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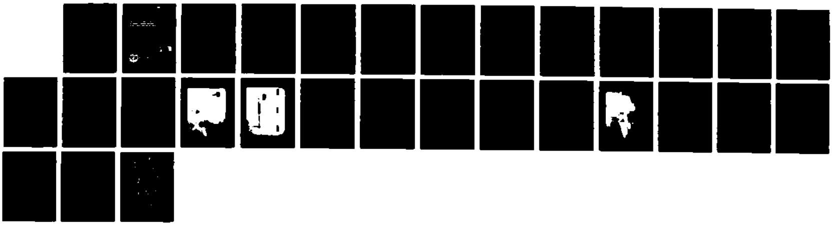

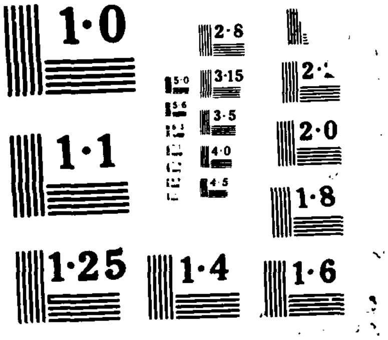
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SAFETY EVALUATION OF THE NC-106 MULTI-ORDER GRADIENT, NOISE-CANCELLING MICROPHONE

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RESEARCH AND TECHNOLOGY DEPARTMENT

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FOREWORD

This work was performed for and funded by the Naval Electronics System Command. The work was conducted under a test regime set forth by NAVSEA INSTRUCTION 9310.1A. The purpose of the tests performed was to determine if the Multi-Order Gradient, Noise Cancelling Microphone containing one Panasonic BR-$\frac{1}{2}$A cell was safe for fleet use.

Approved by:

JAMES F. GOFF, Acting Head
Materials Division

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CHAPTER 1

INTRODUCTION

The Vought Missiles and Advanced Programs Division of LTV Aerospace and Defense Company is developing an NC-106 Multi-Order Gradient, Noise-Cancelling Microphone (MONCM) under U.S. Navy Contract N00039-83-C-0038. The unit is designed to be worn by the user so that the microphone is just in front of the user's face. The MONCM requires an internal power source that will continuously supply 3 volts (V) at 90μA for 12 months. Vought has proposed the use of a lithium/poly-carbonmonofluoride cell to provide the required energy. The operating temperature range of the unit is -40°C to 71°C. The boom-mounted MONCM is constructed of LEXAN plastic manufactured by General Electric. The grade of LEXAN used for the MONCM is LEXAN 141, a medium viscosity polycarbonate resin rated by the manufacturer to be dimensionally stable up to 121°C.

At the request of the Naval Electronics System Command, the Naval Surface Weapons Center, White Oak (NSWC/WO), tested the MONCM under the regime specified in NAVSEA INSTRUCTION 9310.1A in order to characterize the behavior of the system when the lithium cell was subjected to abuse. The test data obtained provide the basis for a recommendation as to the unit's safety. The units tested contained a single Panasonic BR-$\frac{1}{2}$A cell. Figure 1 shows the placement of the BR-$\frac{1}{2}$A in the MONCM unit. This cell is a lithium poly-carbonmonofluoride cell. Panasonic specifications for the BR-$\frac{1}{2}$A give a temperature operating range of -40°C to 85°C. The nominal capacity of the cell is 650 milliampere-hours (mAh) and the maximum continuous drain rate is 120 milli-amperes (mA). The nominal voltage of the cell is 3V.

CHAPTER 2

EXPERIMENTAL

CELL TESTING

Three cells were heated to temperatures of approximately 500°C. Each cell was heated inside a pressure vessel containing a different gaseous environment (air, helium, and oxygen). Gas samples were taken from the pressure vessel and analyzed by the National Bureau of Standards (NBS) using mass spectrometric methods. The open circuit voltage, as well as the external cell can temperature of each cell, was monitored during heating.

Heating in Normal Atmosphere (Air)

A fresh, single BR-½A cell was wrapped with THERMOLYNE BRISKHEAT flexible electric heating tape. The cell was heated in a pressure vessel until venting occurred. At this point, a gas sample was taken from the pressure vessel and labeled as Sample #1. Heating of the cell continued until incineration occurred, then another gas sample was taken and labeled as Sample #2.

Heating in an Atmosphere of Helium

A fresh BR-½A cell was wrapped with heating tape as before and placed in a pressure vessel containing a helium atmosphere. The cell was heated until venting occurred; at which time, a gas sample was taken and labeled Sample #3. The cell was further heated until it had been incinerated; another gas sample was taken at this point. This sample was labeled as Sample #4.

Heating in an Atmosphere of Oxygen

A third fresh BR-½A cell was wrapped with heating tape and placed in a pressure vessel containing an atmosphere of oxygen. The cell was heated until venting occurred; at which time, gas Sample #5 was taken. Gas Sample #6 was taken after incineration of this cell.

SYSTEM TESTING

Tests were performed on the BR-½A cell installed in a MONCM unit to observe the effects of cell failure under abuse at the systems level. These tests involved short circuit, charging a fresh cell, charging a discharged cell, forced overdischarge of two fresh cells, and heating MONCM units containing fresh cells

Short Circuit Test

A BR-$\frac{1}{2}$A cell was installed in a MONCM. Holes had been previously drilled in the unit near each pole of the cell. Leads were connected through these holes to the cell for voltage and current monitoring by a FLUKE DATALOGGER. The holes were then sealed with HYSOL EPOXY. A thermocouple was placed on the -87 cell case to monitor temperature. The cell leads were shorted for one hour. The resistance through the circuit was .0001Ω.

A second fresh BR-$\frac{1}{2}$A cell was installed in a MONCM unit and fitted with monitoring leads as before. An additional thermocouple was added to the arrangement by inserting it through one of the drilled holes and placing it on the can of the BR-$\frac{1}{2}$A cell. The cell was shorted for 80 minutes. The MONCM unit is pictured in Figure 2.

Charging a Fresh Cell

One fresh BR-$\frac{1}{2}$A cell was installed in a MONCM unit and leads were attached, as above, in order to monitor voltage and current. Thermocouples were also attached as in the previous test. This cell was then charged at the 1 ampere (A) rate for 103 minutes, using a constant-current power supply. The cell was charged so that it would receive 150% of the manufacturer rated capacity.

