EVALUATION PROGRAM FOR SECONDARY SPACECRAFT CELLS

INITIAL EVALUATION TESTS OF GENERAL ELECTRIC COMPANY 12.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS FOR THE INTERNATIONAL ULTRAVIOLET EXPLORER SATELLITE

PREPARED FOR
GODDARD SPACE FLIGHT CENTER
CONTRACT S-53742AG

PREPARED BY

WEAPONS QUALITY ENGINEERING CENTER

NAVAL WEAPONS SUPPORT CENTER, CRANE, INDIANA

DEPARTMENT OF THE NAVY
NAVAL WEAPONS SUPPORT CENTER
WEAPONS QUALITY ENGINEERING CENTER
CRANE, INDIANA 47522

EVALUATION PROGRAM
FOR
SECONDARY SPACECRAFT CELLS

INITIAL EVALUATION TESTS
OF
GENERAL ELECTRIC COMPANY
12.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS
FOR THE
INTERNATIONAL ULTRAVIOLET EXPLORER SATELLITE

WQEC/C 76-89 15 MARCH 1976

PREPARED BY

J. D. HARKNESS

PREPARED UNDER THE DIRECTION OF

D. E. MAINS, Manager
Satellite & Shipboard Battery Branch

APPROVED BY

D. G. MILEY

REPORT BRIEF

INITIAL EVALUATION TESTS OF GENERAL ELECTRIC COMPANY 12.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS FOR THE INTERNATIONAL ULTRAVIOLET EXPLORER SATELLITE

Ref: (a) NASA Purchase Order S-53742AG
(b) Initial Evaluation Test Procedure for Nickel-Cadmium Sealed Space Cells; NADC 3053-TP324 of 10 Apr 73

I. TEST ASSIGNMENT BRIEF

A. The purpose of this evaluation test program is to insure that all cells put into the life cycle program are of high quality by the screening of cells found to have electrolyte leakage, internal shorts, low capacity, or inability of any cell to recover its open-circuit voltage above 1.150 volts during the internal short test.

B. The 20 cells were manufactured for the National Aeronautics and Space Administration, Goddard Space Flight Center (GSFC), under NASA contract NAS-5-19584, by General Electric Company, Gainesville, Florida, according to the Manufacturing Control Document (MCD) 232A2222AA-54. They were manufactured to GSFC's specification S-761-P-6. The cells were identified with the manufacturer's catalog number 42B012AB21-G2 with nine cells having auxiliary electrodes. The cells are from a lot of 175 cells procured for the International Ultraviolet Explorer (IUE) Project. Due to a change in requirements, the project selected to use 6.0 ampere-hour cells. Therefore, the remaining cells of this lot have been placed in storage at GSFC for use on a future GSFC project. All the cells are rated at 12.0 ampere-hours and contain double ceramic seals. Testing was funded in accordance with reference (a).

C. Test limits specify those values in which a cell is to be terminated from a particular charge or discharge. Requirements are referred to as normally expected values based on past performance of aerospace nickel-cadmium cells with demonstrated life characteristics. A requirement does not constitute a limit for discontinuance from test.

II. SUMMARY OF RESULTS

A. Cell, S/N 021, exceeded the pressure requirement of 65 psia during the 0° C overcharge test and cell, S/N 093, exceeded this requirement during the capacity test at 20° C. Cell, S/N 093, also exhibited higher auxiliary electrode voltages during testing as compared to the other cells.

B. The cell containers varied in that some had convex contours whereas others had concave contours. Following test, some cells indicated an increase in the plate stack thickness, whereas, others indicated a decrease.

C. Average ampere-hours out during the charge efficiency test at 20° C was 4.5 which was 75 percent of capacity input.

D. Average ampere-hours out following the overcharge at 35° C was 16.3.

E. The average cell voltage at the end of one week open-circuit, during the charge retention test, was 1.324 volts. Average capacity output was 13.2 ampere-hours following the open-circuit stand period.

F. The 24-hour open-circuit cell voltage following a 16-hour short period was 1.231 volts.

G. The cells, with pressure gauges, reached a pressure of 20 psia before reaching the voltage limit of 1.550 volts during the pressure versus capacity test. The average ampere-hours in and voltage at this pressure were 18.5 ah and 1.506 volts respectively. Ten cells exhibited pressure decay in the range of 1 to 4 psia during the last 30 minutes of the 1-hour open-circuit stand. Average capacity out was 15.0 ampere-hours.

