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LONG-TERM STORAGE OF NICKEL-HYDROGEN CELLS*

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Representative samples of nickel-hydrogen cells for the INTELSAT VI program were used to evaluate the effects of prolonged storage under passive conditions such as open-circuit discharged at 0°C, room temperature, and -20°C, and under quasidynamic conditions such as top-off charge and trickle charge. Cell capacity declines when cells are stored open-circuit discharged at room temperature, and a second plateau occurs in the discharge curve. Capacity loss was 47 percent for a cell with hydrogen precharge and 24.5 percent for one with no hydrogen precharge. Capacity recovery was observed following top-off charge storage of cells which had exhibited faded capacity as a result of passive storage at room temperature. Cells stored either at -20°C or on trickle charge maintained their capacity. At 0°C storage, the capacity of all three cells under test was greater than 55 Ah (which exceeds the required minimum of 44 Ah) after 7 months.

INTRODUCTION

Long-term storage of nickel-hydrogen batteries has become an important issue since the storage requirements for the INTELSAT VI battery have been increased from 28 to 60 months as a result of launch delays. The capacity maintenance characteristics of INTELSAT VI nickel-hydrogen cells were discussed in 1986 (ref. 1). This present paper continues that work by elaborating on the capacity variations observed in these cells after extended storage under various conditions.

The nickel-hydrogen cells discussed here are of the U.S. Air Force/Hughes design, containing 40 sets of positive and negative plates, with zircar as the separator, in a recirculating stack configuration. There are two types of cells, positive- and negative-limited, which are defined based on differences in the amount of hydrogen precharge. Positive-limited cells use about 150 psi of hydrogen gas as precharge; negative-limited cells use no hydrogen precharge. A cell capacity of 44 Ah is considered sufficient to meet the load requirements of the INTELSAT VI satellites (ref. 2).

STORAGE MODE STUDY APPROACH

A storage mode investigation was begun using selected nickel-hydrogen cells. First, the initial capacity of the cells was determined at 10°C. The cells were then divided into groups and stored under a variety of conditions, as follows:

- -20°C open-circuit discharged
- 0°C open-circuit discharged
- room temperature open-circuit discharged

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- trickle charge at room temperature
- top charge

Several points must kept in mind when discussing the results of this study. Cells are oriented vertically while in storage. Cells stored at -20°C, 0°C, and room temperature are in the fully discharged state, which is achieved by power discharge at 23.5 A to 0.1 V, followed by draining through 1 Ω for 18 to 24 hours and shorting for 4 hours. Top-charge and trickle-charge cells are charged at 4.8 A for 18 hours at 10°C prior to storage. All capacity determinations are performed at a C/2 rate (23.5 A) at 10°C.

EFFECT OF ROOM TEMPERATURE STORAGE

Five cells were stored at room temperature, and their resulting capacity variation is shown in figure 1. (Cells with negative precharge are denoted by the letter N, and those with positive precharge by the letter P.) In this storage mode, the cells showed capacity loss of as much as 47 percent for a cell with hydrogen precharge and 24.5 percent for one with no hydrogen precharge. The capacity loss appears to level off after 94 days. One result of room temperature storage is the occurrence of a second plateau in the discharge curves, as depicted in figure 2. The capacity below 1 V (not all in the plateau region) increases with time in storage, as shown in figure 3. The occurrence of the second plateau is of major concern, since it is not known whether the plateau can be eliminated by any recovery procedure. The capacity of the cells after almost 1 year of storage at room temperature falls short of the amount required to fully support the spacecraft load.

STORAGE AT 0°C

Three cells were tested after storage at 0°C, and their capacity variation with storage time is shown in figure 4. Two of the cells are maintaining capacity, and the third shows only a negligible decline in capacity. There was no second plateau in the discharge profiles of these cells. After 8 months of storage at 0°C, cell capacity is above the required minimum of 44 Ah. These results appear encouraging.

TOP CHARGE AT ROOM TEMPERATURE

Four cells were used in this experiment in which the cells are recharged for 10 hours at 4.8 A every 7 days. Figure 5 shows the capacity variation of the cells for two periods of top charge. One of the cells showed capacity loss in the first period. In the second period, all the cells exhibited increased capacity. Two of the cells showed remarkable recovery, from capacities in the 30's at the beginning to high 50's at the end of the second period.

