

SECOND QUARTERLY REPORT

for

CHARACTERIZATION OF RECOMBINATION AND CONTROL  
ELECTRODES FOR SPACECRAFT NICKEL-CADMIUM CELLS

September 9, 1966 - December 9, 1966

CONTRACT NO.: NAS 5-10241

Prepared By

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for

GODDARD SPACE FLIGHT CENTER  
Greenbelt, Maryland

FACILITY FORM 502

N67-261.7.0.

(ACCESSION NUMBER)

29  
(PAGES)

CR 83498  
(NASA CR OR TMX OR AD NUMBER)

(THRU)

(CODE)

03  
(CATEGORY)

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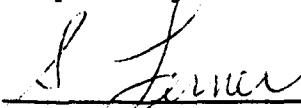
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CHARACTERIZATION OF RECOMBINATION AND CONTROL ELECTRODES  
FOR SPACECRAFT NICKEL-CADMIUM CELLS

by  
S. Lerner and H. N. Seiger

ABSTRACT

Cells containing various materials as oxygen scavenger electrodes, and cells containing active Adhydrodes in various positions, have been prepared and studied in order to determine the best combination for use in cells that will contain both types of electrodes. It has been determined that the best scavenger electrode material is the AB6X fuel cell electrode and the best position for the Adhydrode is in the center of the pack. Preliminary testing of cells with both types of auxiliary electrodes has been initiated.

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## INTRODUCTION

High rate charging (rates in excess of C/5) of sealed nickel-cadmium batteries is a desirable mode of charge. Its desirability is due to the necessity of fast charging after deep discharge in low orbits, and also because a higher rate charge is efficient. High rate charging is avoided except where control of the amount of charge may be employed. When controlling, we must include some overcharge. The minimum input must be that which compensates for charge inefficiency, or else there will be a continual rundown in capacity, and the maximum input avoids building up pressures to the burst point. A good control stops or alters charge after the point where the overcharge compensates for charge inefficiency, and before the point where the internal cell pressure becomes excessive.

A control that has many attractive attributes is the Adhydrode<sup>®</sup> (the adsorbed hydrogen electrode). By careful setting of the trip point, which is the signal across the load resistor between the Adhydrode and the negative electrode, a single level can safely and adequately control high rate charge over a suitable range of temperatures. The Adhydrode is, in a manner of speaking, a self-powered transducer. If the cell characteristics change with use or time, the result is that the signal generated will reflect this change. This situation does, in fact, occur. The negative electrodes recombine oxygen at decreasing rates over several hundred cycles. If we can get the oxygen recombination at faster rates, this disadvantage of the Adhydrode can be overcome. An oxygen getter, or scavenger electrode, appears to be a reasonable approach to this problem.

The objective of this program is to produce cells containing the Adhydrode and scavenger electrodes. This will be accomplished through an investigation of materials as a scavenger electrode, and the fabrication of such cells and batteries for evaluation.

## OUTLINE OF PROGRAM

The program has been completely outlined in the previous quarterly report and will be reviewed here only briefly. The program has been divided into three parts. The first involves the evaluation and improvement of scavenger electrodes. The second part of the program will be an evaluation of the third, or active Adhydrode, electrode characteristics. The final part of the program will be devoted to testing cells containing the best features determined from the first two parts of the program.

### Testing of Scavenger Electrodes

Scavenger electrodes of the Adhydrode type, of various porosities and thicknesses, along with two different types of fuel cell electrodes, were tested to determine their ability to recombine oxygen. These were tested in both working cells and in a specially designed test chamber<sup>(1)</sup>

### Active (Third) Electrode

Three locations for the active electrode were studied; they are:

- (1) A "U" shaped electrode placed in a side position.
- (2) A flat plate electrode placed at one end of the pack.
- (3) A flat plate electrode placed in the center of the pack.

### Testing

When the optimum configurations for the scavenger and signaling electrodes have been determined, they will be used in combination for final testing.

Temperature Characteristics. - The above cells shall be tested at four different temperatures and three different depths of discharge.<sup>(1)</sup> The test shall be 1 week's cycling at each temperature and depth of discharge using a 60-30 minute orbit.

Life Testing. - The best cells will be life tested at room temperature at both 40% and 60% depths of discharge using a 60-30 minute orbit.

## EXPERIMENTAL PROCEDURES & RESULTS

### Construction & Testing Of Cells With Scavenger Electrodes

Eighteen test cells (numbered 1 through 18) were constructed with six different configurations as shown in Table I. The cells were filled with 45 cm<sup>3</sup> of electrolyte, evacuated and pressurized to 50 PSIG with oxygen which was allowed to recombine. From the void volume of the cells (102 cm<sup>3</sup>) it was determined that the capacity of the negatives was reduced by 1.5 AH.

All cells were then placed on a C/10 (1.2 A) charge to determine capacity.

After 12 hours of the C/10 charge rate, only a few cells did not leak and some had high pressures. At the end of 20 hours at the C/10 rate, 3 cells reached a steady state pressure. The cells were then discharged at C/2 (6.0 A) and the capacities are given in Table II.

Based on the low capacity of the cells that contained multiple passive Adhydrodes along with the fact that large amounts of hydrogen were evolved due to the low negative capacity, it was decided to concentrate on the fuel cell electrodes, especially the American Cyanamid AB6X, as the preferred scavenger electrodes.

Twelve additional cells were built and their construction is shown in Table III. The negatives were discharged 1.5 AH by the addition of oxygen. The cells were then subjected to four charge-discharge cycles at 5 amperes to determine their capacity. The results of these capacity tests are shown in Table IV. Based on the capacity data, cells 22, 23, 24, and 26 were chosen for further testing, rated at 9.5 AH capacity, and placed on a manual 55% depth of discharge cycle using a 90 minute orbit with a 20% overcharge. Upon the completion of nine cycles on this orbit, all of the cells had run down to an end discharge voltage of 1.0 volt or less.

Cells 23 and 24 were again placed on cycle at a 55% depth of discharge with a 10% overcharge. The cycle consisted of 60 minutes of charge followed by 30 minutes of discharge. Both cells satisfactorily completed 113 cycles, with cell 23 operating at a pressure of between 1 and 10 PSIA and cell 24 operating between 40 and 50 PSIA. At the end of charge, on the 114th cycle, cell 24 catastrophically failed at 50 PSIA; voltage measurements indicated that the cell had not shorted. A post mortem on the cell revealed that the separator had melted on the bottom edge of four of the plates. If, two of the plates (a positive and a negative) had momentarily shorted and the gas was a mixture of hydrogen and oxygen, the spark caused by this shorting may very well have caused the failure. Cell 23 was put back on cycle and has, to date, (12/9/66) completed 320 satisfactory cycles and is operating in the pressure range of 2 to 10 PSIA. It is probable that if the charge had been controlled by means of the Adhydrode signal, the failure of cell 24 would have been avoided.

TABLE I. CONSTRUCTION OF SCAVENGER TEST CELLS

| CELLS | NO. POSITIVES | NO. NEGATIVES | NO. & TYPE SCAVENGER    | REMARKS |
|-------|---------------|---------------|-------------------------|---------|
| 1-3   | 10            | 10            | 1 AB6X Fuel Cell        |         |
| 4-6   | 10            | 10            | 1 Leeson Moos Fuel Cell |         |
| 7-9   | 10            | 10            | 1 Adhydrode             |         |
| 10-12 | 10            | 9             | 2 Adhydrodes            |         |
| 13-15 | 10            | 11            | Control Cells           |         |
| 16-18 | 10            | 7             | 4 Adhydrodes            |         |

TABLE II. CAPACITIES OF CELLS AFTER 20 HOUR C/10 CHARGE  
DISCHARGED AT C/2

| CELL NO. | CAPACITY - AH | REMARKS                                                         |
|----------|---------------|-----------------------------------------------------------------|
| 2        | 8.6           | Cells 1, 3, 4, 9, 11, 12, 13, and 16 leaked.<br>Cell 18 shorted |
| 5        | 9.3           |                                                                 |
| 6        | 9.2           |                                                                 |
| 7        | 9.0           |                                                                 |
| 8        | 10.4          |                                                                 |
| 10       | 9.1           |                                                                 |
| 14       | 7.6           |                                                                 |
| 15       | 7.6           |                                                                 |
| 17       | 7.6           |                                                                 |

TABLE III

CONSTRUCTION OF CELLS WITH SCAVENGER ELECTRODES

| CELL NO. | NO. POSITIVE PLATES | NO. NEGATIVE PLATES | NO. & KIND SCAVENGER ELECTRODES |
|----------|---------------------|---------------------|---------------------------------|
| 19-21    | 10                  | 10                  | Control Cells                   |
| 22-24    | 10                  | 11                  | 1 AB6X                          |
| 25-27    | 10                  | 10                  | 2 AB6X                          |
| 28-30    | 10                  | 10                  | 1 Leeson Moos                   |

Cells 21, 25, and 27 were shorted and not tested.

