NBSIR 77-1310

Microcalorimetric Study of Cardiac Pacemakers and Batteries

Edward J. Prosen and Jennifer C. Colbert

Institute for Materials Research
National Bureau of Standards
Washington, D.C. 20234

September 1977

Final

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

NBSIR 77-1310

MICROCALORIMETRIC STUDY OF CARDIAC PACEMAKERS AND BATTERIES

Edward J. Prosen and Jennifer C. Colbert

Institute for Materials Research
National Bureau of Standards
Washington, D.C. 20234

September 1977

Final

U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, ***Secretary***

Dr. Sidney Harman, ***Under Secretary***

Jordan J. Baruch, ***Assistant Secretary for Science and Technology***

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Acting Director***

Microcalorimetric Study of Cardiac Pacemakers and Batteries*

by

Edward J. Prosen and Jennifer C. Colbert

National Bureau of Standards, Institute for Materials Research
Washington, DC 20234

Abstract

A feasibility study was carried out to determine if microcalorimetry could be used to measure the energy loss or self-discharge of cardiac pacemakers and power cells. Alkaline and mercury batteries, camera and watch type, were measured both under external load and open-circuit conditions. The results indicate that microcalorimetry can be both a sensitive and useful tool for measuring the self-discharge of cardiac pacemakers and power cells. Microcalorimetry can also be used to measure nondestructively, the power output from the completed (sealed) pacemaker itself.

Keywords: Battery; microcalorimetry; pacemaker; power cell; self-discharge.

*This work is supported by the Non-Destructive Evaluation Program, Institute for Materials Research, National Bureau of Standards.

INTRODUCTION

The present work was undertaken to test the feasibility of using a microcalorimeter for the study of batteries or power cells for cardiac pacemakers and also for developing a possible non-destructive test for the complete pacemaker.

One characteristic of power cells is that of self-discharge or gradual loss of deliverable energy after the cell is stored open-circuited for long periods of time. This is called shelf-life. The self-discharge characteristic is not completely understood and the amount varies for different types of power cells and for different manufacturing methods and sometimes occurs in differing degrees under the "same" manufacturing conditions. Thus it is important to be able to measure this characteristic to gain a more thorough understanding of its causes and hence possible prevention.

It is also not clear at present whether this self-discharge is present when the power cell is under load as in a pacemaker circuit. That is, during use, is energy being drawn from the power cell both by the external circuit and by the self-discharge mechanism or is the self-discharge mechanism absent or perhaps increased during actual usage? Microcalorimetry is a possible tool for the study of these questions.

The useful lifetime of a power cell for implantable cardiac pacemaker use is of prime importance. Present pacemakers using chemical power cells may last four years or more before requiring power cell replacement. It is desirable that the useful lifetime of the power cell be as predictable as possible especially since it is very difficult or impossible in many cases to detect when the power cell is close to failure or complete discharge.

A pertinent question with respect to self-discharge is the following: Is the self-discharge power an appreciable proportion of the power delivered to the working circuit and hence does it have an appreciable effect on the life of the power cell under use? As will be shown, the self-discharge power of some small power cells for camera use may typically be as much as 5 microwatts and it may be larger for the larger pacemaker power cells. Typical pacemakers may draw as little as 25 microwatts of power. Thus the self-discharge may account for 20 percent of the active material depletion of the cell. This, of course, assumes that the self-discharge mechanism is operating at its open-circuit rate during use and is not enhanced or absent. We are thus talking about a possible 1 year loss of life for a 5 year power cell.

Microcalorimetry, as will be shown, can measure open-circuit self-discharge and therefore can non-destructively discover cells which have inordinately large self-discharge rates. Secondly, it can set limits on how long the power cells can be stored before use. Also, with further measurements, it can determine optimum conditions for storage (e.g. temperature).

Measurements on the total pacemaker will constitute a non-destructive test which can help detect any pacemaker which is drawing too much power. This will add a useful test to those already being performed on completed pacemaker circuits and is a test which is performed <u>after</u> the hermetic sealing of the unit.

A microcalorimeter capable of measuring the larger power cells for cardiac pacemakers and for measuring the pacemakers themselves is being assembled.

