

DEVELOPMENT OF NICKEL-METAL HYDRIDE CELL

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ABSTRACT

National Space Development Agency of Japan(NASDA) has conducted the research and developments(R&D) of battery cells for space use. We have started a new R&D program about a Nickel-Metal Hydride(Ni-MH) cell for space use from this year, based on good results in evaluations of commercial Ni-MH cells in Tsukuba Space Center(TKSC). This paper describes the results of those commercial Ni-MH cell's evaluations and recent status about the development of Ni-MH cells for space use.

INTRODUCTION

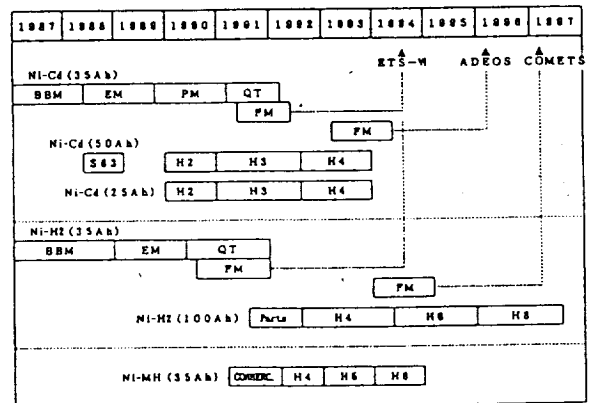
NASDA/TKSC has conducted R&Ds of Nickel-Cadmium(Ni-Cd) and Nickel-Hydrogen(Ni-H2) cells for space use. The recent schedule of the R&Ds is shown in Table-1.

The development of the 35 Ah Ni-Cd cell has finished, and these Ni-Cd cells will be used for Engineering Test Satellite-VI(ETS-VI) to be launched in 1994, and Advanced Earth Observation Satellite(ADEOS) to be launched in 1996. Now we are expanding this technology of the space Ni-Cd cell to wide capacity range of approximately 20 to 50 Ah. Life tests of 25 and 50 Ah cells have been performed, and so far getting good results. The development of the 35 Ah Ni-H2 cell

has also finished already, and these Ni-H2 cells will be tested on ETS-VI flight experiment, and will be used for Communication Engineering Test Satellite(COMETS) to be launched in 1997. The technology of space Ni-H2 cell will be expanded up to 100 Ah, to improve energy density and to reduce cost.

And we have started new programs about new type battery systems. These battery systems are a Ni-MH cell and a secondary Lithium cell, etc., which recently come to be popular for commercial use. Before starting these new programs, we have performed preliminary tests to examine electrically whether these cells can be used

Table-1 Schedule of Batteries Development



Prepared for the 1992 NASA Aerospace Battery Workshop held in Huntsville, AL, USA, 17-19 November, 1992. (Report No.; NASDA-TK-E92043)

for space or not. Unlike the space cells, commercial cells generally have some different properties such as small capacity, cylindrical shape, and crimp sealing with a nylon gasket. But we think it enough to evaluate only a feasibility for space use.

On the Ni-MH cells, we have tested commercial cells from 1991 as the TKSC's in-house R&D. And we have started a development program under contract with SANYO Electric Company(Sanyo) from this year, getting good results from the in-house R&D.

Also on the secondary Lithium cell, we are going to adopt the same procedure, so now preparing the evaluation of some commercial lithium cells in order to start evaluation tests in the next year.

EVALUATION OF COMMERCIAL Ni-MH CELLS

Sample Cell Description

The test samples are 4/3A-size commercial Ni-MH cells, which were shaped cylindrical with 17mm in diameter, and 67mm in height. The rated capacity was 2.2 Ah when these samples were offered from Sanyo last year. Each 5 cells are allotted for GEO and LEO life tests respectively.

For reference, C-size rated 1.8 Ah commercial Ni-Cd cells were tested in the same test packs and the same number of samples in order to compare the Ni-MH cell with the Ni-Cd cell.

Test Conditions

The purpose of these tests was to evaluate the capability of a Ni-MH cell for space use. So we adopted our usual GEO and LEO test conditions that were the same as the space Ni-Cd cell's life tests.

