# STUDY PROGRAM TO IMPROVE FUEL CELL PERFORMANCE BY PULSING TECHNIQUES

1ST QUARTERLY REPORT

1 October, 1963

Technical Management
Auxiliary Power Generation Office
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio
Mr. W. J. Nagle

Contract NAS3-2752

Period Covered: July 1 - September 30, 1963

Prepared by

M. L. Kronenberg
Project Leader

UNION CARBIDE CORPORATION
DEVELOPMENT DEPARTMENT
PARMA RESEARCH LABORATORY
P. O. Box 6116 - Cleveland 1, Ohio

Note: Copies of this report can be obtained from:

National Aeronautics & Space Administration
Office of Scientific & Technical Information
Washington 25, D. C.
Attn: AFSS-A

## NOTICE

This report was prepared as an account of Government-sponsored work. Neither the United States, nor the National Aeronautics and Space Administration (NASA), nor any person acting on behalf of NASA:

A) Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately-owned rights; or

B) Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this report.

As used above, "person acting on behalf of NASA" includes any employee or contractor of NASA, or employee of such contractor, to the extent that such employee or contractor of NASA, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with NASA, or his employment with such contractor.

## TABLE OF CONTENTS

## APPENDIX
## LIST OF ILLUSTRATIONS

Figure

## 1.0 PURPOSE

This investigation is concerned with the effect on performance of porous fuel cell electrodes by changing the gas-electrolyte interface by pulsing techniques. The interface will be disturbed by electrical and mechanical pulses at frequencies in the subsonic, sonic and ultrasonic range. Carbon (hydrophobic), metal (hydrophillic) and composite electrodes will be used in this investigation.

## 2.0 ABSTRACT

Equipment was designed and constructed to provide electrolyte and gas pulsing in the subsonic range (0 to 425 c.p.m.) at controlled amplitudes. Preliminary experiments on electrolyte pulsing using wetproofed carbon electrodes showed cell voltage fluctuations of approximately 60 mv at a pressure amplitude of 12 psig at moderate current densities. The voltage amplitude was independent of frequency over the range 55 to 220 c.p.m.

Data obtained thus far indicate that there is no significant polarization difference between 1/4" electrodes operating on continuous d.c. and those operating on 60-cycle interrupted d.c.

The principal investigator was abroad for almost half of this reporting period.

## 3.0 MEETINGS AND CONFERENCES

G. E. Evans, K. V. Kordesch, and M. L. Kronenberg met with W. J. Nagel, Project Supervisor from NASA on 24 June, 1963 to discuss the scope and program of the contract. It was agreed that initial studies would involve the application of mechanical and electrical pulses that could change the position of the gas-electrolyte interface within the electrode. Three kinds of electrodes (carbon, metal and composite) would be tested at subsonic, sonic and ultrasonic frequencies. The effect of pulse intensity and shape on performance would also be studied. Temperature effects would be studied on optimized systems.

## 4.0 FACTUAL DATA

### 4.1 Test Equipment.

A drawing of the Teflon cell that was designed and built for electrolyte and gas pulsing is shown in Figure 1. The electrode size was chosen to accommodate the porous metal anodes and cathodes that are available to us. Accesses to the electrolyte room are for filling, pressure readings, and reference electrode. A drawing of the stainless steel electrode holders and gas room is shown in Figure 2. An O-ring gasket between the electrode and the cell prevents the electrolyte from penetrating around the electrode.

For electrolyte and gas pulsing in the subsonic range, a 1/8-horsepower motor with a gear box for varying speeds has been coupled with a piston and eccentric cam arrangement to provide controlled amplitudes and frequencies. Electrolyte or gas pulsations from 0 to 425 cycles per minute at amplitudes high enough to displace liquids throughout the total electrode thickness can be provided by the system which is shown in Figure 3. The pressure at the electrode surface is presently sensed with a Marsh pressure gage but a sensitive transducer coupled with a Bourdon tube will be used later for the more precise experiments.

Carbon electrodes have been set aside to provide standard carbon material for the entire testing program. An ample supply of porous metal and composite electrodes will also be available shortly.

### 4.2 Experimental Results.

Electrolyte pulsing experiments in the subsonic range were begun using 1/4-inch carbon electrodes. A Zn-wire reference electrode was used for these preliminary experiments. The effective area of the working electrodes was 4.9 $cm^2$. The polarization curve (prior to the pulsing experiment) is given in data form in Table I.

TABLE I

| Volts | | | Load |
|---|---|---|---|
| A - C | C - R | A - R | (ma) |
| 0. 980 | 1. 383 | 0. 404 | O. C. |
| 0. 880 | 1. 294 | 0. 414 | 20 |
| 0. 837 | 1. 267 | 0. 430 | 50 |
| 0. 793 | 1. 249 | 0. 455 | 100 |
| 0. 753 | 1. 242 | 0. 488 | 150 |

Note 1: A = Anode; C = Cathode; R = Reference.
Note 2: Data for Table I is plotted in Fig. 4

An oscilloscope trace of A - C (anode-cathode) fluctuations at 55 pulses per minute is shown in Figure 5, and at 220 pulses per minute in Figure 6. All traces are 2 sec. /cm and represent an amplitude of 0 to 12 psi. The vertical scale is 100 mv/cm and the peak voltage corresponds to maximum displacement (maximum pressure). The voltage amplitude appears to be independent of the pulsing frequency over this limited range.

