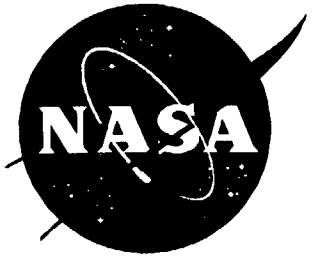


CRANE CELL TESTING SUPPORT OF NASA/GODDARD SPACE FLIGHT CENTER: AN UPDATE

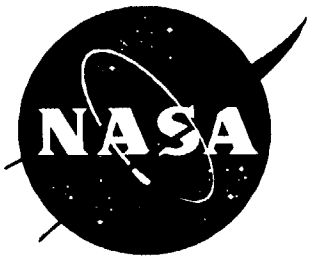
Mike Strawn and Jerry David

NAVSURFWARCENDIV, Crane, Indiana

Gopalakrishna M. Rao

NASA Goddard Space Flight Center

Greenbelt, Maryland



OBJECTIVE

- Verify the Quality and Reliability of aerospace battery cells and batteries for NASA flight programs
- Disseminate the data
  - to develop a Plan for in-orbit battery management
  - to Design a cell/battery for future NASA spacecraft
- Establish a cell test Data Base for rechargeable cell/batteries

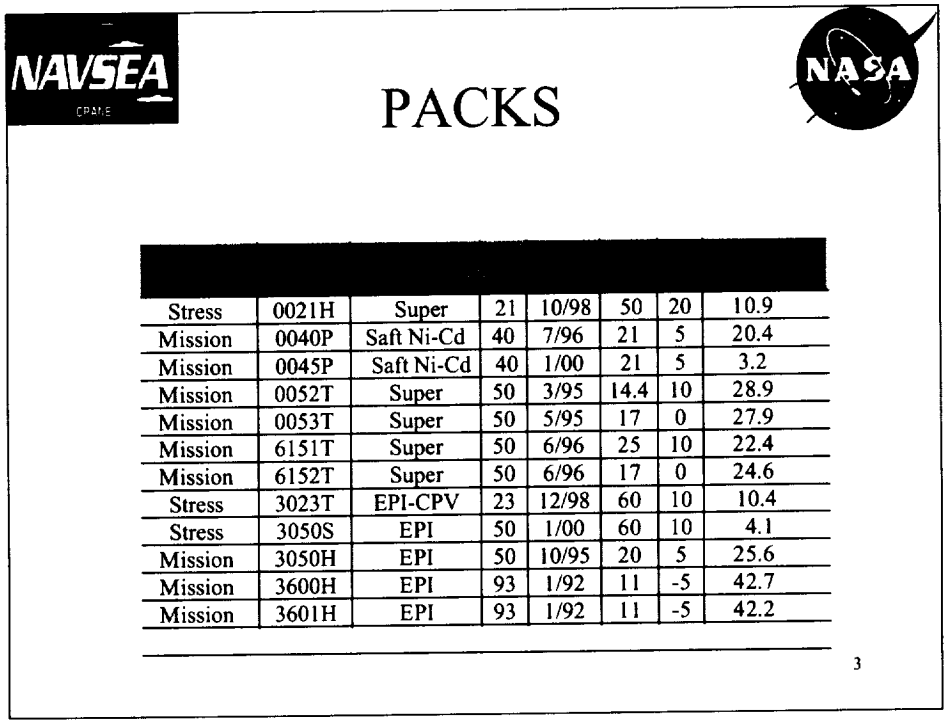


Chart above shows packs cycling at Crane associated with GSFC flight programs. There is a total of 12 project packs currently cycling. Nine of these are mission simulation regimes and three are in a stress test regime.

Charging techniques vary for each pack and are listed below:

A. Constant current with a V/T to a C/D ratio then trickle charge.

B. Constant current with a V/T.

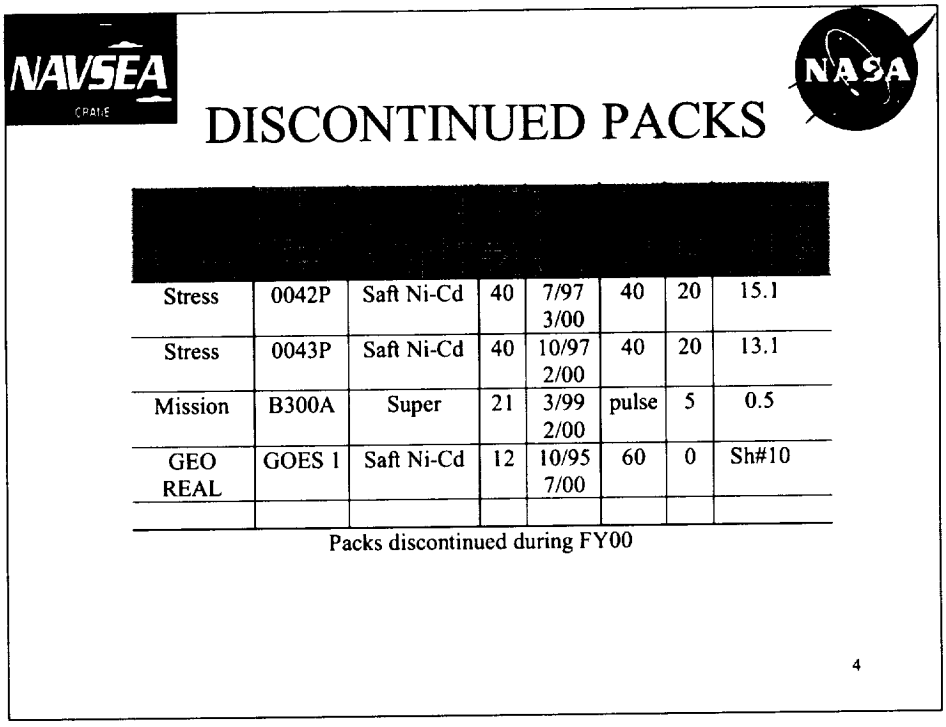
C. Constant current to specific voltage then trickle charge.

NAVSEA CRANE

PACKS

NASA

Stress	0021H	Super	21	10/98	50	20	10.9
Mission	0040P	Saft Ni-Cd	40	7/96	21	5	20.4
Mission	0045P	Saft Ni-Cd	40	1/00	21	5	3.2
Mission	0052T	Super	50	3/95	14.4	10	28.9
Mission	0053T	Super	50	5/95	17	0	27.9
Mission	6151T	Super	50	6/96	25	10	22.4
Mission	6152T	Super	50	6/96	17	0	24.6
Stress	3023T	EPI-CPV	23	12/98	60	10	10.4
Stress	3050S	EPI	50	1/00	60	10	4.1
Mission	3050H	EPI	50	10/95	20	5	25.6
Mission	3600H	EPI	93	1/92	11	-5	42.7
Mission	3601H	EPI	93	1/92	11	-5	42.2



There were 4 packs removed from testing in FY00

Pack B300A was an Image Project -- Super Ni-Cd -- Mission orbit -- 21Ah 60% DoD @ 0° C -- with 521 cycles at Shadow # 10

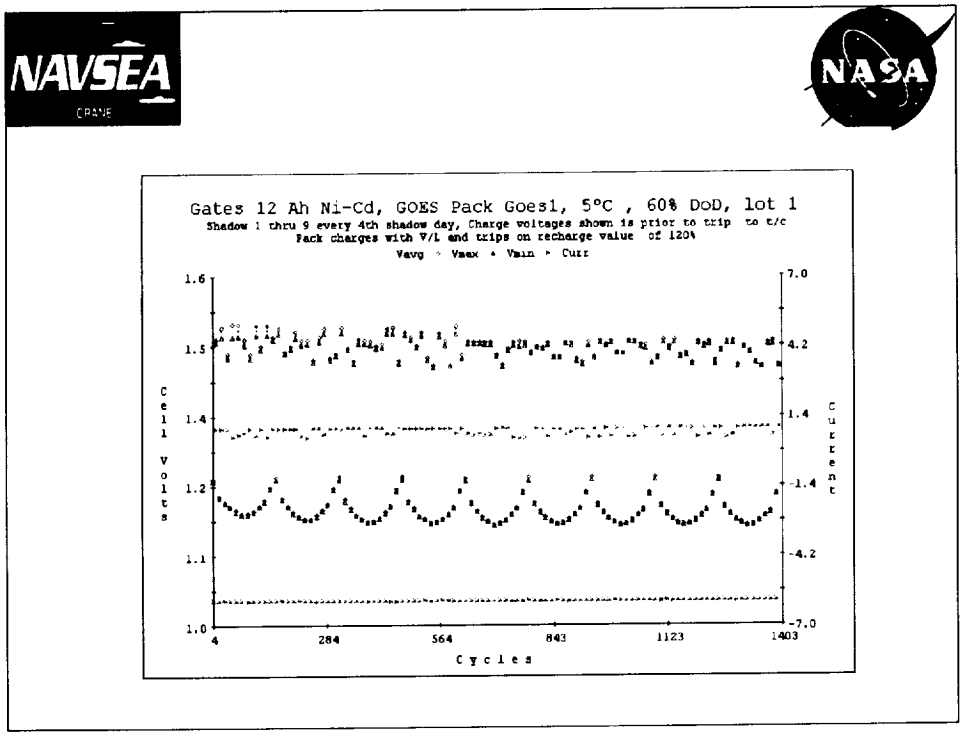
Pack 0043P and 0042 were a POES project -- SAFT Ni-Cd -- Stress test regime -- 40Ah 40% DoD @ 20° C -- with 13,129 cycles.

Pack GOES 1 - real time GOES GEO profile

DISCONTINUED PACKS

Stress	0042P	Saft Ni-Cd	40	7/97 3/00	40	20	15.1
Stress	0043P	Saft Ni-Cd	40	10/97 2/00	40	20	13.1
Mission	B300A	Super	21	3/99 2/00	pulse	5	0.5
GEO REAL	GOES 1	Saft Ni-Cd	12	10/95 7/00	60	0	Sh#10

Packs discontinued during FY00



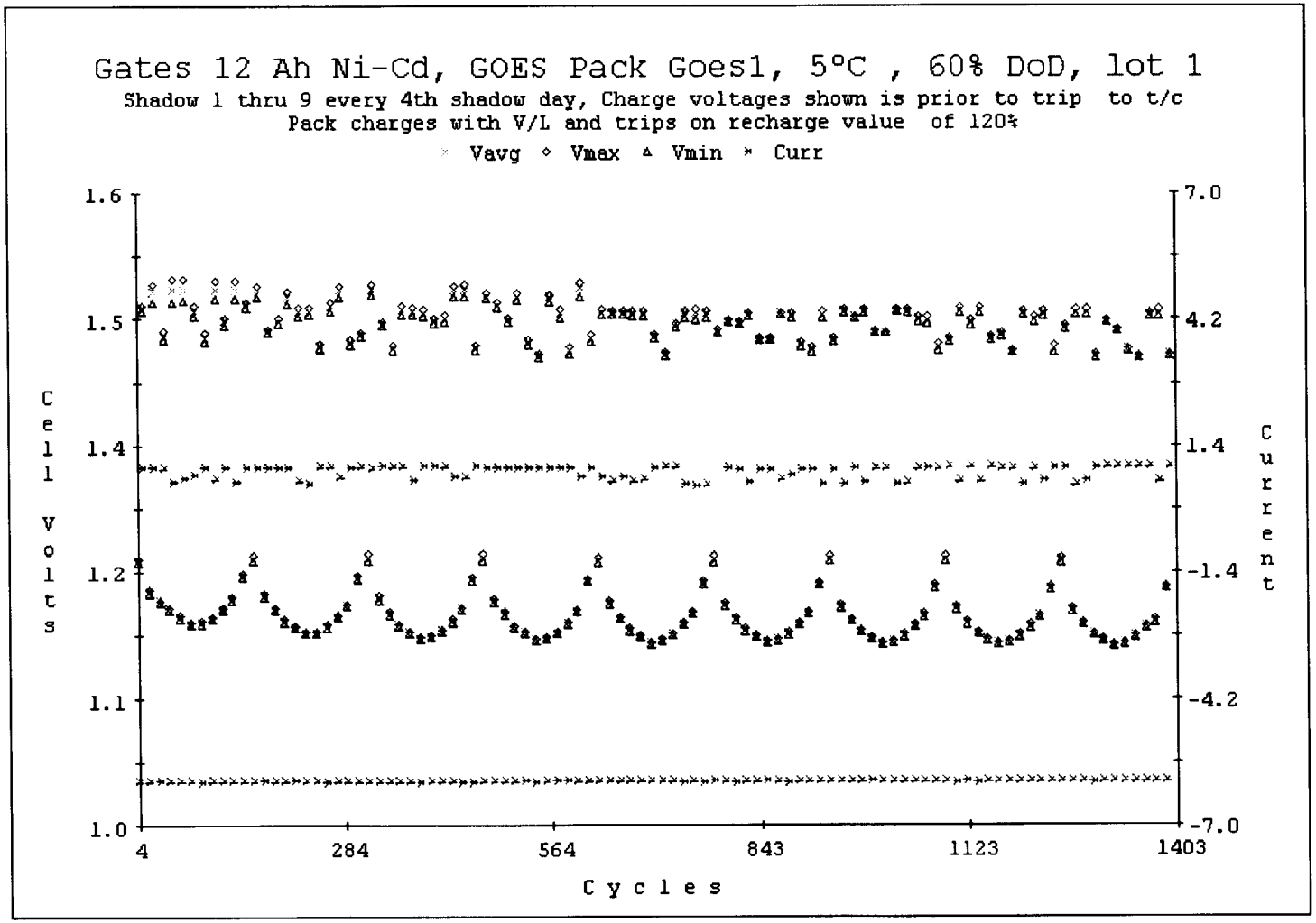
Pack consisted of five 12 Ah cells from lot 5. These cells were manufactured for the Geostationary Operational Environmental Satellite (GOES) project.

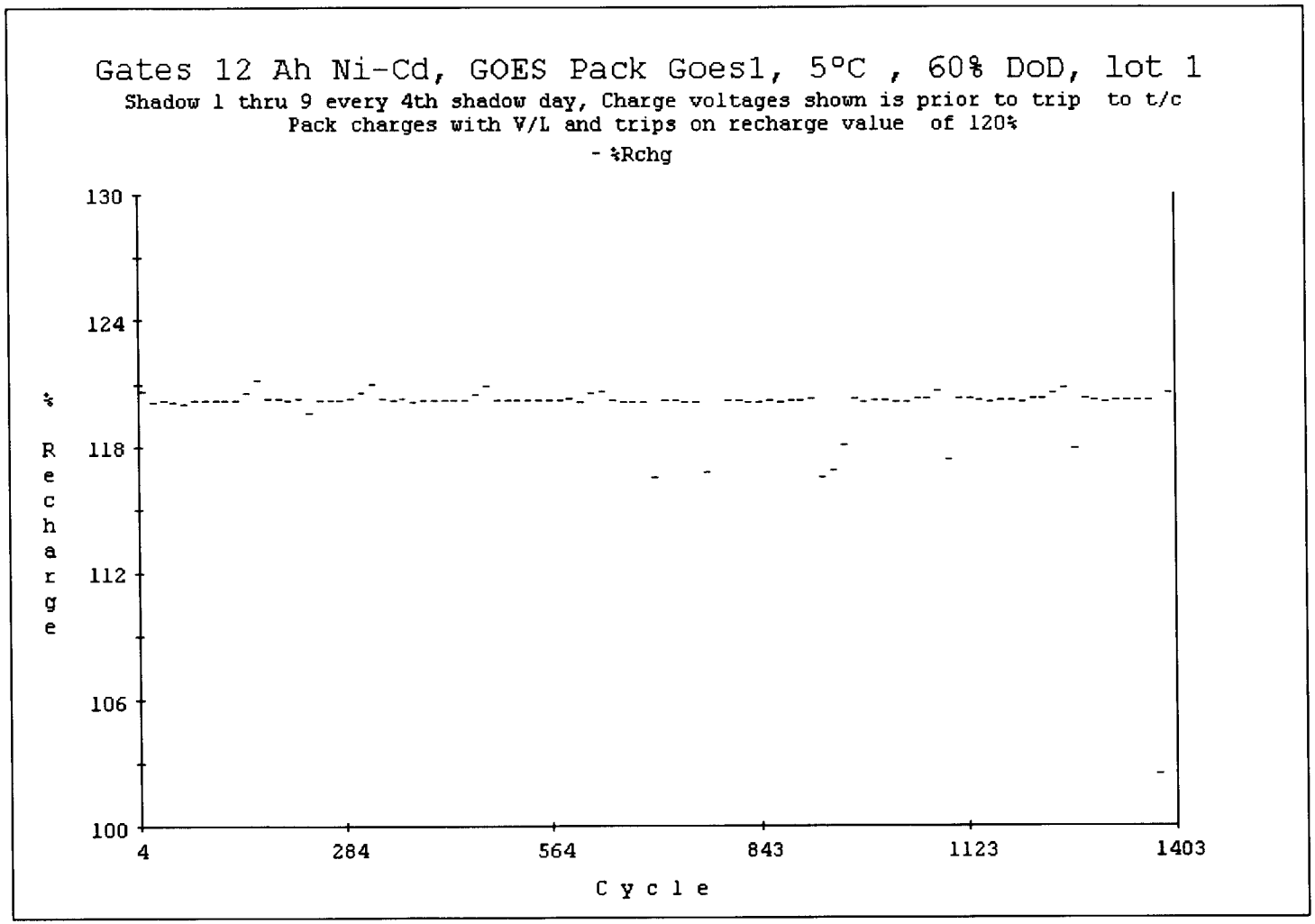
The objective of this testing was to verify the integrity of these cells in a real time GOES orbit. Particular attention is given to trends in the end-of-discharge (EOD) voltage, end-of-charge (EOC) current, charge to discharge ratios, and capacity degradation.

The cells were cycled according to a 42 day GEO 60% DoD real time (two shadows per year) orbit at 5° C GEO cycling regime. They are sequential recharge at .9 A (six minutes on, six minutes open circuit) with V/T of 1.508 V to 120% of Ah out of previous discharge. Then sequentially trickle charge at .3 A (six minutes on, 6 minutes open circuit) with V/T of 1.508 V for remainder of the twenty-four hour cycle.

