TESTING AND EVALUATION OF NICKEL-CADMIUM SPACECRAFT-TYPE CELLS

FINAL TECHNICAL REPORT
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ABSTRACT

This is a continuation of work evaluating the life and performance characteristics of hermetically sealed nickel-cadmium space craft batteries manufactured by Gould-National Batteries, Inc., Gulton Industries, and Sonotone Corporation. Previous work was accomplished by Inland Testing Laboratories under NASA Contracts NAS 5-1048 and NAS 5-9073. The continuation was pursuant to Contract NAS 5-10213.

Initially all test batteries were made up of 10 cells each. Seven batteries were in the test at the beginning and four at the ending of the continued effort. The maximum number of cycles successfully completed was over 23,010. The -10°C tests performed better than the 25°C tests. Leaks and corrosion account for most failures.

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TABLES

I. INTRODUCTION

The scope of this report covers the continuation of the cycle life tests initiated and continued under Contracts NAS 5-1048 and NAS 5-9073 respectively. The procedures and results of the cycle life tests through approximately 15000 cycles were reported in the Final Technical Reports under Contracts NAS 5-1048 and NAS 5-9073.

Cycle life tests were continued under Contract NAS 5-10213 on seven (7) cell groups which had not failed. The cycle life tests were continued in order to further evaluate the cycling performance capabilities of the cells over extended lengths of time.

The cells, which were operated in the cycle life tests, consisted of 3.5 AH nominal capacity cells manufactured by Gould National Batteries and Sonotone Corporation, and 6.0 AH nominal capacity cells manufactured by Gulton Industries, Inc.

II. DISCUSSION

Cycle Life Test

The cycle life tests were 100 minute repetive charge-discharge cycles consisting of a 60 minute charge period followed by a 40 minute discharge period. The cycle life tests were performed at two (2) ambient temperatures and two (2) depths of discharge. The depth of discharge was based on the nominal cell capacity.

The cell groups, on which the cycle life tests were continued under Contract NAS 5-10213, are as follows:

Manufacturer	Nominal Capacity	Depth of Discharge	Ambient Temperature
Gould National	3.5 AH	10%	-10°C
Gould National	3.5 AH	10%	25°C
Gulton Industries	6.0 AH	10%	-10°C
Gulton Industries	6.0 AH	10%	25°C
Gulton Industries	6.0 AH	25%	25°C
Sonotone	3.5 AH	10%	-10°C
Sonotone	3.5 AH	10%	25°C

The cell groups cycled at -10°C were charged at constant current to a pre-set voltage limit of 1.57 Volts per cell at which time the charging system switched to the constant voltage for the remainder of the charge period. The constant current charging rate was 115% of the discharge ampere hours.

The cell groups cycled at 25°C were charged at constant current with no voltage limit. The charging rate was 125% of the discharge

ampere hours.

The cell groups consisted of series connected cells, of the same manufacturer, which were charged and discharged, at constant current rates.

The cycle life tests were continued until one half of the original cells in the group failed. A cell failed when it exhibited an end of discharge terminal voltage less than 0.9 volts for several cycles.

When a cell or group failure occurred the cell or cells were removed from cycling and subjected to post-failure measurements.

The post-failure measurements were cell capacity and open circuit stand for 120 hours. The cell capacity was determined by a 16 hour charge at C/10 rate followed by a discharge to 1.0 volts at a C/2 rate.

The cells were then subjected to a 16 hour charge at a C/10 rate followed by an open circuit stand for 120 hours. The cell terminal voltage was monitored at periodic intervals during the open circuit stand.

After approximately 20,000 cycles all cells were removed from cycling at the end of discharge. The cells were stabilized at room temperature for a period of eight hours and then subjected to a capacity test. The cells were then charged at a C/10 rate for 16 hours and then stabilized for eight hours at their ambient cycling temperature. The cycling test was then resumed on the discharge portion of the cycle. Upon completion of the test program, the cells were stabilized at room temperature and subjected to a capacity test followed by an open circuit stand test

for 120 hours. The cells were also inspected for evidence of seal leakage.

