Marshall Space Flight Center Battery Activity

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Marshall Space Flight Center

NASA Battery Workshop
Alabama Space and Rocket Center
Huntsville, AL
November 17, 1992

Outline:

-- Flight Program History

-- In-House Activities:

Hubble Space Telescope Testing

Other Testing

C-2

MSFC Flight Program History

Program Name	Launch Date	Time of Operation	Regime	Battery Type	Capacity	Cell Manuf.	Battery Manuf.	Remarks
Explorer 1 3 4	 2/58 3/58 7/58	 4 mos. 3 mos. 4 mos.	 LEO LEO LEO	 Ni-Cd Ni-Cd Ni-Cd		 Sonotone Sonotone Sonotone		Explorer 1 -- First free-world satellite, solar array, and Ni-Cd battery power system
Pegasus 1 2 3	 2/65 5/65 7/65	 3+ yrs. 3+ yrs. 3+ yrs.	 LEO LEO LEO	 Ni-Cd Ni-Cd Ni-Cd		 Gulton ? Gulton ? Gulton ?		Three satellites with multi-battery SA/Ni-Cd system for large micro-meteroid satellite
Skylab ATM OWS	 5/73 5/73	 6 yrs. incl. 4 yrs. storage	 LEO LEO	 Ni-Cd Ni-Cd	 20 Ah 33 Ah	 GE EPI-J	 MSFC MDAC-E	First manned space station; two SA/Ni-Cd power systems (ATM & OWS) with total capability of >8 kW; operated in parallel; EPS reactivated after more than 4 years in "orbital storage"
HEAO 1 2 3	 8/77 11/78 9/79	 19 mos. 30 mos. 27 mos.	 LEO LEO LEO	 Ni-Cd Ni-Cd Ni-Cd		 SAFT-Amer. SAFT-Amer. SAFT-Amer.	 TRW TRW TRW	Three satellites with multi-battery SA/Ni-Cd power system built by TRW for MSFC; no battery failures

MSFC Flight Program History

Program Name	Launch Date	Time of Operation	Regime	Battery Type	Capacity	Cell Manuf.	Battery Manuf.	Remarks
HST	4/90	30 mos. (active)	LEO	Ni-H_2	88 Ah	EPI-J	EPI-J	First reported, non-experimental use of Ni-H_2 batteries in LEO; multi-battery SA/Ni-H_2 2.4 kW power system built by LMSC for MSFC; first flight-qualified BPRC (MSFC patent) developed for Ni-Cd batteries before change to Ni-H_2
CRRES	7/90	B1-5 mos. B2-15 mos.	MEO	Ni-Cd	15 Ah	GAB	Ford Aerospace	Battery 1 failed after 5 months of operation; battery 2 failed after 15 months of operation; excessive on-orbit overcharge likely major contributor to failures
AXAF-I *	~1999		Elliptical	TBD	30 Ah	TBD	TBD	TRW is the prime contractor for this effort
AXAF-S *	~1999		Polar	TBD	TBD	TBD	TBD	This is an MSFC in-house project

* – *Planned flights*

MSFC Secondary Battery / Cell Testing Summary

Hubble Space Telescope Support:

Test Name	Cell Manufacturer	Cell Type	Capacity	Completed Cycles	Regime	%DOD	# of Cells
Type 40 Battery 1 *[1]	EPI-J	Ni-Cd RSN55	55 Ah	23211	LEO	13 - 16	22
Type 40 Battery 2 *[2]	EPI-J	Ni-Cd RSN55	55 Ah	6641	LEO	13 - 16	22
Type 41 *[4]	EPI-J	Ni-Cd RSN55	55 Ah	25891	LEO	13 - 16	22
GE Battery *[3]	GE	Ni-Cd	50 Ah	23872	LEO	13 - 16	22
Six Battery System *[5]	EPI-J	Ni-Cd RSN55-15	55 Ah	21856	LEO	13 - 16	132
Six Four-Cell Packs [6]	EPI-J	Ni-Cd RSN55-15	55 Ah	30803	LEO	13 - 16	24
Fourteen-Cell Pack	EPI-J	Ni-H_2 RNH30-1	30 Ah	31860	LEO	6 - 9	14
Three Four-Cell Packs	EPI-J	Ni-H_2 RNH90-3	90 Ah	20992	LEO	6 - 9	12
Six Battery System	EPI-J	Ni-H_2 RNH90-3	90 Ah	19012	LEO	6 - 9	132
Flight Spare Battery	EPI-J	Ni-H_2 RNH90-3	90 Ah	18581	LEO	6 - 9	22

* – *Test has been terminated*
1 – *First cell failure at 14 months*
2 – *First cell failure at 14 months; DPA showed excessive cadmium migration*
3 – *Cell divergence at >14,000 orbits; >100 mV at 19,000 orbits; capacity as low as 30 Ah*
4 – *Cell divergence at >10,000 orbits; capacity as low as 20 Ah*
5 – *Built with reject positive plates; met system reqt. of 36 Ah/battery thru 4 yrs.; had cell short in B3 at 18,300 orbits*
6 – *Cells from flight battery lots; continues to meet system reqt. after 5½ yrs.*

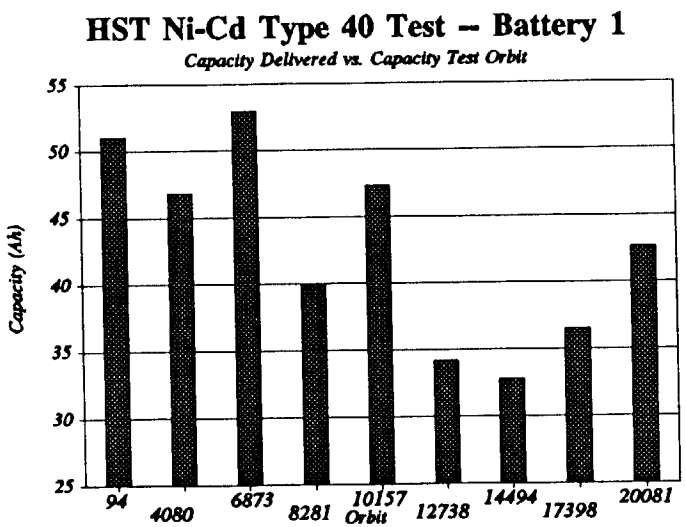
MSFC Secondary Battery / Cell Testing Summary

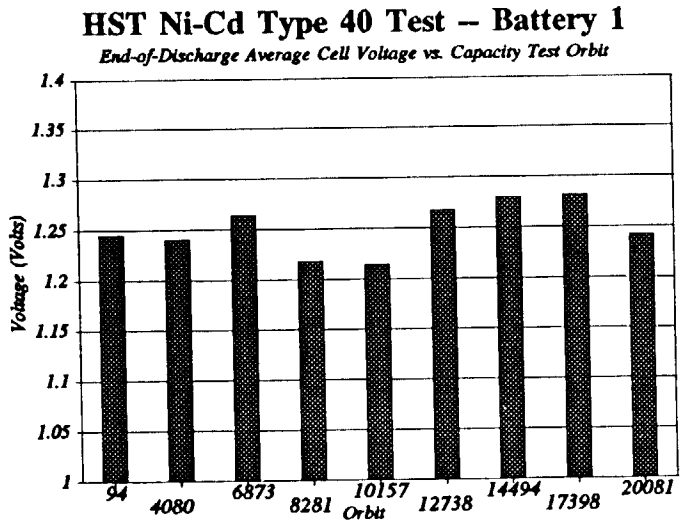
Other Testing:

Test Name	Cell Manufacturer	Cell Type	Capacity	Completed Cycles	Regime	%DOD	# of Cells
Twelve-Cell Pack	EPI-J	Ni-H_2 RNH35-3	33 Ah	22080	LEO	22	12
Four Four-Cell Packs	EPI-J	Ni-H_2 RNH90-3	90 Ah	71	Elliptical	30	16
Reconditioning	EPI-J	Ni-H_2 RNH90-3	90 Ah	6265	LEO	30	8
Parametric Tests	EPI-J	Ni-MH RMH10-1	10 Ah				24
AXAF-S Ni-MH	EPI-J	Ni-MH RMH10-1	10 Ah		LEO		8
SEDS / UAH	EPI-J	Ni-MH RMH10-1	10 Ah		LEO		22
SEDS Satellite	EPI-J	Ni-MH RMH10-1	10 Ah		LEO		22

