N.I.

FOURTH PROGRESS REPORT

FOR

RESEARCH INTO FUNDAMENTAL PHENOMENA ASSOCIATED WITH SPACECRAFT ELECTROCHEMICAL DEVICES — CALORIMETRY OF NICKEL-CADMIUM CELLS

GPO PRICE $ ________

CFSTI PRICE(S) $ ________

Hard copy (HC) 3.00

Microfiche (MF) .65

ff 653 July 65

April 1, 1967 — June 30, 1967

Contract No. NAS 5 — 10105

Prepared by

G. D. MITCHELL and R. T. FOLEY

For

National Aeronautics and Space Administration

Goddard Space Flight Center

Greenbelt, Maryland

The American University

Washington, D. C. 20016

FACILITY FORM 602

N68-18709	
(ACCESSION NUMBER)	(THRU)
20	1
(PAGES)	(CODE)
CR-93430	03
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

TABLE OF CONTENTS

ABSTRACT

The present work on this project consists of calorimetric measurements on nickel-cadmium cells of various capacities undergoing discharge at depths of 15, 25, and 40%, and recharge at 110%.

During this reporting period changes were made in the system to accommodate the larger 20 ampere-hour cell and to increase the reproducibility and sensitivity of the heat measurement. These changes included rebuilding the external heat exchanger, altering the flow pattern of the oil through the calorimeter, and fabricating an improved thermopile.

Calibration experiments on the heater and the pressure transducer were performed.

The data from the charge efficiency study on the six ampere-hour cell reported in the Second Progress Report were replotted to better represent the heat dissipation problem.

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

During the period following the Third Progress Report several changes in the overall system were made. These changes were made necessary when the system was adapted for the twenty ampere-hour nickel-cadmium cell and, subsequently, to achieve greater reproducibility and sensitivity in measuring the heat output on calibration.

These changes included rebuilding the heat exchanger in the constant temperature bath external to the calorimeter, altering the flow pattern of the oil through the calorimeter, and fabricating an improved thermopile. Following these changes calibration experiments were performed on the heater and the pressure transducer.

The charge efficiency study on the six ampere-hour nickel-cadmium cell was reported in the Second Progress Report of this series. These data have been plotted and presented in a form more readily comprehended.

In a final paragraph the work contemplated for future reporting periods is outlined.

II. DESIGN AND FABRICATION CHANGES IN THE SYSTEM

The design and construction of a new and larger calorimeter, as reported in the Third Progress Report, has been accompanied by several improvements and modifications. The areas in which these improvements were made were both in the internal and external systems. The external improvement consisted of replacing the heat exchanger in the Aminco constant temperature bath. The internal improvements were a) a change in the flow system, b) the construction of a new thermopile, and c) a change in the calibration heater on the cell fixture. A general view of the present apparatus is shown in Figure 1.