Through out the cycling test the charge/discharge currents and individual cell voltages were monitored and recorded periodically.

The average end of charge and discharge voltages versus cycle number for the seven (7) cell groups are given in Tables 1-7.

The results of the capacity tests and the open circuit stand tests are also given in the test results.

TABLE 1. Endpoint Voltage Characteristics
Gould National Cells, Cycled 10% Depth at -10°C

Cycle	Average End of Charge Voltage	Average End of Discharge Voltage
14200	1.59	1.28
14500	1.57	1.25
15000	1.57	1.27
15500	1.54	1.24
16000	1.54	1.25
16500	1.55	1.25
17000	1.55	1.24
17500	1.55	1.25
18000	1.55	1.25
18500	1.56	1.24
19000	1.54	1.27
19500	1.56	1.22
20000	1.55	1.21
20500	1.56	1.22
21000	1.58	1.23
21500	1.57	1.22
21800	1.56	1.21
21800	Cycling terminated	

TABLE 2. Endpoint Voltage Characteristics
Gould National Cells, Cycled 10% Depth at 25°C

Cycle	Average End of Charge Voltage	Average End of Discharge Voltage
15200	1.51	1.25
15500	1.51	1.24
16000	1.51	1.23
16500	1.52	1.22
17000	1.53	1.20
17500	1.53	1.19
18000	1.55	1.20
18500	1.57	1.21
19000	1.55	1.21
19500	1.53	1.16
19562	Group failed with failure of cell number 1	

TABLE 3. Endpoint Voltage Characteristics
Gulton Cells, Cycled 10% Depth at -10°C

Cycle	Average End of Charge Voltage	Average End of Discharge Voltage
15200	1.57	1.27
15500	1.55	1.26
16000	1.56	1.27
16500	1.56	1.27
17000	1.55	1.26
17500	1.56	1.27
18000	1.55	1.26
18500	1.56	1.26
19000	1.55	1.25
19500	1.55	1.25
20000	1.54	1.28
20500	1.54	1.28
21000	1.54	1.28
21500	1.55	1.28
22000	1.57	1.28
22500	1.58	1.28
22900	1.58	1.29
22900	Cycling terminated	

TABLE 4. Endpoint Voltage Characteristics
Gulton Cells, Cycled 10% Depth at 25°C

Cycle	Average End of Charge Voltage	Average End of Discharge Voltage
15200	1.48	1.22
15800	1.47	1.22
16000	1.48	1.23
16500	1.45	1.23
17000	1.46	1.23
17500	1.48	1.24
18000	1.48	1.23
18500	1.49	1.23
19000	1.47	1.23
19500	1.48	1.23
20000	1.47	1.22
20500	1.49	1.22
21000	1.47	1.26
21500	1.47	1.24
22000	1.48	1.25
22500	1.48	1.25
23000	1.48	1.24
23300	1.47	1.24
23300	Cycling terminated	

TABLE 5. Endpoint Voltage Characteristics
Gulton Cells, Cycled 25% Depth at 25°C

Cycle	Average End of Charge Voltage	Average End of Discharge Voltage
15200	1.56	1.10
15500	1.57	1.12
16000	1.56	1.10
16500	1.56	1.08
17000	1.56	1.09
17500	1.56	1.07
18000	1.56	1.10
18500	1.54	1.09
19000	1.54	1.07
19500	1.53	1.10
19680	Group failed with failure of cell number 804	

TABLE 6. Endpoint Voltage Characteristics
Sonotone Cells, Cycled 10% Depth at -10°C

Cycle	Average End of Charge Voltage	Average End of Discharge Voltage
15200	1.57	1.25
15500	1.57	1.26
16000	1.57	1.25
16500	1.57	1.25
17000	1.57	1.25
17500	1.58	1.25
18000	1.58	1.26
18500	1.57	1.25
19000	1.58	1.25
19500	1.58	1.25
20000	1.58	1.25
20500	1.57	1.27
21000	1.57	1.26
21500	1.57	1.26
22000	1.58	1.26
22500	1.58	1.26
22900	1.58	1.26
22900	Cycling terminated	