The conditions of GEO test are 0.1C charge for 9 hours and 0.5C discharge for 1.2 hour, so depth of discharge(DOD) is 60% and charge return ratio is 150%. The rated capacity "C" used to define charge and discharge current in these tests is selected 2.2 Ah. A reconditioning discharge and a capacity check are performed in every 45 cycles. The condition of the reconditioning discharge is 1/80C constant current dis-

charge after cycling charge. And conditions of a capacity check are 0.1C charge for 16 hours and then 0.5C discharge to 1.0 V for each cells, after reconditioning discharge.

The conditions of LEO test are 0.3C charge for 52.5 minutes and 0.5C discharge for 30 minutes, so DOD is 25% and charge return ratio is 105%. Capacity checks are performed in 1,000 cycles and then in approximately every 5,000 cycles. The capacity check in a LEO test consist of two kinds of capacities. One of two types is a residual capacity that is obtained by immediate discharge with 0.5C rate after charge of cycling test. Another type of capacity is full-charged capacity that is obtained by 0.5C discharge to 1.0 V after every cells are full-charged with 0.1C rate for 16 hours. These conditions are summarized in Table-2.

Table-2 Test Conditions of Commercial cells

CONDITION	TEST TYPE	
	G E O	L E O
Charge	0.1C, 8 hours	0.3C, 52.5 min
Discharge	0.5C, 1.2 hours	0.5C, 30 min
DOD	60 %	25 %
Charge Return	150 %	105 %
Temperature	20C (COOLING PLATE TEMP.)	
Capacity Check	RECONDITIONING CAPACITY	RESIDUAL CAPACITY
	FULL-CHARGED CAPACITY	FULL-CHARGED CAPACITY
	EVERY 45 CYCLES	ABOUT EVERY 5,000 CYCLES

(C=2.2Ah)

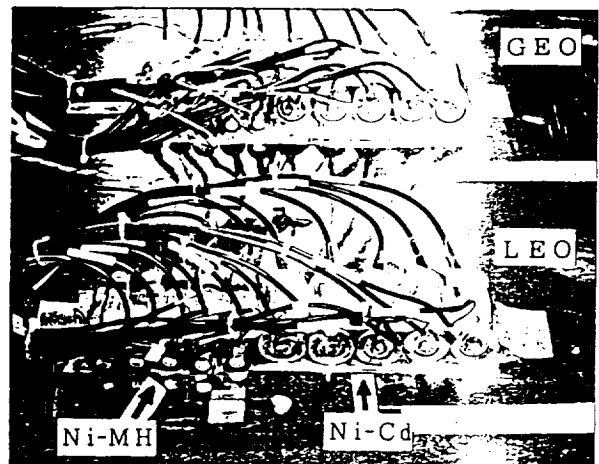


Photo-1 Test Set-up on Cooling Plate

Both cells under GEO and LEO tests are mounted together on a cooling plate whose temperature is maintained about 20 degree C. The set-up of GEO and LEO tests is shown in Photo-1.

GEO Test Result

GEO test started on May-1991, and is over 900 cycles so far with no failures to continue cycling. Charge and discharge characteristics about cell voltages and temperature at 134 cycles are shown in Fig-1 and Fig-2. End of charge voltage(EOCV) and end of discharge voltage(EODV) versus number of cycles about all Ni-MH and Ni-Cd cells are shown in Fig-3. And reconditioning capacities and full-charged capacities in every 45 cycles are shown in Fig-4 and Fig-5.

Cell Voltage; The overcharge voltage of the Ni-MH cell is higher than that of the Ni-Cd cell. The discharge voltage of the Ni-MH cell is also higher than that of the Ni-Cd cell. And EOCV and EODV of the Ni-MH cells are higher than those of Ni-Cd cells. Moreover all voltages of the Ni-MH cells shows a good uniformity during charge and discharge periods. One of the Ni-Cd cells shows gradually degradation of EODV. The reason of degradation is suspected that the No.4 Ni-Cd cell's internal impedance at 1kHz increases larger than the other cells as shown in Table-3.