Figure 6 gives EMF profiles of the four cells, which are of particular interest in regard to the second plateau. Two of the cells show a capacity of about 8 Ah below 1 V, which is much less than for cells stored at room temperature. In addition, the capacity that was in the second plateau at the beginning of the top-charge experiment has moved to the major plateau, as illustrated by the two profiles for cell 8-1127P.

TRICKLE CHARGE

The trickle-charge storage mode closely resembles that of the battery in orbit during non-eclipse periods. Three cells were used in this experiment. One, which had a lower capacity, was trickle charged at 0.65 A for 64 days at 10°C. The cell gained 5 Ah, as shown in figure 7. This cell, along with the other two, was then trickle charged at the same rate but at room temperature. After 184 days, capacity determination revealed almost the same capacity as at the beginning, with negligible capacity below 1 V. These results show that capacity recovery initially occurs when a faded cell is trickle charged, and capacity is maintained thereafter.

-20°C STORAGE

A group of four cells, three with hydrogen precharge and one without, were stored at -20°C and their capacity was determined at intervals. Table 1 presents the resulting capacity variations. Two of the cells gained capacity and the other two maintained capacity. Thus, passive storage at -20°C appears to be an excellent storage method. However, some misgivings exist regarding the stability of the seal at this temperature, although no cell leakage was observed in the four cells tested.

CELL PRESSURE

Pressure variation was monitored for the cells, which were instrumented with strain gauges. Table 2 illustrates the end-of-charge and end-of-discharge (to 1 V) pressure of the cells. As expected, cells with hydrogen precharge show higher pressures than those with positive precharge. The end-of-discharge pressure is abnormally high for the cell stored at room temperature, which indicates that some positive active material is not dischargeable at the C/2 rate.

The pressure of the cell stored in the top-charge mode is higher than expected for a positive precharge cell. The end-of-charge pressure for this cell increased from 740 psi at the beginning of the experiment to 781 psi at the end of the first period and 824 psi at the end of the second period. The increase in end-of-charge pressure corresponded with the increase in capacity. It is unclear whether the present selection of 10 hours at C/10 is appropriate in view of this pressure increase. Additional experiments which use less than 10 hours of recharge are needed. Nevertheless, recharge every 7 days appears to be a successful and practical method for recovering and maintaining cell capacity.

CONCLUSIONS

INTELSAT VI nickel-hydrogen cells exhibit capacity fading when stored passively at room temperature for extended periods. This loss in capacity is accompanied by a gradual growth in capacity in the second plateau. In contrast, capacity is maintained when cells are stored at -20°C and at 0°C in the open-circuit discharged condition.

Top-charge and trickle-charge storage modes also maintain cell capacity. Preliminary results have shown a capacity recovery in the top-charge mode. The second plateau is absent in cells stored in the trickle-charge mode at room temperature. The common denominator in the top-charge and trickle-charge storage modes is the overcharge, which is perpetuated continuously in one procedure and at regular intervals in the other.

REFERENCES

1. Vaidyanathan, H., and Dunlop, J. D., "Capacity Maintenance for INTELSAT VI Nickel-Hydrogen Cells," 22nd Intersociety Energy Conversion Engineering Conference, American Chemical Society, Washington, D.C., 1986, Proc., Vol. 3, pp. 1560-1564.

2. Wong, D. W., Herrin, J., and Stadnick, S. J., " INTELSAT VI Nickel-Hydrogen Battery," 22nd Intersociety Energy Conversion Engineering Conference, American Chemical Society, Washington, D.C., 1986, Proc., Vol. 3, pp. 1541-1546.