TABLE 7. Endpoint Voltage Characteristics
Sonotone Cells, Cycled 10% Depth at 25°C

Cycle	Average End of Charge Voltage	Average End of Discharge Voltage
15200	1.45	1.13
15500	1.44	1.11
16000	1.44	1.11
16500	1.45	1.12
17000	1.45	1.11
17500	1.45	1.09
18000	1.45	1.06
18500	1.45	1.09
19000 *	1.44	1.16
19500	1.44	1.11
19906	1.44	1.03
19906	Group failed with failure of cells numbers R 39 and 66	

* Cell 64 failed on cycle 18610

A TEST RESULTS

During this report period there were five (5) cell failures. The cells which failed were:

Cell No.	Manufacturer	Total Cycles	Ambient Temp.	Depth of Discharge
1	Gould National	19562	25°C	10%
804	Gulton	19690	25°C	25%
64	Sonotone	18610	25°C	10%
66	Sonotone	19906	25°C	10%
R39	Sonotone	19906	25°C	10%

As a result of the five (5) cell failures there were three (3) group failures. The groups which failed were:

Manufacturer	Ambient Temp.	Depth of Discharge
Gould National	25°C	10%
Gulton	25°C	25%
Sonotone	25°C	10%

Four (4) groups were removed from cycling upon completion of the contract period. No cell failures had occurred in these four groups during the contract period. The results of the capacity tests and the 120 hour open circuit stand test are given in Tables 8, 9, 10 and 11.

Examination of the cells revealed that the following cells had seal leakage:

Cell No.	Manufacturer
25	Gould National
38	Gould National
648	Gulton
798	Gulton
822	Gulton
825	Gulton
827	Gulton
51	Sonotone

The following cells had case distortion:

Cell No.	Manufacturer
619	Gulton
54	Sonotone
55	Sonotone

TABLE 8. Cell Capacity and Open Circuit Stand Voltage
Gould National, Cycled 10% Depth at -10°C

Cell No.	Capacity After 18,837 Cycles	Final Capacity 21,800 Cycles	Terminal Voltage After 120 Hours
25	3.67 AH	3.79 AH	1.31
26	3.88 AH	3.94 AH	1.31
27	0.67 AH	0.83 AH	1.32
35	3.21 AH	3.36 AH	1.31
38	3.70 AH	3.74 AH	1.31

TABLE 9. Cell Capacity and Open Circuit Stand Voltage
Gulton, Cycled 10% Depth at 25°C

Cell No.	Capacity After 20,467 Cycles	Final Capacity 23,300 Cycles	Terminal Voltage After 120 Hours
628	1.05 AH	3.25 AH	1.28
644	5.94 AH	5.85 AH	1.28
647	5.85 AH	6.00 AH	1.28
648	1.75 AH	3.25 AH	0.10
653	5.15 AH	5.15 AH	1.27
822	6.20 AH	6.15 AH	1.26
825	6.45 AH	6.45 AH	1.28
827	6.40 AH	6.05 AH	1.27

TABLE 10. Cell Capacity and Open Circuit Stand Voltage
Gulton, Cycled 10% Depth at -10°C

Cell No.	Capacity After 19,967 Cycles	Final Capacity 22,900 Cycles	Terminal Voltage After 120 Hours
617	6.00 AH	6.54 AH	1.28
619	7.45 AH	7.15 AH	1.27
620	6.60 AH	6.73 AH	1.28
623	5.20 AH	5.75 AH	1.28
627	5.95 AH	6.35 AH	1.28
631	7.50 AH	7.15 AH	1.27
780	6.85 AH	6.63 AH	1.28
783	6.55 AH	6.75 AH	1.26
798	6.85 AH	7.00 AH	1.28
801	6.25 AH	6.54 AH	1.28

TABLE 11. Cell Capacity and Open Circuit Stand Voltage
Sonotone, Cycled 10% Depth at -10°C

