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

GULTON INDUSTRIES, INC.
Alkaline Battery Division
212 Durham Ave.
Metuchen, N. J.

for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

SECOND QUARTERLY REPORT

for

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

September 9, 1966 - December 9, 1966

CONTRACT NO.: NAS 5-10241

Prepared By

GULTON INDUSTRIES, INC.
Alkaline Battery Division
212 Durham Ave.
Metuchen, N. J.

for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

Prepared By:

S. Lerner
Research Chemist

Approved By:

H. N. Seiger
Director of Research

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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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® (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.[1]

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.[1] 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^3 of electrolyte, evacuated and pressurized to 50 PSIG with oxygen which was allowed to recombine. From the void volume of the cells (102 cm^3) 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 Leesona 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.
5	9.3	Cell 18 shorted
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 Leesona 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 19	CELL 20	CELL 22	CELL 23	CELL 24	CELL 26	CELL 28	CELL 29	CELL 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 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^3 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.

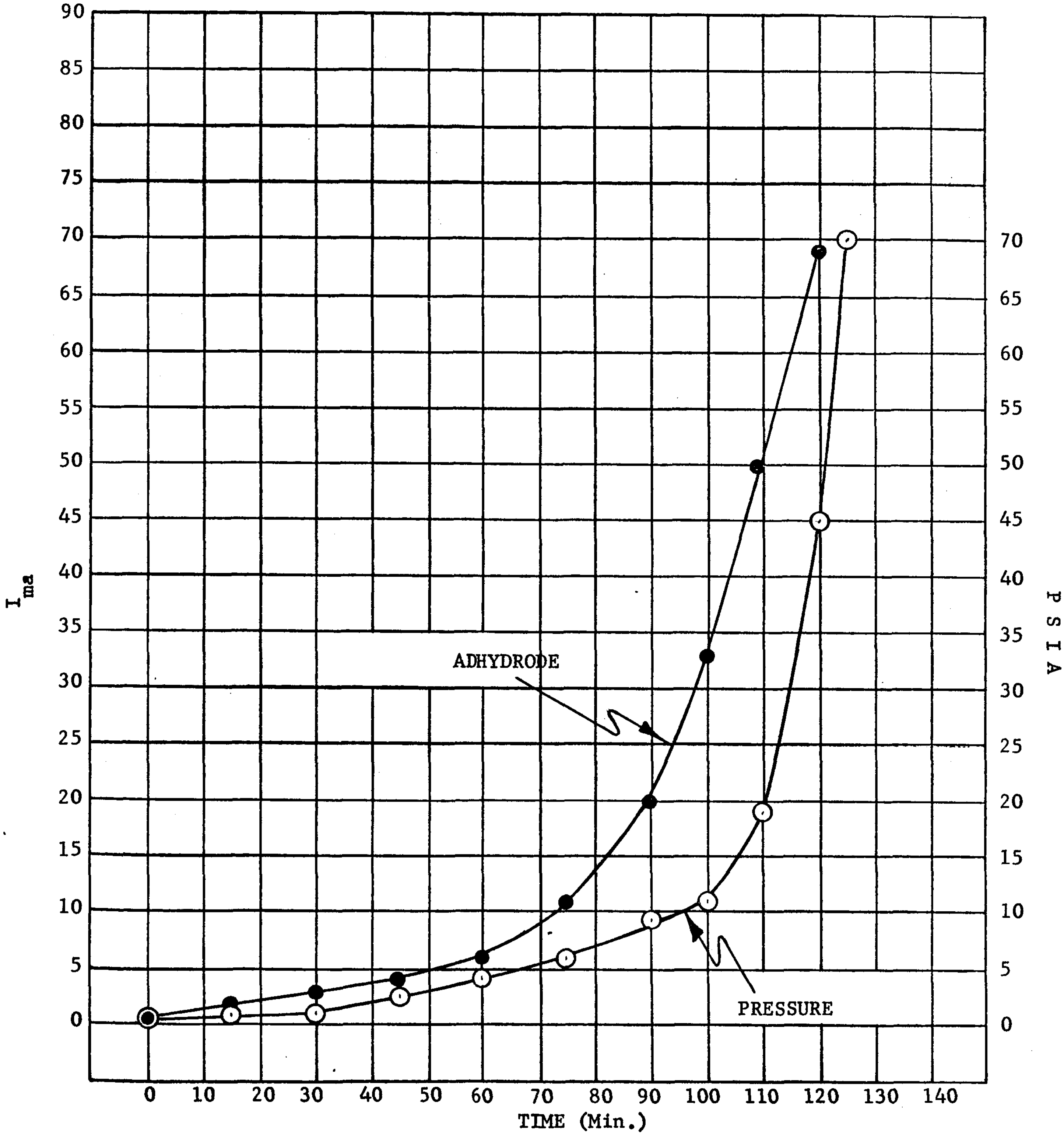

FIGURE 1 "U" SHAPED

4-1011

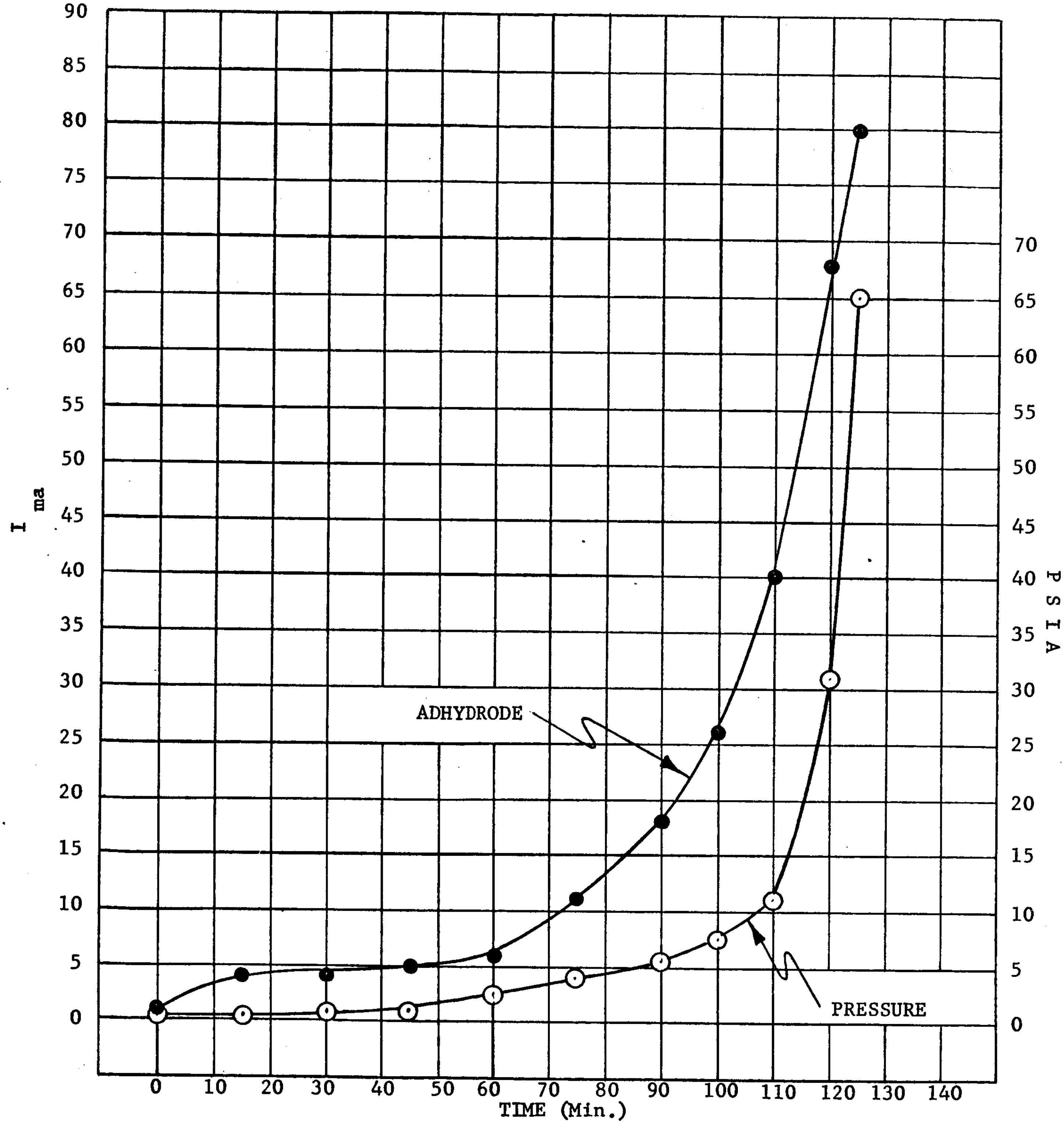

FIGURE 2 END OF PACK

4-1012

NASA/G ADHYDRODE (3060)

