SMALL CAPACITY, LOW COST (NiH_2) DESIGN CONCEPT FOR COMMERCIAL, MILITARY AND HIGHER-VOLUME AEROSPACE APPLICATIONS

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Abstract

Nickel-Hydrogen (Ni-H_2) batteries have become the technology of choice for both commercial and defense-related satellites in geosynchronous orbits. Their use for low-earth-orbit (LEO) applications is not as advanced, but seems just as inevitable because of their inherent advantages over nickel-cadmium batteries. These include superior energy density, longer cycle life, and better tolerance to over-charge and reversal. Ni-H_2 cells have the added advantage in both construction and operation of not presenting the environmental possibility of cadmium pollution. Unfortunately, but necessarily, the design of these cells has been driven to high cost by the sophistication of the satellites and their uses. Now, using most of the same concepts but less costly materials and techniques, a low-cost, small cell design has been developed. Combined with the concept of the common pressure vessel, this new design promises to be ideal for the "small-sat" and commercial markets which, increasingly, are calling for large numbers of less-expensive satellites.

Introduction

The development of Ni-H_2 cells in capacities of 20 ampere-hours (AH) or less has been delayed because of the initial demand for development of the technology for larger satellites. Now, however, much of the same technology can be applied to smaller cells. Two cell design are manufactured at Eagle-Picher which are tailored to the specific requirements of the small satellite, not only in terms of power and volume, but also in terms of economic feasibility. These designs are based upon proven manufacturing processes and component heritage, and therefore retain the reliability and performance advantages of their predecessors. Details of these two designs are described herein.

Background and Forecast

Nickel-Hydrogen batteries are well-established as the technology of choice for geocentric satellite applications. For example, there are now approximately 30 operational satellites presently flying nickel-hydrogen batteries. Eagle-Picher has achieved more than 38 million fault-free cell hours of operation for Ni-H_2 power in orbit. Mid- and Low-orbit (LEO) applications for Ni-H_2 batteries such as military programs and the Hubble Space Telescope are just now entering service. Both commercial and government programs have required extensive development efforts to ensure reliability and optimization of weight and performance.

While these more expensive systems continue to advance, it is not too soon to exploit this technology. In fact, the need for smaller and cheaper satellites and batteries appears to be accelerating with the burgeoning communications business. Direct broadcast satellites, dedicated phone services and government concepts such as Brilliant Pebbles and Brilliant Eyes, and many others demand just such development. Coupled with this demand are increasingly- practical methods of launch such as rail-guns and the recently-successful Pegassus aircraft platform. These should go far to diminish some of the constraints on launching large numbers of less-expensive satellites.

RNH-5-1 Design Concept

There are several areas of construction which elevate the cost of production:

- Close-tolerance mechanical part fabrication
- Electrodes of exacting specification
- Pressure vessels with Mil-Spec requirements
- Labor-intensive construction

The new prototype design has incorporated improvements in these and other areas in order to reduce cost and ease of assembly while maintaining the necessary performance and long life. This represents Phase I of the development. These cells have not, however, been optimized for mass. That will be pursued in the near future in a subsequent phase.

Calculations indicate that the energy efficiency will be superior to present technology. Please see Figure 1 for a table of energy comparisons between present systems and a hypothetical, optimized two-cell CPV unit. Please note that the table does not reveal the principal advantages of a CPV design, i.e., that when built into a battery there are only half as many intercell connectors to contribute to battery mass, and that the footprint of the battery will occupy only half the area of one made with IPV cells. The operational feasibility of two-cell CPV modules has already been established [1].

Cell Energy Weight
Efficiency Comparison
WH/LB

Manufacture	5AH	10AH	15AH	20AH
Equivalent Sealed Lead	9.25	10.14	10.50	10.74
EP Sealed Lead	9.10	9.45	9.87	11.41
EP NiCad	9.27	14.55	12.77	10.00
EP NiH_2*	14.00	16.67	19.74	22.52

* Rated @ 10°C, C/2 Discharge   EP 4/23/90

FIGURE 1

For a cut-away view of the 5 AH CPV module, see Figure 2. This unit contains two cells of equal size mounted in tandem fashion. All of the cell internals are attached to a header, or base plate, which constitutes the principal structural component. The header contains both terminals, the electrolyte filling port, and the mechanical attachment stud for the cell stack assembly. Therefore several machining operations are consolidated in one piece. Cell activation is accomplished with automatic equipment through a small hole in the header. This will be subsequently sealed by insertion of a metal ball. This sealant method was successfully developed and tested at over 2,000 psi for a different type of pressurized cell. Those cells are presently in production with well over a million cells produced.