EXPERIMENTAL

An NBS microcalorimeter (1) was used for these measurements. The detector in the calorimeter is a solid-state thermopile (Metal Specialities Company) which has an output of 1 microvolt per 4.90 microwatts of power generated within the sample box of the calorimeter. The output is amplified by a factor of 1000 by an operational amplifier (Analog Devices 261 K) kept at constant temperature ($\pm$ 0.001 °C) within the calorimeter jacket. This output voltage can then be recorded by a millivolt potentiometric recorder or read by a digital voltmeter and recorded on magnetic tape cassettes and digitally plotted. The latter procedure was used for the plots shown below.

The noise level and stability was such that a few tenths of a microwatt of power could be detected. The calibration factor of 4.90 microwatts/microvolt (at the pile) was determined by use of a four-lead electrical heater in the sample box.

The silver sample box space of the present calorimeter was 3.8 cm x 2.5 cm x 0.8 cm and therefore could accomodate small disc type camera and watch power cells but could not accomodate the larger pacemaker power cells. The camera and watch power cells were therefore used to test the feasibility of the microcalorimeter method for this work. The type, usage, and size of the power cells used in this study are given in Table 1.

Table 1

BATTERY DESCRIPTION

Cell No.	Type	Use	Size, cm Diameter x Thickness
X-2	alkaline	camera	2.3 x 0.6
X-3	mercury	camera	1.55 x 0.6
X-4	alkaline	camera	2.3 x 0.6
X-5	mercury	watch	1.15 x 0.35
X-6	mercury	camera	1.55 x 0.6

To improve thermal contact of the power cell with the sample box, a nonconducting hydrocarbon oil (Cenco Hyvac Oil) was placed in the sample box so as to almost cover the power cell. Transparent adhesive tape was placed over one terminal of the cell to prevent shorting to the box.

Figure 1 shows a test record of self-discharge of power cell X-5 (a mercury watch battery). The initial portion of the curve is the baseline of the calorimeter without any power cell in the sample box. The cell is then inserted and the output is now lower, which is in the exothermic direction. Due to the fact that the power cell is not initially very close in temperature to the calorimeter block, a large offset is first observed and the block temperature is disturbed slightly. Therefore a more reliable effect is observed upon removal of the power cell. Thus a signal of 0.4 μV (the vertical height shown in Figure 1) at the pile is recorded, which corresponds to 2.0 μW, and is the self-discharge rate of the power cell.

RESULTS

Results on four power cells are given in Table 2. It is seen that the alkaline power cells give approximately 4 to 5 microwatts of self-discharge and the mercury power cells give 1.5 to 2 microwatts.

Table 2

MICROCALORIMETRIC DETERMINATION OF SELF-DISCHARGE

Cell	μW
X-4 ALK(CAMERA)	3.9
X-2 ALK(CAMERA)	4.9
X-6 Hg(CAMERA)	1.5
X-5 Hg(WATCH)	2.0
UNDER LOAD IN CALORIMETER	μW
X-3 Hg(CAMERA) with 110 kΩ load in calorimeter	17.6
Power due to 110 kΩ load	15.4
Difference	2.2

Since only a few measurements were made these results are preliminary and are perhaps uncertain by ± 1 or 2 microwatts. No attempt was made to obtain typical or representative samples and therefore more exhaustive calibrations should be made.

One additional test which was made is shown in Figure 2 and tabulated in the lower part of Table 2. In this test a small 110 kΩ resistor was soldered to a mercury power cell and the whole unit placed in the sample box of the calorimeter. Figure 2 shows two insertions and removals of the unit from the calorimeter; the second removal being performed after the unit had been in the calorimeter for several hours and the result (17.6 μW) tabulated in Table 2. The power dissipated in the 110 kΩ load is calculated to be 15.4 μW, leaving 2.2 μW unaccounted for. This may have been leakage or self-discharge. However, no great significance can be attached to this difference since only one experiment of this type was performed and only rough measurements of the power cell voltage before and after the run were made. This value of 15.4 μW is the ΔH of the cell reaction, where both the battery and resistor are in the calorimeter. It does illustrate that power can be measured under load as with a complete pacemaker in the calorimeter and that the result is close to what one would calculate from the load plus leakage or self-discharge.