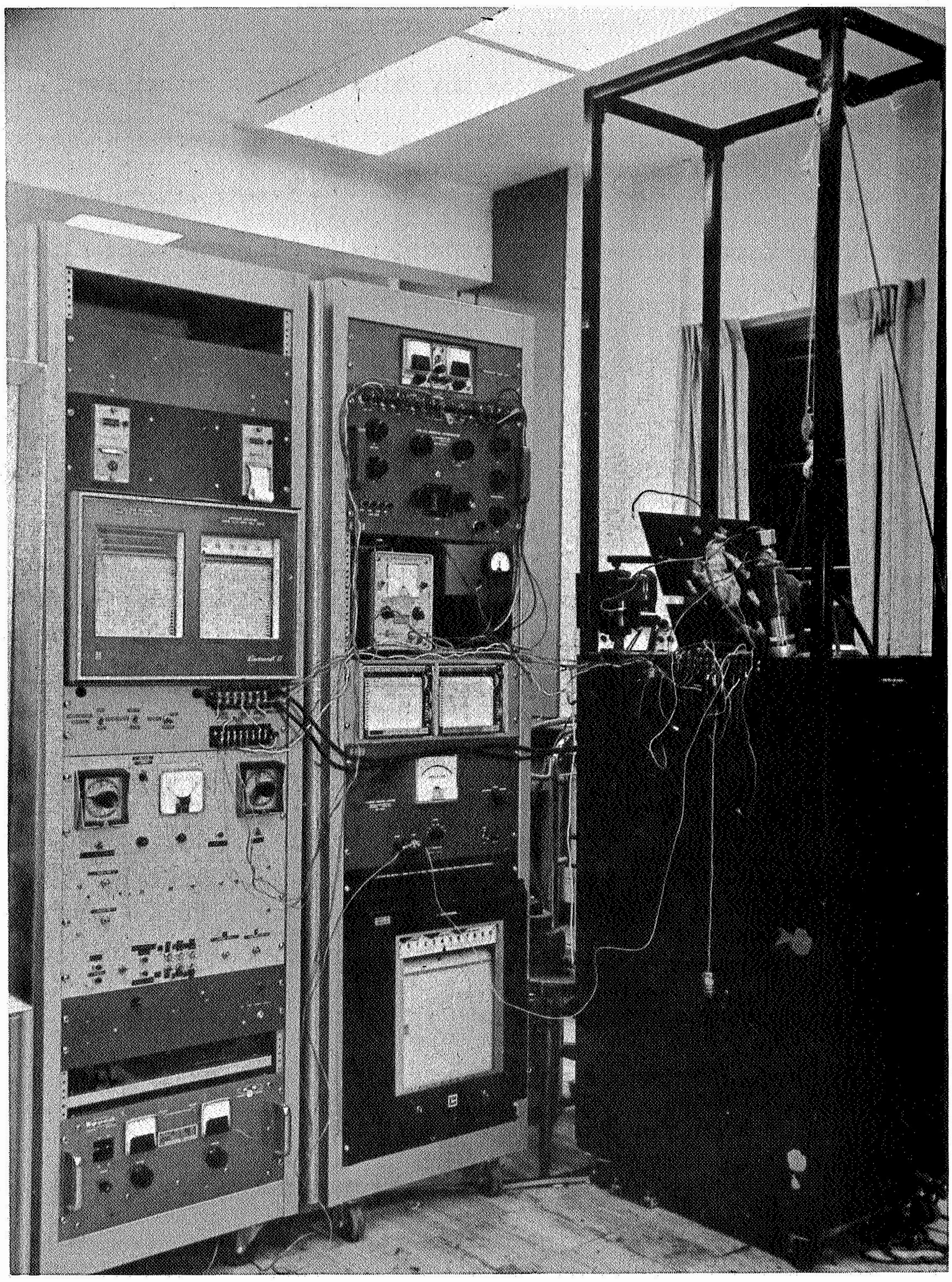

Figure 1. General view of Continuous-Flow Calorimeter and Associated Electrical Equipment

The Heat Exchanger

The construction of a new heat exchanger in the Aminco constant temperature bath was intended to minimize environmental heat effects and to increase the isothermal nature of the calorimetric system. The original heat exchanger, described in the First Progress report was constructed of straight copper tubing. The new exchanger was constructed with aluminum-finned-copper tubing. Twenty inch sections of the 0.75 in. diameter copper tubing were fitted with the appropriate copper elbows and soldered together to make a unit of 13 feet total length. This has improved the stability of the thermostat system.

The Flow System

To further increase the control of environmental effects the flow pattern of the oil was altered. In the previous system the on-off cycling of the refrigeration unit in the Aminco constant temperature bath would appear as a ripple on the chart recording the thermopile output. In the original arrangement, as described in the First Progress Report, the oil was forced from the external constant temperature bath into the calorimeter proper. Such an arrangement did not allow for proper equilibration of the oil and this showed up as a disturbing ripple in the thermopile reading. The new flow pattern for the oil is shown in Figure 2. The modified flow system draws the oil into the calorimeter from the bottom of the tank. The oil passes the cold junction of the thermopile, circulates around the heater and the cell itself, and then passes over the hot junction of the thermopile. Above the hot junction there is a rubber hose connected to the neck of the calorimeter and leading to the metering pump. The oil is drawn through the calorimeter,

