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CONCENTRATION ON LEO CYCLE LIFE OF IPV  
NICKEL-HYDROGEN FLIGHT CELLS-UPDATE 2  
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# Effect of KOH Concentration on LEO Cycle Life of IPV Nickel-Hydrogen Flight Cells-Update II

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Battery cycle life has a major impact on life cycle cost for LEO applications such as Space Station Freedom (30 year life). The primary drivers are transportation to orbit and battery cost. As part of an overall effort to improve the cycle life of nickel-hydrogen cells the influence of potassium hydroxide [KOH] electrolyte concentration on cycle life was investigated at Hughes Aircraft Company under a NASA Lewis contract. Hughes reported a breakthrough in LEO cycle life (2,3). Boiler plate cells containing 26 percent KOH were cycled for about 40 000 accelerated cycles at an 80 percent depth-of-discharge, at 23 °C, compared to 3500 cycles for cells containing 31 percent KOH. These results are in the process of being validated under a NASA Lewis contract with the Naval Weapons Support Center, Crane, Indiana. Six, 48 A-hr capacity Hughes recirculation design IPV nickel-hydrogen flight cells are being evaluated. Three of the cells contain 26 percent KOH (test cells), and the others contain 31 percent KOH (control cells). The effect of a 31-day storage period on the Ah capacity was determined. Discharge voltage and Ah capacity comparisons at 1.4C were also made. The cells are presently undergoing real time LEO cycle life testing at 80 percent depth-of-discharge.

In this report results of cycle life testing of Hughes 48 A-hr flight cells containing 26 and 31 percent KOH electrolyte are updated (4,5).

## EXPERIMENTAL

### *Test Facility*

The facility is capable of testing 45 battery packs with a maximum of 10 cells electrically connected in series per pack. Each pack has its own charge and discharge power supply controlled by a computer programmed to satisfy the particular test requirements. During testing each pack is scanned every 2.4 min to compare data such as voltage, temperature and pressure with programmed limits. If a parameter is out of limit an alarm will be initiated and a message will be printed identifying the cell and parameter. The data is recorded on a 132 MB disc drive and if requested can be obtained in report form. The cell temperature during a test is controlled by a recirculating cooler that circulates a solution of water and ethylene glycol through a cooling plate.

### *Cell Description*

Six Air Force/Hughes recirculation design IPV nickel-hydrogen flight cells manufactured by Hughes are undergoing testing. Three of the cells contain 26 percent KOH electrolyte (test cells). The other three (control cells) are identical to the test cells except they contain 31 percent KOH. Both the test and control cells contain an equal number of components. The name plate capacity is 48 A-hr. The cell is illustrated in Figure 1. It consists of a stack of nickel electrodes, separators, hydrogen electrodes, and a gas screen assembled in a non-back-to-back electrode configuration. In this configuration, electrodes of different types directly face each other. The stack is packaged in a cylindrical pressure vessel, with hemispherical end caps. The pressure vessel is made of inconel 718 and lined with zirconium dioxide which serves as a wall wick. The components are shaped in a pineapple slice pattern. The electrodes are connected electrically in parallel. The separators consist of two layers of zircar, which extend beyond the electrodes to contact the wall wick. Hence, the electrolyte which leaves the stack during cycling will be wicked back. The gas screens are polypropylene. The nickel electrode consists of a dry sinter plaque

containing a nickel screen substrate which was electrochemically impregnated by the alcoholic Pickett process (6).

### *Measurements and Procedure*

For the experiment, the quantities measured every 2.4 min for each cell during charge and discharge and their accuracies are: current ( $\pm 2.0$  percent), voltage ( $\pm 0.001$  percent), pressure ( $\pm 1$  percent), and temperature ( $\pm 1$  percent). Charge and discharge ampere-hour capacities are calculated from current and time. Charge to discharge ratio (ampere-hours into cell on charge to ampere-hours out on discharge) is calculated from the capacities. Cell charge and discharge currents are calculated from the voltage measured across a shunt, using an integrating digital voltmeter. Cell pressure is measured using a strain gauge located on the cell dome. The temperature was measured using a thermistor located on the center of the pressure vessel dome. The thermistor is mounted using a heat sink compound to insure good thermal contact.

