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(NASA-CR-159907) INITIAL EVALUATION TESTS OF EAGLE-PICHER INDUSTRIES 9.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS FOR THE HEAT CAPACITY MAPPING MISSION SATELLITE AND THE STRATOSPHERIC (Naval Weapons Support Center, G3/44 43200

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INITIAL EVALUATION TESTS OF EAGLE-PICHER INDUSTRIES 9.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS FOR THE HEAT CAPACITY MAPPING MISSION SATELLITE AND THE STRATOSPHERIC AEROSOL AND GAS EXPERIMENT SATELLITE

prepared for

GODDARD SPACE FLIGHT CENTER

Contract S-53742AG

WEAPONS QUALITY ENGINEERING CENTER

NWSC Crane, Indiana

WQEC/C 78-37

REPORT BRIEF
INITIAL EVALUATION TESTS
OF
EAGLE-PICHER INDUSTRIES
9.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS
FOR THE
HEAT CAPACITY MAPPING MISSION SATELLITE
AND THE
STRATOSPHERIC AEROSOL AND GAS EXPERIMENT SATELLITE

Ref: (a) NASA Purchase Order S-53742AG
(b) Initial Evaluation Test Procedure for Nickel-Cadmium Sealed Space Cells: NAD 3053-TP324, 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 10 cells were purchased by the National Aeronautics and Space Administration, Goddard Space Flight Center (GSFC), under NASA contract NAS 5-55909 from Eagle-Picher Industries. The cells were manufactured by Eagle-Picher Industries, Joplin, Missouri, according to the Boeing Specification 268-10408 which is similar to the GSFC Specification 74-15000. Five cells were purchased from a lot of cells to be used on the Heat Capacity Mapping Mission Satellite (HCMM) and the other 5 cells from the lot of cells to be used on the Stratospheric Aerosol and Gas Experiment Satellite (SAGE). The HCMM cells were activated in November 1976 and the SAGE cells were manufactured in April 1977. The cells were identified with the manufacturer's type number RSN-10-3. These cells are rated at 9.0 ampere-hours, contain double ceramic seals, and were fitted with pressure transducer assemblies. Testing was funded in accordance with reference (a).

C. Test limits specify those values at which a cell is to be terminated from a particular charge or discharge. Requirements are referenced 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. The HCMM cells exhibited lower voltages and pressures, but delivered higher capacities than the SAGE cells.

B. The HCMM cells exceeded the voltage requirement of 1.52 volts during the 0°C overcharge test, but their end-of-charge voltages were below 1.50 volts.

C. The SAGE cells exceeded the voltage and pressure test limits during the following charges:

Type Change	Number of Cells	Test Limit Exceeded
C/10, 24 hrs, @ 25°C	2	Pressure
C/10, 24 hrs, @ 20°C	2	Voltage
C/10, 24 hrs, @ 20°C	2	Pressure
C/20, 60hrs, @ 0°C	5	Voltage
C/10, 24hrs, @ 35°C	4	Pressure

D. Three SAGE cells delivered less than 55% of the input capacity requirement during the 20°C charge efficiency test.

E. The 24-hour average cell voltage following a 16-hour short period, for the HCMM and SAGE cells was 1.249 and 1.226 volts respectively.

F. The cell containers had a convex contour, in which the thickness was greater in the center of the can than at the edge of the container. Following test, the thickness at the edge was greater (HCMM cells not measured) indicating a reduction in the plate stack thickness.

III. RECOMMENDATIONS

A. It was recommended that these cells be placed on life test under the orbit regimes of the HCMM and SAGE spacecrafts.

B. In May 1977, the HCMM cells (Pack 18H) began life test (1.6 hour obit, 20°C) and in September 1977 the SAGE cells (Pack 18I) began life test (1.64 hour obit, 20°C).

RESULTS OF INITIAL EVALUATION TESTS OF EAGLE-PICHER INDUSTRIES, INCORPORATED 9.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS FOR THE HEAT CAPACITY MAPPING MISSION SATELLITE AND THE STRATOSPHERIC AEROSOL AND GAS EXPERIMENT SATELLITE

I. TEST CONDITIONS AND PROCEDURE

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

1. Phenolphtalein leak tests (2).

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

3. Charge retention test, 20°C.

4. Internal short test.

5. Charge efficiency test, 20°C.

6. Overcharge tests, 0°and 35°C.

7. Phenolphtalein leak test.

(See Appendix I for summary of test procedure.)