After the series summarized in Table I was run, additional electrolyte was added to the cell so that a higher amplitude would result. The increased amplitude did not produce any increase in the voltage effect, and on continued pulsing the voltage fluctuations disappeared. Upon examining the electrodes it was observed that electrolyte penetration had occurred significantly into the electrode, perhaps too deeply for electrolyte pulsing to be of any effect. The new polarization curve data (after the higher pulsing) is shown in Table II.

TABLE II

| Volts | | | Load |
|---|---|---|---|
| A - C | C - R | A - R | (ma) |
| 0. 980 | 1. 460 | 0. 470 | O. C. |
| 0. 860 | 1. 350 | 0. 485 | 50 |
| 0. 825 | 1. 330 | 0. 595 | 100 |
| 0. 760 | 1. 300 | 0. 540 | 200 |

Note 1: A = Anode; C = Cathode; R = Reference
Note 2: Data for Table II is plotted in Fig. 7

Cathode performance improved while anode performance deteriorated as a result of this preliminary electrolyte pulsing. The voltage fluctuations observed in Figure 5 and 6 are encouraging, being of a higher magnitude than anticipated. However, since the results are preliminary, much more data must be obtained before any solid conclusion can be reached.

### 4.3 Comparison of 60-Cycle Pulsing and Direct Current.

Two cells were set up to run on nonfluctuating direct current at 10 $ma/cm^2$ and 50 $ma/cm^2$. Two other cells were set up to run at 10 $ma/cm^2$ and 50 $ma/cm^2$ at pulsed-direct current, the currents stated being average currents. The currents were checked across 1-ohm precision resistors with an electrometer, and also displayed on an oscilloscope, as shown in Figure 8.

The vertical scale is 200 mv/cm, and the sweep time was in the 10 millisecond/cm range. The curve shows current fluctuations corresponding to an average current of 50 $ma/cm^2$.

Polarization data have been taken on all four cells for 20 days thus far and the results are given in Table III. The cell voltages reported are resistance-free values.

TABLE III

| No. of Days Run | Cell Voltage: Nonpulsating, d. c. 10 $ma/cm^2$ | Nonpulsating, d. c. 50 $ma/cm^2$ | 60-Cycle, d. c. 10 $ma/cm^2$ | 60-Cycle, d. c. 50 $ma/cm^2$ |
|---|---|---|---|---|
| 1 | 0.898 | 0.846 | 0.902 | 0.843 |
| 4 | 0.906 | 0.852 | 0.912 | 0.851 |
| 6 | 0.920 | 0.853 | 0.921 | 0.857 |
| 10 | 0.932 | 0.856 | 0.932 | 0.851 |
| 12 | 0.927 | 0.855 | 0.930 | 0.855 |
| 14 | 0.927 | 0.851 | 0.930 | 0.855 |
| 20 | 0.939 | 0.863 | 0.936 | 0.858 |

Note: Data for Table III is plotted in Fig. 9.

The above data show there is no significant difference in performance between continuous d. c. and 60-cycle pulsating d. c. within the 20-day period of testing.

## 5. 0 FUTURE WORK

During the next period electrolyte pulsing experiments will be continued in the subsonic region with carbon, metal and composite electrodes at two or more pressure amplitudes. The effect of pulsing on air operation is of particular interest and this too will be studied with all three types of electrodes. Experiments will then be conducted to see if similar effects can be accomplished by moving the gas-electrolyte interface from the gas side by subsonic fluctuations in gas pressure.

During the next period we also expect to design and construct equipment suitable for extending the above measurements to the sonic range. Pulsating-current experiments with carbon electrodes will continue and similar tests will be set up with metal and composite electrodes.