Prior to cell final hydrogen gas adjustment, the nickel electrodes were positively charged, which resulted in a 0 psia hydrogen gas pressure. After completion of acceptance testing, the cells were discharged at the C/10 rate (4.8 A) to 0.1 V or less. The cells were shipped to NWSO, Crane, Indiana, where they were stored at 10 °C and trickle charged at C/200 for 31 days. After storage, the discharge ampere-hour capacity acceptance test was repeated. The capacity was measured after charging the cells at the C/2 rate (24 A) for 2.0 hr, then C/10 for 6 hr, followed by a 0.5 hr open circuit stand. The discharge capacity was measured to 1.0 V at each of the following rates: C/2, C, 1.4 and 2 C.

Prior to undergoing cycle life testing the capacity retention after a 72 hr open circuit stand (10 °C) was measured for all cells. For the cycle life test, the cells were connected electrically in series to form a six cell pack. The cycle regime was a 90 min LEO orbit consisting of a 54 min charge at a constant 0.93C rate (44.7 A) followed by a 36 min discharge at a 1.33 C rate (64 A). The charge to discharge ratio was 1.048. The depth-of-discharge was 80 percent of name plate capacity (48 A-hr). During the cycle life test the cooling plate temperature was maintained at  $10 \pm 2$  °C. Cell failure for this test was defined to occur when the discharge voltage degrades to 1.0 V during the course of the 36 min discharge.

## RESULTS AND DISCUSSION

### *Storage Test*

The nickel-hydrogen battery could undergo a planned or unplanned storage due to delays prior to launch. What effect will this have on performance? The influence of storage (31 days, trickle charged at C/200, 10 °C) on the capacity of the 48 A-hr IPV nickel-hydrogen flight cells containing 26 and 31 percent KOH electrolyte is shown in Figure 2. The spread in the data indicate there is no significant capacity loss after 31 days for either the 26 or 31 percent KOH cells.

### *Performance Test*

A comparison of the average discharge voltage at 1.4C rate (3 cells) as a function of time for the cells containing 26 and 31 percent KOH was made and is shown in Figure 3. The voltage for the 26 percent KOH cells is higher than for the 31 percent KOH cells up to about an 82 percent depth-of-discharge. The discharge rate was 1.4C (67.2A) and the cell temperature was maintained at 10 °C. The ampere hour capacity for these cells is shown in Table 1 (1.4C, 10 °C). The capacity on the average for the 26 percent KOH cells was about 10 percent lower than the 31 percent KOH cells. This relatively small decrease in initial capacity is traded for a significant increase in cycle life. It should be noted that the data in Table 1 is for a 100 percent DOD. In an actual application the DOD will be much less, for instance the DOD for Space Station Freedom will be about 35 percent. At this DOD the portion of the curve in Figure 3 being operated, at is where the cells containing 26 percent KOH have a higher discharge voltage, and still have adequate capacity reserve.

### *Cycle Test*

The influence of LEO cycling at 80 percent DOD on the end of discharge voltage for the 48 Ah IPV nickel-hydrogen flight cells containing 26 percent KOH is summarized in Figure 4. One of the 26 percent KOH cells failed at cycle 15 314. The other two 26 percent KOH cells have been cycled for over 16 600 cycles during the continuing test. The influence of cycling on the end of charge pressure for the 26 percent KOH cells is shown in Figure 5. The pressure increase on the average is about 36 percent at cycle 10 634. The pressure increase could be indicative of nickel plaque corrosion which converts nickel to active material. The increase in pressure will result in a shift in the beginning of life state-of-charge versus pressure curve.

The influence of LEO cycling at 80 percent DOD on the end of discharge voltage for the cells containing 31 percent KOH is shown in Figure 6. All three cells failed (cycle 3729, 4165, and 11 355). The failure mode for each cell was characterized by degradation of discharge voltage to 1.0 V. No cell failed due to an electrical short. A comparison of the discharge curve at the beginning and end of life for Cell 1, which failed at cycle 3729 is shown in Figure 7. This information also shows a voltage degradation. For this cell the ampere-hour capacity decrease was about 33 percent (1.4C rate, 10 °C), for cell 2 it also was 33 percent and for cell 3 it was 36 percent. The influence of cycling on the end of charge pressure for the 31 percent KOH cells is shown in Figure 8. The pressure change can be correlated with the discharge voltage change due to cycling. The pressure increase for cell 3 at cycle 10 634 is 37 percent. The pressure increase is about the same as for the 26 percent KOH cells which on the average was 36 percent at this cycle.