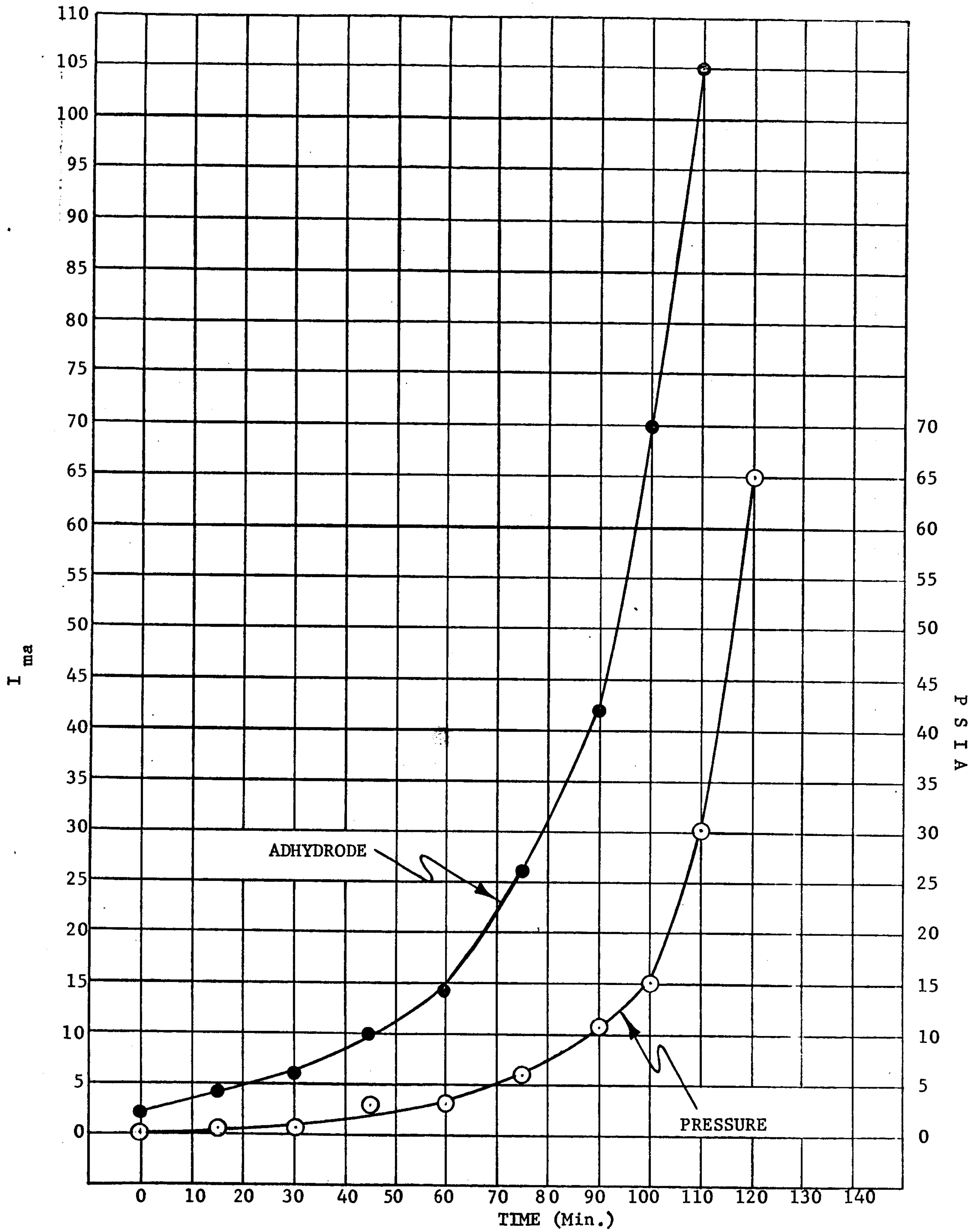

FIGURE 3 MIDDLE OF PACK

4-1013

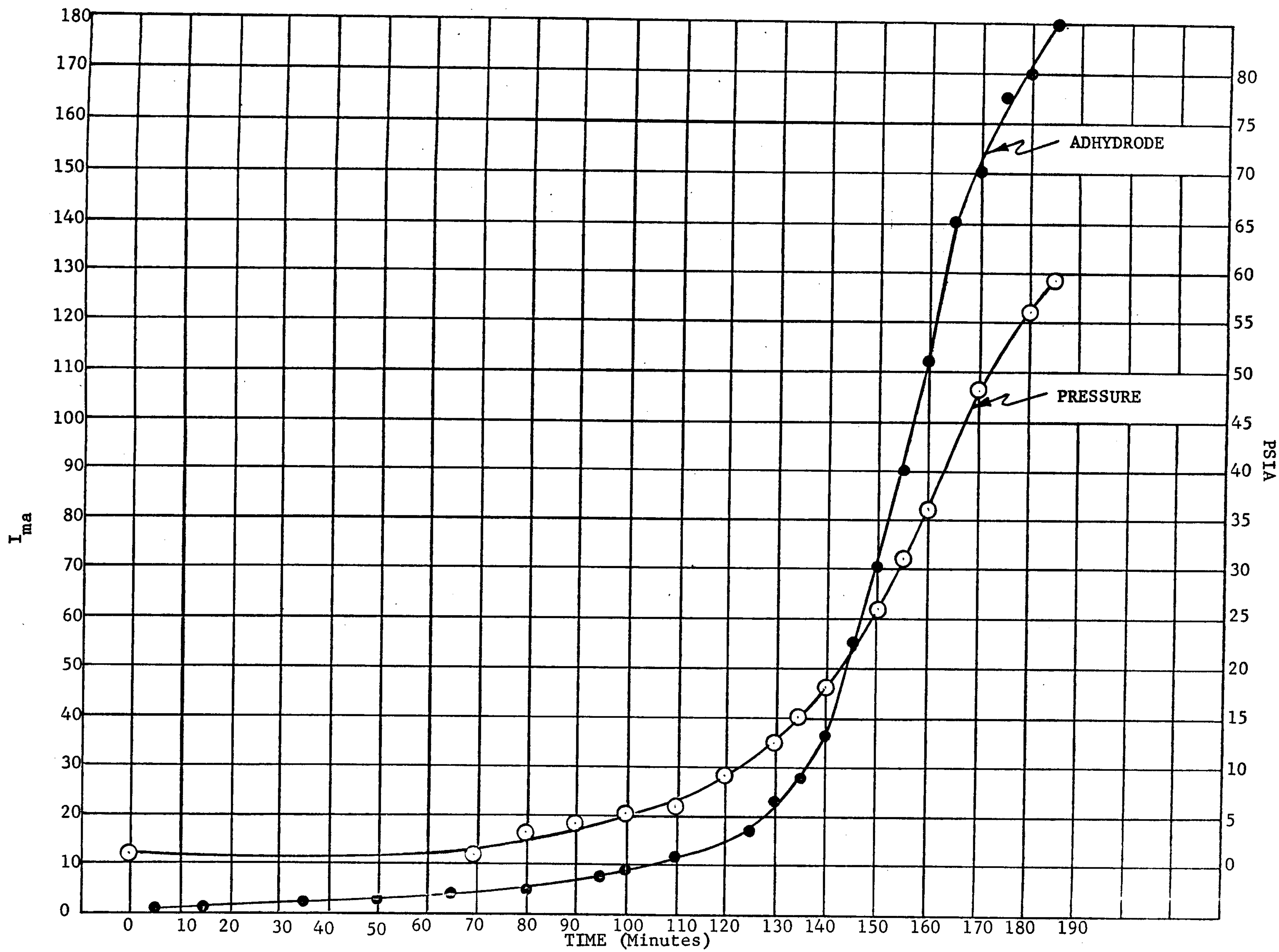

FIGURE 4. TYPICAL ADHYDRODE SENSITIVITY CURVE - 1/4 AND 1 OHM RESISTOR

4-1134

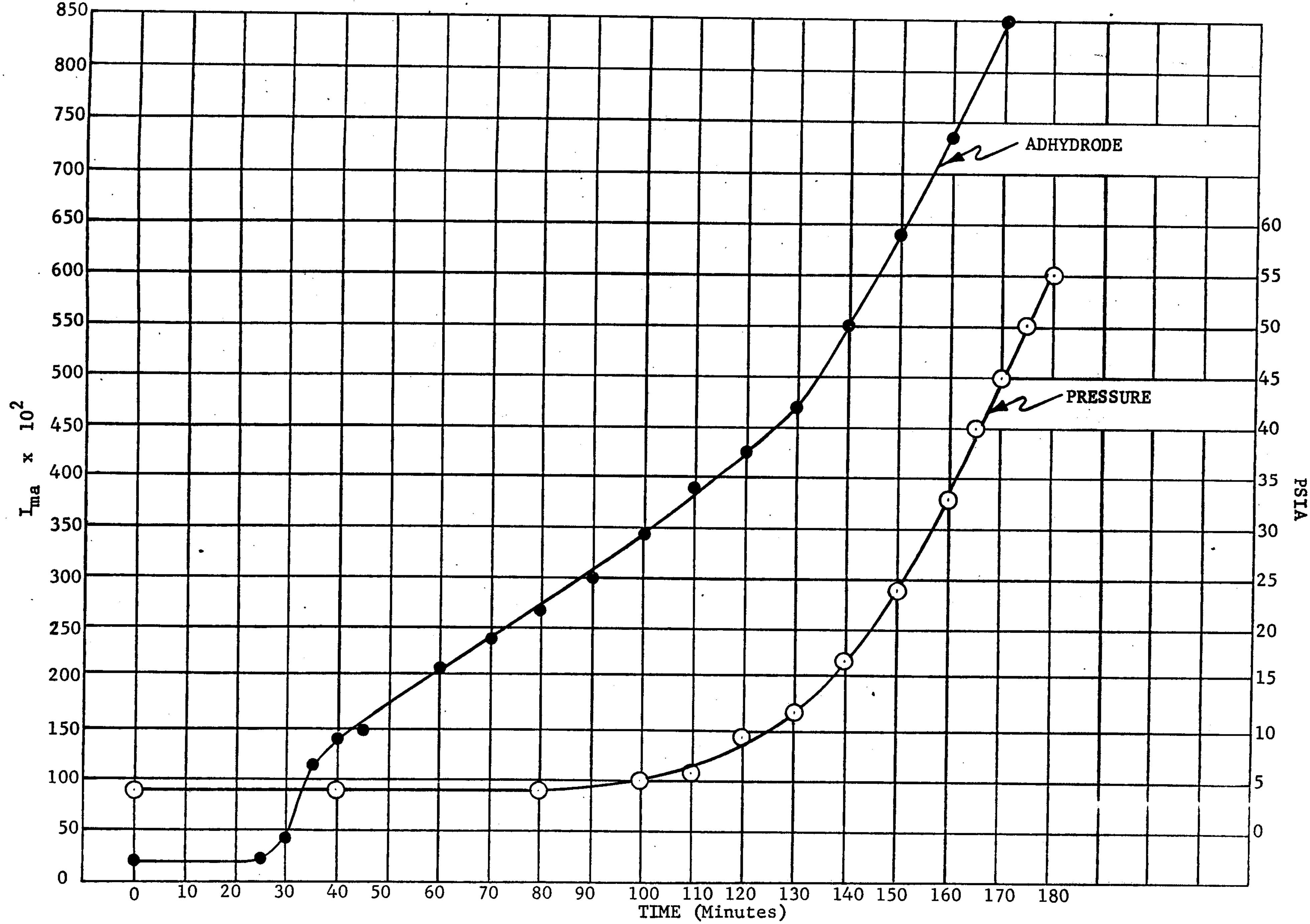

FIGURE 5. TYPICAL ADHYDRODE SENSITIVITY CURVE -- 100 OHM RESISTOR

4-1135

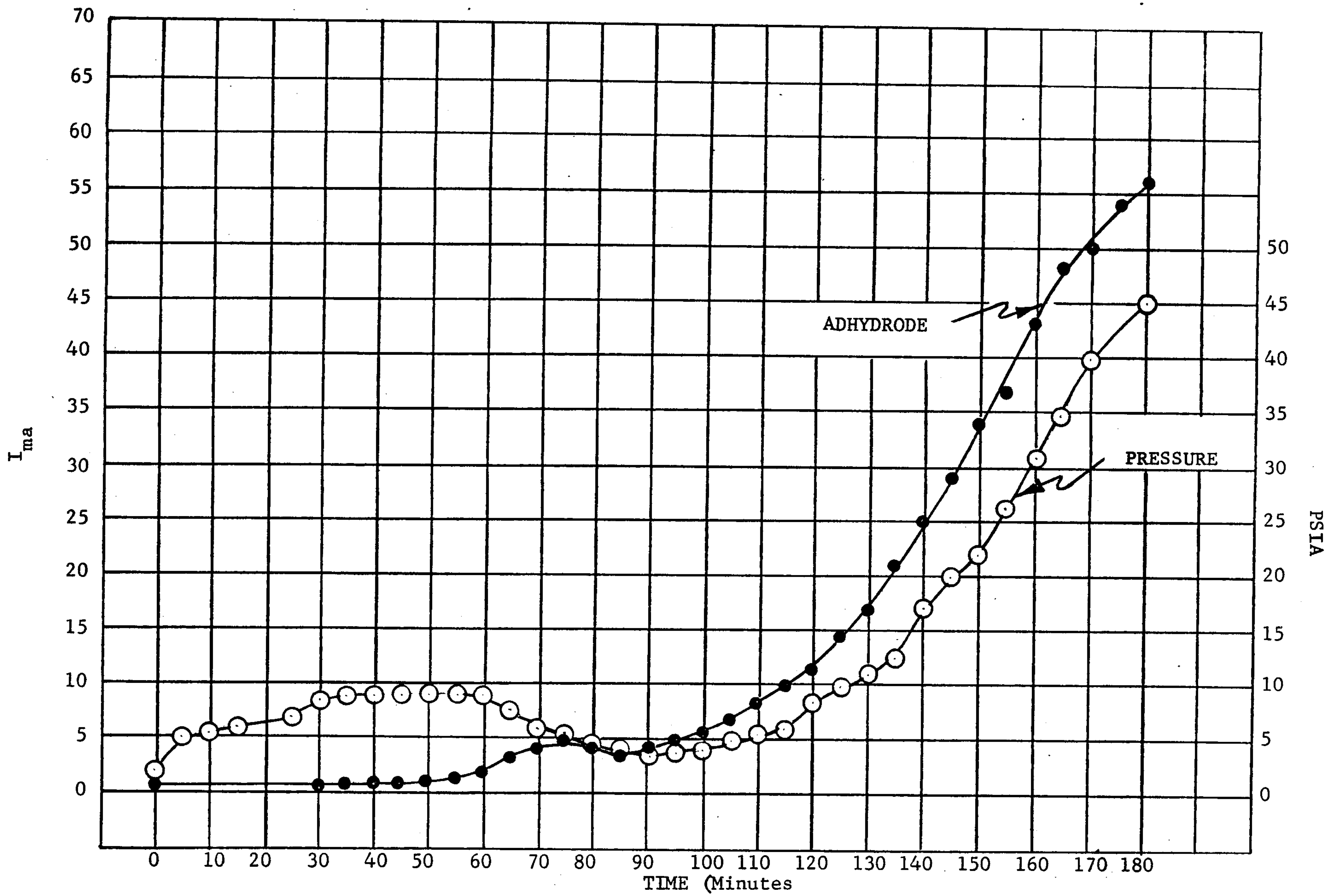

FIGURE 6. TYPICAL ADHYDRODE SENSITIVITY CURVE -- 7 OHM RESISTOR

4-1136

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 repitition 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 cycler, 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 = 1/4 ma	PSIA	mv = 1/4 ma	PSIA	mv = 1/4 ma	PSIA	mv = 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