Cell Temperature; In charge period the temperature behavior of the Ni-MH cell is almost same as the Ni-Cd cell. And in discharge period the temperature of the Ni-MH cell becomes as same as the cooling

plate. The temperature of the Ni-Cd cell is balanced above the temperature of the cooling plate due to heat generation during discharge period.

Cell Capacity; It is thought to be reasonable that reconditioning capacities of Ni-Cd cells are less than full-charged capacities, because 0.5C discharge rate of full-charged capacity check is larger than 1/80C rate of reconditioning discharge. But in the case of Ni-MH cell, both capacities are observed identically. The reason is suspected that a rate of self-discharge in the Ni-MH cell is larger than that of the Ni-Cd cell.

LEO Test Result

LEO test started on May-1991, and is over 8,000 cycles so far with no failures as well as GEO test. Charge and discharge characteristics about cell voltages and temperature at 7,975 cycles are shown in Fig-6 and Fig-7. EOCV and EODV versus number of cycles about 5 Ni-MH and 5 Ni-Cd cells are shown in Fig-8. Results of capacity checks are shown in Fig-9.

Cell Voltage; During charge period, the voltage of the Ni-MH cell is almost same as the Ni-Cd cells. And the discharge voltage of the Ni-MH cell is higher than the Ni-Cd cell. So it shows no difference of EOCV between the Ni-MH and Ni-Cd cells, but EODV of the Ni-MH cells are higher than the Ni-Cd cells. Moreover voltages of both cells show good uniformities respectively.

Cell Temperature; In charge period the temperature of the Ni-MH cell is balanced above the temperature of the cooling plate, though the temperature of the Ni-Cd cell is gradually decreasing below temperature of the cooling plate. And in discharge period it is observed the temperature of the Ni-MH cell is decreasing, but the temperature of the Ni-Cd cell is reversely increasing. These thermal properties of the Ni-MH cell implies heat generation during charge and heat absorption during discharge which is contrary to the property of the Ni-Cd cell. These thermal property is thought to be caused by reaction of hydrogen absorbing metal, but a quantitative discussion on the

Table-3 Change of Cell Internal Impedance

Number of Cycles	Ni-MH	Ni-Cd	
	Average (5 cells)	No. 4	Average (others)
Initial	1.6 mΩ	2.2 mΩ	2.1 mΩ
225	1.6 mΩ	8.4 mΩ	2.0 mΩ
540	6.0 mΩ	24.5 mΩ	2.2 mΩ
675	10.1 mΩ	41.7 mΩ	7.8 mΩ
900	9.4 mΩ	97.0 mΩ	2.9 mΩ

thermal property can not be derived from these data.

Cell Capacity; According to the capacity trend of Fig-9, all Ni-MH cells show a very good performance though all Ni-Cd cell shows a gradual degradation. The reason of Ni-Cd cell's degradation is thought that cadmium electrodes are easy to degrade by agglomeration of active materials.

Summary of Commercial Ni-MH Tests

It is recognized that the Ni-MH cell has a good performance about charge/discharge cycling, especially about capacity remaining. So the Ni-MH cell is electrically thought to has capability for space use. On overcharge characteristics for GEO application, a test of continuous charge for commercial Ni-MH cells has been initiated recently.

DEVELOPMENT OF Ni-MH CELLS FOR SPACE USE

Cell Design

At the first phase of development, the Ni-MH cell with rectangular shape and large capacity has been designed in order to evaluate its characteristics and to examine an issues related to large-scale cell. As a cell case and terminal for the trial Ni-MH cell, those of the 25 Ah Ni-Cd cell of H2 phase on Table-1 are utilized in order to compare the Ni-MH cell with the Ni-Cd cell. So dimensions of the Ni-MH cell for space use are 95.0 mm in case height, 106.9mm in width, and 25.2 mm in thickness.

A positive electrode is manufactured using a nickel sinter plate and a chemical impregnation method, and has the same electrode parameters as the Ni-Cd cell's that are 85% of porosity and 2.4 g/cc-void of loading level, except thickness that has been modified to 0.60mm from 0.63mm of the Ni-Cd cell. Dimensions of an electrode are 80.0mm in height, and 104.4mm in width, and 16 positive electrodes are used in a cell.

