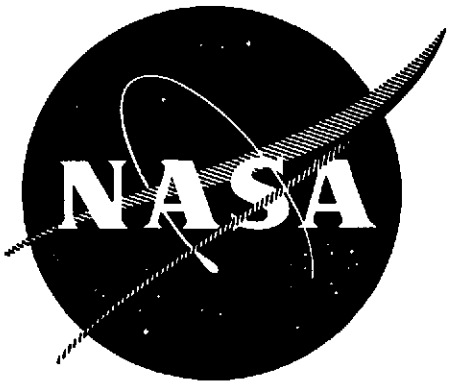

EVALUATION PROGRAM
for
SECONDARY SPACECRAFT CELLS

INITIAL EVALUATION TESTS
OF
EAGLE-PICHER INDUSTRIES, INCORPORATED
3.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS

prepared for
GODDARD SPACE FLIGHT CENTER
CONTRACT S-23404-G

QUALITY EVALUATION AND ENGINEERING LABORATORY
NAD CRANE, INDIANA

DEPARTMENT OF THE NAVY
NAVAL AMMUNITION DEPOT
CRANE, INDIANA 47522

IN REPLY REFER TO:
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18 DEC 1973

From: Commanding Officer, Naval Ammunition Depot, Crane, Indiana
To: National Aeronautics and Space Administration, Goddard Space Flight Center (761, Mr. T. J. Hennigan), Greenbelt, Maryland 20771

Subj: Evaluation program for secondary spacecraft cells; initial evaluation tests of 3.0 ampere-hour nickel-cadmium spacecraft cells manufactured by Eagle-Picher Industries, Incorporated

Ref: (a) NASA Purchase Order S-23404-G

Encl: (1) Report QEEL/C 73-380

1. In compliance with reference (a), enclosure (1) is forwarded for information and retention.

D. G. MILEY
By direction

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DEPARTMENT OF THE NAVY
NAVAL AMMUNITION DEPOT
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CRANE, INDIANA 47522

EVALUATION PROGRAM FOR SECONDARY SPACECRAFT CELLS

INITIAL EVALUATION TESTS OF EAGLE-PICHER INDUSTRIES, INCORPORATED 3.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS

QEEL/C 73-380

29 October 1973

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REPORT BRIEF
EAGLE-PICHER INDUSTRIES, INCORPORATED
3.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS

Ref: (a) NASA P.O. S-23404-G
(b) Initial Evaluation Test Procedure for Nickel-Cadmium Sealed Space Cells: NAD 3053-TP324, 10 Apr 1973

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 on the cell short test.

B. The five cells were purchased by Philco-Ford under contract NAS5-71575 for the National Aeronautics and Space Administration, Goddard Space Flight Center, from Eagle-Picher Industries, Inc., Joplin, Missouri. The cells are to be evaluated for a proposed flight battery on the Synchronous Meteorological Satellite to be launched in 1974. These cells are rated at 3.0 ampere-hours (EP Lot #4), contain double ceramic seals, and were fitted with pressure transducers prior to testing. The 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 normal expectant 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 capacity of the cells ranged from 3.58 to 3.97 ampere-hours during the three capacity tests.

B. Three cells were removed from test, due to high pressure, during the C/10, 24-hour charge at room ambient temperature.

C. The voltage requirement of 1.480 volts was exceeded by the cells during the C/10, 24-hour charge at 20°C, although the end-of-charge voltage was below this value (1.466-1.475 volts).

D. Average capacity out during the 20°C charge efficiency test was 0.84 AH which represents 48% and is below the minimum requirement of 55%.

E. Two cells exceeded the voltage limit (1.560 volts) during the 0°C overcharge test and the other cells exceeded the voltage requirement of 1.520 volts.

F. All cells were terminated from charge during the 35°C overcharge test when their pressure reached 93 psia. One cell failed to meet the minimum requirement of 55 percent of capacity out as was obtained during capacity test #3.

G. The cells exhibited no pressure decay during the open-circuit stand portion of the pressure versus capacity test, as all cells reached their voltage limit (1.550 volts) before their pressure reached 20 psia with the highest pressure being 8 psia during charge.

III. RECOMMENDATIONS

A. It was recommended that these cells be placed on a synchronous-type orbit test program for evaluation since there is no previous test data on cells of this type, manufacture and test regime.