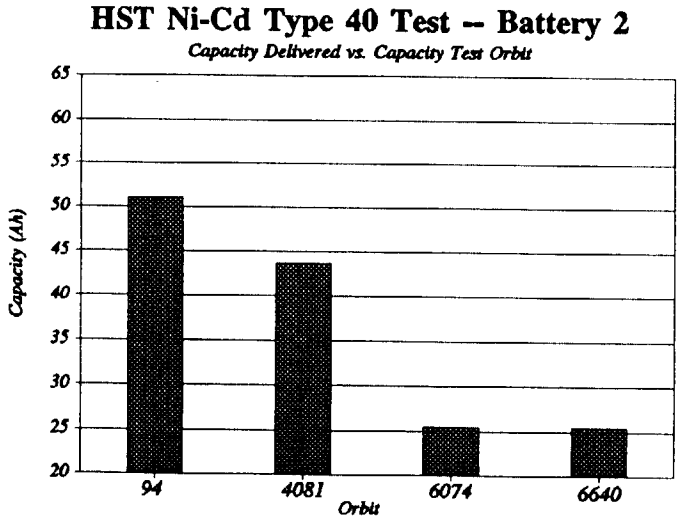
Hubble Space Telescope Test Data Update -- Type 40 Battery 1

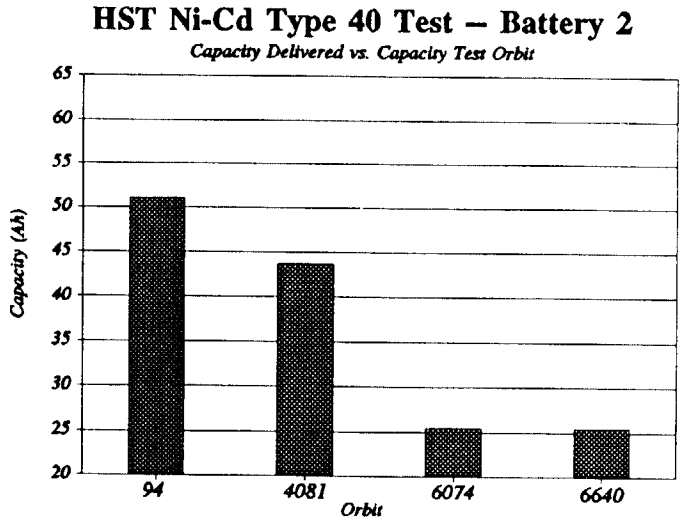
Two 22-cell Ni-Cd type 40 baseline HST batteries were placed on test in April, 1983. These batteries along with the type 41 battery were used to evaluate the longevity and applicability of these early designs to HST mission requirements.





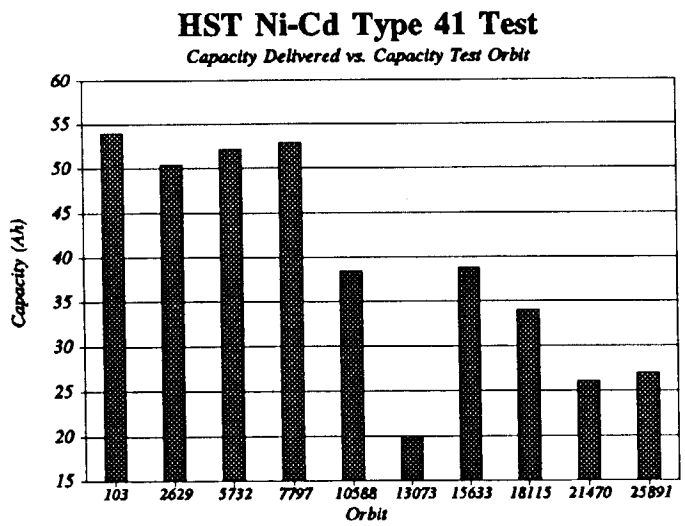
Hubble Space Telescope Test Data Update -- Type 40 Battery 2

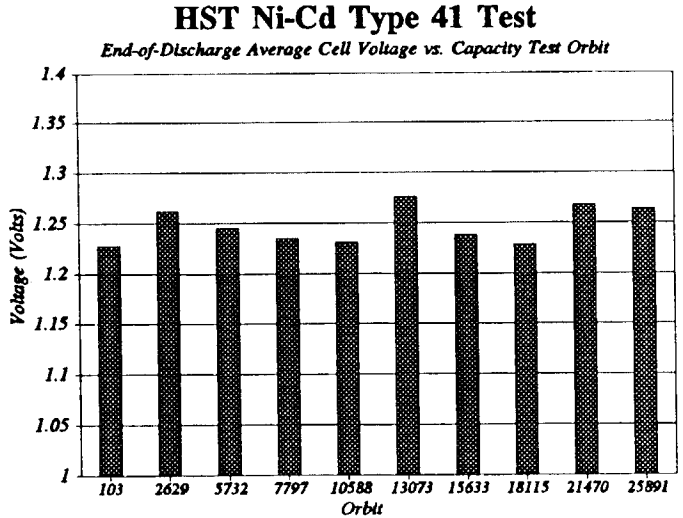




Hubble Space Telescope Test Data Update -- Type 41 Battery

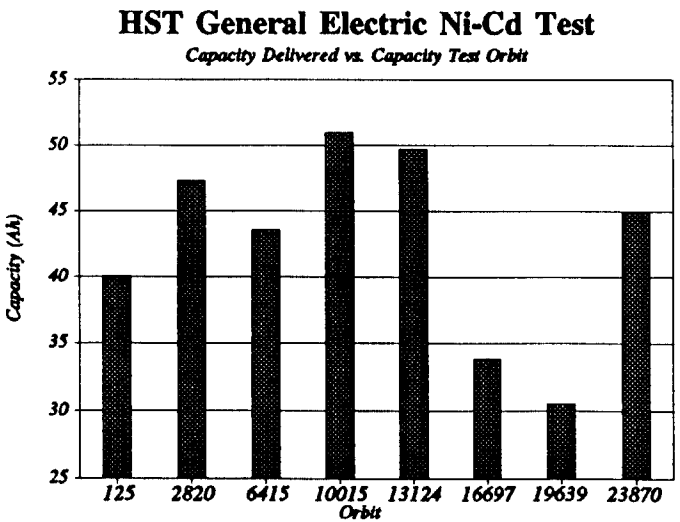
A 22-cell Ni-Cd type 41 battery incorporating improvements on the type 40 design were placed on test in February, 1984. This battery was one of three early-design batteries that were tested in support of the HST.

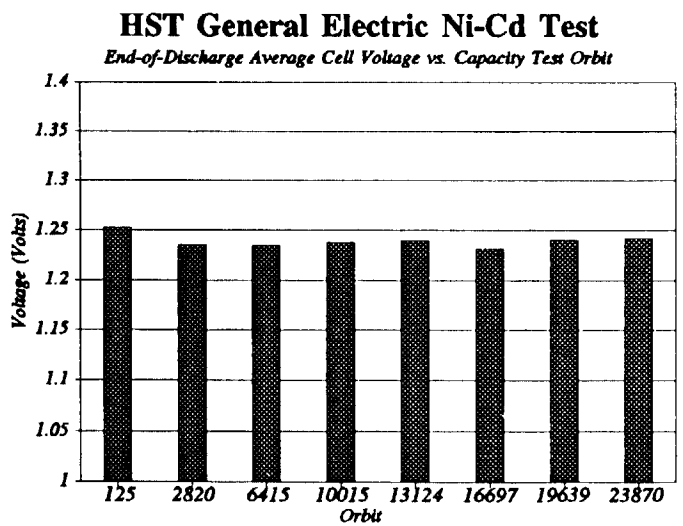




Hubble Space Telescope Test Data Update -- General Electric Battery

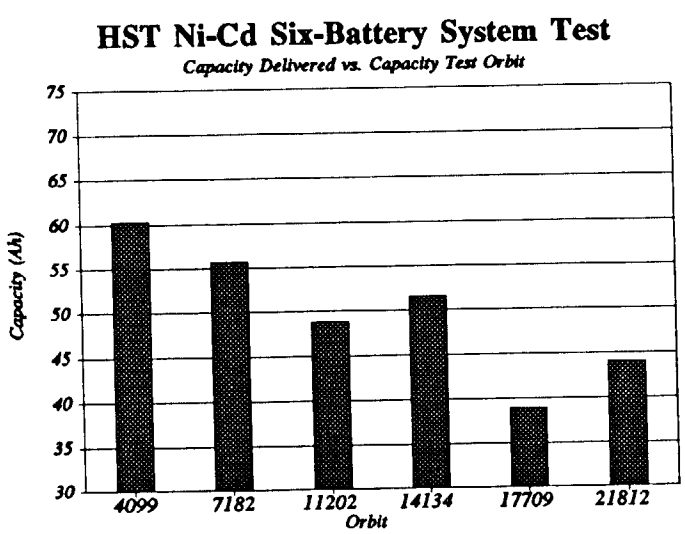
A 22-cell Ni-Cd battery made up of 50 Ah General Electric cells were placed on test in May, 1986. This battery was used to evaluate the longevity and applicability of this design to HST mission requirements.