Form AB-1031

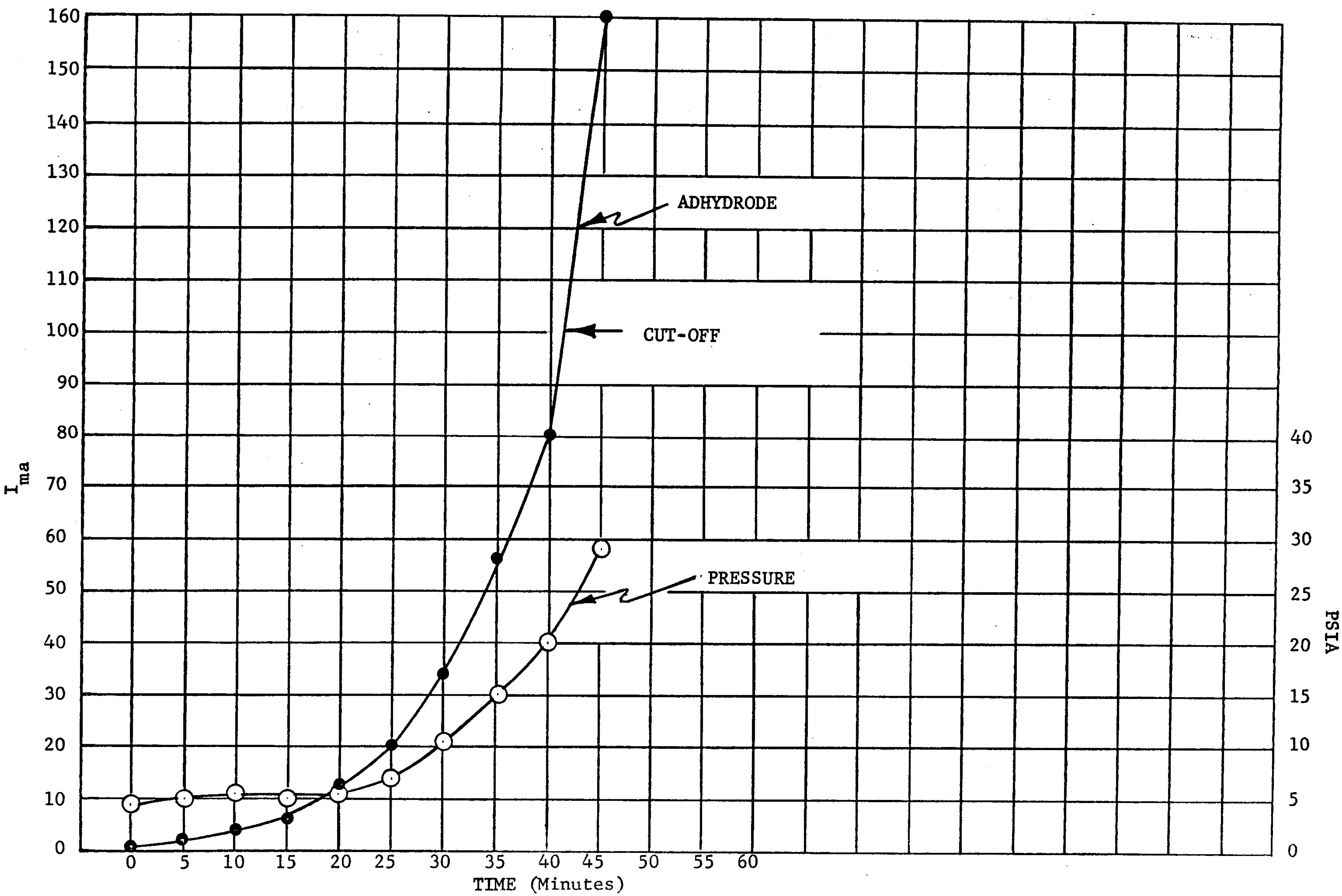

FIGURE 7. ADHYDRODE SIGNAL FOR CONTROL CELL 42, 1/4 OHM RESISTOR

4-1137

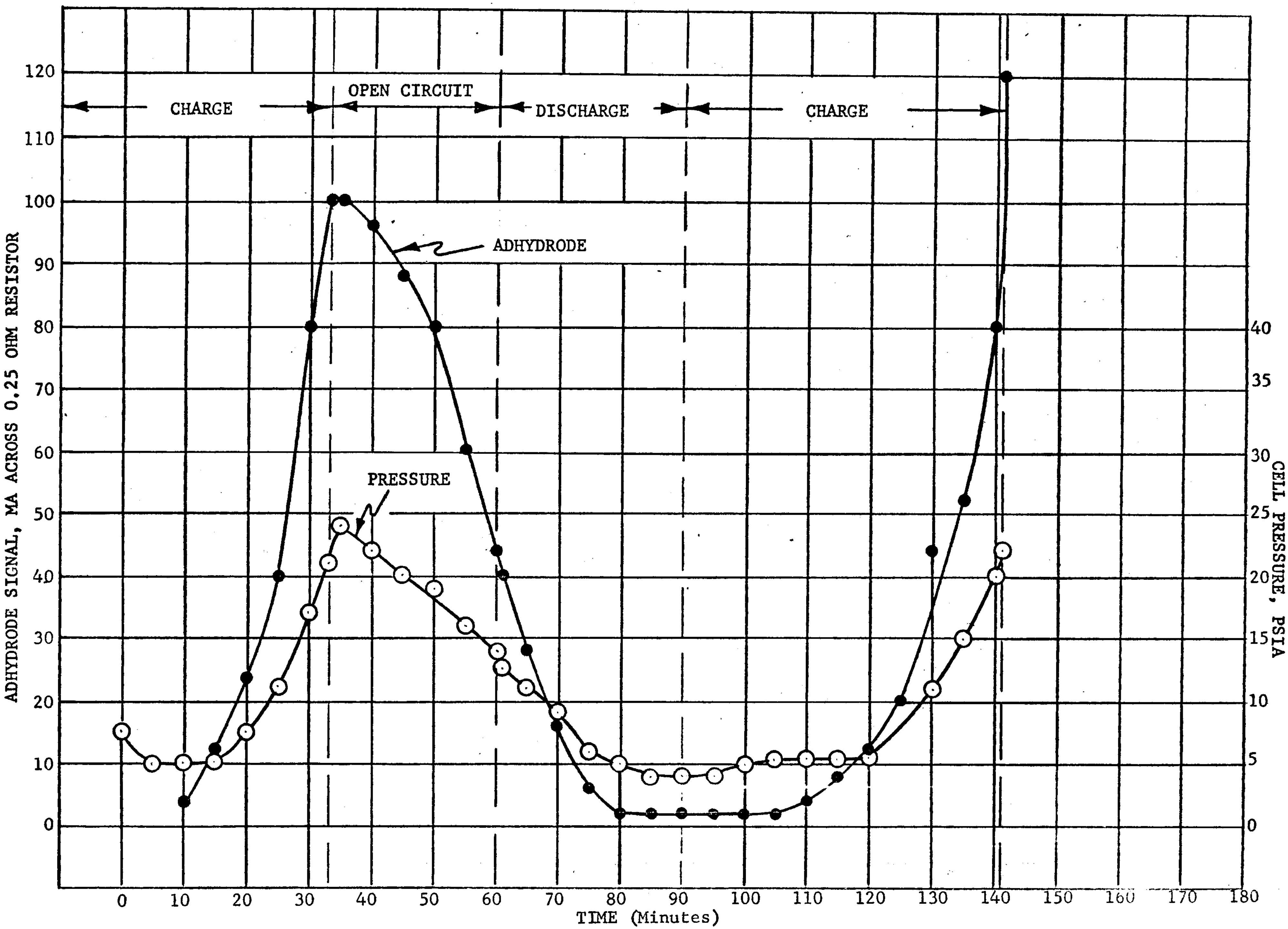

FIGURE 8. TYPICAL CYCLING ROUTINE - 50% DEPTH OF DISCHARGE - 2 CYCLES CELL 42

4-1138

NASA/G ADHYDRODE (3060)

