Journal of Power Sources, 18 (1986) 209 - 221

NOAA 26.5 A h LEO CHARACTERIZATION TEST

GEORGE W MORROW

NASA/Goddard Space Flight Center, Greenbelt, MD 20771 (U S A)

Summary

Five General Electric (GE) 26.5 A h NOAA-G flight nickel–cadmium cells were obtained from RCA-Astro Electronics to undergo performance characterization testing at the Goddard Space Flight Center (GSFC). This lot of cells was manufactured with passivated positive plate, to control nickel structure attack during active material impregnation, and less electrolyte than normal (<3 ml/A h). The cells were tested in a parametric Low Earth Orbit (LEO) cycling regime that had previously been used to test and characterize GSFC standard 50 A h cells. Life cycle testing at the U.S. Naval Weapons Support Center (NWSC) in Crane, Indiana followed The results of the test showed nominal performance by comparison with previous test data on the standard 50. Life cycle testing in the NOAA orbital regime is continuing at NWSC

Introduction

The NOAA-G spacecraft battery cell flight lot was manufactured by General Electric (GE) in Gainesville, Florida, the subcontractor for RCA-Astro Electronics, the satellite contractor GE fabricated these cells using a new positive electrode processing step designed to increase the strength of the electrode by reducing attack on the nickel-sintered-structure by active material impregnation solutions. This passivation process reduces the void volume of the cell, thus reducing the amount of electrolyte that can be added. Questions about the reliability of cells with this new processing step and less electrolyte brought about characterization testing by the GSFC.

Characterization was accomplished by subjecting 5 cells to a parametric LEO cycling regime developed to characterize GSFC standard 50 A h cells. Data were then compared between the cell designs Following the characterization test, the cells were shipped to U.S. Naval Weapons Support Center (NWSC) for life cycle evaluation.

Test objectives

The objectives of this test program were (i) to study the behaviour of aerospace cells manufactured with GE positive-electrode nickel-attack-control passivation; (ii) to compare this behavior with that of cells without

3078-7753/86/$3.50

passivation, (iii) to characterize the performance of these cells in a typical NOAA orbit with the same charge voltage levels as the NOAA-F spacecraft.

Cell description

The cells tested were GE 26.5 A h aerospace nickel–cadmium cells containing third (signal) electrodes. They were manufactured with Teflonated negative electrodes, cadmium treated positive electrodes, and positive-electrode nickel-attack-control passivation The cells were manufactured to an internal GE specification approved by RCA for the NOAA-G spacecraft. The cells were from NOAA lot 11 activated in February 1984 and acceptance tested by GE prior to shipment to RCA

LEO performance characterization test description

The cells were tested in a series connected 5-cell pack separated and isolated by 3/8-in. aluminum plates followed by 0 032 in PVC sheets. The pack was held by 3/8-in. stainless steel bolts torqued to 30 lb in $^{-2}$ The cell bottoms were filled with RTV to provide a flat, thermally conductive surface The pack was wired with individual cell voltage monitors and 5 thermocouples The thermocouples were located on the tops of cells 1, 3, and 5 and on the broadface center of cells 2 and 4 For the test, the pack bottom was coated with thermal grease and placed on an active thermal cooling plate in an environmental chamber

The parametric test regime is shown in Table 1. Four charge rates (0 2 C, 0 3 C, 0.5 C, 0.8 C) and 4 discharge rates (0.1 C, 0.2 C, 0.5 C, 0.8 C) were chosen for the test. The discharge rates coupled with a discharge time of 30 min resulted in depths of discharge (DOD) of 5, 10, 25 and 40% Three voltage–temperature (V–T) charge voltage levels were chosen (GSFC 3, 5, 7) as were 3 temperatures (0, 10, 20 °C) The charge voltages corresponding to each temperature are shown in Fig. 1

During the test, 8 cycles of each of the 13 charge–discharge combinations, shown in Table 1, were completed at each temperature and voltage level Before each temperature or voltage level change, 16 stabilization cycles were run A stabilization cycle consisted of one 30 min discharge at 0.5 C followed by a 60 min voltage limit taper charge at 0.5 C to GSFC voltage level 6 at 20 °C Eight hundred stabilization cycles were also run prior to test startup to stabilize pack characteristics The entire parametric test consisted of approximately 1900 cycles

Results

Throughout the test each set of 16 stabilization cycles was compared to chart the state of the pack. End-of-discharge (EOD) voltage remained constant throughout the test as did the end-of-charge (EOC) taper current level and C/D recharge ratio. This is shown on Fig 2 Capacity performance was also very good considering the varying conditions experienced A precycling

TABLE 1

LEO performance characterization regime

Charge rate (*C*)	Discharge rate (*C*)			
	0 1	0 2	0 5	0 8
0 2	X	X		
0 3	X	X	X	
0 5	X	X	X	X
0 8	X	X	X	X

8 Cycles at each condition
Discharge time 30 min
Charge time 60 min
Voltage limits GSFC 3, 5, 7
Temperatures 0, 10, 20 °C
Note 16 baseline cycles run between each voltage limit/temperature test to stabilize pack