A Negative electrode is manufactured using a Mischmetal Nickel5(MmNi5) based alloy as the Hydrogen Absorbing Metal and a stripped metal sheet. 17 negative elec-

trodes are used in a cell.

A separator is selected a nylon as same as the Space Ni-Cd cells. And thickness of separator is 0.21mm in a cell.

The trial Ni-MH cell has 35.5 Ah of designed cell capacity, compared with 27.5 Ah of the Ni-Cd cell when the cell case with same dimensions is used. Another saying, the designed energy density of 50.7 Wh/kg is larger than the space 35Ah Ni-Cd cell's 44.1 Wh/kg. The cell design for space use is summarized in Table-4.

Table-4 Design of Ni-MH Cell for Space

Ni-MH CELL DESIGN	(+)	(-)
Active Material	Ni (OH) ₂	MmNi ₅
Plate Area	80.0×104.4 mm	
Plate Thickness	0.60 mm	0.49 mm
Sinter Porosity	85 %	—
Loading Level	2.4g/cc-void	—
Number of Plates	16	17
Electrodes Capacity (actual)	38.8 Ah	75.2 Ah
Separator	Nylon	
Electrolyte	31%KOH	
Cell Dimension (case)	95.0H×106.9W×25.2T mm	
Cell Weight	840 g	
Cell Capacity	35.5 Ah	
Energy Density (Actual)	50.7 Wh/kg	

REFERENCE (35Ah Space Ni-Cd Cell)	
Cell Dimension (case)	115.2H×106.9W×25.2T mm
Cell Weight	max. 1050 g
Cell Capacity	38.8 Ah
Energy Density (Actual)	44.1 Wh/kg

Test Description

Testing consists of two steps; the first step is to evaluate an electrical characteristics of electrodes stack using dummy cells; the second step is full-evaluation using flight type cells.

The dummy cell is composed of two end-plates of stainless steel, a cell-wall of poly-acryl, and electrodes stack, and then fasten these elements with bolts & nuts, so it can be assembled easily. The external view of a dummy cell are shown in Photo-2. But this dummy cell cannot be used for life test because a sealing between 2 end-plates and a cell-wall is not enough for long time. Pressure value of a dummy cell is not equal to a flight type cell because of a

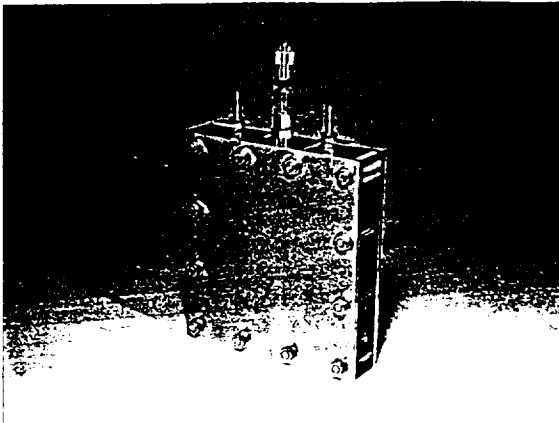


Photo-2 External View of Ni-MH Dummy Cell

difference of free spaces. Moreover electrical resistance of terminal is larger than flight type cell's one, so we must revise the cell voltage in order to compare with flight type cell. So tests of dummy cells are purposed to get only initial characteristics of the charge/discharge voltage and capacity versus temperature. The charge conditions of these tests are 0.1C rate for 24 hours at the cell temperature of 20 and 35 degree C, and 0.05C rate for 48 hours at -5 degree C. And the discharge condition is 0.5C rate to 1.0 V at every temperatures. The rated capacity "C" in this test is tentatively selected 35 Ah. Cell temperature is controlled by computer using a temperature chamber.

The flight type cells will be assembled after reviewing dummy cell's data. The flight type cell are planned to get correct pressure values, and then get to long term performance. After initial performance tests, the flight type cells will be subjected to life tests in TKSC.