The superior performance of the 26 percent KOH cells compared to the 31 percent cells is in agreement with boiler plate cell results reported previously (2,3). It is attributed to a crystallographic change of active material (7). Gamma NiOOH to beta in 26 percent KOH. Beta NiOOH has a lower capacity but longer life.

### *Destructive Physical Analysis*

Destructive physical analysis (DPA) of all three of the 31 percent KOH cells was completed and documented at Hughes under a NASA Lewis Contract (8). DPA of the 26 percent cell is in

process. A summary of the DPA results for the 31 percent KOH cells is as follows: All three cells failed during cycling due to a decrease in voltage and nickel electrode capacity. The capacity decrease was confirmed by measuring nickel electrode capacity in flooded electrolyte cells. Some observations which could cause the capacity decrease are nickel electrode expansion, rupture and corrosion of the nickel electrode substrate, active material redistribution, and accumulation of electrochemically undischARGEABLE active material with cycling. Cell 3 appears to have failed by gradual wear-out due to these changes. Some of the electrodes from cells 1 and 2 showed a premature capacity fading which was responsible for early failure. However, chemical analysis of these electrodes did not show anomalous results. The mechanism of the premature capacity fading is not fully understood by the present DPA. No cells failed due to an electrical short. All cells showed some increase in internal resistance after the cycle test; however, this increase itself does not appear to be the direct cause of failure. All cells showed a decrease in discharge voltage and an increase in charge voltage after the cycle test.

### CONCLUDING REMARKS

A breakthrough in the low-earth-orbit cycle life of individual pressure vessel nickel-hydrogen battery cells was reported. The cycle life of boiler plate cells containing 26 percent KOH electrolyte was about 40 000 accelerated LEO cycles at 80 DOD compared to 3500 cycles for cells containing 31 percent KOH. Results of the boiler plate cell test are in the process of being validated at NWSC, Crane. Forty-eight ampere-hour flight cells containing 26 and 31 percent KOH are undergoing real time LEO cycle life testing at an 80 percent DOD, 10 °C. All three cells containing 31 percent KOH failed (cycle 3729, 4165, and 11 355). One of the 26 percent KOH cells failed at cycle 15 314. The other two 26 percent KOH cells have been cycled for over 16 600 cycles during the continuing test.

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TABLE I.- CAPACITY OF HUGHES  
FLIGHT CELLS CONTAINING  
26 AND 31 PERCENT KOH  
ELECTROLYTE

Cell	Capacity, <sup>a</sup> A-hr	KOH concentration, percent
1	59.0	31
2	59.9	31
3	59.0	31
4	53.8	26
5	53.2	26
6	52.3	26

<sup>a</sup>Discharge at 1.4C rate, 10 °C.

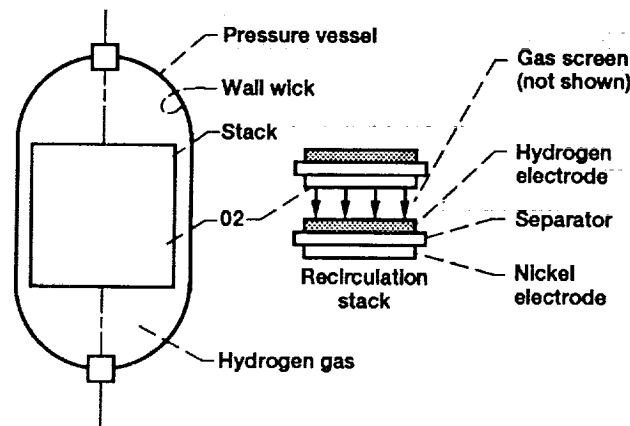


Figure 1.—Illustration of Hughes recirculation stack individual pressure vessel nickel-hydrogen cell.