TABLE IV

CAPACITY DETERMINATIONS OF CELLS WITH SCAVENGER  
ELECTRODES

| CYCLE                 | CAPACITY (AH)/CELL |            |            |            |            |            |            |            |            |
|-----------------------|--------------------|------------|------------|------------|------------|------------|------------|------------|------------|
|                       | CELL<br>19         | CELL<br>20 | CELL<br>22 | CELL<br>23 | CELL<br>24 | CELL<br>26 | CELL<br>28 | CELL<br>29 | CELL<br>30 |
| 1                     | 10.3               | 10.2       | 10.9       | 10.8       | 10.8       | 11.0       | 10.0       | 9.3        | 9.3        |
| 2                     | 8.8                | 8.8        | 10.1       | 9.2        | 9.5        | 9.3        | 9.3        | 8.7        | 8.3        |
| 3                     | 8.9                | 8.8        | 10.2       | 9.5        | 9.3        | 9.6        | 9.1        | 8.7        | 8.7        |
| 4                     | 8.3                | 8.0        | 9.8        | 9.5        | 9.3        | 9.5        | 8.8        | 8.8        | 8.1        |
| Avg. Last<br>3 Cycles | 8.7                | 8.5        | 10.0       | 9.4        | 9.4        | 9.5        | 9.1        | 8.8        | 8.4        |

### Construction & Testing Cells With Active Adhydrodes

Nine cells with active Adhydrodes were built. Three cells had the Adhydrode in the "U" shape, three had the Adhydrode at one end of the pack, and three had the Adhydrode in the middle of the pack. The construction of these cells is shown in Table V..

Before testing, the cells were pressurized with enough oxygen to reduce the capacity of the negative by 1.5 AH. Three charge-discharge cycles at 5 A were completed. During the charge, both the pressure and Adhydrode signal (across a 1 ohm resistor) were monitored. A typical Adhydrode signal versus pressure curve for each of the three Adhydrode positions is shown in Figures 1-3. The trend, shown by these figures, is followed in the other cycles in that the Adhydrode placed in the center of the pack showed a consistently greater signal to pressure ratio than the Adhydrodes placed in either of the other two positions.

A possible explanation for the experimental results is the availability of water to the Adhydrode. In the "U" position, water is available only due to the wicking action of the separator. However, when the Adhydrode is in the pack, water is available by direct contact with that absorbed in the electrodes and separator. Also, the Adhydrode in the center of the pack has both sides in contact, while in the end position, only one side is in direct contact with the liquid phase.

### Construction and Testing Cells With Scavenger Electrodes and Active Adhydrodes

Four cells with scavenger electrodes and active Adhydrodes were constructed. Each cell contained 10 positives, 11 negatives, 1 AB6X fuel cell electrode shorted to the negative terminal and an active Adhydrode placed in the center of the pack and connected to a third terminal. The cells contained 45 cm<sup>3</sup> KOH and were numbered 40, 41, 42, and 43. After construction, the cells were pressurized with enough oxygen that the capacity of the negatives was reduced by 1.5 AH. The capacity of the cells was determined to be:

| CELL        | 40  | 41  | 42  | 43  |
|-------------|-----|-----|-----|-----|
| CAPACITY AH | 8.3 | 8.5 | 6.4 | 8.0 |

The Adhydrode sensitivity was measured with a 1/4, 1, 7, and 100 ohm resistor between the Adhydrode and the negative. The sensitivity curves are shown in Figures 4, 5, and 6. The cells were fully charged and then discharged to a 50% depth based on an 8.0 ampere-hour capacity.

TABLE V

CONSTRUCTION OF CELLS WITH ACTIVE ADHYDRODE

| CELL NO. | NO. POSITIVE PLATES | NO. NEGATIVE PLATES | NO. & POSITION OF ADHYDRODE |
|----------|---------------------|---------------------|-----------------------------|
| 31-33    | 10                  | 10                  | 1 U Shaped                  |
| 34-36    | 10                  | 10                  | 1 End of Pack               |
| 37-39    | 10                  | 10                  | 1 Middle of Pack            |

Cell 31 was shorted and not tested.