Cell No.	Capacity After 19,967 Cycles	Final Capacity 22,900 Cycles	Terminal Voltage After 120 Hours
51	3.33 AH	3.33 AH	1.28
52	3.50 AH	3.36 AH	1.27
53	3.82 AH	3.96 AH	1.27
54	4.20 AH	4.11 AH	1.27
55	4.23 AH	4.19 AH	1.28
73	3.24 AH	3.30 AH	1.27
R34	3.61 AH	3.31 AH	1.27
R35	3.33 AH	3.22 AH	1.28
R36	3.61 AH	3.35 AH	1.27
R38	3.41 AH	3.22 AH	1.27

B FAILURE ANALYSIS

The results, of the post-failure tests on the three groups of cells, are given in Tables 12, 13 and 14. Upon completion of the post-failure test, the cells, which had an end of discharge voltage less than 0.9 volts, were opened and examined for causes of failure. The results of the internal examinations are also given in Tables 12, 13 and 14.

TABLE 12. Failure Analysis Results
Gould National Cells, Cycled 10% Depth 25°C

Cell No.	Total Cycles	Case Leakage	Case Distortion	Seal Leakage	Final Capacity	Terminal Voltage After 120 Hours
1	19562	None	None	Extensive	0.03 AH	1.24
6	19562	None	None	None	3.55 AH	1.26
8	19562	None	None	Extensive	3.54 AH	1.27
9	19562	None	None	Extensive	3.03 AH	1.26
14	19562	None	Minor	Minor	3.48 AH	1.24
24	19562	None	Minor	Extensive	3.32 AH	1.26

Terminal voltage of cell 1 was less than 0.9 volts at the end of discharge. Failure of cell1 resulted in group failure.

Internal examination of cell 1 revealed dry separators as the cause of failure.

TABLE 13. Failure Analysis Results
Gulton Cells, Cycled 25% Depth at 25°C

Cell No.	Total Cycles	Case Leakage	Case Distortion	Seal Leakage	Final Capacity	Terminal Voltage After 120 Hours
660	19680	None	Minor	None	2.70 AH	1.23
661	19680	None	None	Minor	2.79 AH	1.14
804	19680	Minor	Minor	None	2.00 AH	0.00
812	19680	None	None	None	2.92 AH	1.22
816	19680	None	Extensive	Minor	4.50 AH	1.32
820	19680	None	Minor	None	2.74 AH	1.25

Terminal voltage of cell 804 was less than 0.9 volts at the end of discharge. Failure of cell 804 resulted in group failure.

Internal examination of cell 804 revealed corrosion on the ceramic seal of the positive terminal.

The result of the corrosion was a resistive path, in the order of 20 ohms, between the positive and negative terminals.

TABLE 14. Failure Analysis Results
Sonotone Cells, Cycled 10% Depth 25°C

Cell No.	Total Cycles	Case Leakage	Case Distortion	Seal Leakage	Final Capacity	Terminal Voltage After 120 Hours
64	18610	None	None	Minor	1.37 AH	0.02
66	19906	None	Minor	Extensive	1.71 AH	1.20
74	19906	None	None	None	1.87 AH	1.28
R39	19906	None	None	Extensive	0.04 AH	0.00
R41	19906	None	None	Minor	2.73 AH	1.21
R42	19906	Extensive	Minor	Minor	1.92 AH	1.21
R43	19906	None	None	Minor	2.79 AH	1.24

Terminal voltage of cells 64, 66 and R39 were less than 0.9 volts at the end of discharge. Failure of cells 66 and R39 resulted in group failure.

Internal examination of cell 64 revealed corrosion between the positive terminal and the case as the cause of failure.

Internal examination of cell 66 revealed dry separators and corrosion between positive terminal and the case as the cause of failure.

Internal examination of cell R39 revealed a poor weld between the positive tab and terminal as well as corrosion as the cause of failure.

III NEW TECHNOLOGY

Data for this section is not applicable

IV CONCLUSIONS AND RECOMMENDATIONS

At the end of this contract period, three (3) of the seven (7) cell groups continued on cycle life tests have failed through individual cell failures. The cell failures were caused by seal leakage and corrosion at the positive terminal.