In Figure 3 is shown the result of measurements made with the external load outside of the calorimeter while the power cell is inside the calorimeter. In this way various resistors could be connected and disconnected to give the power W_i dissipated in the power cell in the calorimeter and, by measurement of current and voltage, the power W_x dissipated in the resistor outside the calorimeter. These measurements were made by attaching small copper leads (No. 32 AWG) to the power cell and running these leads out of the calorimeter to an external resistor.

In Figure 3 a 5 kΩ, 10 kΩ, and 3 kΩ resistor were connected and disconnected as shown. Similar experiments were performed on two other power cells and the results for two alkaline power cells are tabulated

Table 3

ALKALINE BATTERIES WITH EXTERNAL LOAD

X-2 ALK(CAMERA)

R_x Ω	I μA	W_x μW	W_i μW	W_i/W_x
10010	146	213	8.3	.0390
4996	292	426	17.2	.0404
3005	484	703	29.4	.0418

X-4 ALK(CAMERA)

R_x Ω	I μA	W_x μW	W_i μW	W_i/W_x
9999	144	207	8.8	.0425
5003	285	405	18.1	.0447
3005	476	681	29.9	.0439
2004	711	1012	47.7	.0471
1001	1412	1996	101.9	.0511

in Table 3 and for a mercury power cell in Table 4. Listed are the values of the external resistor R_x(Ω), the current through the external resistor I(μA), the external power delivered W_x(μW), the power dissipated internally in the power cell W_i(μW), and the ratio of the internal power to the external power W_i/W_x. In Figure 4 the internal power is plotted against the external power for the three power cells tested. It will be noted that W_i is a linear function of W_x and that

Table 4

MERCURY BATTERIES WITH EXTERNAL LOAD

X-3 Hg(CAMERA)

R_x	I	W_x	W_i	W_i/W_x
Ω	μA	μW	μW	
4996	269	361	2.1	.0058
3005	445	596	6.6	.0111
2005	666	889	10.8	.0121
1001	1329	1767	27.0	.0153

the slope or ratio W_i/W_x is about 4 percent (W_i is 4% of W_x) for the alkaline cells and about 1 percent for the mercury cell. It will also be noted that the lines in Figure 4 extrapolate to near zero W_i for zero W_x (or open-circuit). Some curvature can be noted. This is due to the finite internal resistance of the power cell. However, extrapolation to zero W_i is inevitable here since the method used for measuring W_i excluded any open-circuit power. That is, W_i was obtained in these external load experiments from the vertical height (for example, A in Figure 3) of the shift of output upon connecting and disconnecting the external load.

It should also be stated that the ratio of W_i/W_x does not give a measure of lost power over what could be obtained if the cell reaction taking place were ideal. Each type of cell reaction has a characteristic W_i which must be dissipated internally. This can be calculated from the thermodynamics of the cell reaction if all the thermodynamic quantities are known. Alternatively, such measurements could aid in obtaining these thermodynamic properties. Theoretically W_i should be a linear function of W_x since both of them are proportional to the amount or number of moles of cell reaction taking place. Variation from strict linearity may be due to the effect of self-discharge or leakage or high internal resistance of the power cell or other non-ideal effects. Such non-ideal or self-discharge effects are not truly significant in Figure 4 and Tables 3 and 4 and the difference in the two alkaline power cells, X-2 and X-4, is also not significant.

SUMMARY

The feasibility of using a heat conduction type of microcalorimeter for measuring self-discharge of pacemaker power cells and for measuring internal power dissipation under external load was tested by means of an NBS microcalorimeter on small camera and watch power cells. Preliminary results on small alkaline type power cells for camera use indicated 4 to 5 microwatts of self-discharge and small mercury type power cells for camera or watch use showed 1.5 to 2 microwatts of self-discharge. A test of a power cell with a resistor across it in the calorimeter yielded a power value in fair agreement with that calculated as dissipated across the resistance load plus the self-discharge.