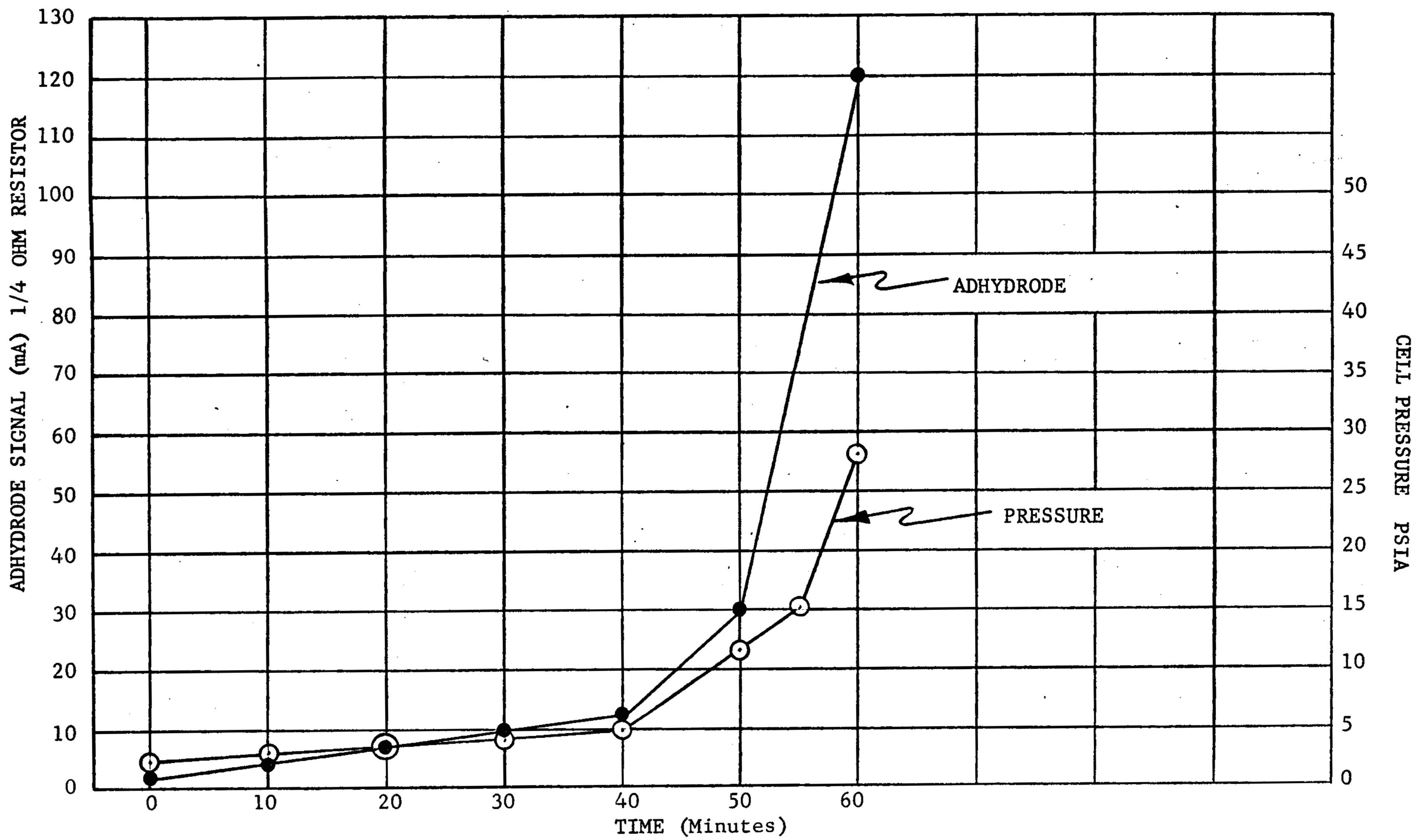

FIGURE 9. TYPICAL CHARGE CURVE, CELL 41, AUTOMATIC CYCLING

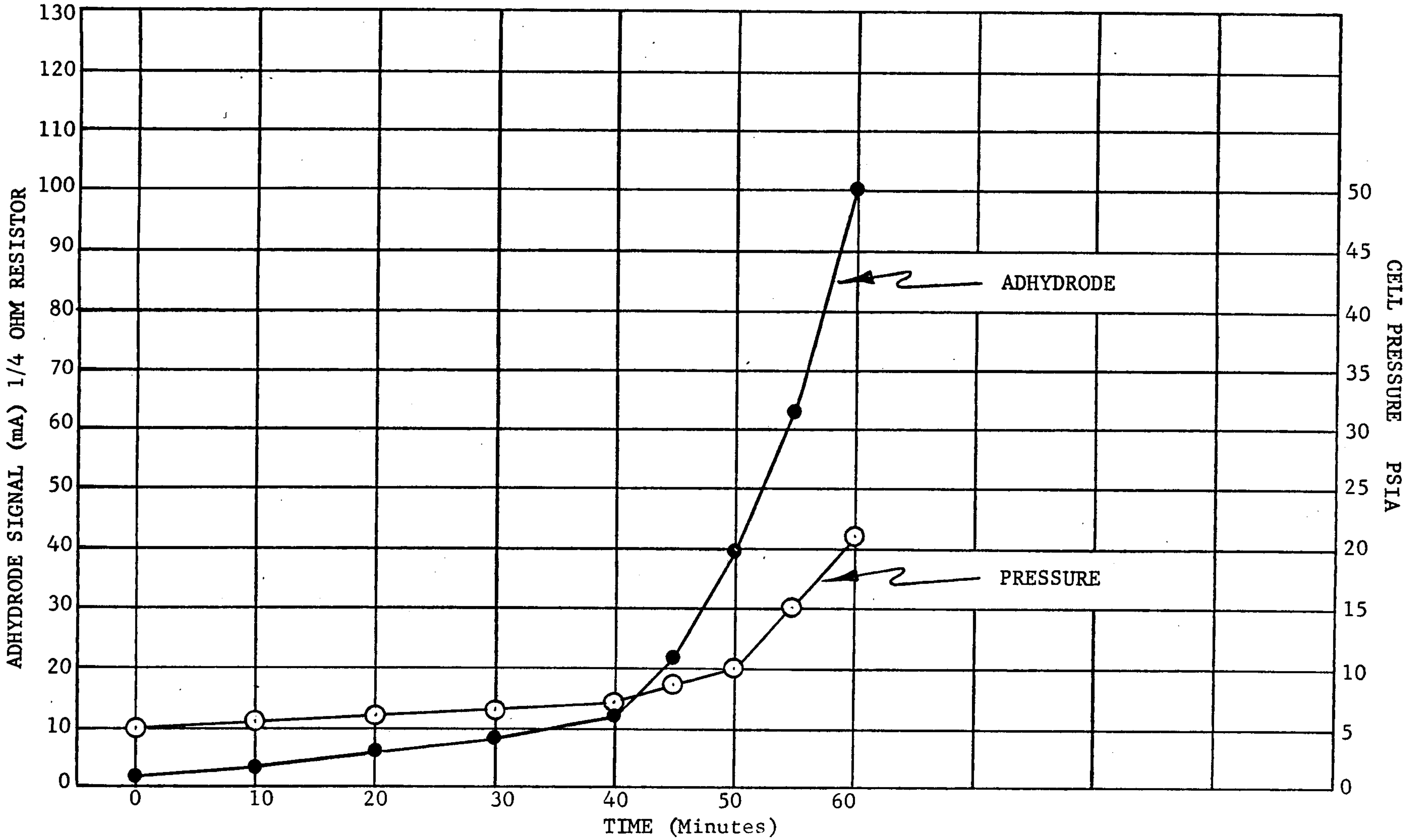

FIGURE 10. TYPICAL CHARGE CURVE, CELL 42, AUTOMATIC CYCLING

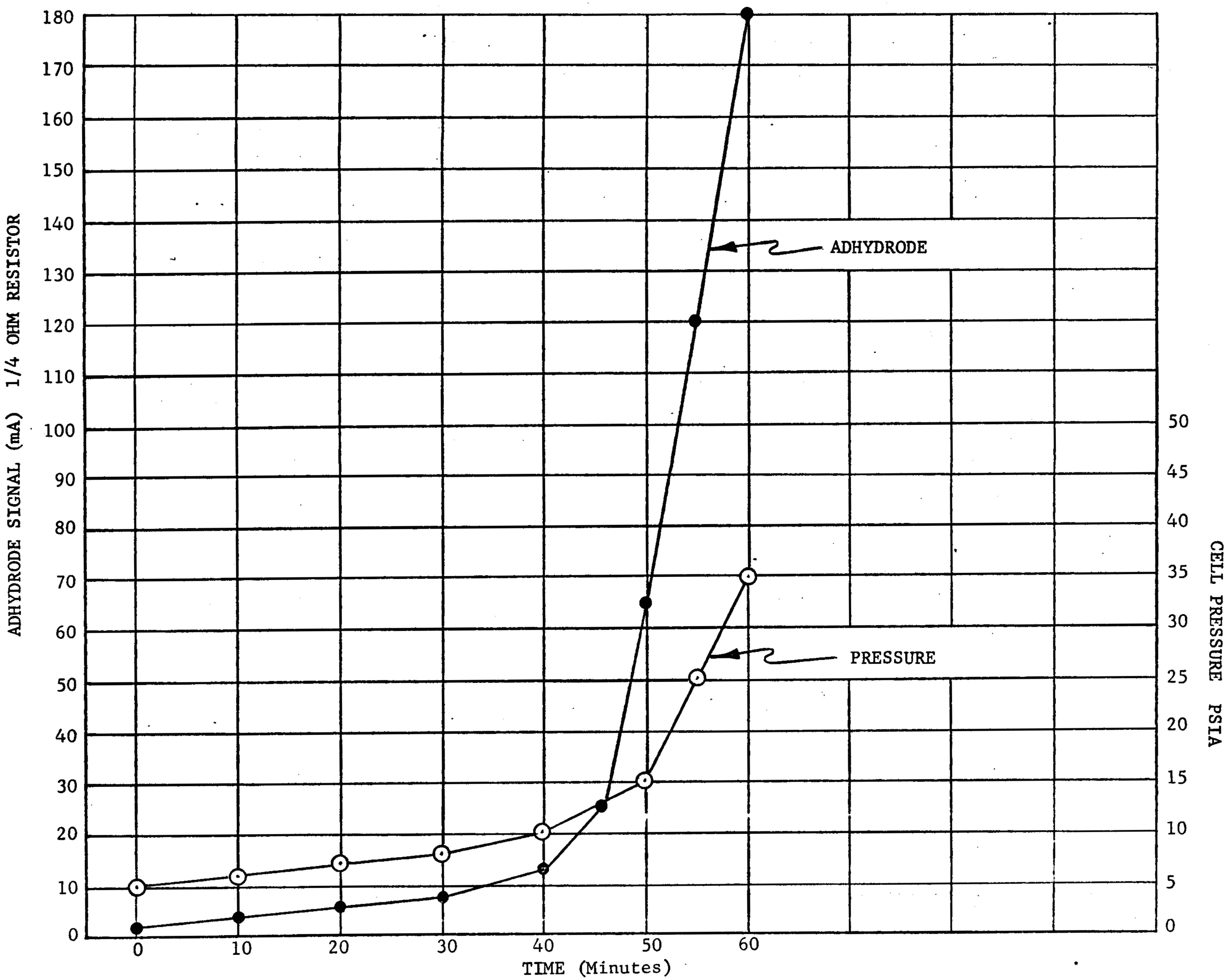

FIGURE 11. TYPICAL CHARGE CURVE, CELL 43, AUTOMATIC CYCLING

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

DISTRIBUTION LIST

CONTRACT NO.: NAS5-10241

NASA and JPL

National Aeronautics & Space Admin.
Scientific and Technical Information
Facility
College Park, Maryland 20740
Attn: NASA Representative
Send 2 copies plus 1 reproducible