Charging a Discharged Cell

A fresh BR-$\frac{1}{2}$A cell was installed in the MONCM unit with leads attached as before. The temperature of the cell can was also monitored. The cell was discharged through 6Ω at the 500mA rate for 45 minutes. Fifty percent of the rated capacity was removed. The system was allowed to incubate at room temperature for seven days. After the incubation period, the cell was charged at the 1A rate for 45 minutes. This charge returned the cell back to its original capacity and then added an additional 50% beyond the original capacity.

Forced Overdischarge of Two Cells

Two fresh BR-$\frac{1}{2}$A cells were force overdischarged in MONCM units at the 500mA rate through 6Ω. The cells were discharged to 0 volts and then driven, with a power supply, 150% into voltage reversal. The voltage, current, and thermocouple temperatures were monitored as they were on previous MONCM units with one exception; only the thermocouple on the cell can was monitored.

Heating MONCM Units Containing Fresh Cells

Two tests were conducted as follows. A fresh BR-$\frac{1}{2}$A cell was inserted in the MONCM and voltage, current, and temperature monitoring leads were attached. The MONCM was wrapped with THERMOLYNE BRISKHEAT flexible electric heating tape. Heat was applied to the unit until incineration occurred.

Data for the tests performed were collected with a Fluke 2240B Datalogger at NSWC/WO.

CHAPTER 3

RESULTS AND DISCUSSION

The following discussions give the results of tests described in Chapter 2.

CELL TESTING

Cell testing consisted of heating Panasonic BR-$\frac{1}{2}$A cells in gaseous environments to temperatures around 500°C. The cells were heated so that each vented and, after further heating, was incinerated. Gas samples were taken of the venting products and incineration products. The NBS analyzed the six samples by mass spectrometric analysis. Figure 3 shows a gas collection vessel and the three incinerated cells.

Heating in Normal Atmosphere (Air)

As can be seen in Figure 4, venting of the cell occurred approximately 19 minutes into the test at which point a gas sample (Sample #1) was taken as indicated by *1. The temperature at this point was about 240°C. Heating continued until the cell was incinerated with temperatures exceeding 500°C. A gas sample (Sample #2) was taken after the cell was incinerated as indicated by *2 in Figure 4. Table 1 gives the composition in mole percent of venting gases as reported by NBS. The venting products (Sample #1) present no health hazard to personnel. Most of the components in this sample are merely constituents of air. The components of gas Sample #2, taken after burning of the cell, were not identified by the NBS because of the complexity of the spectra and the inability to identify the source of higher mass fragments.

TABLE 1. COMPLETE MASS SPECTROMETRIC ANALYSIS OF THREE SAMPLES TAKEN AFTER VENTING WITH COMPOSITION GIVEN IN MOLE PERCENT

COMPONENT	SAMPLE		
	#1	#3	#5
H_2	-	0.1	0.1
He	-	99	0.3
N_2	79	0.4	0.4
O_2	19	-	99
Ar	0.1	-	0.1
CO_2	0.1	0.1	0.3
HC(26)	0.01	0.04	0.0[illegible]

Heating in an Atmosphere of Helium

After 25 minutes of heating the BR-$\frac{1}{2}$A cell in a helium atmosphere, a venting occurred. A gas sample (Sample #3) was collected as indicated by *3 in Figure 5. The temperature of the cell at this point was about 200°C, and the voltage had dropped to less than .5V. Heating continued until the battery was incinerated; at which point, gas Sample #4 was taken as indicated by the *4 in Figure 5. As Shown in Table 1, Sample #3 consisted mostly of He (99%); there were no toxic amounts of harmful gases present. Gas Sample #4 was analyzed, but because of the complexity of the spectra and the inability to identify the source of higher mass fragments, the compounds could not be identified.

Heating in an Atmosphere of Oxygen

A BR-$\frac{1}{2}$A cell was heated in an oxygen atmosphere to about 225°C, at which point the cell vented. A gas sample, labled Sample #5, was taken as indicated by *5 in Figure 6. The cell was further heated until it was burned. At incineration the highest temperature measured was about 525°C. In Figure 6, *6 indicates the point at which the incineration gas sample was taken. Gas Sample #5 consists mainly of oxygen (99%). There were no toxic amounts of harmful gases present in the sample. NBS reported that specific compounds in Sample #6, as in the other incineration samples, could not be identified because of its complex spectra and the source of higher mass fragments.

SYSTEM TESTING

The following safety tests were conducted on BR-$\frac{1}{2}$A cells that were installed in a MONCM unit which utilizes a single cell.

Short Circuit Test

In separate tests, two BR-$\frac{1}{2}$A cells were shorted in a MONCM unit. Data for voltage, current, and -87 cell case temperature during the first experiment are presented in Figure 7. The temperature peaked at 41°C 12 minutes into the test. The BR-$\frac{1}{2}$A cell did not explode or vent during the test. At the conclusion of the test, no change in appearance of the cell could be observed; no electrolyte leakage was observed.

The second BR-$\frac{1}{2}$A cell shorted was fitted with two thermocouples; one on the -87 cell case and one on the cell can. The data are given in Figure 8. The temperature of the -87 cell case peaked at 32°C, 12 minutes after shorting began; the temperature of the cell can peaked at 50°C, 10 minutes after shorting began. This cell did not explode or vent during the test; upon examination of the cell, there was no change in appearance or evidence of leakage of electrolyte.

Charging a Fresh Cell

A fresh BR-$\frac{1}{2}$A was inserted in a MONCM unit and charged at the 1A rate. After 20 minutes of charging, the current passing through the system fell to 10 mA. During the first 10 minutes of this period the voltage climbed above 14V and then dropped to a steady 10V. This occurred due to an increase in impedance in the cell. During the time when the current was dropping, the temperature of the cell can climbed from 25°C to 59°C. The temperature decreased throughout the remainder of the test. Figure 9 presents the data for this test. There were no explosions or ventings, and examination of the cell after the test showed no change in cell appearance or leakage of electrolyte.