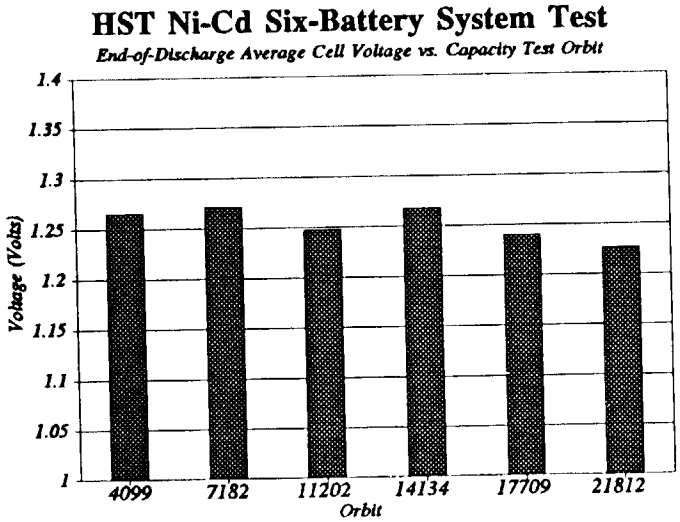




Hubble Space Telescope Test Data Update -- Ni-Cd Six-Battery System

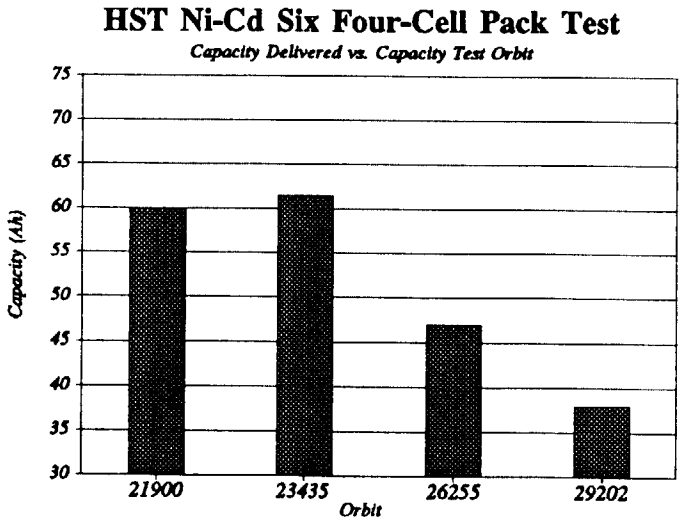
A Ni-Cd six-battery electrical power system simulation began in April, 1986, utilizing six 22-cell type 44 batteries configured for flight including being equipped with a battery protection and reconditioning circuit. These batteries cycled for 21855 cycles demonstrating fully the capability of this Ni-Cd cell to meet HST mission requirements. The test terminated when the batteries failed to meet the capacity requirement.

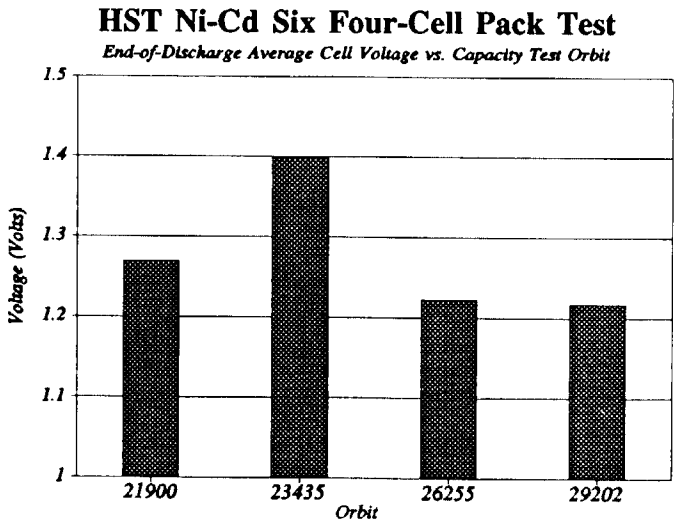




Hubble Space Telescope Test Data Update -- Six Four-Cell Packs

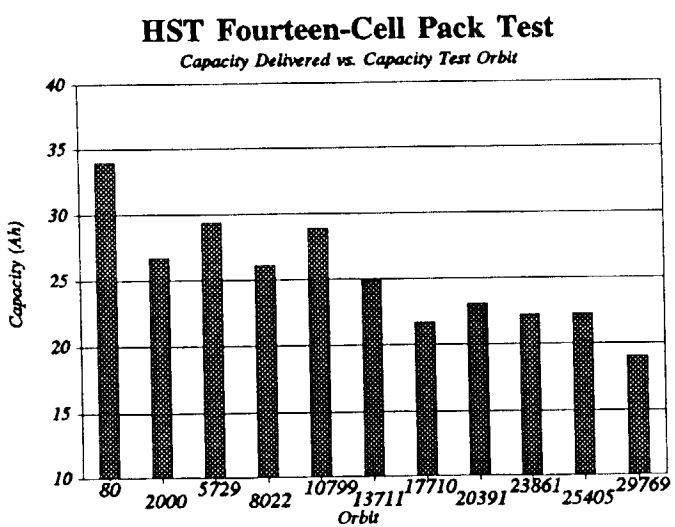
Six, 4-cell packs of type 44 cells were placed on test at MSFC in October, 1990. These cells had been cycling at Lockheed in a parallel test to the Ni-Cd six-battery system test being run at MSFC. When the contract that provided funding to operate this test terminated, the cells were moved to MSFC where they have continued cycling to a point that far exceeds their original program requirements. They have currently completed 30803 cycles.

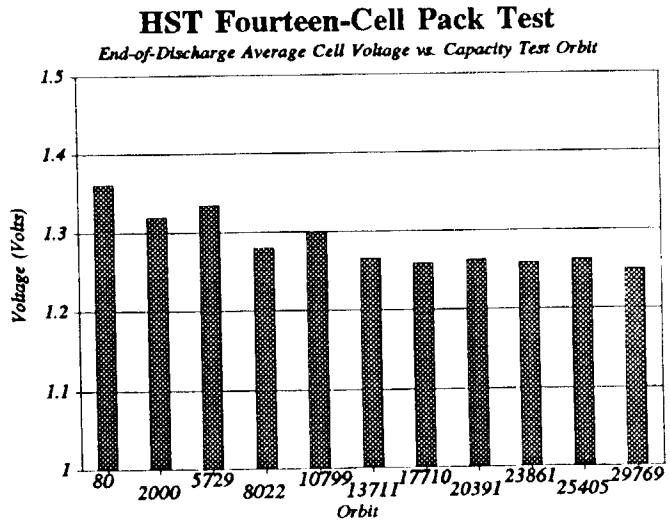




Hubble Space Telescope Test Data Update -- Fourteen-Cell Pack

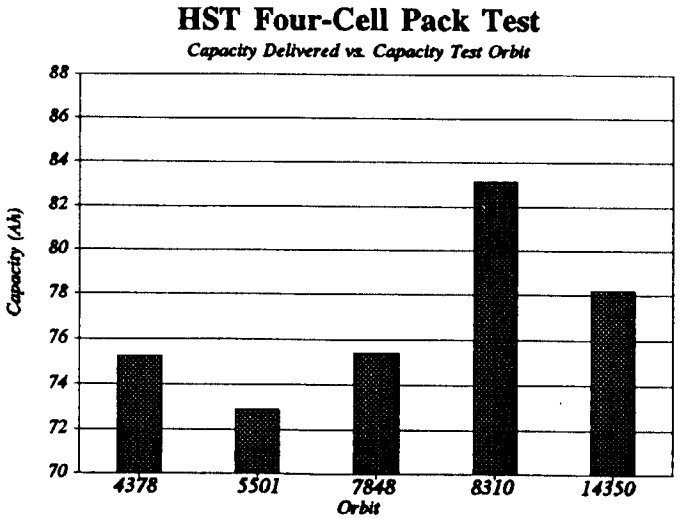
Fourteen 30 Ah Ni-H_2 cells of COMSAT design were placed on test in 1986 in the first Ni-H_2 test bed established for the HST program at MSFC. These cells were used to gather preliminary data on the operation of Ni-H_2 cells in a LEO profile in anticipation of a decision to fly Ni-H_2 cells on the HST. The cells will continue to cycle indefinitely according to current test parameters to enhance the database for Ni-H_2 LEO operation at shallow depths of discharge. They have currently completed 31860 cycles.