Table 1. Capacity Variation at -20°C

Cell No.	Precharge	Initial Capacity (to 1 V) (Ah)	Storage Period (days)	Final Capacity (to 1 V) (Ah)
4-1104N	H_2	63.6	270	66.0
5-1116N	H_2	60.7	270	67.2
13-1382P	None	66.7	112	66.3
1-1081N	H_2	59.9	112	60.3

Table 2. Cell Pressure Variation

Cell No.	Precharge	Storage Mode	End-of-Charge Pressure (psi)	End-of-Discharge Pressure (to 1 V) (psi)	Cell Capacity (Ah)
15-1110P	Positive	Trickle charge	742	125	61.9
8-1127P	Positive	Top-off charge	824	264	54.5
4-1104N	H_2	0°C	847	219	59.5
3-1033N	H_2	Room temperature	766	432	31.0

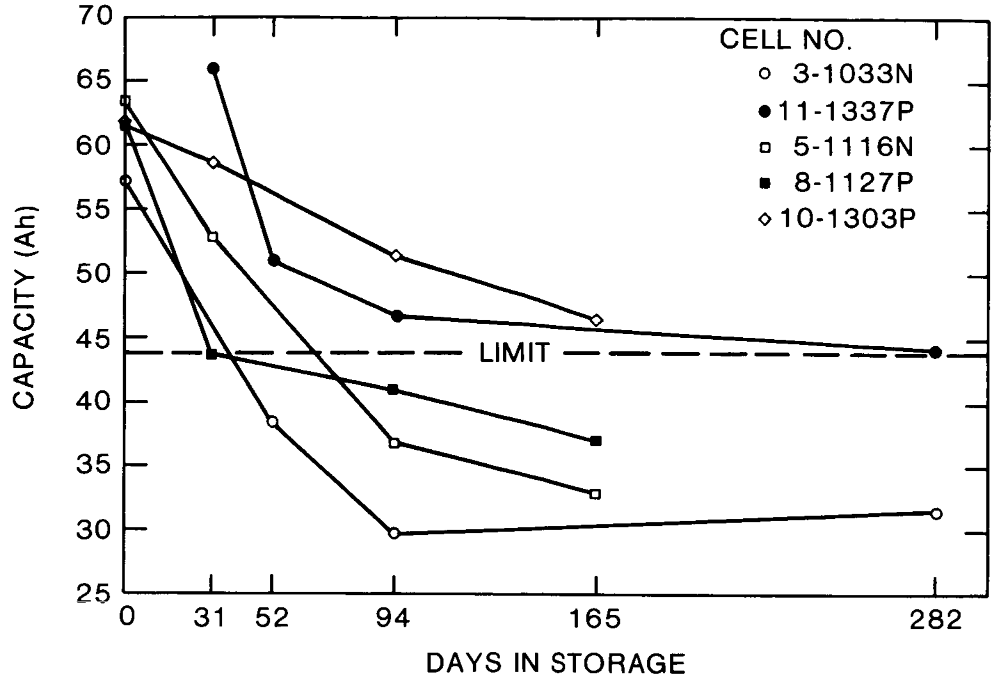


Figure 1. Capacity (to 1 V) Variation for Cells Stored at Room Temperature

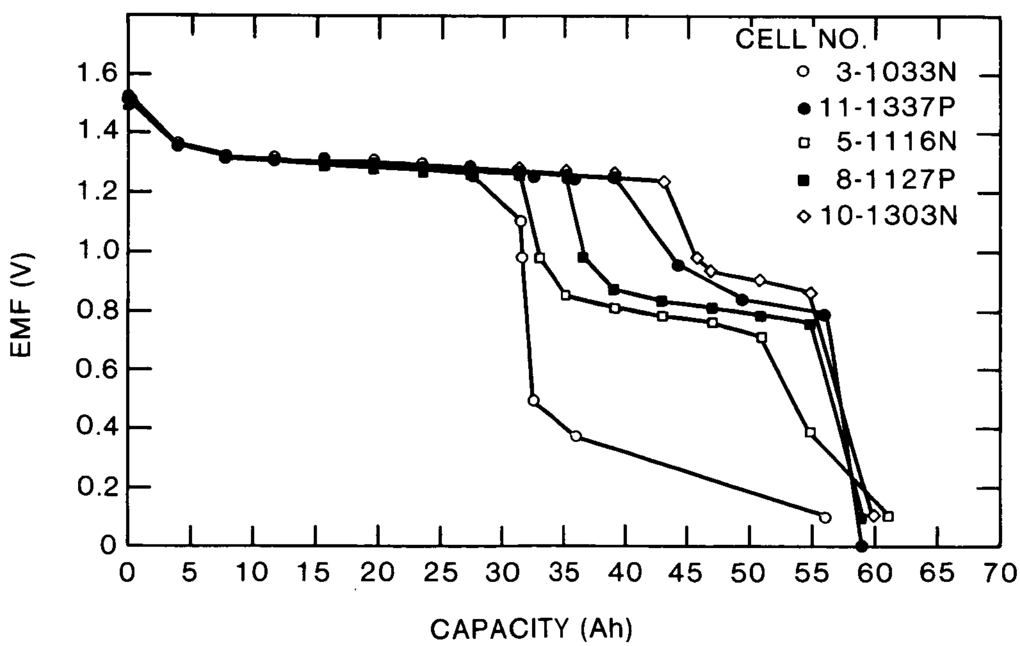


Figure 2. EMF Profile of Cells Stored at Room Temperature at 23.5-A Discharge Rate

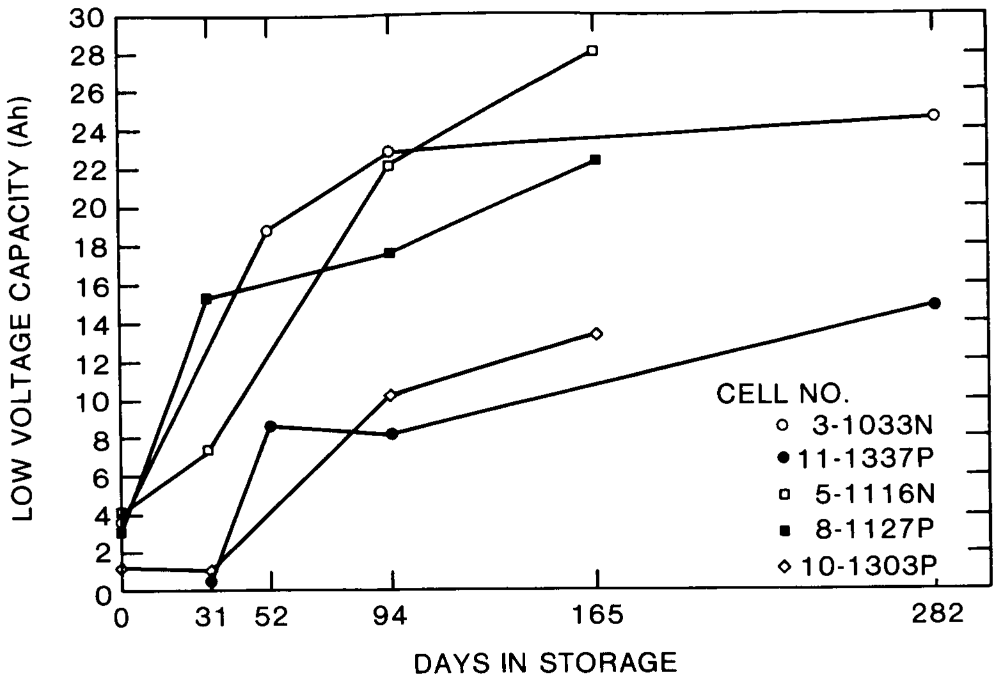


Figure 3. Variation of Additional Capacity at Low Voltages With Storage Time at Room Temperature