M. L. Kronenberg

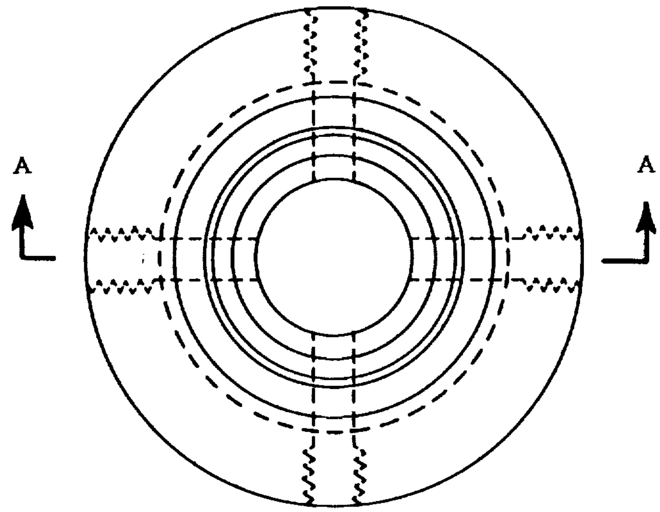
MLK/jdh

M. L. Kronenberg
Project Leader

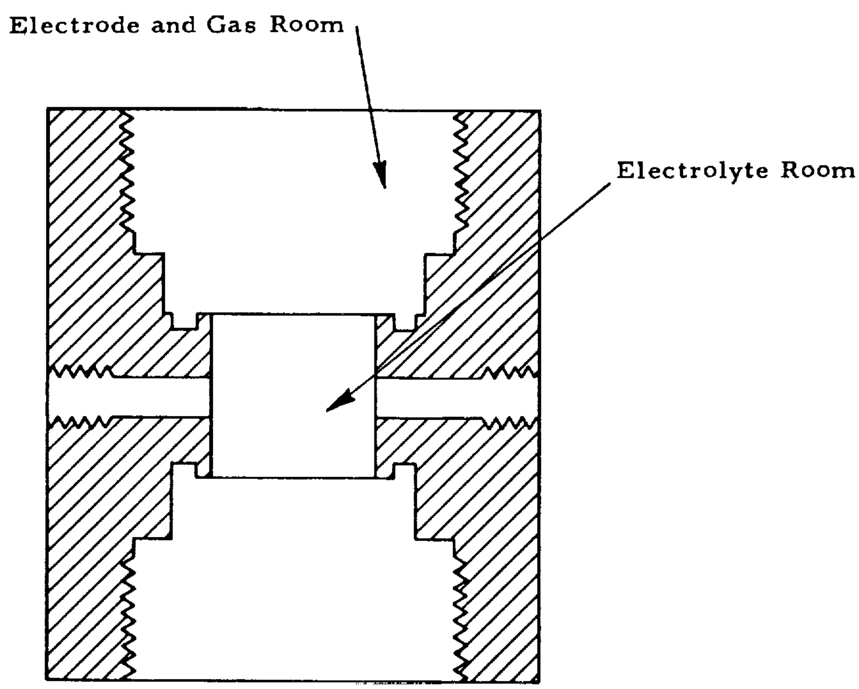
# APPENDIX

FIGURE 1

DRAWING OF TEFLON CELL
USED FOR ELECTROLYTE AND GAS PULSING



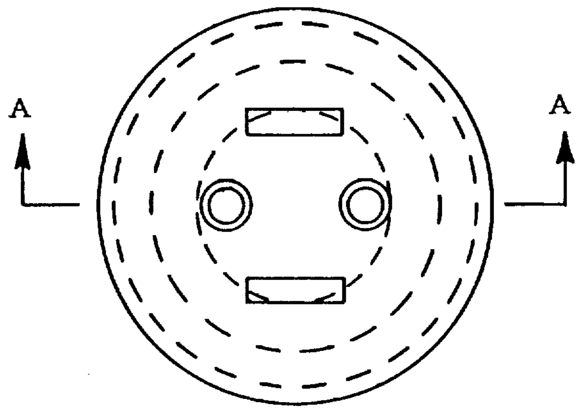

Front View