NAVSEA
CRANE

NASA

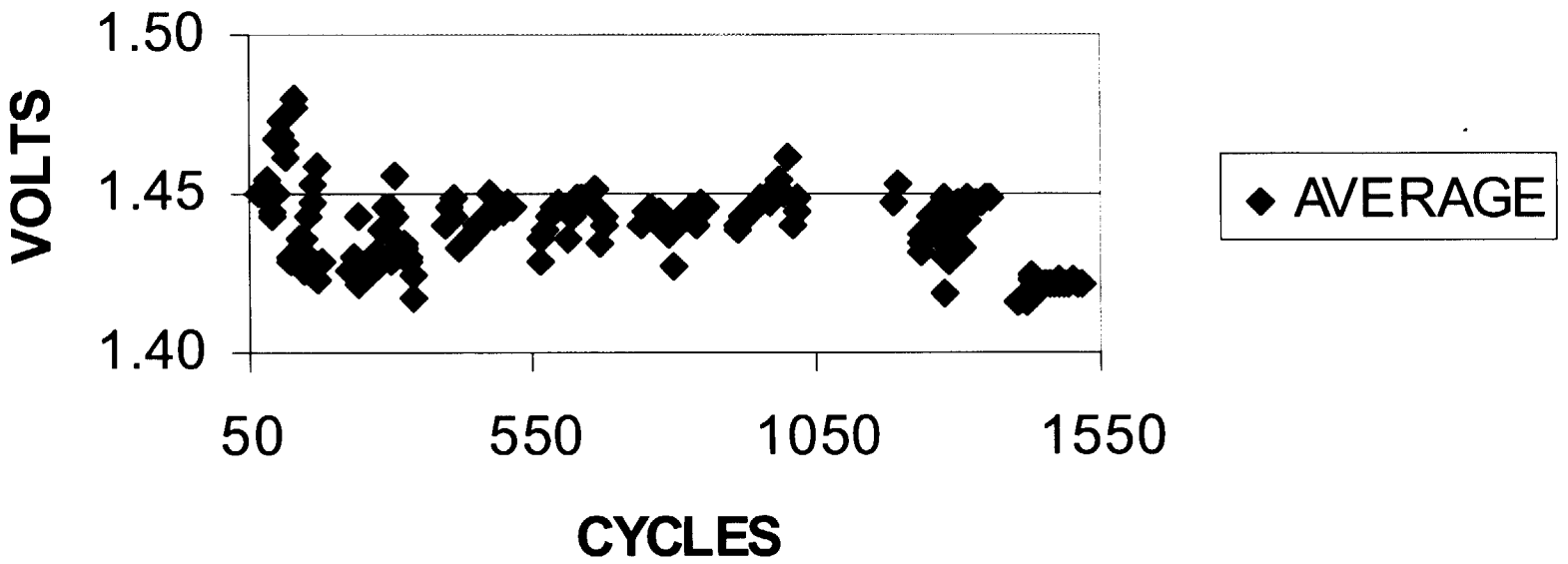


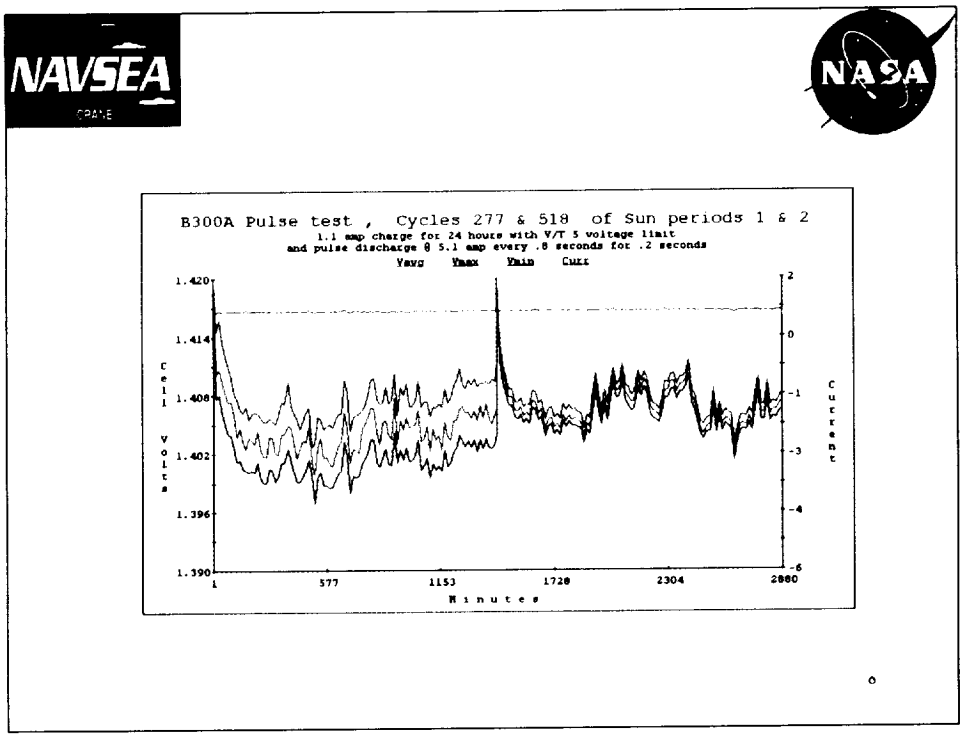

Gates 12 Ah Ni-Cd, GOES Pack Goes1, 5°C , 60% DoD, lot 1
Shadow 1 thru 9 every 4th shadow day, Charge voltages shown is prior to trip to t/c
Pack charges with V/L and trips on recharge value of 120%
- %Rchg
130
124
118
112
106
100
% Recharge
4
284
564
843
1123
1403
Cycle

NAVSEA
CRANE

NASA

GOES 1 DURING SUN PERIODS 1 - 9

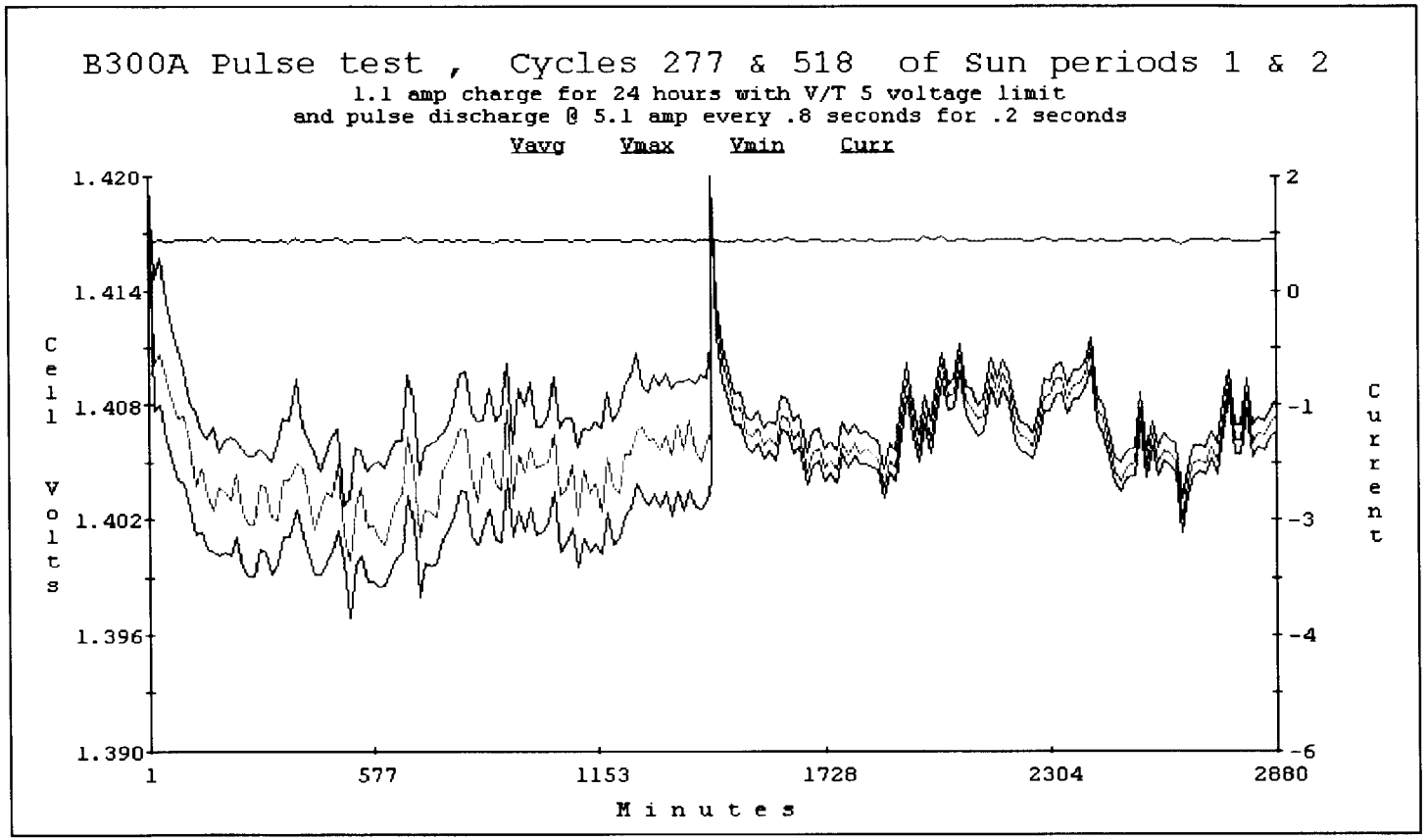


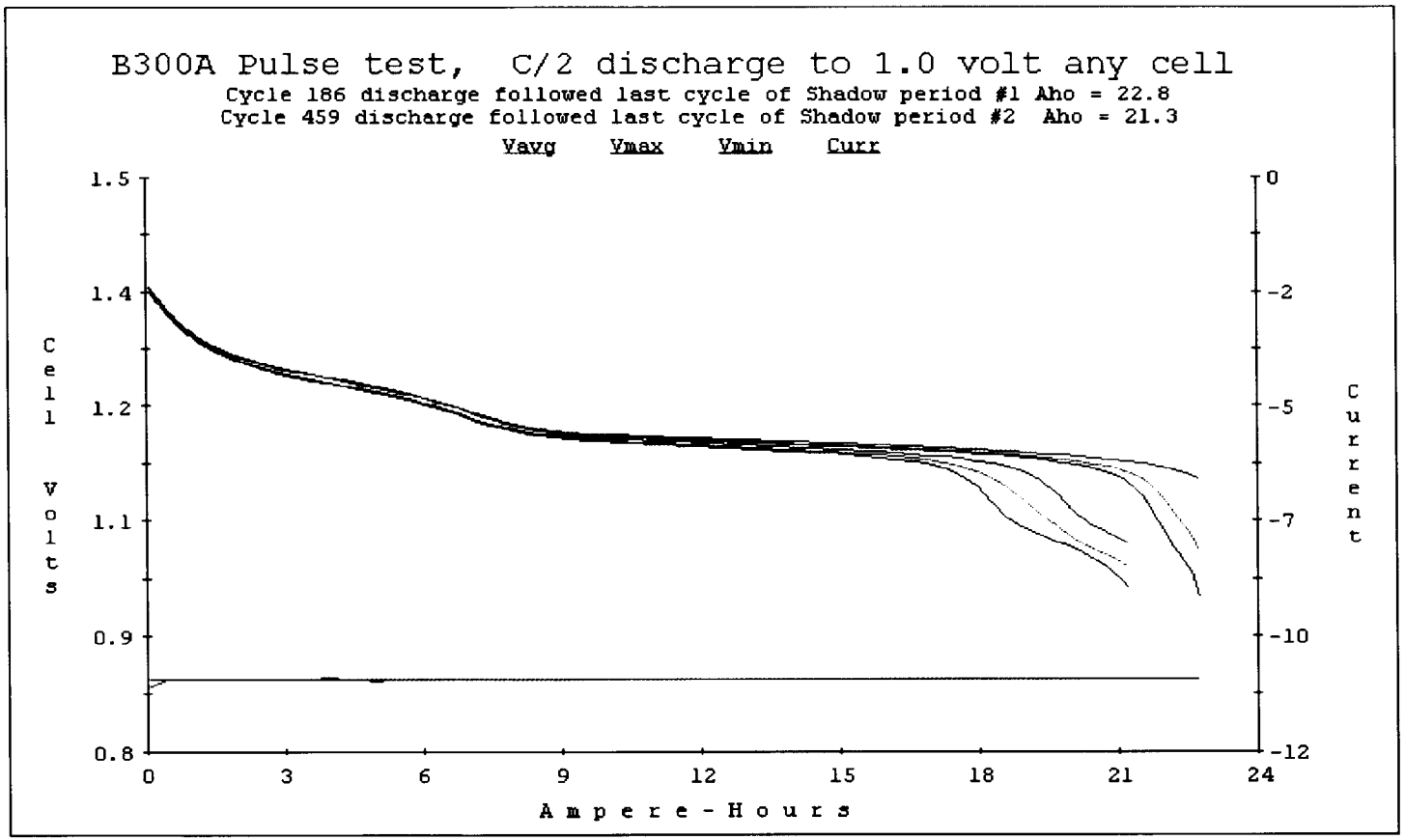


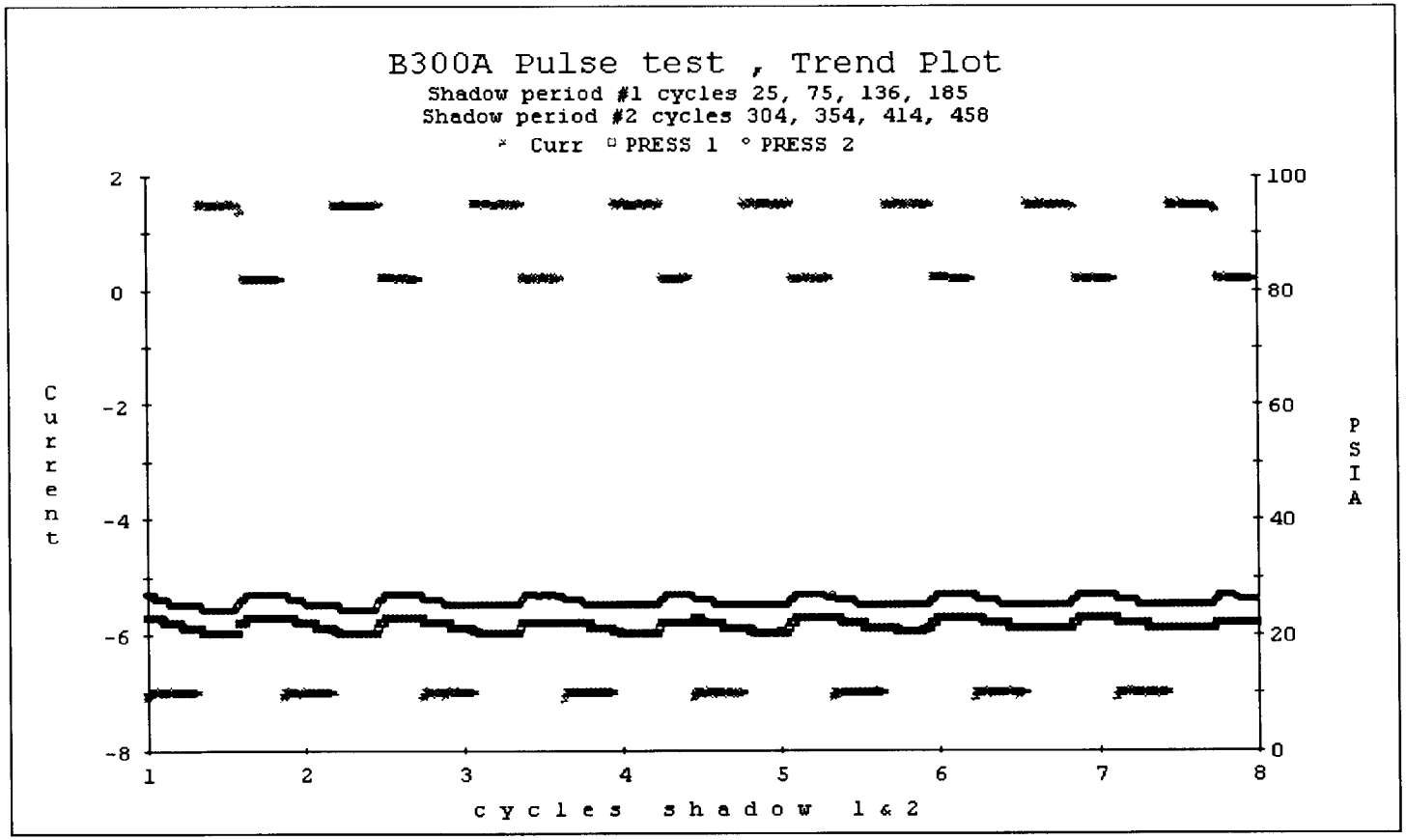
Pack B300A consist of 21 Ah EPT cells. The test objective was to verify cell lot quality by subjecting the cells to stress test conditions. This data may also be used to develop on orbit battery maintenance and operation requirements of the IMAGE mission.

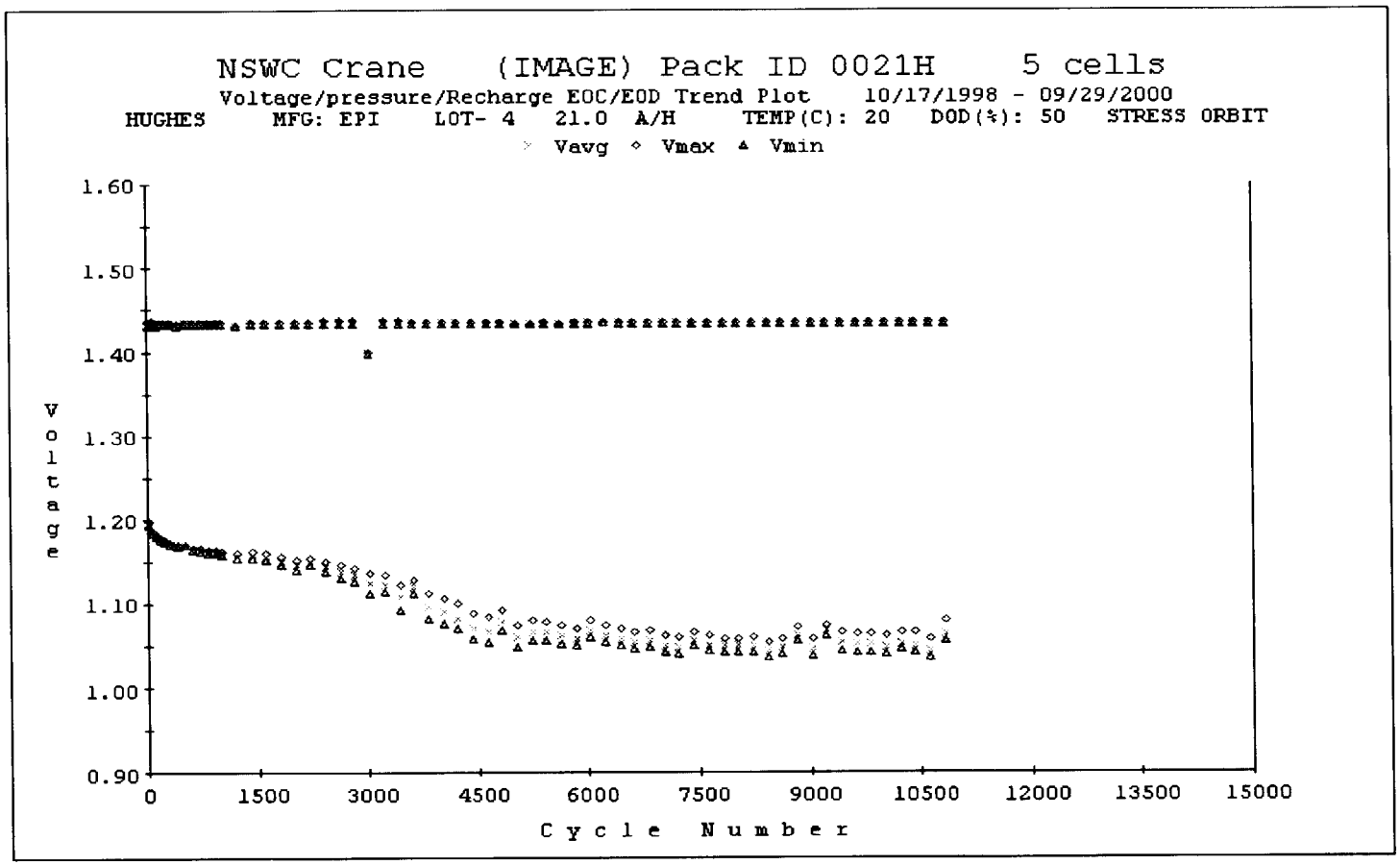
The pack was cycling at 20° C; 90 minute orbit; constant current discharge of 32.0 ± 0.05 A for 30 minutes; 40% DoD; and charged constant current of 32.0 ± 0.05 A with temperature compensated voltage (V/T 7) 1.454 V, for 60 minutes.