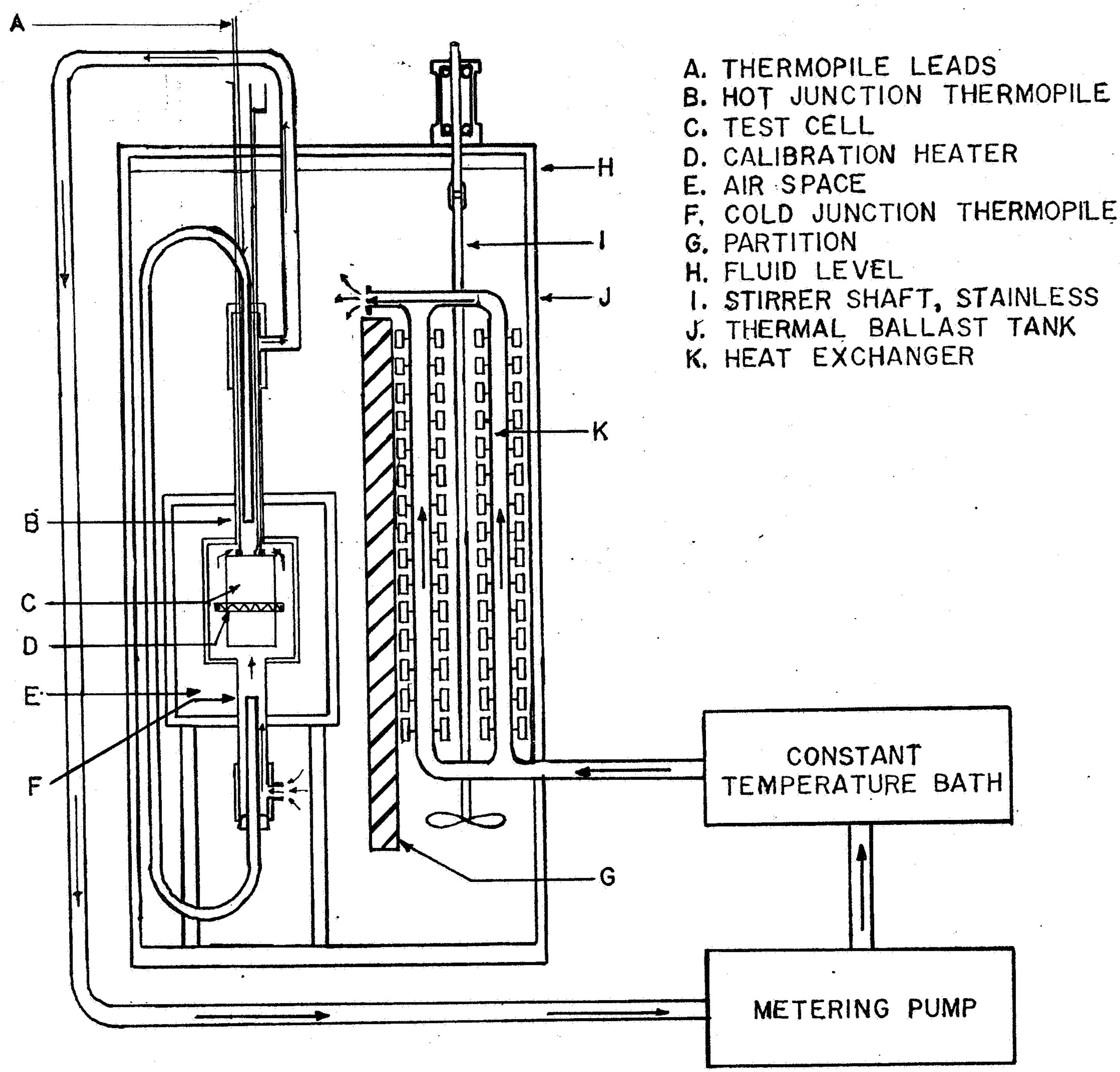

Figure 2. Flow pattern of oil through calorimeter, pump, constant temperature bath and heat exchangers

in the manner described above, into the metering pump which pumps it through the new heat exchanger, and then through the copper-finned internal heat exchanger before depositing it into the thermal ballast tank. The flow described above allows the calorimeter to take in oil from a constant temperature reservoir rather than from the constant temperature bath, thus eliminating the cycling effect of the bath on the signal output of the heat recorder.

The Thermopile

The third change made was the construction of a new and more sensitive thermopile. The new twenty-five junction copper-constantan thermopile was constructed to eliminate the use of bulky solder joints and Teflon tubing. The previously constructed thermopile was described in the First Progress Report, page 34, and Fig. 8. In principle the system has not been changed. The modifications made have been in the construction of the thermopile itself. The improvements in the thermopile are as follows: (1) the copper-constantan junctions were spot welded; (2) the leads were mounted on a Teflon support (1.00 inch in length and 0.625 inch in diameter). Therefore the Teflon tubing, the Armstrong Epoxy cement and the solder have all been eliminated. The new Teflon support was machined in such a way that each lead going into making the junction would be shielded to prevent shorting from one junction to another. Aside from the obvious advantages of eliminating the Teflon tubing, the epoxy cement and the bulky solder joints, the overall advantage is greater response and increased thermal sensitivity. This construction is schematically shown in Figure 3.