Tests of internal power W_i dissipated in the power cell in the calorimeter as a function of external power W_x dissipated in a resistor outside the calorimeter yielded results which are characteristic of the ideal cell reaction; that is, W_i is a linear function of W_x (within the precision of the measurements). This was true for both the alkaline and the mercury power cells tested within the precision of the present tests. Valuable thermodynamic information can be obtained from the ratio W_i/W_x. For example, W_i is mainly the $-T\Delta S$ term of the cell reaction and W_x is the useful work or $-\Delta G$. There is also an I^2R_0 term in W_i, where R_0 is the internal resistance of the power cell. There are also small junction potential terms. If both the power cell and the external resistance are in the calorimeter (as in Figure 2) then $-\Delta H$ of the cell reaction is measured. Therefore the self-discharge is also $-\Delta H$ and it should be corrected by $+T\Delta S$ to get $-\Delta G$ which is the true self-discharge loss. It should also be noted that "self-discharge" may also be caused

by side reactions, such as corrosion reactions in the power cell. A search for thermodynamic data on the cell reactions involved has not as yet been made for comparison with these experimental results. More thorough and accurate measurements of W_i versus W_x will need to be made in order to be able to state whether self-discharge or leakage is increased or absent when the power cell is in use (under load).

Thus it has been shown that valuable measurements of self-discharge of small power cells can be made with an NBS microcalorimeter or other microcalorimeter of comparable sensitivity. This will be useful for eliminating cells with higher than normal self-discharge rates and for determining the shelf life of the power cells. Measurements under load may be useful in determining whether leakage or self-discharge is operating when the power cell is under load. Valuable thermodynamic data for the cell reaction may be obtained by these microcalorimetric methods.

A new conduction calorimeter similar to the NBS microcalorimeter is being assembled. Some improvements are planned with the capability for handling the larger pacemaker type power cells or the complete pacemaker. This will allow us to develop a non-destructive test method for pacemaker power cells and for the complete pacemaker.

REFERENCES

1. Prosen, E. J., "Design and Construction of the NBS Clinical Microcalorimeter," NBS Report 73-179 (April 1973).

Prosen, E. J., and Goldberg, R. N., "Testing of the NBS Clinical Microcalorimeter," NBS Report 73-180 (April 1973).

Prosen, E. J., Goldberg, R. N., Staples, B. R., Boyd, R. N., and Armstrong, G. T., "Microcalorimetry Applied to Biochemical Processes," p. 253-289 of "Thermal Analysis: Comparative Studies on Materials," H. Kambe and P. D. Garn, editors, John Wiley and Sons (1974) New York.