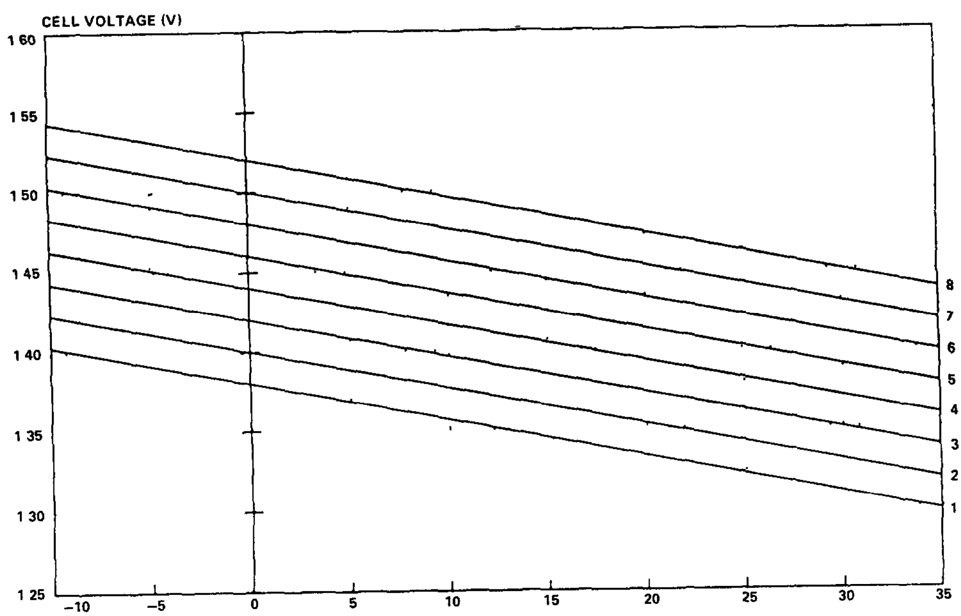


Fig 1 NASA/GSFC standard Ni–Cd voltage/temperature charge characteristics on a cell basis

capacity measurement provided 33.2 A h from the cells at an average plateau voltage of 1.24 V/cell, while a post-cycling capacity check yielded 30.1 A h capacity at an average plateau voltage of 1.22 V/cell Capacity test data are provided in Fig. 3.

Parametric test data were plotted in the form of percent. recharge (C/D) *versus* voltage level and C/D *versus* charge current level. These data were plotted against data from the standard 50 A h cells under the same

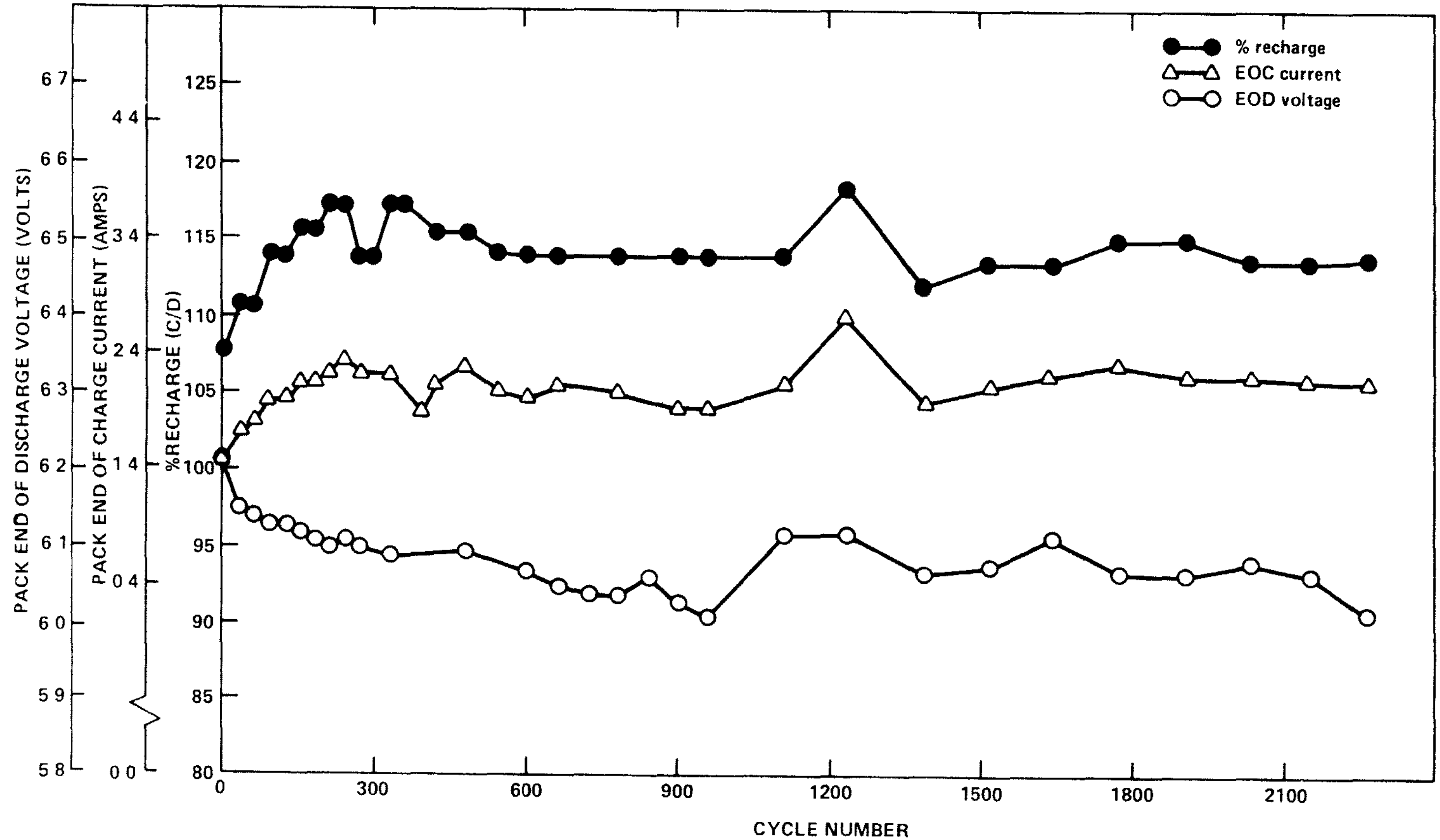


Fig 2 NOAA 26 5 A h cell parametric LEO cycling test % recharge, EOD voltage, EOC current *vs* cycle number 25% DOD, GSFC V_T6 = 1 433 V/cell, 20 °C Cycles 0 - 965 burn in, 966 - 2300 test