II. CELL IDENTIFICATION AND DESCRIPTION

A. The cells were identified by the manufacturer's type number, RSN-10-3, and serial numbers as follows:

Project	Manufacturer's Serial Numbers
HCMM	233, 242, 248, 252, 256
SAGE	290, 311, 334, 346, 352

The cells were placed in pack configurations for initial testing: (Pack 18H (HCMM) and Pack 18I (SAGE). Each cell was equipped with a pressure transducer.

B. The 9.0 ampere-hour cell is retangular with an average weight and physical dimensions as follows:

Weight(g)*	Overall Height (in.)	Thickness (in.)** Minimum	Pre-Test Maximum	Post-Test*** Maximum	Width (in.)
570.8*(HCMM)	3.301	.898	.902		2.990
420.1(SAGE)	3.285	.900	.906	.894	2.992

* - includes weight of pressure transducer assembly
** - minimum measured at edge of can and maximum at center
*** - SAGE cell data only

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. (See Appendix II for detailed cell description)

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

A. The cell containers had a convex contour, in which the thickness was greater in the center of the can than at the edge of the container. Following test, the thickness at the edge was greater (HCMM cells not measured) indicating a reduction in the plate stack thickness.

B. The SAGE cells exhibited higher average end-of-charge (EOC) voltages and pressures (PSIA) than the HCMM cells; but exceeded the voltage and pressure test limits during various charges. The HCMM cells delivered a higher capacity output in ampere-hours (ah) following these charges. The following is a listing of these averages:

	HCMM Cells			SAGE CELLS		
Charge	Volts	PSIA	ah Out	Volts	PSIA	ah Out
C/20 for 48 hrs @ 25°C	1.445	28	11.5	1.453	62	10.8
C/10 for 24 hrs @ 25°C	1.441	51	11.4	1.461	88	10.7
C/10 for 24 hrs @ 20°C	1.459	63	11.2	1.502	66	10.7
C/10 for 24 hrs @ 20°C	1.457	64	10.1	1.495	66	9.9
C/40 for 20 hrs @ 20°C*	1.380	4	2.7	1.384	6	2.5
C/20 for 60 hrs @ 0°C	1.483	69	10.8	1.616	31	10.4
C/10 for 24 hrs @ 35°C	1.418	70	10.8	1.436	91	10.3

*Charge Efficiency Test, 4.5 ah input

C. Average Internal Resistance Measurements (milliohms):

Measurement Taken	Resistance HCMM	SAGE
30 min before end-of-charge (Cycle 1)	3.0	2.1
1 hr after start-of-discharge (Cycle 2)	2.9	2.5
2 hrs after start-of-discharge (Cycle 2)	2.9	2.5

D. Two SAGE cells exceeded 100 PSIA during the C/10 charge @ 25°C.

E. Four SAGE cells exceeded the test limits (2 on pressure and 2 on voltage) during the C/10 charges @ 20°C.

F. Three SAGE cells delivered less than 55% of the input capacity requirement during the 20°C charge efficiency test.

G. All the SAGE cells exceeded the voltage test limit during the overcharge test @ 0°C. The HCMM cells exceeded the voltage requirement of 1.52 volts during this test although their end-of-charge voltages were below 1.50 volts.

H. Four SAGE cells exceeded the pressure test limit during the 35°C overcharge test.

I. The average cell voltage at the end of one week open-circuit, during the charge retention test was 1.303 and 1.301 volts respectively for the HCMM and SAGE cells.

J. The 24-hour average cell voltage following a 16-hour short period, for the HCMM and SAGE cells was 1.249 and 1.226 volts respectively.

TABLE I
MEASUREMENT AND LEAK TEST DATA

SERIAL NUMBER	WEIGHT (Grams)	HEIGHT (Inches)	LENGTH (Inches)**			WIDTH (Inches)	PHENOLPHTHALEIN LEAK TESTS								
							INITIAL			POST HI VAC			POST TEST		
			MINIMUM	MAXIMUM (Pre-Test)	MAXIMUM Post-Test		Terminals		Other	Terminals		Other	Terminals		Other
							+	-		+	-		+	-	
233	571.9 *	3.314	.906	.910	NA	2.991									
242	568.0 *	3.302	.895	.901	NA	2.991									
248	571.6 *	3.293	.897	.898	NA	2.991									
252	570.4 *	3.299	.893	.897	NA	2.990									
256	572.0 *	3.295	.898	.903	NA	2.986									
								NO	LEAKS					NO LEAKS	
290	420.7	3.290	.902	.907	.892	2.990									
311	420.2	3.290	.898	.905	.896	2.992									
334	419.8	3.275	.898	.904	.897	2.999									
346	420.3	3.305	.902	.905	.896	2.993									
352	419.7	3.275	.898	.910	.890	2.988									

