NICKEL-HYDROGEN CELL LIFE TEST

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ABSTRACT

Over 6,900 LEO cycles have been accumulated at 30% DOD on twelve Intelsat-design nickel-hydrogen cells. Physical equipment and cells are described. Performance characteristics are seen to be uniform. Further testing is planned to seek a failure mode, and also to investigate the effects of a new additive for nickel-hydrogen cells. Initial results indicate improved performance at higher temperatures and diminished swelling of positive nickel plates.

INTRODUCTION

Nickel-hydrogen battery cells are now in general use for geo-synchronous (GEO) satellites. Five satellites with nickel-hydrogen batteries have been successfully launched in the last two years and over a dozen are scheduled for the near future. All of these use the Intelsat design. However, the use of this design for low earth orbit (LEO) has not been widely explored.

To investigate the efficacy of the Intelsat design for LEO applications twelve standard production cells (RNH-30-1) with nominal 30 ampere-hour capacities each are being cycled in a LEO regime. The results to-date are described herein. Future plans are also discussed.

CELL DESCRIPTION

The twelve cells were constructed as part of standard production cell lots. A typical RNH-30-1 cell is shown in Figure 1. Eight cells were of completely normal construction. Two (numbers 2 and 4 in accompanying figures) contain negative plate substrates of a unique patented design and two (numbers 1 and 3) contain special positive plates. However, the latter four cells are normally constructed in every other respect and were processed and given acceptance testing with a production cell lot.

The new negative plate substrates, Figure 2, are designed to enhance electrical efficiency by minimizing the electrical current path length to the tab. At the same time, the tab area is considerably strengthed structurally in comparison with previously-used designs by a concentration of radial ribs near the tab-rib and by tapering of the tab-rib itself. The overall geometric design provides roughly-rectangular structural sectors which are essentially identical in surface area, thus providing a relatively homogenous surface for adhesion of platinum catalyst.

The two cells with special positive plates were designed to investigate performance characteristics of a particular nickel-oxide sinter lot.

TEST FIXTURING

The test fixture is shown in Figure 3. Each cell is mounted in an aluminum thermal flange which is bonded to it with RTV-560 and which is electrically isolated by a layer of photo-etched mylar. The cells are mounted in a common vertical aluminum fixture which is 0.8 inches thick. Its large mass enables it to serve effectively as a stabilizing heat reservoir.

The entire fixture is contained in a refrigerated chamber which is able to regulate temperature to $4 \pm 3^{o}C$. Each cell is mounted horizontally. Some additional cells may be seen in Figure 3 alongside the vertically-standing fixture. These are part of another life test being run concurrently with this one.

As safety features the test chamber contains a catalytic hydrogen gas sensor and a temperature-sensitive switching element. These are wired to a fault-relay which will terminate cycling and trigger an audible alarm in the event of a hydrogen leak or excessive heat build-up. Over/under voltage protection is also provided.

Ancillary equipment includes a small computer which controls cycling automatically, a power supply, and a monitor for recording voltage.

CYCLE REGIME AND PERFORMANCE

The cells have, as of November 1984, completed over 6,900 LEO cycles at a 30% depth-of-discharge (DOD), i.e., 55 minutes of charge at C/3 and 35 minutes of discharge at C/2 for 16 cycles per day.

The initial charge/discharge (C/D) ratio of 1.08 was reduced to 1.04 after 3,300 cycles to maintain an EOC V near 1.57 volts per cell. C/D was further reduced to 1.02 at 6,000 cycles and then re-adjusted to 1.03 at 6,400 cycles.

EOC and EOD voltages have remained quite uniform throughout cycling. Data representative of the lowest and highest cell at each measurement are displayed in Figures 4 and 5.

Discharge capacities are measured at intervals to monitor cell performance. This typically consists of a C/2 discharge to 1.0 volt which is preceded by a C/10 charge for 16 hours. Capacities are shown in Figure 6. Note that capacities increased significantly at cycle 4200. A mechanical failure occurred at that time which caused the unintended reversal of all twelve cells to an average of -0.25 volts per cell.

Charge retention is also measured at intervals. The cells are charged at C/10 to knee-over (typically eighteen hours) and EOC voltages obtained. After a four to twelve day open-circuit stand another OCV is obtained. Capacity after one such stand is shown in the last column of Figure 6. Charge-retention voltage data are tabulated in Figure 7.

FUTURE PLANS FOR LIFE TESTING

It is planned to continue life-testing of the twelve cells indefinitely with the intention of eventually determining a failure mode. In addition, life testing of two additional RNH-30-1 cells is planned. These are identical to those of a recent production cell lot except that they contain a special additive.