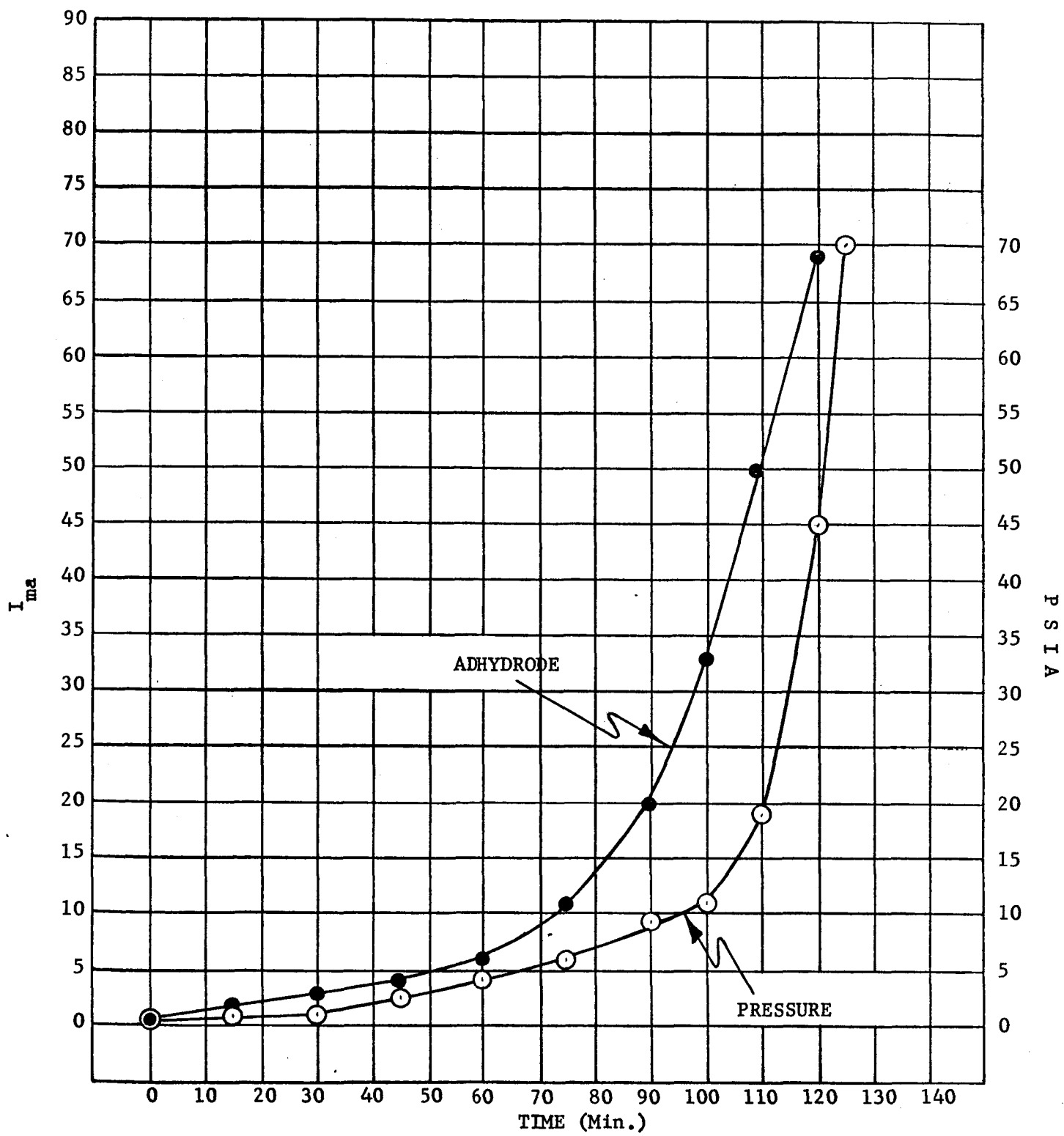


FIGURE 1

"U" SHAPED

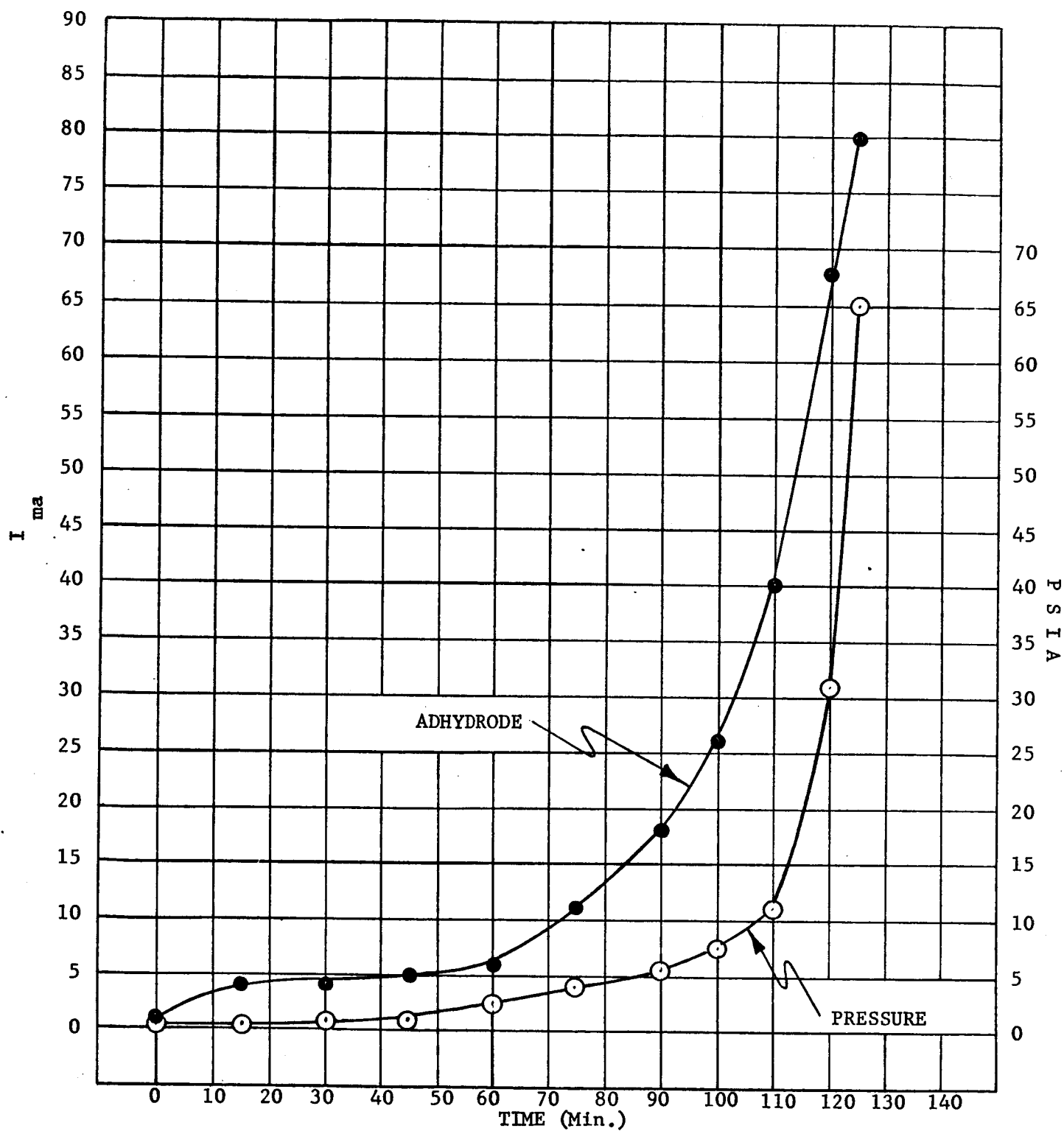


FIGURE 2 END OF PACK

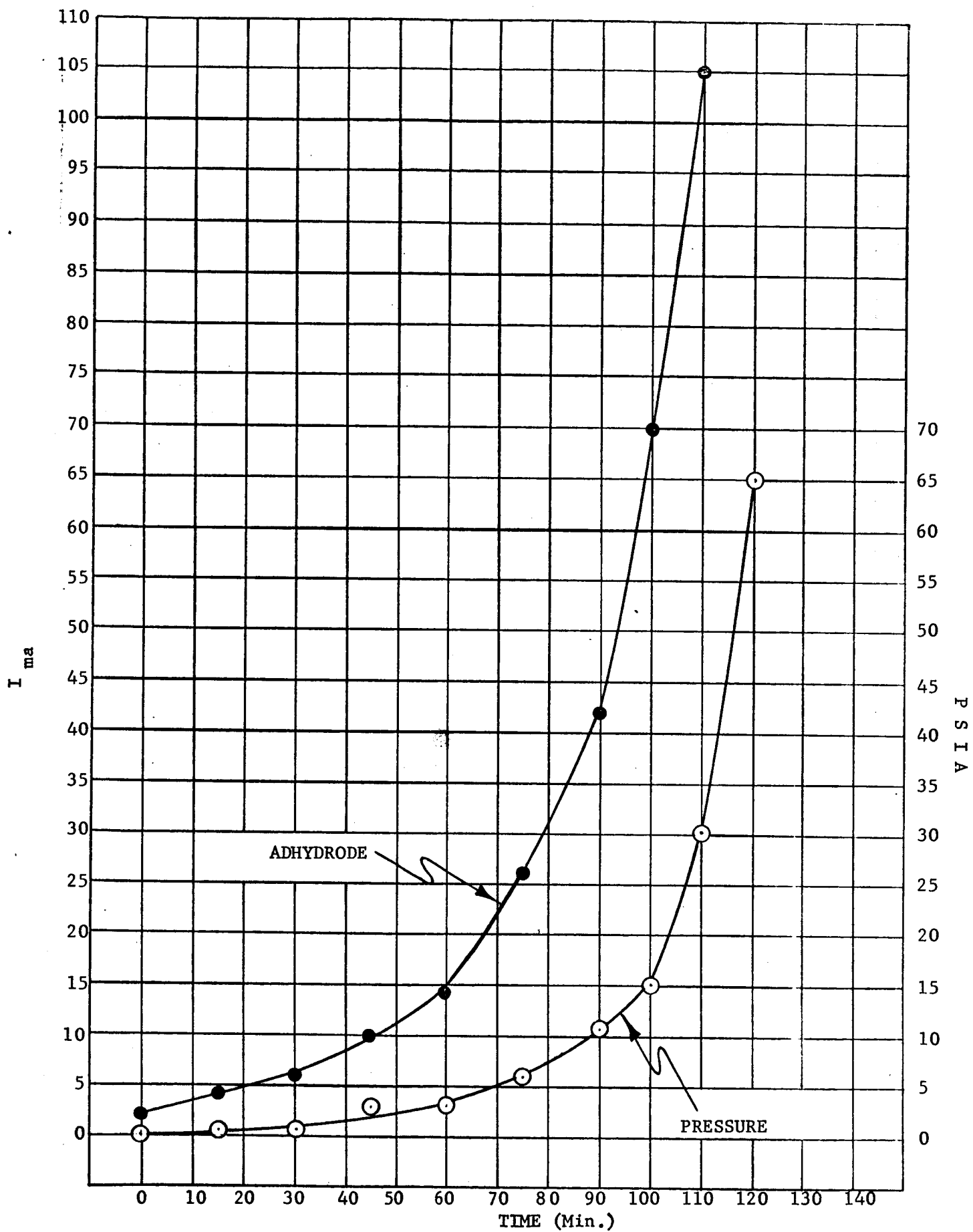


FIGURE 3

MIDDLE OF PACK

4-1013

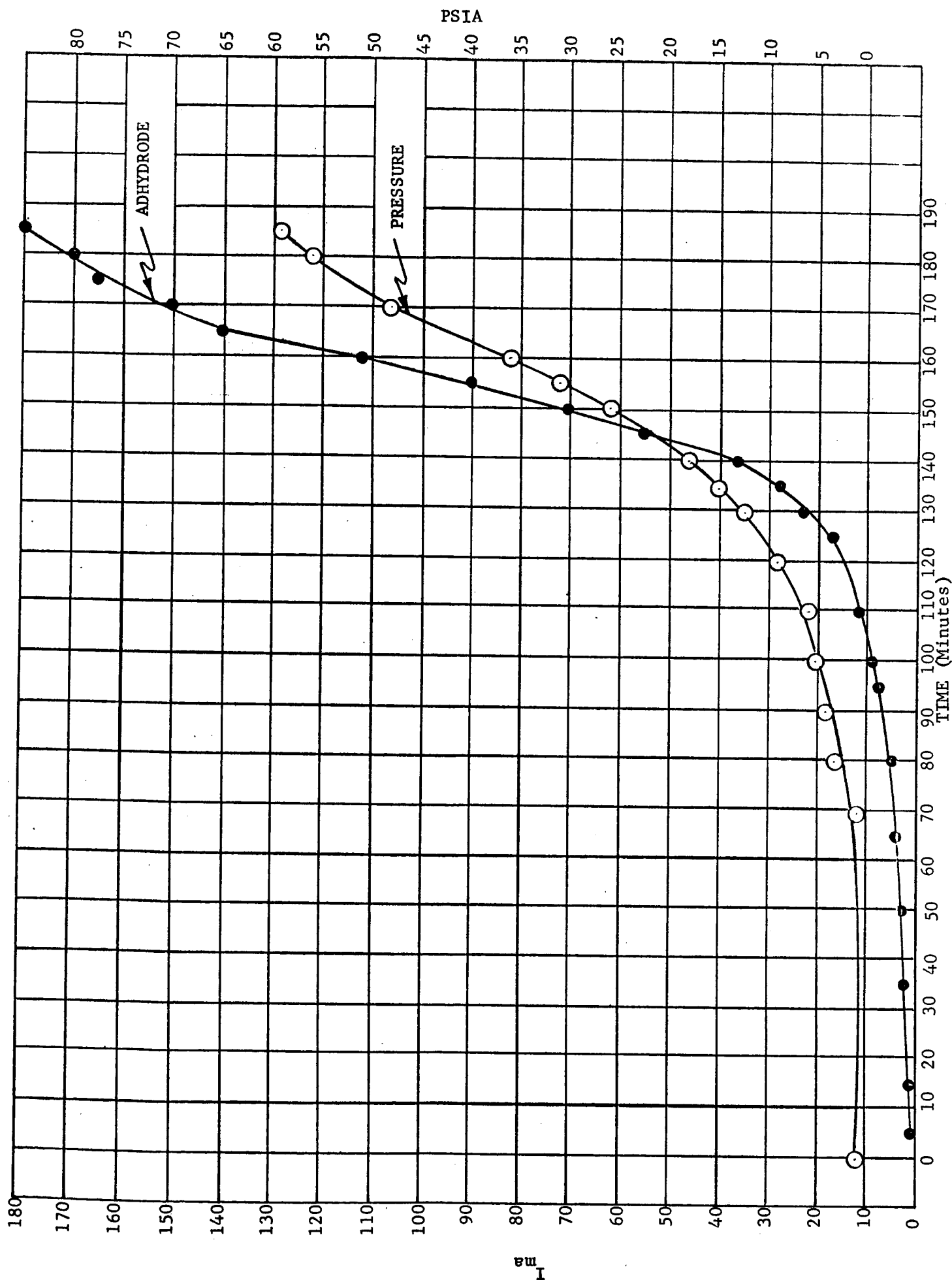


