MULTIKILOWATT HYDROGEN-NICKEL OXIDE BATTERY SYSTEM*

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INTRODUCTION

A new development program has resulted from a favorable assessment (ref. 1) of the potential of the H_2-NiO battery for terrestrial applications. This program uses a multicell design approach that differs significantly from the aerospace individual pressure vessel design. A number of experimental 100-Ah cells were built to evaluate the new design concepts and components. Results from these experimental cells provided the input needed for a multicell battery design. Several experimental 100-Ah cells and one 6-cell battery were delivered to Sandia National Laboratories for life testing.

This new multicell H_2-NiO battery has a number of potential advantages for aerospace applications such as the manned space station. Thes advantages are discussed, and a design concept is presented for a multikilowatt battery in a lightweight pressure vessel.

AEROSPACE HYDROGEN-NICKEL OXIDE BATTERIES

Aerospace H_2-NiO cells and batteries have been developed to replace Ni-Cd batteries as the energy storage subsystem for commercial communications satellites (refs. 2-4). These batteries increase cyclic life and calendar lifetime, improve reliability, and reduce battery mass. Figure 1 shows the INTELSAT V aerospace battery.

AEROSPACE FLIGHT PROGRAMS

Programs using or planning to use aerospace H_2-NiO batteries are outlined in table I. The NTS-2 satellite launched in June 1977 was the first satellite to use H_2-NiO batteries in space. The INTELSAT V program was the first commercial communications satellite series to use H_2-NiO batteries. To date, three satellites in this series (F-6, F-7, and F-8) have been launched with H_2-NiO batteries on board, and the remaining seven satellites in the series are scheduled to use H_2-NiO batteries. All of the H_2-NiO battery systems in space are performing well.

*This paper is based on work performed at COMSAT Laboratories under the sponsorship of Sandia National Laboratories.

EXPERIMENTAL TERRESTRIAL 100-Ah CELLS

For the Sandia-sponsored program, the design approach departed from the cylindrical individual pressure vessel (IPV) aerospace cell, and instead used a prismatic multicell design approach. Cost reduction was a major incentive for using the prismatic arrangement. The challenge was to produce a workable design in this geometry. A number of experimental 100-Ah cells were designed, fabricated, and tested to evaluate new concepts and different electrode stack components.

DESCRIPTION OF 100-Ah CELLS

Figure 2 shows an assembled 100-Ah cell with the following key features:

a. The electrodes are sized at 14 cm x 12 cm x 0.76 mm.

b. The polypropylene container is one section of a standard, 6-cell, injection-molded battery container such as that employed in a 54-Ah lead-acid battery (Johnson Controls, Inc.*).

c. Threaded negative and positive nickel post terminals are employed, with nickel hex nuts.

d. The cover is heat-sealed to the case, and a gas-permeable plug is provided for hydrogen flow into and out of the cell.

e. A total of 21 or 22 positive electrodes were used to build one 100-Ah cell.

Table II describes the nine 100-Ah experimental cells fabricated to date. Reference 5 describes these cells and their performance data in detail.

PERFORMANCE

Test data were collected for these 100-Ah cells, with emphasis on the data which were most relevant to the battery design. The platinum/carbon electrode with reduced platinum loading generally performed well. Above 20°C, the positive electrodes with cadmium additive performed better than those with cobalt additive. Cells with the back-to-back electrode stack design performed best.

*Johnson Controls, Inc. (JCI) is a subcontractor to COMSAT Laboratories on the Sandia program.

Platinum/Carbon Electrode

This electrode was developed to reduce cost. The platinum content of the electrode was reduced by more than an order of magnitude, from 7 to 0.4 mg/cm^2, with no degradation in performance (see fig. 3). Cell 1 had the aerospace negative electrodes, and Cell 2 had the carbon/platinum negative electrodes. Otherwise, the components in these two cells were the same.

Self-Discharge

At 10°C, the self-discharge data for Cells 1 and 2 were identical, as shown in figure 4. The time constant was 1,748 hr.

Back-to-Back Design

Cells 3 and 9, with cadmium additive in the positive electrodes, asbestos separator material, and back-to-back design, gave the best performance. Figure 5 gives performance data for Cell 3 at 10°C. This cell completed 89 cycles at COMSAT Laboratories, and then was shipped to Sandia National Laboratories. Sandia currently has Cells 3 and 9 on a life test.

6-CELL, 7.5-V, 100-Ah BATTERY

From the experimental development effort, Cell 9 evolved as the most advanced cell design. The 6-cell stacks for the H_2-NiO battery were built to this design.

BATTERY ASSEMBLY INTO POLYPROPYLENE CONTAINER

The H_2-NiO battery, shown in figure 6, has the following salient features:

a. a standard, polypropylene, injection-molded container to house the six cell stacks;

b. a cover which was heat-sealed on the assembly line;

c. negative and positive nickel post terminals injection-molded into the cover;

d. cell interconnects within the polypropylene case; and

e. individual voltage-sensing leads to monitor the individual cell voltages, with individual caps for each of the six cells.

BATTERY ASSEMBLY INTO PRESSURE VESSEL

Figure 7 shows the battery being assembled into the pressure vessel. Note that a heat exchanger is placed around the battery case to allow temperature control of the battery during testing. The completely assembled battery is shown on test in figure 8. Also note that a gas cylinder is connected to the battery to allow for external storage of hydrogen gas. During long periods of stand, hydrogen gas can be stored externally by closing a valve, thus preventing self-discharge.

PERFORMANCE DATA

After activation, the first sealed discharge produced the voltage and pressure profiles displayed in figure 9. The capacity measured when the first cell reached 1 V was 103.7 Ah. The maximum pressure reached on charge was 332 psig without external hydrogen storage, and 230 psig with external hydrogen storage. Precharge in this battery was set at 70 psig.

COST

The battery shown in figure 6 was assembled by JCI at their lead acid battery pilot plant. All of the assembly steps followed established semiautomatic procedures. A detailed cost study is underway for a multikilowatt H_2-NiO energy storage system based on this new multicell battery. Significant cost reductions (over 30/1) are projected for this system, as compared with present aerospace IPV batteries.

SANDIA NATIONAL LABORATORIES BATTERY TEST RESULTS*

The H_2-NiO cell being cycled at room temperature (ID 351, Cell 3), has accumulated 681 cycles at 80-percent depth of discharge, and the capacity is stable at 88.5 Ah, as presented in table III. The other cell (ID 373, Cell 9), and the battery (ID 385, Battery 2), were also deep cycled, but the amount of overcharge was controlled based on the slope of the pressure-time curve. Different values of $\Delta P/\Delta T$ were used to terminate charge. The 6-cell battery has over 100 cycles at Sandia and is performing well (table III). The cell voltages are very uniform; the end-of-discharge and end-of-charge voltages for the last cycle of the set are presented in table IV.