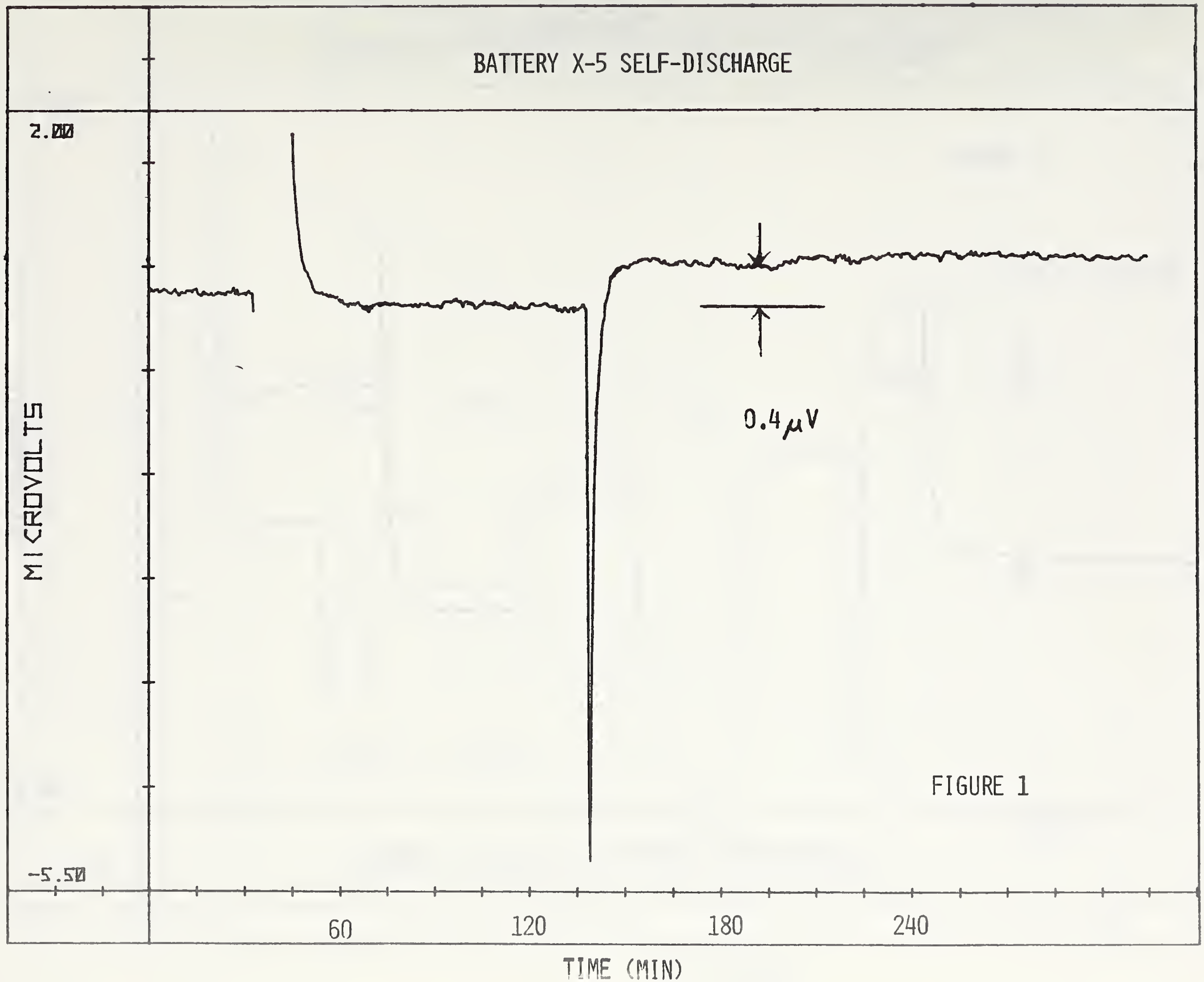
LEGEND FOR FIGURES

Figure 1. Battery X-5 Self-Discharge

Figure 2. Battery X-3 with 110 kΩ Load in Calorimeter

Figure 3. Battery X-2 with 5 kΩ, 10 kΩ and 3 kΩ External Load

Figure 4. Plot of W_i (energy discharged in the calorimeter or power cell) Versus W_x (useful energy discharged into the external load).



BATTERY X-5 SELF-DISCHARGE
MICROVOLTS
2.00
-5.50
0.4μV
60
120
180
240
TIME (MIN)