Charging a Discharged Cell

A BR-$\frac{1}{2}$A cell was discharged at a constant rate of 500mA for [illegible] minutes inside a MONCM unit through a 6Ω resistor. This removed, in theory, 50% of the capacity from the cell. The data for this discharge are presented on the left hand side of Figure 10. The temperature of the cell can did not exceed 50°C during discharge. The current fell from 500mA to 375mA after about one-third of the discharge had been completed. The cell and MONCM unit were allowed to incubate at room temperature for seven days prior to charging.

The cell was to be charged for 45 minutes at a current not to exceed the 1A rate, with the voltage limited to approximately 3V to simulate charging by another cell. The current measured through the system during this experiment was less than 10mA. No external changes in the cell were observed either during or after charging.

Forced Overdischarge of Two Cells

Cell number one was forced into voltage reversal, using a power source, at a constant current rate of 500mA. Figure 11 presents the data for this test, which shows that the cell went into voltage reversal about 15 minutes after the discharge began. The cell was well behaved during discharge, with the temperature of the cell not exceeding 52°C. The cell did not vent during discharge, and afterwards there were no visible signs of electrolyte leakage or cell disfiguration.

A second cell was forced into voltage reversal in the same manner. As presented in Figure 12, the data were essentially the same as in the first experiment.

Heating MONCM Units Containing Fresh Cells

Two units were heated with heating tape to the point of incineration. Each unit contained a fresh BR-$\frac{1}{2}$A that was wired with monitoring leads for voltage and cell can temperature.

Figure 13 presents the data for the first unit exposed to high temperatures. Nineteen minutes after heating began, the temperature of the cell can was 210°C, and smoke was visible around the unit. One minute later an audible venting occurred; and, as shown in Figure 13, simultaneously a negative voltage spike occurred. Seven minutes later small flames were visible around the unit and the temperature on the cell can jumped from 400°C to 680°C. Figure 14 is a picture of an incinerated unit that clearly shows the -87 cell case which contains the burned remains of a cell.

The second unit heated followed a pattern very similar to the first unit heated. Figure 15 presents the data for heating the second unit. An audible venting occurred 30 minutes into the test at which time the temperature was 260°C. Five minutes prior to venting the voltage on the cell fell dramatically and began to fluctuate. The temperature on the cell was around 200°C when the voltage change occurred.

Both cells reached temperatures in excess of 179°C, the melting point of lithium, before venting. Therefore, the cells, as well as the units, are stable up to the maximum operating temperature range specified for the unit (71°C) and the cell (85°C).

CHAPTER 4

CONCLUSIONS

The scenario for use of the Multi-Order Gradient, Noise-Cancelling Microphone indicates that a power source is needed that will continuously supply 3V for 12 months. The temperature operating range of the microphone is -40°C to 71°C.

The plastic used for construction of the microphone is dimensionally stable up to 121°C, which is more than sufficient to meet the temperature specifications of the microphone. The temperature range for operation of the Panasonic BR-$\frac{1}{2}$A poly-carbonmonofluoride cell is -40°C to 85°C, which meets the requirements for the battery. Heated cells reached temperatures in excess of 179°C, the melting point of lithium, before ventings occurred. The cells were further heated to the point of incineration. Mass spectrometric analysis on venting gas samples, performed by the National Bureau of Standards, indicated that the venting products did not contain harmful amounts of toxic gases. Incineration products could not be identified.

The MONCM unit, constructed with the -87 cell case, containing one Panasonic BR-$\frac{1}{2}$A lithium poly-carbonmonofluoride cell performed well under all abusive conditions outlined in NAVSEA INSTRUCTION 9310.1A. Therefore, we recommend that the MONCM unit configuration reviewed is appropriately safe for fleet use.