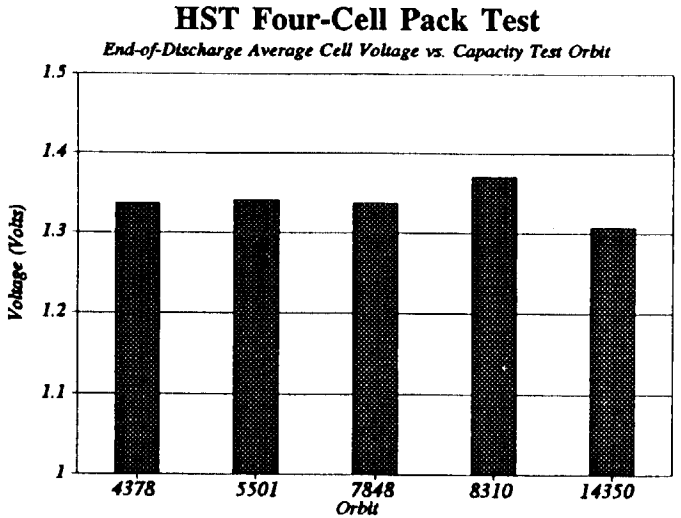




Hubble Space Telescope Test Data Update – Three Four-Cell Packs

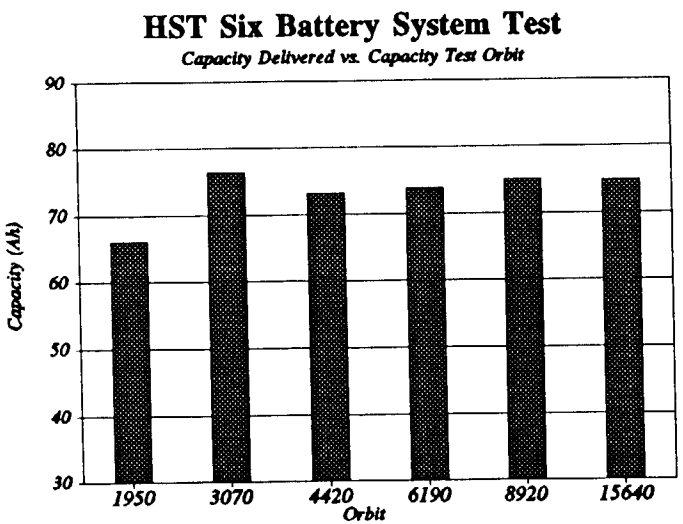
Three four-cell packs comprised of FSM, TM1, and TM2 cells were placed on test in March 1989, November 1988, and February 1989, respectively, and are operating on a simulated HST LEO profile. The packs provided early data on the performance of HST Ni-H_2 cells being charged on the VT curve already in place for use on the HST. These cells have been used extensively in parametric and investigative testing and will continue to be used primarily for that purpose. They have currently completed 20992 cycles.

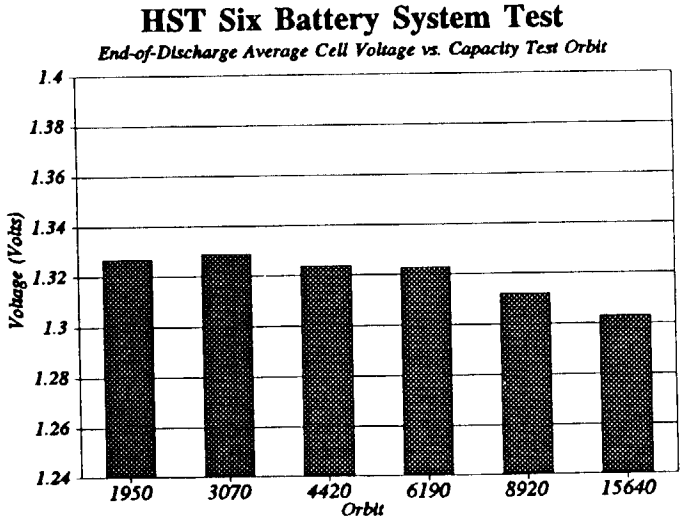




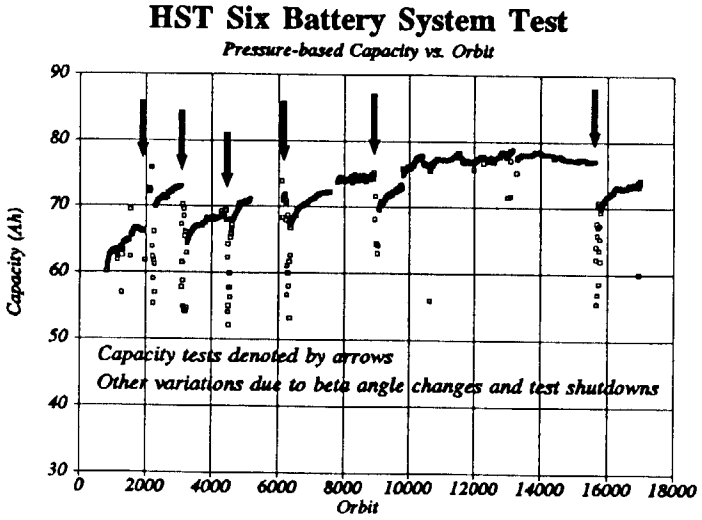
Hubble Space Telescope Test Data Update -- Ni-H_2 Six-Battery System

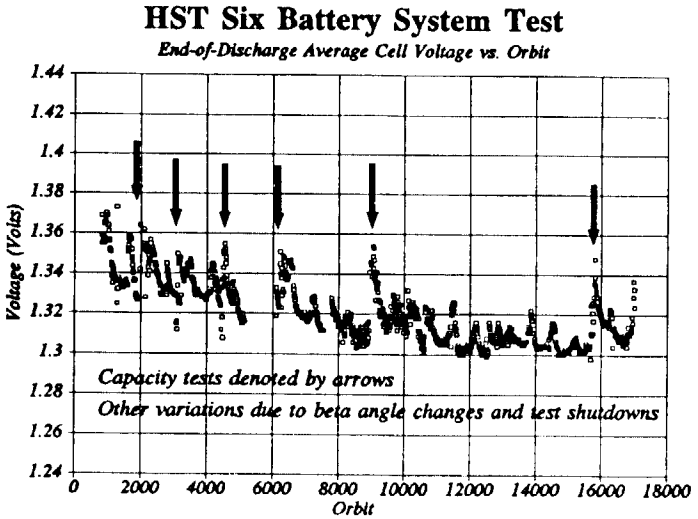
A Ni-H_2 six-battery electrical power system (EPS) simulation began in May, 1989, utilizing TM1 and TM2 modules configured for flight. Solar panel assemblies were simulated with power supplies, the electrical loads with load banks, and the flight computer with a system control computer. This test is to provide information on the operation of the HST EPS by simulating the expected mission profile of the HST and will continue to operate for an indefinite period of time in support of the HST. They have currently completed 19012 cycles.