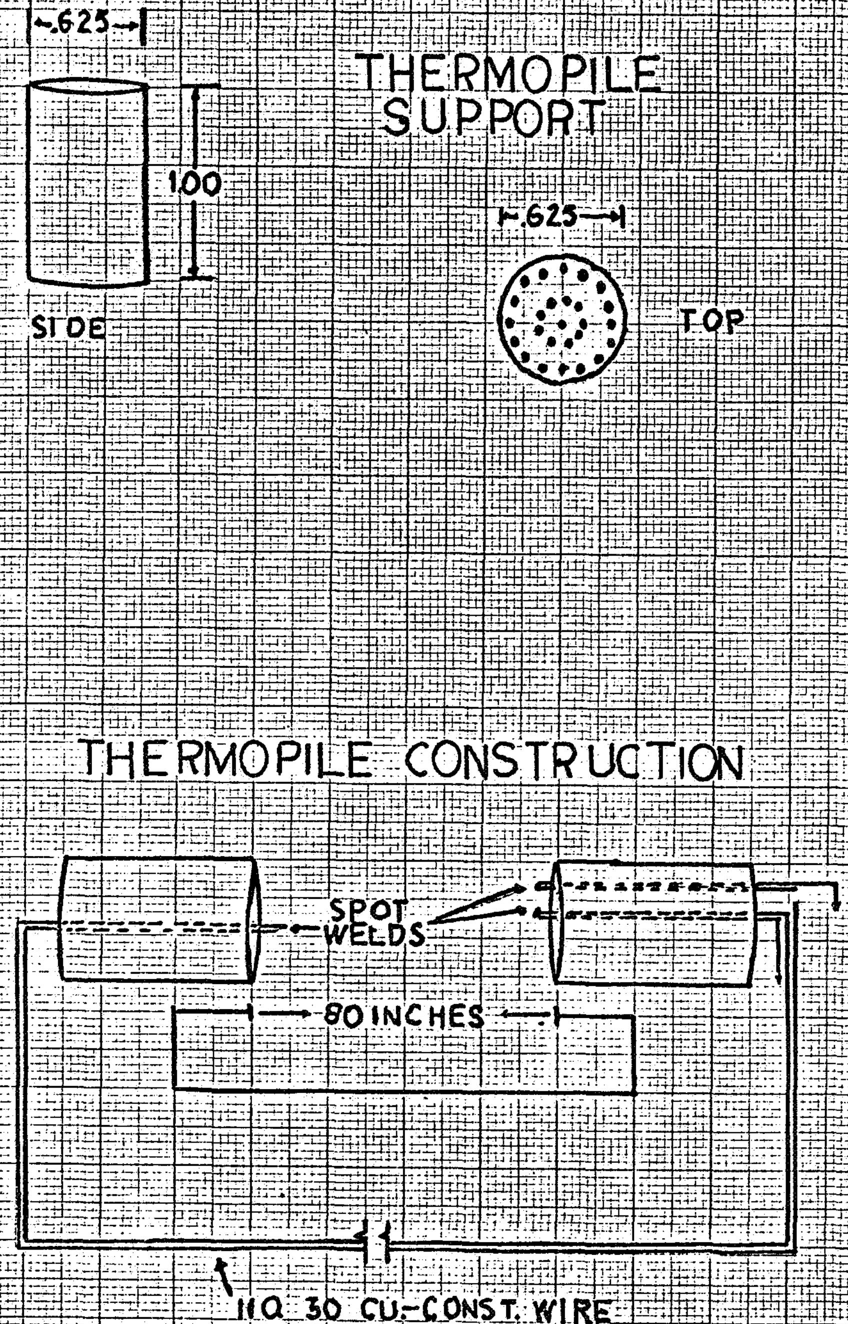

Figure 3. Thermopile construction

The Calibration Heater

In order to allow for the larger size of the 20-AH nickel-cadmium cell as compared with the 6-AH cell a modification of the Lucite fixture supporting the unit was required. From the diagram of the flow system (Fig. 2), it will be observed that the distance between the calibration heater and the lower (cold) junction of the thermopile is critical. Whereas the heater should approximate, in a geometrical way, the heat given off by the cell, it must be positioned within the limits of the critical distance. To have the calibration heater uniformly heat the system the fixture was redesigned so that the resistance heater was located 1/2 inch from the cell on both sides of the cell. Previously the heater was located under the cell, but the same distance from the lower end of the Lucite fixture. The advantages of this rearrangement are twofold: (1) it does not interfere with the positioning of the cell; (2) more heat is put into the system and less heat or no heat goes into heating the bottom end of the cell.

III. CALIBRATION STUDIES

Heater Calibration

In order to calibrate the newly constructed thermopile, the calorimeter was fitted with a calibration heater as described above. The procedure for making the calibration consisted of the following steps: (1) with the cell in place and the calorimeter ready to be operated a heat versus flow rate profile was established. From the results so obtained the flow rate corresponding to a maximum signal output from the thermopile was obtained; (2) the resistance of the heater was next determined; (3) the current input to give the desired voltage was then calculated; (4)

the microvolt signal of the thermopile versus the voltage over the desired calibration range was recorded.

A series of calibrations is given in Table 1. The plot of watts versus microvolt output for a pumping rate corresponding to 45% stroke rate of the metering pump is given in Figure 4. The 45% stroke rate corresponds to a flow rate of approximately 2500 cc/minute and was obtained by the step one procedure. The resistance of the heater was 0.426 ohms (an average of several measurements). This calibration curve was carried to about 5 watts output which covered the range of output for the 20 ampere-hour cell under the conditions of the planned experiment.

Pressure Transducer Calibration

The 20 ampere-hour cell was fitted with a Glennite pressure transducer to monitor the oxygen pressure in the cell and also to check and interpret the readings observed from the third electrode. A preliminary calibration value for Glennite transducer #101 measured at the Goddard Space Flight Center was 400 millivolts, equivalent to 150 psia under an operating voltage of 8.85 v. The output of this transducer at a number of pressure values was measured.* During these tests the cell was filled with a known oxygen pressure as determined by a mercury barometer. The output of the transducer was plotted against the actual oxygen pressure in Figure 5. The so-called "indicated psia" is taken from the linear relationship based on 400 mv = 150 psia.

IV. CHARGE EFFICIENCY OF THE SIX AMPERE-HOUR CELL

The charge efficiency study carried out on a Gulton 6 ampere-hour cell was reported in part in the Second Progress Report (pp. 3, 11-15). To give a more complete picture of the cell's efficiency at the various

*Data in table 2.

Table 1. Heater Calibration Data

45% Stroke,
Heater Resistance = 0.426 ohms

Signal (μv)	Heat (watts)
-6	0.0
36	0.5
79	1.0
121	1.5
165	2.0
208	2.5
250	3.0
292	3.5
336	4.0
380	4.5