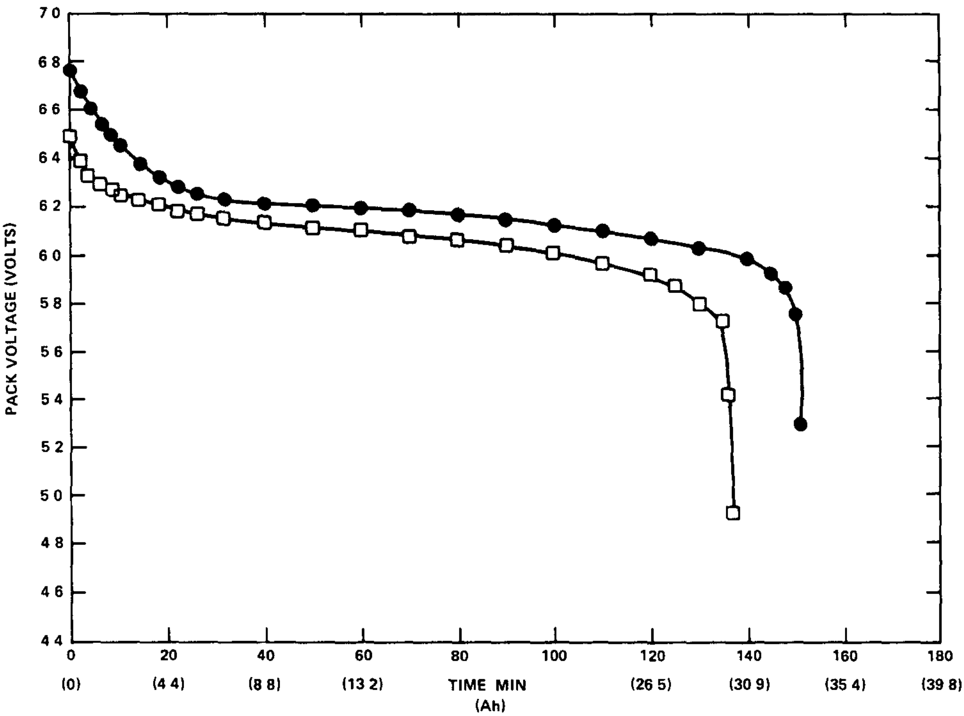


Fig 3 NOAA 26 5 A h cell LEO cycling test Precycling capacity *vs* postcycling capacity 0 5 *C* discharge to 0 75 V first cell. Temperature, 23 °C ●, precycling capacity, □, postcycling capacity

conditions The trends of these plots compare very well, as can be seen in the sample plots of Figs. 4 - 12. Actual numerical data cannot be directly compared because of differences in cell design. Trend data are expected to compare very well for all aerospace nickel–cadmium cells regardless of design, as is the case here. Poor correlation of trend data between cell designs may indicate problems related to manufacture and fabrication of the cells.

Data from this test also indicate that the cells exhibit slightly lower voltage characteristics than the 50 A h cells with which they were compared. Full recharge was reached in almost all cases at both voltage levels 5 and 7. There was, therefore, no indication of slightly higher voltages, as might have been expected from cells with low amounts of electrolyte.

NOAA regime test results

Following the LEO performance characterization test, the cells were cycled in a parametric regime with characteristics similar to those experienced on the NOAA-F spacecraft. The pack was discharged for 35 min at 0.42 *C* and charged for 69 min to RCA voltage levels 1, 2, 3 and 4 at 10 °C. Eight cycles at each voltage level were performed with 16 stabilization