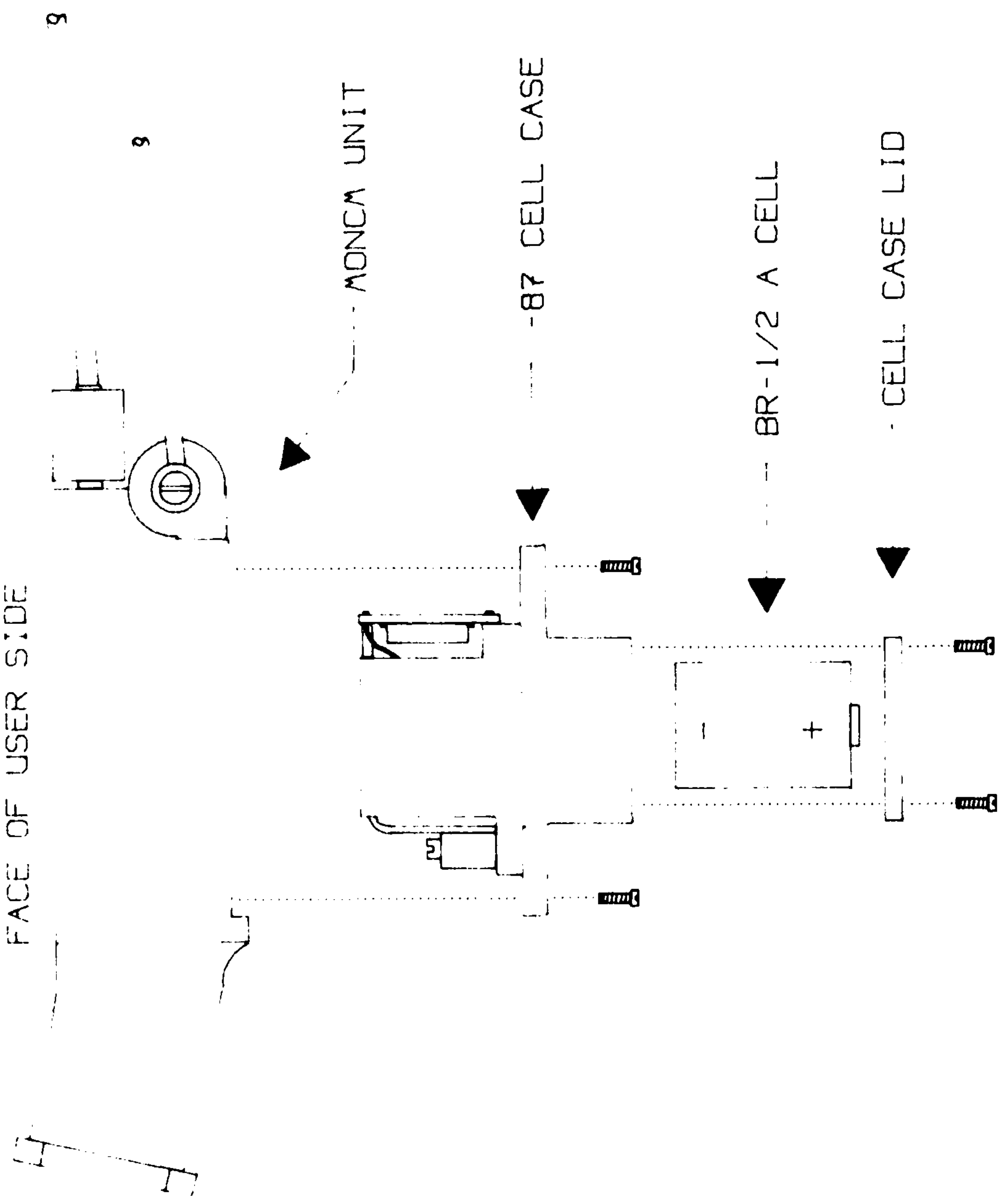

FIGURE 1. BR -1/2 A PLACEMENT IN THE -87 CELL CASE

FIGURE 2. WIRING OF THE MULTI-ORDER GRADIENT, NOISE-CANCELLING MICROPHONE FOR VARIOUS TESTS

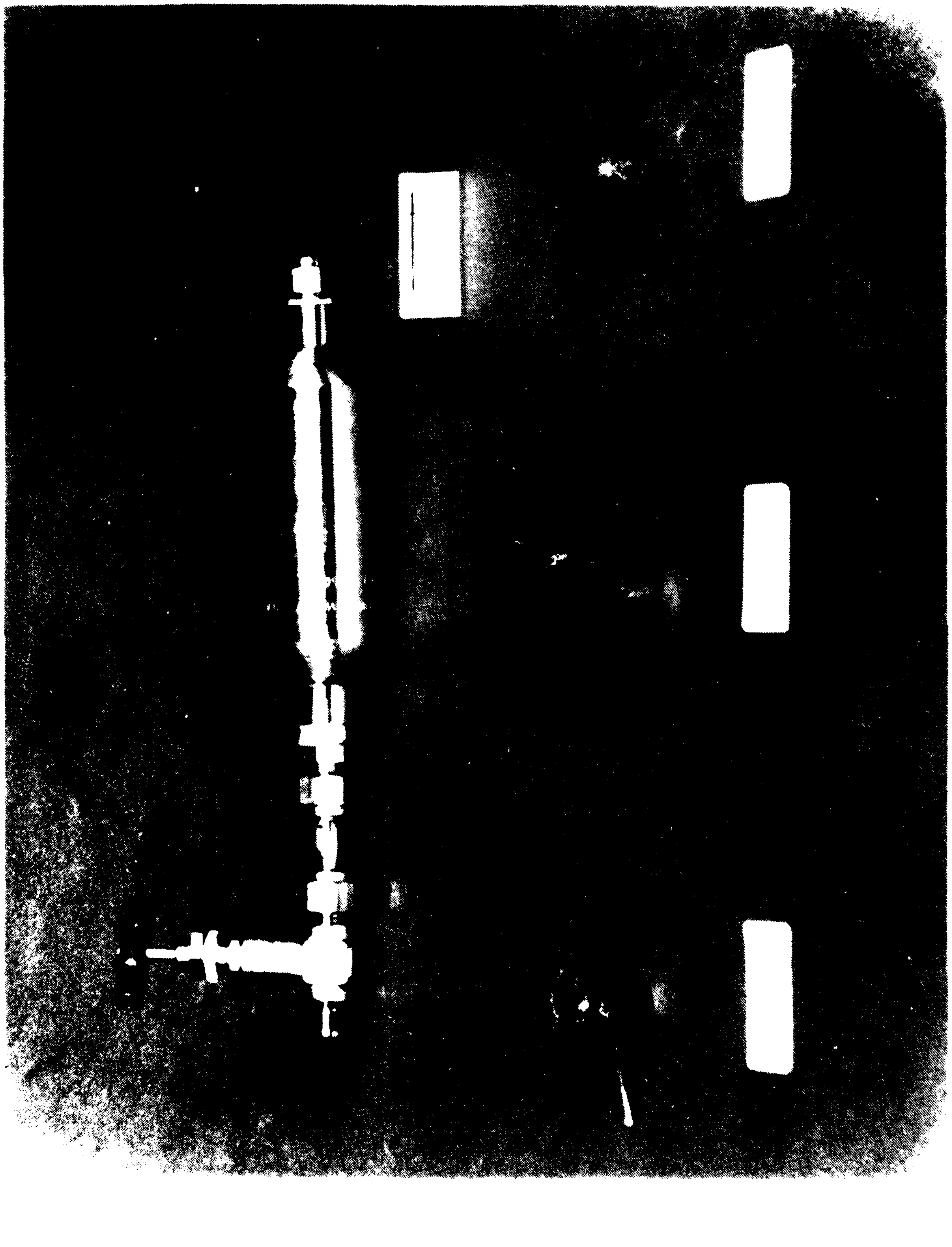

FIGURE 3. CELLS HEATED IN AIR, HELIUM, AND OXYGEN ALONG WITH A GAS COLLECTION VESSEL

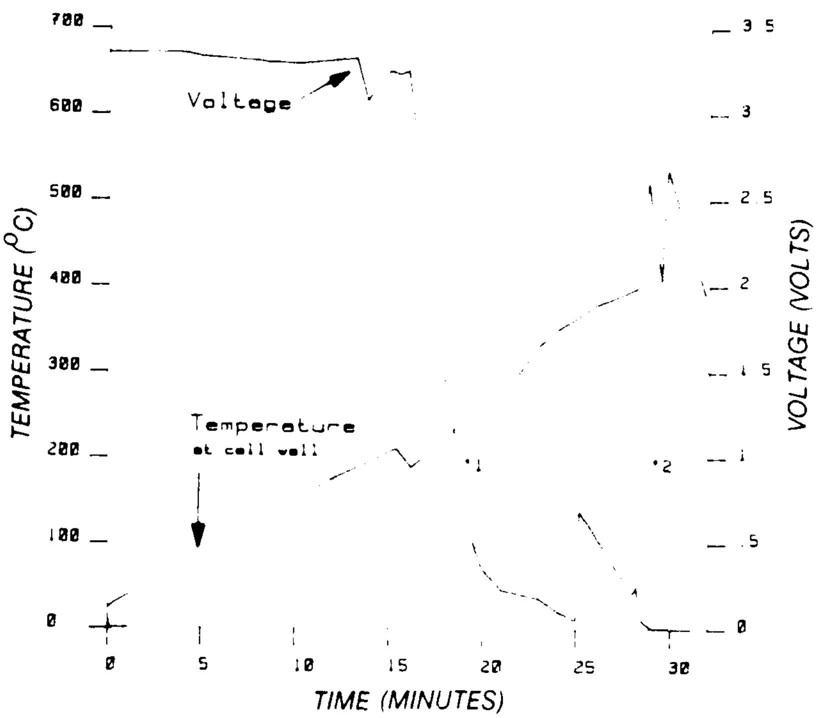