MULTIKILOWATT BATTERY SYSTEM

This 6-cell, 7.5-V, 100-Ah battery will be the building block for a multikilowatt battery system. Ten to fifteen of these batteries could readily be connected in series and installed into one common pressure vessel, as shown

*Data courtesy of D. Bush, Program Manager, Sandia National Laboratories.

in figure 10. This configuration would provide approximately 10 kWh of stored energy (100 Ah at 100 V).

Figure 11 shows a lightweight pressure vessel version of this multikilowatt battery system. The potential advantages of this battery system for multikilowatt aerospace applications are presented in table V.

CONCLUSIONS

To date, performance data for the H_2-NiO prismatic multicell battery design approach have been very encouraging. Many of the design concepts demonstrated in the multicell 100-Ah battery are suitable for both terrestrial and aerospace applications.

REFERENCES

1. Clifford, J. E.; and Brooman, E. W.: "Assessment of Nickel-Hydrogen Batteries for Terrestrial Solar Applications: Final Report," NTIS No. SAND-80-7191, 1981.

2. Dunlop, J.: "Nickel-Hydrogen Batteries," Handbook of Batteries and Fuel Cells, David Linden, ed., New York: McGraw-Hill, 1984, p. 22-1.

3. Dunlop, J.; and Stockel, J.: "Nickel-Hydrogen Battery Technology--Development and Status," Journal of Energy, Vol. 6, No. 28, 1982, pp. 28-33.

4. Dunlop, J.; Stockel, J.; and van Ommering, G.: "Sealed Metal Oxide-Hydrogen Secondary Cells," Power Sources 5, D. H. Collins, ed., London and New York: Academic Press, 1974, p. 315.

5. Dunlop, J; Vaidyanathan, H.; Sindorf, J.; and Earl, M.: "Design and Development of a Sealed 100-Ah Nickel-Hydrogen Battery," Contract Report SAND-84-7155, August 1984.

TABLE I. AEROSPACE PROGRAMS USING H_2-NiO BATTERIES

Spacecraft Program	Spacecraft Manufacturer	Cell Capacity (Ah)	Design	Cell Manufacturer	No. of Cells Per Spacecraft	Satellite Orbit
INTELSAT V	FACC[a]	35	IPV-COMSAT[b]	EPI[c]	54	Synchronous
A	RCA[d]	30	IPV-COMSAT	EPI	66	Synchronous
B	RCA	40	IPV-COMSAT	EPI	66	Synchronous
C	RCA	50	IPV-COMSAT	EPI	66	Synchronous
D	RCA	35	IPV-COMSAT	EPI	44	Synchronous
INTELSAT VI	HAC[e]	48	IPV-HAC	HAC	64	Synchronous
SDS (Military)	HAC	25	IPV-HAC	HAC	36	Synchronous
MMBI (Military)	HAC	25	IPV-HAC	HAC	36	Synchronous

[a]Ford Aerospace Communications Corporation.
[b]COMSAT Laboratories.
[c]Eagle Picher Industries.
[d]Radio Corporation of America.
[e]Hughes Aircraft Corporation.

TABLE II. EXPERIMENTAL CELLS

Cell Number	Positive[a]		Negative[b]		Separator[c]	Design
	Number	Type	Number	Type		
1	22	JCI	22	Platinum	W. R. Grace	Back-to-back
2	22	JCI	22	10% Platinum/carbon	W. R. Grace	Back-to-back
3	22	JCI	22	10% Platinum/carbon	Asbestos	Back-to-back
4	22	255 JCI	22	10% Platinum/carbon	Asbestos	Back-to-back
5	21	255 JCI	22	10% Platinum/carbon	Asbestos	Recirculating
6	21	255 JCI	22	10% Platinum/carbon	Asbestos	Recirculating
7	21	JCI*	22	10% Platinum/carbon	Asbestos	Recirculating
8	21	255 JCI	21	10% Platinum/carbon	Asbestos	Back-to-back
9	21	JCI	21	10% Platinum/carbon	Asbestos	Back-to-back

[a]Positive Electrodes

JCI : 0.76-mm-thick wet slurry plaque, aqueous impregnation process with cadmium additive.

255 JCI : 0.76-mm-thick dry sinter plaque, aqueous impregnation process with cobalt additive.

JCI* : 0.76-mm-thick wet slurry plaque, aqueous impregnation process with cobalt additive.

[b]Negative Electrodes

Platinum : Standard aerospace platinum catalysts with 6 to 8 mg Pt/cm^2 surface area.

10% Platinum/Carbon : Carbon/platinum catalyst with 0.4 mg Pt/cm^2 surface area.

[c]Separator

W. R. Grace : Inorganic/organic composite consisting of non-woven polyolefine with inorganic filler material.

Asbestos : Quin-T fuel cell grade asbestos.

TABLE III. ACTIVE H_2-NiO BATTERY TEST SUMMARY (SEPTEMBER 1984)

ID Number	Nominal Rating		Test Condition*	Cycles	Capacity (Ah)
	V	Ah			
Cell 3: 351	1.25	90	NEMA	681	89
Cell 9: 373	1.25	100	NEMA	272	88
Battery 2: 385	7.5	100	NEMA	108	98

*80-percent depth of discharge based on National Electric Manufacturers Association (NEMA) standard.

TABLE IV. BATTERY VOLTAGES

Cell Number	End-of-Discharge Voltage	End-of-Charge Voltage
1	1.199	1.524
2	1.201	1.521
3	1.200	1.520
4	1.201	1.522
5	1.194	1.521
6	1.199	1.523

TABLE V. COMSAT/JCI H_2-NiO BATTERY: POTENTIAL ADVANTAGES FOR AEROSPACE

Advantage	Description
High Energy Density	65 Wh/kg
High Power Density	600 W/kg
Improved Energy per Unit Volume	64 Wh/L
	Two times better than battery fabricated from present IPV H_2-NiO cells.
Advanced Design Concepts for a Multikilowatt Energy Storage System	Multicell design, activation procedures, etc., represent a significant advancement over present state-of-the-art IPV cells.
High Watt-Hour Efficiency	$\geq$85%
Background Data Base	100-Ah battery and cells on test.
Building-Block Concept	1-kWh modules can be connected to make multikilowatt systems.
Manufacturing Reliability	JCI has applied proven and reliable manufacturing processes to the assembly of these batteries.
Cost Reduction	30/1 reduction compared with IPV cell technology.