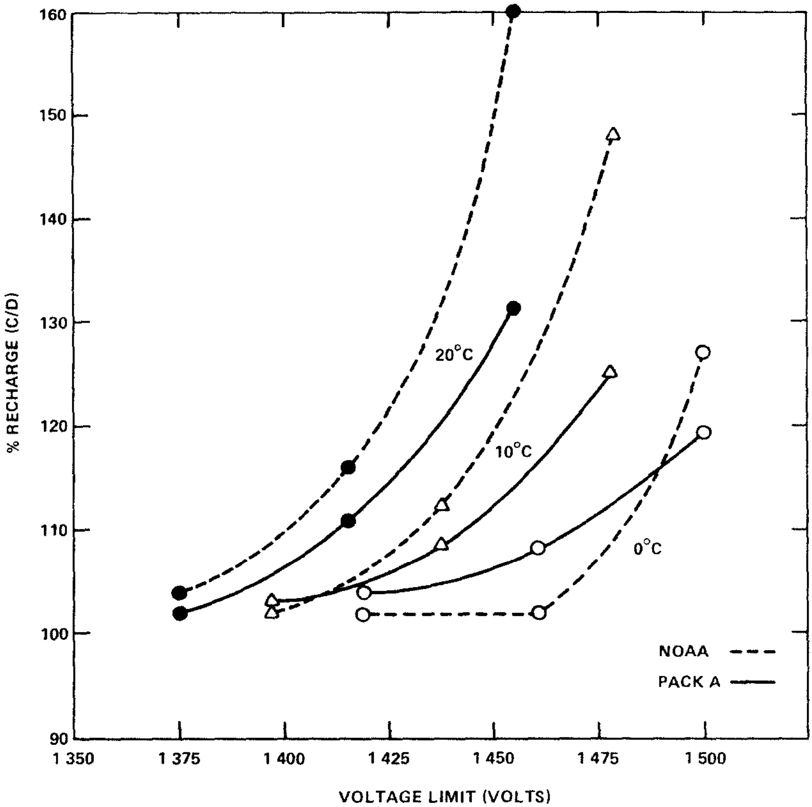


Fig 4 NOAA 26 5 A h *vs* Pack A 50 A h cells LEO cycling test % Recharge (C/D) *vs* voltage limit Charge current 0 2 *C*, depth of discharge 10% Test temperatures 0, 10, 20 °C

cycles between each voltage level change. Full recharge (>106% C/D) was reached at RCA levels 3 and 4 In all other aspects, the cells performed nominally.

Life cycle test at NWSC

In June 1985 following all testing at the GSFC, the cells were sent to NWSC to undergo life cycle testing The life cycle regime is detailed in Table 2 The cells have performed nominally since the start of testing and

TABLE 2

Life cycling regime

Temperature	10 °C
Orbit	104 min — 69 min charge 35 min discharge
Depth of discharge	25% (11 35 A, constant *I*)
Charge	7 5 A constant *I* to a voltage limit and taper
Voltage limit	1 47 V/cell (initially)

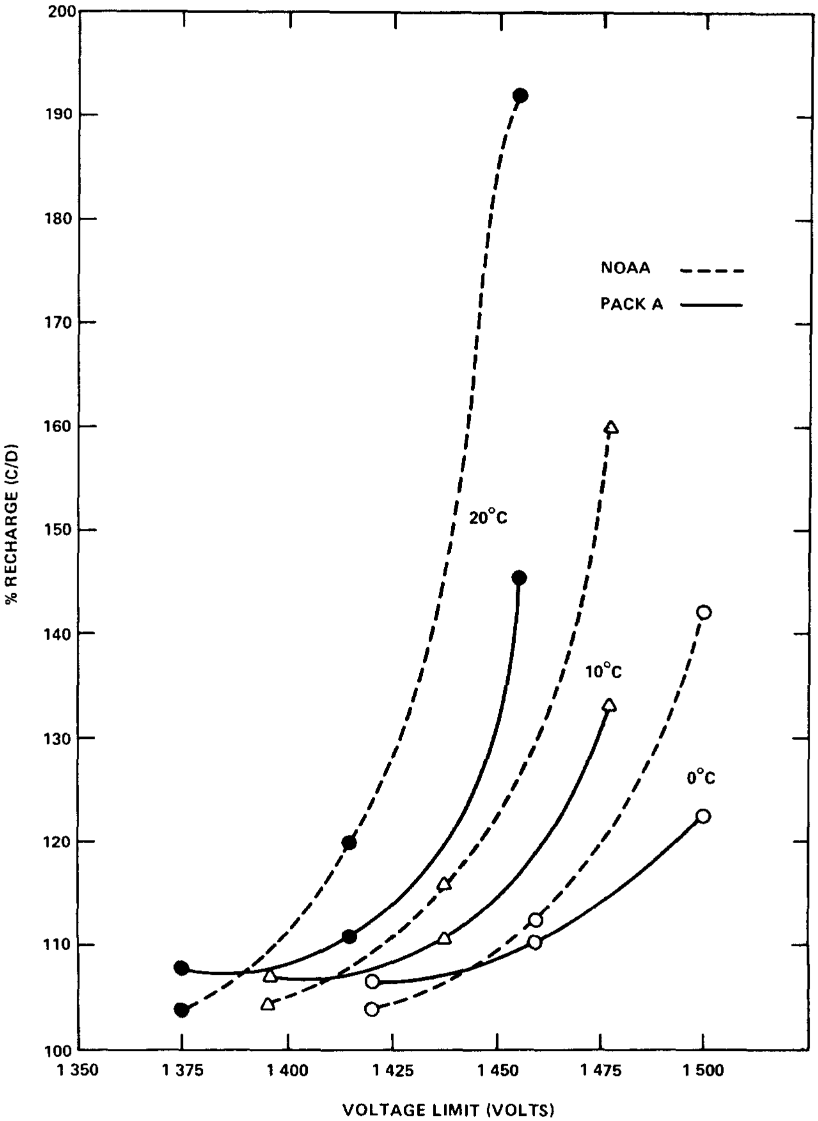
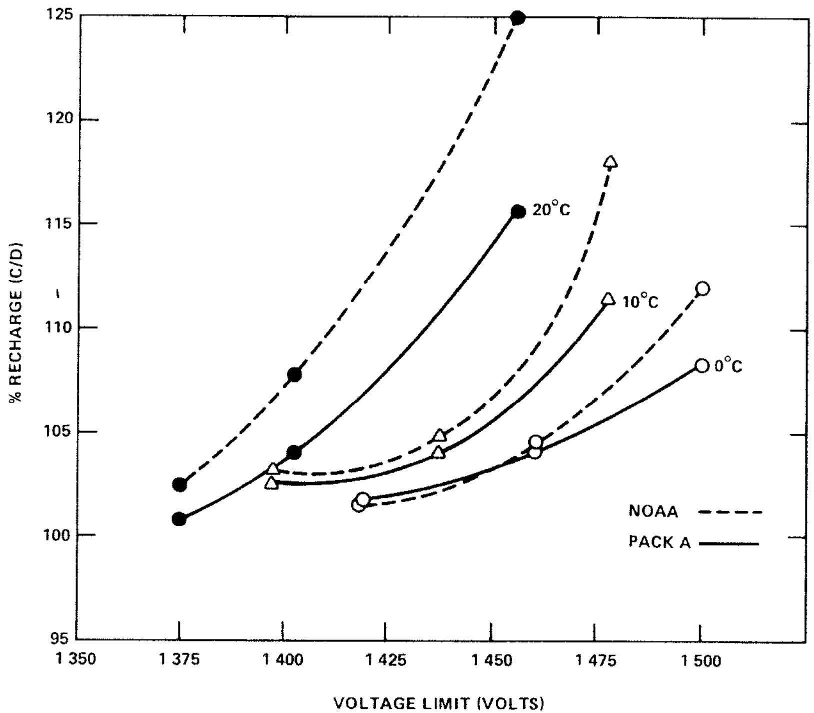