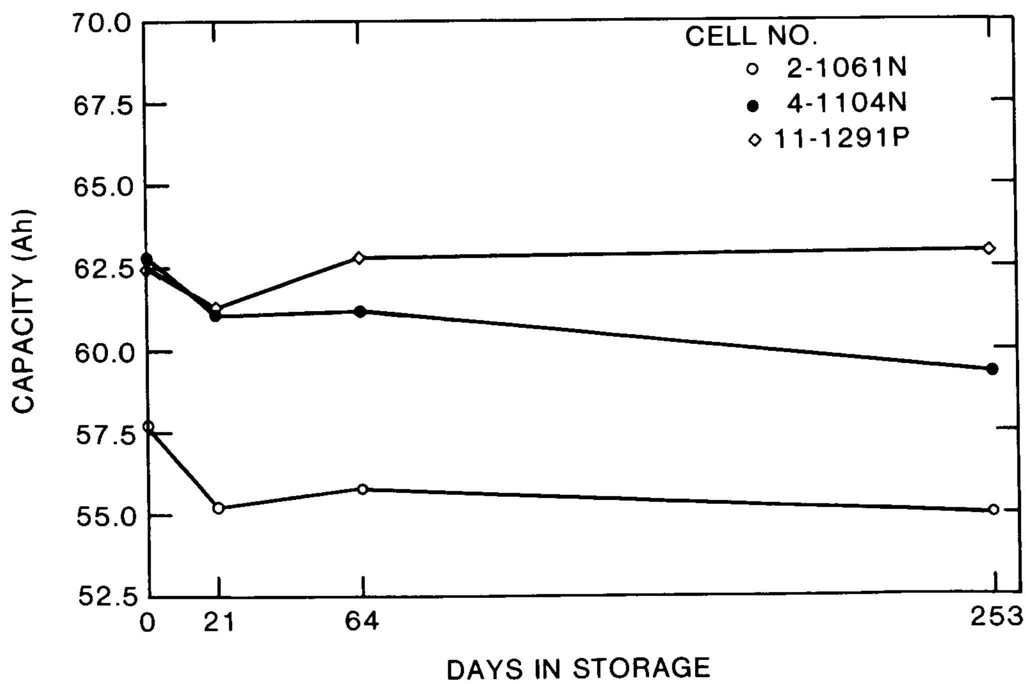


Figure 4. Capacity (to 1 V) Maintenance for Cells Stored at 0°C

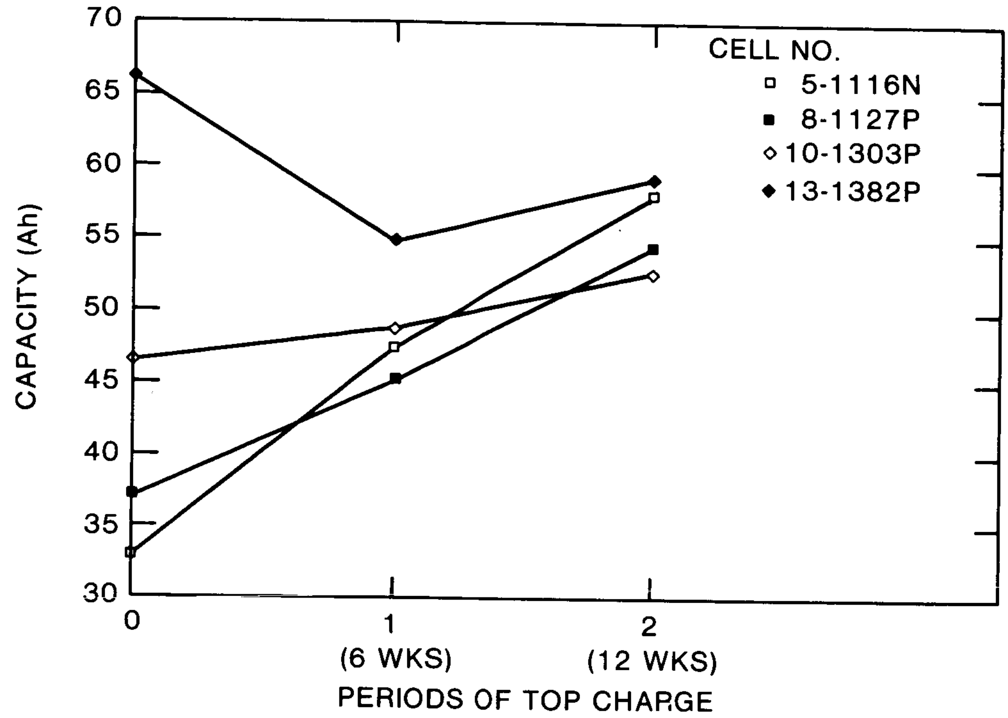
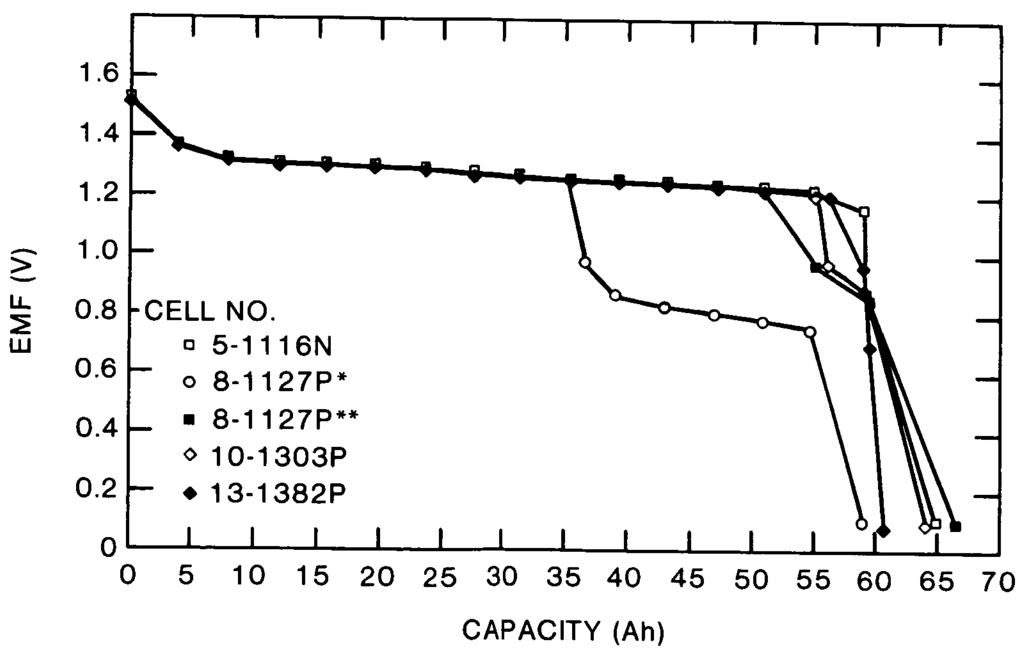