Test Results of Ni-MH Dummy Cell and Comparison with Space Ni-Cd Cell

Charge and discharge characteristics at -5, 20, and 35 degree C of dummy cells are shown in Fig-10 and Fig-11. These dummy cell's voltages are revised to cancel for increase of terminal resistance compared with flight type cell's terminal. For reference, those of the 35 Ah space Ni-Cd

cell are shown in Fig-12 and Fig-13.

Charge Voltage and Pressure; Charge voltage of the Ni-MH dummy cell becomes higher at lower temperature. And charge pressures at 20 and -5 degree C start to increase when overcharging starts. Charge pressure at 35 degree C is gradually increasing. The trend of these characteristics in charge period is almost same as the space Ni-Cd cell shown in Fig-12. Charge characteristics is thought to be mainly dominated by Nickel electrodes.

Discharge Voltage and capacity; Discharge voltages and capacities at 20 and 35 degree C are almost identical, and it can confirm that the measured capacity almost meets the designed capacity 35.5 Ah. But the discharge voltage and capacity at -5 degree C are about 50 mV and 20% lower than those at the other temperatures. And these characteristics versus temperature are different from the space Ni-Cd cell's discharge data shown in Fig-13. The reason is suspected that activity or capacity of the hydride metal decreases at lower temperature.

CONCLUSION

The results of evaluations and comparison of commercial Ni-MH and Ni-Cd cells show that Ni-MH cell system has a capability for space use. As a result of Ni-MH cell design for space use, the Ni-MH cell has advantages of small size and light weight compared with the space Ni-Cd cell, so the Ni-MH cell is thought to be promising battery cell.

We will confirm the cell characteristics at various temperatures, especially at lower temperatures, cycling life and failure modes, and mechanical strength using flight type cells. As the first technology demonstration, we are now proposing Ni-MH cells to be applied to a small satellite for NASDA mission.