Fig 5 NOAA 26 5 A h *vs* Pack A 50 A h cells LEO cycling test % Recharge (C/D) *vs* voltage limit Charge current 0 5 *C*, depth of discharge 10% Test temperatures 0, 10, 20 °C

have undergone approximately 1200 cycles at the time of writing. The initial voltage level of 1.47 V/cell has provided approximately 106% C/D, as is shown in the typical cycle plots of Figs. 13 - 16.



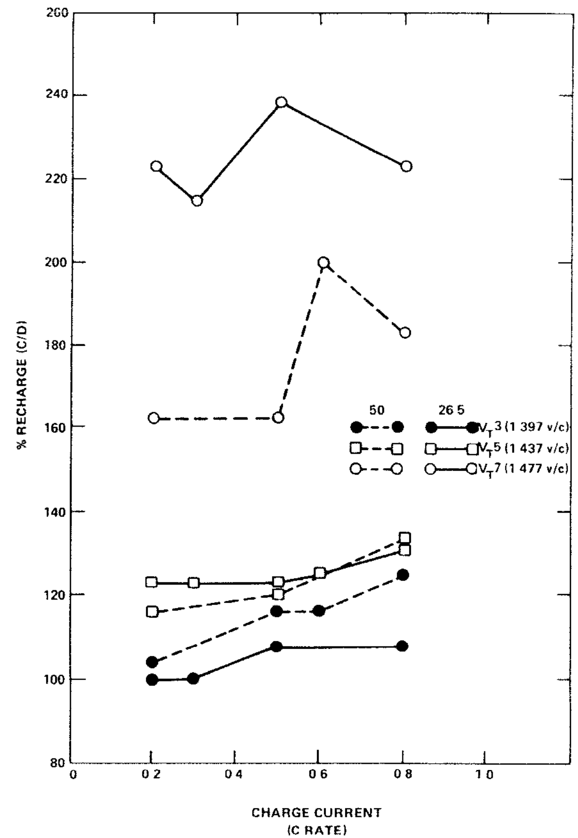


Fig 6 NOAA 26 5 A h *vs* Pack A 50 A h cells LEO cycling test % Recharge (C/D) *vs* voltage limit Charge current 0 5 C, depth of discharge 25% Test temperatures 0, 10, 20 °C

Fig 7 NOAA 26 5 A h *vs* Pack A 50 A h cells LEO cycling test % Recharge (C/D) *vs* charge current Depth of discharge 5%, temperature 10 °C

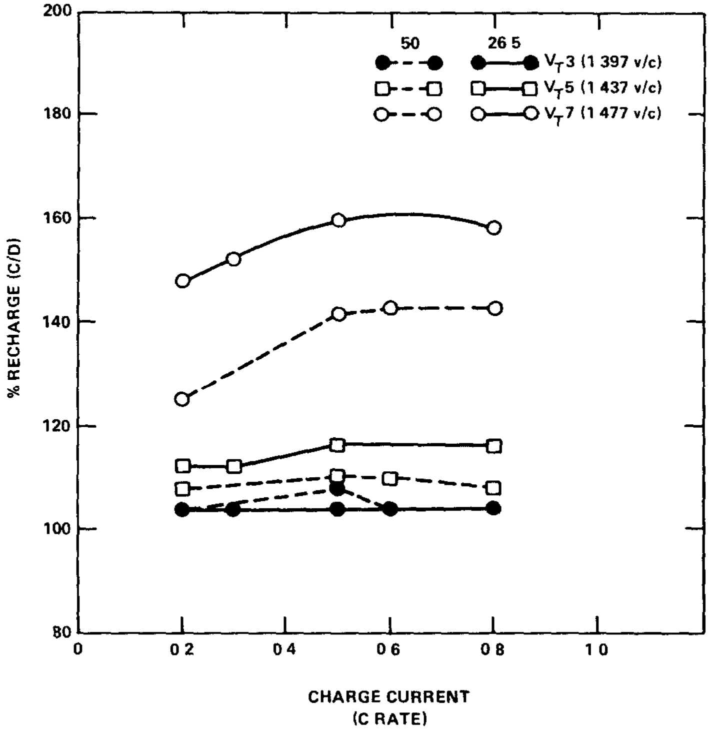


Fig 8 NOAA 26 5 A h *vs* Pack A 50 A h cells LEO cycling test % Recharge (C/D) *vs* charge current Depth of discharge 10%, temperature 10 °C