The additive used increased cell capacity at higher temperatures and also improved charge retention at 10°C. Figure 8 shows capacity comparisons between the two additive cells (cells A and B) and the production cell lot in which they were built and tested. The change is most striking at 30°C where an eight ampere-hour improvement is seen. The improvement in 10°C capacity after a 72-hour charge-retention stand is nearly four ampere-hours.

Figures 9 through 19 show time/voltage comparisons between one of the additive cells (labeled "A") and one cell representative of the production lot average. The abrupt, brief rise in voltage near the end of some discharge curves is an artifact of the curve-smoothing algorithm and should be disregarded.

Beyond the improvements in capacity and charge retention an interesting feature is a rise in voltage near EOC for the additive cell which invariably crosses-over the non-additive cell's voltage.

As a check on possible effects of the additive used, a 10C stress test was performed on similar positive plates, using a 12-minute charge/6-minute discharge cycle. Six plates were immersed in normal KOH (1.300 SpG) and six in the same KOH with the additive. Thickness measurements were made before testing and after cycles 55, 160, 240 and

320. The measurements are tabulated in Figure 20. Notably, the plates in the additive grew only 1 to 4 mils compared to those in the regular KOH which thickened 4 to 8 mils. This stress test was extremely severe and went far beyond the number of cycles normally employed.

SUMMARY

Over 6,900 LEO cycles have been accumulated at 30% DOD on twelve Intelsat-design nickel-hydrogen cells. Although the cells are from two different production lots, voltage and capacity performances have been very uniform and charge retention characteristics remain nominal. Voltage reversal on one discharge was seen to have a positive effect on capacity and did not otherwise affect performance. New design negative-plate substrates have not affected performance at the low charge/discharge rates used.

Future plans include continued testing of the twelve cells with the intent of determining a failure mode. Two cells with a special additive will also be tested in a regime yet to be determined. Initial results indicate improved capacity at higher temperatures and improved charge-retention characteristics. Plate growth may also be reduced because of the additive.

Not least of all, the efficacy of nickel-hydrogen cells without wall-wicks in LEO cycles is being shown as superior to previous estimates. A useful life-test data base in this regard continues to be generated.