All cell failures occurred in groups cycled at 25°C and no failures have occurred in the groups cycled at -10°C.

The results of these cycle life tests under Contract NAS 5-10213 along with the results of the previous cycle life tests under Contracts NAS 5-1048 and NAS 5-9073, indicate that maximum cell life can be obtained at -10°C rather than 25°C or 50°C.

It is recommended that half of the cells in each of the four (4) groups, which were terminated at the end of this contract period, be subjected to teardown analysis. The teardown analysis could possibly give insight to the cause of corrosion or the effect of low temperature on the corrosion. The analysis might also be directed toward the cause or reason for lower cell capacity of the 25°C cells as compared to the -10°C cells.

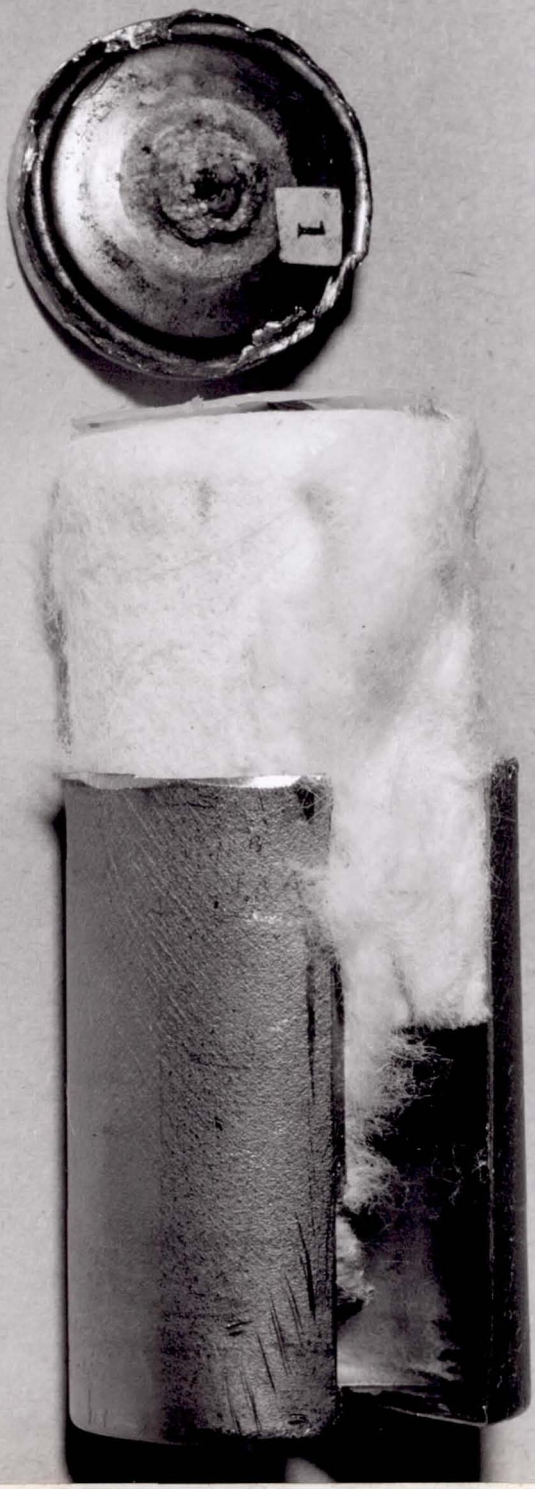
It is also recommended that the remaining cells be continued on cycle life tests until one or more failures occur at -10°C.