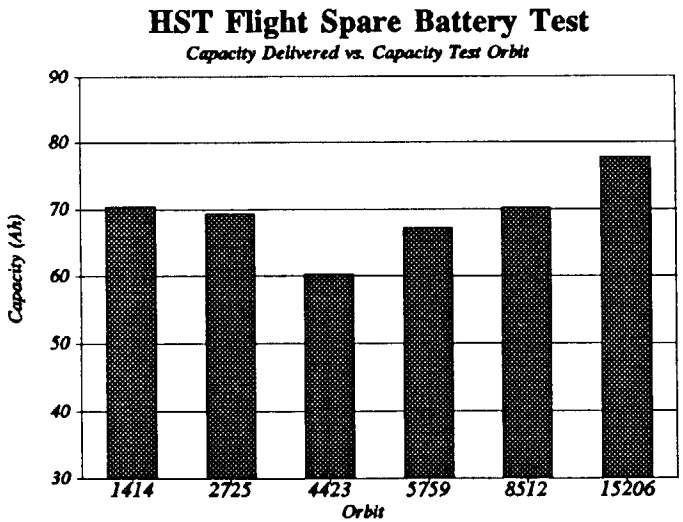
Hubble Space Telescope Test Data Update -- Ni-H_2 Six-Battery System

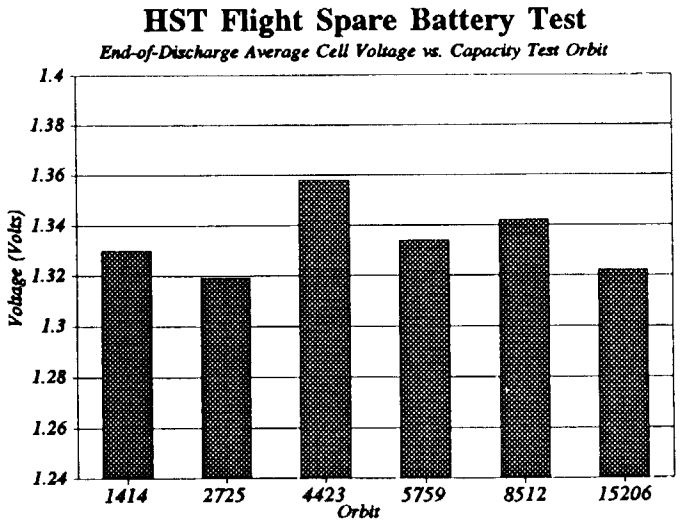




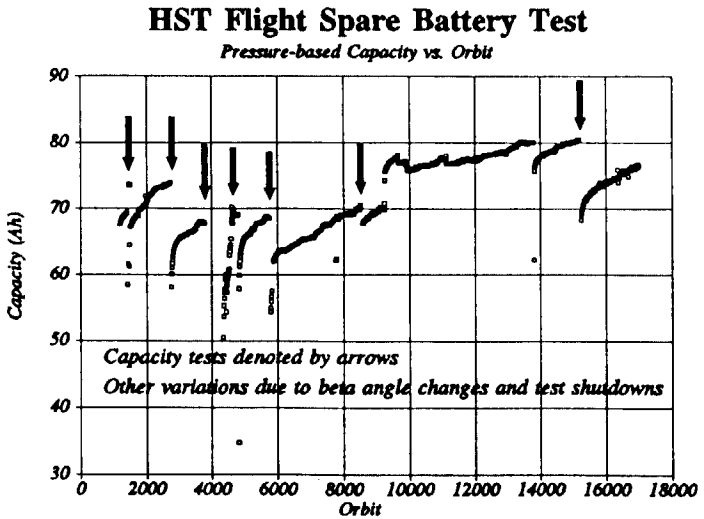
Hubble Space Telescope Test Data Update -- Flight Spare Battery

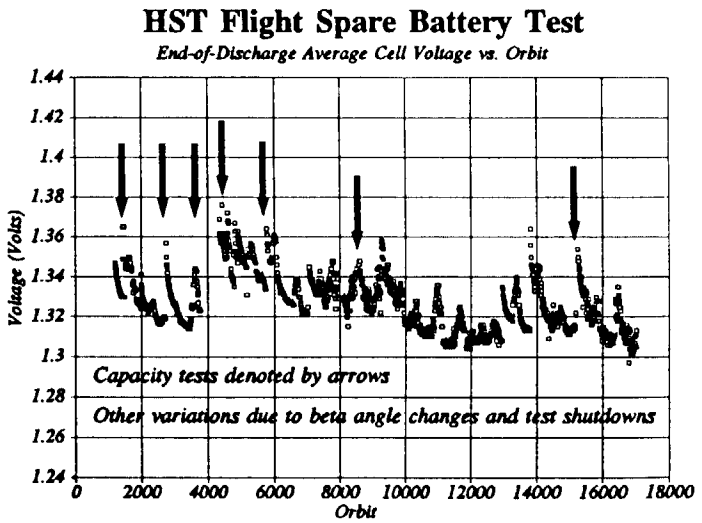
One 22-cell Ni-H_2 battery comprised of flight spare module cells was placed on test in June, 1989, to serve as a life test article for the HST flight cells. Operation of this battery test is similar to that of the six-battery system test in that an accurate mission simulation is desired. Plans for this test are to continue to operate for an indefinite period of time in support of the HST. It has currently completed 18581 cycles.





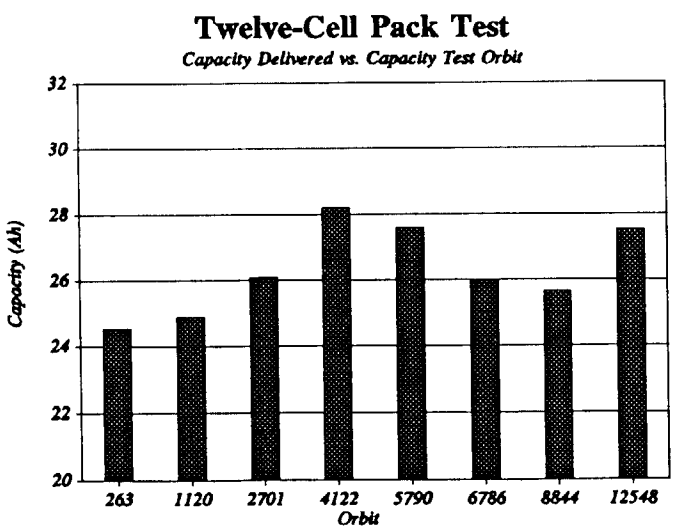
Hubble Space Telescope Test Data Update -- Flight Spare Battery

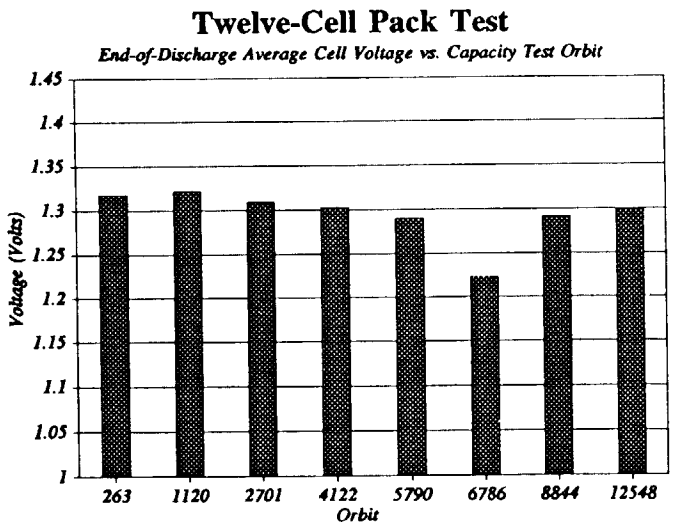




General Test Data Update -- Twelve-Cell Pack

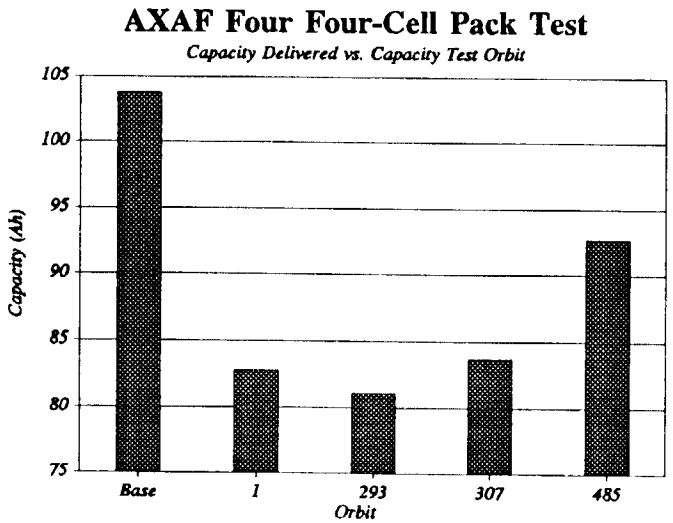
Twelve 33 Ah Ni-H_2 cells of Air Force design were placed on test in May, 1988. These cells are currently cycling to a 22% DOD based on their 33 Ah nameplate capacity and charging with a taper charge at constant voltage. These cells cycled initially for over 2 years using an HST LEO profile. Since the profile change, the cells have cycled nearly an additional 2 years.