FIGURE 4. PLOT OF VOLTAGE AND TEMPERATURE AS FUNCTIONS OF TIME FOR A BR-$\frac{1}{2}$A HEATED IN AIR

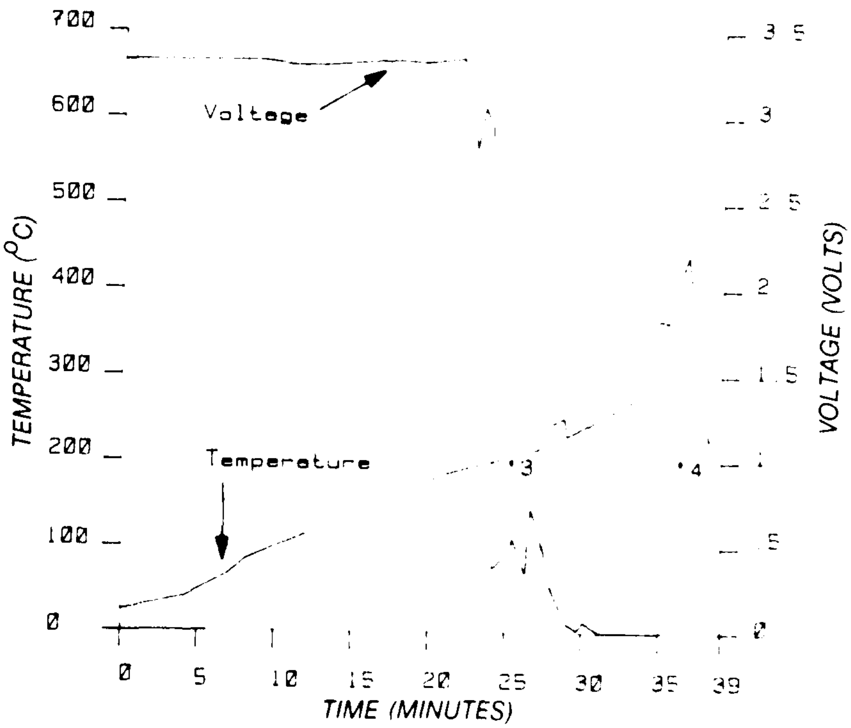

FIGURE 5. PLOT OF VOLTAGE AND TEMPERATURE AS FUNCTIONS OF TIME FOR A BR-$\frac{1}{2}$A HEATED IN HELIUM

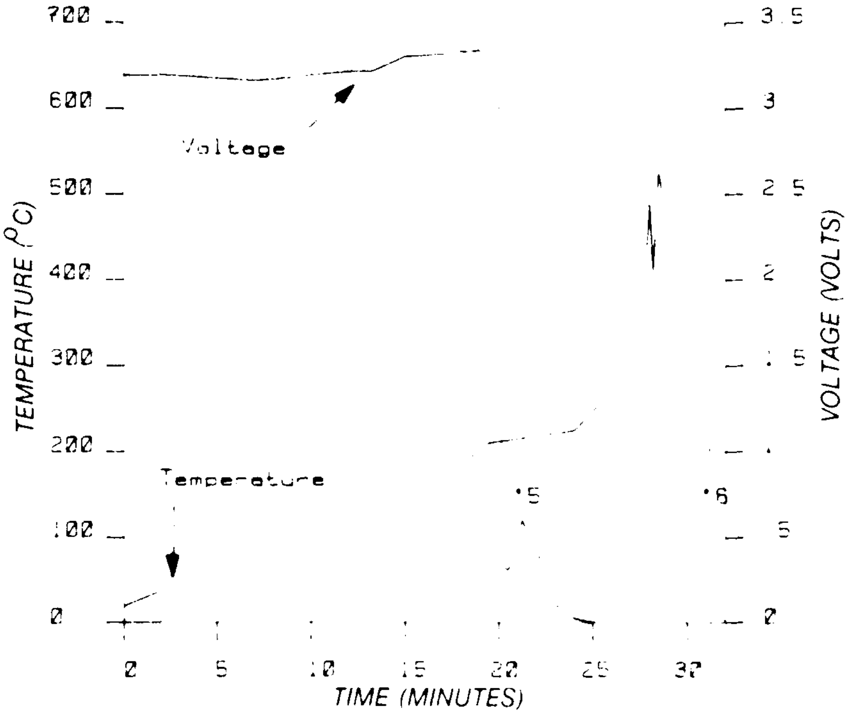

FIGURE 6. PLOT OF VOLTAGE AND TEMPERATURE AS FUNCTIONS OF TIME FOR A BR-$\frac{1}{2}$A HEATED IN OXYGEN