National Aeronautics & Space Admin.
Washington, D. C. 20546
Attn: RNW/E.M. Cohn

National Aeronautics & Space Admin.
Washington, D. C. 20546
Attn: FC/A. Am Greg Andrus

National Aeronautics & Space Admin
Goddard Space Flight Center
Greenbelt, Maryland
Attn: Thomas Hennigan, Code 716.2

National Aeronautics & Space Admin.
Goddard Space Flight Center
Greenbelt, Maryland 20771
Attn: Joseph Sherfey, Code 735

National Aeronautics & Space Admin.
Langley Research Center
Instrument Research Division
Hampton, Virginia 23365
Attn: John L. Patterson, MS-234

National Aeronautics & Space Admin.
Langley Research Center
Instrument Research Division
Hampton, Virginia 23365
Attn: M. B. Seyffert, MS 112

National Aeronautics & Space Admin.
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: N. D. Sanders, MS 302-1

National Aeronautics & Space Admin.
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: R. L. Cummings, MS 500-201

National Aeronautics & Space Admin.
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: R. R. Miller, MS 500-202

National Aeronautics & Space Admin.
Geo. C. Marshall Space Flight Center
Huntsville, Alabama 35812
Attn: Philip Youngblood

National Aeronautics & Space Admin.
Geo. C. Marshall Space Flight Center
Huntsville, Alabama 35812
Attn: Richard Boehme
Bldg. 4487-BB

National Aeronautics & Space Admin.
Manned Spacecraft Center
Houston, Texas 77058
Attn: William R. Dusenbury
Propulsion & Energy Systems Branch
Bldg. 16, Sit 1

National Aeronautics & Space Admin.
Manned Spacecraft Center
Houston, Texas 77058
Attn: Robert Cohen
Gemini Project Office

National Aeronautics & Space Admin.
Manned Spacecraft Center
Houston, Texas 77058
Attn: Richard Ferguson (EP-5)

National Aeronautics & Space Admin.
Manned Spacecraft Center
Houston, Texas 77058
Attn: James T. Kennedy (EE-5)

National Aeronautics & Space Admin.
Manned Spacecraft Center
Houston, Texas 77058
Attn: Forrest E. Eastman

National Aeronautics & Space Admin.
Ames Research Center
Pioneer Project
Moffett Field, California 94035
Attn: James R. Swain/A. S. Hertzog

National Aeronautics & Space Admin.
Ames Research Center
Moffett Field, California 94035
Attn: Jon Rubenzer
Biosatellite Project

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103
Attn: Aiji Uchiyama

Department of the Army

U. S. Army Engineer R&D Labs.
Fort Belvoir, Virginia 22060
Electrical Power Branch
SMOFB-EP

Commanding Officer
U. S. Army Electronics R&D Labs.
Fort Monmouth, New Jersey 07703
Attn: Power Sources Division
Code SELRA/PS

Research Office
Rand D. Directorate
Army Weapons Command
Rock Island, Illinois 61201
Attn: Mr. G. Riensmith, Chief

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
Washington, D. C. 20315
Attn: John W. Crellin

Army Materiel Command
Development Division
AMCRD-DE-MO-P
Washington, D. C. 20315
Attn: Marshall D. Aiken

U. S. Army TRECOM
Fort Eustis, Virginia 23604
Attn: Dr. R. L. Echols (SMOFE-PSG)

U. S. Army TRECOM
Fort Eustis, Virginia 23604
Attn: Leonard M. Bartone (SMOFE-ASE)

U. S. Army Mobility Command
Research Division
Center Line, Michigan 48090
Attn: O. Renius (AMSMO-RR)

Department of the Navy

Office of Naval Research
Washington, D. C. 20360
Attn: Head, Power Branch, Code 429

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
Attn: Dr. J. C. White, Code 6160

U. S. Navy
Marine Engineering Laboratory
Annapolis, Maryland 21402
Attn: J. H. Harrison

Bureau of Naval Weapons
Department of the Navy
Washington, D. C. 20360
Attn: Whitewall T. Beatson
(Code RAAE-52)

Bureau of Naval Weapons
Department of the Navy
Washington, D. C. 20360
Attn: Milton Knight (Code RAAE-50)

Naval Ammunition Depot
Crane, Indiana 47522
Attn: E. Bruess/H Shultz

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
Attn: Philip B. Cole (Code WB)

Bureau of Ships
Department of the Navy
Washington, D. C. 20360
Attn: C. F. Viglotti (Code 660)

Bureau of Ships
Department of the Navy
Washington, D. C. 20360
Attn: Bernard B. Rosenbaum (Code 340)

Department of the Air Force

Space Systems Division
Los Angeles AF Station
Los Angeles, California 90045
Attn: SSSD

Flight Vehicle Power Branch
Aero Propulsion Laboratory
Wright-Patterson AFB, Ohio 45433
Attn: James E. Cooper

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

Rome Air Development Center, ESD
Griffis AFB, New York 13442
Attn: Frank J. Mollura (RASSM)

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
Attn: Dr. S. O. Rosenberg

Aeronutronic Division
Philco Corporation
Fort Road
Newport Beach, California 92660

Aerospace Corporation
P. O. Box 95085
Los Angeles, California 90045
Attn: Library

Allis-Chalmers Manufacturing Co.
1100 South 70th Street
Milwaukee, Wisconsin 53201
Attn: Dr. P. Joyner

American University
Mass. & Nebraska Avenues, N. W.
Washington, D. C. 20016
Attn: Dr. R. T. Foley,
Chemistry Department

Arthur D. Little, Inc.
Acorn Park
Cambridge, Massachusetts 02140
Attn: Dr. Ellery W. Stone

Atomics International Division
North American Aviation, Inc.
8900 De Sota Avenue
Canoga Park, California 91304
Attn: Dr. H. L. Recht

Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201
Attn: Dr. C. L. Faust

Bell Laboratories
Murray Hill, New Jersey 07971
Attn: U. B. Thomas/D. A. Feder

The Boeing Company
P. O. Box 98124
Seattle, Washington 98124

Borden Chemical Company
Central Research Lab.
P. O. Box 9524
Philadelphia, Pennsylvania 19124

Burgess Battery Company
Foot of Exchange Street
Freeport, Illinois 61032
Attn: Dr. Howard J. Strauss

C & D Batteries
Division of Electric Autolite Co.
Conshohocken, Pennsylvania 19428
Attn: Dr. Eugene Willihnganz

Calvin College
Grand Rapids, Michigan 49506
Attn: Prof. T. P. Dirkse

Catalyst Research Corporation
6101 Falls Road
Baltimore, Maryland 21209
Attn: J. P. Wooley

ChemCell Inc.
3 Central Avenue
East Newark, New Jersey 07029
Attn: Peter D. Richman

Delco Remy Division
General Motors Corporation
2401 Columbus Avenue
Anderson, Indiana 46011
Attn: Dr. J. J. Lander

Douglas Aircraft Company, Inc.
Astropower Laboratory
2121 Campus Drive
Newport Beach, California 92663
Attn: Dr. Carl Berger

Dynatech Corporation
17 Tudor Street
Cambridge, Massachusetts 02138
Attn: R. L. Wentworth

Eagle-Picher Company
Post Office Box 47
Joplin, Missouri 64802
Attn: E. M. Morse

Elgin National Watch Company
107 National Street
Elgin, Illinois 60120
Attn: T. Bosewell

Electric Storage Battery Co.
Missile Battery Division
2510 Louisburg Road
Raleigh, North Carolina 27604
Attn: A. Chreitzberg

Electric Storage Battery Co.
Carl F. Norberg Research Center
19 West College Avenue
Yardley, Pennsylvania 19068
Attn: Dr. R. A. Schaefer/W. S. Herbert

Electrochimica Corporation
1140 O'Brien Drive
Menlo Park, California 94025
Attn: Dr. Morris Eisenberg

Electro-Optical Systems, Inc.
300 North Halstead
Pasadena, California 91107
Attn: E. Findl

Emhart Manufacturing Co.
Box 1620
Hartford, Connecticut 06101
Attn: Dr. W. P. Cadogan

Englehard Industries, Inc.
497 DeLancy Street
Newark, New Jersey 07105
Attn: Dr. J. G. Cohn

Dr. Arthur Fleischer
466 South Center Street
Orange, New Jersey 07050

General Electric Company
Schenectady, New York, 12301
Attn: Dr. R. C. Osthoff/Dr. W. Carson
Advanced Technology Lab.