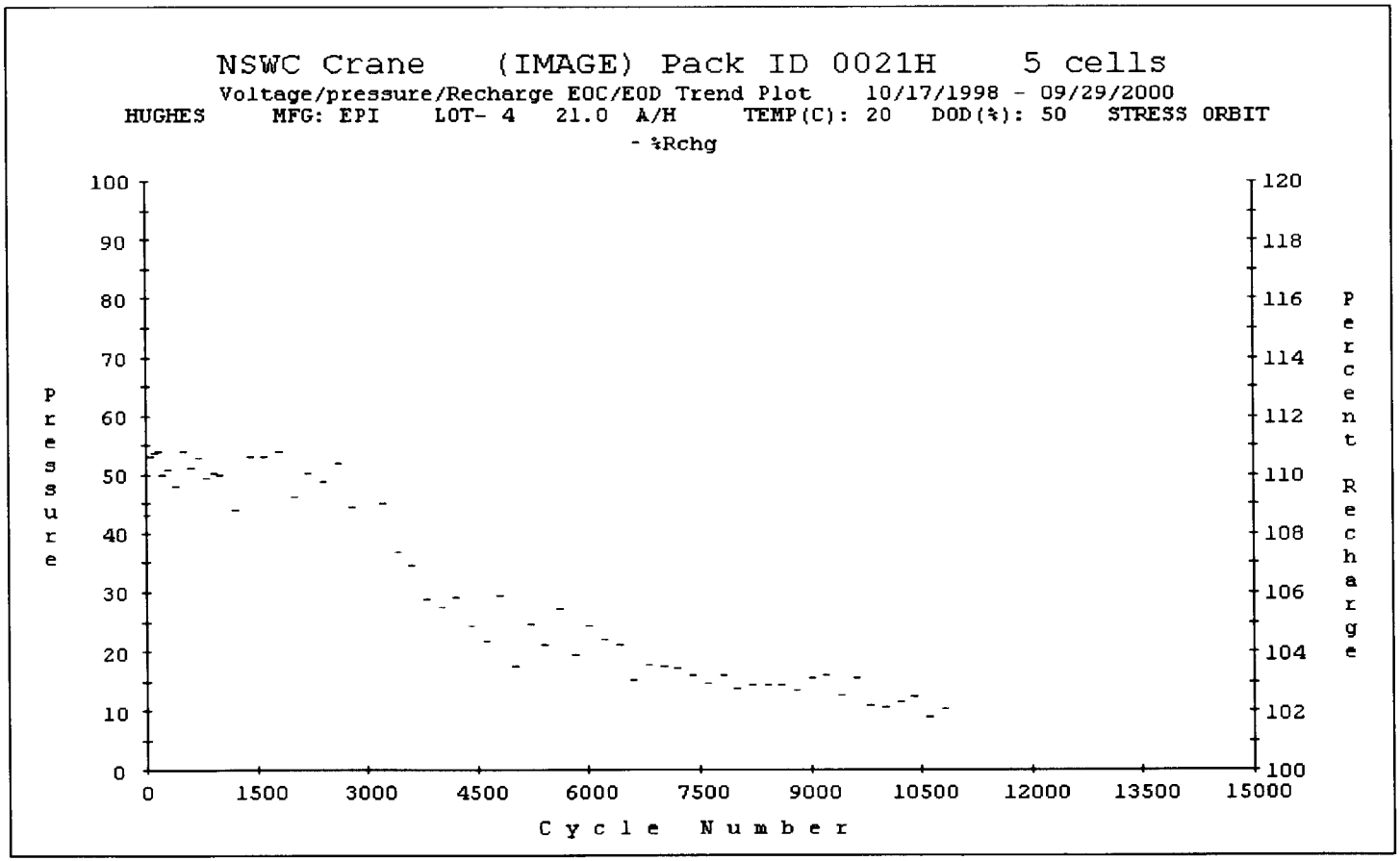
Life Cycling started in October 1997 and was discontinued per sponsor's request on 26 February 2000. The pack completed 521 cycles.

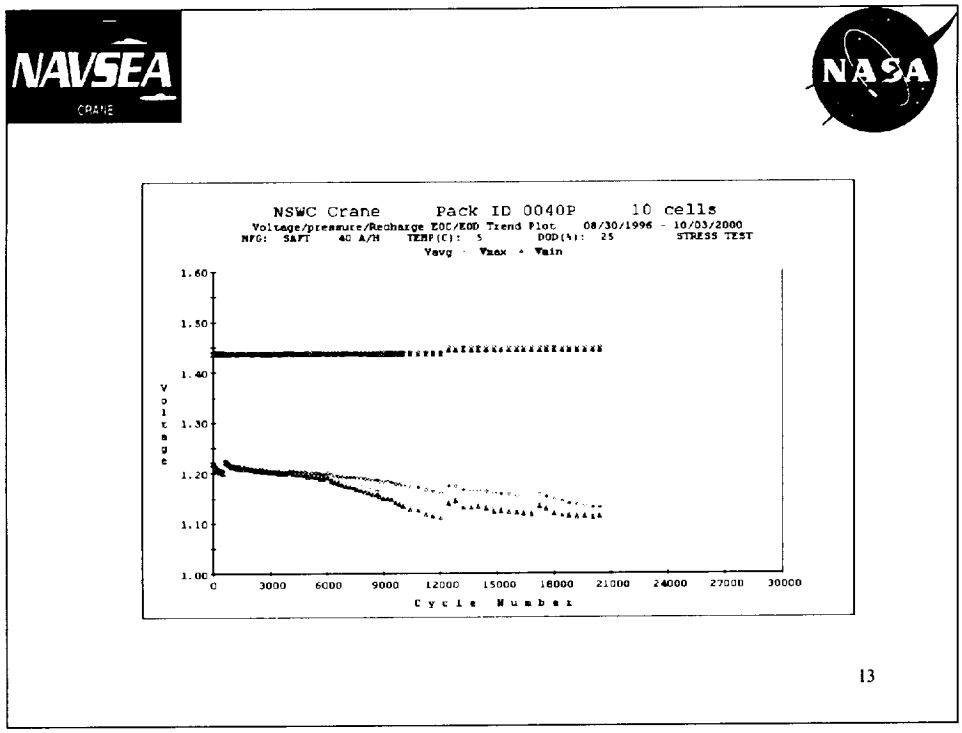

B300A Pulse test , Cycles 277 & 518 of Sun periods 1 & 2
1.1 amp charge for 24 hours with V/T 5 voltage limit
and pulse discharge @ 5.1 amp every .8 seconds for .2 seconds
Vavg
Vmax
Vmin
Curr
1.420
1.414
1.408
1.402
1.396
1.390
Cell Volts
2
0
-1
-3
-4
-6
Current
1
577
1153
1728
2304
2880
Minutes


B300A Pulse test, C/2 discharge to 1.0 volt any cell
Cycle 186 discharge followed last cycle of Shadow period #1 Aho = 22.8
Cycle 459 discharge followed last cycle of Shadow period #2 Aho = 21.3
Vavg Vmax Vmin Curr
1.5
1.4
1.2
1.1
0.9
0.8
Cell Volts
0
-2
-5
-7
-10
-12
Current
0
3
6
9
12
15
18
21
24
Ampere-Hours


B300A Pulse test , Trend Plot
Shadow period #1 cycles 25, 75, 136, 185
Shadow period #2 cycles 304, 354, 414, 458
* Curr □ PRESS 1 ° PRESS 2
Current
PSIA
2
0
-2
-4
-6
-8
100
80
60
40
20
0
1
2
3
4
5
6
7
8
cycles shadow 1 & 2


NSWC Crane (IMAGE) Pack ID 0021H 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 10/17/1998 - 09/29/2000
HUGHES MFG: EPI LOT- 4 21.0 A/H TEMP(C): 20 DOD(%): 50 STRESS ORBIT
Vavg Vmax Vmin
Voltage
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
Cycle Number


NSWC Crane (IMAGE) Pack ID 0021H 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 10/17/1998 - 09/29/2000
HUGHES MFG: EPI LOT- 4 21.0 A/H TEMP(C): 20 DOD(%): 50 STRESS ORBIT
- %Rchg
Pressure
Percent Recharge
Cycle Number
0
10
20
30
40
50
60
70
80
90
100
100
102
104
106
108
110
112
114
116
118
120
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000



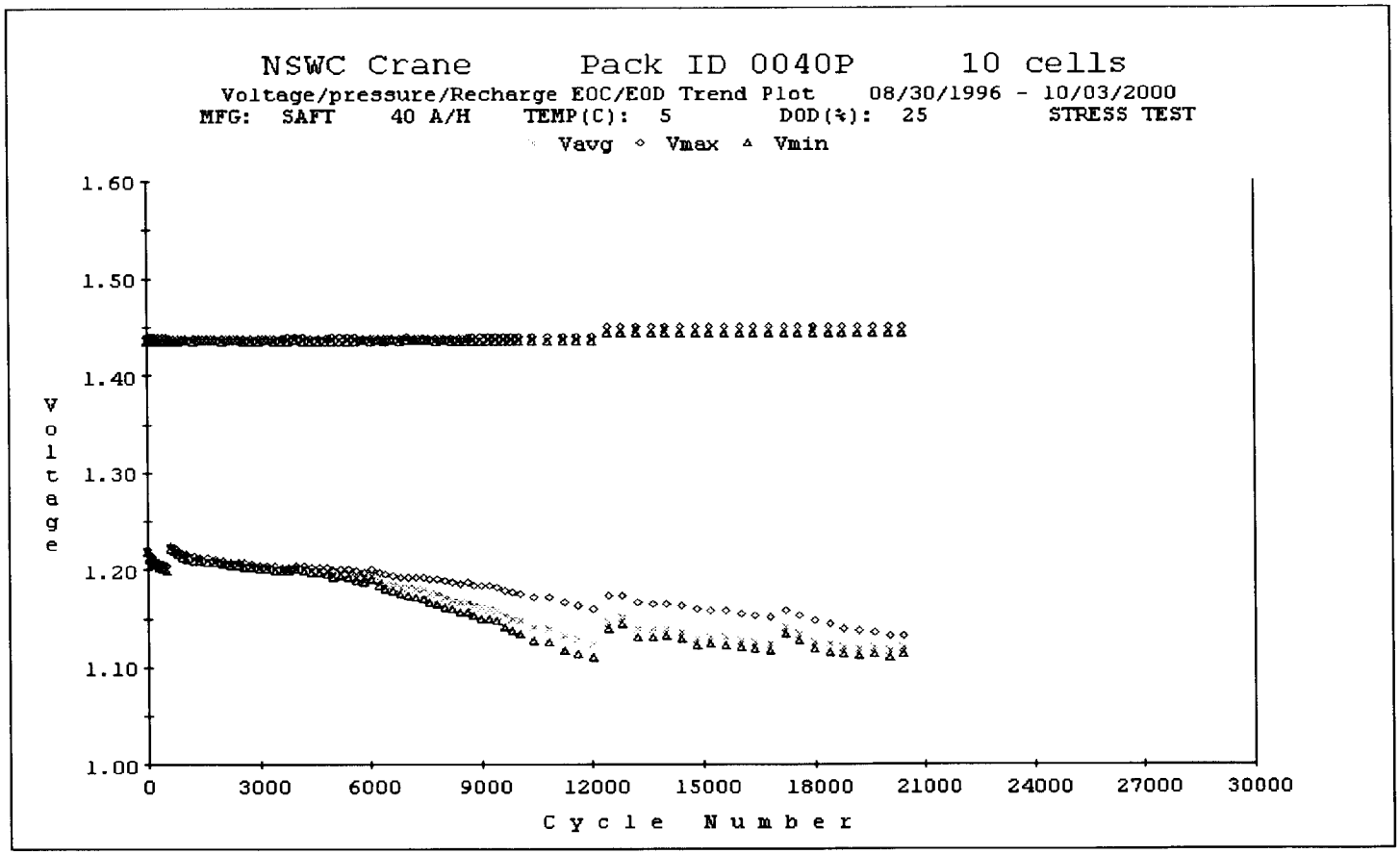
These 40 Ah Ni-Cd cells are contained in one pack consisting of ten cells connected in series. These Lot 2 cells are designated with SAFT, France part number VOS40AHBC.

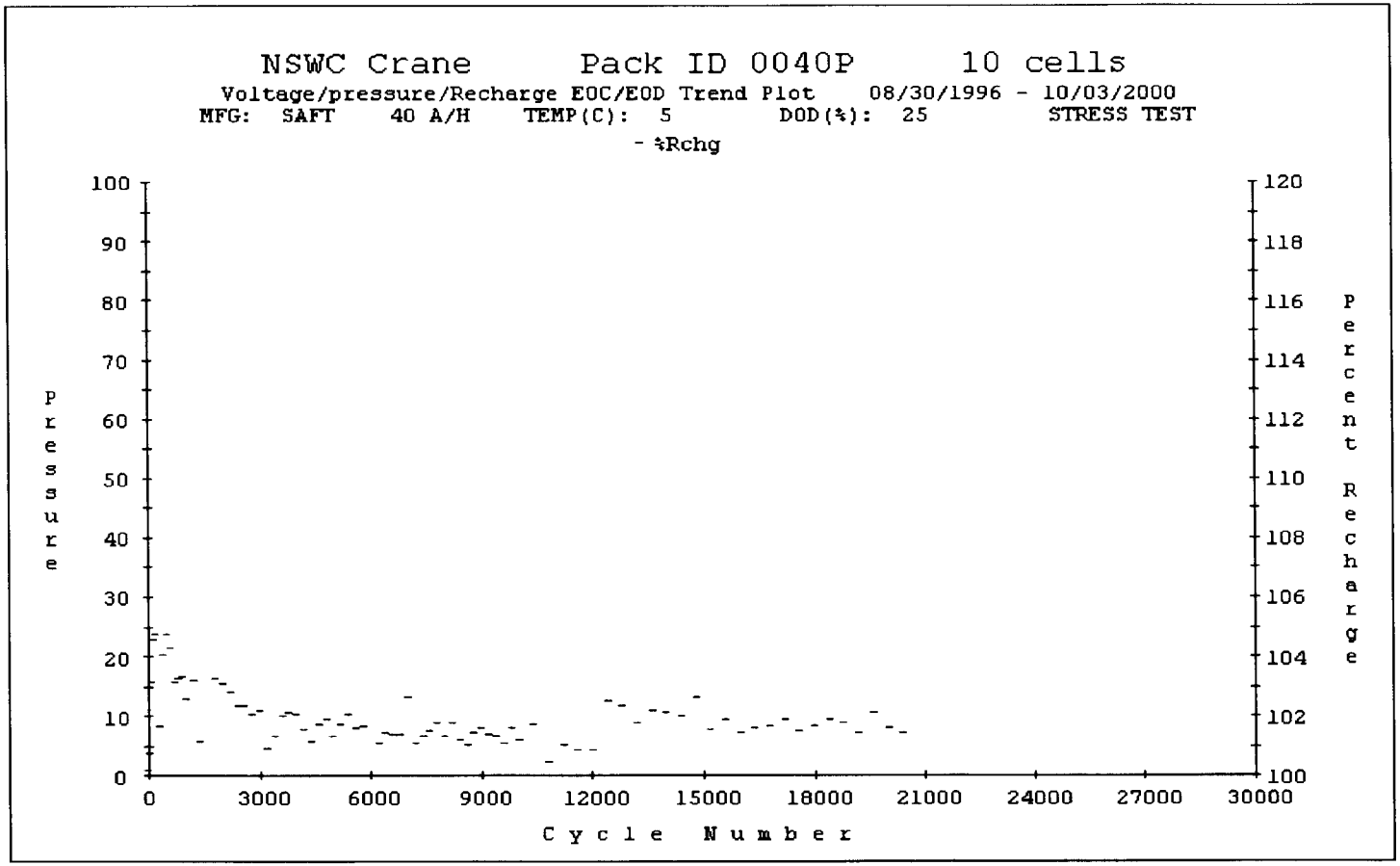
The objective of this testing is to evaluate flight-worthiness for the POES program in a simulated worst case LEO mission. Particular attention is given to trends in the end-of-discharge (EOD) voltage, end-of-charge (EOC) current, charge to discharge ratios, and capacity degradation.

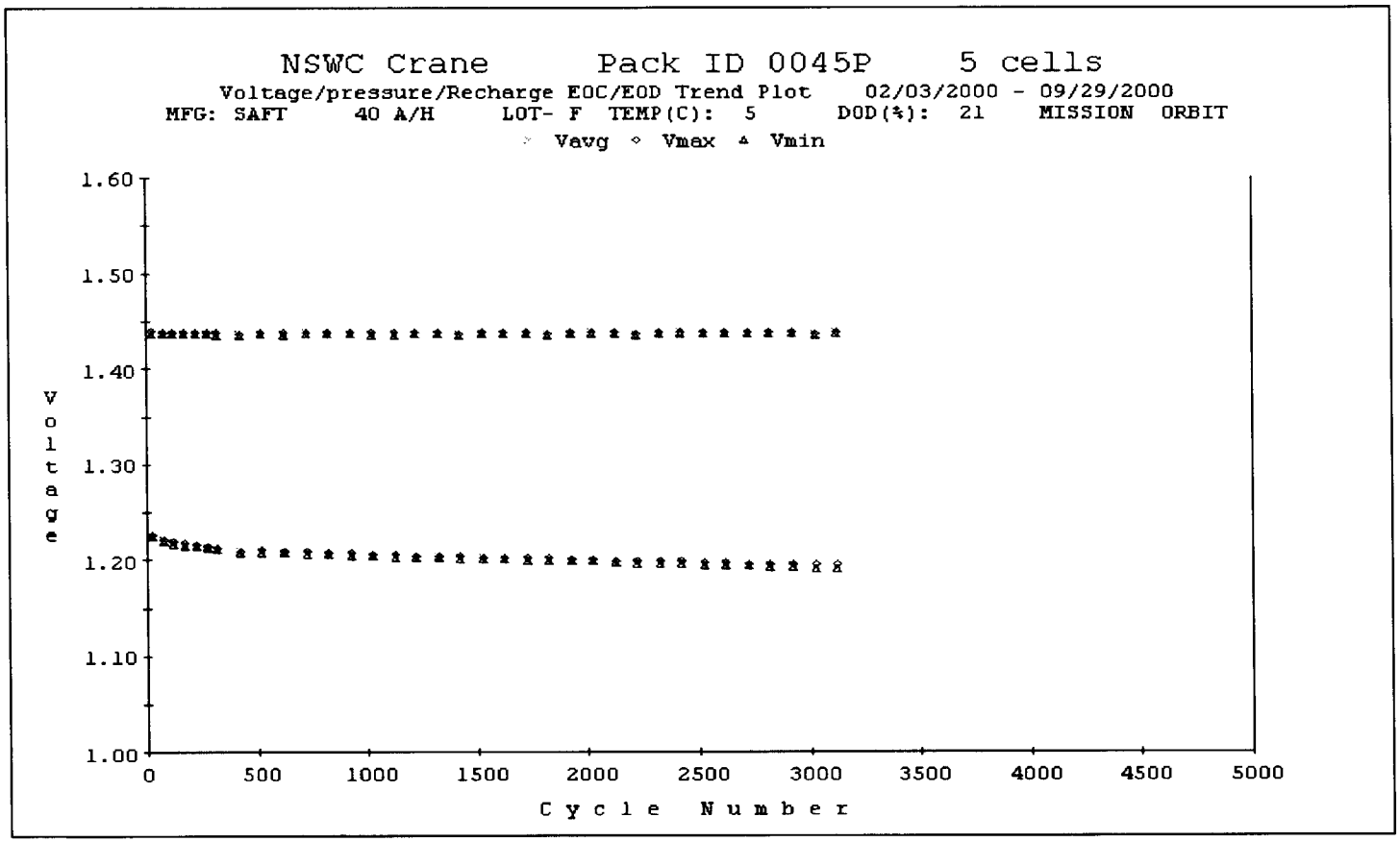
The pack is cycling according to these current test conditions.