FIGURE 4. TYPICAL ADHYDROPORE SENSITIVITY CURVE - 1/4 AND 1 OHM RESISTOR

4-1134

NASA/G ADHYDROPORE

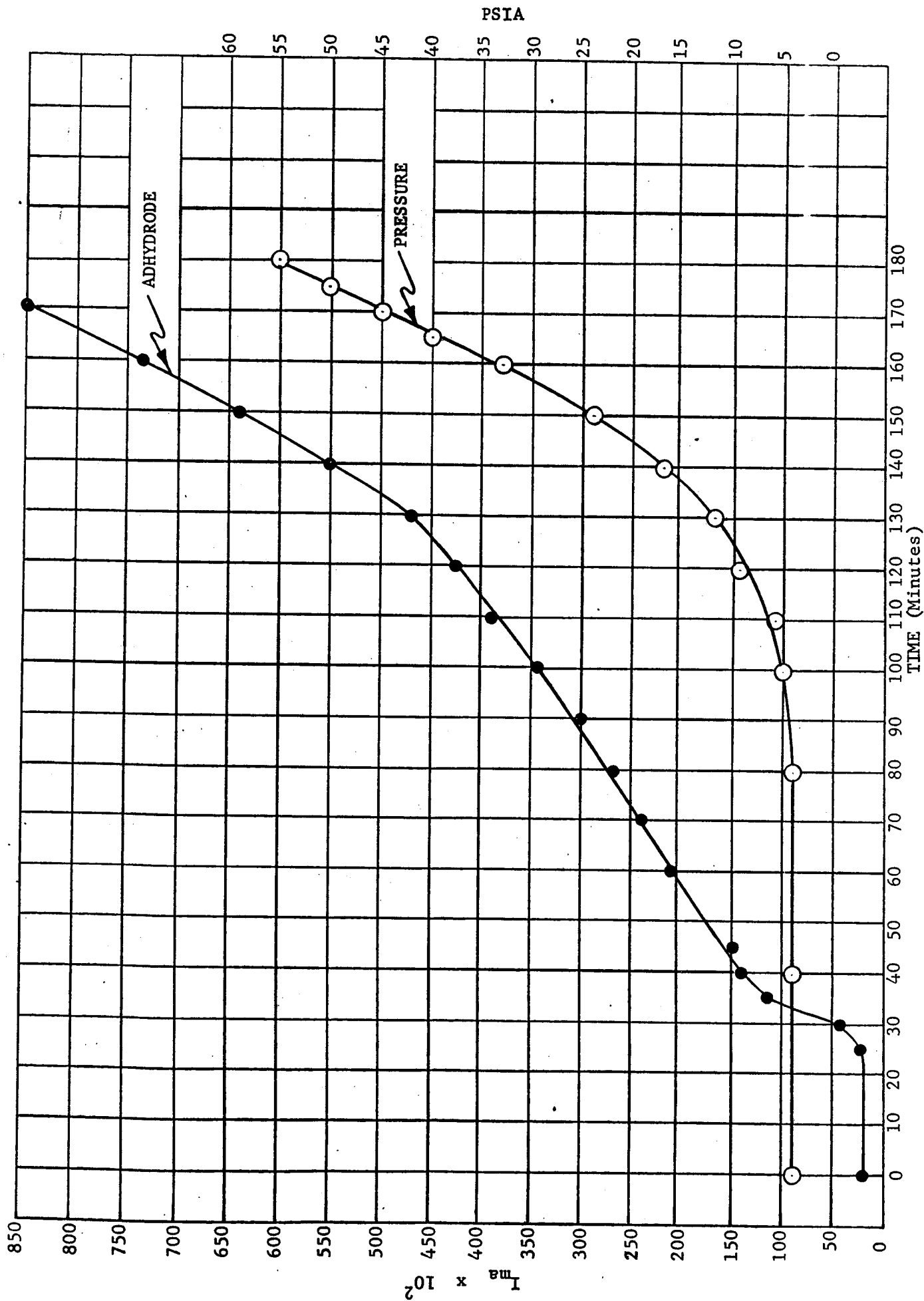


FIGURE 5. TYPICAL ADHYDRODE SENSITIVITY CURVE -- 100 OHM RESISTOR

4-1135

ADHYDRODE (3000)