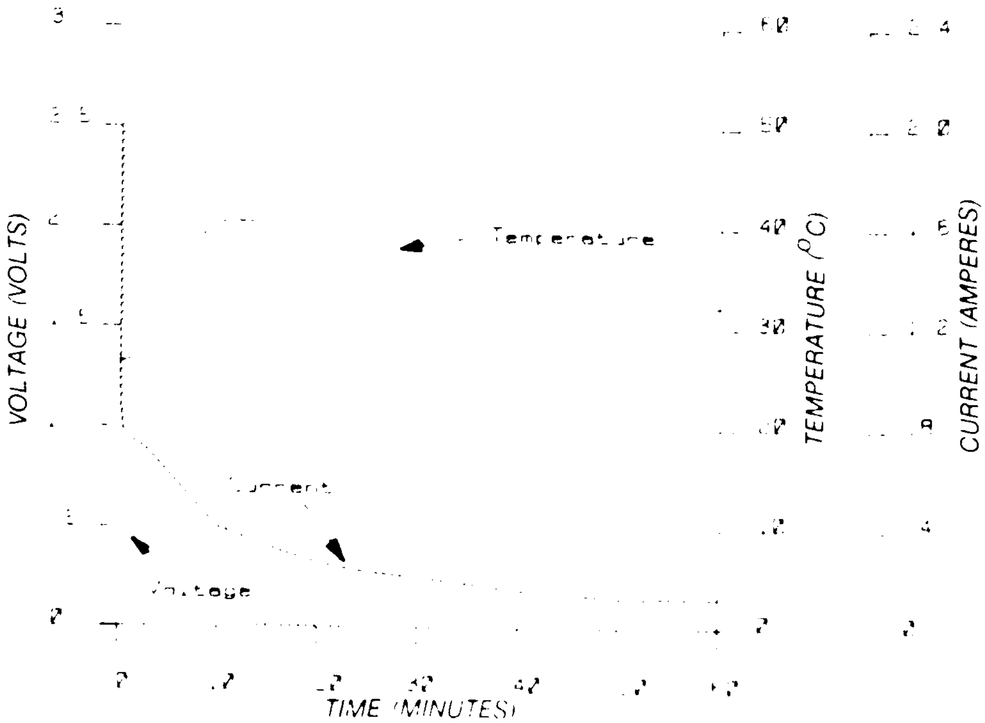

FIGURE 7. SHORT CIRCUIT DATA FOR FIRST BR $\frac{1}{2}$A CELL IN MICROPHONE

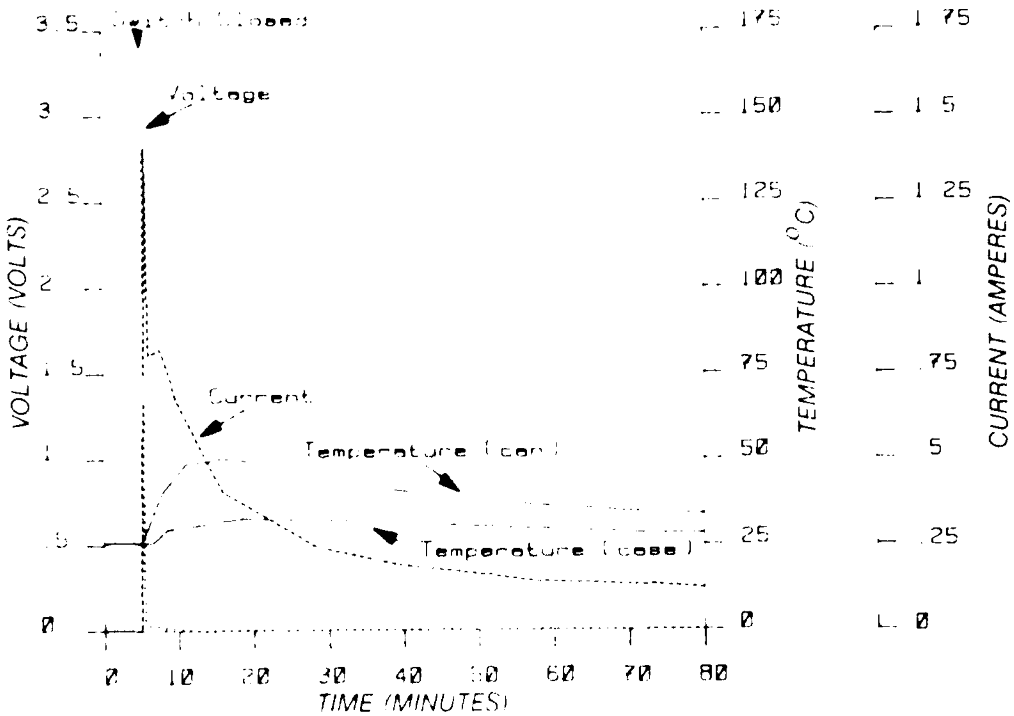

FIGURE 8. SHORT CIRCUIT DATA FOR SECOND BR-½A CELL IN MICROPHONE

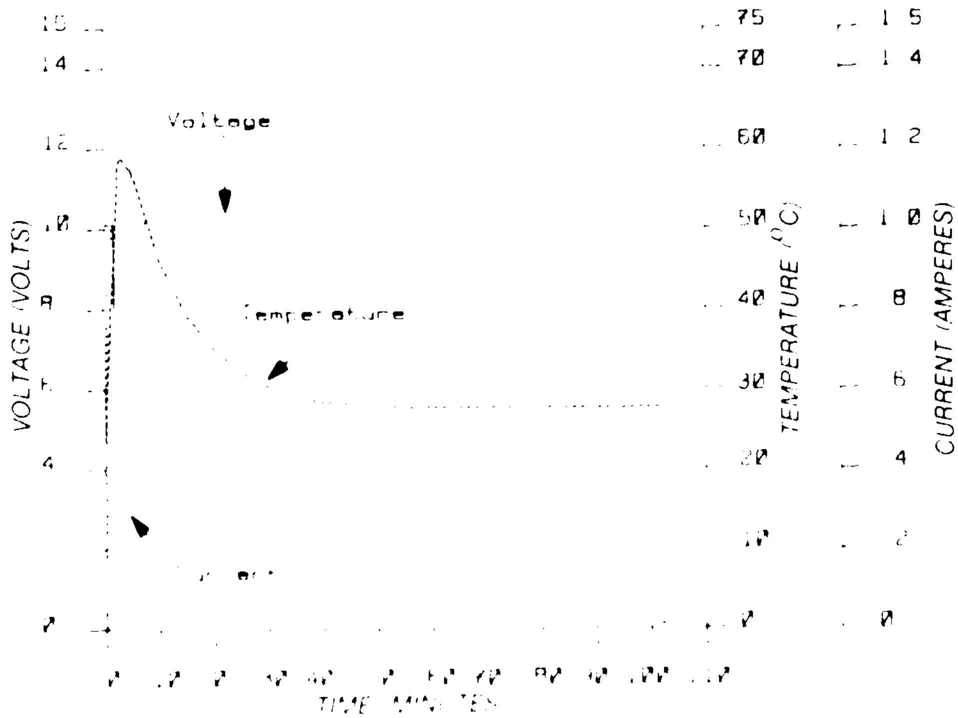

FIGURE 9. CHARGING DATA FOR FRESH BR-½A CELL IN MICROPHONE