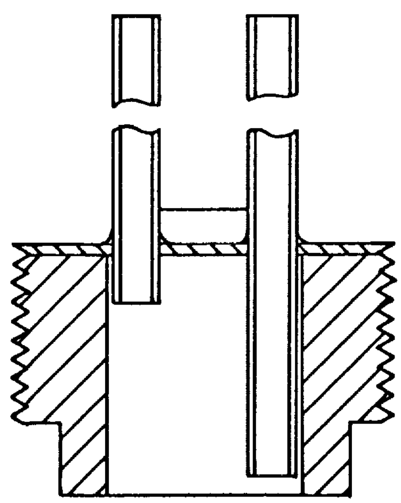

Section AA

FIGURE 2

DRAWING OF STAINLESS STEEL
ELECTRODE HOLDER AND ELECTROLYTE ROOM




Front View



Section AA

FIGURE 3

SYSTEM FOR SUBSONIC GAS AND ELECTROLYTE PULSING

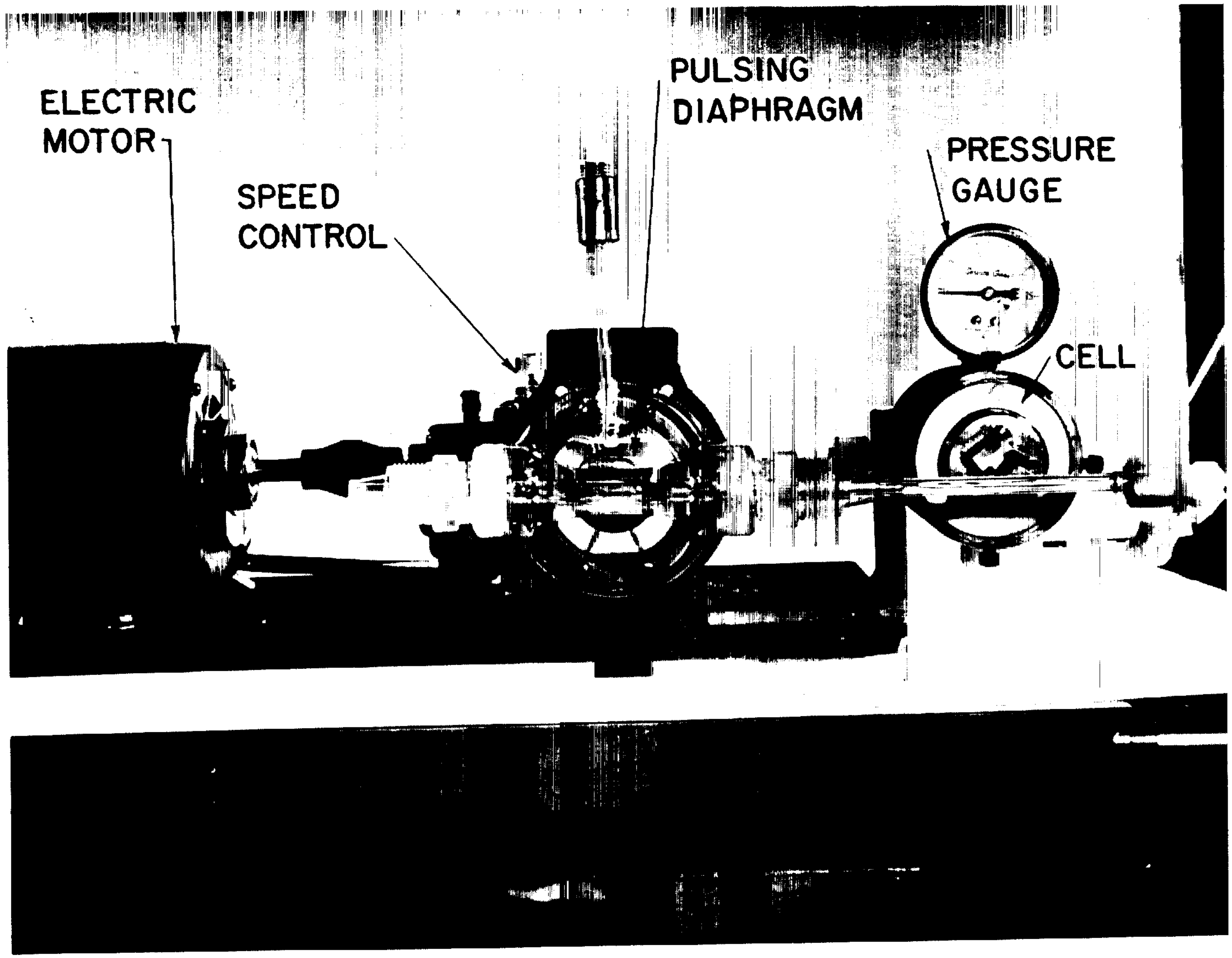
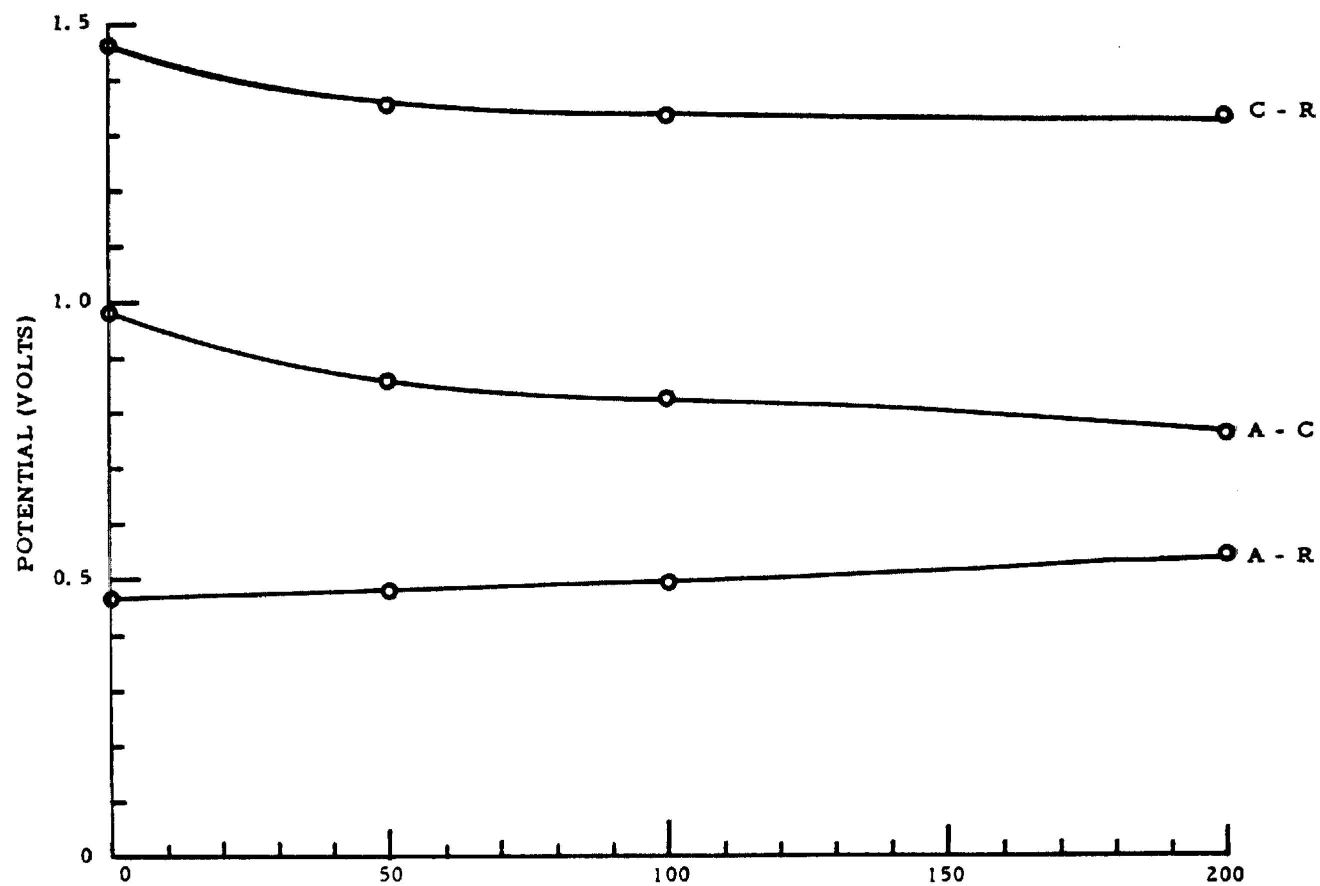