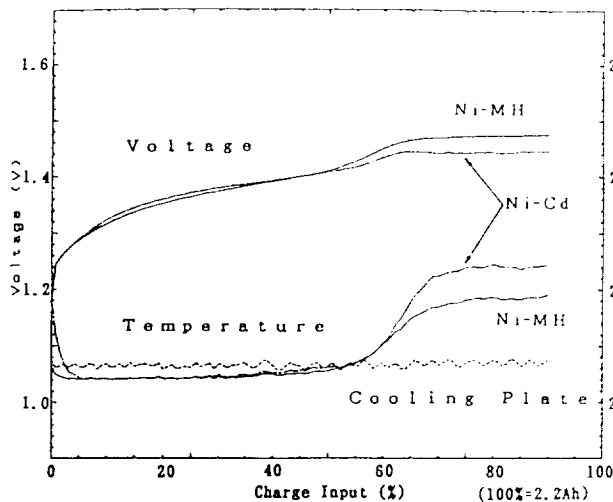


Fig-1 Charge Characteristics of Commercial Ni-MH & Ni-Cd Cells in GEO Test

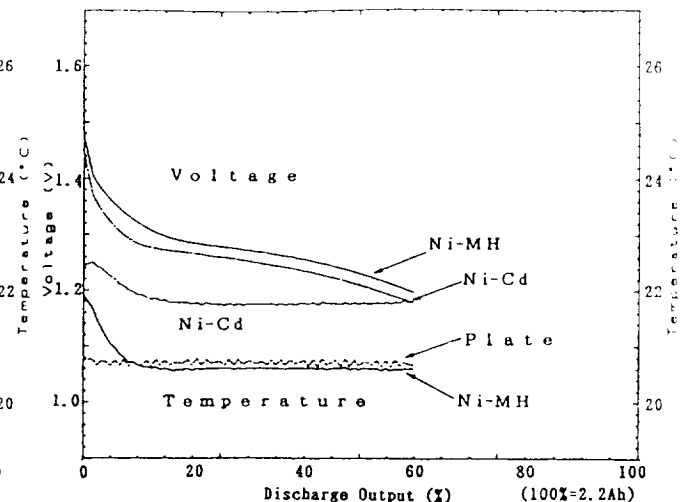


Fig-2 Discharge Characteristics of Commercial Ni-MH & Ni-Cd Cells in GEO Test

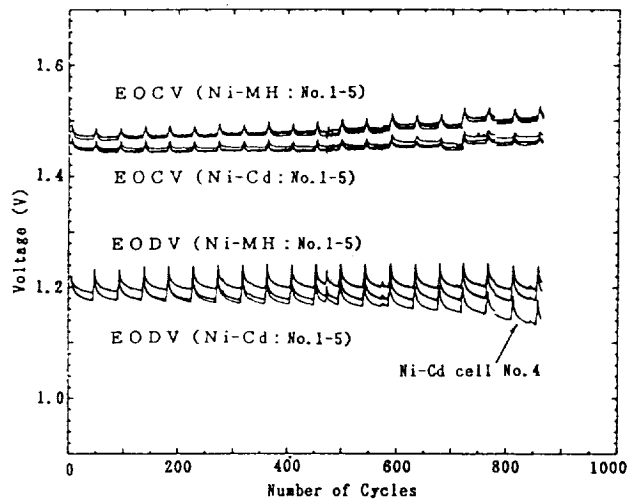


Fig-3 EOCV & EODV Trend of Commercial Ni-MH & Ni-Cd Cells in GEO Test

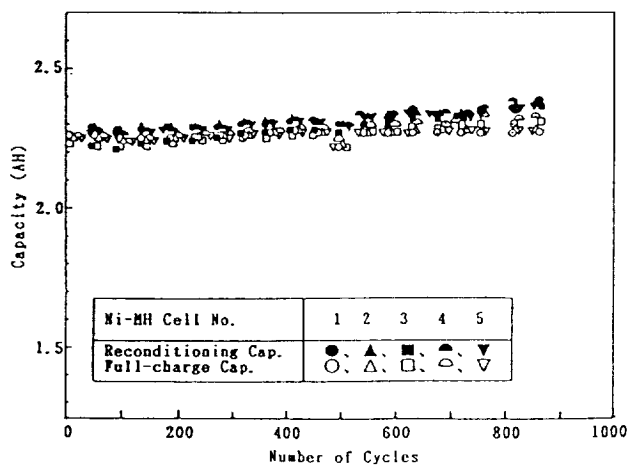


Fig-4 Capacity Trend of Commercial Ni-MH & Ni-Cd Cells in GEO Test