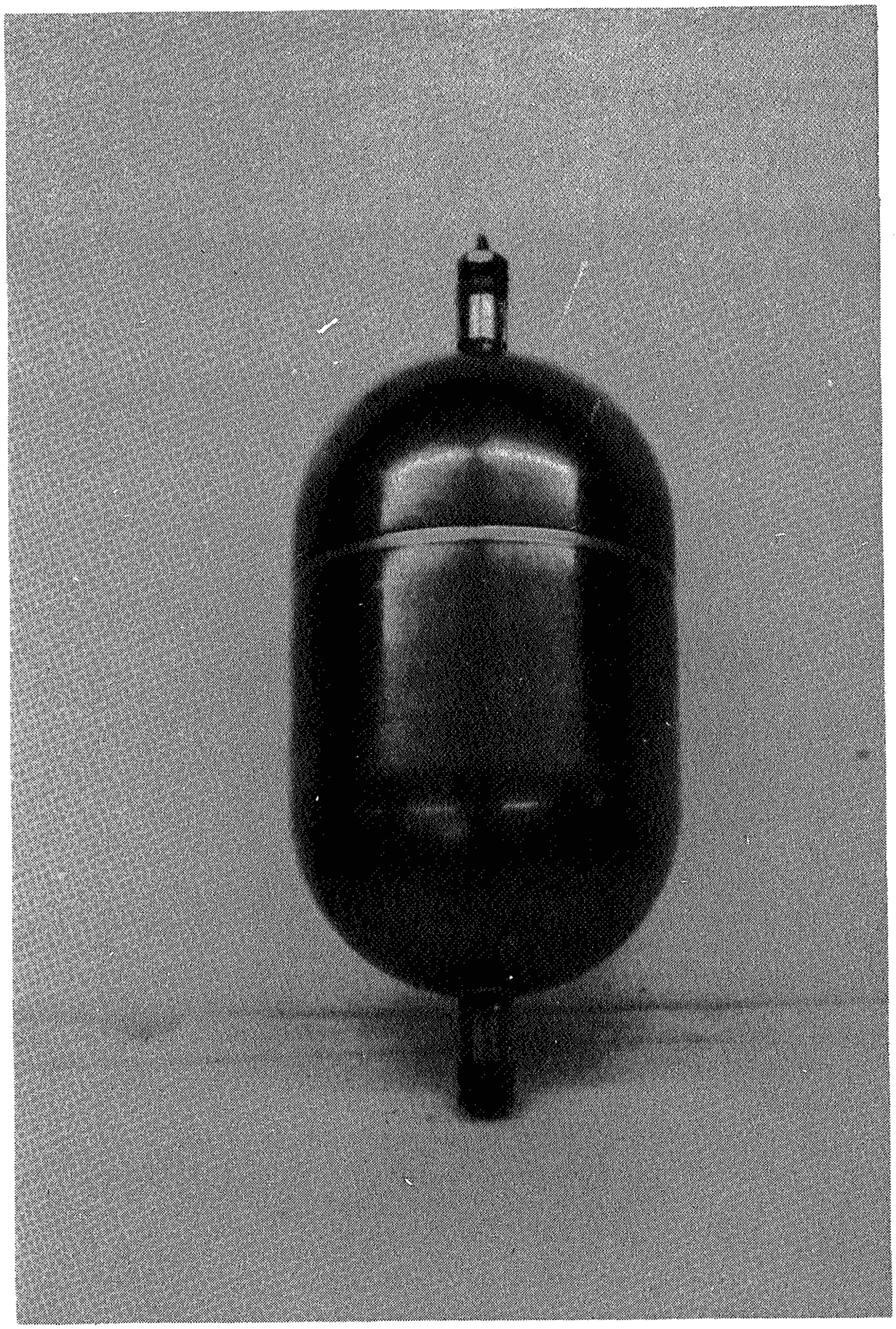

Figure 1. Typical RNH-30-1 Nickel-Hydrogen Cell

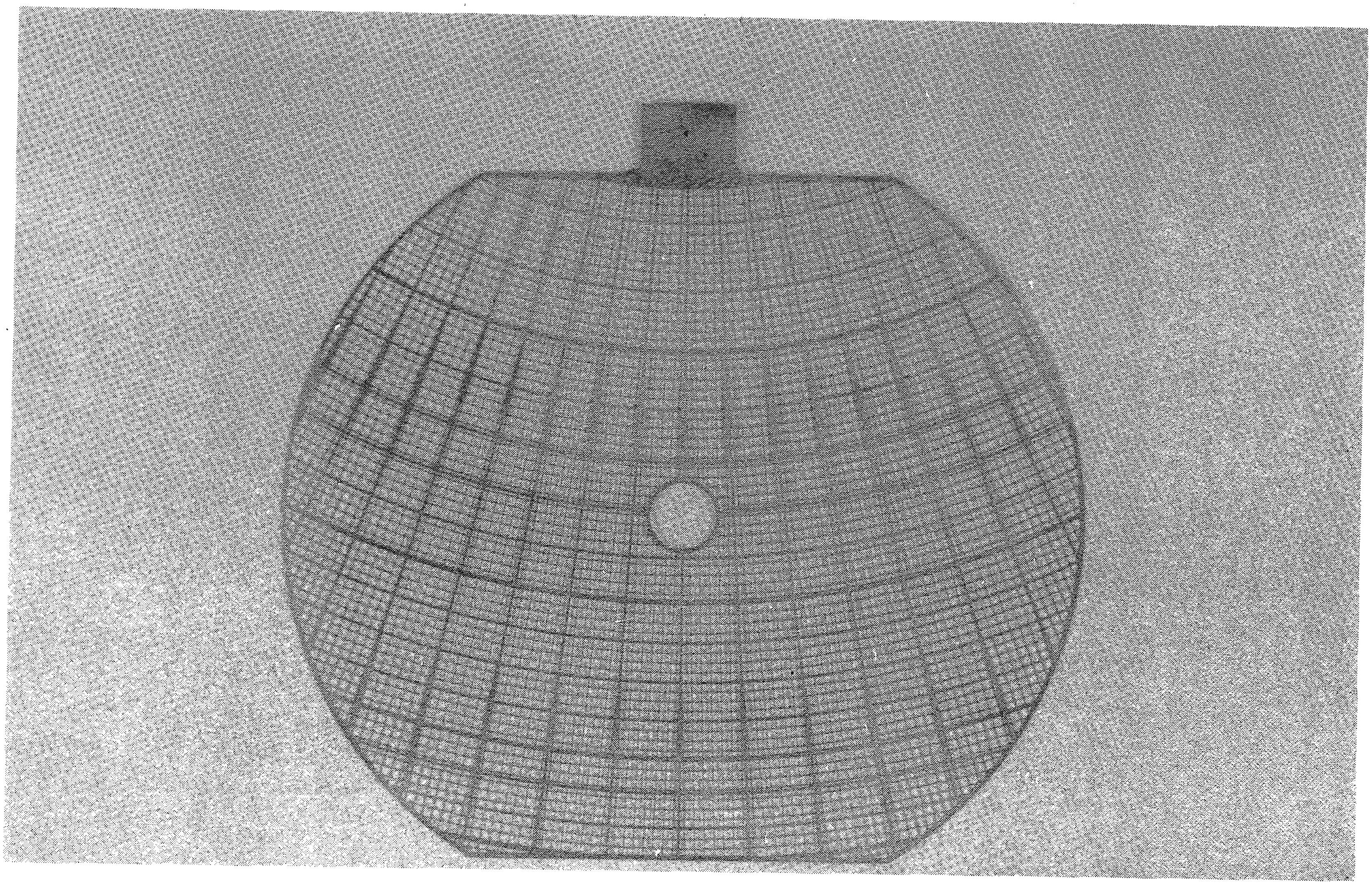