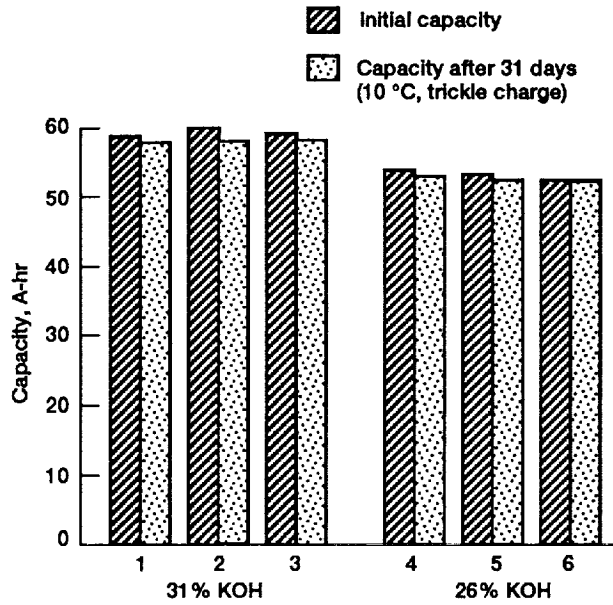


Figure 2.—Effect of storage on capacity of 48 A-hr Hughes IPV No/H<sub>2</sub> flight cells.

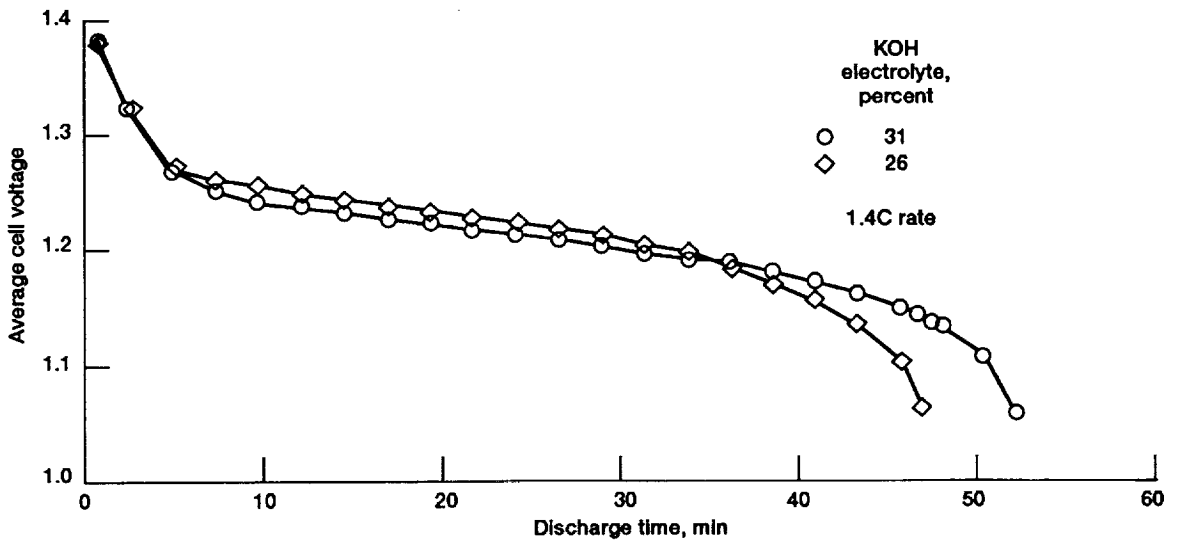


Figure 3.—Comparison of Hughes 48 A-hr IPV Ni/H<sub>2</sub> flight cells containing 26% and 31% KOH electrolyte.