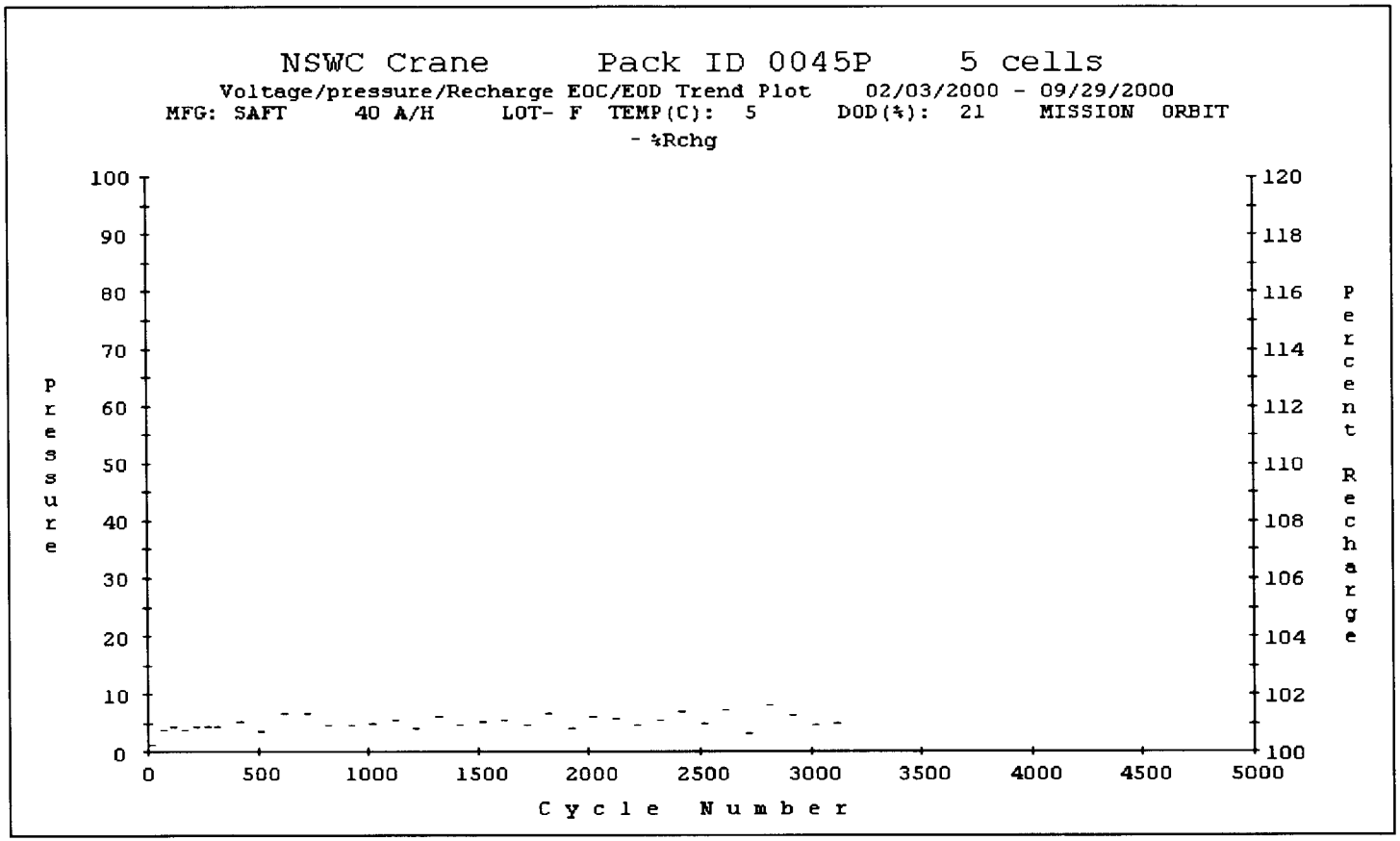
5°C -- 90 minute orbit-- Constant current of 20.0 ± 0.05 A for 30 minutes -- 25% DoD -- Constant current of 20.0 ± 0.05 A with temperature compensated voltage (V/T 5) 1.438V, for 60 minutes.

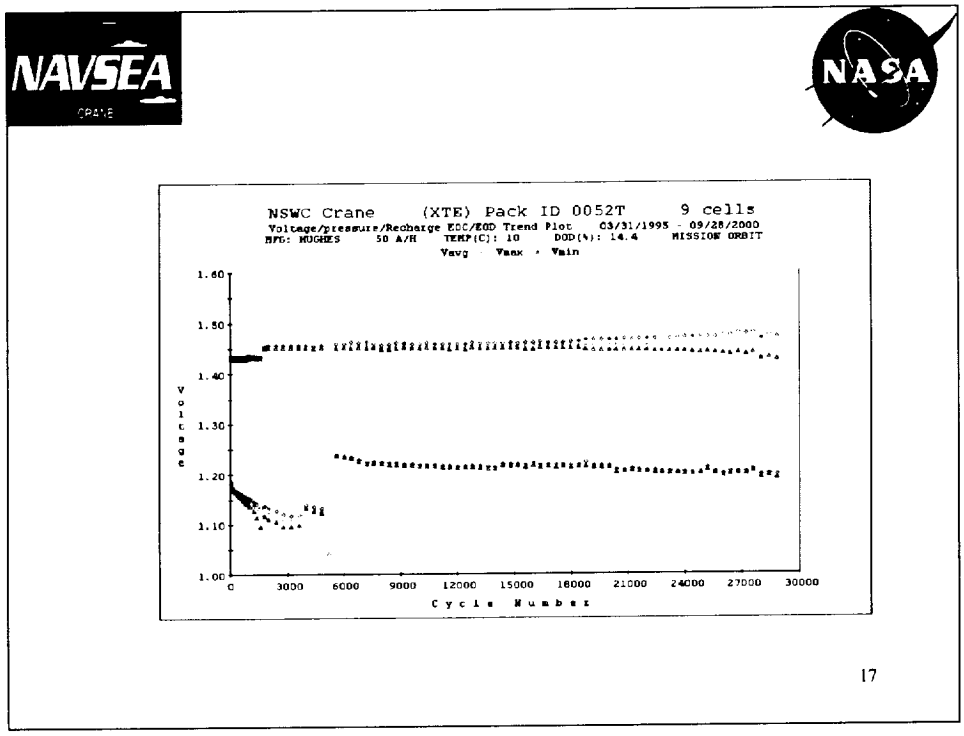
Performance on Cycling Pack 0040P. Pack testing started in July, 1996. Initial Evaluation of cells was performed as pack 6556X and 6557X. Pack has completed 20.5K cycles.


NSWC Crane Pack ID 0040P 10 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 08/30/1996 - 10/03/2000
MFG: SAFT 40 A/H TEMP(C): 5 DOD(%): 25 STRESS TEST
Vavg Vmax Vmin
Voltage
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000
Cycle Number


NSWC Crane Pack ID 0040P 10 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 08/30/1996 - 10/03/2000
MFG: SAFT 40 A/H TEMP(C): 5 DOD(%): 25 STRESS TEST
- %Rchg
Pressure
Percent Recharge
Cycle Number
0
10
20
30
40
50
60
70
80
90
100
100
102
104
106
108
110
112
114
116
118
120
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000

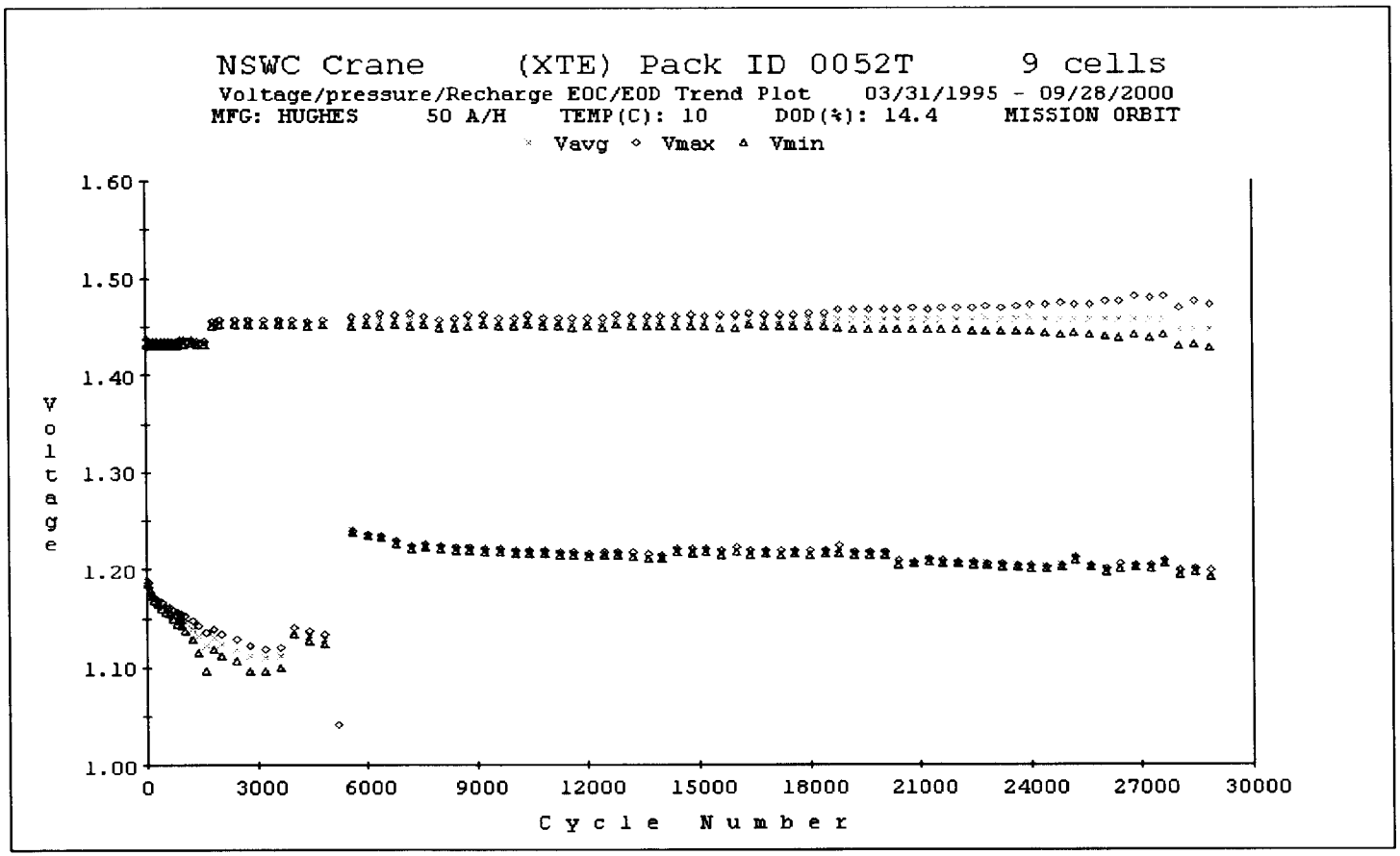

NSWC Crane Pack ID 0045P 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 02/03/2000 - 09/29/2000
MFG: SAFT 40 A/H LOT- F TEMP(C): 5 DOD(%): 21 MISSION ORBIT
Vavg Vmax Vmin
1.60
1.50
1.40
1.30
1.20
1.10
1.00
Voltage
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Cycle Number

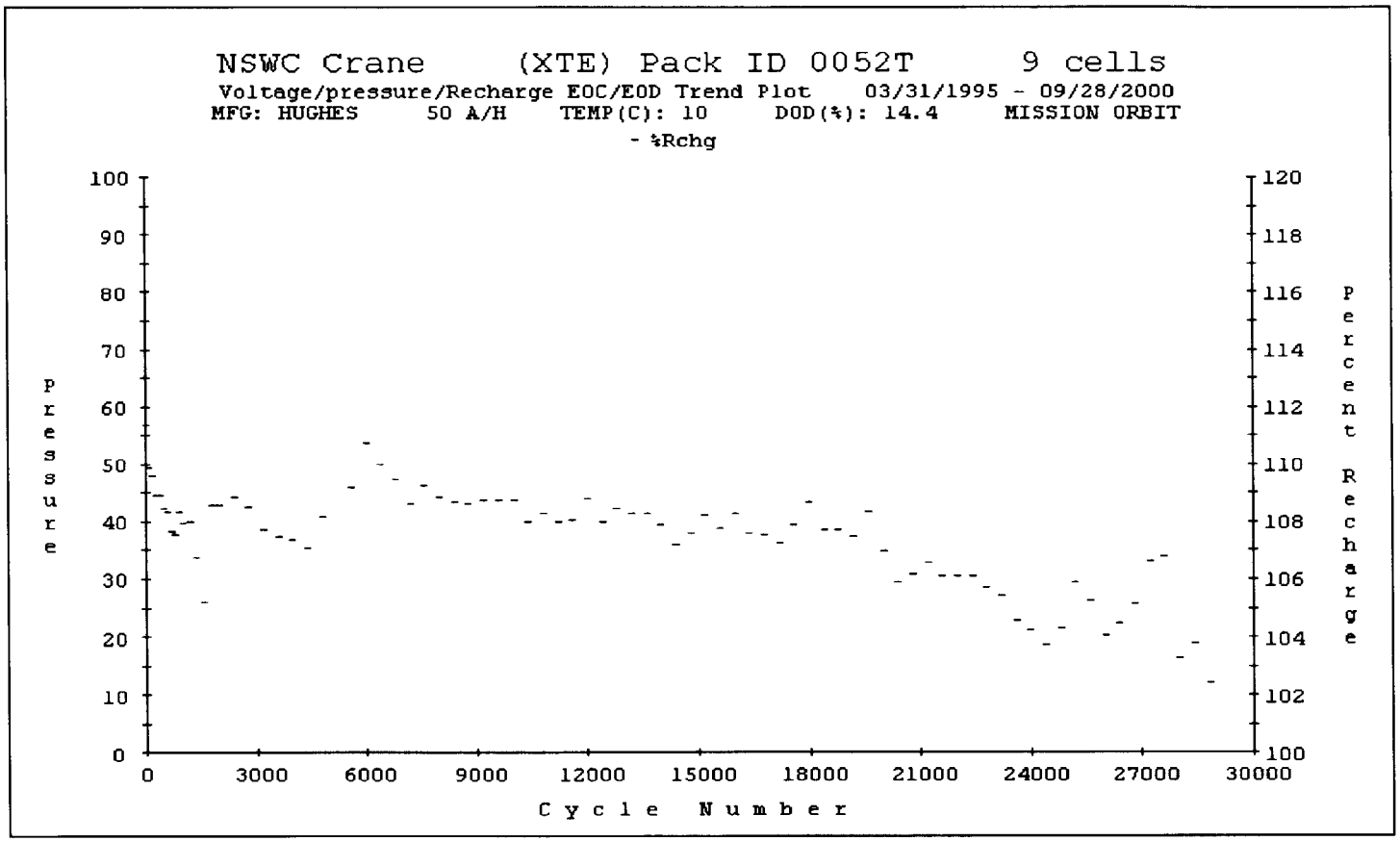

NSWC Crane Pack ID 0045P 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 02/03/2000 - 09/29/2000
MFG: SAFT 40 A/H LOT- F TEMP(C): 5 DOD(%): 21 MISSION ORBIT
- %Rchg
Pressure
Percent Recharge
Cycle Number
0
10
20
30
40
50
60
70
80
90
100
100
102
104
106
108
110
112
114
116
118
120
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

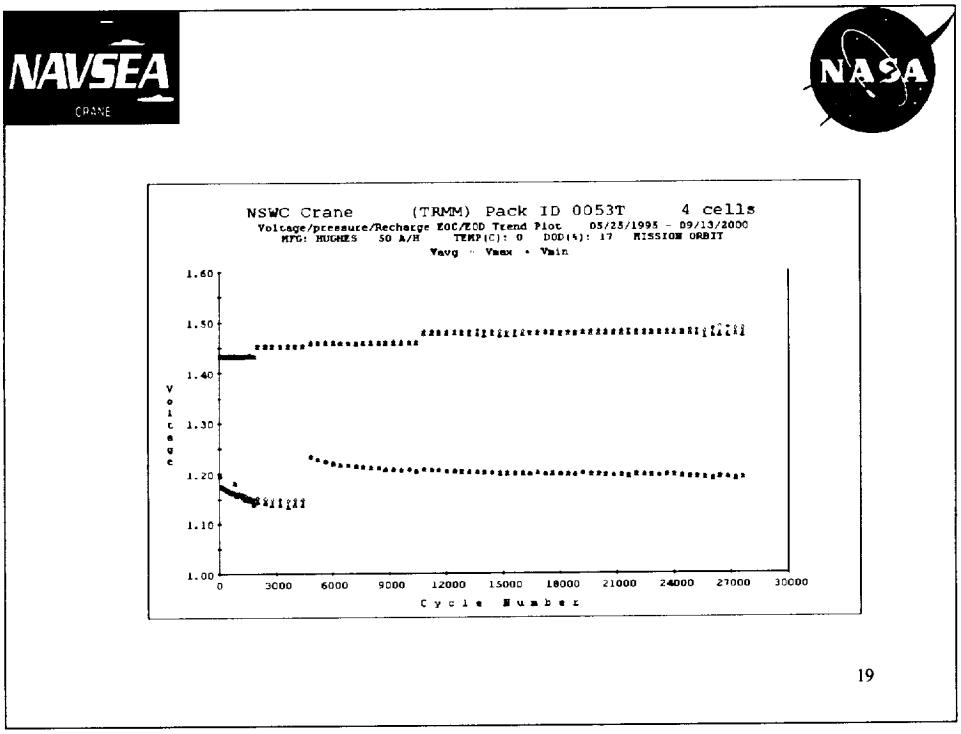


These 50 Ah Super Ni-Cd cells are contained in one pack consisting of nine cells connected in series. They were manufactured by Hughes Aircraft Company (HAC) and Eagle-Picher Technologies. (EPT) for the X-ray Timing Explorer (XTE) and the Tropical Rainfall Measuring Mission programs. These lot 3 cells were manufactured at EPT to CS-MCD-118 REV. D. They were activated with potassium hydroxide with Hughes proprietary additives on November 29, 1994 and under went both EPT and Hughes acceptance test.

The pack is cycling according to this current Mission profile. 10°C -- 90 minute orbit -- Constant current discharge of 12.0 ± 0.05 A for 30 minutes during the eclipse duration -- 14.4% DoD -- Constant current charge of 12.0 ± 0.05 A with temperature compensated voltage (V/T) level taper at V/T 6 to a recharge ratio of 103.5 ± 2%. Followed by a trickle charge at a rate of 0.50 ± 0.02 A with V/T limit for the remainder of 60 minutes.


NSWC Crane (XTE) Pack ID 0052T 9 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 03/31/1995 - 09/28/2000
MFG: HUGHES 50 A/H TEMP(C): 10 DOD(%): 14.4 MISSION ORBIT
Vavg Vmax Vmin
1.60
1.50
1.40
1.30
1.20
1.10
1.00
Voltage
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000
Cycle Number

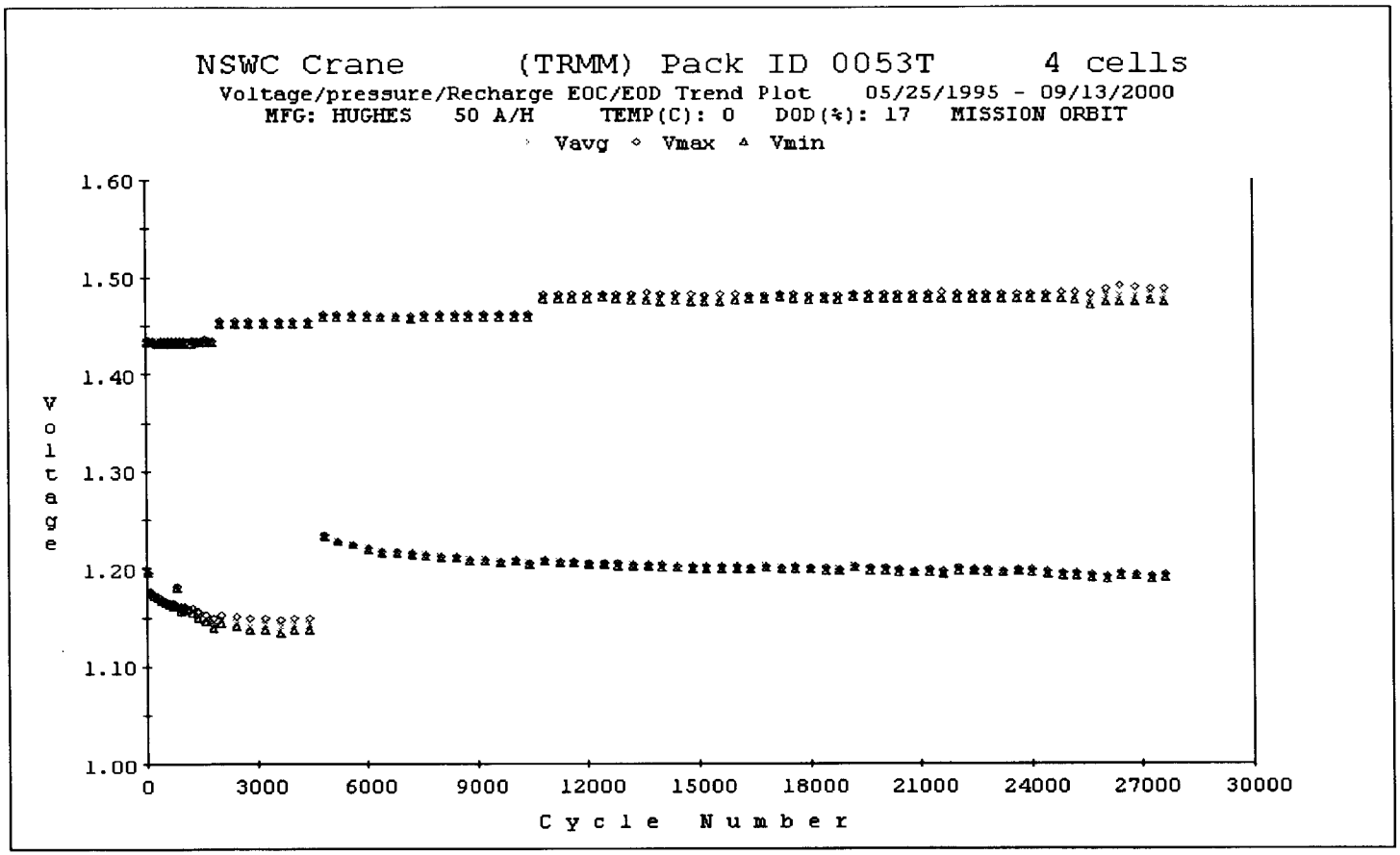

NSWC Crane (XTE) Pack ID 0052T 9 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 03/31/1995 - 09/28/2000
MFG: HUGHES 50 A/H TEMP(C): 10 DOD(%): 14.4 MISSION ORBIT
- %Rchg
Pressure
Percent Recharge
Cycle Number
0
10
20
30
40
50
60
70
80
90
100
102
104
106
108
110
112
114
116
118
120
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000