5AH CPV

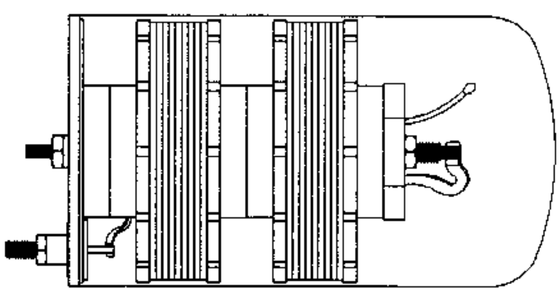


FIGURE 2

Negative electrodes are constructed on less-expensive nickel substrates and have a reduced quantity of platinum catalyst which, tests show, does not degrade performance but which substantially reduces cost. The positive electrodes are designed to be impregnated on a new, automated impregnation line which minimizes human handling. This not only reduces time, but handling damage as well.

Because all components are assembled on the header as a base plate, construction is simplified. Further, the basic design is rugged for improved resistance to launch-vibration damage and can be made even more so by optional internal bracing. This bolsters the inherent advantage of smaller mass which, in itself, makes the unit more vibration resistant. This is an obvious complement to recent innovations in less-expensive launch methodologies. The basic design has the flexibility to incorporate IPV (individual pressure vessel) or CPV arrangements and can vary in size from 5 to 20 AH's in capacity. When stacking is complete, the pressure vessel is simply slid over the cell stack assembly and mated to the header.

The pressure vessel is die-formed of stainless steel. It is electron-beam welded to the header. Due to the thickness and edge design of the header however, it can be easily arc-welded instead and that would reduce welding cost.

Prototype Operation

As Phase I, several dozen prototype modules were constructed to develop the smaller size and less-expensive materials. Five units of the most recent design iteration are undergoing electrical testing at the time of this writing. These units are designed to operate at a maximum pressure of 375 psig. Operation, as expected, conforms to the very good performance previously experienced with 40 AH CPV modules [1]. Unlike those modules these do not have a Teflon inner coating. However, the activation process was effective in overcoming the effects of electrolyte bridging. If desired for added assurance however, the Teflon coating could be easily added. It is also notable that the capacity-retention characteristics of two-module CPV cells are no different from those of IPV cells [1]. Figure 3 is a photograph of the prototype modules on test and of the preliminary Phase II design. Electrical discharge characteristics at different current densities, and pressures are shown in Figure 4.

Phase II is the weight-optimization phase. Modules for this are being built at the time of this writing (April '90) and the results should be available in the future.

The prototype modules described herein offer a significant improvement in ease of manufacture of small inexpensive nickel-hydrogen cells or CPV modules. Significant cost savings are realized from a combination of manufacturing methods and design improvements. This concept has the potential to reduce the cost of cells by a factor of 70% or more. The attributes which make $Ni\text{-}H_2$ superior to Ni-Cd and sealed lead acid batteries, i.e. higher energy density, longer cycle life and better tolerance to overcharge and reversal, will now also become cost effective for applications such as small satellites and remote power systems which