Figure 5. Capacity (to 1 V) Variation in the Top-Off Charge Storage Mode



* BEFORE TOP CHARGE
** AFTER TOP CHARGE

Figure 6. EMF Profile of Cells at 23.5-A Discharge Rate After Two 6-Week Periods of Top-Off Charge

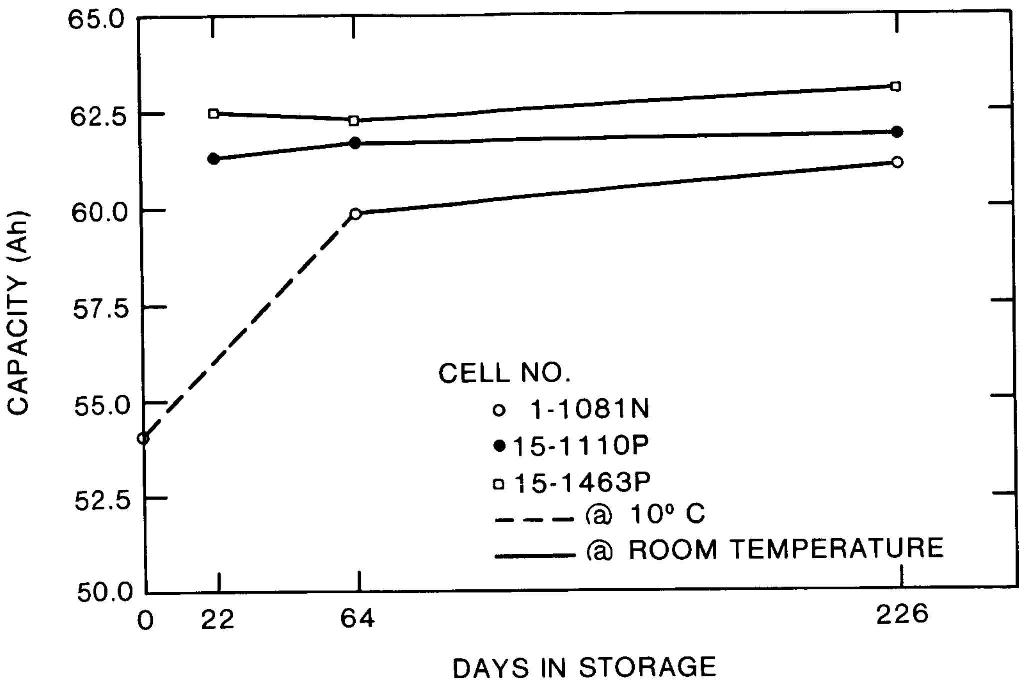


Figure 7. Variation of Capacity (to 1 V) for Cells in the Trickle-Charge Storage Mode