General Test Data Update -- Four Four-Cell Packs

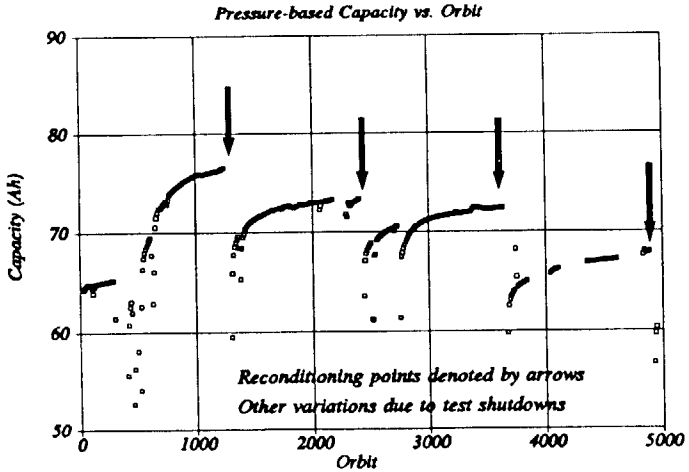
Four four-cell Ni-H_2 packs comprised of HST FM1 and FSM cells were placed on test in June, 1991, and are following as closely as possible to the AXAF-I cycle profile (elliptical orbit). This testing will provide early information about the behavior of Ni-H_2 cells during long periods of trickle charge. These cells were previously LEO cycled for one year following the original AXAF cycle profile. The data below reflects capacity tests run during that period of LEO cycling.



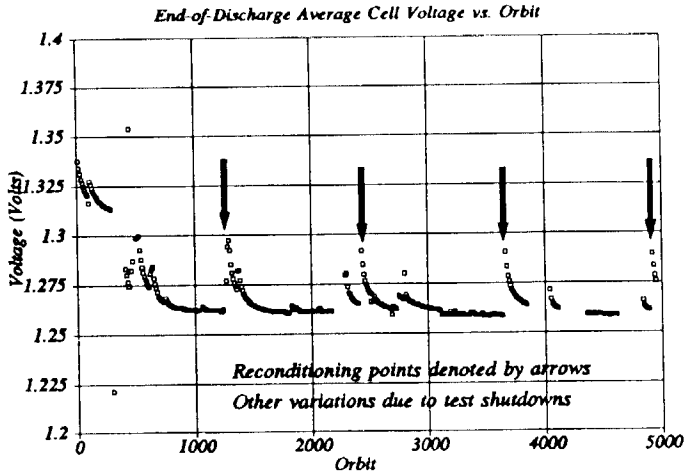
General Test Data Update -- Reconditioning Test

Two four-cell Ni-H_2 packs comprised of HST TM1 and FM2 cells were placed on test in June, 1991, and are studying the effects of reconditioning on Ni-H_2 cells. Another objective is to enhance the capabilities to perform Destructive Physical Analyses (DPA) at MSFC. One pack will cycle with no reconditioning while the other will cycle identically but with quarterly reconditionings. A control cell will be DPA'd uncycled with cycled cells being reconditioned after 12,000 and 20,000 cycles.

Two Four-Cell Pack Reconditioning Test -- Pack 1

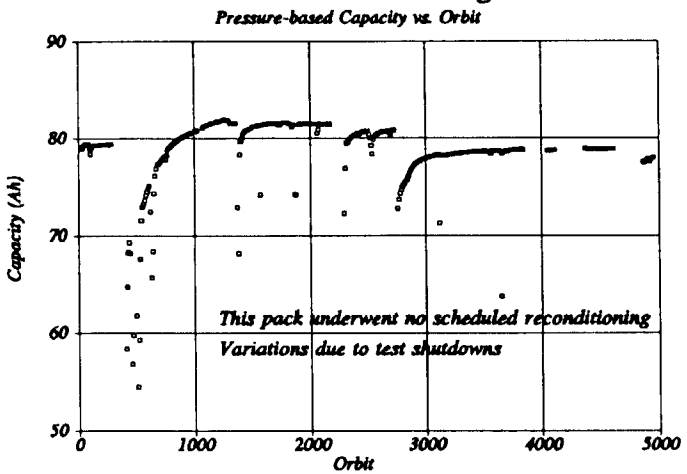


Two Four-Cell Pack Reconditioning Test -- Pack 1

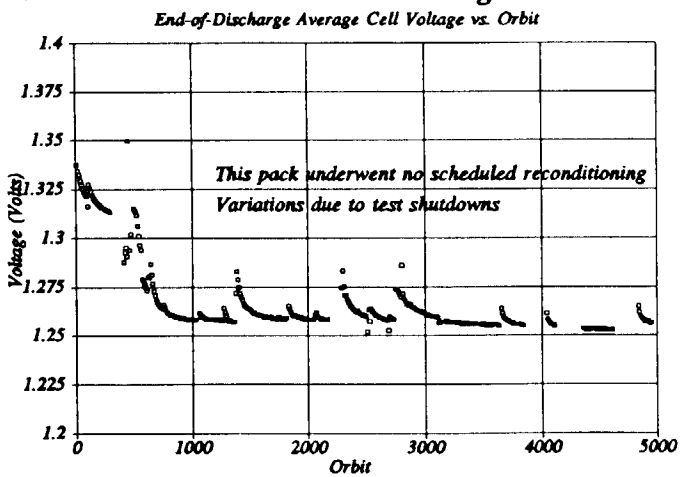


General Test Data Update -- Reconditioning Test

Two Four-Cell Pack Reconditioning Test -- Pack 2



Two Four-Cell Pack Reconditioning Test -- Pack 2



General Test Data Update -- Planned Ni-MH Testing

-- Parametric tests using 10 Ah EPI RMH10-1 cells shall be conducted to characterize the behavior of Ni-MH cells.

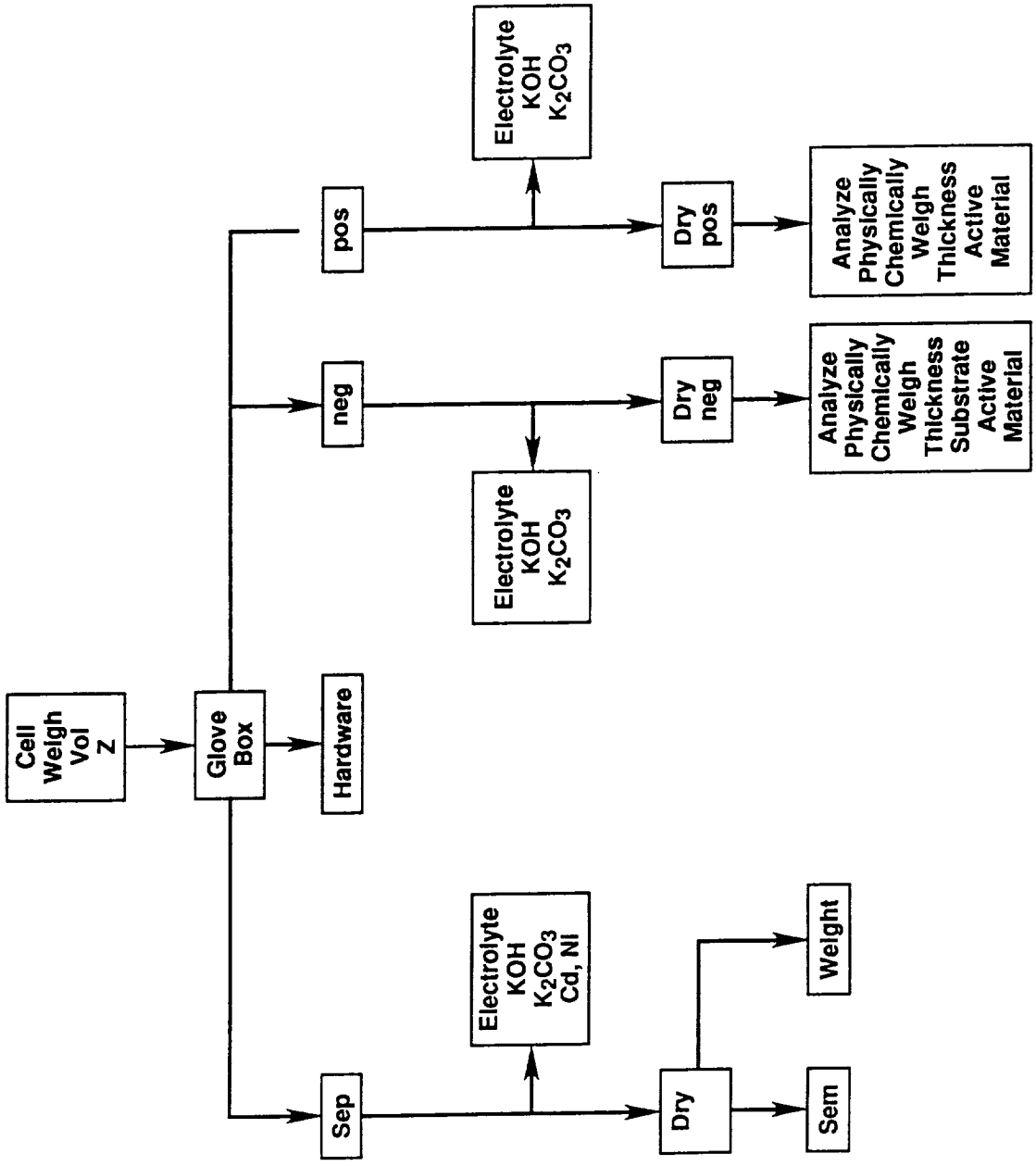
-- Eight 10 Ah EPI RMH10-1 cells shall be tested to investigate the applicability of Ni-MH cells to the AXAF-S mission.