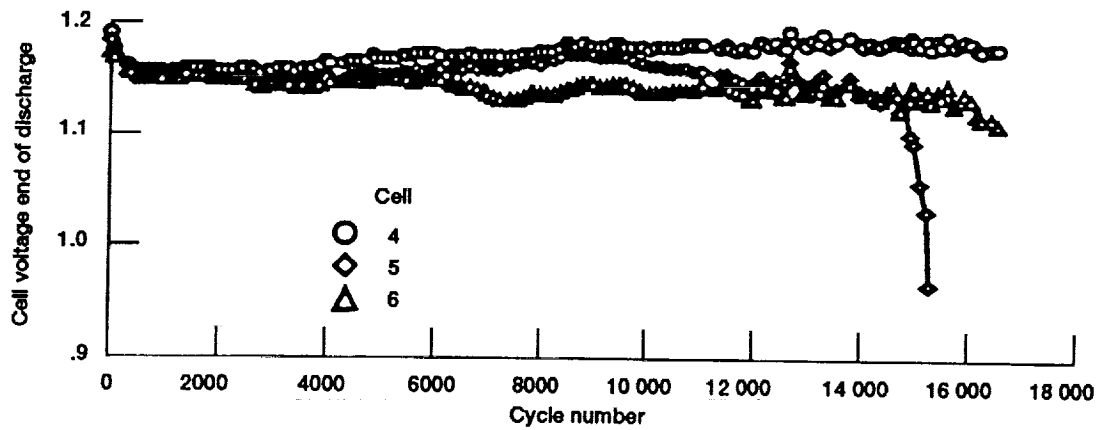


Figure 4.—Effect of Leo cycling at 80 percent DOD on Hughes flight cells containing 26 percent KOH, 10 °C.

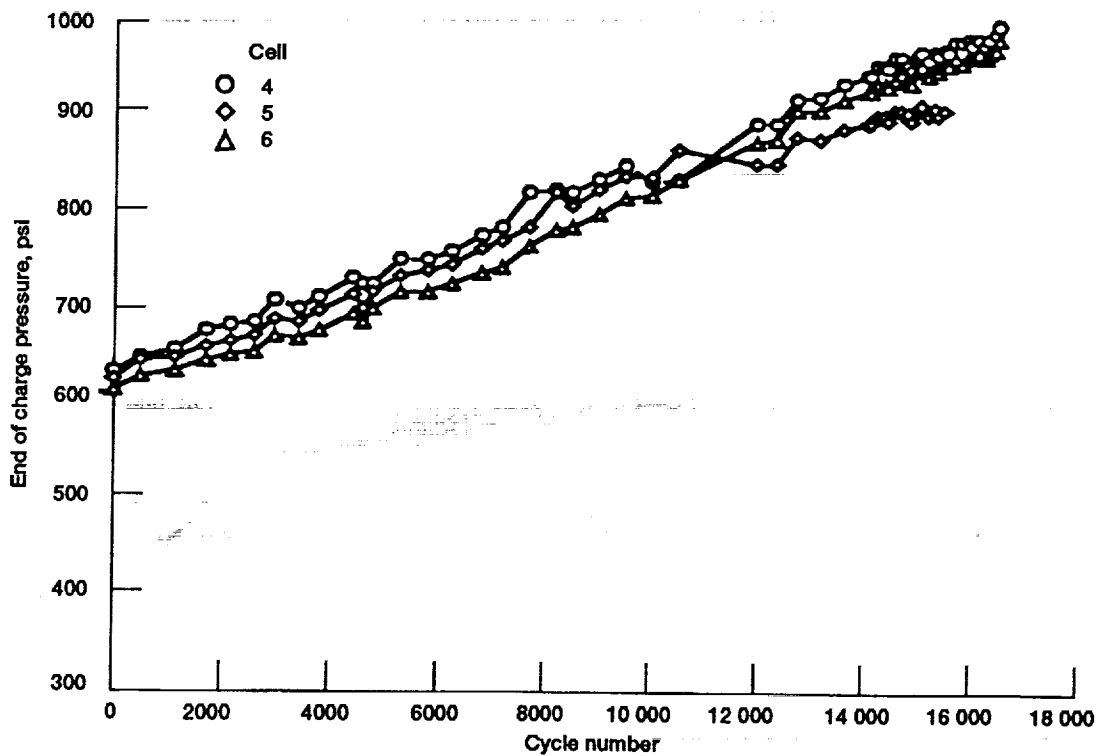


Figure 5.—Effect of Leo cycling at 80 percent DOD on Hughes flight cells containing 26 percent KOH, 10 °C.



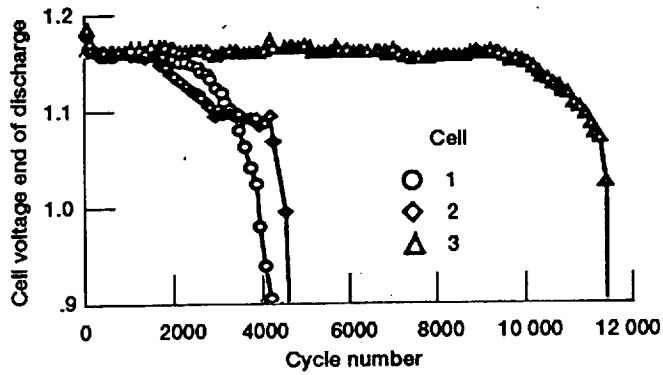


Figure 6.—Effect of Leo cycling at 80 percent DOD on Hughes flight cells containing 31 percent KOH, 10 °C.