V BIBLIOGRAPHY

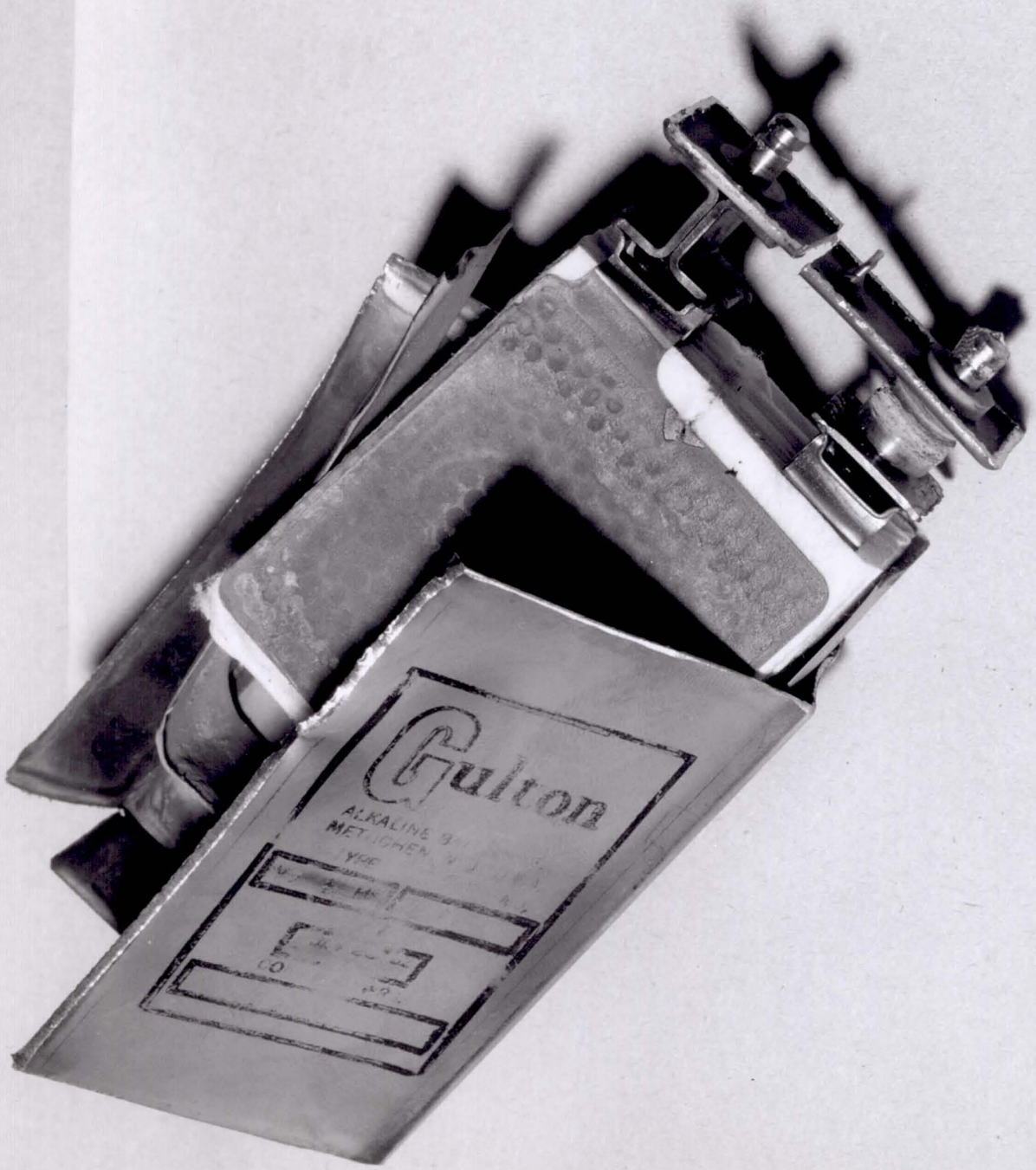
Final Technical Report, Contract NAS 5-1048, "Testing and Evaluation of Spacecraft-Type Cells", Prepared for Goddard Space Flight Center.

Final Technical Report, Contract NAS 5-9073, "Testing and Evalution of Spacecraft-Type Cells" Prepared for Goddard Space Flight Center.