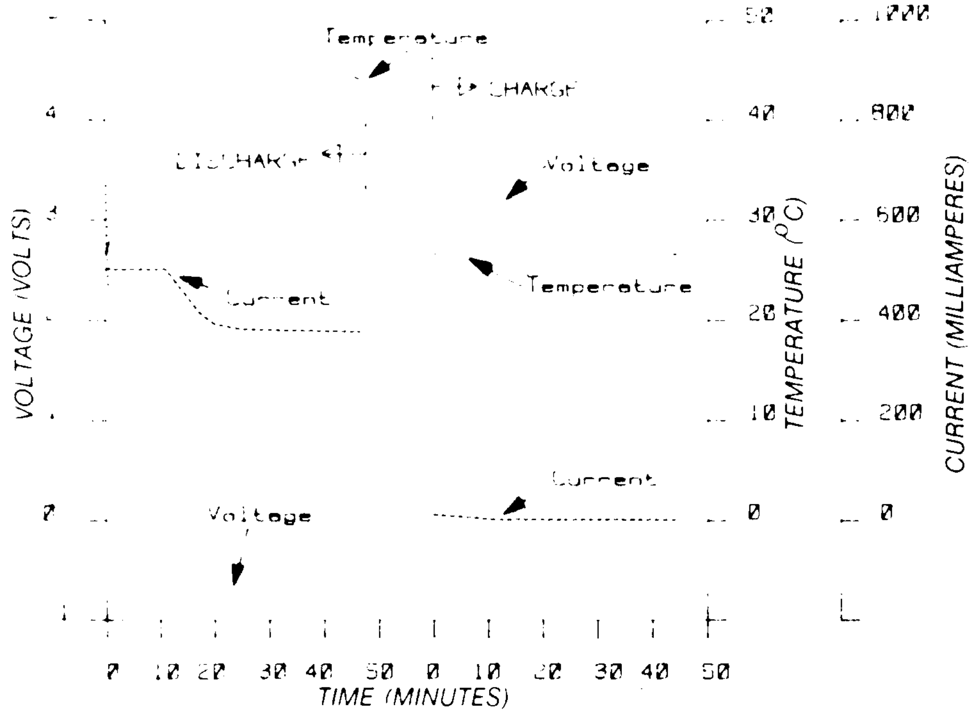

FIGURE 10. DISCHARGE/CHARGE DATA FOR BR-$\frac{1}{2}$A CELL IN MICROPHONE

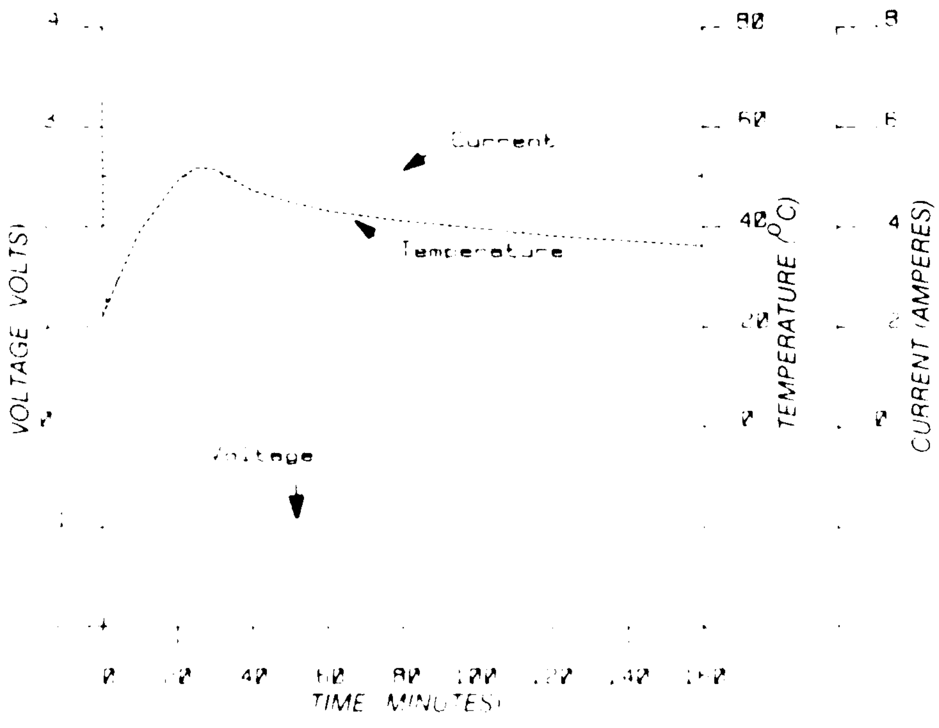

FIGURE 11. DATA FOR FIRST BR-$\frac{1}{2}$A CELL FORCE OVERDISCHARGED IN MICROPHONE

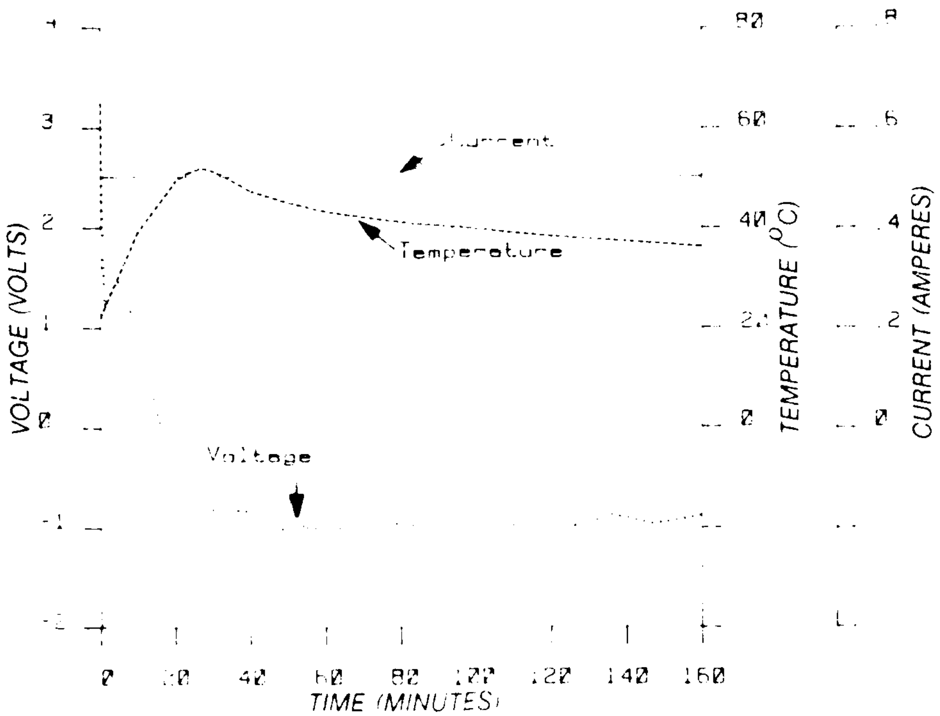

FIGURE 12. DATA FOR SECOND BR-½A CELL FORCE OVERDISCHARGED IN MICROPHONE