III. RECOMMENDATIONS

A. Manufacturing processes and controls should be such to prevent swelling of the plate stack, thereby preventing cell case distortion.

B. It was recommended that these cells be placed on life test under various orbit regimes simulating various spacecraft load requirements.

C. In March 1976, three packs (8F--1.5 hour orbit, 20° C; 8G--1.5 hour orbit, 0° C; 8H--24 hour orbit, 20° C) and in April pack 228A--synchronous orbit, 20° C, will begin test.

RESULTS OF INITIAL EVALUATION TESTS OF GENERAL ELECTRIC COMPANY 12.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS FOR THE INTERNATIONAL ULTRAVIOLET EXPLORER SATELLITE

I. TEST CONDITIONS AND PROCEDURE

A. All evaluation tests were performed at room ambient (RA) pressure and temperature (25° ± 2° C), with discharges at the 2-hour rate, and in accordance with reference (b), unless otherwise specified, and consisted of the following:

1. Phenolphthalein leak tests (2).

2. Three capacity tests, third at 20° C, with internal resistance measurements during second charge/discharge.

3. Auxiliary electrode characterization test.

4. Charge retention test, 20° C.

5. Internal short test.

6. Charge efficiency test, 20° C.

7. Overcharge tests; 0° and 35° C.

8. Pressure versus capacity test.

9. Phenolphthalein leak test.

(See Appendix I for summary of test procedure.)

II. CELL IDENTIFICATION

A. Eleven cells were manufactured without auxiliary electrodes while the other nine cells have auxiliary electrodes. The cells were identified by the manufacturer's catalog number 42B012AB21-G2, with serial numbers 01640208- (021 to 172, noninclusive) -L03. Fourteen cells were fitted with pressure gauge assemblies and all the cells were placed in temporary pack configurations for initial testing.

B. The 12.0 ampere-hour cell is rectangular with average physical dimensions as follows:

	Length (In)			
Overall Height (In)	Edge Maximum	Center Pre-Test Maximum	Center Post-Test Maximum	Width (In)
4.564	.879	.886	.889	2.982

C. The cell containers and covers are made of stainless steel. The positive and negative terminals are insulated from the cell cover by ceramic seals and protrude through the cover as solder-type terminals.

D. The production of the cells for the I.U.E. Program represents the second generation of cells manufactured with the specific objective of reducing the active material loading. As a result, several key cell design parameters were incorporated into the production. Details of cell design, construction, manufacturing and performance during acceptance testing by the manufacturer are summarized and reported in GSFC Report X-711-16-18 of January 1976.

III. RESULTS--The following was condensed from Tables I through VII.

A. Cell, S/N 021, exceeded the pressure requirement of 65 psia during the 0° C overcharge test and cell, S/N 093, exceeded this requirement during the capacity test at 20° C. Cell, S/N 093, also exhibited higher auxiliary electrode voltages during testing as compared to the other cells.

B. The cell containers varied in that some had convex contours whereas others had concave contours. Following test, some cells indicated an increase in the plate stack thickness, whereas, others indicated a decrease.

C. Following is a listing of the average end-of-charge (EOC) voltages and capacity output in ampere-hours (ah):

Charge	Volts	ah Out
c/20 for 48 hours at 25° C	1.436	15.7
c/10 for 24 hours at 25° C	1.442	14.9
c/10 for 24 hours at 20° C	1.454	14.4
c/10 for 24 hours at 20° C*	1.450	13.2
c/40 for 20 hours at 20° C**	1.369	4.5
c/20 for 60 hours at 0° C	1.485	15.0
c/10 for 24 hours at 35° C	1.401	16.3

* Charge retention test.
** Charge efficiency test, 6 ah input.

D. Average internal resistance measurements (milliohms):

Measurement Taken	Resistance
30 Min before end of charge (cycle 1)	2.70
1 Hr after start of discharge (cycle 2)	2.68
2 Hrs after start of discharge (cycle 2)	2.52

E. The auxiliary electrode characteristic test was performed in which maximum signal power was obtained with a 200-ohm resistance; but a 300-ohm resistance was used throughout the tests as instructed by Goddard Space Flight Center's Technical Officer.