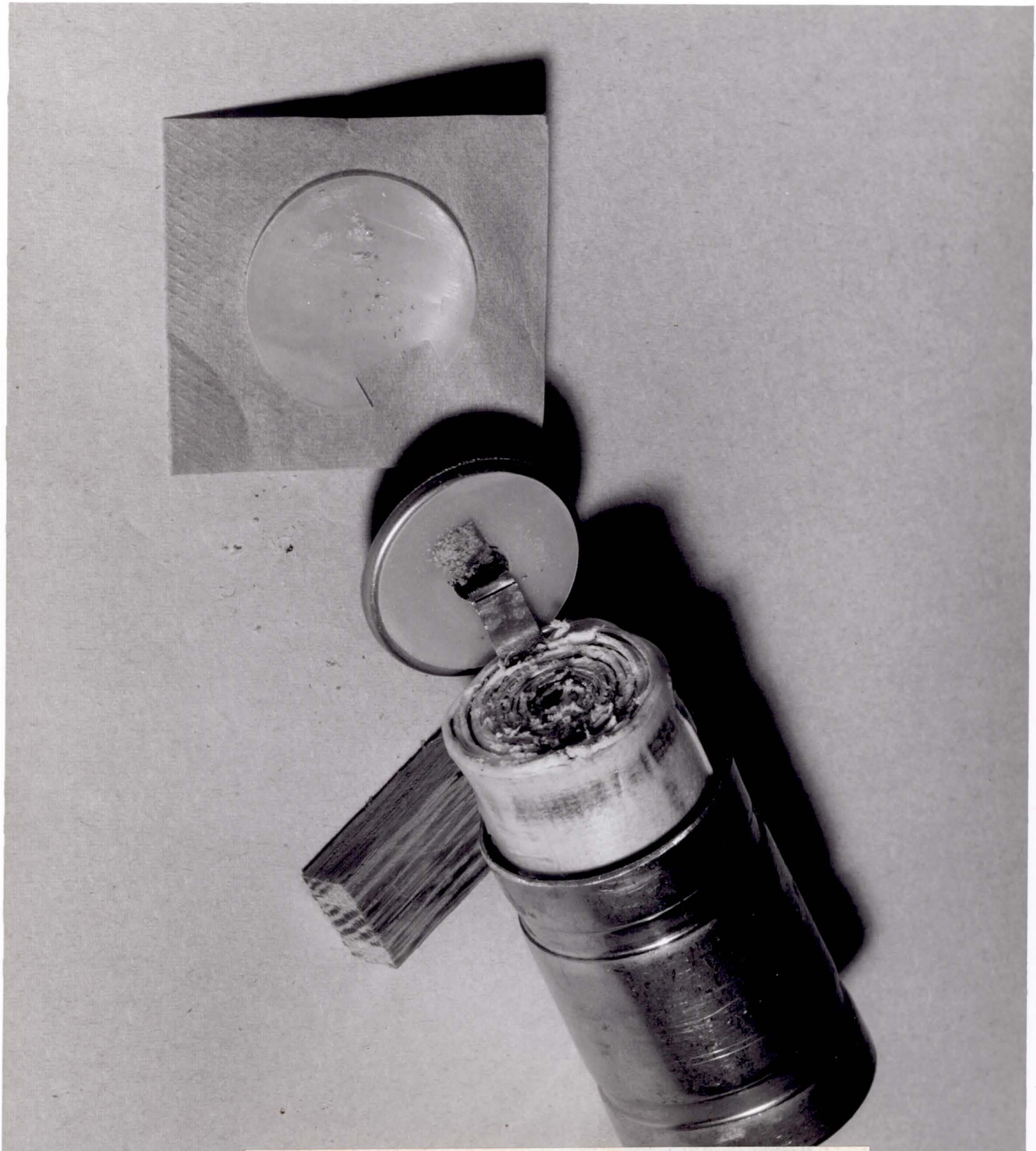
APPENDIX I
(Illustrations)