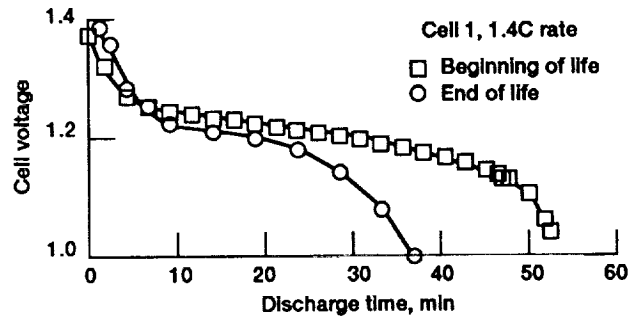


Figure 7.—Cell voltage for Hughes 48 A-hr IPV Ni/H<sub>2</sub> flight cell containing 31 percent KOH electrolyte.

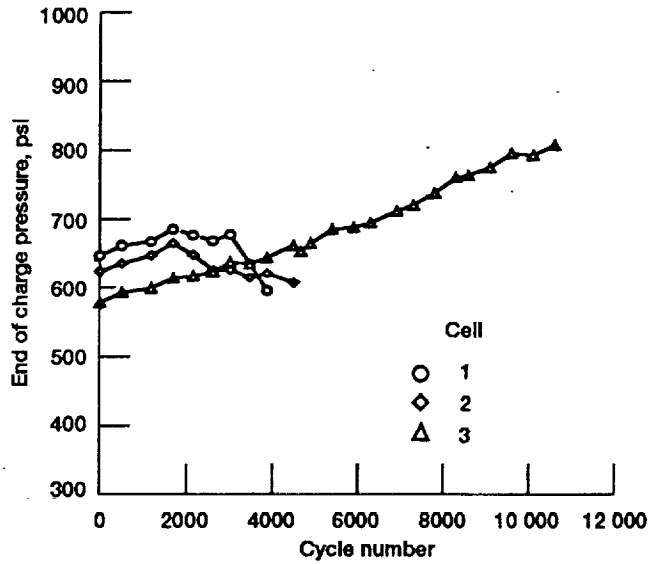


Figure 8.—Effect of Leo cycling at 80 percent DOD on Hughes flight cells containing 31 percent KOH, 10 °C.

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<b>13. ABSTRACT (Maximum 200 words)</b>  An update of validation test results confirming the breakthrough in LEO cycle life of nickel-hydrogen cells containing 26 percent KOH electrolyte is presented. A breakthrough in the low-earth-orbit (LEO) cycle life of individual pressure vessel (IPV) nickel-hydrogen cells has been previously reported. The cycle life of boiler plate cells containing 26 percent potassium hydroxide (KOH) electrolyte was about 40 000 LEO cycles compared to 3500 cycles for cells containing 31 percent KOH. This test was conducted at Hughes Aircraft Company under a NASA Lewis contract. The purpose for the contract was to investigate the effect of KOH concentration on cycle life. The cycle regime was a stressful accelerated LEO, which consisted of a 27.5 min charge followed by a 17.5 min discharge (2x normal rate). The depth of discharge (DOD) was 80 percent. The cell temperature was maintained at 23 °C. The boiler plate test results are in the process of being validated using flight hardware and real time LEO test at the Naval Weapons Support Center (NWSC), Crane, Indiana under a NASA Lewis Contract. Six 48 Ah Hughes recirculation design IPV nickel-hydrogen flight battery cells are being evaluated. Three of the cells contain 26 percent KOH (test cells), and three contain 31 percent KOH (control cells). They are undergoing real time LEO cycle life testing. The cycle regime is a 90-min LEO orbit consisting of a 54-min charge followed by a 36-min discharge. The depth-of-discharge is 80 percent. The cell temperature is maintained at 10 °C. The three 31 percent KOH cells failed (cycles 3729, 4165, and 11 355). One of the 26 percent KOH cells failed at cycle 15 314. The other two 26 percent KOH cells have been cycled for over 16 600 cycles during the continuing test.				
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