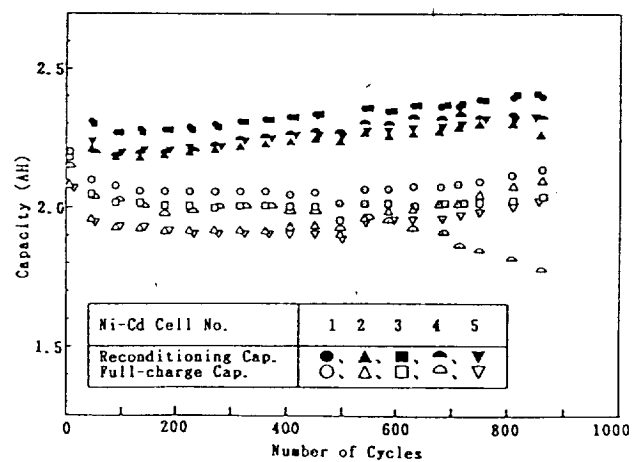


Fig-5 Capacity Trend of Commercial Ni-MH & Ni-Cd Cells in GEO Test

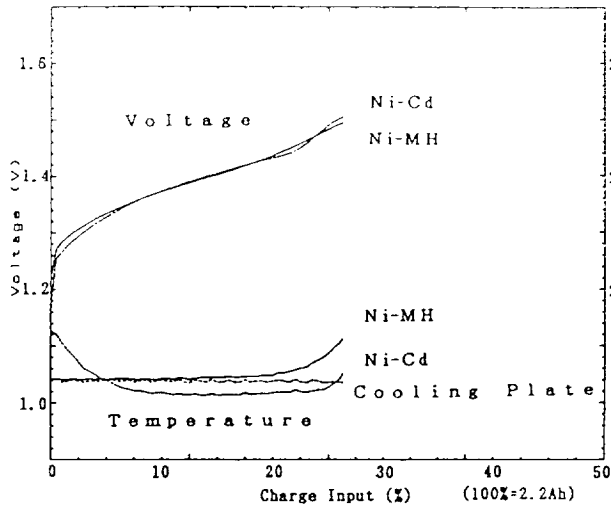


Fig-6 Charge Characteristics of Commercial Ni-MH & Ni-Cd Cells in LEO Test

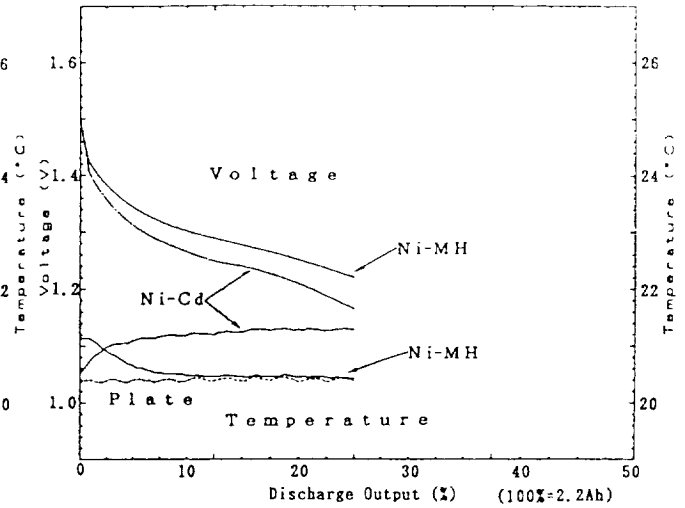


Fig-7 Discharge Characteristics of Commercial Ni-MH & Ni-Cd Cells in LEO Test

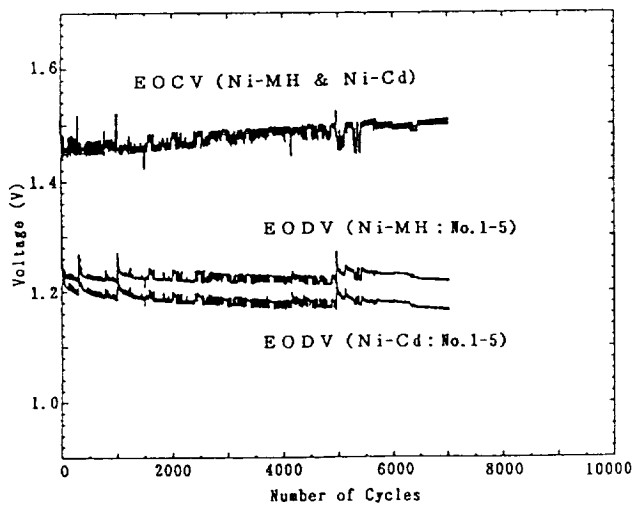


Fig-8 EOCV & EODV Trend of Commercial Ni-MH & Ni-Cd Cells in LEO Test

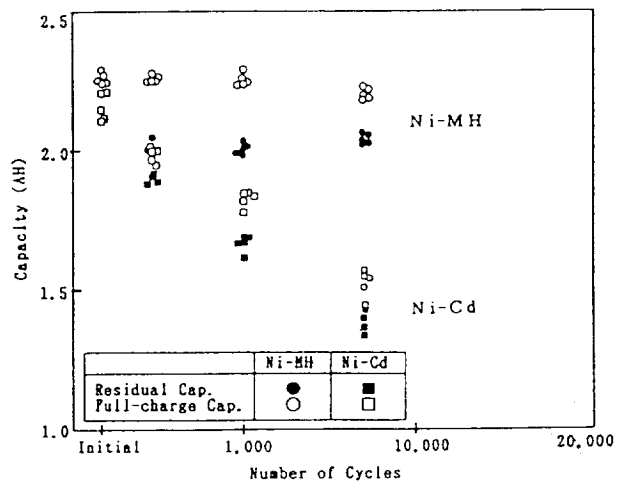