F. The average cell voltage at the end of 1 week open-circuit, during the charge retention test, was 1.324 volts.

G. The 24-hour open-circuit average cell voltage following a 16-hour short period was 1.231 volts.

H. The 14 cells, with pressure gauges, reached a pressure of 20 psia before reaching the voltage limit of 1.550 volts during the pressure versus capacity test. The average ampere-hours in and voltages at this pressure were 18.5 ah and 1.506 volts respectively. The cells exhibited pressure decay in the range of 1 to 4 psia during the last 30 minutes of the 1-hour open-circuit stand. Average capacity out was 15.0 ampere-hours.

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE I

SERIAL NUMBER	WEIGHT (Grams)	HEIGHT (Inches)	LENGTH (Inches)			WIDTH (Inches)	PHENOLPHTHALEIN LEAK TESTS								
							INITIAL			POST HI VAC			POST TEST		
			CENTER MAXIMUM (PRE-TEST)	EDGE MAXIMUM	CENTER MAXIMUM (POST-TEST)		Terminals		Other	Terminals		Other	Terminals		Other
							+	-		+	-		+	-	
021	869.3	4.568	.893	.880	.890	2.978									
030	544.3	4.556	.880	.885	.890	2.987									
038	905.1	4.562	.873	.875	.880	2.986									
045	543.8	4.560	.892	.877	.890	2.980									
083	549.0	4.556	.900	.878	.950	2.979									
088	547.6	4.567	.885	.873	.883	2.983									
089	549.5	4.568	.894	.884	.887	2.984									
090	766.0	4.565	.875	.874	.895	2.988									
091	936.0	4.565	.879	.875	.895	2.985									
093	769.2	4.580	.892	.885	.895	2.977		NO LEAKS			NO LEAKS			NO LEAKS	
094	934.1	4.567	.885	.875	.885	2.990									
096	549.4	4.568	.886	.880	.888	2.980									
099	888.2	4.560	.895	.877	.890	2.980									
147	887.5	4.556	.883	.877	.886	2.983									
151	872.5	4.550	.885	.880	.870	2.982									
152	869.8	4.561	.883	.875	.885	2.977									
158	913.9	4.570	.893	.878	.880	2.979									
159	761.5	4.565	.884	.883	.885	2.990									
163	931.9	4.568	.870	.880	.877	2.978									
172	869.0	4.564	.891	.882	.886	2.981									

TABLE II

Capacity Data

SERIAL NUMBER	Capacity Test 1						Capacity Test 2						Capacity Test 3 (20°C)					
	END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE		
	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC-ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC-ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC-ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)
021	1.434		16	16.2		4	1.441		28	15.5		6	1.456		58	14.1		14
030	1.432			15.8			1.439			14.8			1.451			13.9		
038	1.433		20	16.2		6	1.440		29	15.3		10	1.453		52	14.1		14
045	1.433			16.2			1.439			15.2			1.452			14.1		
083	1.436	.385		15.8	.015		1.442	.497		14.9	.020		1.458	.539		14.0	N.A	
093	1.435	.611	6	15.8	.021	5	1.440	.709	47	14.5	.013	18	1.454	.715	69	14.2	N.A	25
089	1.436	.407		15.2	.137		1.442	.519		14.6	.013		1.454	.530		14.2	N.A	
090	1.438	.413	29	15.2	.257	16	1.443	.533	21	14.5	N.A.	2	1.456	.562	35	14.1	N.A	4
091	1.442	.476	19	15.1	.071	6	1.446	.555	33	14.2	.207	12	1.455	.536	33	14.6	.055	7
088	1.436	.399		15.8	.002		1.441	.509		15.2	.023	17	1.453	.538		14.5	N.A	
094	1.443	.509	14	15.2	.018	5	1.444	.553	22	14.3	.178	3	1.453	.541	22	14.7	-.026	5
096	1.438	.404		15.8	.004		1.444	.496		14.9	.019		1.461	.514		14.4	N.A.	
099	1.438	.468	13	15.8	.015	3	1.442	.549	25	14.7	.014	7	1.458	.545	30	14.1	N.A.	7
147	1.437		18	15.6		4	1.444		29	15.4		3	1.451		44	15.6		10
151	1.435		20	15.6		5	1.443		31	15.3		5	1.450		46	15.5		12
152	1.439		13	15.5		5	1.446		21	15.2		2	1.451		26	15.3		7
158	1.435		18	15.8		6	1.443		33	14.7		10	1.459		46	14.3		12
159	1.435		16	15.8		5	1.448		27	14.8		1	1.453		51	14.1		11
163	1.432		17	15.7		7	1.438		31	14.8		7	1.451		70	14.2		14
172	1.437		14	15.8		6	1.443		22	14.6		6	1.454		43	14.3		10
N.A — not available																		