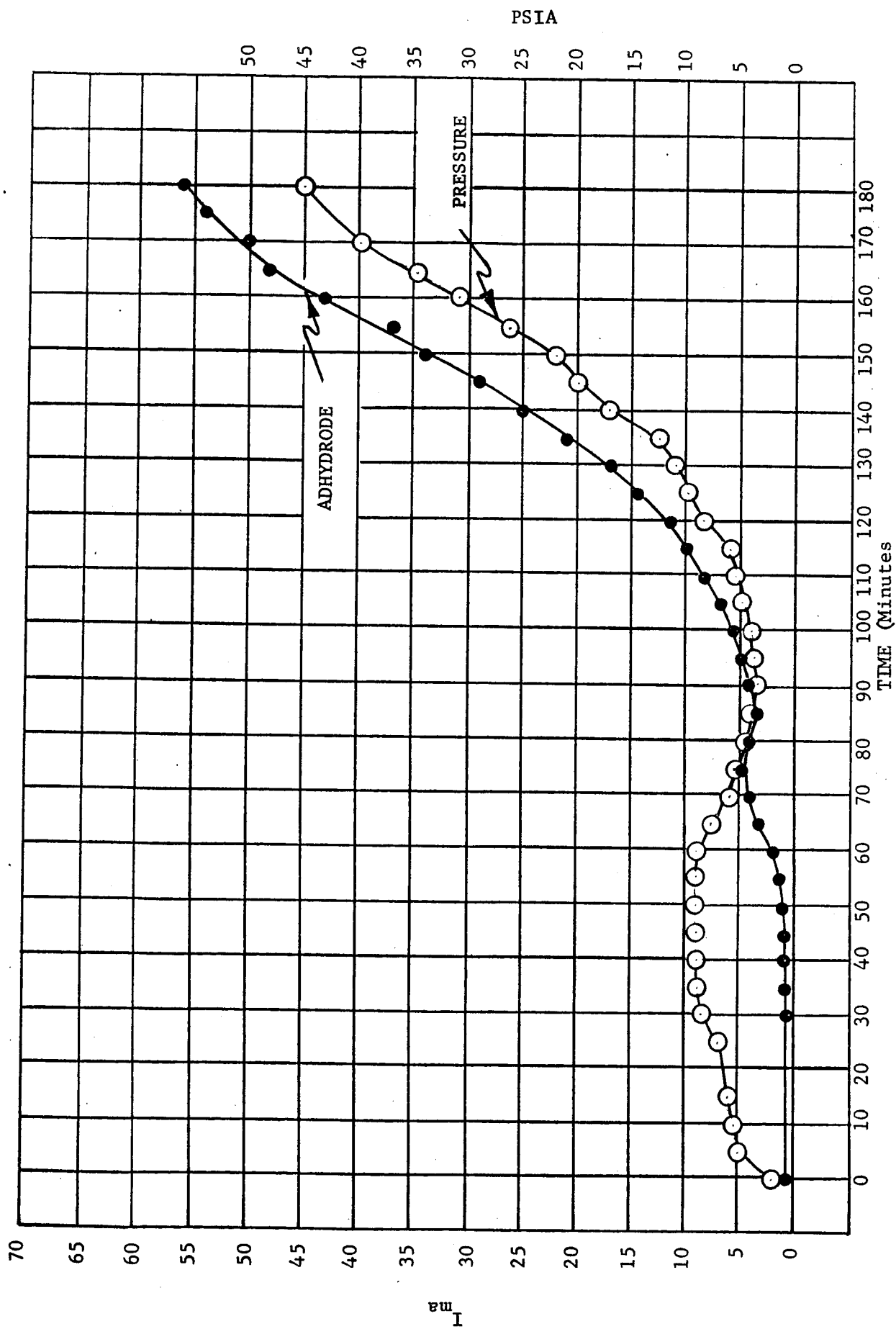


FIGURE 6. TYPICAL ADHYDRODE SENSITIVITY CURVE -- 7 OHM RESISTOR

The cells were then charged at 7.0 A (at this rate, 34 minutes is required to exactly return the removed capacity) and the pressure rise and Adhydrode signal (across a 1/4 ohm resistor) were recorded. These data are shown in Table VI. A 1/4 ohm resistor was used since the quantity measured is actually voltage and the meter on the automatic cycling device which will be used has a maximum full-scale deflection of 50 mv. From the data in Table VI and a subsequent repetition of the experiment, it was decided to use Cell 42 as the controlling cell using a 25 mv Adhydrode cut-off. Figure 7 shows the Adhydrode signal developed as a function of pressure for Cell 42..

Since the automatic cyclers, which allows the cells to be charged to an Adhydrode signal cut-off and then discharged, is under construction but is not yet operable, the four cells were manually cycled on a 60 minute charge-30 minute discharge orbit to 50% depth of discharge, consisting of a charge lasting to the Adhydrode cut-off (25 mv on Cell 42); an open circuit stand for the remainder of the 60 minute period and a 30 minute discharge. The cells completed sixteen such cycles. Figure 8 is a typical two cycle curve for the control cell. Three of the cells were placed on an auto-cycling routine which consisted of a 5.5 A charge for 60 minutes and a 9.5 A discharge for 30 minutes (60% DOD).

This type of cycle allows for no open circuit stand between the end of charge and the beginning of discharge. However, even under this regime, two of the cells are operating close to, or in, vacuum ( $P < 15$  PSIA) and the third is operating in the range of 15 to 40 PSIA. To date, the cells have completed 48 successful cycles and will be continued on cycle and monitored for the remainder of the program. Figures 9-11 are typical curves for all three cells.

PROJECT \_\_\_\_\_

DATA SHEET

DATE \_\_\_\_\_

TEST DESCRIPTION

OPERATOR \_\_\_\_\_

TABLE VI

PRESSURE VERSUS ADHYDRODE SIGNAL

1/4 OHM, 7.0 AMPERE CHARGE

| CELL NO. |  | 40   |                | 41   |                | 42   |                | 43   |                |
|----------|--|------|----------------|------|----------------|------|----------------|------|----------------|
| TIME     |  | PSIA | mv =<br>1/4 ma | PSIA | mv =<br>1/4 ma | PSIA | mv =<br>1/4 ma | PSIA | mv =<br>1/4 ma |
| 0        |  | 21   | 29             | 40   | 9              | 5    | 1              | 5    | 1              |
| 3        |  | 20   | 27             | 39   | 9              | 5    | 1              | 5    | 1              |
| 5        |  | 20   | 26             | 39   | 9              | 5    | 1              | 5    | 1              |
| 7        |  | 19   | 25             | 38   | 9              | 5    | 1              | 5    | 1              |
| 10       |  | 18   | 20             | 36   | 10             | 5    | 1              | 5    | 1              |
| 13       |  | 18   | 19             | 36   | 10             | 5    | 2              | 5    | 2              |
| 15       |  | 18   | 19             | 36   | 10             | 5    | 2              | 5    | 2              |
| 18       |  | 19   | 20             | 38   | 11             | 5    | 2              | 5    | 2              |
| 20       |  | 20   | 21             | 39   | 11             | 5    | 3              | 5    | 3              |
| 22       |  | 21   | 23             | 39   | 12             | 5    | 4              | 5    | 3              |
| 25       |  | 24   | 27             | 41   | 14             | 7    | 5              | 5    | 5              |
| 27       |  | 26   | 29             | 43   | 15             | 9    | 6              | 7    | 6              |
| 29       |  | 29   | 34             | 44   | 16             | 10   | 8              | 8    | 7              |
| 30       |  | 30   | 35             | 45   | 18             | 11   | 9              | 9    | 8              |
| 32       |  | 32   | 39             | 46   | 19             | 11   | 10             | 10   | 10             |
| 34       |  | 35   | 42             | 50   | 20             | 13   | 12             | 10   | 12             |
| 36       |  | 39   | 48             | 52   | 22             | 15   | 14             | 11   | 15             |
| 38       |  | 41   | 50+            | 55   | 24             | 18   | 17             | 14   | 30             |
| 40       |  | 45   | 50+            | 59   | 27             | 20   | 20             | 19   | 33             |
| 42       |  | 49   | 50+            | 63   | 26             | 23   | 27             | 23   | 36             |
| 45       |  | 55   | 50+            | 67   | 29             | 29   | 40             | 26   | 41             |
| 48       |  | 60   | 50+            | 70   | 33             | 34   | 50+            | 30   | 56             |
|          |  |      |                |      |                |      |                |      |                |