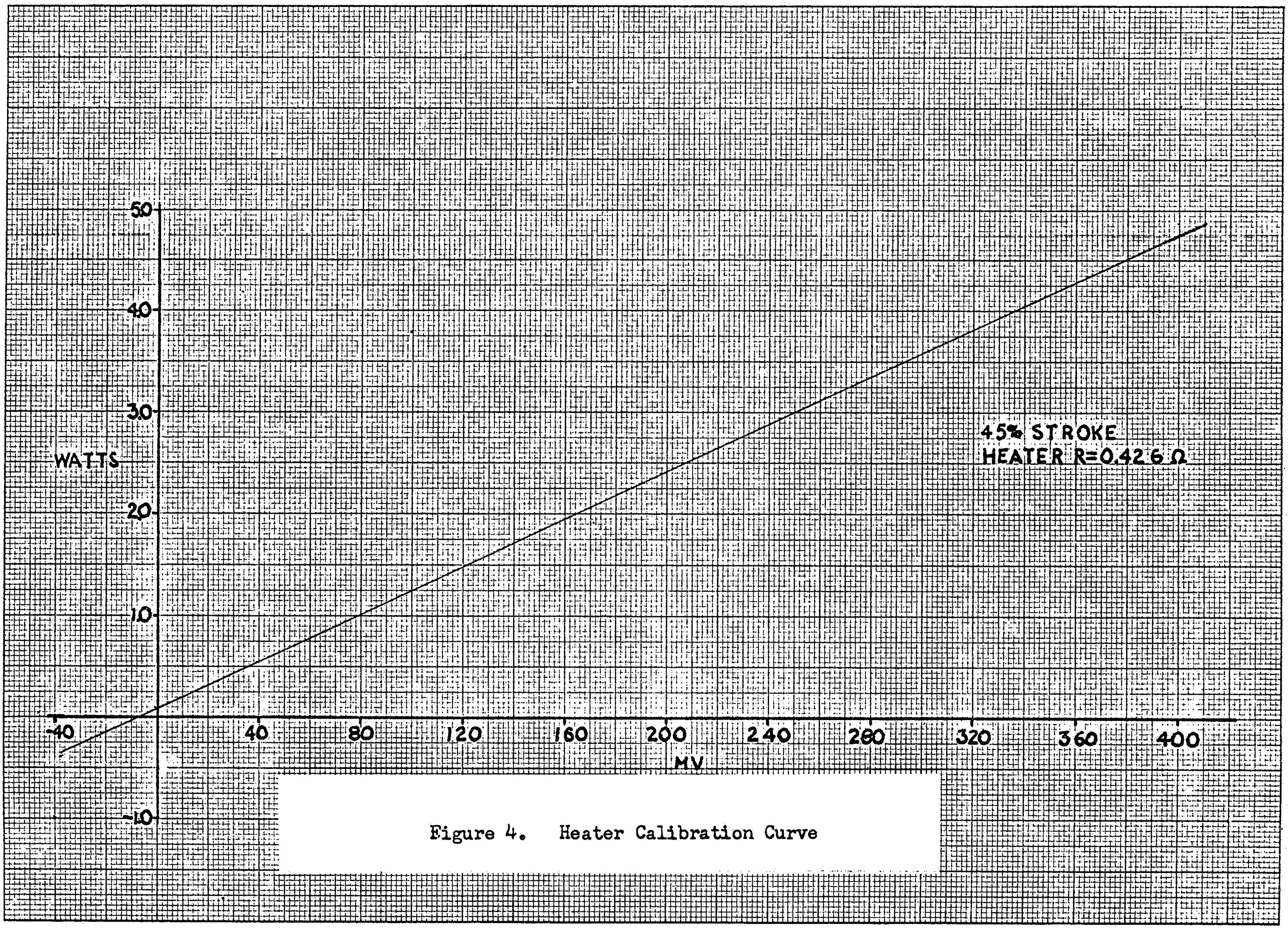

Figure 4. Heater Calibration Curve

Table 2. Pressure Transducer Calibration Data

	Pressure	
Signal (μv)	Indicated P.S.I.A.	Actual P.S.I.A.
10	3.5	<0
20	7.5	3.0
30	11	7.5
40	15	11.5
50	18.5	15.5
60	22.5	19.5
70	26	23.5
80	30	27.5
90	34	32.5
100	37.5	35.5
110	41.5	40
120	45	44
130	49	48

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. 46 1510 MADE IN U.S.A. KEUFFEL & ESSER CO.