FIGURE 1

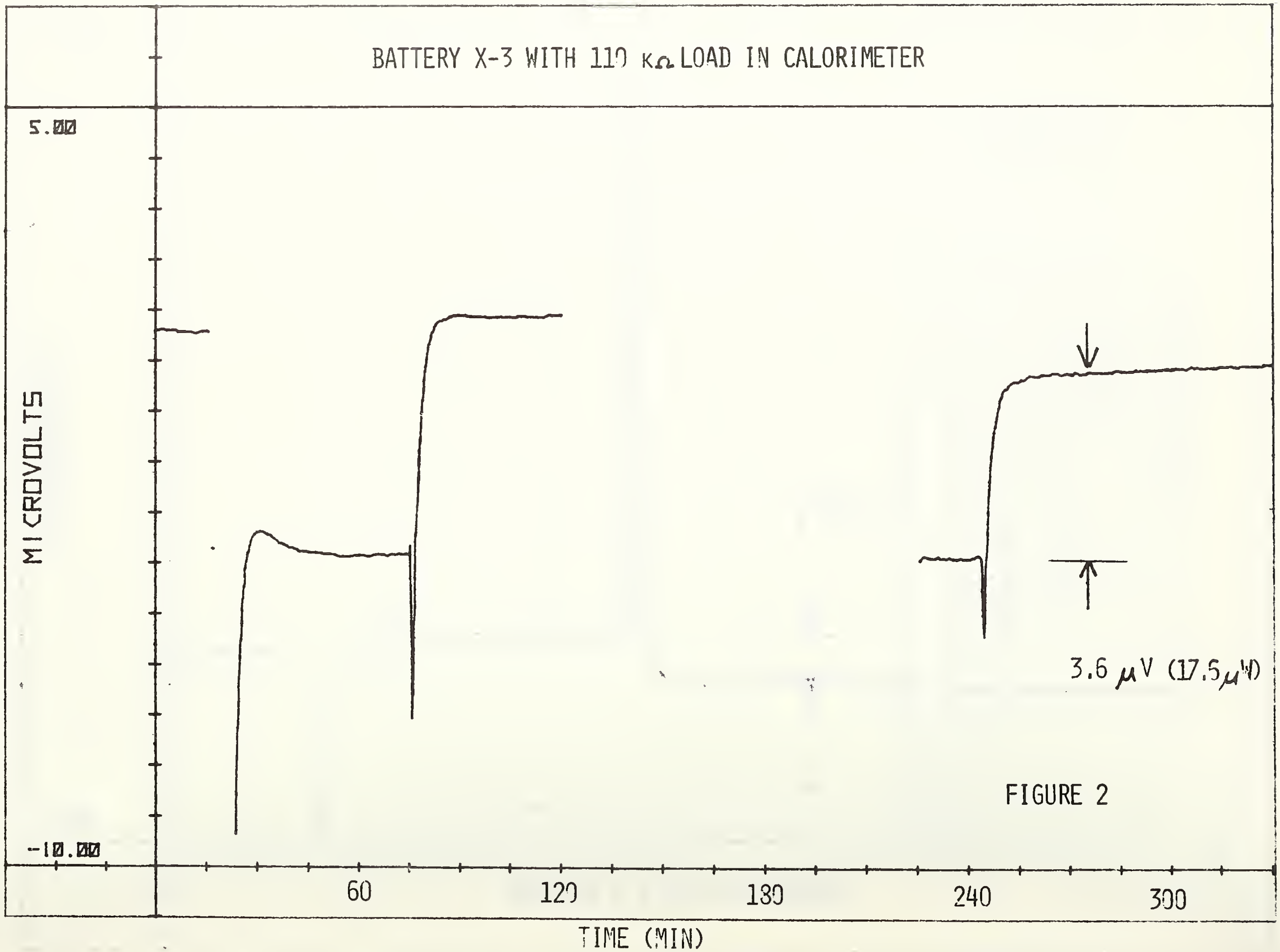

BATTERY X-3 WITH 110 kΩ LOAD IN CALORIMETER
5.00
-10.00
MICROVOLTS
60
120
180
240
300
TIME (MIN)
3.6 μV (17.5 μW)