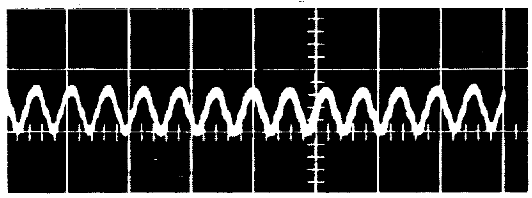
FIGURE 4

TABLE I DATA - POLARIZATION CURVES PRIOR TO PULSING




NOTE: A = Anode; C = Cathode; R = Reference

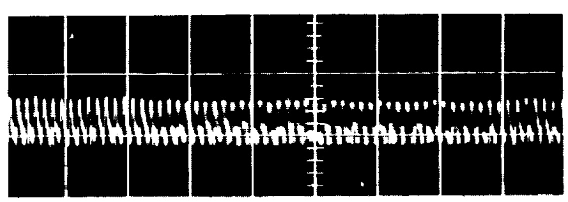
Potential (100 mv/cm)



Time (2 sec/cm)

Fig. 5 Oscilloscope Trace of Anode-Cathode Fluctuations at 55 Pulses/Min.

Potential (100 mv/cm)

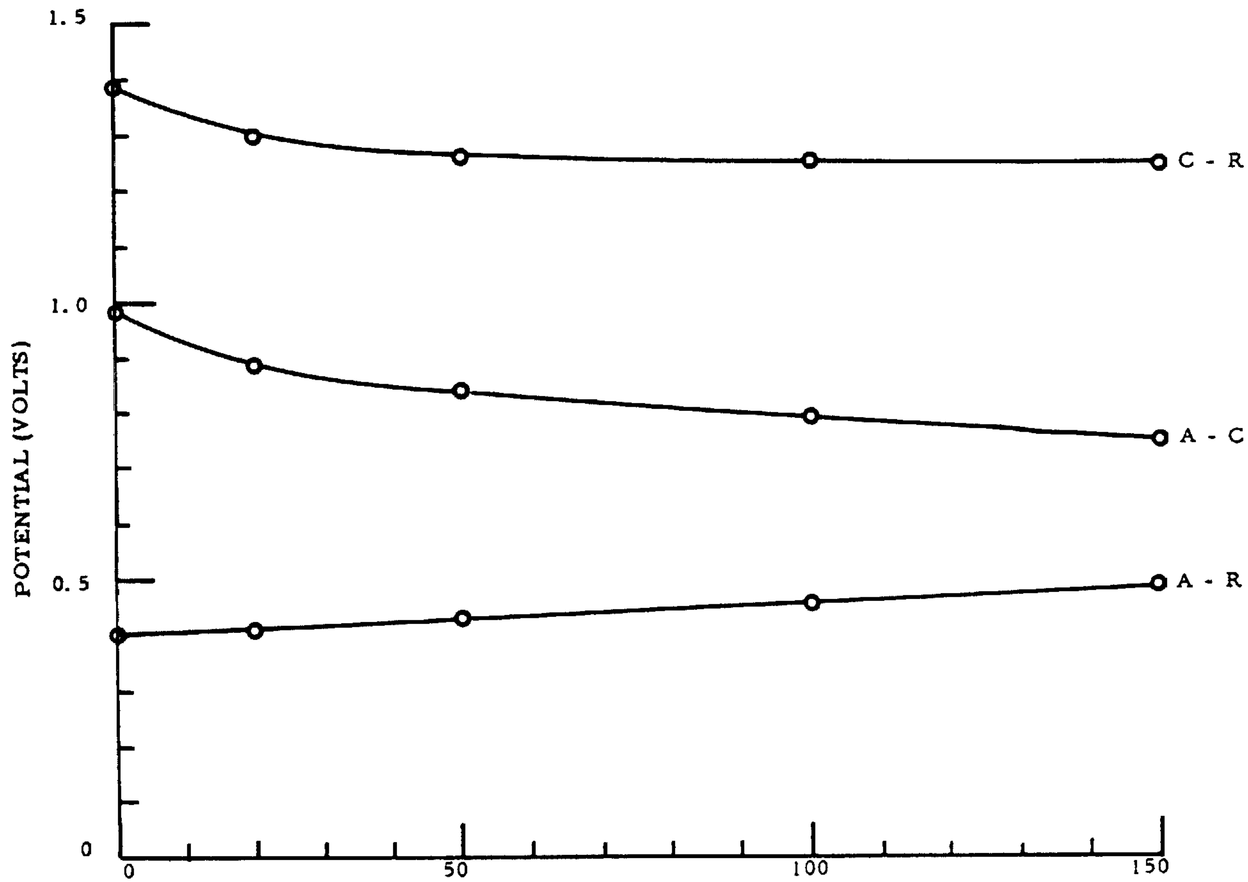


Time (2 sec/cm)

Fig. 6 Oscilloscope Trace of Anode-Cathode Fluctuations at 220 Pulses/Min.

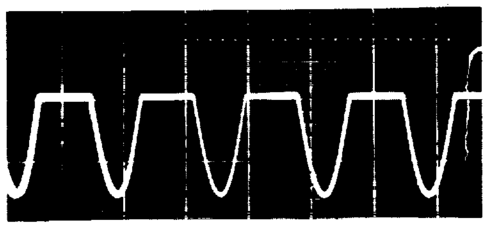
FIGURE 7

TABLE II DATA - POLARIZATION CURVES AFTER ELECTROLYTE PULSING




NOTE: A = Anode; C = Cathode; R = Reference

Potential
(200 mv/cm)