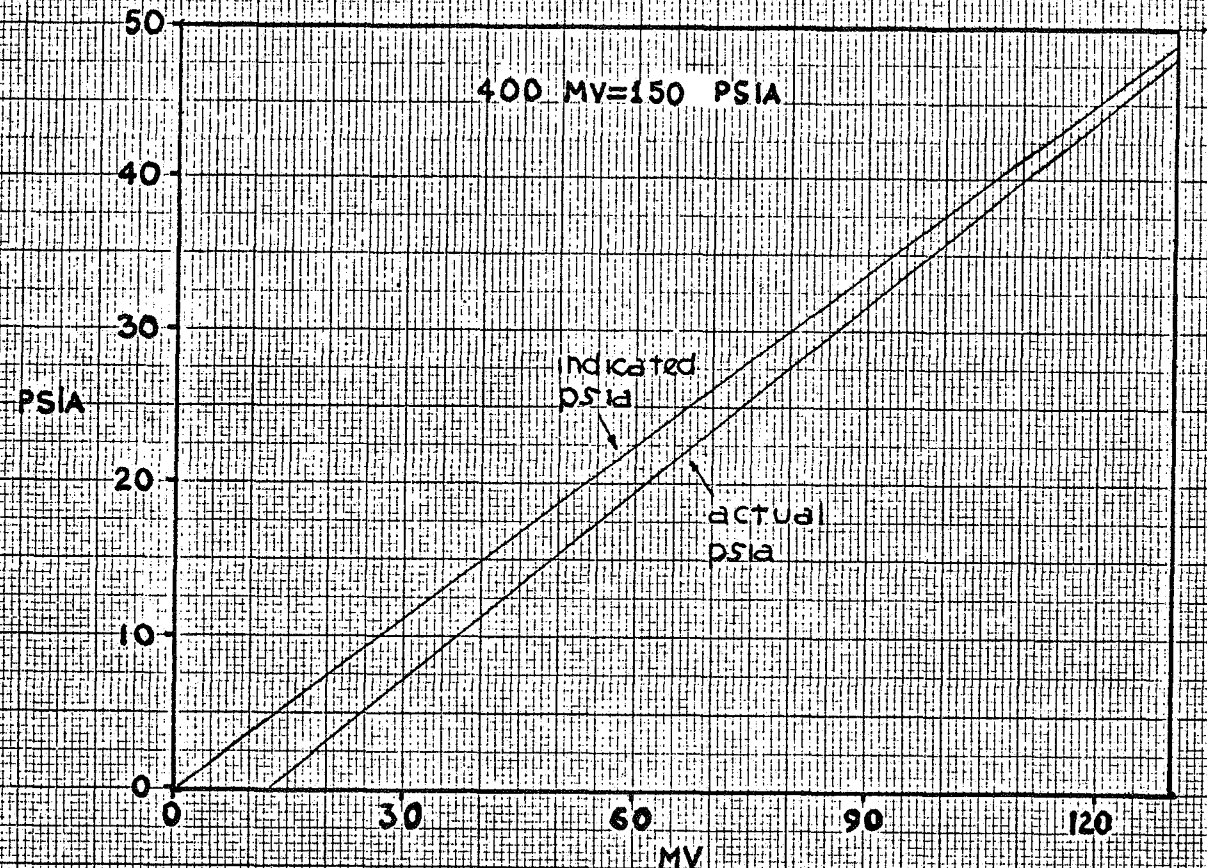

Figure 5. Pressure Transducer Calibration Curve

charging rates some of these data are plotted in Figure 6. This plot gives the heat output as a function of time. The time axis is divided into charge and discharge zones where discharge for all experiments are carried out at a C/2 rate to a voltage of 1 volt. For the charge cycle the cut-off point was taken as a signal of 100 µv across the 6.8 ohm resister of the third electrode. The charge rates used were C/10 (0.60 amp), C/8 (0.75 amp), C/6 (1.00 amp), C/4 (1.50 amp), C/2 (3.00 amp), and C/1.2 (5.00 amp), each at the constant indicated current. The discharge was at the 3.00 amp rate. Table 3 in the referenced report gives the results of the study in terms of cell efficiency and heat generated. Column 3 in Table 3 shows that, within the range of charging rates studied, the cell % efficiency varies by only 3.7%. The discharge process carried out at a constant current of 3.00 amps shows a constant endothermic output. Figure 6 illustrates graphically the heat dissipation problems associated with different rates of charging.

V. PLANNED FUTURE WORK

The thermal characteristics of the twenty ampere-hour cell will be evaluated at the same depths of discharge and recharge rates as those to which the six ampere-hour cell was subjected.

Figure 6. Charge Efficiency Study of Gulton 6 A-H Cell
(See Second Progress Report for Data)