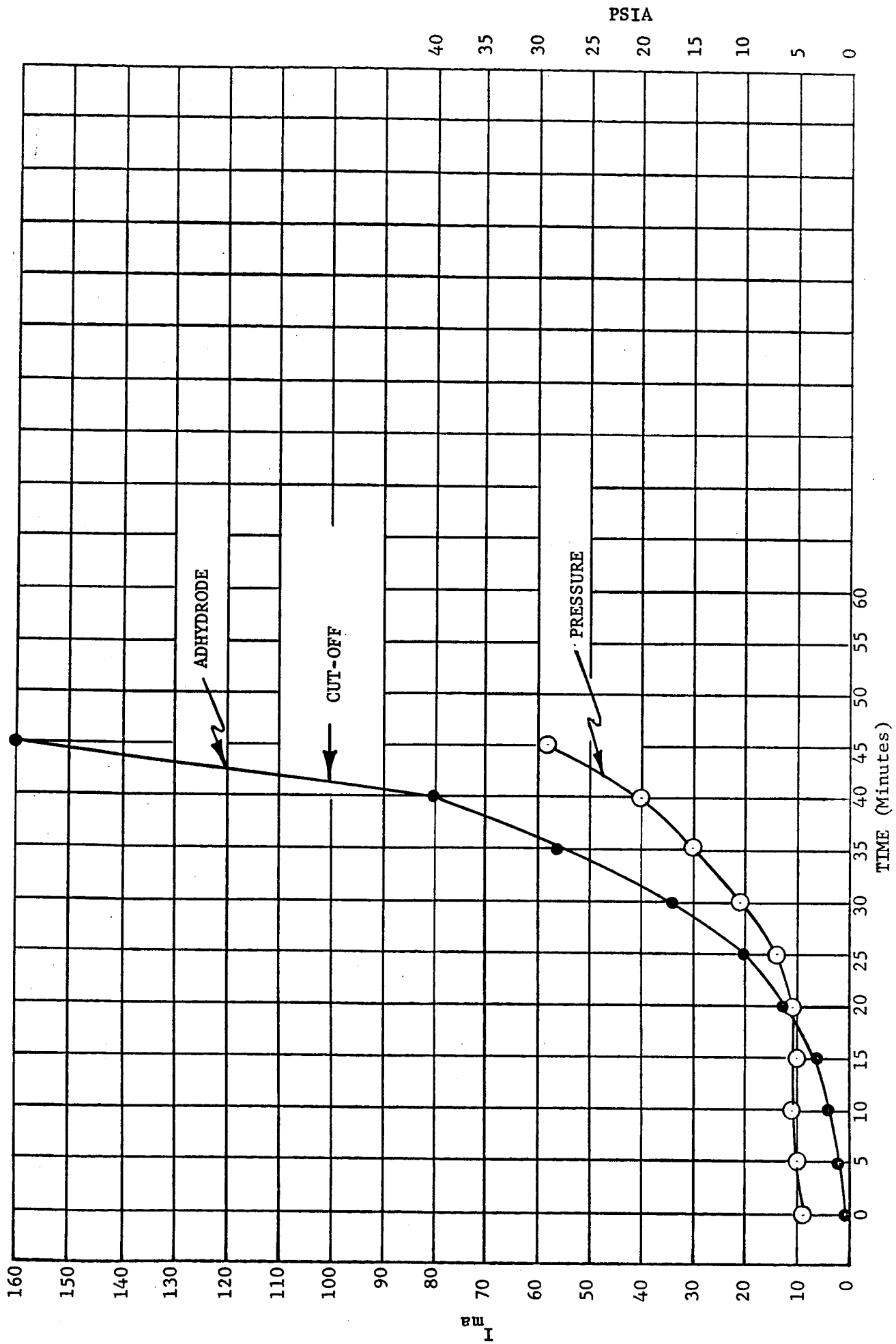


FIGURE 7. ADHYDRODE SIGNAL FOR CONTROL CELL 42, 1/4 OHM RESISTOR

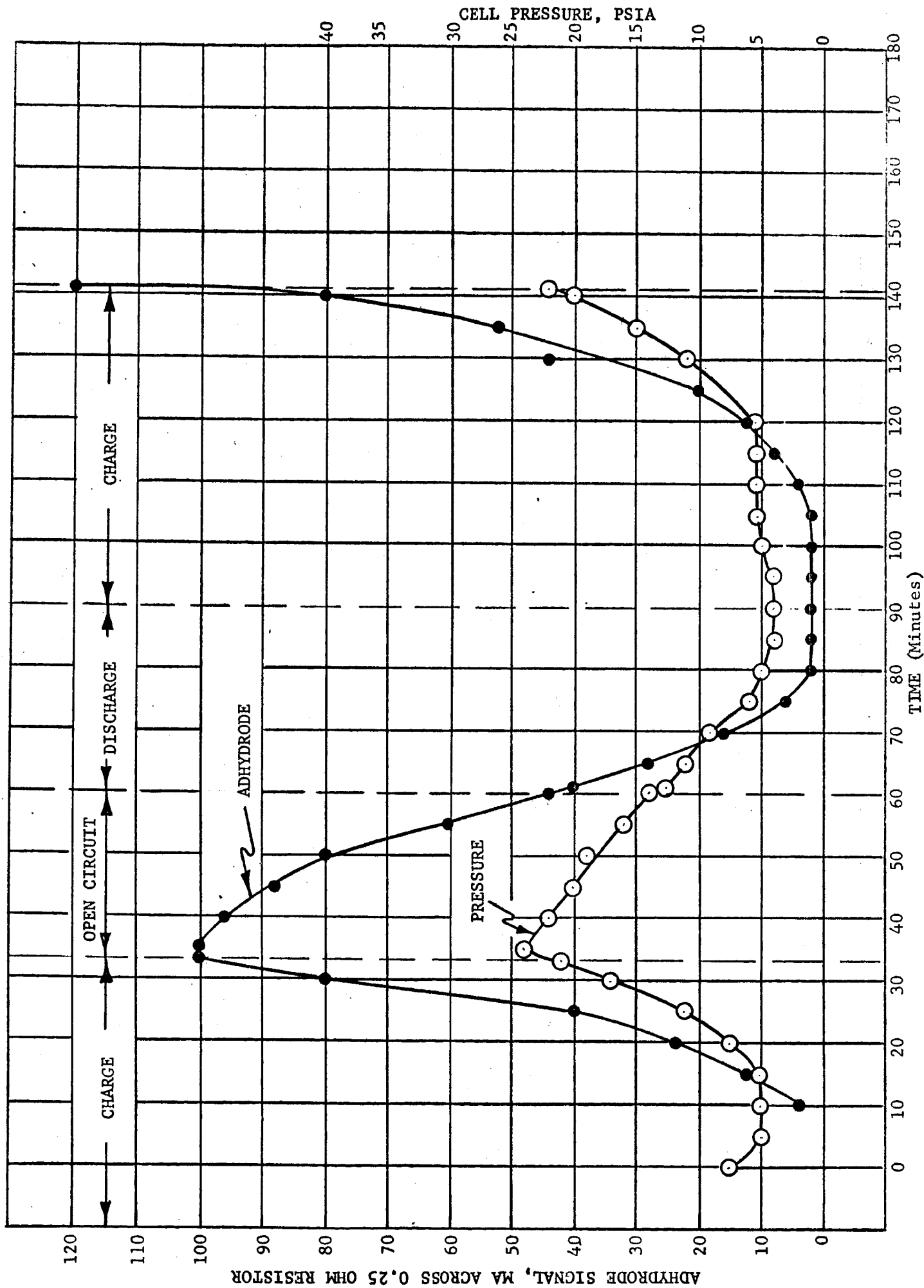


FIGURE 8. TYPICAL CYCLING ROUTINE - 50% DEPTH OF DISCHARGE - 2 CYCLES CELL 42

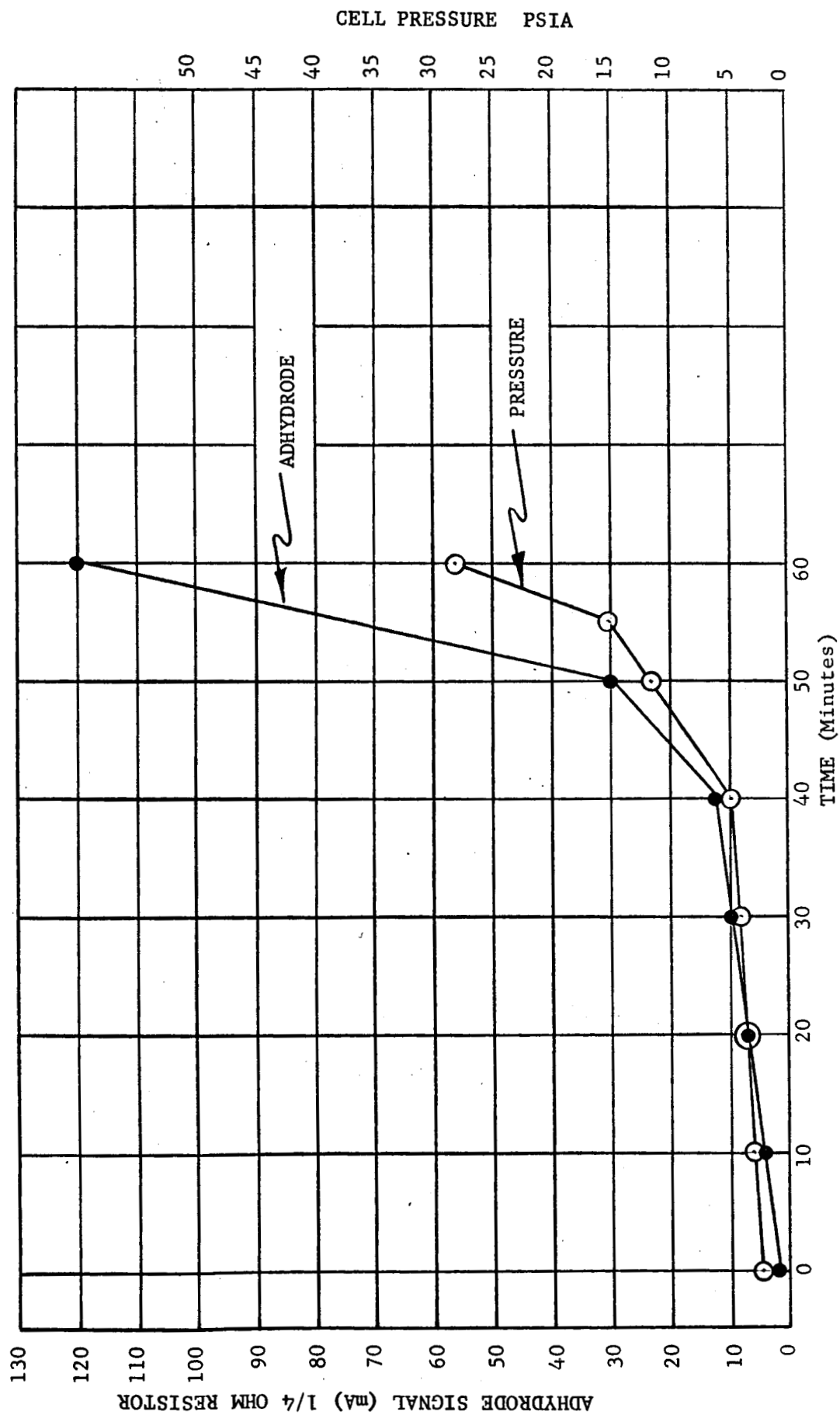


FIGURE 9. TYPICAL CHARGE CURVE, CELL 41, AUTOMATIC CYCLING

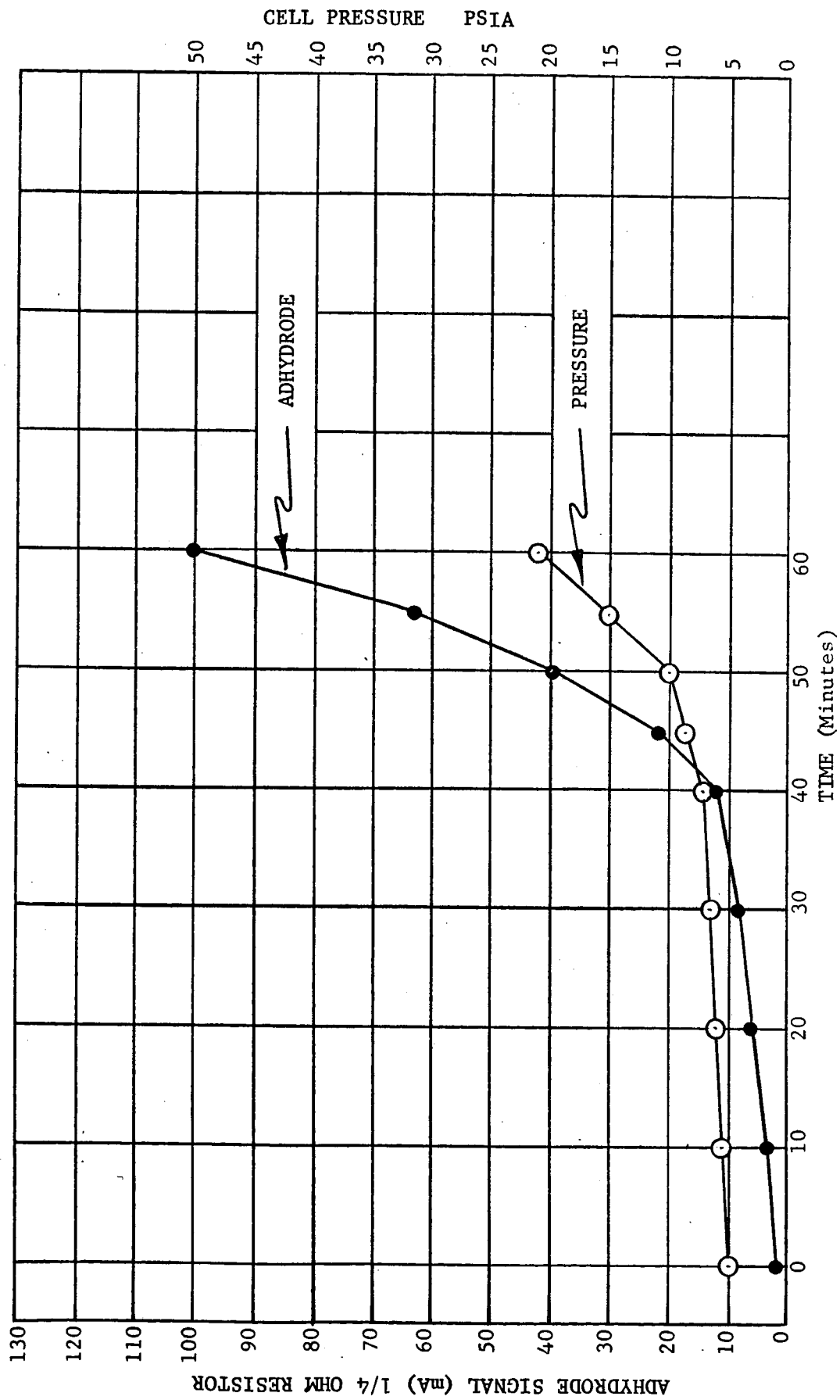


FIGURE 10. TYPICAL CHARGE CURVE, CELL 42, AUTOMATIC CYCLING

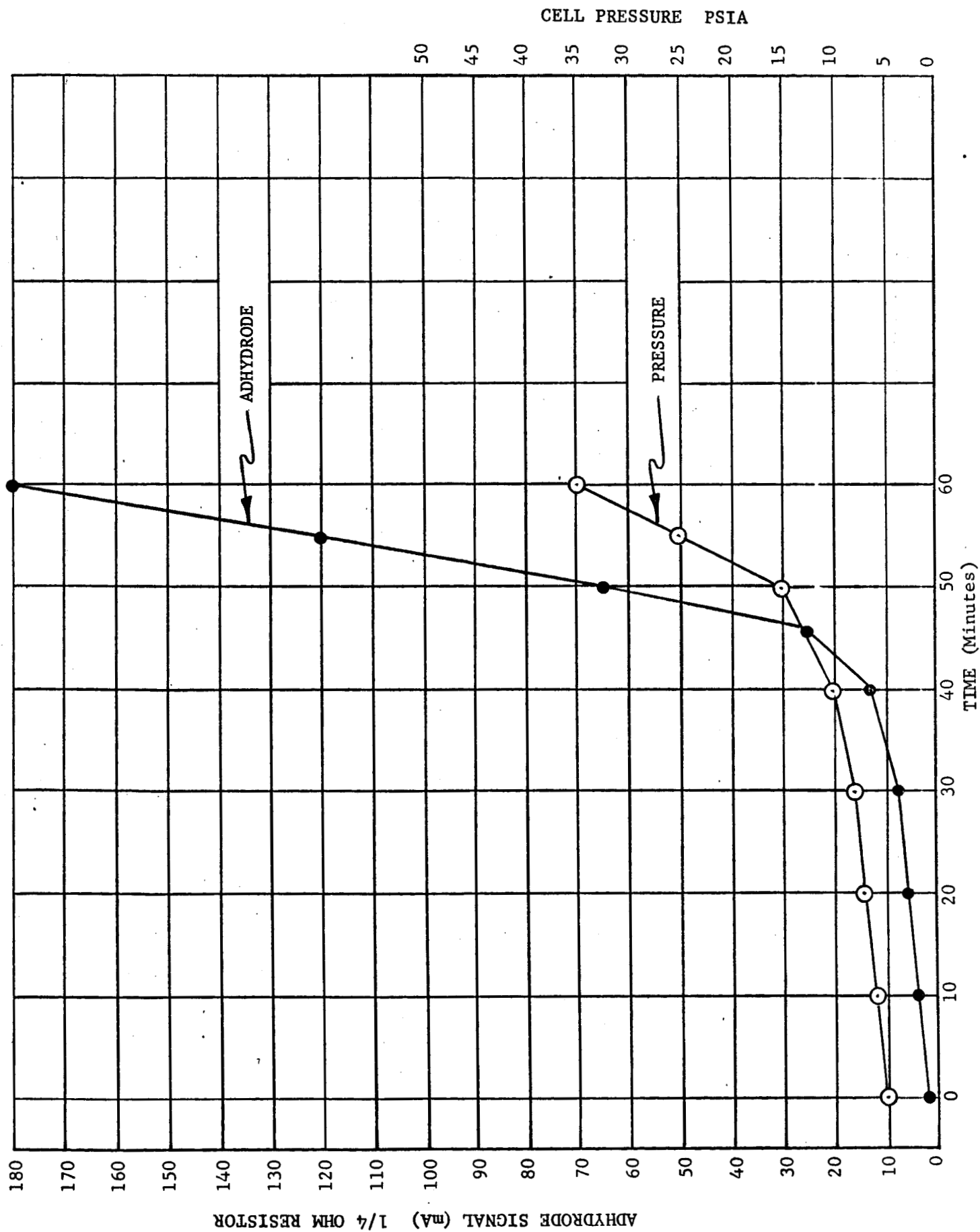


FIGURE 11. TYPICAL CHARGE CURVE, CELL 43, AUTOMATIC CYCLING

## CONCLUSIONS

The first six months of the contract work period has emphasized the preliminary design and testing of cells with scavenger and signalling electrodes separately.

It has been found that the best scavenger electrode material for oxygen recombination is the AB6X fuel cell electrode, and that for signalling purposes, the active Adhydrode placed in the center of the pack yields the highest signal to pressure ratio as compared to Adhydrodes placed in other positions.

## FUTURE WORK

Due to the low capacity obtained with the electrode configuration presently used, future cells that are being built will have the following configurations: 13 positives, 14 negatives, 1 AB6X fuel cell electrode at one end, and 1 active adhydrode in the center of the pack. This configuration is different than the one used to date in that it has additional electrodes (3 positives and 3 negatives) to increase capacity.

At present, 10 cells of the above configuration are under construction. These cells, along with three VO-12HSAD cells from the Pilot Plant will be tested for 1 week at various temperatures and depths of discharge as outlined in the First Quarterly Report.

#### REFERENCES

- (1) S. Lerner and H. N. Seiger, First Quarterly Report, "Characterization of Recombination and Control Electrodes for Spacecraft Nickel Cadmium Cells", Contract No. NAS 5-10241, Sept. 9, 1966

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#### Department of the Army

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U. S. Army Electronics R&D Labs.  
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Attn: Power Sources Division  
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Research Office  
Rand D. Directorate  
Army Weapons Command  
Rock Island, Illinois 61201  
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U. S. Army Research Office  
Box CM, Duke Station  
Durham, North Carolina 27706  
Attn: Dr. Wilhelm Jorgensen

Natick Laboratories  