Fig-9 Capacity Trend of Commercial Ni-MH & Ni-Cd Cells in LEO Test

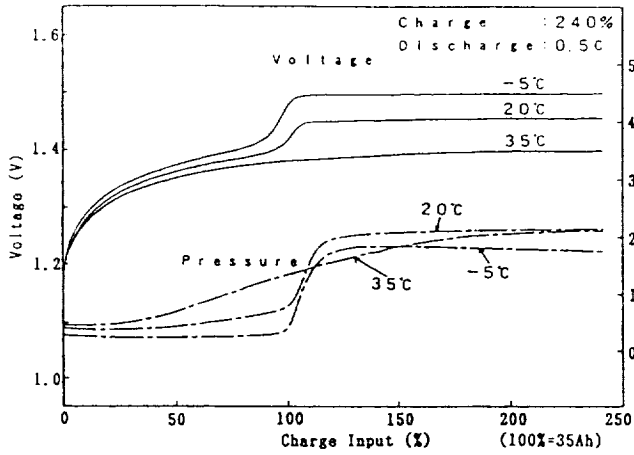


Fig-10 Charge Characteristics
of Ni-MH Dummy Cell

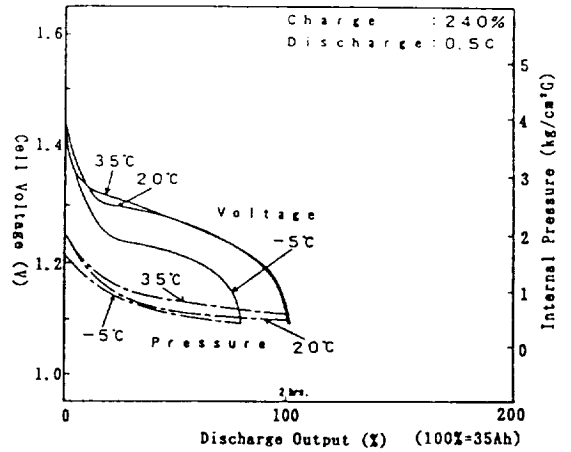


Fig-11 Discharge Characteristics
of Ni-MH Dummy Cell

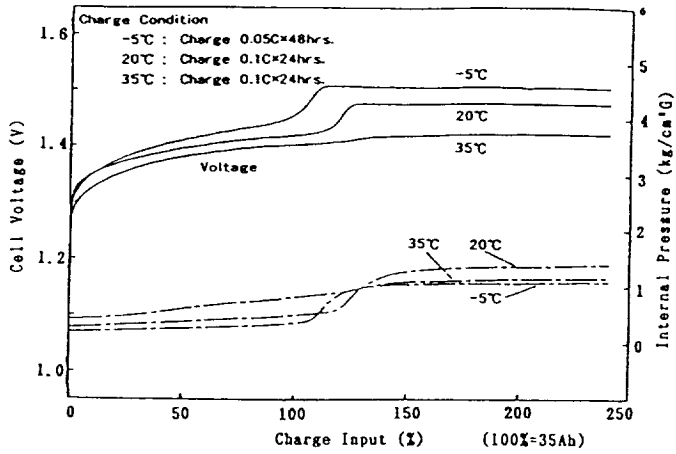


Fig-12 Charge Characteristics of
the 35Ah Space Ni-Cd Cell

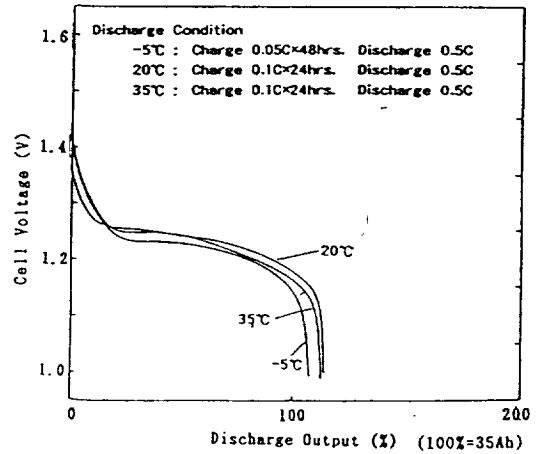


Fig-13 Discharge Characteristics of
the 35Ah Space Ni-Cd Cell