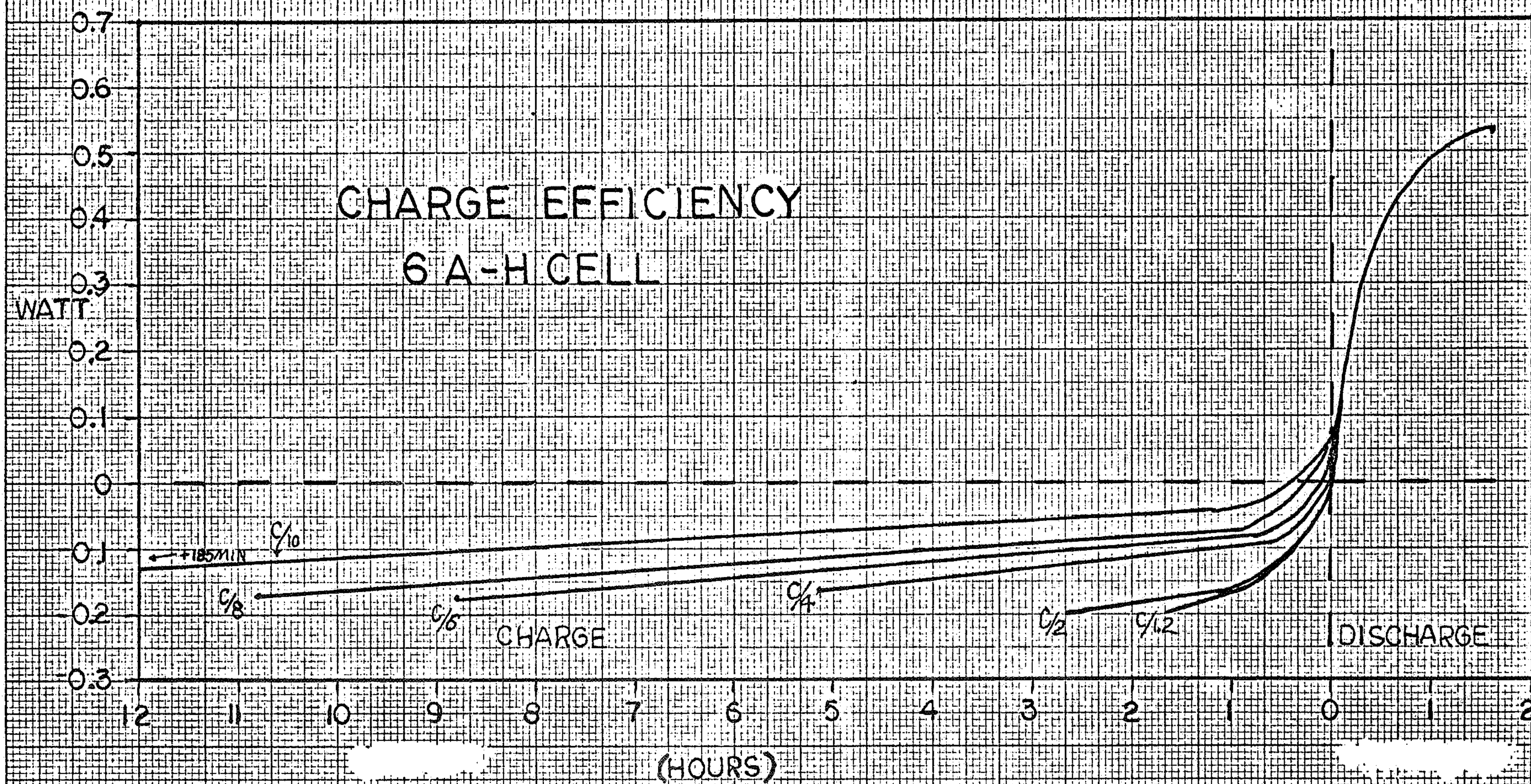

TABLE 3 - Comparison of Efficiency, Charge Rate, and Thermal Response

Charge Rate	AH Out / AH In	% Eff.	CHARGE Max. Endothermic Output(Watt)	CHARGE Max. Exothermic Output(Watt)	DISCHARGE Max. Exothermic Output(Watt)
$\frac{C}{1.2}$	$\frac{6.734}{8.134}$	82.7	+0.10	-0.24	-0.69
$\frac{C}{2}$	$\frac{6.835}{7.959}$	85.8	+0.12	-0.12	-0.69
$\frac{C}{4}$	$\frac{6.879}{8.200}$	83.8	+0.08	-0.10	-0.68
$\frac{C}{6}$	$\frac{6.902}{8.237}$	83.7	+0.07	-0.10	-0.69
$\frac{C}{8}$	$\frac{6.943}{8.466}$	82.1	+0.10	-0.10	-0.70
$\frac{C}{10}$	$\frac{6.867}{8.190}$	83.8	+0.06	-0.12	-0.72

NASA/Goddard Space Flight Center

OFFICIAL DISTRIBUTION LIST
FOR BATTERY REPORTS

May 1, 1967

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. M. Greg Andrus

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

National Aeronautics & Space Admin.
Goddard Space Flight Center
Greenbelt, Maryland 20771
Attn: Thomas Hennigan, Code 716.2
Send 3 copies

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: M. J. Saari, MS 500-202

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, Site 1

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: Mr. Barry Trout

National Aeronautics & Space Admin.
Manned Spacecraft Center
Houston, Texas 77058
Attn: Forrest E. Eastman (EE-4)

National Aeronautics & Space Admin.
Washington, D.C. 20546
Attn: Office of Technology Utilization

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

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

National Aeronautics & Space Admin.
Electronics Research Center
575 Technology Square
Cambridge, Mass. 02139
Attn: Dr. Sol Gilman

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

Department of the Army

U. S. Army Engineer R&D Labs.
Fort Belvoir, Virginia 22060
Electrical Power Branch
Energy Conversion Research Lab.

Commanding General
U. S. Army Weapons Command
Attn: AMSWE-RDR, Mr. G. Reinsmith
Rock Island Arsenal
Rock Island, Illinois 61201

U. S. Army Natick Laboratories
Clothing and Organic Materials Div.
Natick, Massachusetts 01760
Attn: G. A. Spano

Commanding Officer
U. S. Army Electronics R&D Labs.
Power Sources Division
Fort Monmouth, New Jersey 07003
Attn: Code SELRA/PS

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

Department of the Navy

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

Naval Research Laboratory
Washington, D.C. 20390
Attn: Dr. J. C. White, Code 6160

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

Naval Air Systems Command
Department of the Navy
Washington, D.C. 20360
Attn: Milton Knight (Code AIR-340C)

Commanding Officer
(Code QEWE, E. Bruess/H. Schultz)
U. S. Naval Ammunition Depot
Crane, Indiana 47522

Naval Ordnance Laboratory
Department of the Navy
Corona, California 91720
Attn: William C. Spindler (Code 441)

Naval Ordnance Laboratory
Silver Spring, Maryland 20910
Attn: Philip B. Cole (Code 232)

Commander, Naval Ship Sys. Command
Department of the Navy
Washington, D.C. 20360
Attn: C. F. Viglotti (Code 66605)

Commander, Naval Ship Sys. Command
Department of the Navy
Washington, D.C. 20360
Attn: Bernard B. Rosenbaum
(Code 03422)

Department of the Air Force

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

AF Cambridge Research Lab.
Attn: CRE
L. G. Hanscom Field
Bedford, Massachusetts 01731
Attn: Francis X. Doherty
Edward Raskind (Wing F)

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

Other Government Agencies

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

National Bureau of Standards
Washington, D.C. 20234
Attn: Dr. A. Brenner

Office, Sea Warfare System
The Pentagon
Washington, D.C. 20310
Attn: G. B. Wareham

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

Bureau of Mines
4800 Forbes Avenue
Pittsburgh, Pennsylvania 15213
Attn: Dr. Irving Wender

Private Organizations

Aerojet-General Corporation
Chemical Products Division
Azusa, California 91702
Attn: William H. Johnson

Aeronutronic Division of Philco Corp.
Technical Information Services
Ford Road
Newport Beach, California 92663

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

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

A. M. F.
Attn: Dr. Lloyd H. Shaffer
689 Hope Street
Springdale, Connecticut 06879

American University
Mass. & Nebraska Avenue, 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

Bell Telephone Laboratories, Inc.
Whippany, N. J. 07981
Attn: D. O. Feder, Room 3B-294

The Boeing Company
P. O. Box 3868
Seattle, Washington 98124
Attn: Sid Gross, MS 85-86

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

Burgess Battery Company
Foot of Exchange Street
Freeport, Illinois 61033
Attn: Dr. Howard J. Strauss

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

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

Catalyst Research Corporation
6101 Falls Road
Baltimore, Maryland 21209
Attn: H. Goldsmith

ChemCell Inc.
150 Dey Road
Wayne, New Jersey 07470
Attn: Peter D. Richman

G. & W. H. Corson, Inc.
Plymouth Meeting
Pennsylvania 19462
Attn: Dr. L. J. Minnick

Cubic Corporation
9233 Balboa Avenue
San Diego, California 92123
Attn: Librarian
Mrs. Judy Kalak