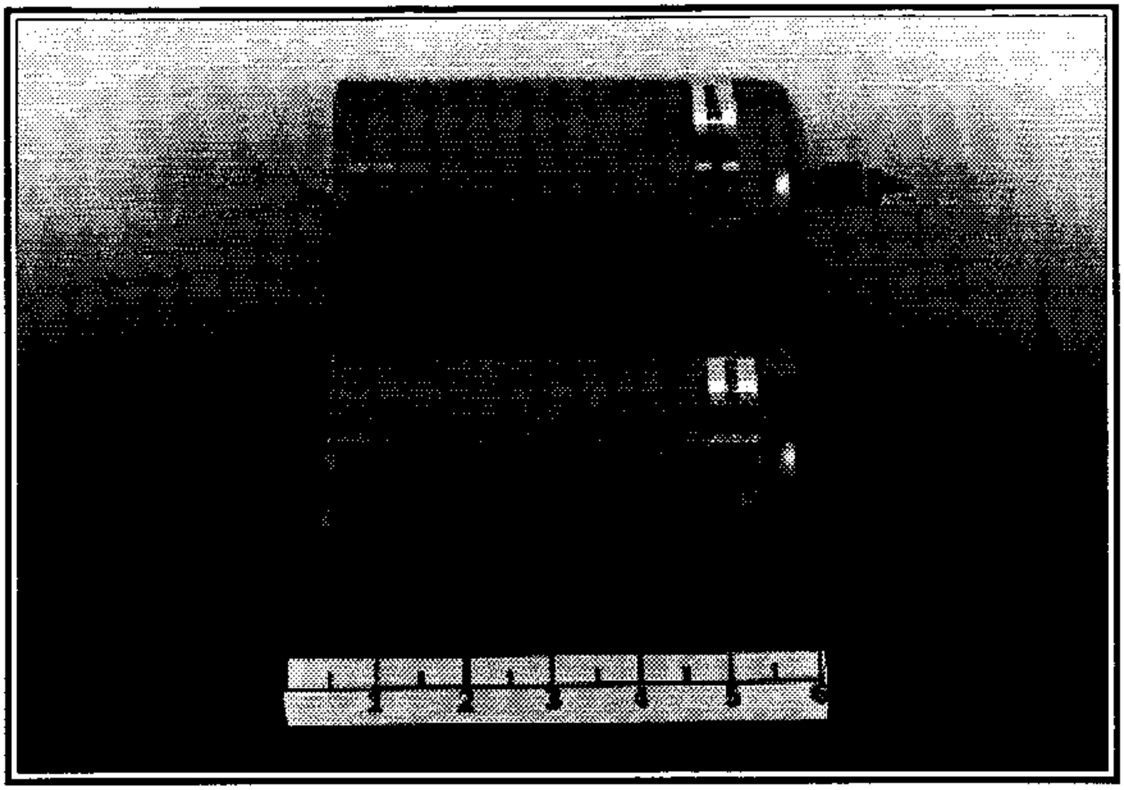


FIGURE 3

require long life (2 to 20 years) and maintenance-free operation.

For terrestrial applications the small Ni-H_2 module is less toxic in nature than Ni-Cd's, both in production and operation. Naturally the cell operating pressure can be adjusted by design as desired: higher for space use and lower for less weight-sensitive terrestrial applications.

As for use in space, the fortunate availability of CPV design at this time is especially beneficial because of the weight savings of battery-packaging. Halving the number of intercell connectors, and the half-size footprint, both serve to make this battery even more ideally-suited to smaller-diameter, smaller throw-weight launch vehicles.

RNH-12-1 Design Concept

Another design concept which is suited for use in the small satellite is Eagle-Picher's RNH-12-1, a 12 ampere-hour common pressure vessel cell. This cell design has been manufactured, tested, and delivered to Intraspace Corporation (North Salt Lake City, Utah) for use as a power source on a SPINSAT (Special Purpose Inexpensive Satellite) mission. The SALT spacecraft, designed to carry an altimeter, has a mission life specification of three years.

The RNH-12-1 is a standard 3.5 inch diameter common pressure vessel cell, with two 12 amp-hour stacks connected in series, as depicted in the accompanying sketch, Figure 5. The CPV design offers significant advantages for this battery configuration which are of particular value to the small spacecraft. By eliminating half the number of units which would be required to construct an equivalent power system of IPV (individual pressure vessel) units, the CPV design provides a 30% improvement in specific energy, a 39% improvement in energy density, and a 9.9 pound reduction in overall mass.

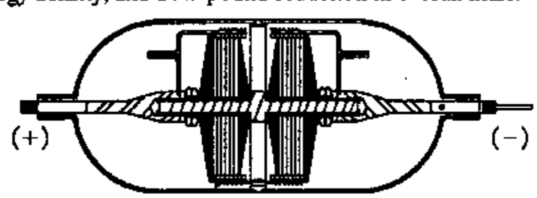
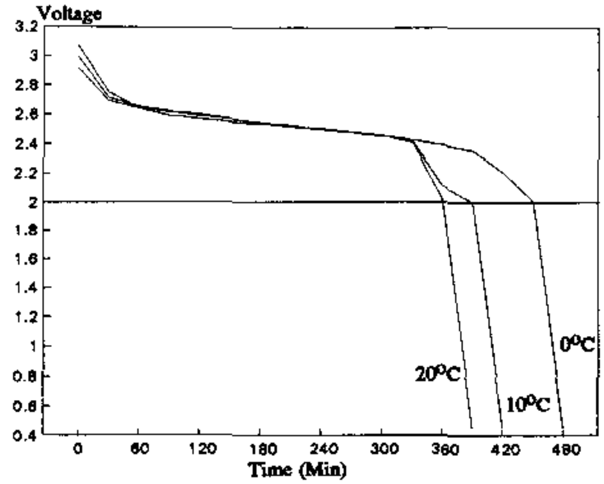