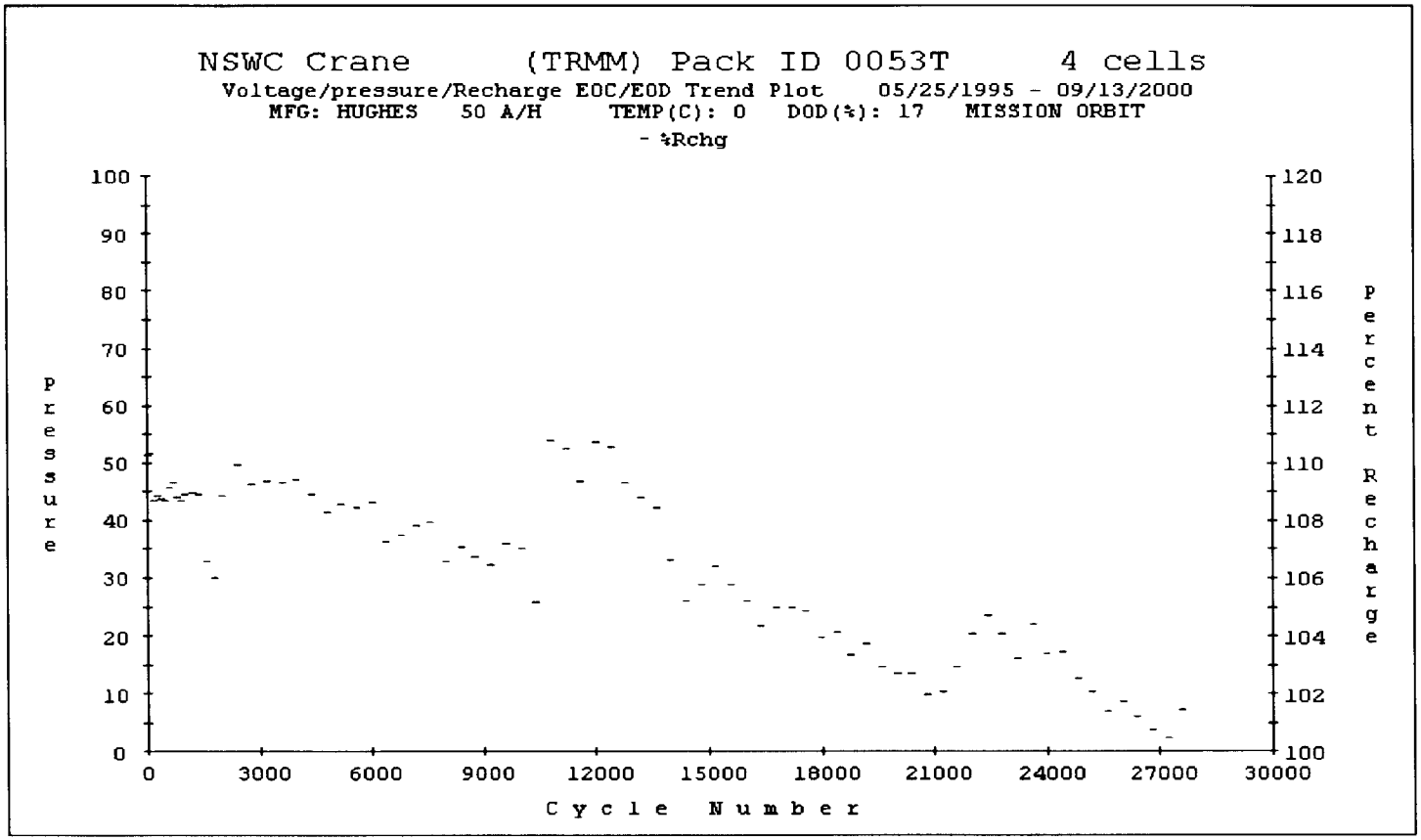


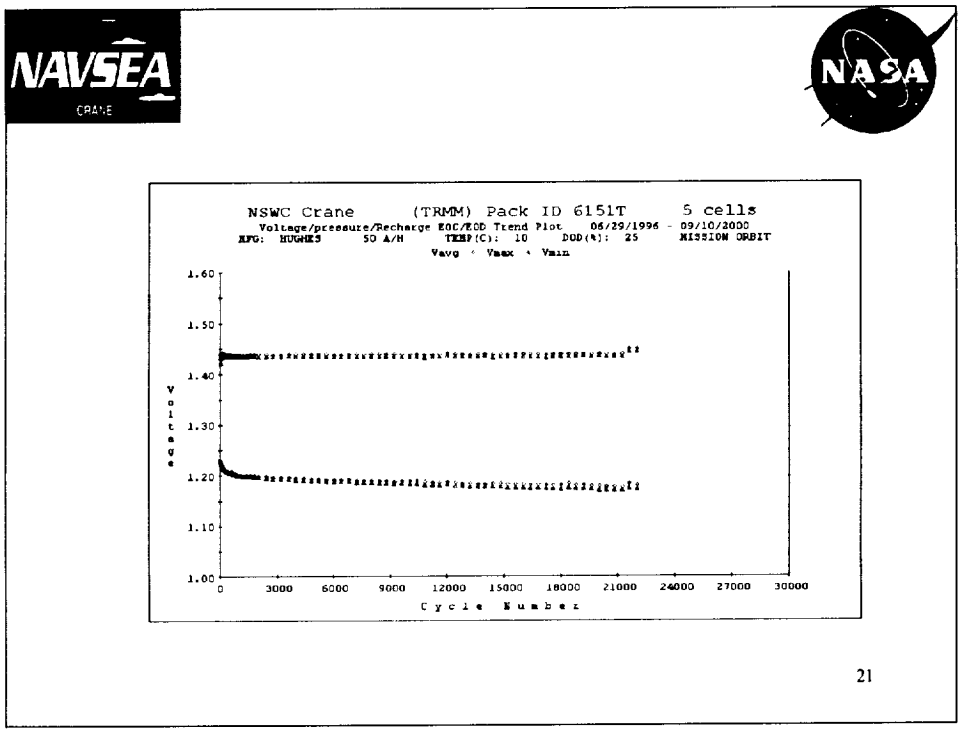
This battery was disassembled for removal of a shorted cell and other cells with pontential plate corner bend defects(?).

The objective of this testing is to evaluate the performance of cells that may have been subjected to elevated temperatures and extended open-circuit stands during the SN 002 battery rework under cyclic test conditions.

The pack is currently cycling according to these current stress profile. 0°C -- 90 minute orbit -- Constant current discharge of 20.0 ± 0.05 A for .43 hrs during the eclipse duration -- 17% DoD -- Constant current charge of 16.0 ± 0.05 A with temperature compensated voltage (V/T) level taper at V/T 6 to a recharge ratio of 101 ± 2%. Followed by a trickle charge at a rate of 0.50 ± 0.02 A with V/T limit for the remainder of 60 minutes.


NSWC Crane (TRMM) Pack ID 0053T 4 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 05/25/1995 - 09/13/2000
MFG: HUGHES 50 A/H TEMP(C): 0 DOD(%): 17 MISSION ORBIT
Vavg Vmax Vmin
1.60
1.50
1.40
1.30
1.20
1.10
1.00
Voltage
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000
Cycle Number

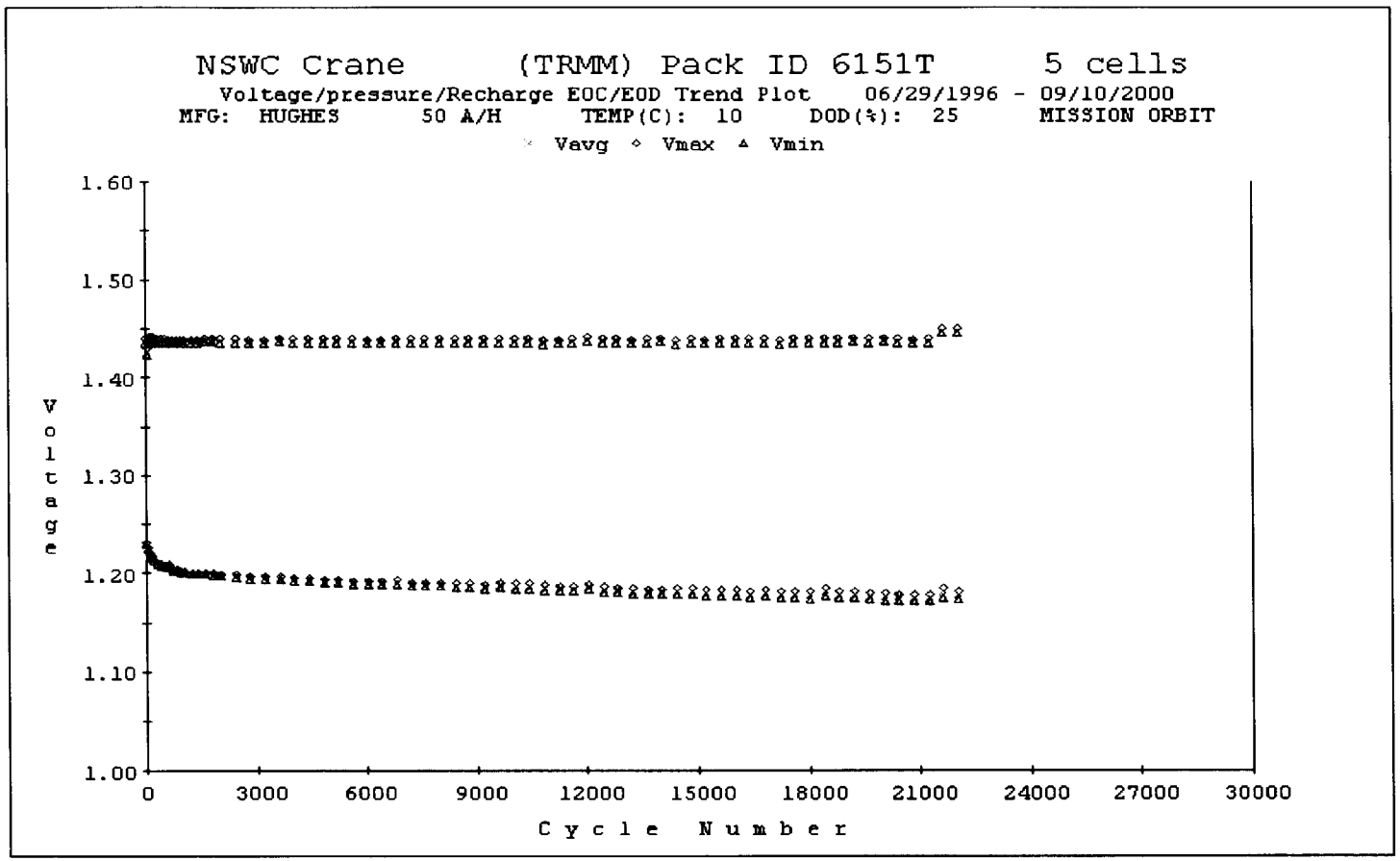

NSWC Crane (TRMM) Pack ID 0053T 4 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 05/25/1995 - 09/13/2000
MFG: HUGHES 50 A/H TEMP(C): 0 DOD(%): 17 MISSION ORBIT
- %Rchg
pressure
percent Recharge
Cycle Number
0
10
20
30
40
50
60
70
80
90
100
100
102
104
106
108
110
112
114
116
118
120
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000

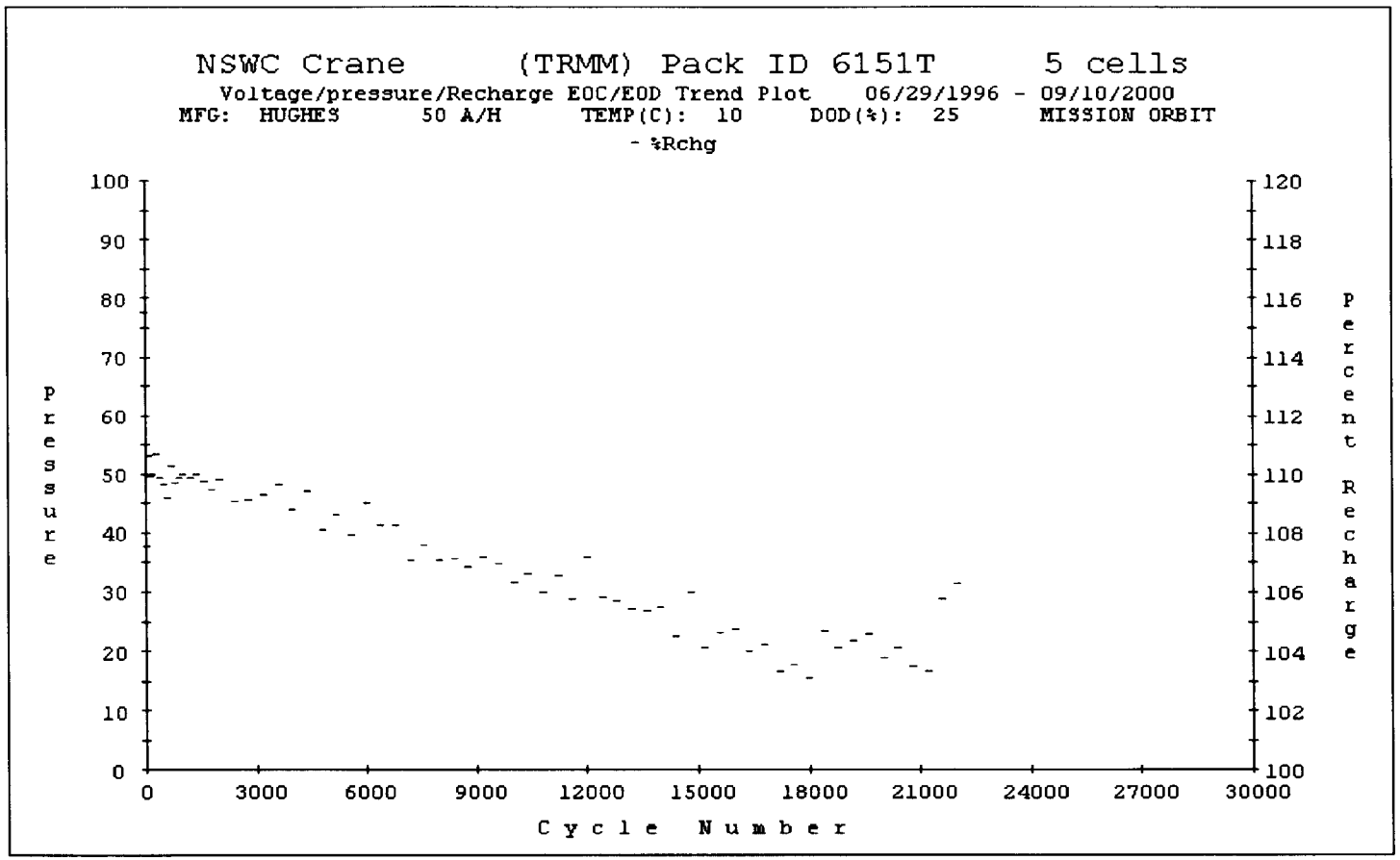


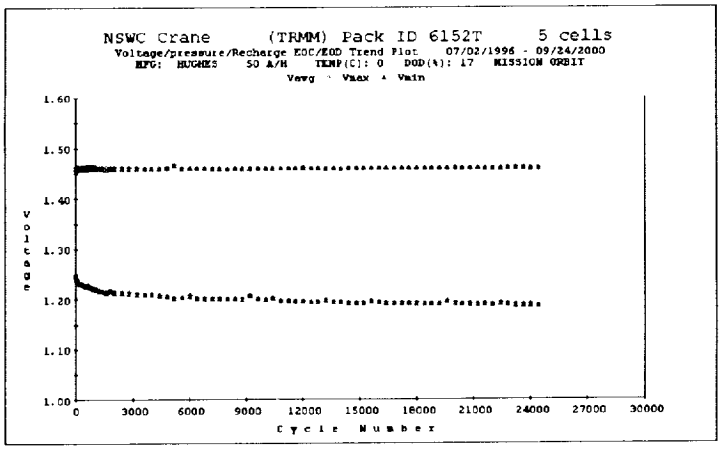
These 50 Ah Super Ni-Cd cells are contained in one pack consisting of five cells connected in series. They were manufactured by Hughes Aircraft Company (HAC) and Eagle-Picher Technologies. (EPT) for the Tropical Rainfall Measuring Mission programs.

This battery is currently baselined for EO-1 spacecraft.

The pack is currently cycling according to the worst case TRMM MISSION profile conditions. 10°C -- 96 minute orbit -- Constant current discharge of 21.0 ± 0.05 A for 36 minutes during the eclipse duration -- 25% DoD--Constant current charge of 30.0 ± 0.05 A with temperature compensated voltage (V/T) level taper at V/T 5 to a recharge ratio of 108 ± 2%. Followed by a trickle charge at a rate of 0.50 ± 0.02 A with V/T limit for the remainder of 60 minutes.