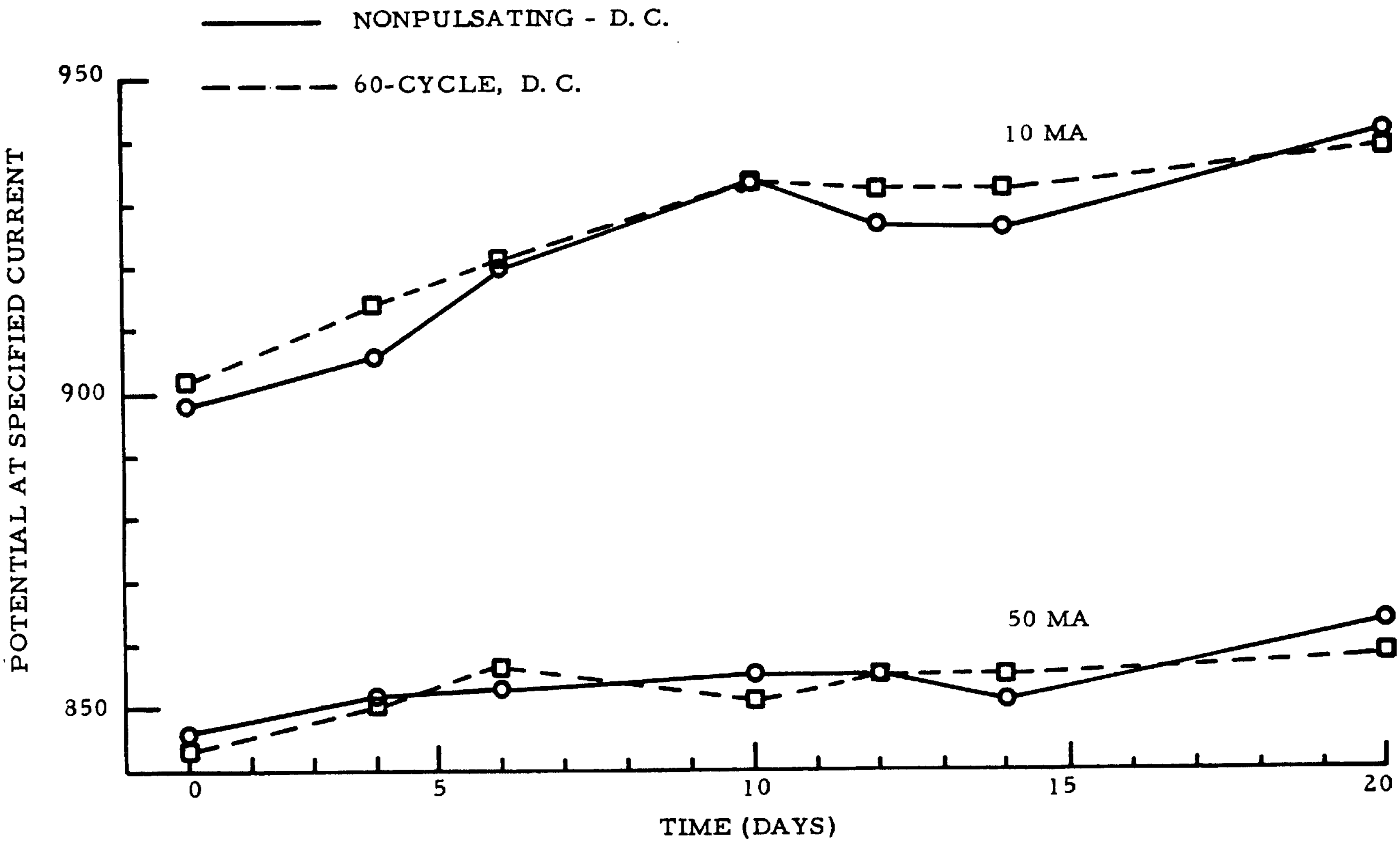


Time (10 millisec. /cm)

Fig. 8 Oscilloscope Trace of Pulsating 60-Cycle Direct Current - 50% Duty Cycle

FIGURE 9

TABLE III DATA - POLARIZATION CURVES FOR ELECTRICALLY-PULSED CELLS




D-485

## DISTRIBUTION LIST

National Aeronautics & Space Administration
Scientific & Technical Information Facility
Box 5700
Bethesda 14, Maryland
Attn: NASA Representative (2 copies + 1 repro.)

National Aeronautics & Space Administration
Washington, D. C. 20546
Attn: Miss Millie Ruda, Code AFSS-LD (3)
Walter C. Scott, Code RPP
Ernst M. Cohn, Code RPP
George F. Esenwein, Code MSA
John L. Sloop, Code RP
A. M. Andrus, Code FC
Fred Schulman, Code RN

National Aeronautics & Space Administration
Goddard Space Flight Center
Greenbelt, Maryland
Attn: Thomas Hennigan

National Aeronautics & Space Administration
Marshall Space Flight Center
Huntsville, Alabama
Attn: Philip Youngblood
Eugene Cagle

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: B. Lubarsky
N. T. Musial, Patent Counsel
Martin J. Saari
Robert L. Cummings
N. D. Sanders
Harvey J. Schwartz
William J. Nagle (3 copies + 1 repro.)
John J. Fackler, Contracting Officer

National Aeronautics & Space Administration
Manned Space Craft Center
Houston 1, Texas
Attn: William R. Dusenbury,
Systems Evaluation & Development Division
Rich Building
6040 Telephone Road
Robert Cohen, Gemini Project Office

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

U. S. Army Engineer R&D Labs.
Fort Belvoir, Virginia
Attn: Mr. B. C. Almula,
Electrical Power Branch

U. S. Army Engineer R&D Labs.
Fort Monmouth, New Jersey
Attn: David Linden (Code SELRA/SL-PS)
Dr. Adolph Fischbach (Code SELRA/SL-PS)
Arthur F. Daniel (Code SELRA/SL-PS)