Figure 5

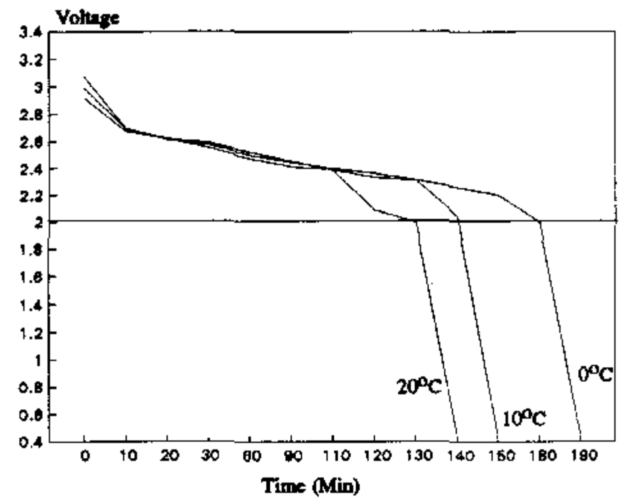
Using this concept, sizes up to 30 AH are obtainable. This cell features performance-proven components which have been used in the manufacture of over 14000 nickel-hydrogen cells at Eagle-Picher. Several of the key components are described herein.

FIGURE 4

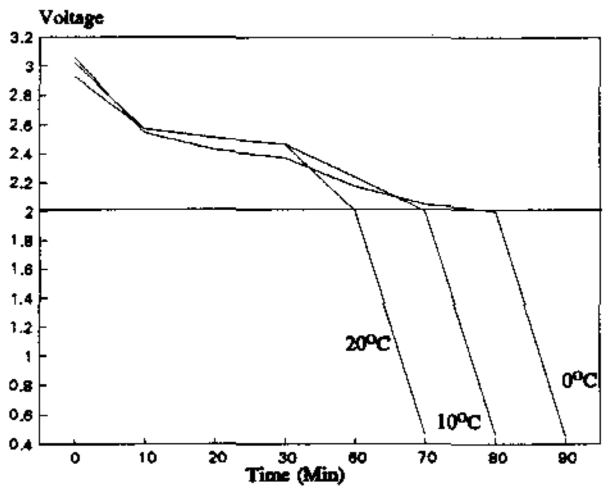
5 AH CPV CELL
Discharge 1.1A



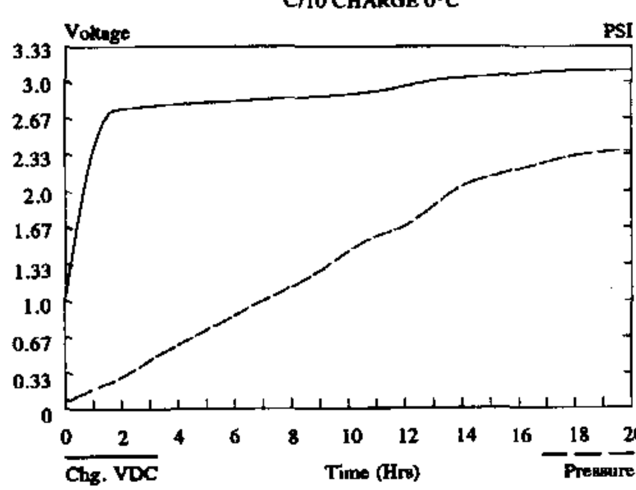
5 AH CPV CELL
Discharge 2.75A



5 AH CPV CELL
Discharge 5.5A



5 AH CPV CHARGE VOLTAGE/PRESSURE
C/10 CHARGE 0°C



A high mechanical-strength nickel slurry sinter positive electrode is used. The plate is manufactured to a thickness of .030 inches and loaded by an aqueous impregnation process.

The negative electrode used is the standard catalyzed nickel substrate collector with a Teflon film barrier backing. The catalyst is a fuel cell grade platinum mixture.

The separator is 10 mil thick and die-punched in the same profile as the electrodeswith provision for electrolyte redistribution.