B. On 5 September 1973, these cells began a synchronous orbit test at the beginning of the shadow period.

RESULTS OF INITIAL EVALUATION TESTS OF 3.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS MANUFACTURED BY EAGLE-PICHER INDUSTRIES, INCORPORATED

I. TEST CONDITIONS AND PROCEDURE

A. All evaluation tests were performed at room ambient (R.A.) pressure and temperature (25°C ± 2°C) unless otherwise specified, and in accordance with reference (b) 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. Internal short test.

4. Charge efficiency test, 20°C.

5. Overcharge tests, 0°C and 35°C.

6. Pressure versus capacity test.

7. Phenolphthalein leak test.

See Appendix I for summary of test procedure.

II. CELL IDENTIFICATION AND DESCRIPTION

A. The cells were identified by the manufacturer's serial numbers and placed in a pack configuration (Pack 227A) for testing as follows:

Serial Number -	361	364	369	379	383
Cell Number -	1	2	3	4	5

B. The 3.0 ampere-hour cell is rectangular with an average weight and physical dimension as follows:

Weight (g)	Height (in.)	Length (in.)	Width (in.)
168.1	2.489	0.805	2.079

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.

III. RESULTS--THE FOLLOWING WAS CONDENSED FROM TABLES I THROUGH V

A. Leak Tests--No leaks indicated before or after testing.

B. Average Capacity (ampere-hours, AH):

Type of Charge	AH Out
C/20, 48 hrs. RA	3.94
C/10, 24 hrs. RA*	3.67
C/10, 24 hrs. 20°C**	3.77

*Cells 1, 2 and 3 removed from charge due to high pressure.
**All cells exceeded requirement of 1.480 volts during charge.

C. Average Internal Resistance Measurements (milliohm):

Measurement Taken	Resistance
30 min. before end of charge (Cycle 1)	7.64
1 hr. after start of discharge (Cycle 2)	8.18
2 hrs. after start of discharge (Cycle 2)	8.12

D. Twenty-four hour average cell voltage following a 16-hour short period was 1.156 volts.

E. Average capacity out following the 20°C charge efficiency test was 0.84, which represents 48% efficiency and is less than the minimum requirement of 55%.

F. Average capacity out following the 0°C and 35°C overcharge tests was 3.52 and 2.12 respectively. All cells exceeded the requirement of 1.520 volts during the 0°C test and two cells were removed from charge during the 35°C test because of high pressure and one cell did not meet the requirement of capacity out.

G. During the pressure versus capacity test, all the cells were removed from charge when their voltage reached 1.550, with an average capacity input of 4.78 ampere-hours. Three cells reached a pressure of 8 psia during charge and there was no pressure decay exhibited during the one-hour OCV stand following the charge. The ampere-hours out on discharge ranged from 3.44 to 3.66.

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 (R.A.), Cycle 0, with a test limit of 1.52 volts or pressure of 100 psia.

b. C/10, 24 hours, R.A., 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 Cycle 1.

C. Internal Resistance:

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

D. 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.

E. 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 were then discharged and the requirement was that the minimum capacity out equal 55 percent of capacity in during the preceding charge.

F. 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 a cell voltage of 1.56 or greater for a continuous time period of 2 hours or a pressure 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.

G. 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 then are discharged with a requirement that capacity out equal 55 percent capacity out as obtained in discharge Cycle 3.

H. 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.

TABLE I

SERIAL NUMBER	WEIGHT (Grams) *	HEIGHT (Inches)	LENGTH (Inches)	WIDTH (Inches)	PHENOLPHTHALEIN LEAK TESTS											
					Initial				Following Hi Vac				Following Test Completion			
					Terminals		Fill Tube	Other	Terminals		Fill Tube	Other	Terminals		Fill Tube	Other
					+	-			+	-			+	-		
361	169.0	2.470	.803	2.081												
364	168.1	2.512	.806	2.085												
369	168.0	2.498	.809	2.085				NO	LEAKS							
379	167.7	2.492	.802	2.071												
383	167.6	2.475	.805	2.075												
* w/o PRESSURE TRANSDUCERS																
							4									