U. S. Army Research Office
Physical Sciences Division
3045 Columbia Pike
Arlington, Virginia
Attn: Dr. Sidney J. Magram

Harry Diamond Labs.
Room 300, Bldg. 92
Connecticut Ave. & Van Ness St., N. W.
Washington, D. C.
Attn: Robert Goodrich

U. S. Army Research Office
Box CM, Duke Station
Durham, North Carolina
Attn: Paul Greer
Dr. Wilhelm Jorgensen

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

Office of Naval Research
Department of the Navy
Washington 25, D. C.
Attn: Mr. Ralph Roberts
Dr. J. C. White
H. W. Fox (Code 425)

Bureau of Ships
Department of the Navy
Washington 25, D. C.
Attn: Bernard B. Rosenbaum (Code 340)
C. F. Viglotti (Code 660)
James B. Trout (Code 660S)
CDR. Joseph W. Thornbury (Code 649)

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

Naval Ordnance Laboratory
Department of the Navy
Silver Spring, Maryland
Attn: Philip B. Cole (Code WB)

Wright-Patterson AFB
Aeronautical Systems Division
Dayton, Ohio
Attn: George W. Sherman
Robert L. Kerr
James E. Cooper

AF Cambridge Research Lab
Attn: CRZE
L. G. Hanscom Field
Bedford, Mass.
Attn: Francis X. Doherty
Edward Raskind (Wing F)
Commander (CRO)

Rome Air Development Center, ESD
Griffiss AFB, New York
Attn: Commander (RAALD)
Frank J. Mollura (RASSM)

Hq., USAF (AFRST-PM)
Washington 25, D. C.
Attn: Lt. Col. William G. Alexander

Capt. William H. Ritchie
Space Systems Division
Attn: SSZAE-11
Air Force Unit Post Office
Los Angeles 45, California

Capt. William Hoover
Air Force Ballistic Missile Division
Attn: WEZYA-21
Air Force Unit Post Office
Los Angeles 45, California

Mr. Charles F. Yost
Asst. Director, Material Sciences
Advanced Research Projects Agency
The Pentagon, Room 3E 153
Washington 25, D. C.