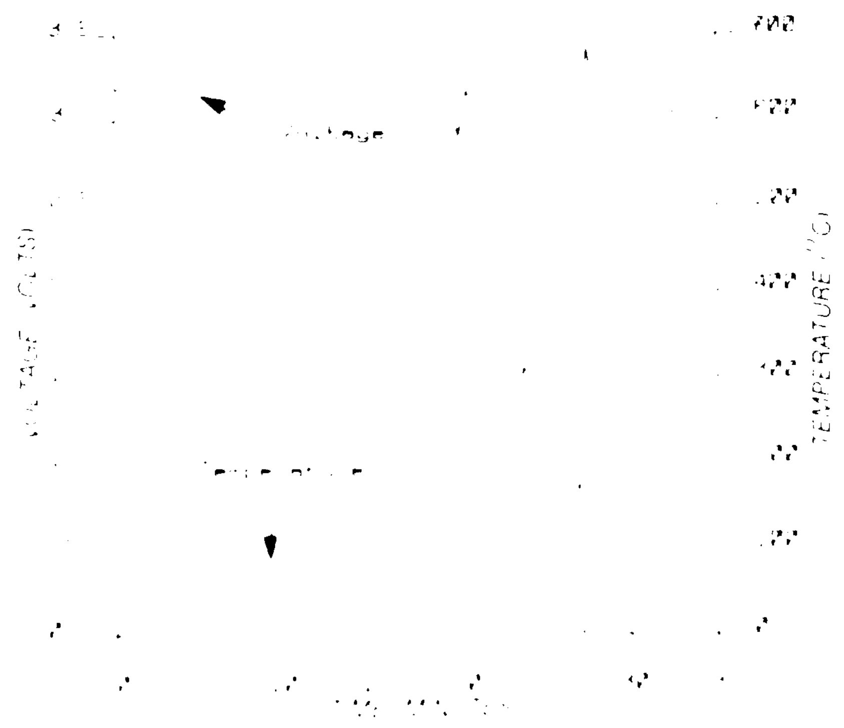

FIGURE 13. DATA FOR HEATING A BR-½A CELL IN MICROPHONE

FIGURE 14. A HEATED MICROPHONE UNIT WITH THE VENTED BR-1/2 A CELL EXPOSED

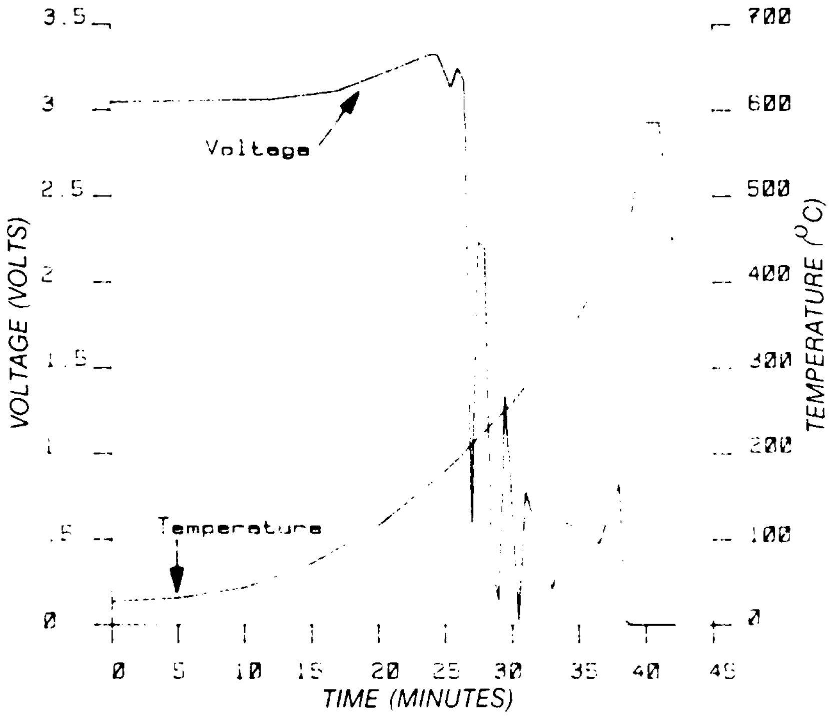

FIGURE 15. DATA FOR HEATING A SECOND BR-$\frac{1}{2}$A CELL IN MICROPHONE

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