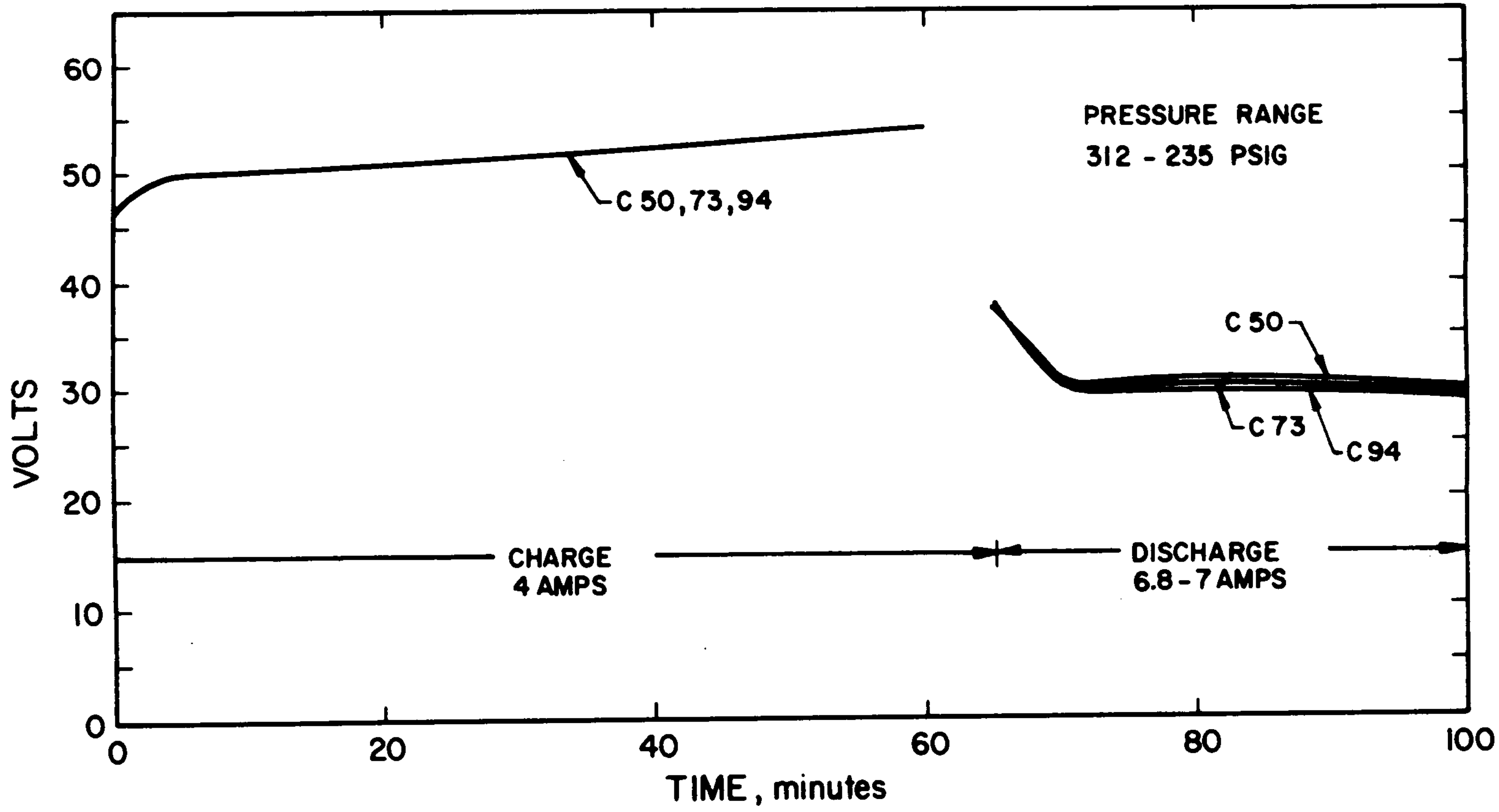

FIG. 12 CYCLING PERFORMANCE OF REGENERATIVE FUEL CELL

All other aspects of the unit were in excellent condition. The fuel cell stack was clean, and showed no obvious effects of the chemical reaction.

The cause of the gradual build-up in hydrogen differential pressure with cycling was not readily apparent. It could have been caused by a slow oxygen leak in the tankage. However, pressure testing of the tankage prior to the disassembly did not reveal any leakage. Another possible explanation could be some irreversible combination of oxygen with the porous nickel electrodes, or any of the materials in the oxygen side of the system.

3.3 Asbestos Studies

To obtain a better understanding of the composition of the asbestos material, and to determine what chemical changes occur within the material, samples were submitted to outside testing laboratories for a semi-quantitative spectrographic analysis.

Two different laboratories were used due to some questions concerning the results obtained from the first laboratory. The first submissions consisted of three different samples (a) the pure asbestos material, (b) asbestos from a used mat adjacent to the oxygen electrode, and (c) asbestos from a used mat adjacent to the hydrogen electrode. The first results are shown on Table 2. This data is presented as a weight ratio compared to magnesium in order to make it easier for relative comparisons. Actual data from the laboratories is reported on a percentage basis, and can be misleading since different total quantities reduce the relative percentages. The actual data obtained is presented in Appendix I.

Table 3 shows the second set of data on four samples also on the basis of a ratio to magnesium content.