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. George Moe

Dynatech Corporation
17 Tudor Street
Cambridge, Massachusetts 02139
Attn: R. L. Wentworth

E. I. DuPont De Nemours & Co.
Explosives Department
Repauno Development Laboratory
Gibbstown, New Jersey 08027
Attn: Mr. R. W. Prugh
(Contract NASw-1233)

Eagle-Picher Company
Post Office Box 47
Joplin, Missouri 64801
Attn: E. P. Broglio

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

Electric Storage Battery Co.
Carl F. Norberg Research Center
19 West College Avenue
Yardley, Pennsylvania 19067
Attn: Dr. R. A. Schaefer

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: Martin Klein

Emhart Corp
Box 1620
Hartford, Connecticut 06102
Attn: Dr. W. P. Cadogan

Engelhard 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 Department
P. O. Box 8555
Philadelphia, Pennsylvania 19101
Attn: E. W. Kipp, Room U-2307

General Electric Company
Battery Products Section
P. O. Box 114
Gainsville, Florida 32601
Attn: W. H. Roberts

General Electric Company
Research and Development Center
P. O. Box 8
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
P. O. Box 591
Milwaukee, Wisconsin 53201
Attn: Mr. J. D. Onderdonk
V. P. Marketing

Gould-National Batteries, Inc.
Engineering & Research Center
(Dr. D. Douglas)
2630 University Avenue, S. E.
Minneapolis, Minnesota 55418

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

Gulton Industries
Alkaline Battery Division
212 Durham Avenue
Metuchen, New Jersey 08840
Attn: H. N. Seiger
Contract NAS W-12,300 only

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

Hughes Aircraft Corporation
Bldg. 366, M. S. 524
El Segundo, California 90245
Attn: P. C. Ricks

IIT 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

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

Idaho State University
Department 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

International Nickel Co.
1000-16th Street, N. W.
Washington, D.C. 20036
Attn: Wm. C. Mearns

Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland 20910
Attn: Richard E. Evans

Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland 20910.
Attn: Mr. Louis Wilson

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

Livingston Electronic Corporation
Route 309
Montgomeryville, Pa. 18936
Attn: William F. Meyers

Lockheed Missiles & Space Company
Technical Information Center
3251 Hanover Street
Palo Alto, California 93404

Mallory Battery Company
Broadway & Sunnyside Lane
North Tarrytown, New York 10591
Attn: R. R. Clune

P. R. Mallory & Co., Inc.
Northwest Industrial Park
Burlington, Massachusetts 01803
Attn: Dr. Per Bro

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

Martin Company
Denver Division
(P1001, Mr. R. C. Wildman)
Mail No. P-6700-1
Denver, Colorado 80201

Martin Company
Electronics Research Department
P. O. Box #179
Denver, Colorado 80201
Attn: William B. Collins, MS 1620

Mauchly Systems, Inc.
Fort Washington Industrial Park
Fort Washington, Pennsylvania
Attn: John H. Waite

Melpar
Technical Information Center
7700 Arlington Blvd.
Falls Church, Virginia 22046

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

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: Physical Science Laboratory

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

North American Aviation Co.
S & ID Division
Downey, California 90241
Attn: Dr. James Nash

Oklahoma State University
Stillwater, Oklahoma 74075
Attn: Prof. William L. Hughes
School of Electrical Engineering

Paul Howard Associates Inc.
Centerville, Maryland 21617

Power Information Center
University of Pennsylvania
3401 Market St., Rm. 2107
Philadelphia, Pennsylvania 19104

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

Prime Battery Corp.
15600 Cornet Street
Santa Fe Springs, California 90670
Attn: David Roller

RAI Research Corp.
36-40 37th Street
Long Island City, N. Y. 11101

Radio Corporation of America
Astro Corporation
P. O. Box 800
Hightstown, New Jersey 08540
Attn: Seymour Winkler

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

Radio Corporation of America
415 South Fifth Street
Harrison, New Jersey 07029
Attn: Dr. G. S. Lozier
Bldg. 18-2

Southwest Research Institute
8500 Culebra Road
San Antonio, Texas 78206
Attn: Library

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

Texas Instruments, Inc.
P. O. Box 5936
Dallas, Texas 75222
Attn: Dr. Isaac Trachtenberg

TRW Systems, Inc.
One Space Park
Redondo Beach, California 90278
Attn: Dr. A. Krausz, Bldg. 60, Rm. 147

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 Laboratories, Inc.
Bear Hill
Hickory Drive
Waltham, Massachusetts 02154
Attn: Dr. A. C. Makrides

Unified Sciences Associates, Inc.
826 S. Arroyo Parkway
Pasadena, California 91105
Attn: Dr. S. Naiditch

Union Carbide Corporation
Development Laboratory Library
P. O. Box 5056
Cleveland, Ohio 44101

Electromite Corporation
Attn: R. H. Sparks
General Manager
562 Meyer Lane
Redondo Beach, California 90278

Union Carbide Corporation
Parma Laboratory
Parma, Ohio 44130
Attn: Dr. Robert Powers

University of Pennsylvania
Electrochemistry Laboratory
Philadelphia, Pennsylvania 19104
Attn: Prof. John O'M. Bockris

Westinghouse Electric Corporation
Research and Development Center
Churchill Borough
Pittsburgh, Pennsylvania 15235

Whittaker Corporation
3850 Olive Street
Denver, Colorado 80237
Attn: J. W. Reiter

Whittaker Corporation
Narmco R&D Division
3540 Aero Court
San Diego, California 92123
Attn: Dr. M. Shaw

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