SND-NADC (SP 11/73)

TABLE III
INTERNAL RESISTANCE AND SHORT TEST DATA

9ND-NADC (SP 11/73)

SERIAL NUMBER	INTERNAL RESISTANCE (MILLIOHMS)			INTERNAL SHORT TEST		
	END-OF-CHARGE	ONE HOUR AFTER START-OF-DISCHARGE	TWO HOURS AFTER START-OF-DISCHARGE	AFTER 16 HR SHORT	AFTER 24 HOUR OCV STAND	
				CELL	CELL	PRESS
021	3.0	3.1	2.8	.044	1.229	5
030	2.6	2.3	2.2	.041	1.231	
038	2.8	3.0	2.6	.043	1.228	10
045	3.2	3.0	3.0	.048	1.235	
083	2.8	3.0	2.8	.047	1.238	
093	2.9	2.9	2.8	.047	1.238	14
089	2.6	2.6	2.4	.047	1.236	
090	3.1	3.0	2.4	.050	1.238	2
091	2.9	2.1	2.5	.060	1.222	4
088	2.2	2.5	2.4	.046	1.235	
094	2.4	2.6	2.5	.059	1.220	3
096	3.1	3.0	2.4	.050	1.242	
099	2.8	2.9	2.6	.050	1.241	5
147	2.3	2.5	2.2	.023	1.213	2
151	2.1	2.2	2.4	.027	1.216	4
152	2.2	2.1	2.2	.020	1.216	2
158	2.6	2.8	2.3	.049	1.242	5
159	2.6	2.5	2.6	.046	1.236	0
163	3.4	3.1	2.9	.047	1.234	5
172	2.3	2.3	2.3	.047	1.238	5

TABLE IV
CHARGE RETENTION TEST DATA

SERIAL NUMBER	END-OF-CHARGE			24 HR. OCV			1 WEEK OCV			END-OF-DISCHARGE		
	CELL (VOLTS)	AUX. ELECT. (VOLTS)	PRESS (PSIA)	CELL (VOLTS)	AUX. ELECT. (VOLTS)	PRESS. (PSIA)	CELL (VOLTS)	AUX. ELECT (VOLTS	PRESS. (PSIA)	CAPAC-ITY (AH)	AUX. ELECT. (VOLTS)	PRESS. (PSIA)
021	1.454	.	55	1.363		6	1.323		5	13.8		5
030	1.450			1.364			1.323			13.1		
038	1.451		50	1.364		11	1.325		9	13.7		9
045	1.449			1.363			1.325			13.4		
083	1.455	.526		1.364	N.A.		1.324	.003		13.0	.010	
093	1.451	.709	63	1.362	N.A.	17	1.323	N.A.	16	12.8	.015	15
089	1.451	.508		1.364	N.A.		1.325	N.A.		12.9	.010	
090	1.454	.541	30	1.363	N.A.	3	1.324	N.A.	2	12.7	.018	2
091	1.448	.552	35	1.359	.047	6	1.324	.003	5	13.2	.008	5
088	1.451	.508		1.363	N.A.		1.325	N.A.		13.3	.013	
094	1.446	.542	23	1.360	.041	5	1.324	.003	5	13.3	.013	5
096	1.457	.497		1.364	N.A.		1.326	.003		13.0	.008	
099	1.453	.537	25	1.363	N.A	7	1.325	.001	5	13.0	.040	4
147	1.444		41	1.362		5	1.325		3	14.2		3
151	1.443		43	1.362		5	1.326		2	14.1		5
152	1.445		23	1.362		5	1.320		2	13.8		4
158	1.456		40	1.363		9	1.327		6	13.0		6
159	1.451		47	1.362		1	1.325		0	12.9		0
163	1.449		60	1.363		10	1.325		5	13.0		5
172	1.451		35	1.362		6	1.325		6	12.6		6