TABLE 2

ASBESTOS SPECTROGRAPHIC ANALYSIS

	Pure Material	Sample Adjacent to Hydrogen Electrode	Sample Adjacent to Oxygen Electrode
Magnesium	1.00	1.00	1.00
Silicon	.86	.54	.58
Potassium	Nil	.71	1.315
Boron	.00153	.00022	.00038
Manganese	.0027	.00067	.0011
Aluminum	.0005	.00375	.0017
Iron	.0046	.0116	.0205
Platinum	Nil	.00125	.005
Calcium	.0039	.0396	.0115
Vanadium	.00016	.00006	.0001
Copper	.00021	.00003	.00016
Sodium	Nil	.00167	.028
Titanium	Nil	.000075	.000033
Nickel	Nil	.000067	.00018
Strontium	Nil	Trace	Trace
Chromium	.000023	.000017	.00009

TABLE 3

ASBESTOS SPECTROGRAPHIC ANALYSIS

	Pure Sample	Pure Material with KOH	Sample Adjacent to Hydrogen Electrode	Sample Adjacent to Oxygen Electrode
Magnesium	1.00	1.00	1.00	1.00
Silicon	1.17	1.11	.84	1.00
Potassium	Nil	.67	.78	2.27
Boron	.00034	.00094	.00061	.0001
Manganese	.005	.0036	.0026	.0048
Aluminum	.0046	.0016	.0012	.00091
Iron	.0058	.0035	.0035	.0062
Platinum	.0008	Nil	.0007	.01
Calcium	.0062	.0038	.0035	.0018
Vanadium	Nil	.00009	.00007	.0001
Copper	Nil	.00025	.00025	.00011
Sodium	Nil	.0046	.0023	.057
Nickel	.0003	.00026	.00025	.012
Chromium	Trace	Trace	.00008	Trace

4. CONCLUSIONS

The successful cycling of the 34 cell 500 watt unit has demonstrated the feasibility of a 34 series cell device. Once again the major area of deficiency and performance appears to be the oxygen electrode. This factor will be extensively investigated and during the next quarter. Single cell tests results point to the possibility of utilizing American Cyanamid electrodes with minor modifications as a solution to the limitations of existing oxygen electrodes.

5. REVISION OF PROGRAM

During the early part of this quarter it became apparent that cycle life of the H_2/O_2 secondary battery is limited by degradation of the electrodes and/or asbestos matrices. Therefore, in the best interests of developing a long term device having a high watt hour per pound capability, it was deemed necessary to investigate the causes of degradation prior to completing hardware development. Approval for this program revision was obtained during the last week of the quarter.

6. PLANS FOR THE NEXT PERIOD

Single cell tests will be conducted to evaluate in depth the following oxygen electrodes:

1. American Cyanamid electrodes.
2. Porous nickel plaques that have been gold coated prior to platinization.
3. Felt metal nickel plaques that have been gold coated prior to platinization.
4. Non sintered teflon, platinum black electrodes.

When one of the above type electrode structures looks promising and cycles continuously for 100 hours, this type structure will be incorporated in a six cell unit and subjected to long term cycling. Additional single cell test stations with appropriate instrumentation will be assembled and built to enable conducting of a greater number of tests simultaneously. Two test stations with instrumentation for 6 cell assemblies will also be added during the period.

Asbestos studies to evaluate chemical and/or electrochemical reactions that occur between the asbestos and electrolyte will be initiated. The Johns Manville Corporation has been generous in their advice to us on this subject, and is cooperating in a commendable manner.

APPENDIX

Actual Spectrographic Analysis on a Percentage Basis of Asbestos Samples

Series 1

	Pure Material	Sample Adjacent to Hydrogen Electrode	Sample Adjacent to Oxygen Electrode
Silicon	24.	13.	11.
Magnesium	28.	24.	19.
Potassium	nil	17.	25.
Boron	0.043	0.0049	0.0073
Manganese	0.075	0.016	0.021
Aluminum	0.014	0.090	0.032
Iron	1.3	0.28	0.39
Platinum	nil	0.030	0-095
Calcium	0.11	0.95	0.22
Vanadium	0.0046	0.0014	0.0020
Copper	0.0058	0.00079	0.0031
Sodium	nil	0.040	0.54
Titanium	nil	0.0018	0.00062
Nickel	nil	0.0016	0.0034
Strontium	nil	trace	trace
Chromium	0.00065	0.00041	0.0017

Series 2.	Pure Material with KOH	Adjacent to Hydrogen Electrode	Adjacent to Oxygen Electrode	Pure Material
Potassium	12.	15.	25.	Not detected less than 0.20 %
Magnesium	18.	19.	11.	24.
Silicon	20.	16.	11.	28.
Iron	0.064	0.066	0.068	0.14
Calcium	0.069	0.066	0.020	0.15
Manganese	0.065	0.050	0.048	0.12
Platinum	not detected less than 0.001	0.013	0.11	0.019
Boron	0.0017	0.0037	0.0011	0.0081

Lead	trace less than 0.01	not detected	0.010	not detected less than 0.01
Aluminum	0.021	0.024	0.010	0.11
Vanadium	0.0016	0.0014	0.0012	not detected less than 0.001
Copper	0.0046	0.0046	0.0013	0.0097
Sodium	0.083	0.44	0.62	not detected less than 0.04
Nickel	not detected less than 0.0005	0.0047	0.13	0.0073
Chromium	trace less than 0.0005	0.0015	trace less than 0.0005	trace
Other elements	nil	nil	nil	nil

7. FINANCIAL STATEMENT

Manhours and dollar expenditure for the period August 27 through October 1, 1965 were as follows:

Direct Labor Hours	700.5
Direct Labor Dollars	$3,264.74
Purchases and Commitments	- 397.11 *
Total Dollar Expenditure	$8,290.66

* Represents credit due to cancellation of commitment for insulator separators from W. Shamban, Inc.