Figure Captions

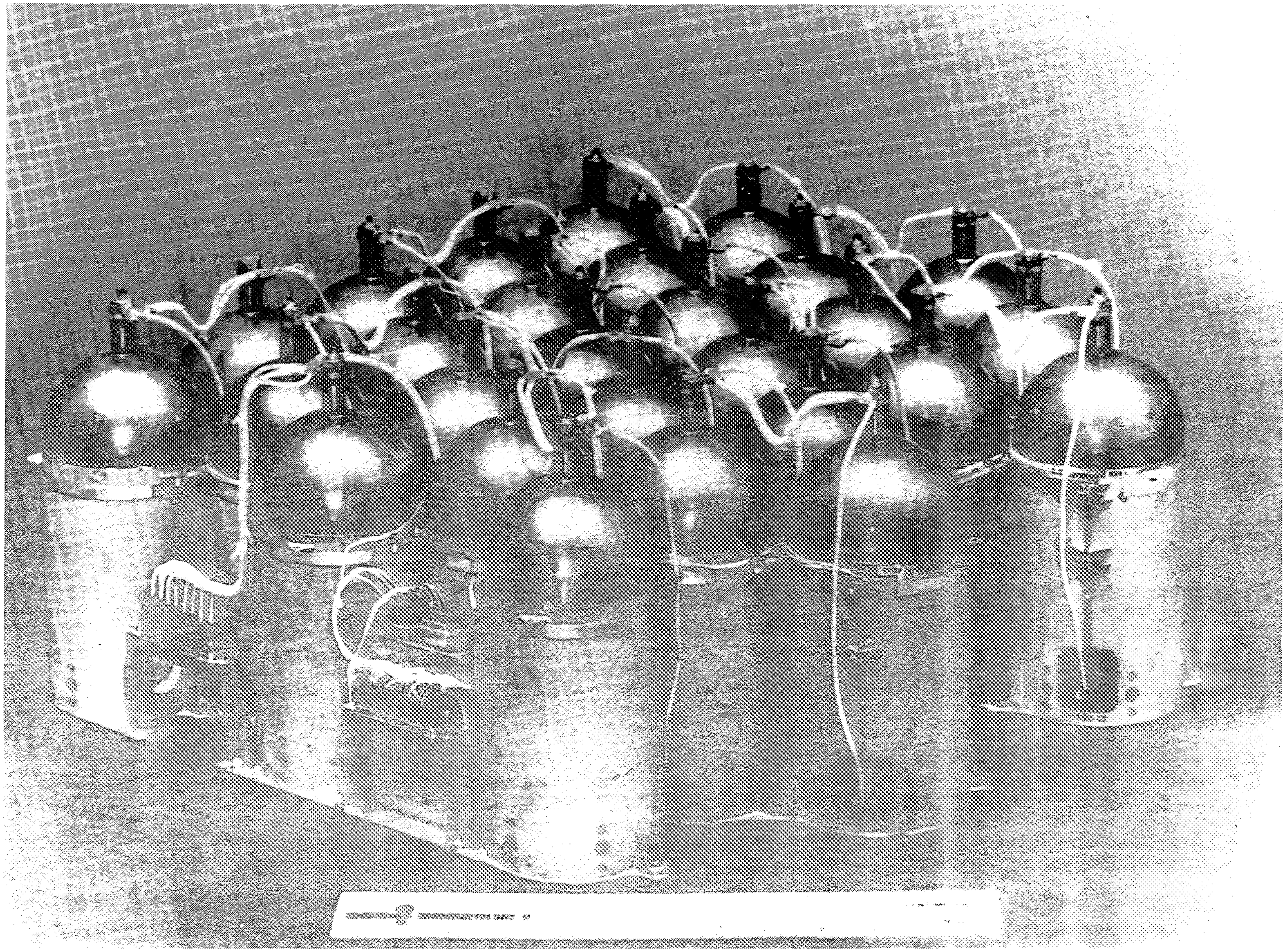

Figure 1. INTELSAT V H_2-Ni0 Battery

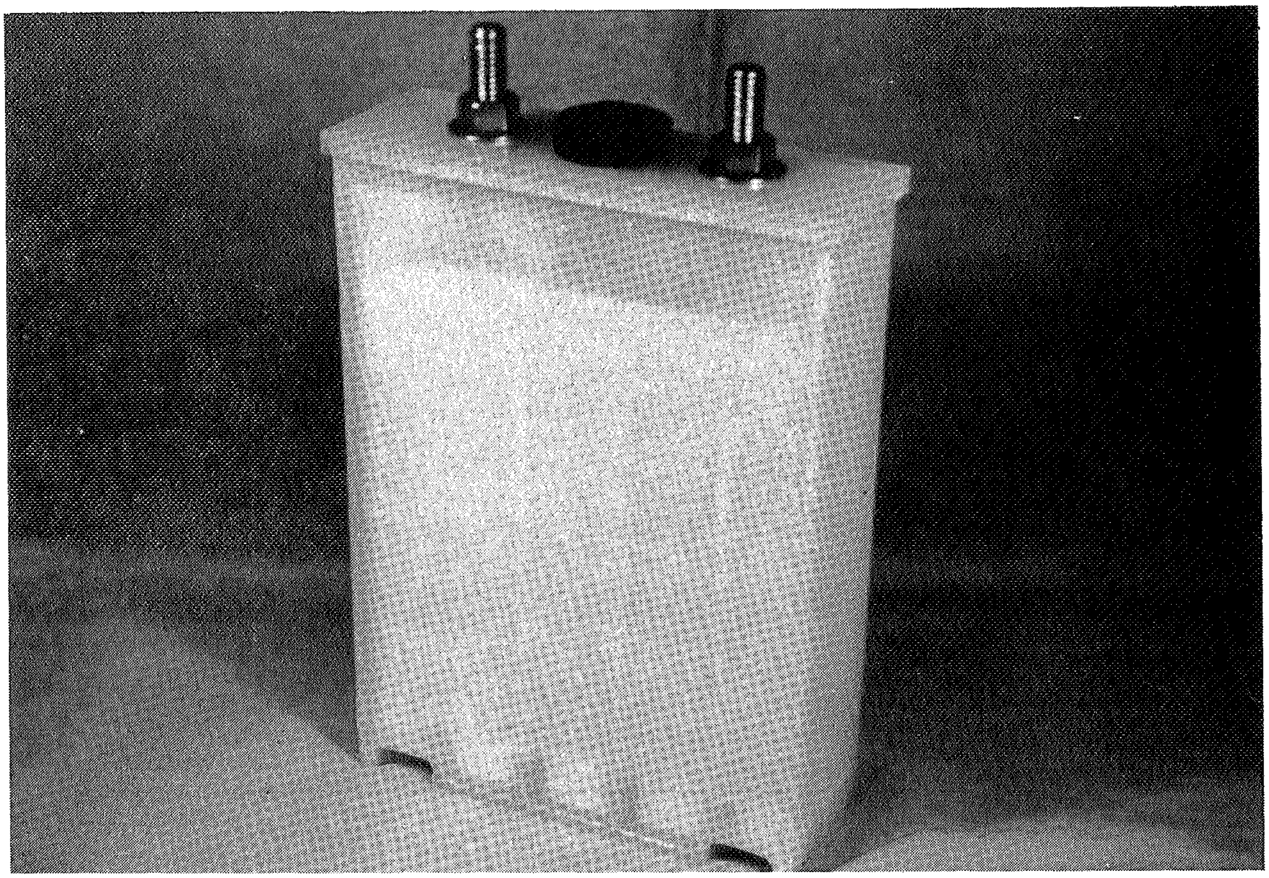

Figure 2. 100-Ah Experimental Cell