U.S. Atomic Energy Commission
Auxiliary Power Branch (SNAP)
Division of Reactor Development
Washington 25, D. C.

Lt. Col. John H. Anderson
Advanced Space Reactor Branch
Division of Reactor Development
U.S. Atomic Energy Commission
Washington 25, D. C.

Defense Documentation Center Headquarters
Cameron Station, Bldg. 5
5010 Duke Street
Alexandria 4, Virginia
Attn: TISIA

Office, DDR&E, USW & BSS
The Pentagon
Washington 25, D. C.
Attn: G. B. Wareham

Institute for Defense Analyses
Research and Engineering Support Division
1666 Connecticut Avenue, N. W.
Washington 9, D. C.
Attn: Dr. George C. Szego

Power Information Center
University of Pennsylvania
Moore School Building
200 South 33rd St.
Philadelphia 4, Pa.

Office of Technical Services
Department of Commerce
Washington 25, D. C. 20009

Alfred University
Alfred, New York
Attn: Prof. T. J. Gray

Allis-Chalmers Mfg. Co.
1100 S. 70th Street
Milwaukee 1, Wisconsin
Attn: Dr. T. G. Kirkland

Allison Division of General Motors
Indianapolis 6, Indiana
Attn: Dr. Robert E. Henderson

American Cyanamid Company
1937 W. Main St.
Stamford, Connecticut
Attn: Dr. R. G. Haldeman

Astropower, Incorporated
2968 Randolph Ave.
Costa Mesa, California
Attn: Dr. Carl Berger

Battelle Memorial Institute
Columbus 1, Ohio
Attn: Dr. C. L. Faust

Bell Telephone Laboratories, Inc.
Murray Hill, New Jersey
Attn: Mr. U. B. Thomas

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

Electro-Optical Systems, Inc.
300 North Halstead St.
Pasadena, Calif.
Attn: Dr. Joseph Neustein

Englehard Industries, Inc.
497 Delancy Street
Newark 5, New Jersey
Attn: Dr. J. G. Cohn

ESSO Research and Engineering Co.
Products Research Division
P. O. Box 215
Linden, New Jersey
Attn: Dr. Carl Heath

General Electric Company
Direct Energy Conversion Operations
Lynn, Massachusetts
Attn: Dr. E. Oster

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

General Electric Company
Missile and Space Vehicle Dept.
P. O. Box 8555
Philadelphia 1, Pa.
Attn: A. D. Taylor

Globe-Union, Incorporated
Milwaukee 1, Wisconsin
Attn: Dr. C. K. Morehouse

Hoffman Electronics Company
Research Laboratory
Santa Barbara, California
Attn: Dr. Joseph Smatko

John Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland
Attn: W. A. Tynan

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

McDonnell Aircraft Corporation
Attn: Project Gemini Office
P. O. Box 516
St. Louis 66, Missouri

Monsanto Research Corporation
Everette 49, Mass.
Attn: Dr. J. O. Smith

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

Pratt and Whitney Aircraft Division
United Aircraft Corporation
East Hartford 8, Conn.
Attn: Librarian

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

Radio Corporation of America
Sommerville, New Jersey
Attn: Dr. G. Lozier

Thompson Ramo Wooldridge
23555 Euclid Avenue
Cleveland 17, Ohio
Attn: Librarian

University of California
Space Science Laboratory
Berkeley 4, California
Attn: Prof. Charles W. Tobias

University of Pennsylvania
Electrochemistry Laboratory
Philadelphia 4, Pa.
Attn: Prof. John O'M Bockris

Western Reserve University
Cleveland, Ohio
Attn: Prof. Ernest Yeager

Yardney Electric Corporation
New York, New York
Attn: Dr. Paul Howard

National Aeronautics & Space Administration
Ames Research Center
Pioneer Project
Moffett Field, Calif.
Attn: James R. Swain

Research Office
R & D Directorate
Army Weapons Command
Rock Island, Ill.
Attn: G. Reinsmith, Chief

Bell & Howell Research Center
360 Sierra Madre Villa
Pasadena, Calif.
Attn: Alan G. Richards

Lockheed Missiles and Space Co.
Sunnyvale, California
Attn: Dr. George B. Adams

Ford Motor Company
Aeronutronics Division
Newport Beach, Calif.
Attn: Dr. R. C. Bean

Globe-Union, Incorporated
900 East Keefe Ave.
Milwaukee, Wisconsin
Attn: Dr. C. K. Marbouse

Livingston Electronic Corporation
Route 309 Opposite Springhouse Quarry
Montgomeryville, Pa.
Attn: William F. Meyers

Dr. John H. Huth
Advanced Research Projects Agency
The Pentagon, Room 3E 157
Washington 25, D. C.