-- A 22-cell 10 Ah EPI RMH10-1 battery is to be used as a test article in an EPS simulation for a small satellite.

-- A 22-cell 10 Ah EPI RMH10-1 battery is to be placed on a LEO satellite in a microgravity testing environment. This could be the first reported use of Ni-MH in a LEO satellite. Launch date is set for March, 1994.

An Update on the Marshall Space Flight Center DPA Facility

November 17, 1992


Cell
Weigh
Vol
Z
Glove
Box
Hardware
pos
neg
Sep
Electrolyte
KOH
K_2CO_3
Electrolyte
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K_2CO_3
Electrolyte
KOH
K_2CO_3
Cd, Ni
Dry
pos
Dry
neg
Dry
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Weigh
Thickness
Substrate
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Weight
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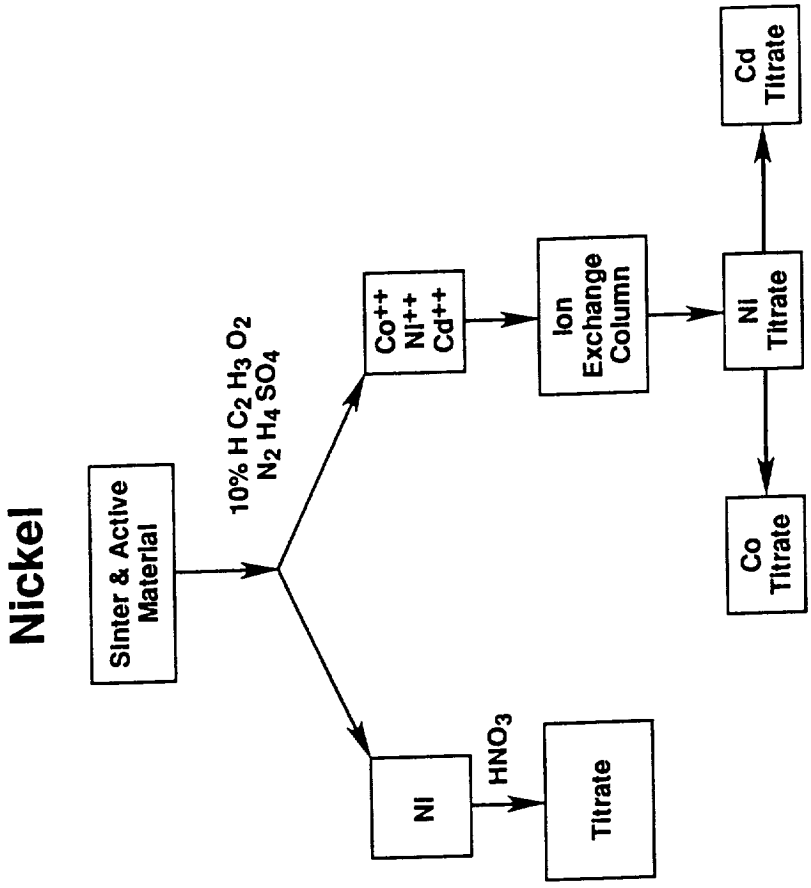
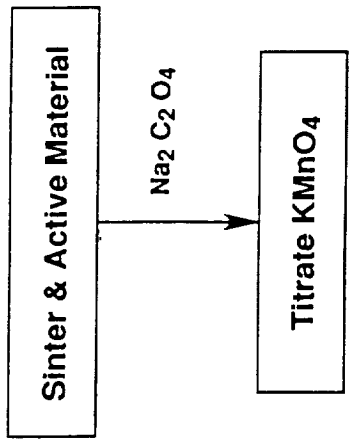
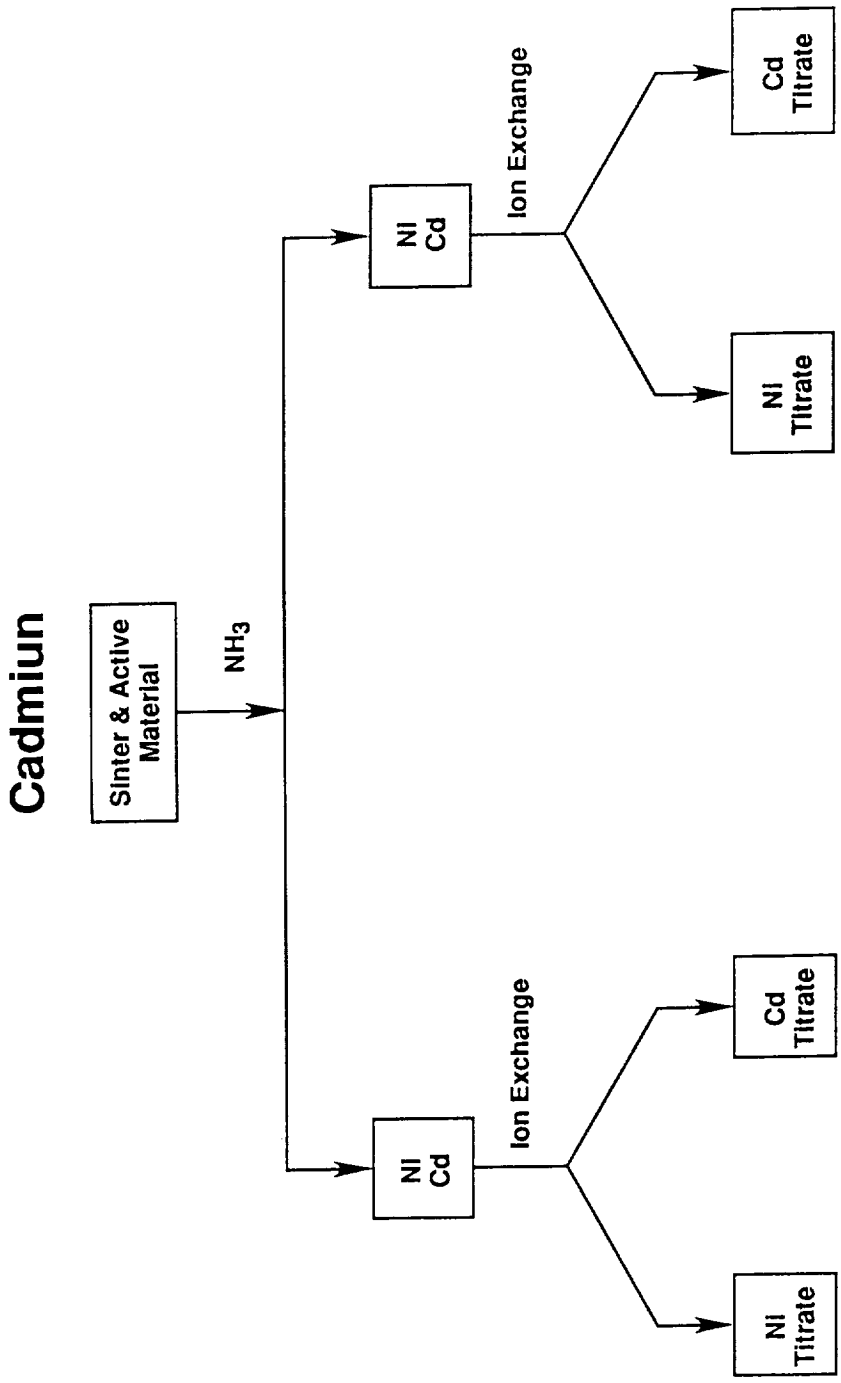
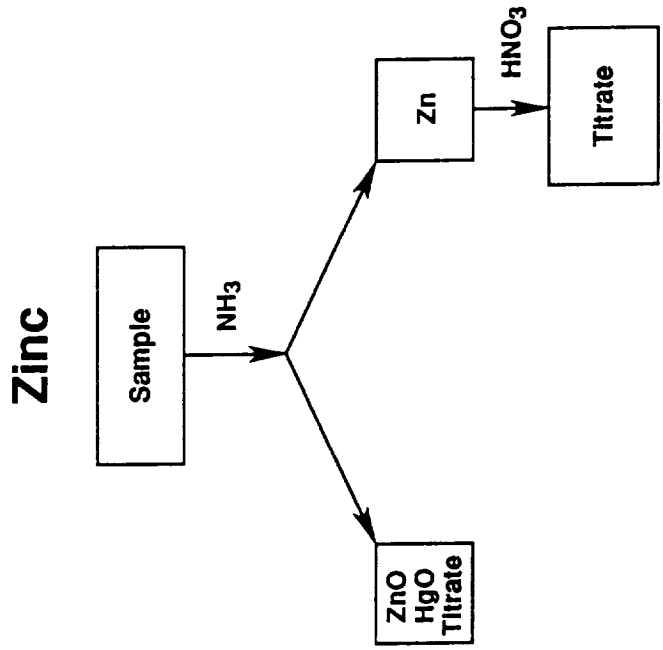
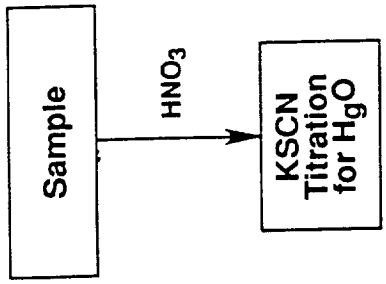
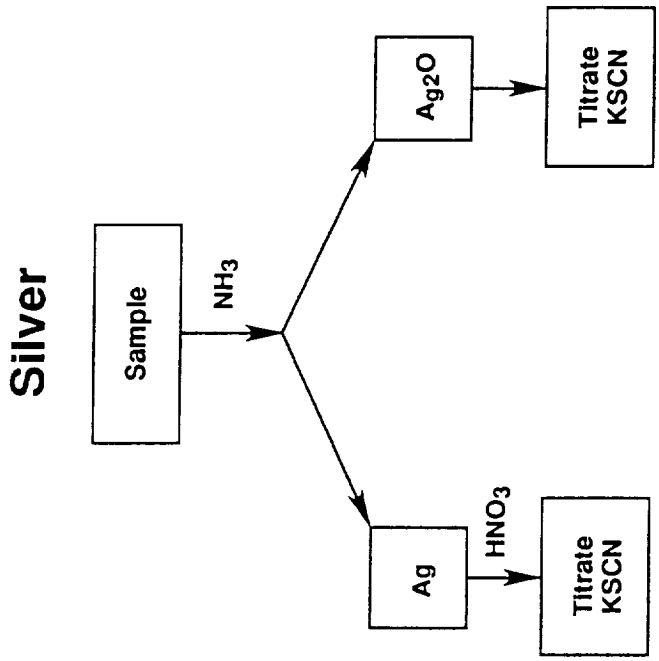