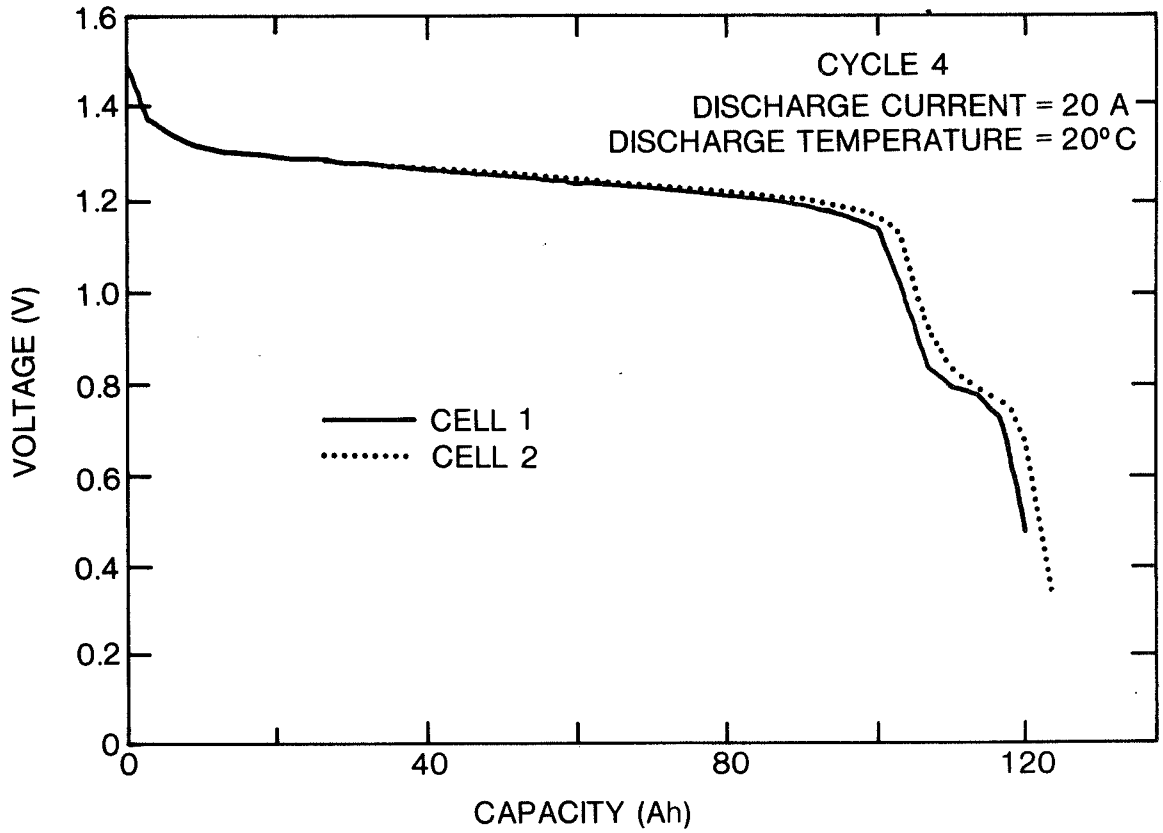

Figure 3. Voltage on Discharge for Cells 1 and 2

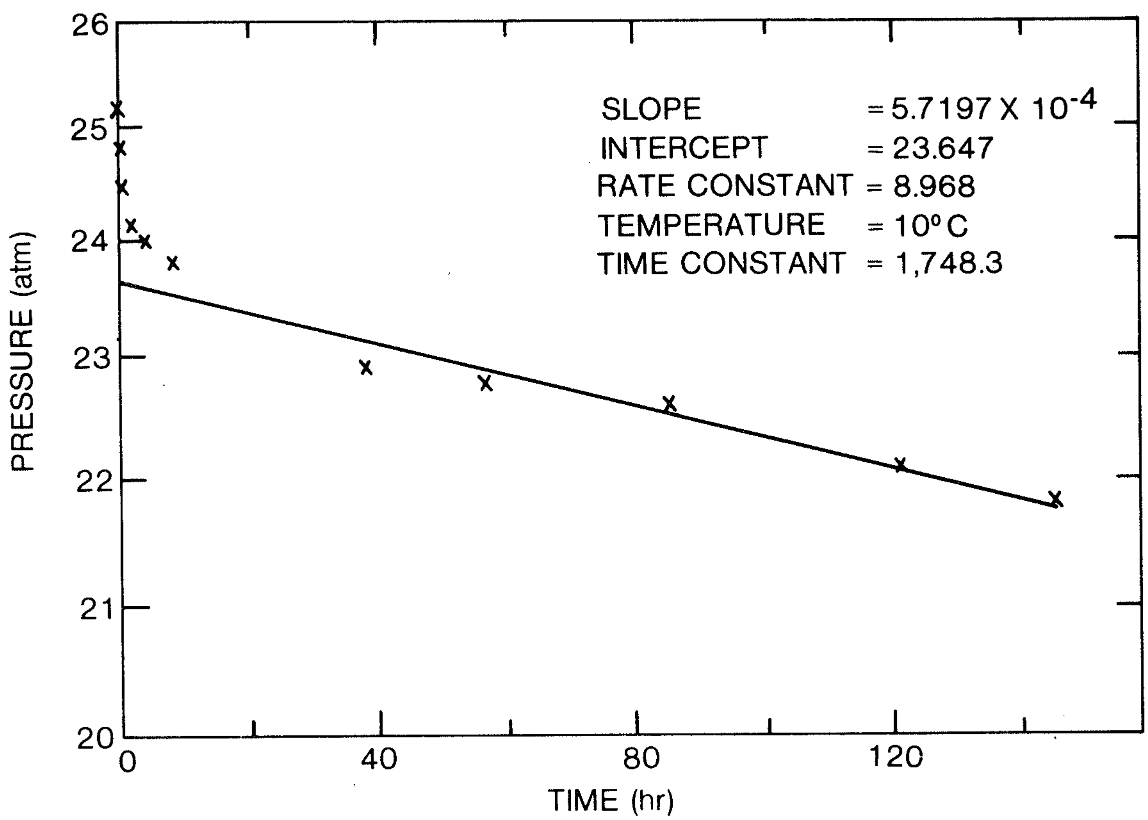