Clothing and Organic Materials Div.  
Natick, Massachusetts 01760  
Attn: Robert N. Walsh/G. A. Spano

Harry Diamond Laboratories  
Room 300, Building 92  
Conn. Ave. & Van Ness Street, N.W.  
Washington, D. C. 20438  
Attn: Nathan Kaplan

Army Materiel Command  
Research Division  
AMCRD-RSCM-T-7  
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Attn: John W. Crellin

Army Materiel Command  
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U. S. Army TRECOM  
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U. S. Army TRECOM  
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U. S. Army Mobility Command  
Research Division  
Center Line, Michigan 48090  
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#### Department of the Navy

Office of Naval Research  
Washington, D. C. 20360  
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Office of Naval Research  
Department of the Navy  
Washington, D. C. 20360  
Attn: H. W. Fox, Code 425

Naval Research Laboratory  
Washington, D. C. 20390  
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U. S. Navy  
Marine Engineering Laboratory  
Annapolis, Maryland 21402  
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Bureau of Naval Weapons  
Department of the Navy  
Washington, D. C. 20360  
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Bureau of Naval Weapons  
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Crane, Indiana 47522  
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Naval Ordnance Laboratory  
Department of the Navy  
Corona, California 91720  
Attn: William C. Spindler (Code 441)

Naval Ordnance Laboratory  
Department of the Navy  
Silver Spring, Maryland 20900  
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Bureau of Ships  
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Bureau of Ships  
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Flight Vehicle Power Branch  
Aero Propulsion Laboratory  
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Attn: James E. Cooper

Air Force Cambridge Research Lab.  
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Bedford, Massachusetts 01731  
Attn: Commander (CRO)

Rome Air Development Center, ESD  
Griffis AFB, New York 13442  
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#### Other Government Agencies

National Bureau of Standards  
Washington, D. C. 20234  
Attn: Dr. W. J. Hamer

Office, DDR&E, USE & BSS  
The Pentagon  
Washington, D. C. 20310  
Attn: G. B. Wareham

Mr. Donald B. Hoatson  