FIGURE 2

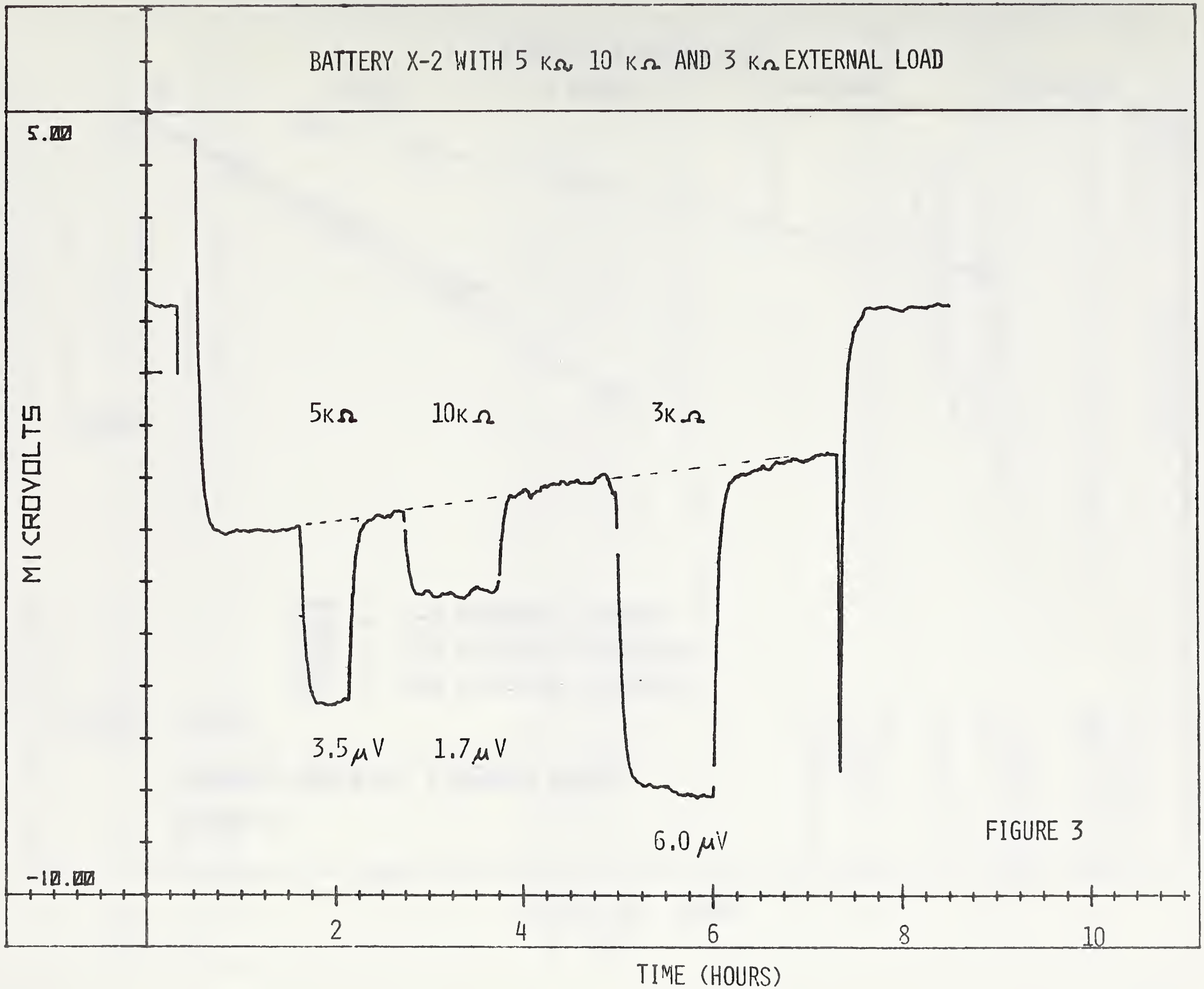
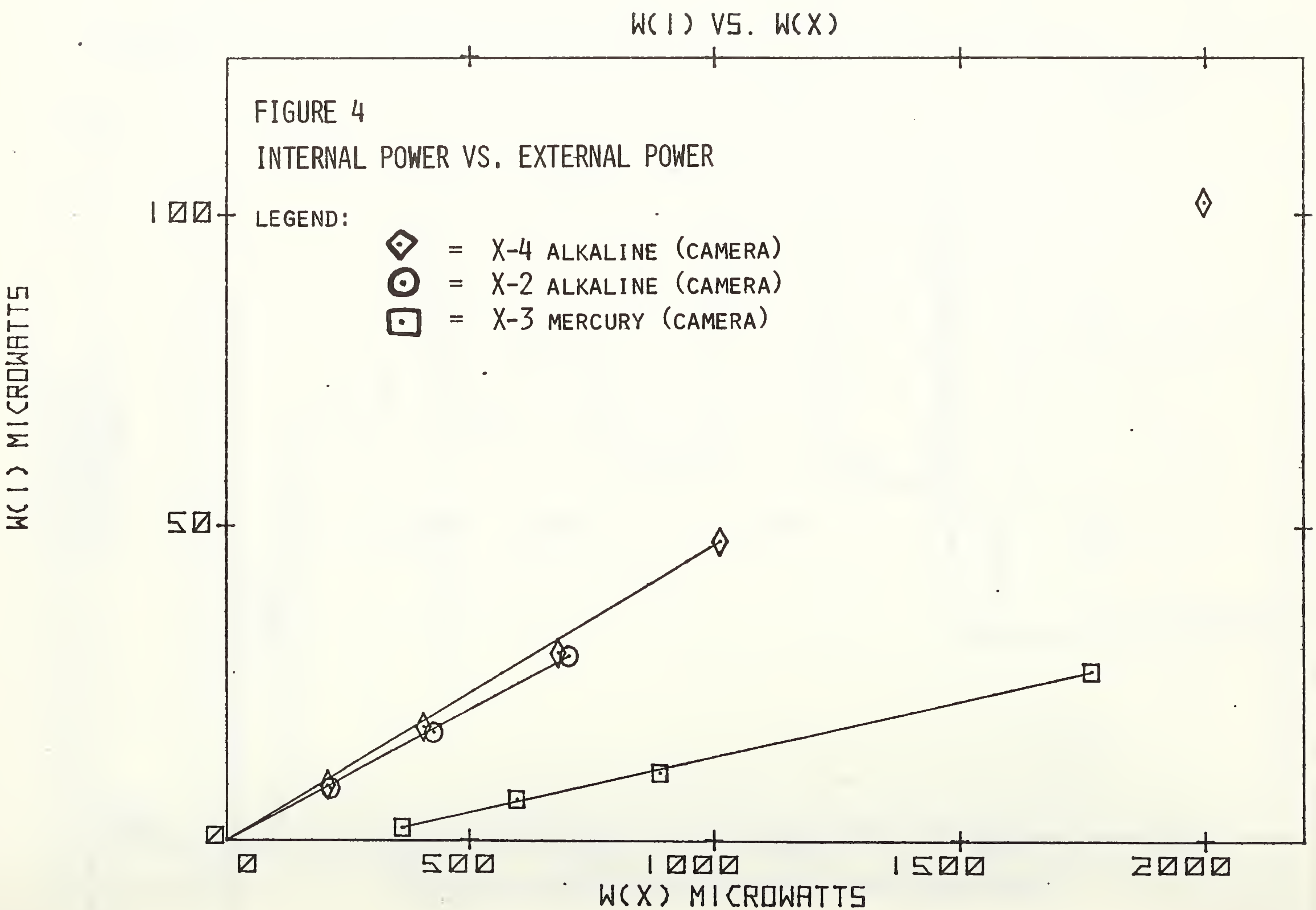