Figure 4. Self-discharge for Cells 1 and 2

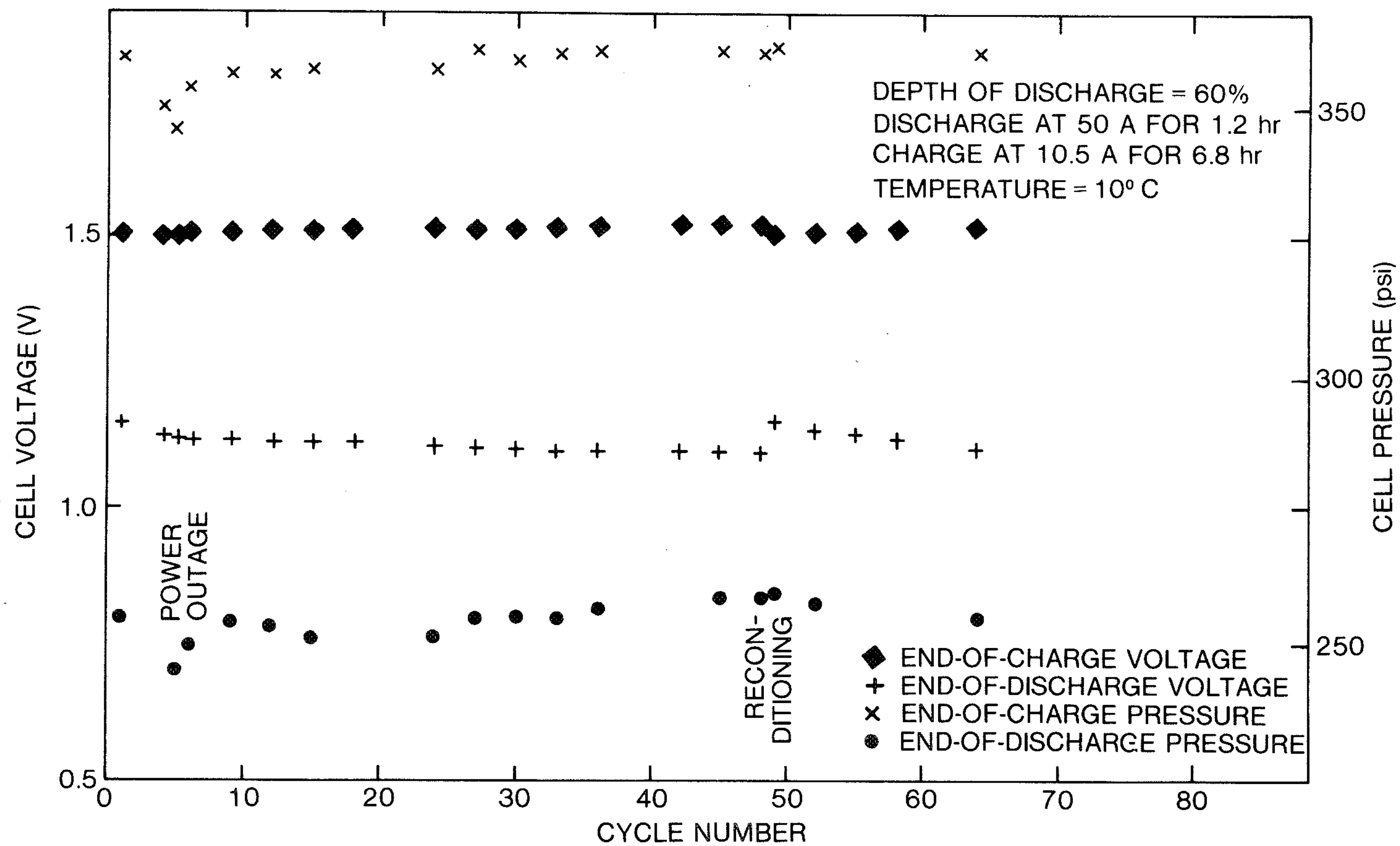

Figure 5. 8-hr Cycle Test Data for Cell 3

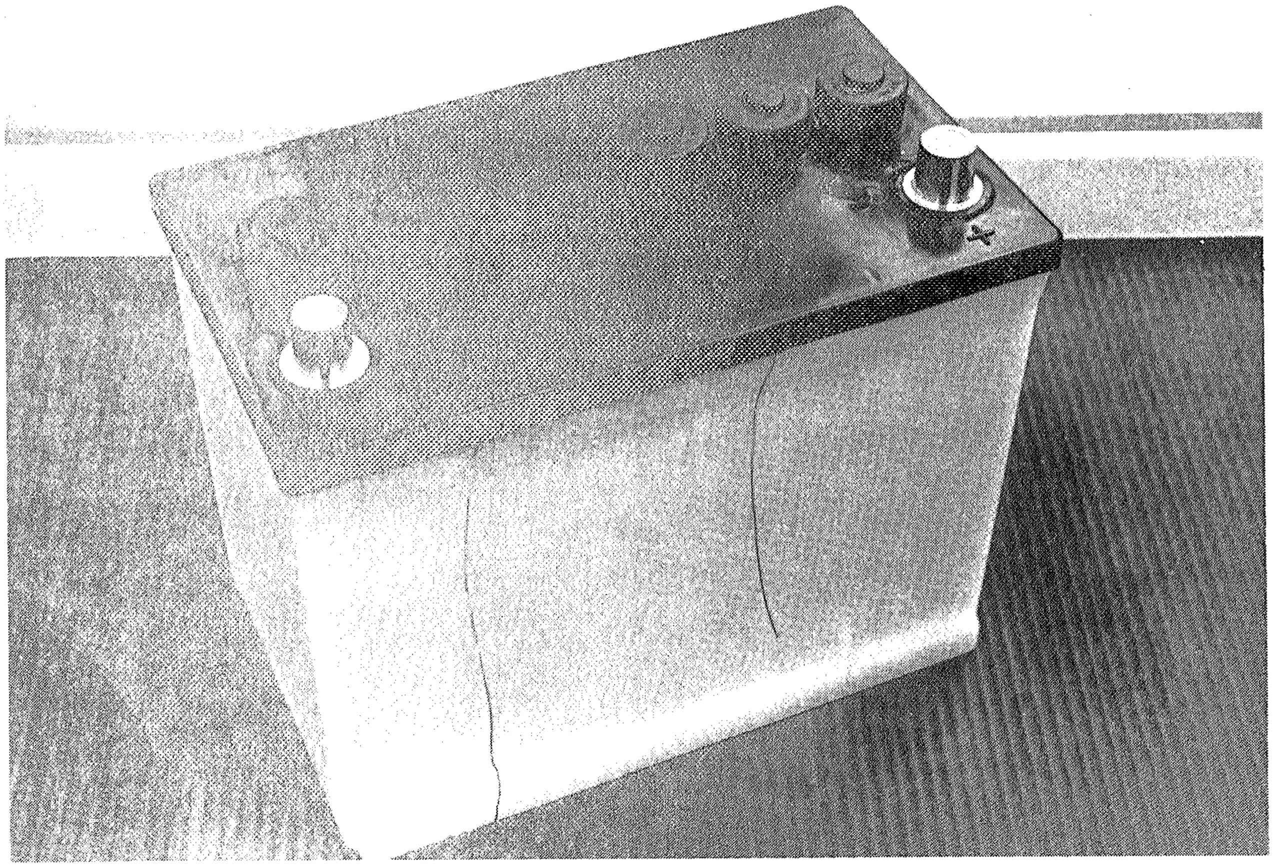