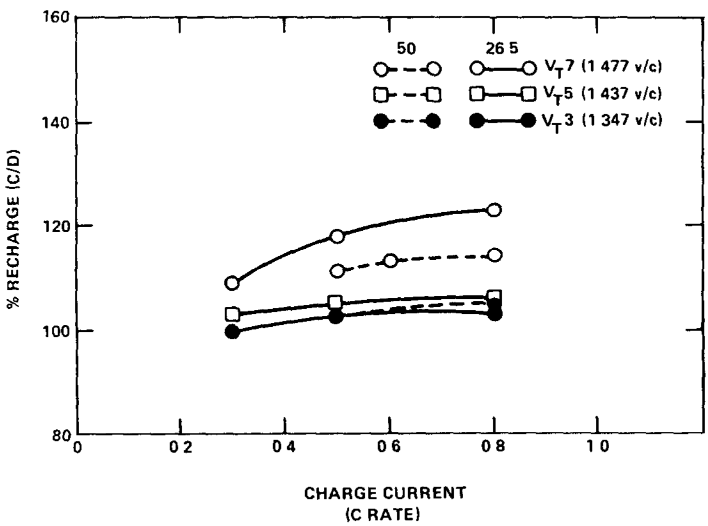
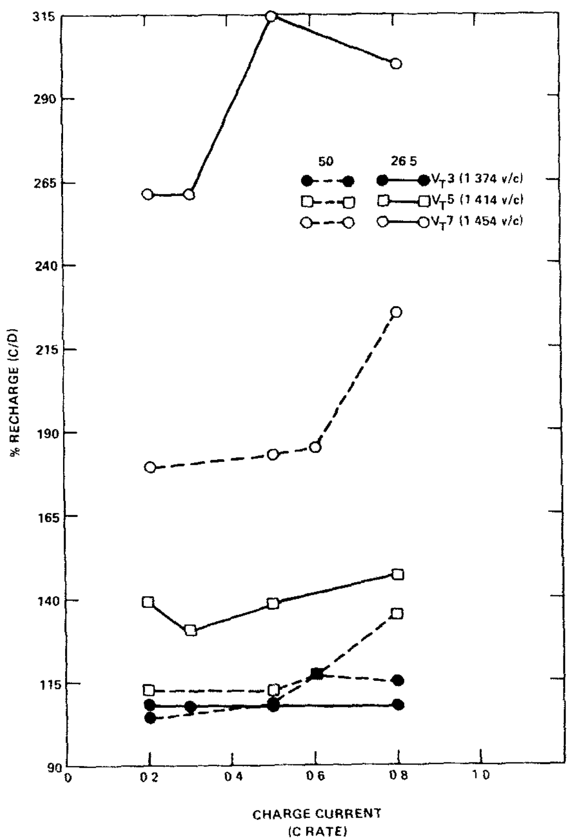


Fig 9 NOAA 26 5 A h *vs* Pack A 50 A h cells LEO cycling test % Recharge (C/D) *vs* charge current Depth of discharge 25%, temperature 10 °C



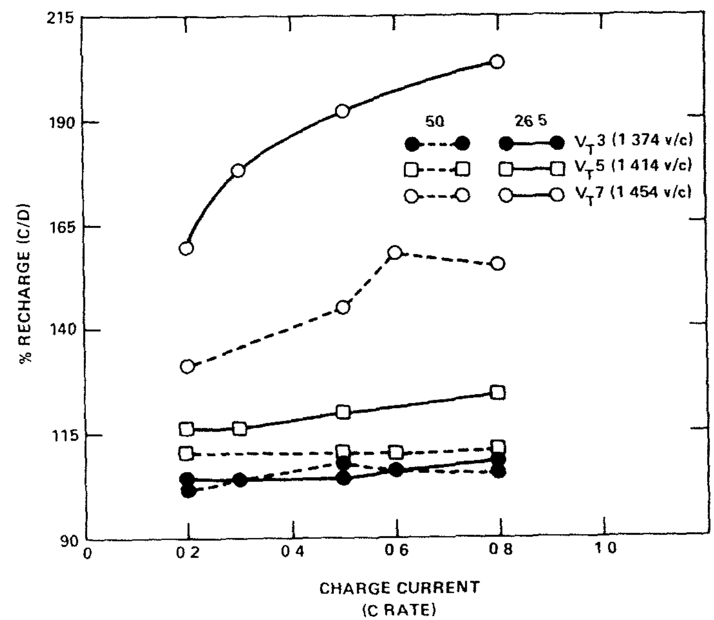


Fig 10 NOAA 26 5 A h *vs* Pack A 50 A h cells LEO cycling test % Recharge (C/D) *vs* charge current Depth of discharge 5%, temperature 20 °C

Fig 11 NOAA 26 5 A h *vs* Pack A 50 A h cells LEO cycling test % Recharge (C/D) *vs* charge current Depth of discharge 10%, temperature 20 °C