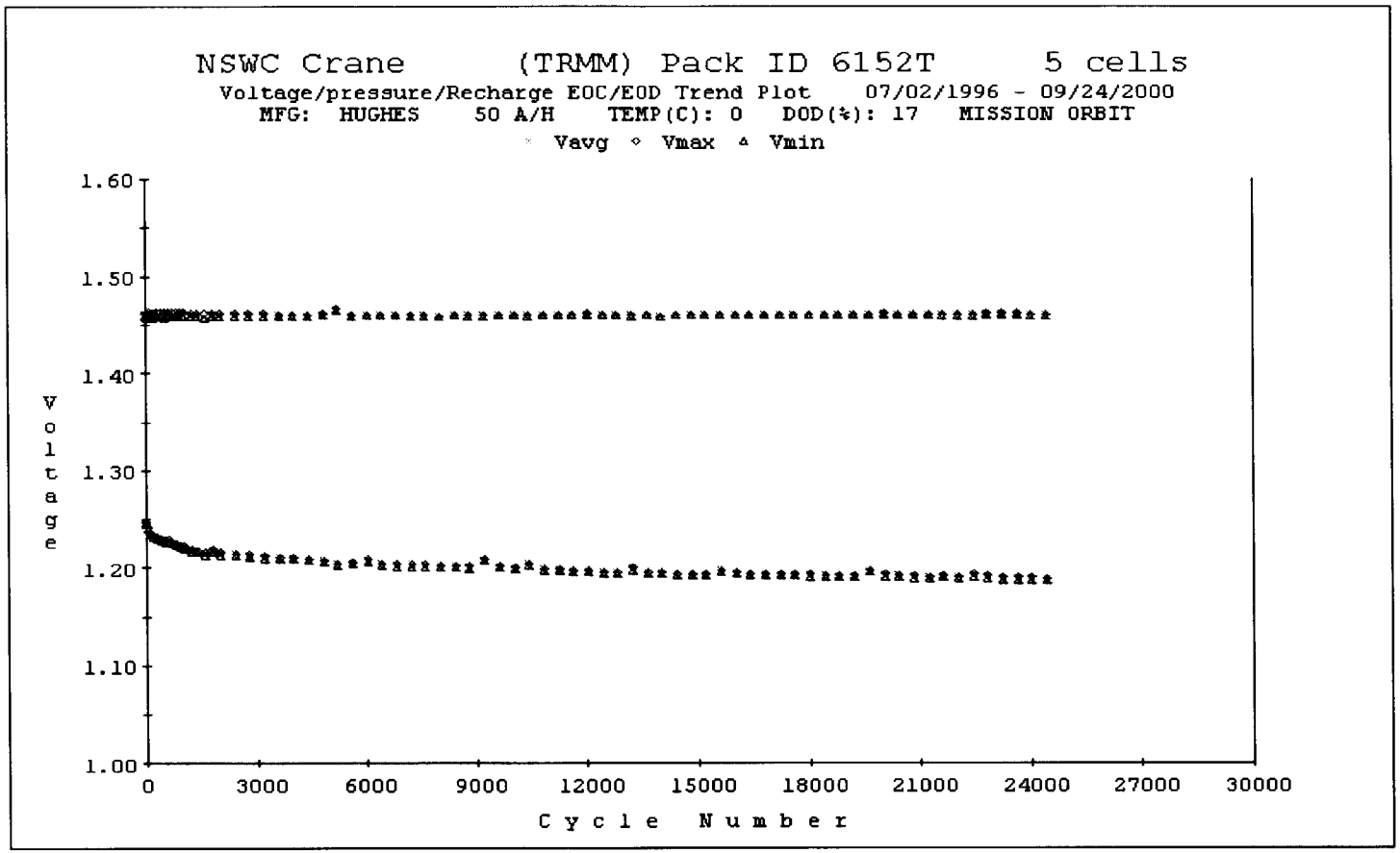

NSWC Crane (TRMM) Pack ID 6151T 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 06/29/1996 - 09/10/2000
MFG: HUGHES 50 A/H TEMP(C): 10 DOD(%): 25 MISSION ORBIT
Vavg Vmax Vmin
1.60
1.50
1.40
1.30
1.20
1.10
1.00
Voltage
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000
Cycle Number

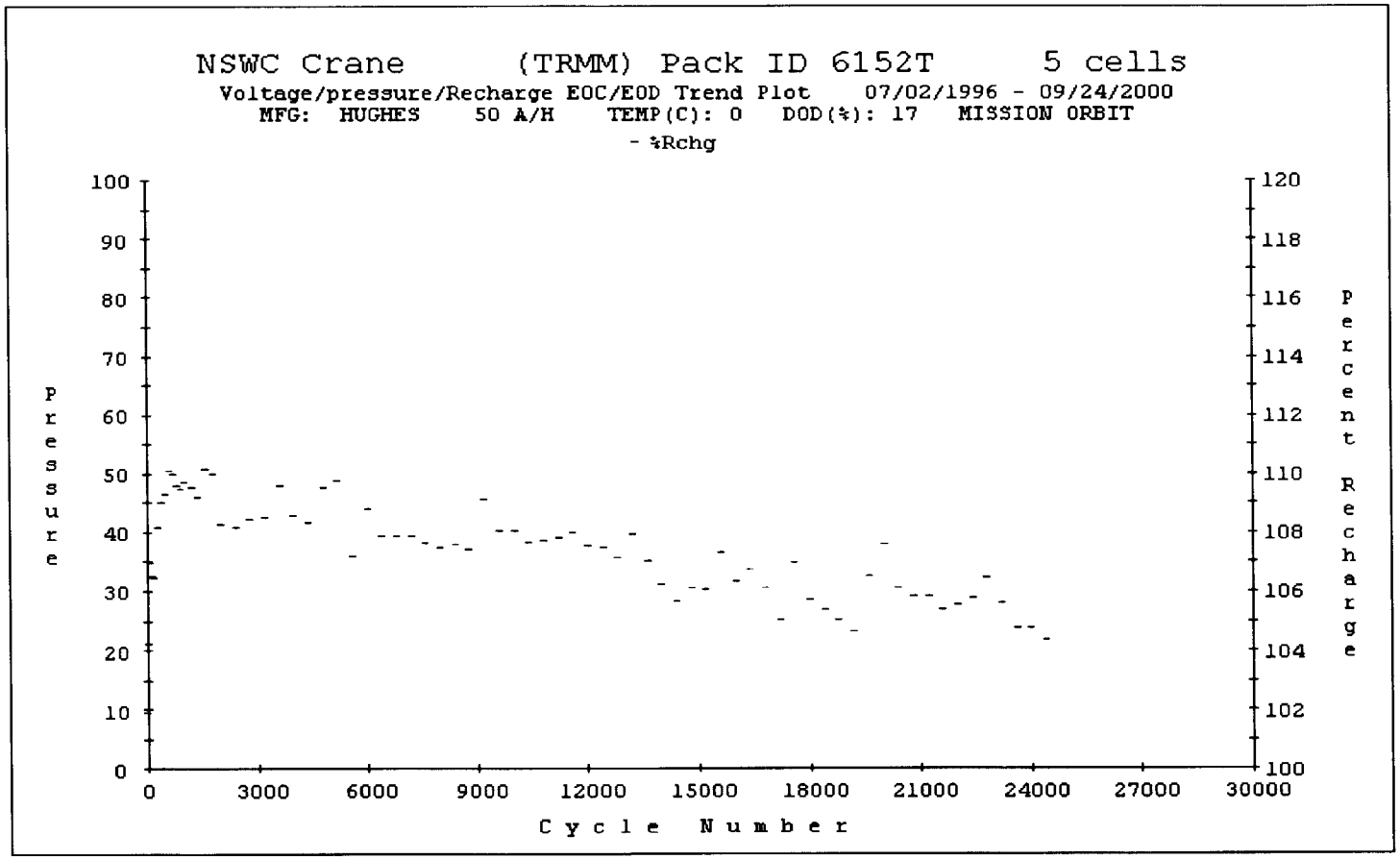

NSWC Crane (TRMM) Pack ID 6151T 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 06/29/1996 - 09/10/2000
MFG: HUGHES 50 A/H TEMP(C): 10 DOD(%): 25 MISSION ORBIT
- %Rchg
pressure
percent Recharge
Cycle Number
0
10
20
30
40
50
60
70
80
90
100
100
102
104
106
108
110
112
114
116
118
120
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000

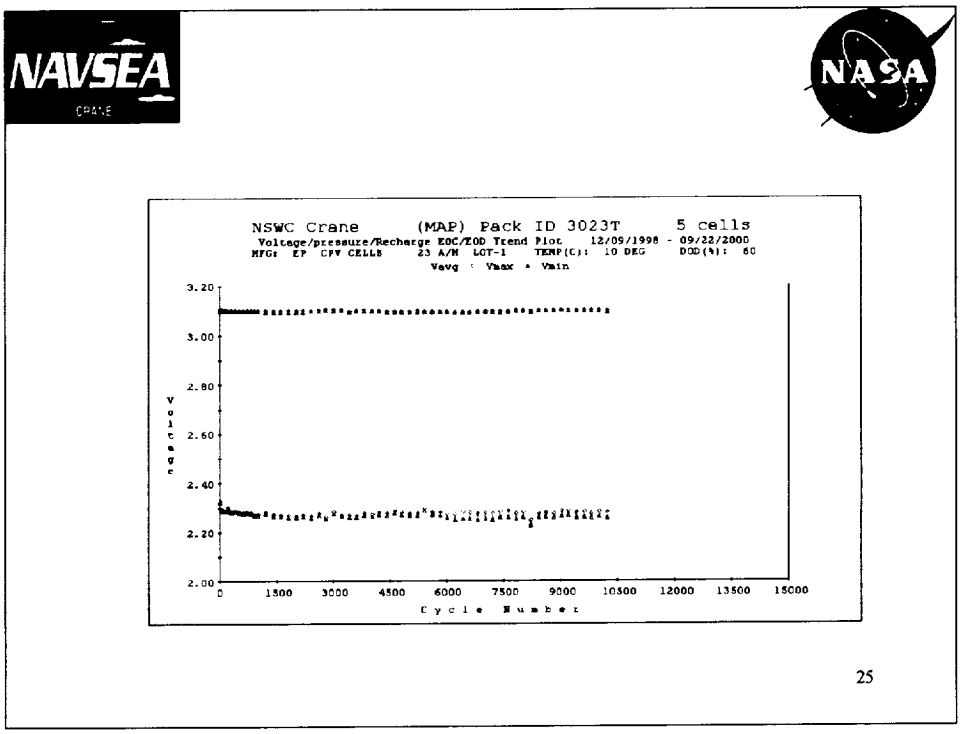


23

The pack is currently cycling according to TRMM MISSION profile conditions -- 0°C -- 96 minute orbit -- Constant current discharge of 20.0 ± 0.05 A for 26 minutes during the eclipse duration -- 17% DoD -- Constant current charge of 16.0 ± 0.05 A with temperature compensated voltage (V/T) level taper at V/T 5 to a recharge ratio of 108 ± 2%. Followed by a trickle charge at a rate of 0.50 ± 0.02 A with V/T limit for the remainder of 60 minutes.


NSWC Crane (TRMM) Pack ID 6152T 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 07/02/1996 - 09/24/2000
MFG: HUGHES 50 A/H TEMP(C): 0 DOD(%): 17 MISSION ORBIT
Vavg Vmax Vmin
1.60
1.50
1.40
1.30
1.20
1.10
1.00
Voltage
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000
Cycle Number

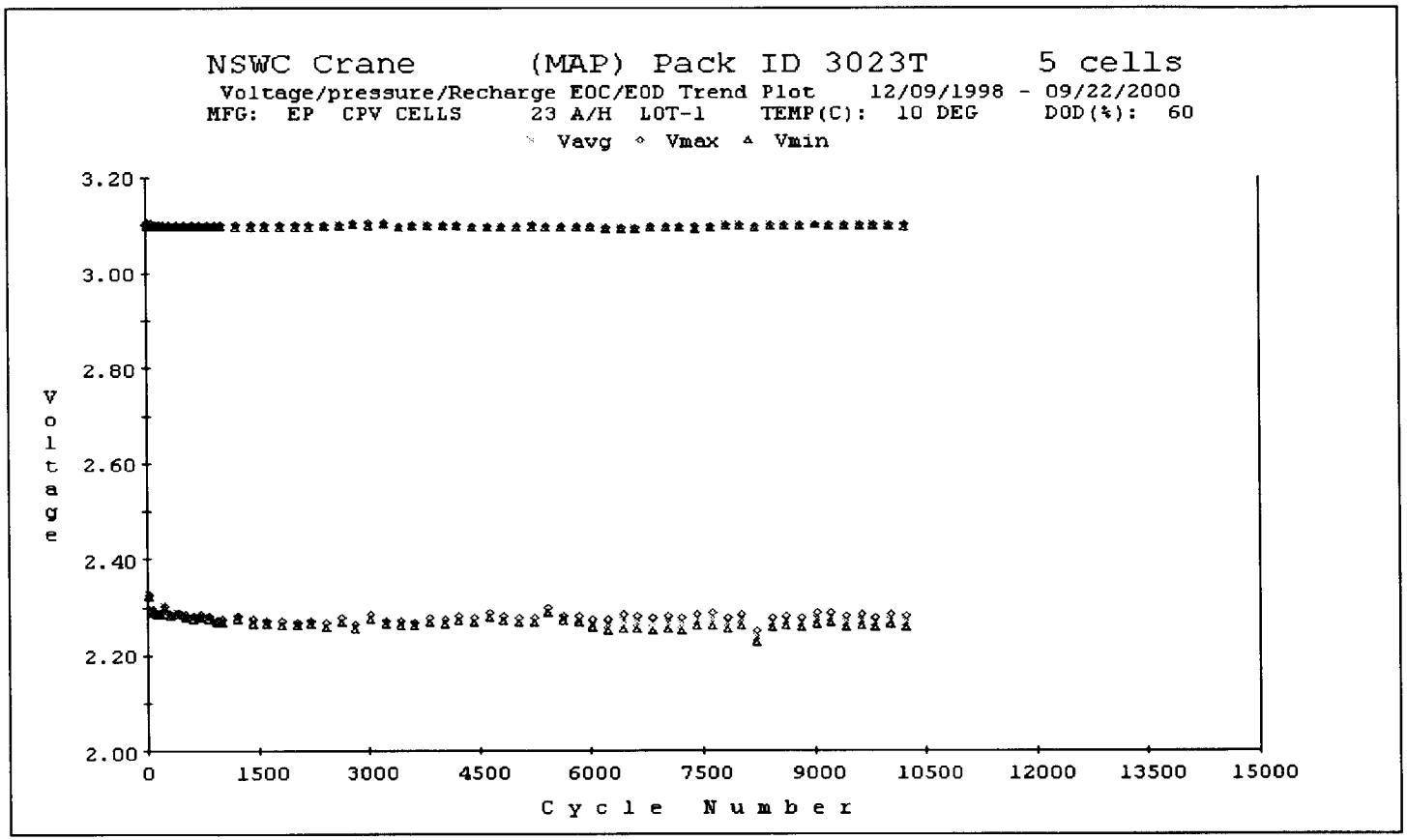

NSWC Crane (TRMM) Pack ID 6152T 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 07/02/1996 - 09/24/2000
MFG: HUGHES 50 A/H TEMP(C): 0 DOD(%): 17 MISSION ORBIT
- %Rchg
Pressure
Percent Recharge
Cycle Number
0
10
20
30
40
50
60
70
80
90
100
102
104
106
108
110
112
114
116
118
120
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000

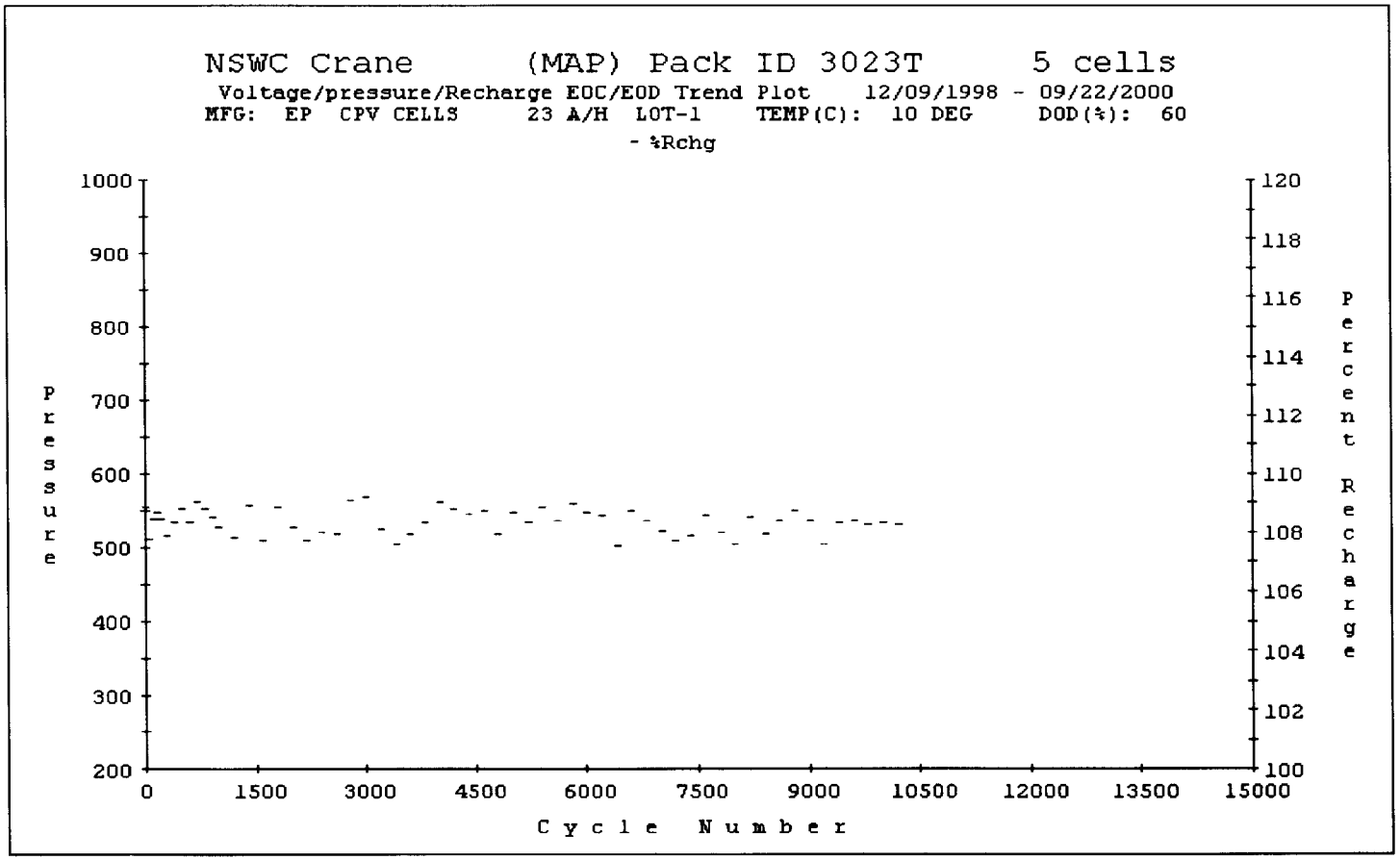


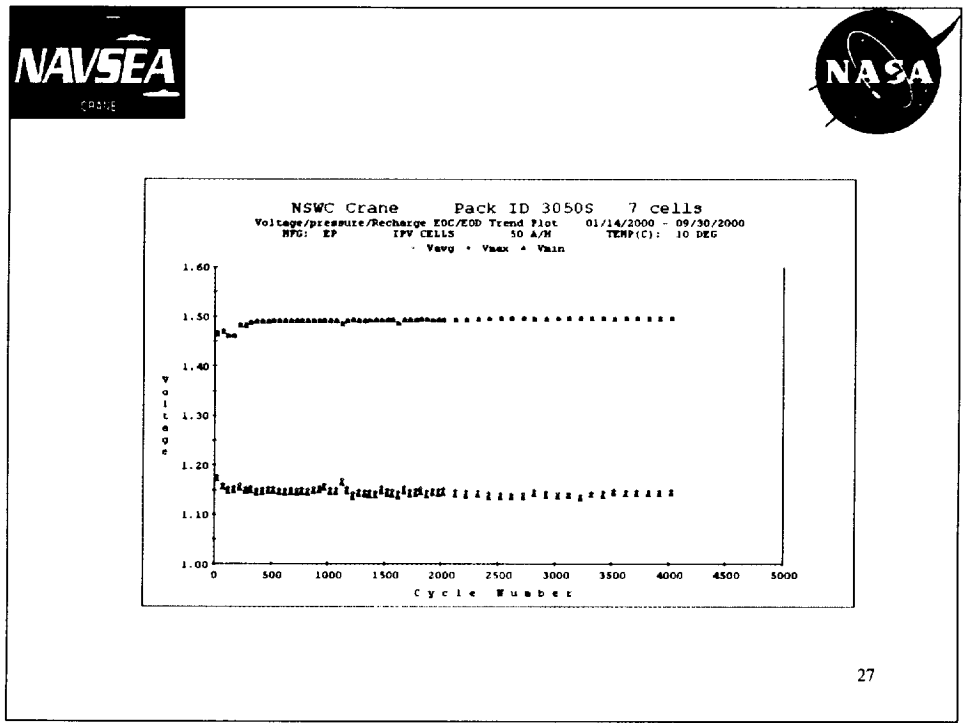
Cells from battery for CLARK spacecraft

About 3 years of wet storage

STRESS TEST - The pack is currently cycling according to the following conditions -- 10°C -- 90 minute orbit -- Constant current discharge of 28.0 ± 0.05 A for 30 minutes -- 60% DoD -- Constant current charge of 19.0 ± 0.05 A with temperature compensated voltage (V/T) level taper at V/T 5 to a recharge ratio of 108 ± 2%. Followed by a trickle charge at a rate of 0.23 ± 0.02 A with V/T limit for the remainder of 60 minutes.