N.A.- Not available

TABLE V

Charge Efficiency and Overcharge Data

CELL NUMBER	Charge Efficiency (20°C)						Overcharge Test (C°)						Overcharge Test (35°C)					
	END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE		
	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC-ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC-ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC-ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)
021	1.370		5	4.4		4	1.480		65	15.4		29	1.405		15	16.9		6
030	1.371			4.3			1.476			15.2			1.399			16.0		
038	1.370		10	4.3		9	1.490		19	15.4		9	1.398		10	16.9		4
045	1.369			4.6			1.480			15.4			1.398			16.5		
093	1.370	.011		4.6	.007		1.484	.385		15.4	N.A		1.402	.369		16.5	.067	
093	1.370	.014	15	4.9	.001	15	1.495	.489	14	15.2	N.A.	13	1.396	.547	21	16.6	.128	13
089	1.370	.010		4.6	.007		1.479	.401		15.2	N.A		1.398	.395		16.6	.029	
090	1.370	.014	2	4.5	.006	2	1.484	N.A	14	15.2	N.A.	6	1.399	.389	23	16.6	.045	15
091	1.368	.025	5	4.3	-.030	5	1.495	.378	38	13.4	.010	15	1.403	.386	12	15.6	.097	5
088	1.370	.014		4.6	.006		1.480	.345		15.2	N.A		1.397	.388		16.5	.070	
094	1.368	.025	4	4.4	-.060	3	1.493	.436	22	13.5	.006	9	1.401	.426	10	15.6	.088	5
096	1.370	.011		4.6	.007		1.484	.374		15.4	N.A		1.409	.381		17.0	.035	
099	1.370	.020	6	5.1	.011	6	1.485	.444	22	15.4	N.A.	11	1.400	.434	20	15.8	.070	11
147	1.368		2	3.8		2	1.491		51	14.6		23	1.403		15	15.9		7
151	1.368		6	3.9		6	1.490		45	14.3		22	1.403		13	16.1		7
152	1.368		3	4.0		3	1.491		30	13.9		11	1.404		14	16.0		7
158	1.370		6	4.8		5	1.483		40	15.4	N.A	47	1.406		39	15.5		25
159	1.370		0	4.6		0	1.479		48	15.2	N.A.	28	1.396		21	16.4		5
163	1.370		5	4.5		5	1.475		55	15.2	N.A	33	1.396		22	16.5		15
172	1.369		6	4.7		6	1.480		29	15.2	N.A	28	1.395		25	16.5		18