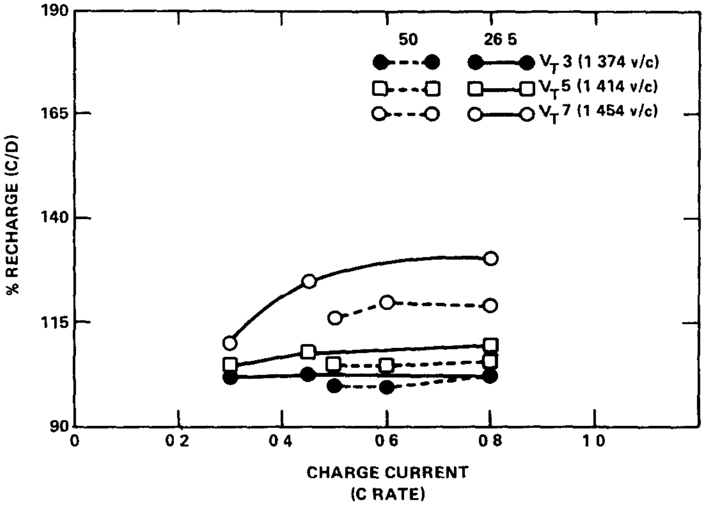


Fig 12 NOAA 26 5 A h *vs* Pack A 50 A h cells LEO cycling test % Recharge (C/D) *vs* charge current Depth of discharge 25%, temperature 20 °C

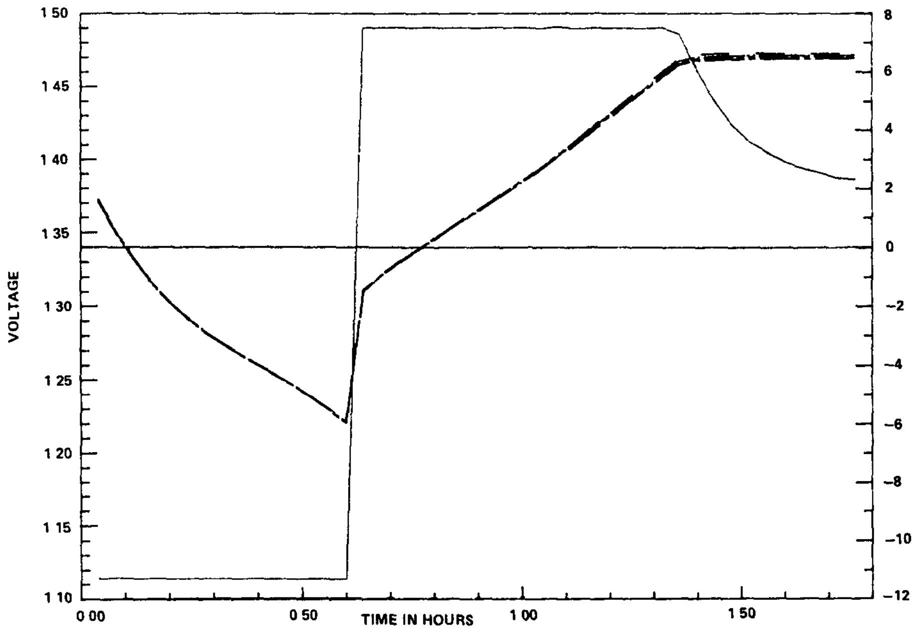


Fig 13 NWSC Crane life cycle 304 plot Pack 26J, 26 5 A h cells, manufacturer. General Electric (GE), orbit LEO, life cycle 304, temp 10 °C, depth of discharge 25 0%, C/D limit 1 036, discharge (A/h) 11.35/0 60, charge (A/h) 7 50/1 16, voltage limit (V/C) 1 470, GSFC voltage level 7, time to voltage limit (h), C/D ratio 1 058, A h out 6 781, A h in 7 175, EOC (*I*) 2 31 ——, current, voltage cell 1, ——, cell 2, ——, cell 3, — — —, cell 4, —·—·—, cell 5, —··—·— Some loss of definition is inevitable due to superimposition of the individual lines

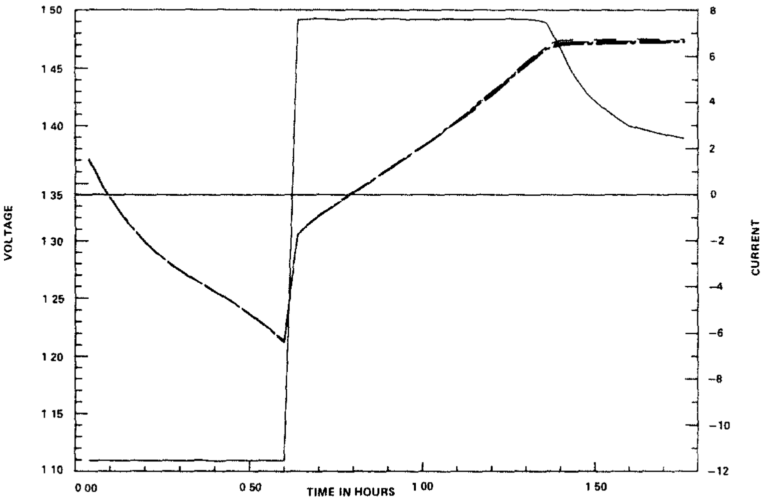


Fig 14 NWSC Crane life cycle 608 plot Pack 26J, 26 5 A h cells, manufacturer GE, orbit LEO, life cycle 608, temp 10 °C, depth of discharge 25 0%, C/D limit 1 036, discharge (A/h) 11 35/0 60, charge (A/h) 7 50/1 16, voltage limit (V/C) 1 470, GSFC voltage level 7, time to voltage limit (h), C/D ratio 1 058, A h out 6 917, A h in 7 315, EOC (I) 2 44 ——, current, voltage cell 1, ———, cell 2, ——–, cell 3, — — —, cell 4, —·—·—, cell 5, —··—··— Some loss of definition is inevitable due to superimposition of the individual lines