Figure 6. 6-cell, 7.5-V, H_2-Ni0 Battery

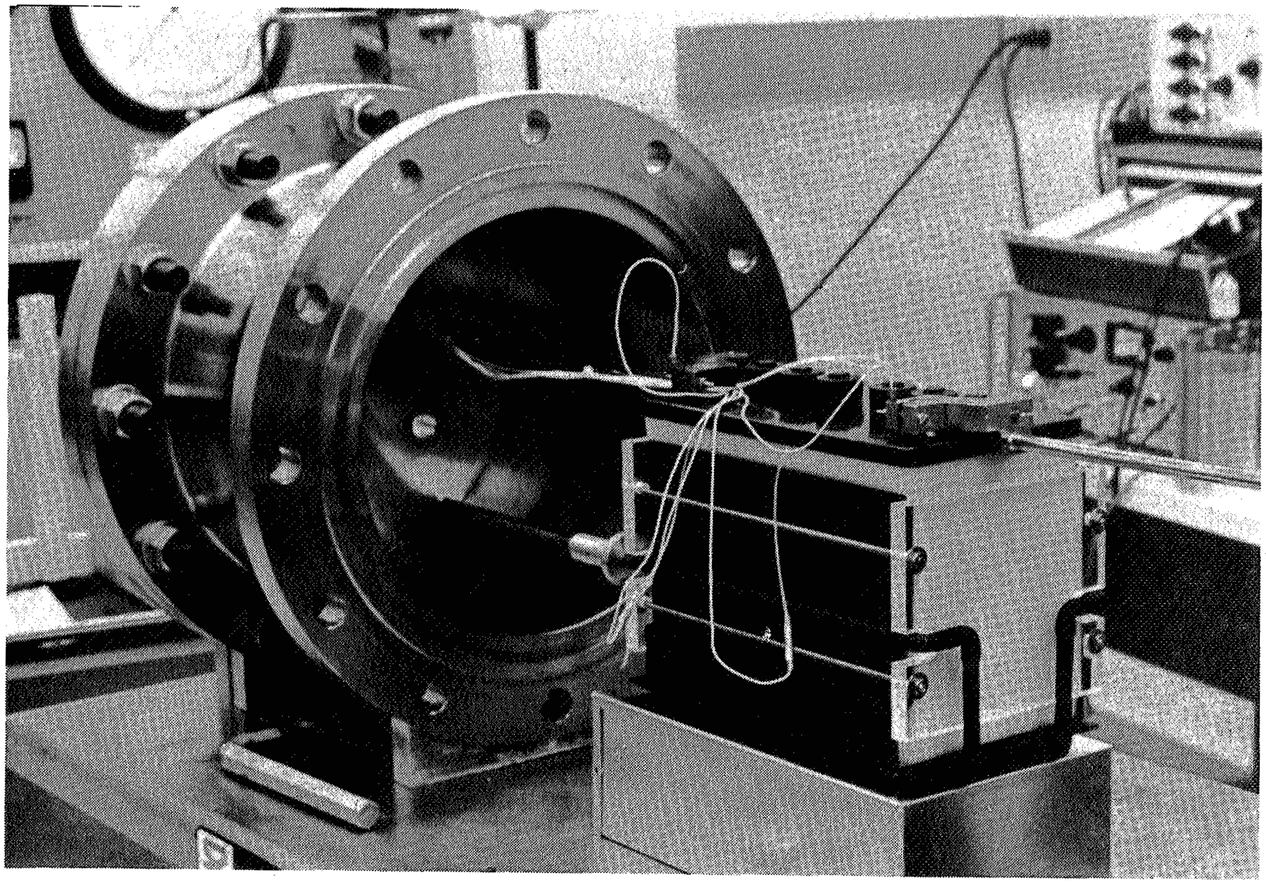

Figure 7. H_2-NiO Battery Assembly in Pressure Vessel

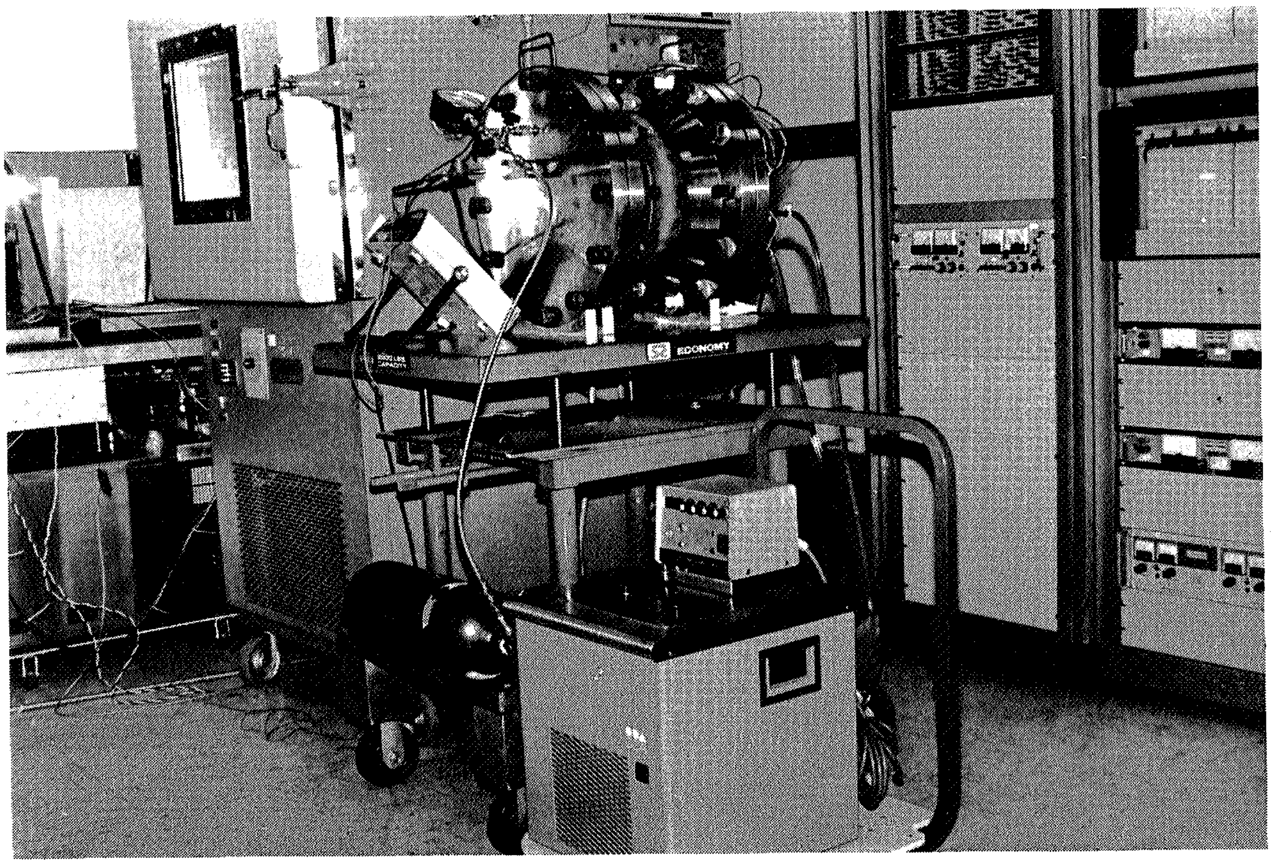