BATTERY X-2 WITH 5 KΩ, 10 KΩ AND 3 KΩ EXTERNAL LOAD
5.00
-10.00
MICROVOLTS
5KΩ
10KΩ
3KΩ
3.5 μV
1.7 μV
6.0 μV
2
4
6
8
10
TIME (HOURS)

FIGURE 3


W(I) VS. W(X)
FIGURE 4
INTERNAL POWER VS. EXTERNAL POWER
LEGEND:
= X-4 ALKALINE (CAMERA)
= X-2 ALKALINE (CAMERA)
= X-3 MERCURY (CAMERA)
100
50
0
500
1000
1500
2000
W(X) MICROWATTS
W(I) MICROWATTS

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 77-1310	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Microcalorimetric Study of Cardiac Pacemakers and Batteries			5. Publication Date September 1977
			6. Performing Organization Code
7. AUTHOR(S) Edward J. Prosen and Jennifer C. Colbert			8. Performing Organ. Report No. NBSIR 77-1310
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No.
			11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)* Same as above			13. Type of Report & Period Covered Final
			14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A feasibility study was carried out to determine if microcalorimetry could be used to measure the energy loss or self-discharge of cardiac pacemakers and power cells. Alkaline and mercury batteries, camera and watch type, were measured both under external load and open-circuit conditions. The results indicate that microcalorimetry can be both a sensitive and useful tool for measuring the self-discharge of cardiac pacemakers and power cells. Microcalorimetry can also be used to measure nondestructively, the power output from the completed (sealed) pacemaker itself.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Battery; microcalorimetry; pacemaker; power cell; self-discharge.

18. AVAILABILITY [X] Unlimited	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
[ ] For Official Distribution. Do Not Release to NTIS	UNCLASSIFIED	20
[ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13	20. SECURITY CLASS (THIS PAGE)	22. Price
[X] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	UNCLASSIFIED	$3.00

USCOMM-DC 29042-P74