An Inconel 718 pressure vessel is used, hydroformed in the standard domed cylinder configuration with axial terminal ports and a flame-sprayed ceramic wall wick (reservoir) on the inner surface. The pressure vessel is hermetically sealed at the girth using an electron beam weld and meets the requirements of MIL-STD-1522A, having a burst test strength in excess of 5 times the maximum expected operating pressure of the unit at full state of charge.

The RNH-12-1 CPV is fitted with an aluminum thermal sleeve/flange as shown in Figure 9 which provides a path for heat dissipation and serves as an interface for installation into the power system.

A select number of the cells were delivered with cell pressure monitors attached to the surface of the vessel which provide an electronic signal that indicates the state-of-charge for the battery as shown in Figure 9. The unit consists of four self-temperature-compensated strain gages connected in a Wheatstone bridge configuration which is calibrated prior to cell activation.

	RNH-5-1 (CPV)	RNH-12-1 (CPV)
Cell Diameter	2.51 inches	3.51 inches
Overall Cell Length	5.5 inches	9.0 inches
Cell Mass	1.1 lbs.	2.25 lbs.
Maximum Operating Pressure	350 PSIG	480 PSIG
Safety Factor	5:1	5:1
Capacity (at 10°C to 1.1 V/Cell)	5 amp-hours	15 amp-hours
Nominal Voltage	2.5 Volts	2.5 Volts
Specific Energy	11.3 WH/lb.	16.6 WH/lb.
Energy Density	0.55 WH/CU. IN.	0.81 WH/cu. in.
Maximum Charge Voltage	3.2 Volts	3.2 Volts

Small Satellite Cell Features
Figure 6

RNH-12-1 Testing

Twenty RNH-12-1 cells (Lot 1) were tested and found to be compliant with all the requirements of the SALT detail specification. Tests were designed which would evaluate the cell's Coulombic efficiency, voltage characteristics, and capacity, as well as tolerance of environmental conditions (random vibration and thermal cycling tests).

The cell is proven capable of maintaining full state-of-charge using a 1.05 charge/discharge ratio in a range between 5 and 80% depth of discharge. Reference Figures 7 and 8.

Voltage characteristics for the CPV cell are easily predicted by doubling the normal voltage values of an IPV cell at any point during the electrical cycle. The CPV cell design has shown through demonstration that plate-to-terminal current paths are adequate to avoid IR drop which would affect cell voltage.