Army Reactors, DRD  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

#### Private Organizations

Aeroject-General Corporation  
Chemical Products Division  
Azusa, California 91702  
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Aeronutronic Division  
Philco Corporation  
Fort Road  
Newport Beach, California 92660

Aerospace Corporation  
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Los Angeles, California 90045  
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Allis-Chalmers Manufacturing Co.  
1100 South 70th Street  
Milwaukee, Wisconsin 53201  
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Arthur D. Little, Inc.  
Acorn Park  
Cambridge, Massachusetts 02140  
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Atomics International Division  
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Canoga Park, California 91304  
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Columbus, Ohio 43201  
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Bell Laboratories  
Murray Hill, New Jersey 07971  
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Philadelphia, Pennsylvania 19124

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Freeport, Illinois 61032  
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C & D Batteries  
Division of Electric Autolite Co.  
Conshohocken, Pennsylvania 19428  
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ChemCell Inc.  
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General Motors Corporation  
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Anderson, Indiana 46011  
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Douglas Aircraft Company, Inc.  
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Newport Beach, California 92663  
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Eagle-Picher Company  
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Elgin National Watch Company  
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Electric Storage Battery Co.  
Missile Battery Division  
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Electric Storage Battery Co.  
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Electro-Optical Systems, Inc.  
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Livingston Electronic Corp.  
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Mallory Battery Co.  
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Union Carbide Corporation  
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