Nickel
Sinter & Active Material
10% H C_2 H_3 O_2
N_2 H_4 SO_4
Co^{++} Ni^{++} Cd^{++}
Ion Exchange Column
Ni Titrate
Cd Titrate
Co Titrate
Ni
HNO_3
Titrate


Sinter & Active Material
$Na_2 C_2 O_4$
Titrate $KMnO_4$


Cadmium
Sinter & Active Material
NH_3
Ni Cd
Ion Exchange
Cd Titrate
Ni Titrate
Ni Cd
Ion Exchange
Cd Titrate
Ni Titrate


Zinc
Sample
NH3
Zn
HNO3
Titrate
ZnO
HgO
Titrate


Sample
HNO_3
KSCN Titration for H_gO


Silver
Sample
NH_3
Ag_2O
Titrate KSCN
Ag
HNO_3
Titrate KSCN

Bottle	Sample Size (mg)	% HgO
024	452.9	1.13
038	402.9	1.01
090	408.4	.49
007	436.6	1.80

Ag-Zn	Ni-H2	Ni-Cd
9	1	25

NiCd DPA Summary

Type	Serial No.	Negative Charged Capacity	Prechg Ahrs	Ovrchg Protect Ahrs	History
RSN 55-15 (44)	189	20.50	20.50	19.40	100 acceptance cycles followed by storage
RSN 55-15 (44)	399	18.50	18.50	10.70	4 years activated storage followed by 444 LEO cycles
RSN 55-15 (44)	417	16.13	16.13	16.50	100 acceptance cycles followed by storage
RSN 55-15 (44)	438	21.60	21.60	19.70	4 yrs activated storage
RSN 55-15 (44)	440	20.02	20.02	22.50	4 yrs activated storage +128 LEO cycles
RSN 55-3 (41)	3	17.30	17.30	11.20	66 months activated storage
RSN 55-3 (41)	12	23.40	23.40	28.10	63 months activated storage
RSN 55-3 (41)	81	21.20	21.20	11.10	cycled 5 years
RSN 55-3 (41)	119	19.25	19.25		54 months activated storage
RSN 55-3 (41)	176	15.90	15.90	11.90	66 months activated storage
RSN 55-3 (41)	197	23.50	23.50		54 months activated storage
RSN 55-3 (41)	198	21.20	21.20	11.10	cycled 5 years
(40)	1399	15.80	15.80	1.97	cycled until the cells were badly deteriorated
(40)	1400	15.80	15.80	1.97	cycled until the cells were badly deteriorated
(40)	1406	15.80	15.80	1.97	cycled until the cells were badly deteriorated

NiCd DPA Summary

Type	Serial No.	Pos Plt. %Ni(OH)2 avg	Pos Plt. %Co(OH avg	Pos Plt. %NiOOH avg	Pos Plt. thickness avg (in.)	mg Cd Separ avg	mg Ni Separ avg	Positive Dischd Capacity	Positive Charged Capacity	Negative Dischd Capacity
RSN 55-15 (44)	189	48.62	3.37	5.40	0.0318	99.35	15.95	69.10	7.20	88.50
RSN 55-15 (44)	399	45.25	2.25	12.70	0.0300	152.60	8.95	70.60	14.98	81.30
RSN 55-15 (44)	417	49.57	3.27	5.47	0.0306	81.28	13.15	71.00	7.40	87.50
RSN 55-15 (44)	438	51.80	4.30	6.65	0.0297	63.90	3.95	64.20		83.90
RSN 55-15 (44)	440	46.60	3.90	11.35	0.0295	90.15	7.10	64.20	15.70	86.70
RSN 55-3 (41)	3	49.00	4.00	5.60	0.0286	136.00	8.73	76.30	5.62	87.50
RSN 55-3 (41)	12	49.00	2.20	5.40	0.0283	158.00		70.40	7.80	98.50
RSN 55-3 (41)	81	44.10	3.65	9.80	0.0302	117.24	9.70	71.30	14.70	82.40
RSN 55-3 (41)	119				0.0290					75.91
RSN 55-3 (41)	176	48.60	3.20	4.80	0.0282	145.70	20.30	73.80	6.80	85.70
RSN 55-3 (41)	197				0.0284					95.40
RSN 55-3 (41)	198	45.10	3.60	10.10	0.0301	129.40	8.80	71.30	14.70	82.40
(40)	1399	49.10	1.10	6.16	0.0311			70.93	9.62	72.90
(40)	1400	44.10	4.14	5.90	0.0314			70.93	9.62	72.90
(40)	1406	46.83	2.80	6.92	0.0310			70.93	9.62	72.90