10°C Charge at 1.2 Amps
RNH-12-1 Cells

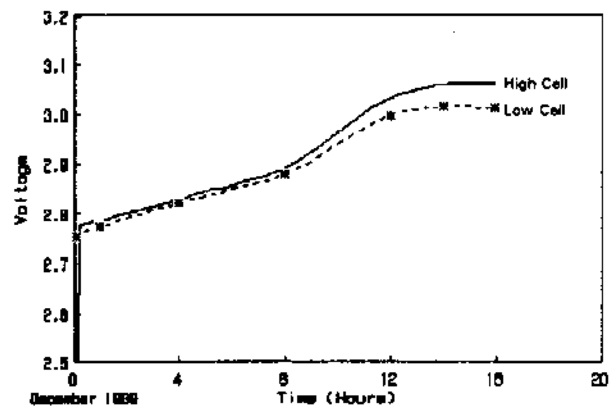


Figure 7

10°C Discharge at 6 Amps
RNH-12-1 Cells

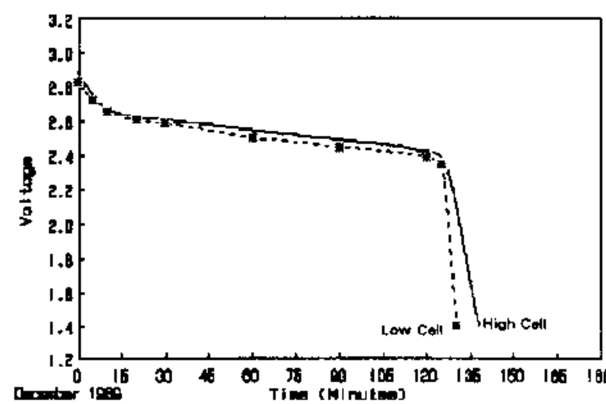


Figure 8

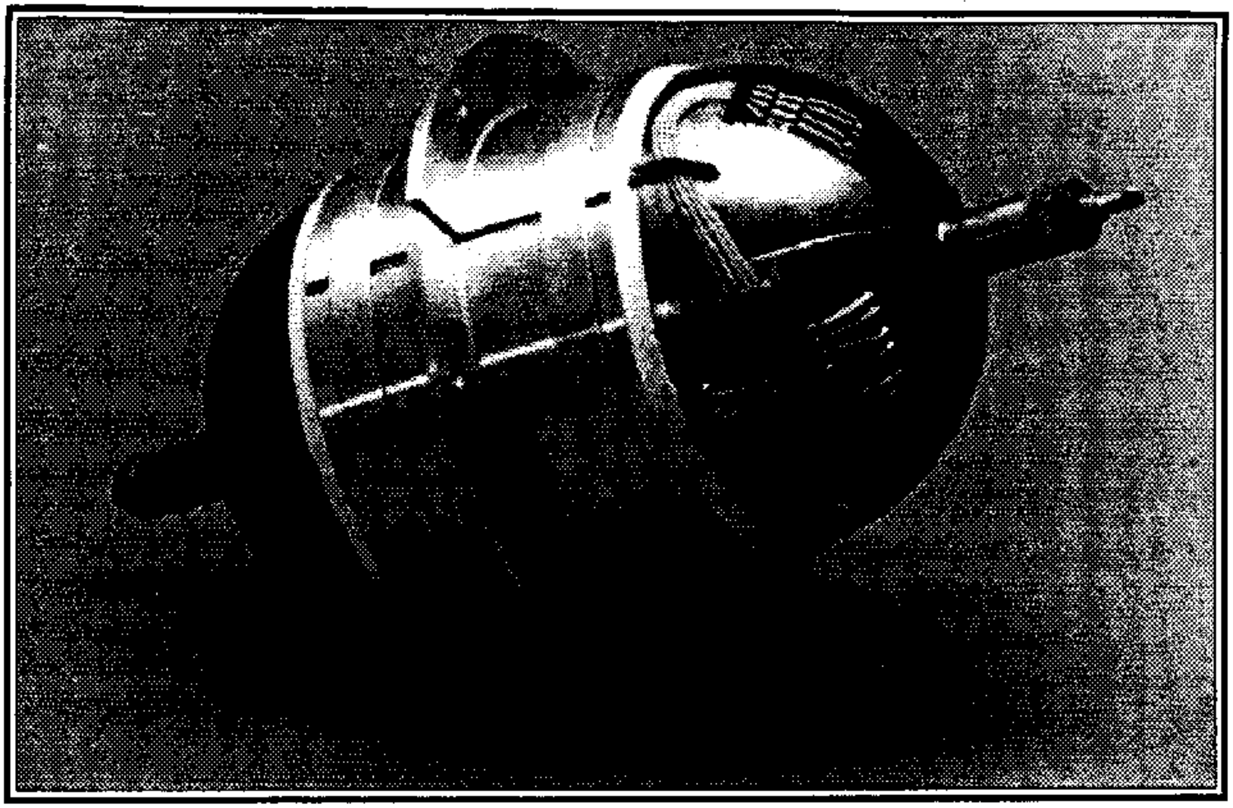


Figure 9
RNH-12-1
With Strain gage and Mounting Flange

Qualification units from Lot 1 of the RNH-12-1 cells were subjected to random vibration levels up to 18.5 grms in each of the three axes with no evidence of subsequent performance degradation. Similarly, no difference in performance was seen during or after a thermal exposure test, where the cells were subjected to 8 temperature cycles between -15° C and +35° C.

Post-Storage Testing

At the time of delivery for RNH-12-1 Cell Lot 1 (January 1990) the residual units were placed in refrigerated storage (approximately 0° C) in the fully discharged open- circuit condition. Following an approximate 5 months of such storage a standard capacity check was performed (at 10° C) and the results indicated no performance degradation secondary to storage. In fact, capacities for the two cells which were tested were slightly improved from the pre-storage acceptance tests results.

	Acceptance Testing	Post-Storage Testing
S/N 10	13.5 AH	15.0 AH
S/N 22	13.7 AH	15.1 AH

References

(1) James R. Wheeler, Burton M. Otzinger, "Common Pressure Nickel-Hydrogen Battery Development, Proceedings of the 24th Intersociety Energy Conversion Engineering Conference (August 1989), Vol. 3, pp. 1381-1386.