NSWC Crane (MAP) Pack ID 3023T 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 12/09/1998 - 09/22/2000
MFG: EP CPV CELLS 23 A/H LOT-1 TEMP(C): 10 DEG DOD(%): 60
Vavg Vmax Vmin
3.20
3.00
2.80
2.60
2.40
2.20
2.00
Voltage
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
Cycle Number

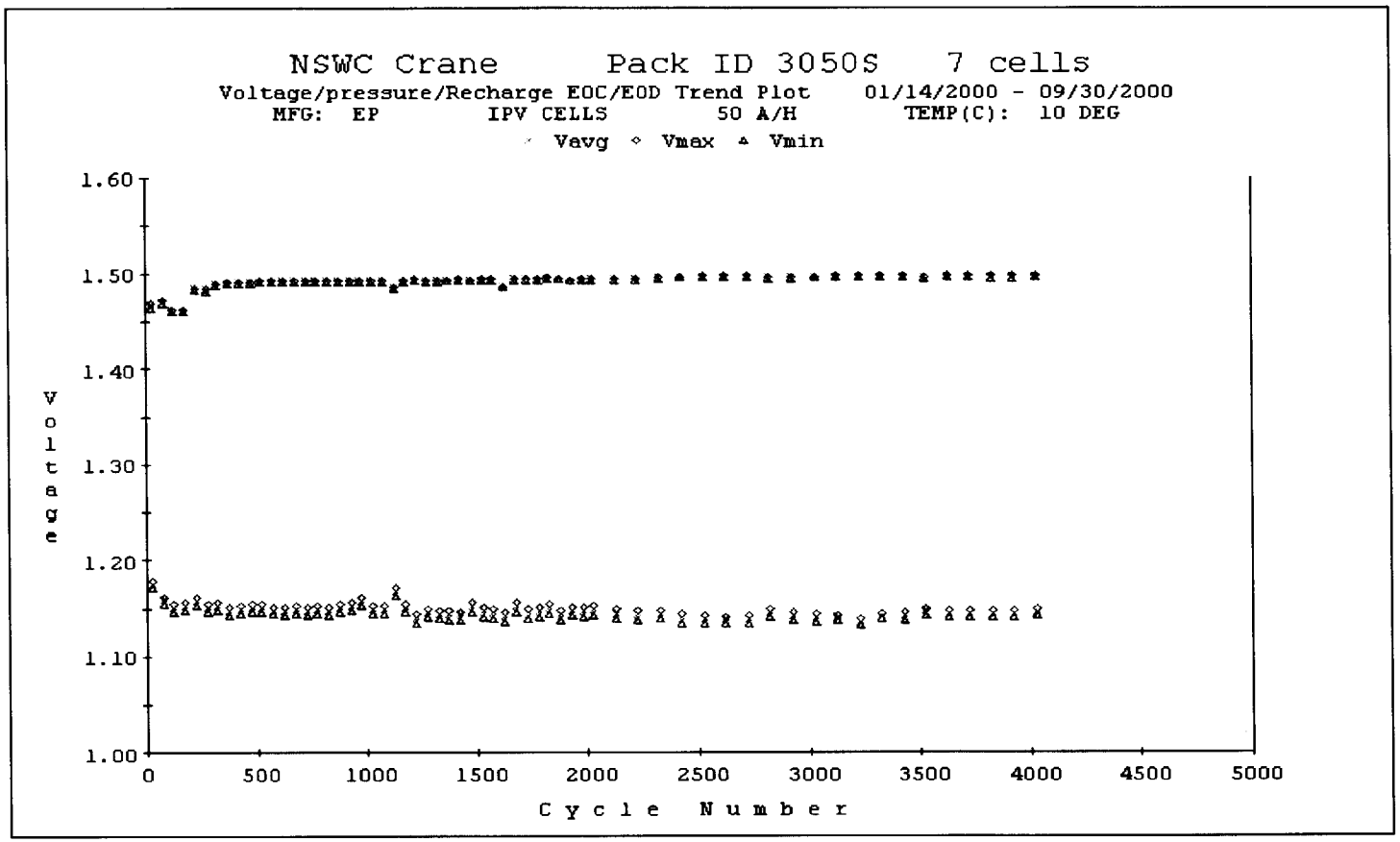

NSWC Crane (MAP) Pack ID 3023T 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 12/09/1998 - 09/22/2000
MFG: EP CPV CELLS 23 A/H LOT-1 TEMP(C): 10 DEG DOD(%): 60
- %Rchg
Pressure
Percent Recharge
Cycle Number
1000
900
800
700
600
500
400
300
200
120
118
116
114
112
110
108
106
104
102
100
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000

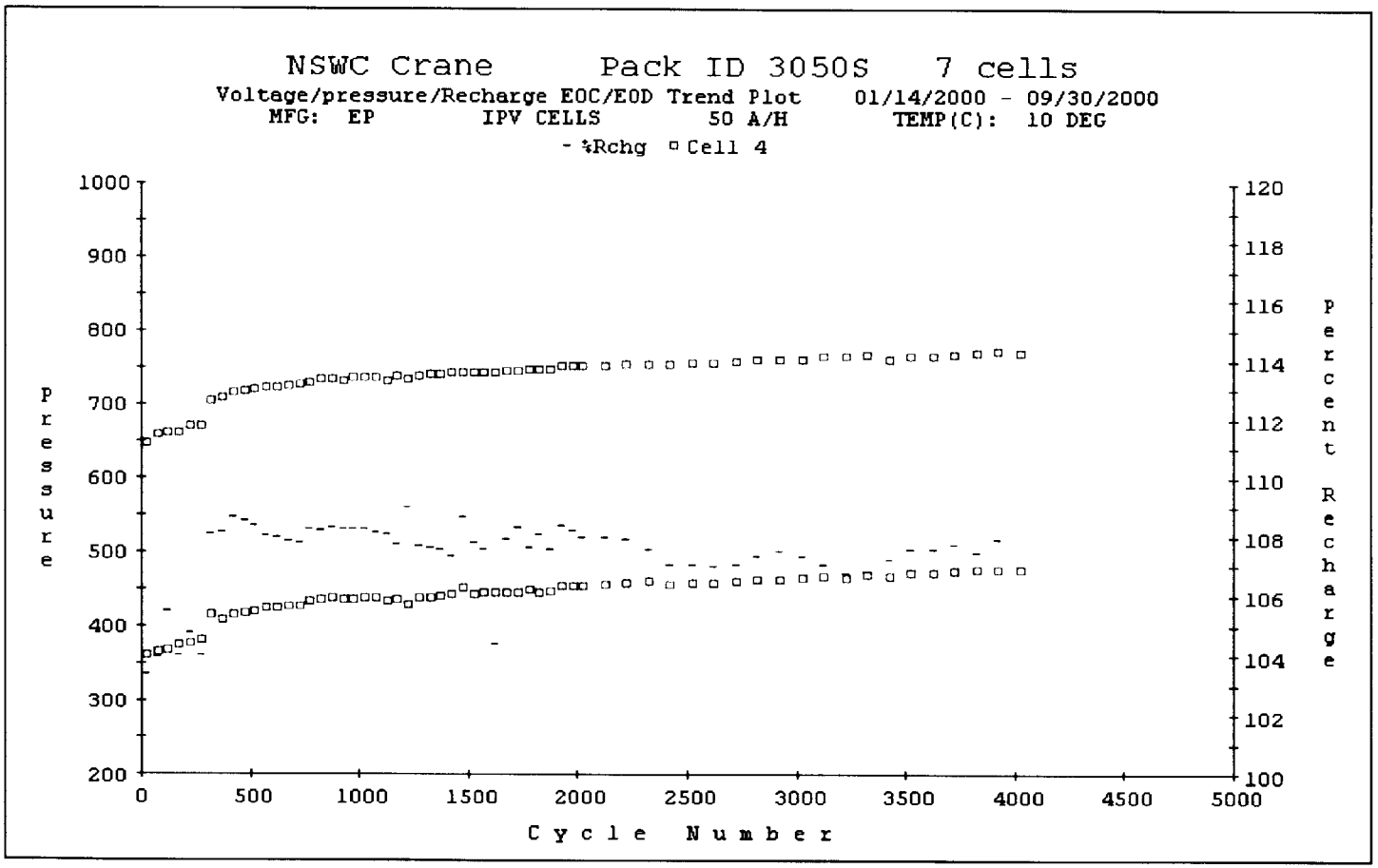


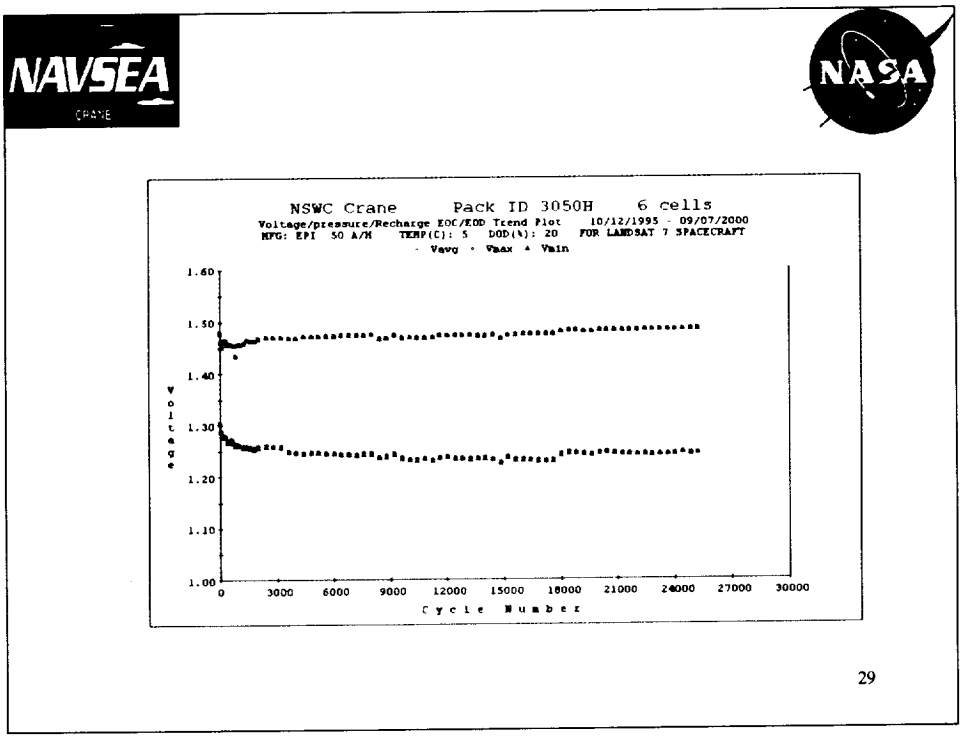
Cells from battery for LANDSAT spacecraft

About 3 years of wet storage

STRESS TEST - The pack is currently cycling according to the following conditions -- 20°C -- 90 minute orbit -- Constant current discharge of 60.0 ± 0.05 A for 30 minutes -- 60% DoD -- Constant current charge of 40.7 ± 0.05 A to a voltage limit o 1.54V per cell then trip at a recharge ratio of 108 ± 2%. Followed by a trickle charge for the remainder of 60 minutes.


NSWC Crane Pack ID 3050S 7 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 01/14/2000 - 09/30/2000
MFG: EP IPV CELLS 50 A/H TEMP(C): 10 DEG
Vavg Vmax Vmin
1.60
1.50
1.40
1.30
1.20
1.10
1.00
Voltage
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Cycle Number

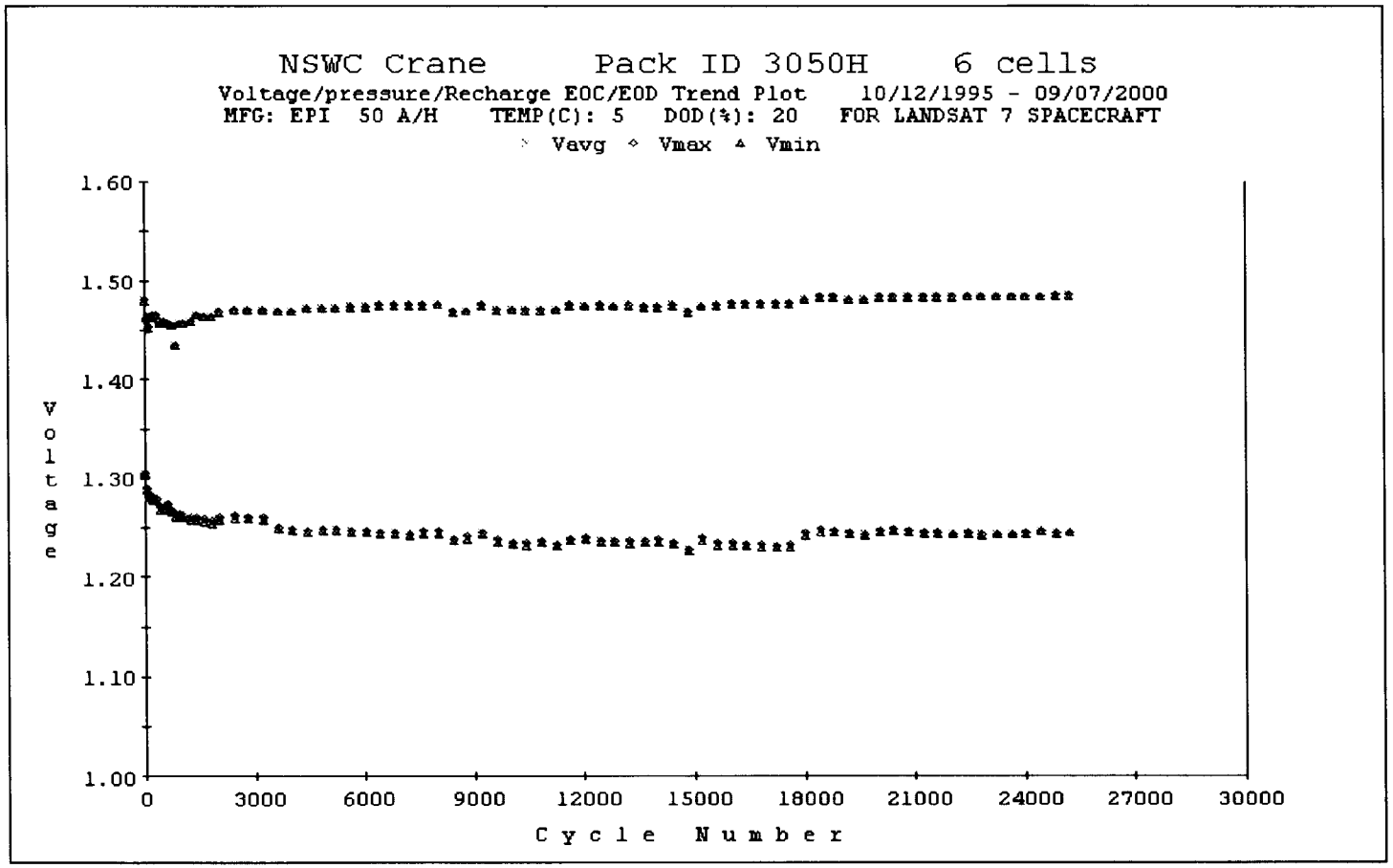

NSWC Crane Pack ID 3050S 7 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 01/14/2000 - 09/30/2000
MFG: EP IPV CELLS 50 A/H TEMP(C): 10 DEG
- %Rchg Cell 4
Pressure
Percent Recharge
Cycle Number
1000
900
800
700
600
500
400
300
200
120
118
116
114
112
110
108
106
104
102
100
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

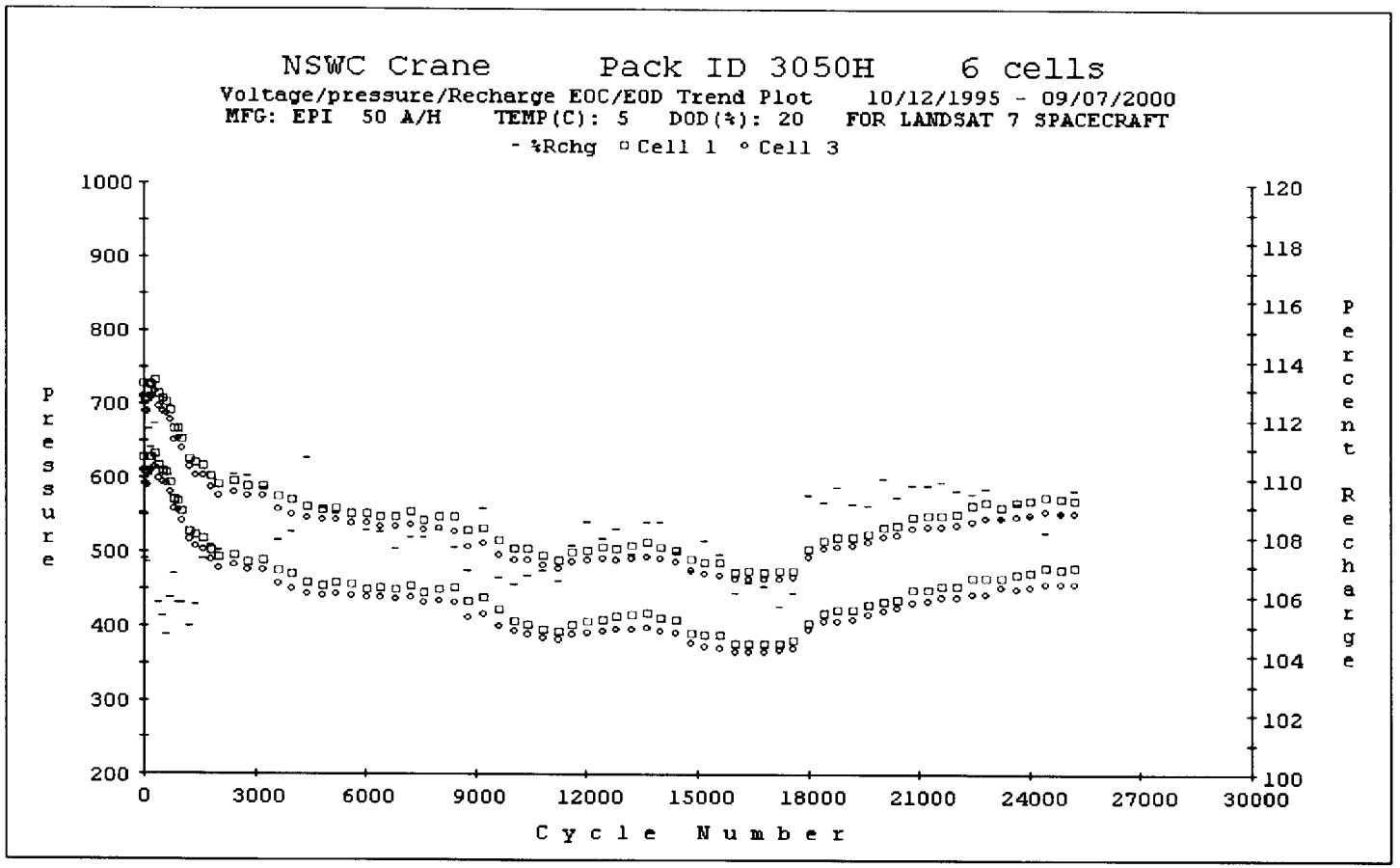


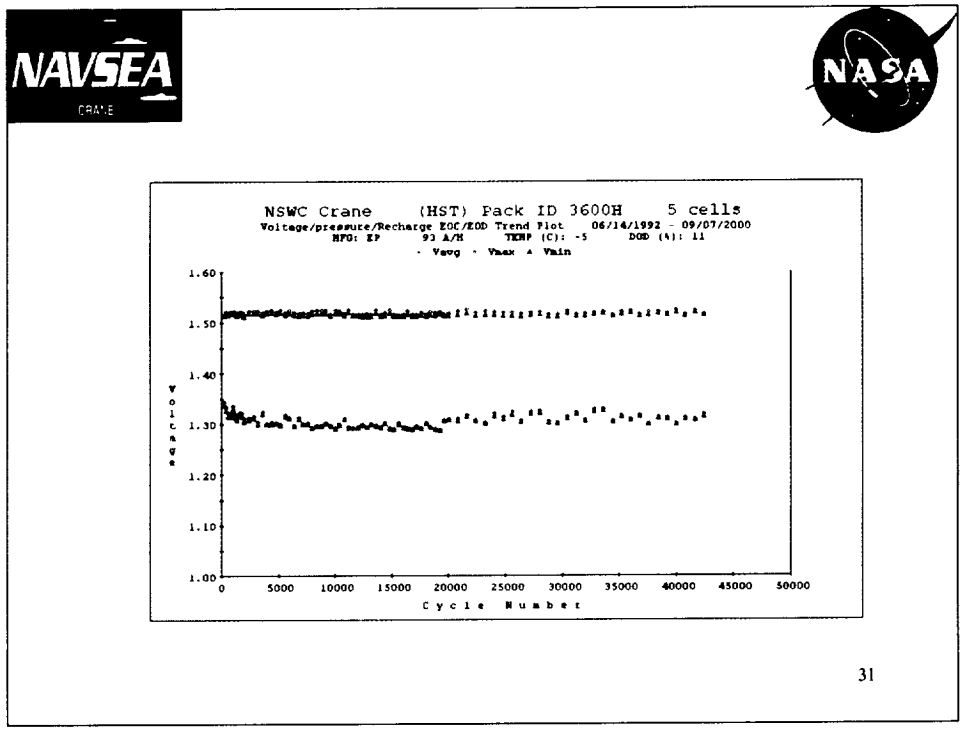
These 50 Ah Nickel Hydrogen cells are contained in one pack consisting of six cells connected in series. They were manufactured by Eagle-Picher Tech. and are identified with part number RNH-50-55 Lot 1. Pack 3050H consists of SN'S 36, 1, 56, 11, 21, and 61. Cells 36 and 56 have strain gages.