Figure 8. H_2-NiO Battery on Test

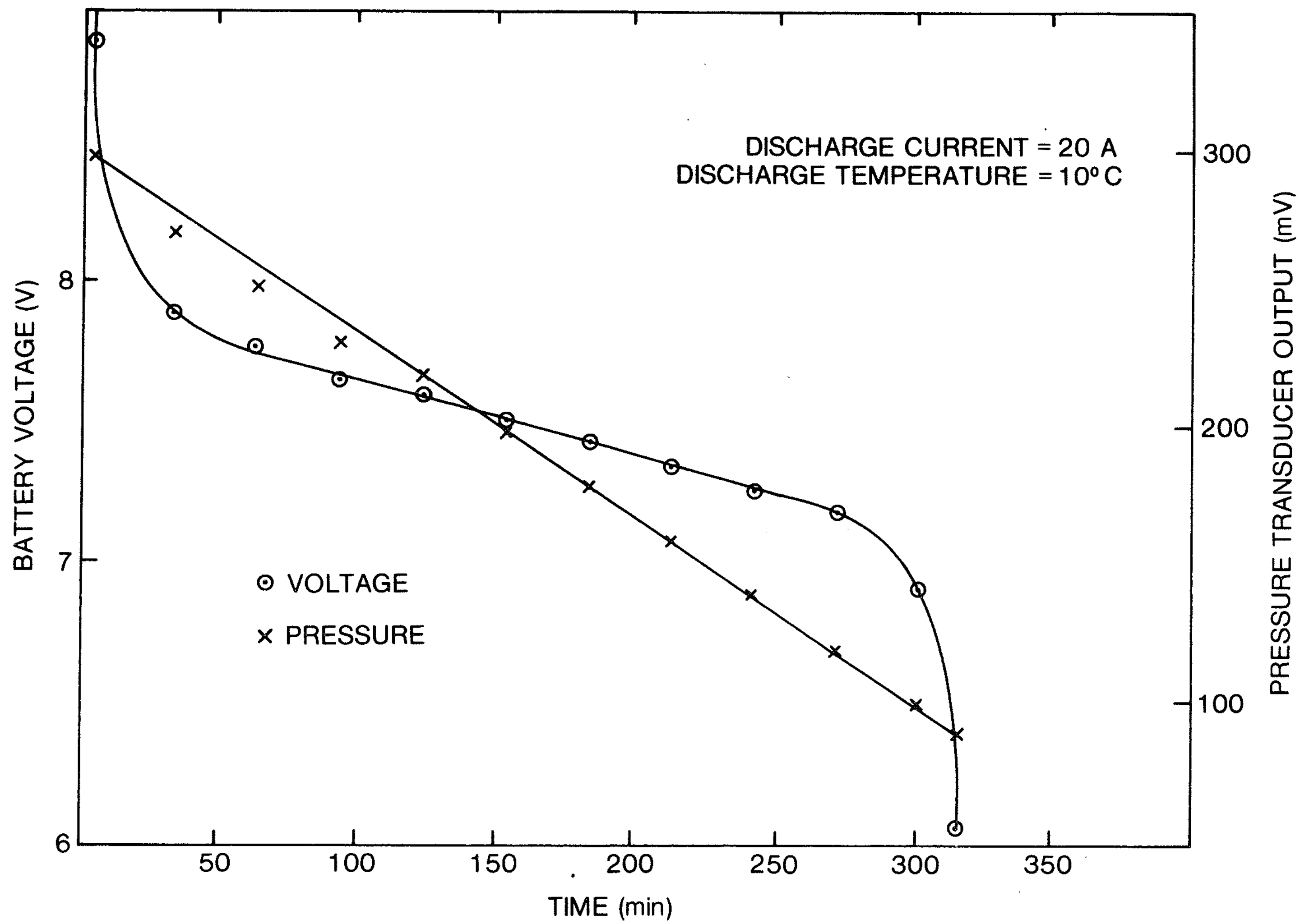

Figure 9. Discharging Profiles for Battery Voltage and Pressure

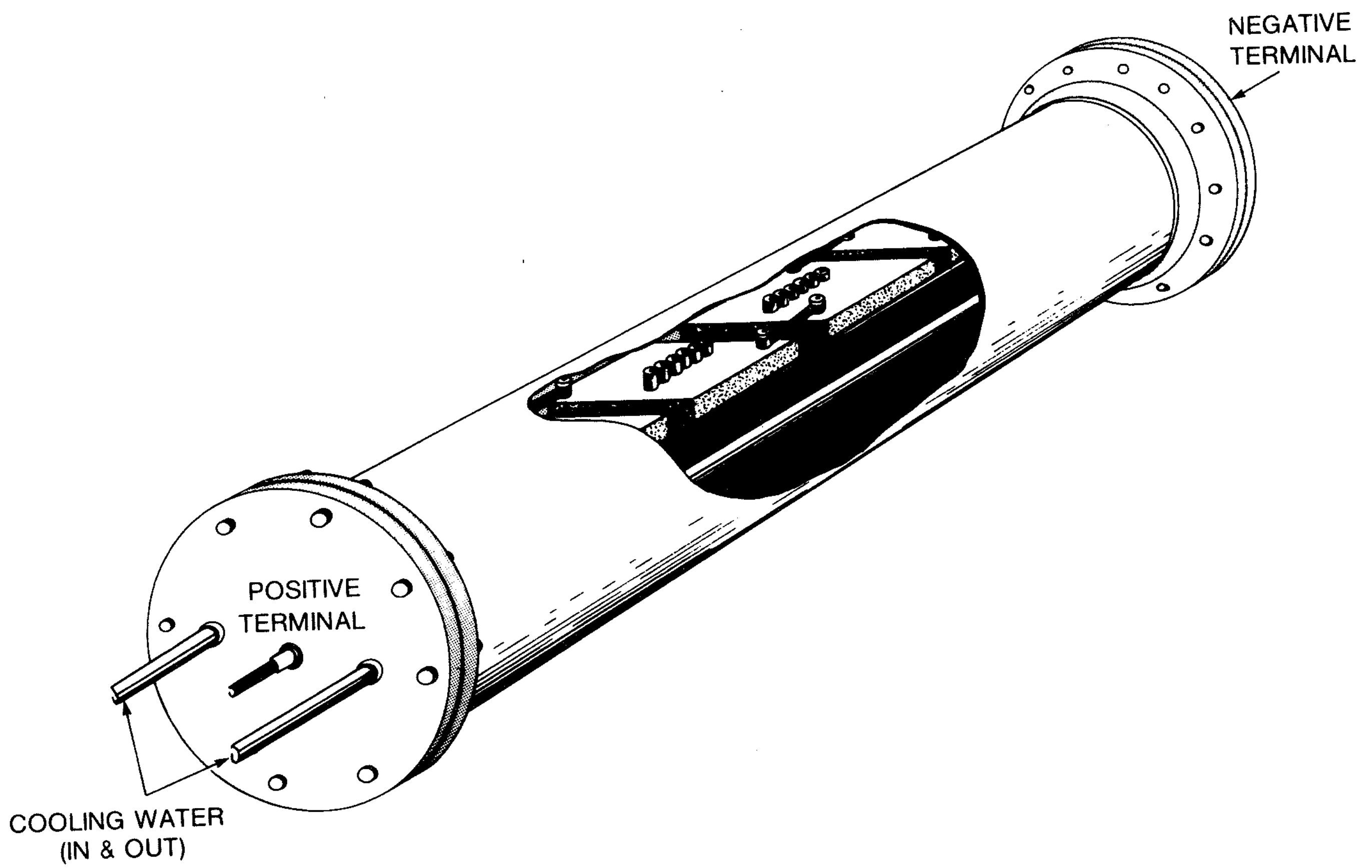