TABLE II
CAPACITY CHECK DATA

SERIAL NUMBER	FIRST CAPACITY CHECK						SECOND CAPACITY CHECK						THIRD CAPACITY CHECK (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)
361	1.452	N/A	53	3.91	N/A	18	1.466	N/A	101*	3.58	N/A	62	1.467	N/A	83	3.73	N/A	61
364	1.450	↓	43	3.94	↓	26	1.450	↓	94*	3.60	↓	57	1.469	↓	61	3.76	↓	42
369	1.450	↓	39	3.90	↓	24	1.447	↓	94*	3.63	↓	61	1.471	↓	73	3.75	↓	55
379	1.450	↓	32	3.97	↓	18	1.437	↓	90	3.73	↓	58	1.466	↓	61	3.78	↓	44
383	1.451	↓	33	3.97	↓	18	1.443	↓	76	3.79	↓	43	1.475	↓	53	3.83	↓	33

* THESE CELLS REMOVED FROM CHARGE WITH 6.0–6.5 AH INPUT.

** ALL CELLS EXCEEDED 1.48 VOLTS DURING CHARGE.

y vacuum ile pt

TABLE III
INTERNAL RESISTANCE AND SHORT TEST DATA

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
361	8.0	8.4	8.6	.014	1.155	33
364	7.4	8.5	8.0	.008	1.157	22
369	7.5	7.8	7.8	.011	1.154	31
379	7.8	8.2	8.4	.009	1.162	19
383	7.5	7.8	7.8	.004	1.151	15

TABLE IV
CHARGE EFFICIENCY AND OVERCHARGE DATA

SERIAL NUMBER	CHARGE EFFICIENCY (20°C)						OVERCHARGE TEST (0°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)	CAPACITY (ah)*	AUX ELECT (Volts)	PRESS (PSIA)	** CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPACITY (ah)	AUX ELECT (Volts)	*** PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPACITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)
361	1.376	N/A	N/A.	.83	N/A	22	1.516	N/A	42	3.53	N/A	32	1.390	N/A	93	1.86	N/A	94
364	1.376	↓	↓	.86	↓	21	1.542	↓	38	3.65	↓	31	1.392	↓	93	2.10	↓	92
369	1.376			.83		24	1.523		41	3.50		33	1.392		95	2.10		92
379	1.375			.83		19	1.565		38	3.41		17	1.392		93	2.10		93
383	1.375			.86		18	1.580		36	3.53		16	1.395		93	2.46		84
AH IN	1.74						9.04						3.25 TO 3.95					

N.A – NOT AVAILABLE

* CELLS 1,2,44 REVERSED (-.18 TO -.22 VOLTS)

** CELLS 4 & 5 OFF (AH = 5.3) DUE TO HIGH VOLTAGE.

*** ALL CELLS OFF BECAUSE OF HIGH PRESSURE.

TABLE V
PRESSURE VS. CAPACITY TEST DATA

Serial No.	361	364	369	379	383											
Start-of-Charge, Press.	0	0	2	0	4											
AH in to 5 PSIA	4.93	↓	4.76	↓	4.16											
Cell (volts)	1.550	↓	1.538	↓	1.481											
Aux (volts)	↓	↓	↓	↓	↓											
AH in to 10 PSIA	↓	↓	↓	↓	↓											
Cell (volts)	↓	↓	↓	↓	↓											
Aux (volts)	↓	↓	↓	↓	↓											
AH in to 15 PSIA	↓	↓	↓	↓	↓											
Cell (volts)	↓	↓	↓	↓	↓											
Aux (volts)	↓	↓	↓	↓	↓											
AH in to 20 PSIA	↓	↓	↓	↓	↓											
Cell (volts)	↓	↓	↓	↓	↓											
Aux (volts)	↓	↓	↓	↓	↓											
AH in to V/L (1.55V)	4.93	4.87	4.87	4.78	4.48											
Aux (volts)	N/A	N/A	N/A	N/A	N/A											
Press (PSIA)	5	4	8	4	8											
30 Min OCV, Cell	1.396	1.392	1.391	1.388	1.388											
Aux (volts)	N/A	N/A	N/A	N/A	N/A											
Press (PSIA)	8	5	8	4	8											
1 hour OCV, Cell	1.386	1.383	1.382	1.380	N.A.											
Aux (volts)	N/A	N/A	N/A	N/A	N/A											
Press (PSIA)	8	5	8	4	8											
EOD AH out *	3.66	3.66	3.63	3.60	3.44											
Aux (volts)	N/A	N/A	N/A	N/A	N/A											
Press (PSIA)	8	5	8	4	8											

N.A. - NOT AVAILABLE

* CELLS 4 & 5 REVERSED (-.174 & -.147 VOLTS)