NA - not available

* - includes pressure transducer weight

** - measurements: minimum taken at edge of cell
maximum taken at center

NICMM

5 STAGE

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)	AH IN	PRESS (PSIA)	CAPACITY (ah)		PRESS (PSIA)	CELL (Volts)	AH IN	PRESS (PSIA)	CAPACITY (ah)		PRESS (PSIA)	CELL (Volts)	AH IN	PRESS (PSIA)	CAPACITY (ah)		PRESS (PSIA)
233	1.445	21.6	26	11.6		5	1.441	21.6	49	11.4		17	1.459	21.6	60	11.2		22
242	1.445	21.6	25	11.6		6	1.440	21.6	50	11.4		15	1.459	21.6	63	11.2		23
248	1.445	21.6	30	11.6		12	1.441	21.6	50	11.4		20	1.459	21.6	62	11.2		27
252	1.443	21.6	31	11.3		10	1.441	21.6	54	11.4		20	1.458	21.6	64	11.1		25
256	1.446	21.6	30	11.6		9	1.442	21.6	55	11.4		22	1.460	21.6	67	11.1		29
290	1.451	21.6	73	11.1		39	1.466	16.9	100	10.5		39	1.511	15.7	100	10.8		51
311	1.457	21.6	44	10.9		22	1.462	21.6	65	11.0		36	1.520	13.5	7	10.7		5
334	1.451	21.6	66	10.5		32	1.456	21.6	94	10.6		58	1.486	17.1	100	10.5		41
346	1.452	21.6	72	10.7		36	1.461	16.9	100	10.3		36	1.520	14.3	38	10.5		2
352	1.453	21.6	57	10.7		26	1.458	21.6	83	10.8		45	1.473	21.6	84	10.9		52
NOTE:	NORMAL AH_{IN} is			21.6	Ah	each	charge											

SND-NADC (SP 11/73)

TABLE III
INTERNAL RESISTANCE AND SHORT TEST DATA

GND-NADC (SP 11/73) WQEC/C 78-37

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
HCMM						
233	2.8	2.9	2.8	.008	1.249	0
242	2.9	3.0	3.1	.008	1.248	2
248	3.2	3.0	2.8	.009	1.249	7
252	3.1	2.9	2.9	.009	1.248	5
256	3.2	2.8	2.9	.008	1.249	5
SAGE						
290	2.1	2.5	2.6	.013	1.230	6
311	2.1	2.5	2.6	.011	1.228	4
334	2.1	2.6	2.7	.011	1.225	3
346	2.2	2.4	2.4	.014	1.224	9
352	2.1	2.3	2.3	.014	1.222	5

TABLE IV

Charge Efficiency and Overcharge Data

SERIAL NUMBER	Charge Efficiency (20°C)						Overcharge Test (0°)						Overcharge Test (35°C)					
	END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE		
	CELL (Volts)	AH IN	PRESS (PSIA)	CAPACITY (ah)		PRESS (PSIA)	CELL (Volts)	AH IN	PRESS (PSIA)	CAPACITY (ah)		PRESS (PSIA)	CELL (Volts)	AH IN	PRESS (PSIA)	CAPACITY (ah)		PRESS (PSIA)
233	1.379	4.5	1	2.7		0	1.483	27.0	66	10.8		34	1.418	21.6	74	10.2		26
242	1.379	4.5	2	2.7		2	1.483	27.0	69	10.8		35	1.417	21.6	69	10.2		22
248	1.380	4.5	7	2.7		7	1.483	27.0	69	10.8		40	1.415	21.6	70	11.0		29
252	1.380	4.5	5	2.7		4	1.482	27.0	71	10.8		39	1.419	21.6	66	10.2		22
256	1.380	4.5	4	2.7		4	1.484	27.0	70	10.8		37	1.419	21.6	73	10.2		28
290	1.383	4.5	7	2.6		7	1.601	13.3	42	10.5		37	1.440	15.2	100	10.4		54
311	1.385	4.5	5	2.6		5	1.650	13.0	7	10.4		7	1.431	21.6	54	10.2		29
334	1.384	4.5	4	2.4		4	1.611	13.3	57	10.2		45	1.422	15.3	100	10.0		41
346	1.383	4.5	9	2.4		9	1.617	13.0	17	10.4		16	1.424	15.2	100	10.0		41
352	1.384	4.5	6	2.4		6	1.602	13.3	34	10.4		32	1.445	15.3	100	10.2		42
↓ —	Hemm	Cells	Exceeded	1.5	10 volts		During	charge.										
Note:	Normal	Ratio	for	the	3	charges (L→R)	are	4.5,	27.0	and	21.6							