N.A. -- not available

TABLE VI
PRESSURE VS. CAPACITY TEST DATA

Serial No.	021	038	093	090	091	094	099	147	151	152	158	159	163	172		
Start-of-Charge, Press.	4	2	8	10	5	5	7	3	4	5	5	3	3	7		
AH in to 5 PSIA	5.0	6.0	N/A	N/A	N/A	N/A	N/A	14.9	9.4	N/A	N/A	15.0	14.0	N/A		
Cell (volts)	1.406	1.407						1.434	1.410			1.450	1.436			
Aux (volts)																
AH in to 10 PSIA	17.2	18.1	15.4	N/A	17.0	17.5	5.0	17.8	17.6	17.5	17.0	17.5	17.0	14.5		
Cell (volts)	1.474	1.504	1.413		1.470	1.487	1.406	1.487	1.478	1.472	1.485	1.488	1.485	1.446		
Aux (volts)			.361		.271	.371	.010									
AH in to 15 PSIA	18.1	18.7	17.5	16.5	17.9	18.2	17.8	18.5	18.3	18.3	17.8	17.9	17.9	17.5		
Cell (volts)	1.506	1.516	1.503	1.462	1.503	1.505	1.516	1.503	1.498	1.495	1.512	1.496	1.504	1.494		
Aux (volts)			.565	.316	.366	.475	.359									
AH in to 20 PSIA	18.7	19.5	18.0	17.3	18.4	18.7	18.3	18.8	18.7	18.8	18.0	18.4	18.3	18.4		
Cell (volts)	1.514	1.512	1.512	1.490	1.505	1.503	1.520	1.502	1.499	1.499	1.512	1.525	1.502	1.507		
Aux (volts)			.587	.387	.427	.529	.455									
AH in to V/L (1.55V)																
Aux (volts)																
Press (PSIA)																
30 Min OCV, Cell	1.405	1.408	1.402	1.391	1.393	1.393	1.405	1.394	1.394	1.395	1.401	1.401	1.401	1.402		
Aux (volts)			.553	.309	.458	.488	.448									
Press (PSIA)	22	19	20	16	21	20	22	23	20	20	20	21	25	22		
1 hour OCV, Cell	1.399	1.401	1.397	1.388	1.387	1.387	1.399	1.387	1.388	1.389	1.396	1.396	1.396	1.396		
Aux (volts)			.533	.277	.421	.413	.432									
Press (PSIA)	20	17	18	15	19	17	20	20	18	17	18	19	22	18		
EOD AH out	15.1	15.8	14.6	14.1	15.5	15.6	14.4	15.9	15.8	15.8	14.6	14.4	14.4	14.2		
Aux (volts)			.125	.132	.099	.080	.126									
Press (PSIA)	8	6	9	16	7	6	10	7	8	7	7	2	6	3		

N/A - not applicable

SMD-NADC (SP 11/73)

MDEC/C 76-89

TABLE VII
SPECIAL RESISTANCE CHARACTERISTIC DATA ON THE AUXILIARY ELECTRODES

SERIAL NO.	91		93		94		99				AVERAGE *	
OHMS	VOLTS	PRESS	VOLTS	PRESS	VOLTS	PRESS	VOLTS	PRESS	VOLTS	PRESS	VOLTS	MILLIWATTS
10,000	.821	15	.870	31	.845	15	.841	15			.836	.07
5,000	.775	15	.858	31	.809	15	.795	15			.793	.13
2,000	.688	15	.798	31	.695	15	.692	15			.692	.24
1,000	.596	15	.735	31	.602	15	.610	15			.603	.36
500	.469	15	.662	31	.512	15	.527	15			.503	.51
200	.294	15	.555	31	.387	15	.400	14			.360	.65
100	.198	15	.462	31	.266	15	.282	14			.249	.62
50	.130	15	.344	31	.175	15	.194	14			.166	.55
20	.073	15	.204	31	.098	15	.118	14			.096	.46
10	.041	15	.128	31	.056	15	.076	14			.058	.34
5	.023	15	.077	31	.033	15	.046	14			.034	.23
2	.010	15	.036	31	.014	15	.022	14			.015	.11
1	.006	15	.020	31	.008	15	.012	14			.009	.08
0.5	.003	15	.012	31	.005	15	.007	14			.005	.05
0.2	.002	15	.005	31	.003	15	.003	14			.003	.04
0.1	.001	15	.004	31	.002	15	.002	14			.002	.04

Note: All pressures in PSIA.

$$\text{POWER} = \frac{V^2}{R} \text{ Watts } 10^3 \frac{\text{Milliwatts}}{\text{Watt}} : \text{Milliwatts}$$

* Excluding Cell S/N 93 because of High Pressure during test

APPENDIX I

I. TEST PROCEDURE

A. Phenolphthalein Leak Tests:

1. This test is a determination of the condition of the welds and ceramic seals on receipt of the cells and following the last discharge of the cells (Cycle #8).

2. The cells were initially checked with a one-half of one percent phenolphthalein solution applied with a cotton swab and then placed in a vacuum chamber and exposed to a vacuum of 40 microns of mercury or less for 24 hours. Upon removal they were rechecked for leaks and then received a final check following test completion. The requirement is no red or pink discoloration which indicates a leak.

B. Capacity Tests:

1. The capacity test is a determination of the cells' capacity at the c/2 discharge rate to 0.75 volt per cell, where c is the manufacturer's rated capacity. This type discharge follows all charges of this evaluation test.