General Electric Company
Missile & Space Division
Spacecraft Dept.
P. O. Box 8555
Philadelphia, Pennsylvania 19101
Attn: E. W. Kipp, Room T-2513

General Electric Company
Battery Products Section
P. O. Box 114
Gainsville, Florida 32601

General Electric Company
Research Laboratories
Schenectady, New York 12301
Attn: Dr. H. Liebhafsky

General Motors-Defense Research Labs.
6767 Hollister Street
Santa Barbara, California 93105
Attn: Dr. J. S. Smatko/Dr. C. R. Russell

Globe Union, Incorporated
900 East Keefe Avenue
Milwaukee, Wisconsin 53201

Gould National Batteries, Inc.
Engineering and Research Center
2630 University Ave., S. E.
Minneapolis, Minnesota 55418
Attn: J. F. Donahue

Gulton Industries
Alkaline Battery Division
212 Durham Avenue
Metuchen, New Jersey 08840
Attn: Dr. Robert Shair

Hughes Aircraft Corporation
Centinda Ave., & Teale St.
Culver City, California 90230
Attn: T. V. Carvey

Hughes Aircraft Corporation
Bldg. 366, M.S. 524
El Segundo, California 90245
Attn: R. B. Robinson

Hughes Research Laboratories Corp.
3011 Malibu Canyon Rd.
Malibu, California 90265

ITT Research Institute
10 West 35th Street
Chicago, Illinois 60616
Attn: Dr. H. T. Francis

Institute for Defense Analyses
R&E Support Division
400 Army-Navy Drive
Arlington, Virginia 22202
Attn: Mr. R. Hamilton/Dr. Szego

Idaho State University
Dept. of Chemistry
Pocatello, Idaho 83201
Attn: Dr. G. Myron Arcand

Institute of Gas Technology
State and 34th Street
Chicago, Illinois 60616
Attn: B. S. Baker

Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland 20910

Johns Manville R&E Center
P. O. Box 159
Manville, New Jersey 08835
Attn: J. S. Parkinson

Leesona Moos Labs.
Lake Success Park, Community Dr.
Great Neck, New York 11021
Attn: Dr. H. Oswin

Livingston Electronic Corp.
Route 309
Montgomeryville, Pa. 18936

Lockheed Missiles & Space Co.
3251 Hanover Street
Palo Alto, California 93404
Attn: Library

Mallory Battery Co.
60 Elm Street
North Tarryton, New York 10593
Attn: R. R. Clune

P. R. Mallory & Co., Inc.
Northwest Industrial Park
Burlington, Massachusetts 02103
Attn: Dr. Per Bro

P. R. Mallory & Co., Inc.
3029 E. Washington Street
Indianapolis, Indiana 46206
Attn: Technical Librarian

Melpar
Technical Information Center
3000 Arlington Blvd.
Falls Church, Virginia 22046

Metals and Controls Division
Texas Instruments, Inc.
34 Forest Street
Attleboro, Massachusetts 02703
Attn: Dr. E. M. Jost

Midwest Research Institute
425 Voker Blvd.
Kansas City, Missouri 64110
Attn: Dr. B. W. Beadle

Monsanto Research Corporation
Everett, Massachusetts 02149
Attn: Dr. J. O. Smith

North American Aviation, Inc.
Rocketdyne Division
6633 Canoga Avenue
Canoga Park, California 91303
Attn: Library

North American Aviation, Inc.
12214 Lakewood Boulevard
Downey, California 90241
Attn: Burton M. Otzinger

Dr. John Owen
P. O. Box 87
Bloomfield, New Jersey 07003

Power Information Center
University of Pennsylvania
Moore School Bldg.
200 S. 33rd St.
Philadelphia, Pa. 19104

Power Sources Division
Whittaker Corp.
9601 Canoga Ave.
Chatsworth, California 91311
Attn: Dr. M. Shaw

Philco Corp.
Div. of the Ford Motor Co.
Blue Bell, Pennsylvania 19422
Attn: Dr. Phillip Cholet

Radiation Applications, Inc.
36-40 37th Street
Long Island City, New York 11101

Radio Corporation of America
Astro Division
Hightstown, New Jersey 08520
Attn: Seymour Winkler

Radio Corporation of America
P. O. Box 800
Princeton, New Jersey 08540
Attn: I. Schulman

Radio Corporation of America
Somerville, New Jersey 08873
Attn: Dr. H. S. Lozier

Southwest Research Institute
8500 Culebra Rd.
San Antonio, Texas 78206
Attn: Dr. Jan Al

Sonotone Corporation
Saw Mill River Rd.
Elmsford, New York 10523
Attn: A. Mundel

Texas Instruments, Inc.
13500 North Central Expressway
Dallas, Texas 75222
Attn: Dr. Isaac Trachtenberg

Thomas A. Edison Research Laboratory
McGraw Edison Co.
Watchung Avenue
West Orange, New Jersey 07052
Attn: Dr. P. F. Grieger

Trw Systems, Inc.
One Space Park
Redondo Beach, California 90278
Attn: Dr. A. Krausz, Bldg. 60 Rm 929

TRW Systems Inc.
One Space Park
Redondo Beach, California 90278
Attn: Dr. Herbert P. Silverman

TRW, Inc.
23555 Euclid Avenue
Cleveland, Ohio 44117
Attn: Librarian

Tyco Labs., Inc.
Bear Hill
Hickory Drive
Waltham, Massachusetts 02154
Attn: W. W. Burnett

Union Carbide Corporation
Development Lab. Library
P. O. Box 6056
Cleveland, Ohio 44101

Union Carbide Corporation
Parma Research Center
P. O. Box 6116
Cleveland, Ohio 44101
Attn: Library

University of California
Space Science Laboratory
Berkeley, California 94720
Attn: Dr. C. W. Tobias

University of Pennsylvania
Electrochemistry Laboratory
Philadelphia, Pennsylvania 19104

Western Electric Co.
Suite 902, RCA Bldg.
Washington, D. C. 20006
Attn: R. T. Fiske

Westinghouse Elec. Corp.
Research & Development Center
Churchill Borough
Pittsburgh, Pennsylvania 15235

Whittaker Corporation
P. O. Box 337
Newbury Park, California 91320

Whittaker Corporation
3850 Olive Street
Denver, Colorado 80237
Attn: Borch Wendir

Yardney Electric Corporation
40-50 Leonard Street
New York, New York 10013
Attn: Dr. Geo. Dalin