This testing is to characterize cells from this lot and to life test the cells in a simulated LANDSAT 7 mission profile.

The pack is cycling according to these current LANDSAT 7 profile conditions. 5°C -- 100 minute orbit -- Constant current discharge of 17.6 ± 0.05 A for 34 minutes during the eclipse duration -- 20% DoD -- Constant current charge of 13.0 ± 0.05 A with temperature compensated voltage (V/T) level taper at 1.500 V to a recharge ratio of 105 ± 2%. Followed by a trickle charge at a rate of 0.85 ± 0.02 A with V/T limit for the remainder of 60 minutes.


NSWC Crane Pack ID 3050H 6 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 10/12/1995 - 09/07/2000
MFG: EPI 50 A/H TEMP(C): 5 DOD(%): 20 FOR LANDSAT 7 SPACECRAFT
Vavg Vmax Vmin
1.60
1.50
1.40
1.30
1.20
1.10
1.00
Voltage
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000
Cycle Number

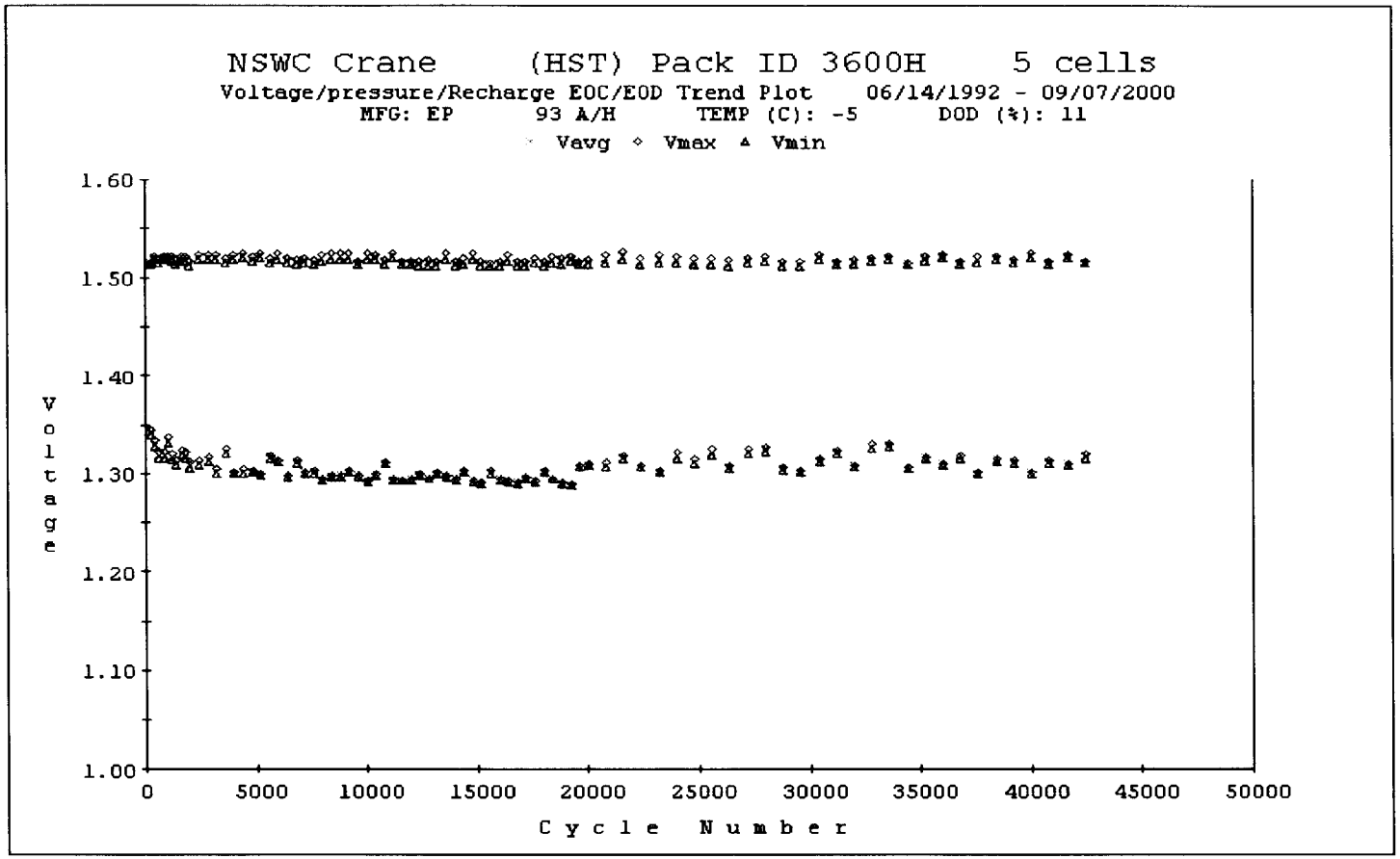

NSWC Crane Pack ID 3050H 6 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 10/12/1995 - 09/07/2000
MFG: EPI 50 A/H TEMP(C): 5 DOD(%): 20 FOR LANDSAT 7 SPACECRAFT
- %Rchg □ Cell 1 ◦ Cell 3
pressure
Percent Recharge
Cycle Number
1000
900
800
700
600
500
400
300
200
120
118
116
114
112
110
108
106
104
102
100
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000

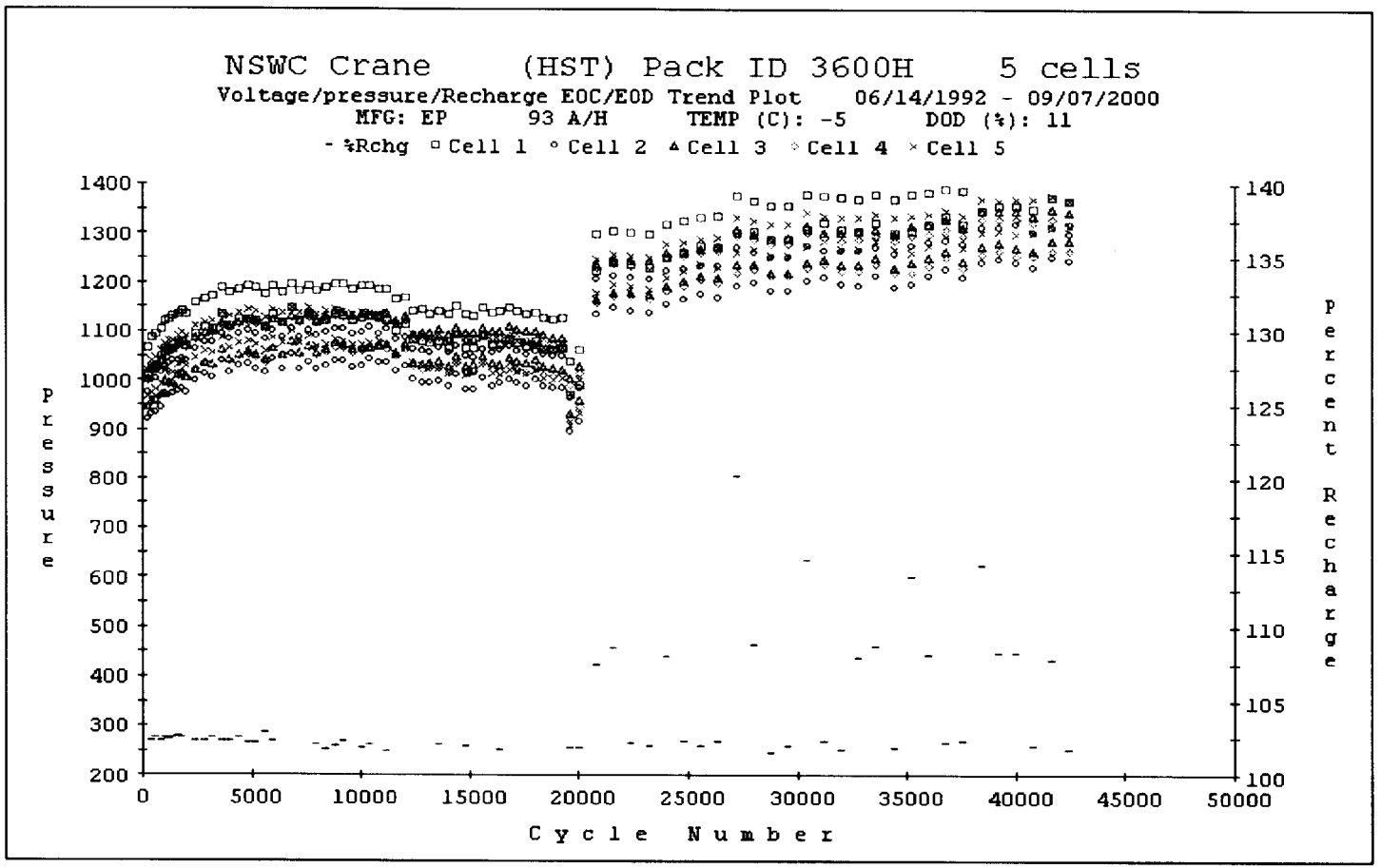


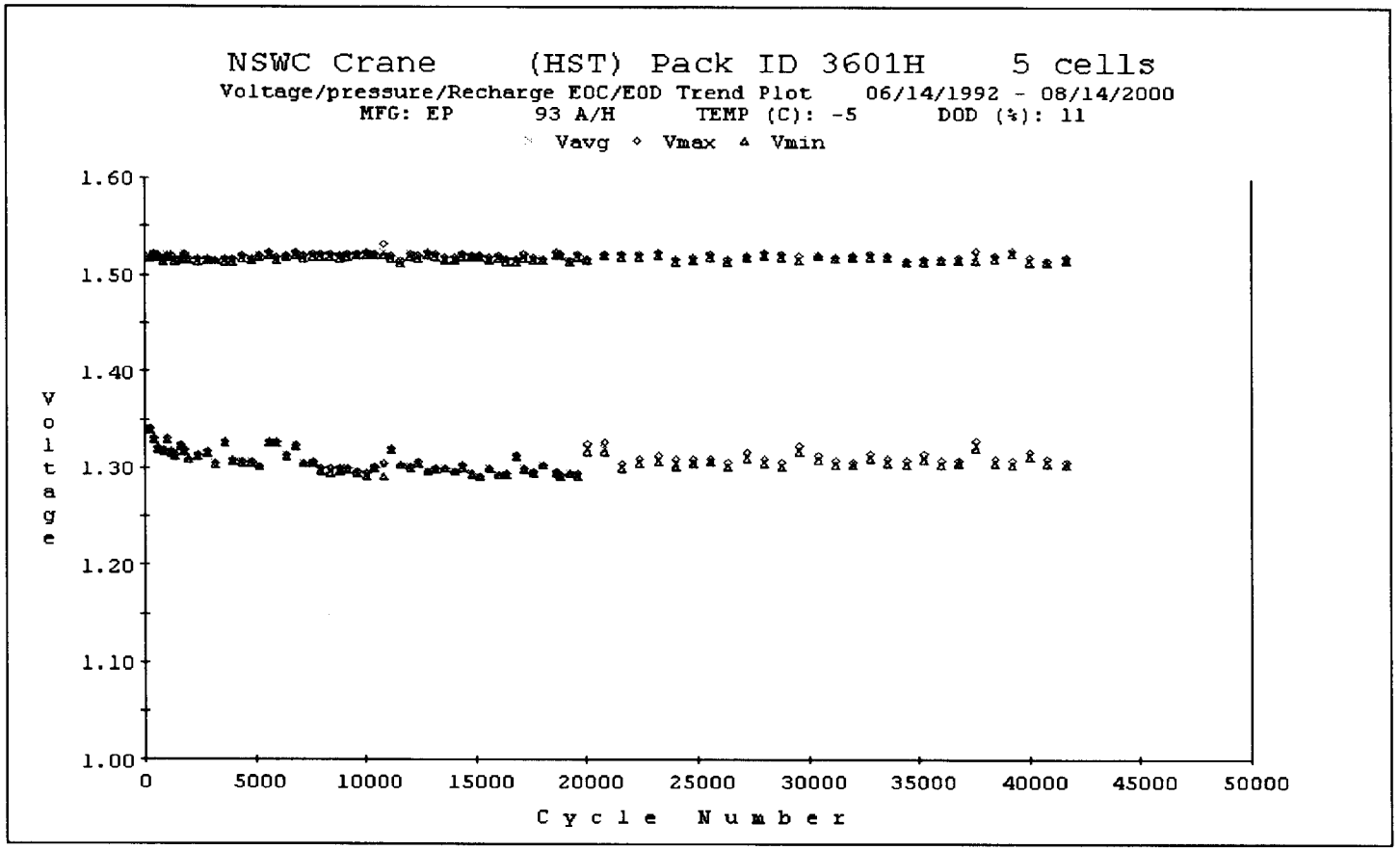
The ten cells used in these two packs were manufactured by Eagle-Picher Technologies, Inc. for the Hubble Space Telescope (HST) project and are from the Flight Module 1(FM1) and Flight Module 2(FM2) lots. The cells are connected in series. The cells from pack 3600H are from lot FM1 with the serial numbers of 308, 312, 315, 320, 323. The cells from pack 3601H are from lot FM2 with the serial numbers of 413, 414, 416, 417, 418. The cells from pack 3600H had been placed in cold storage before testing. The cells from pack 3601H are from the same lot as the cells that have been in orbit on the HST spacecraft since April 24, 1990.

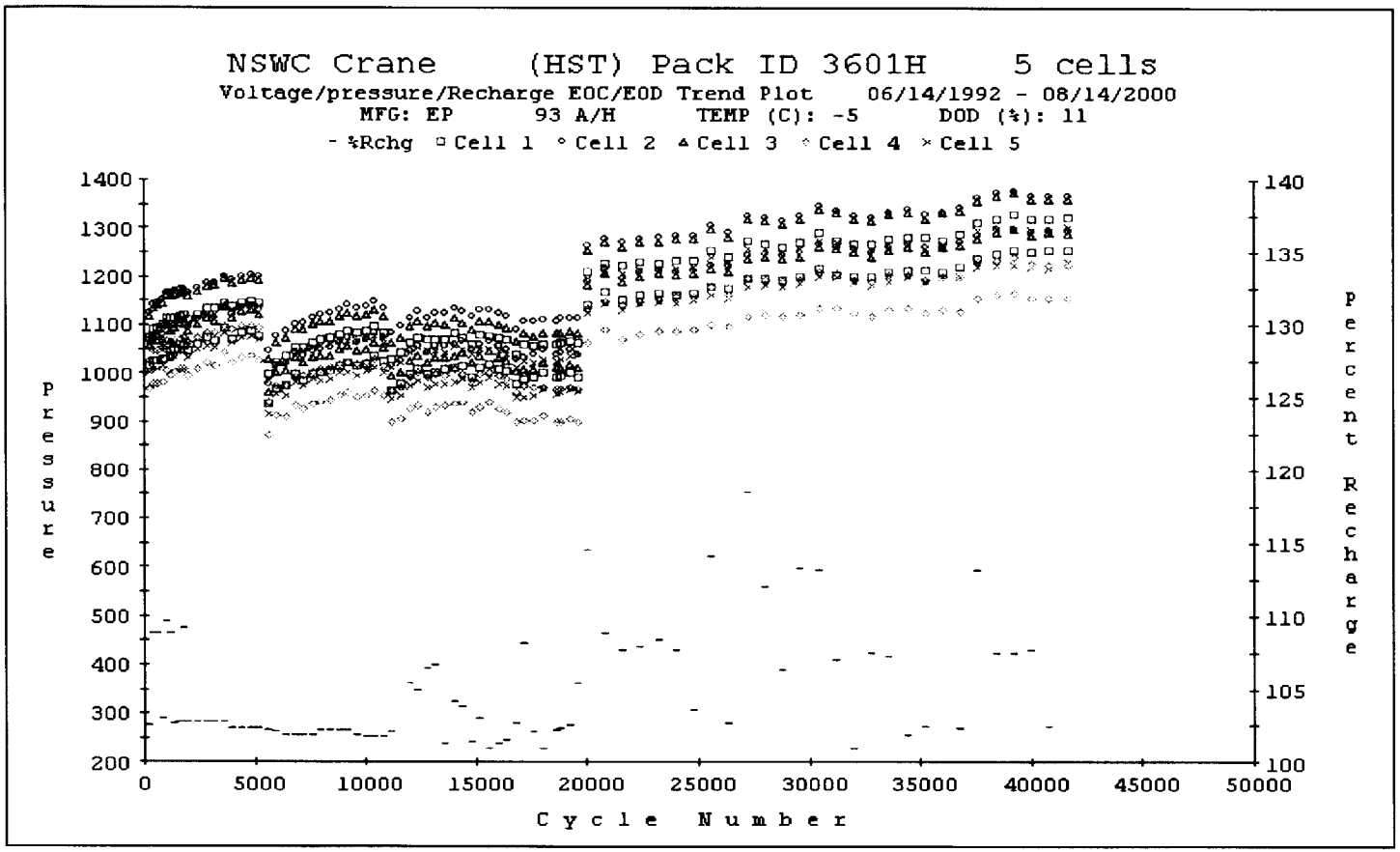
This testing is to evaluate the effects of real-time aging on the performance under HST mission operation.

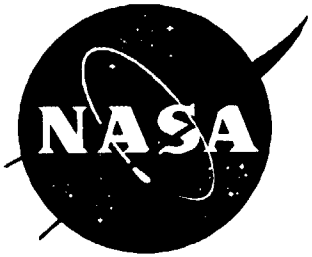
The cycling of the packs currently is being done according to the following regime. -5 ± 5°C -- 94-97 minute orbit -- Constant current discharge of 13 A during the eclipse duration -- DoD varies with eclipse duration. (6-9%) -- Constant current charge of 13.3 A to a temperature compensated voltage level and then step to trickle charge at a rate of 1.3 A for the sun duration.


NSWC Crane (HST) Pack ID 3600H 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 06/14/1992 - 09/07/2000
MFG: EP 93 A/H TEMP (C): -5 DOD (%): 11
Vavg Vmax Vmin
1.60
1.50
1.40
1.30
1.20
1.10
1.00
Voltage
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Cycle Number


NSWC Crane (HST) Pack ID 3600H 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 06/14/1992 - 09/07/2000
MFG: EP 93 A/H TEMP (C): -5 DOD (%): 11
- %Rchg □ Cell 1 ○ Cell 2 △ Cell 3 ◇ Cell 4 × Cell 5
pressure
percent Recharge
Cycle Number
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
140
135
130
125
120
115
110
105
100
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000


NSWC Crane (HST) Pack ID 3601H 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 06/14/1992 - 08/14/2000
MFG: EP 93 A/H TEMP (C): -5 DOD (%): 11
Vavg Vmax Vmin
1.60
1.50
1.40
1.30
1.20
1.10
1.00
Voltage
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Cycle Number


NSWC Crane (HST) Pack ID 3601H 5 cells
Voltage/pressure/Recharge EOC/EOD Trend Plot 06/14/1992 - 08/14/2000
MFG: EP 93 A/H TEMP (C): -5 DOD (%): 11
- %Rchg □ Cell 1 ◇ Cell 2 △ Cell 3 ◇ Cell 4 × Cell 5
pressure
percent Recharge
Cycle Number
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
140
135
130
125
120
115
110
105
100
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000



SUMMARY

- Quality EPT NI-H2, EPT Super NiCd and SAFT NiCd cells have been demonstrated for Aerospace applications
- The data has been provided to NASA Centers and other Agencies for their use and application
  - Developed plan and used in NASA in-orbit battery management
- Data Base on rechargeable cell/batteries is now available for customer use