2. The charges for the capacity tests are as follows:

a. c/20, 48 hours, room ambient (RA), cycle 0, with a test limit of 1.52 volts or pressure of 100 psia;

b. c/10, 24 hours, RA, cycle 1, with a test limit of 1.52 volts or 100 psia pressure and a requirement of maximum voltage (1.48) or pressure (65 psia);

c. c/10, 24 hours, 20° C, cycle 2, with the same limits and requirements as the charge of cycle 1.

C. Special Resistance Characterization Tests for Auxiliary Electrode Cells:

1. The purpose of this test is to determine the resistance to be placed across the cell's auxiliary electrode and negative terminals which will provide maximum signal when the cell is fully charged.

2. The cells are charged at c/10 for 24 hours at the room ambient temperature following their initial charge/discharge cycle. Following this the cells are continued on charge with the current reduced, if necessary, to maintain the cell's voltage below 1.520 volts and to stabilize the pressure between [illegible] psia. Resistance values, between 10,000 ohms and 0.1

ohm are then placed between the auxiliary electrode and the negative terminal. The cells are allowed a minimum of 5 minutes, at each resistance value, to obtain an equilibrium voltage across this resistance. This voltage value is then recorded and by calculation using the equation $P = E^2/R$ the resistance that produces maximum power is determined.

D. Internal Resistance:

1. Measurements are taken across the cell terminals 0.5 hour before the end-of-charge (EOC) on cycle 1; and 1 and 2 hours after the start-of-discharge of cycle 2. These measurements were made with a Hewlett-Packard milliohmmeter (Model 4328A).

E. Special Charge Retention Test, 20° C:

1. This test is to establish the capacity retention of each cell following a 7-day open-circuit stand in a charge mode.

2. The cells are charged at c/10 for 24 hours with a test limit of 1.52 volts or 100 psia pressure. They then stand on open-circuit for 7 days, with the requirement that the open-circuit voltage of each cell, following this period, is within $\pm$ 5 millivolts of the average cell voltage. The cells are then discharged and 80 percent capacity out of that obtained in cycle 3 is required.

F. Internal Short Test:

1. This test is a means of detecting slight shorting conditions which may exist because of imperfections in the insulating materials, or damage to element in handling or assembly.

2. Following completion of the third capacity discharge, the cells are shunted with a 0.5-ohm, 3-watt resistor for 16 hours. At the end of 16 hours the resistors are removed and the cells stand on open-circuit voltage (OCV) for 24 hours. A minimum voltage of 1.15 is required at the end of 24 hours.

G. Charge Efficiency Test, 20° C:

1. This test is a measurement of the cells' charge efficiency when charged at a low current rate.

2. The cells are charged at c/40 for 20 hours with a test limit of 1.52 volts or 100 psia pressure. They are then discharged and the requirement is that the minimum capacity out equals 55 percent of capacity in during the preceding charge.

H. Overcharge Test #1, 0° C:

1. The purpose of this test is to determine the degree to which the cells will maintain a balanced voltage, and to determine the cells' capability to be overcharged without overcharging the negative electrode.

2. The cells are charged at c/20 for 60 hours. The test limits are cell voltages of 1.56 or greater for a continuous time period of 2 hours or pressures of 100 psia. The requirement is a voltage of 1.520 or a pressure of 65 psia. The cells are then discharged and 85 percent capacity out of that obtained in cycle 3 is required.

I. Overcharge Test #2, 35° C:

1. This test is a measurement of the cells' capacity at a higher temperature when compared to its capacity at 20° C. This test also determines the cells' capability of reaching a point of pressure equilibrium; oxygen recombination at the negative plate at the same rate it is being generated at the positive plate.

2. The cells are charged at c/10 for 24 hours with a test limit of 1.52 volts or 100 psia pressure and a requirement of 1.45 volts or 65 psia pressure. The cells are then discharged with a requirement that capacity out equals 55 percent capacity out as obtained in cycle 3.

J. Pressure Versus Capacity Test:

1. The purpose of this test is to determine the capacity to a pressure and the pressure decay during charge and open-circuit stand respectively.

2. Each cell is charged at c/2 to either a pressure of 20 psia or a voltage of 1.550. Recordings are taken on each cell when it reaches 5, 10, 15 and 20 psia pressure. The cells then stand OCV for 1 hour with 30-minute recordings and then are discharged, shorted out and leak tested.