SND-NADC (SP 11/73)

MFC/C 78-37

TABLE V
CHARGE RETENTION TEST DATA

WQEC/C 78-37

	SERIAL NUMBER	END-OF-CHARGE			24 HR OCV			1 WEEK OCV			END-OF-DISCHARGE		
		CELL (VOLTS)	AH IN	PRESS. (PSIA)	CELL (VOLTS)		PRESS. (PSIA)	CELL (VOLTS)		PRESS. (PSIA)	CAPACITY (AH)		PRESS. (PSIA)
HCMM	233	1.457	21.6	60	1.339		2	1.303		0	10.1		0
	242	1.457	21.6	64	1.340		3	1.302		2	10.1		2
	248	1.457	21.6	63	1.340		8	1.303		7	10.1		7
	252	1.457	21.6	67	1.340		6	1.303		4	10.1		4
	256	1.458	21.6	68	1.340		6	1.303		5	10.1		4
SAGE	290	1.487	16.6	100	1.339		20	1.304		6	10.2		7
	311	1.520	12.2	7	1.339		5	1.304		5	10.0		4
	334	1.479	17.6	100	1.338		16	1.299		4	9.7		4
	346	1.520	17.5	36	1.328		11	1.300		9	9.8		9
	352	1.471	21.6	85	1.339		14	1.297		6	9.8		5
	Note:	Normal	AH in	is	21.6								

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 #7).

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 (75 psia).

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

C. Internal Resistance:

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

D. 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 ±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.

E. 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 the 24 hours.

F. 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.

G. 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 75 psia. The cells are then discharged and 85 percent capacity out of that obtained in Cycle 3 is required.

H. 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 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 75 psia pressure. The cells are then discharged and 55 percent capacity out of that obtained in Cycle 3 is required.

APPENDIX II

HCMM CELL DESIGN

These cells were activated at Eagle-Picher in November 1976 and have the following properties:

Lot Number 1 Positive Plates (P-1913)	Lot Number 2 Negative (N-1393)
11.2 Ah to + 1.0v	20.0 Ah to -1.0v
12.11 Ah theoretical	28.13 Ah theoretical
92 percent efficiency	71 percent efficiency
Neg/Pos Ratio 1.79	Neg/Pos Ratio 1.79
Loading 0.69 g/in^2	Loading 1.15 g/in^2
Avg. thickness 0.027 inch	Avg. thickness 0.030 inch
Number of Plates 11	Number of Plates 12
Area of a Plate 5.5 in^2	

Free Volume of Cell: 52 cc

Amount of Electrolyte: 40g or 32 cc of 31 percent KOH

Separator: 12 mils pellon 2505 non-woven nylon

Cell Case Thickness: .022 inch, 304 stainless steel

Precharge: 2.4 to 2.8 Ah (measured)

Excess Negative: 8.8 Ah

These cells were subjected to acceptance tests at Eagle-Picher where they exhibited the following results:

ATP 408 Paragraph 4.4, 35°C (12-3-76)

S/N	AH	Voltage	PSIG
233	8.6	1.399	+14
242	8.0	1.387	+21
248	8.1	1.386	+13
252	7.8	1.385	+21
256	7.7	1.386	+17

S/N	AH	Voltage	PSIG
233	10.7	1.495	+20
242	10.7	1.493	+19
248	10.7	1.493	+16
252	10.7	1.493	+22
256	10.7	1.494	+22

Following acceptance test at Eagle-Picher the cells were stored at GSFC in a freezer discharged and shorted.

SAGE CELL DESIGN

These cells were activated at Eagle-Picher in March 1977 and have the following properties:

Positive Plates (T-1992)	Negative (N-1416)
11.0 Ah to +1.0v	16.2 Ah to -1.0v
12.11 Ah theoretical	25.69 Ah theortical
91 Percent efficiency	63 percent efficiency
Neg/Pos Ratio 1.47	Neg/Pos Ratio 1.47
Loading 0.69 g/in^2	Loading 1.04 g/in^2
Avg thickness 0.027 inch	Avg thickness .031 inch
Number of plates 11	Number of plates 12

Area of a plate 5.54 in^2

Free Volume of Cell: 52 cc

Amount of Electrolyte: 40g or 32 cc of 31 percent KOH

Separator: 12 mils pellon 2505 non-woven nylon

Cell Case Thickness: .022 inch, 304 stainless steel

Precharge: 2.2 to 2.7 Ah

Excess Negative: 5.2 Ah