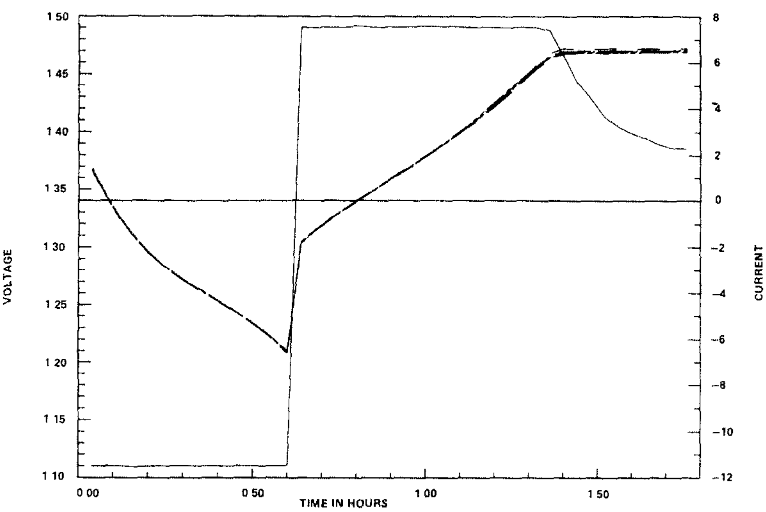


Fig 15 NWSC Crane life cycle 801 plot Pack 26J, 26.5 A h cells, manufacturer GE, orbit LEO, life cycle 801, temp 10 °C, depth of discharge 25%, C/D limit 1 036, discharge (A/h) 11 35/0 60, charge (A/h) 7 50/1 16, voltage limit (V/C) 1 470, GSFC voltage level 7, time to voltage limit (h), C/D ratio 1 047, A h out 6 908, A h in 7 233, EOC (I). 2 29 ——, current, voltage cell 1, ———, cell 2,——–, cell 3, — — —, cell 4, —·—·—, cell 5, —··—··— Some loss of definition is inevitable due to superimposition of the individual lines

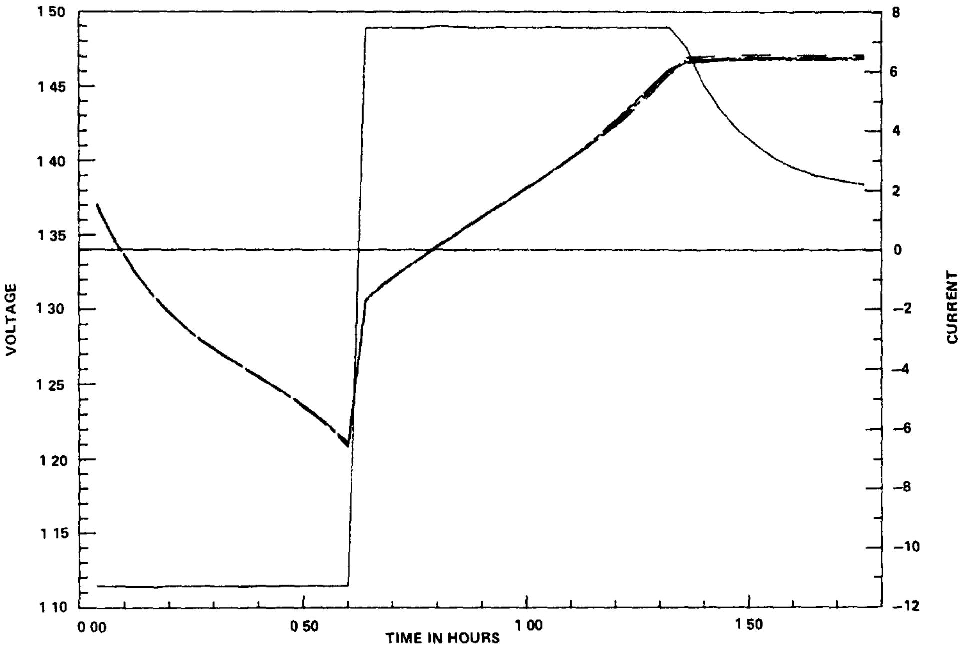


Fig 16 NWSC Crane life cycle 1001 plot Pack 26J, 26.5 A h cells, manufacturer GE; orbit· LEO, life cycle 1001, temp 10 °C, depth of discharge. 25%, C/D limit: 1 036, discharge (A/h) 11 35/0 60, charge (A/h). 7.50/1.16, voltage limit (V/C) 1 470, GSFC voltage level 7, time to voltage limit (h), C/D ratio 1 040, A h out 6 781, A h in 7 051, EOC (I) 2 19 ——, current, voltage cell 1, ——, cell 2, ——, cell 3, — — —, cell 4, —·—·—, cell 5, —··—··— Some loss of definition is inevitable due to superimposition of the individual lines.

Conclusions

LEO performance characterization tests have shown that the capacity and voltage performance of these cells are nominal. Also, parametric test data trend plots show that these cells react in a manner consistent with other aerospace nickel–cadmium cells when subjected to various charge–discharge currents, charge voltage levels, and temperatures. Further, these tests have shown that these cells obtain full recharge with the same range of charge voltage levels as experience predicts.

Parametric tests using the voltage levels and charge–discharge currents of the NOAA-F spacecraft indicate that these cells will perform satisfactorily under those conditions. Lastly, life cycle data during the first 1200 cycles of simulated LEO operation show no abnormal or unexpected behavior. In the light of the above findings, the cells should perform nominally in orbit. No problems are foreseen and no concern exists with regard to the low electrolyte levels or the positive-plate nickel-attack-control passivation.