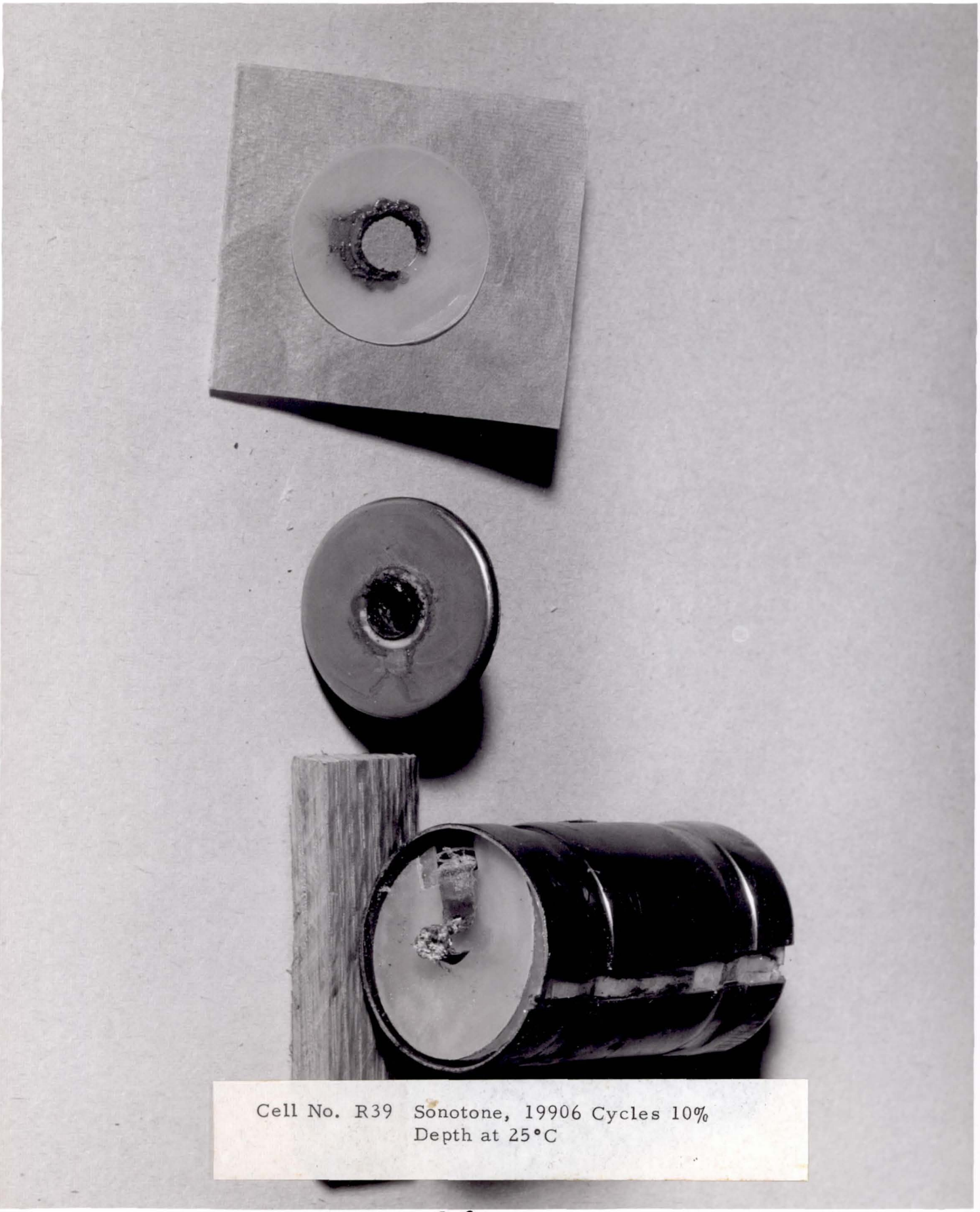
Cell No. 1 Gould National, 19562 Cycles 10% Depth at 25°C



Cell No. 804 Gulton, 19680 Cycles 25%
Depth at 25°C



Cell No. 64 Sonotone, 18610 Cycles 10%
Depth at 25°C



Cell No. R39 Sonotone, 19906 Cycles 10%
Depth at 25°C

Cell No. 66 Sonotone, 19906 Cycles 10%
Depth at 25°C