Figure 10. Conceptual Drawing of a 15-kWh H_2-NiO Battery System

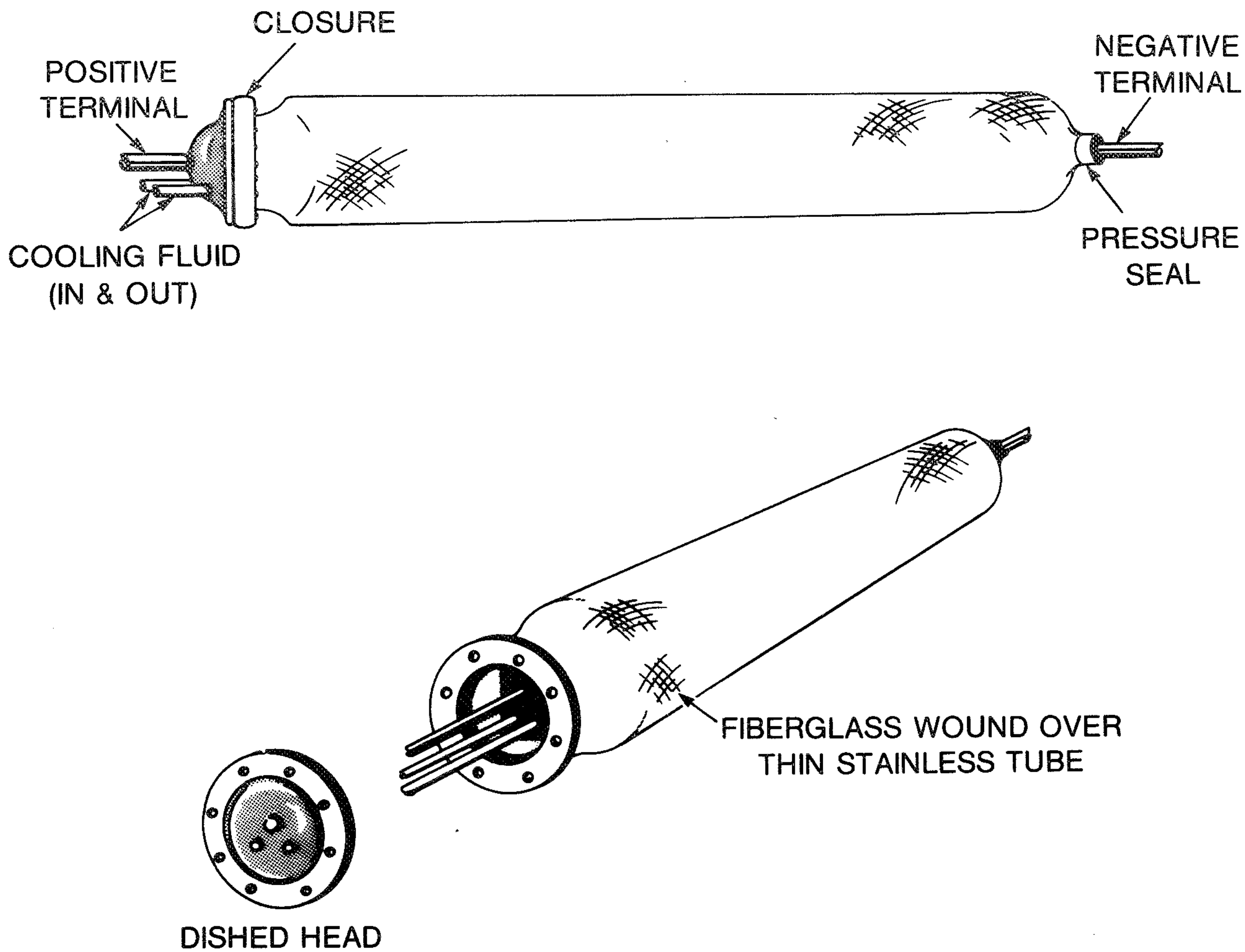

Figure 11. Lightweight Pressure Vessel