Figure 2. Negative Plate Substrate (U.S. Pat. No. 4,477,546)

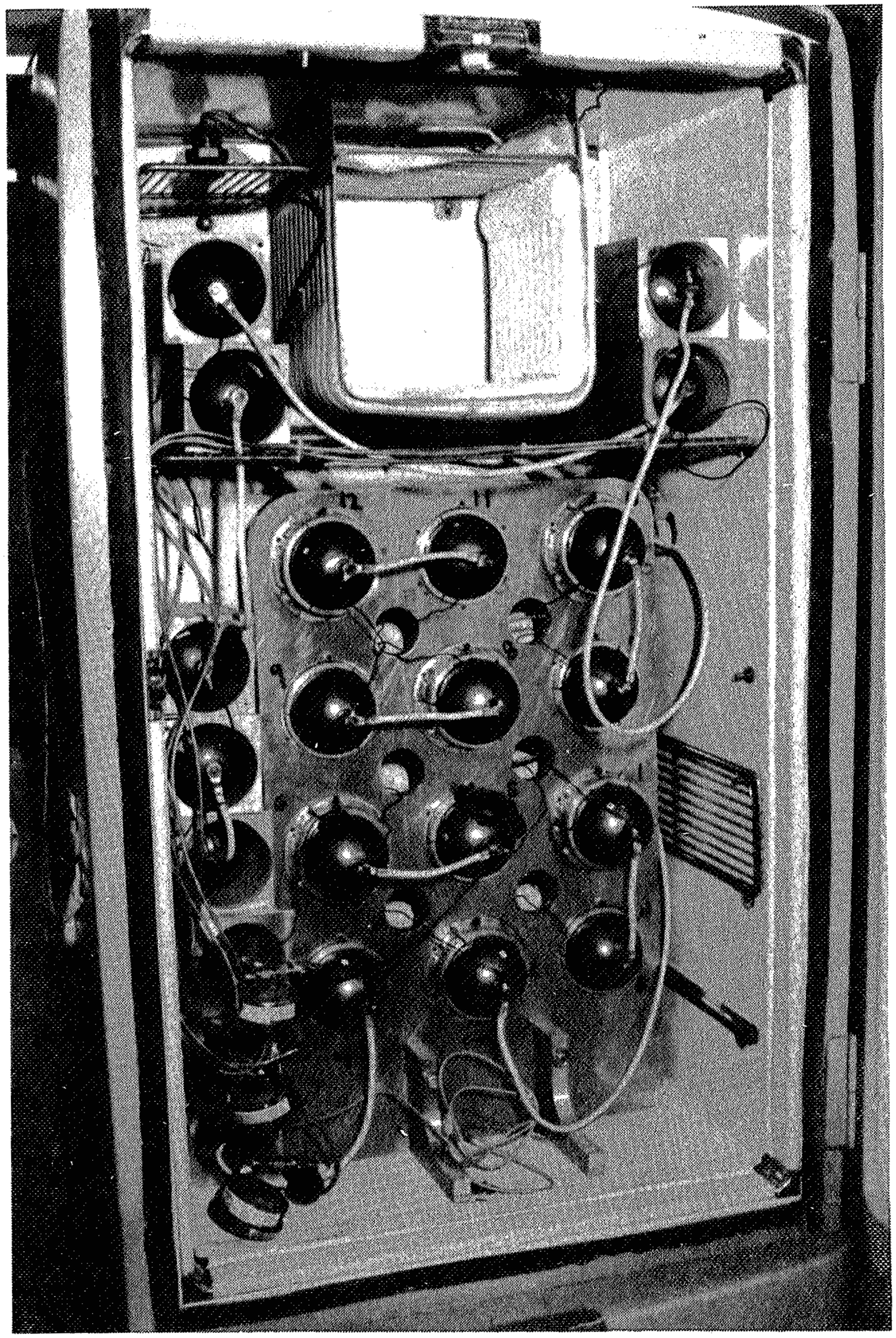

Figure 3. Test Fixture and Refrigeration Chamber

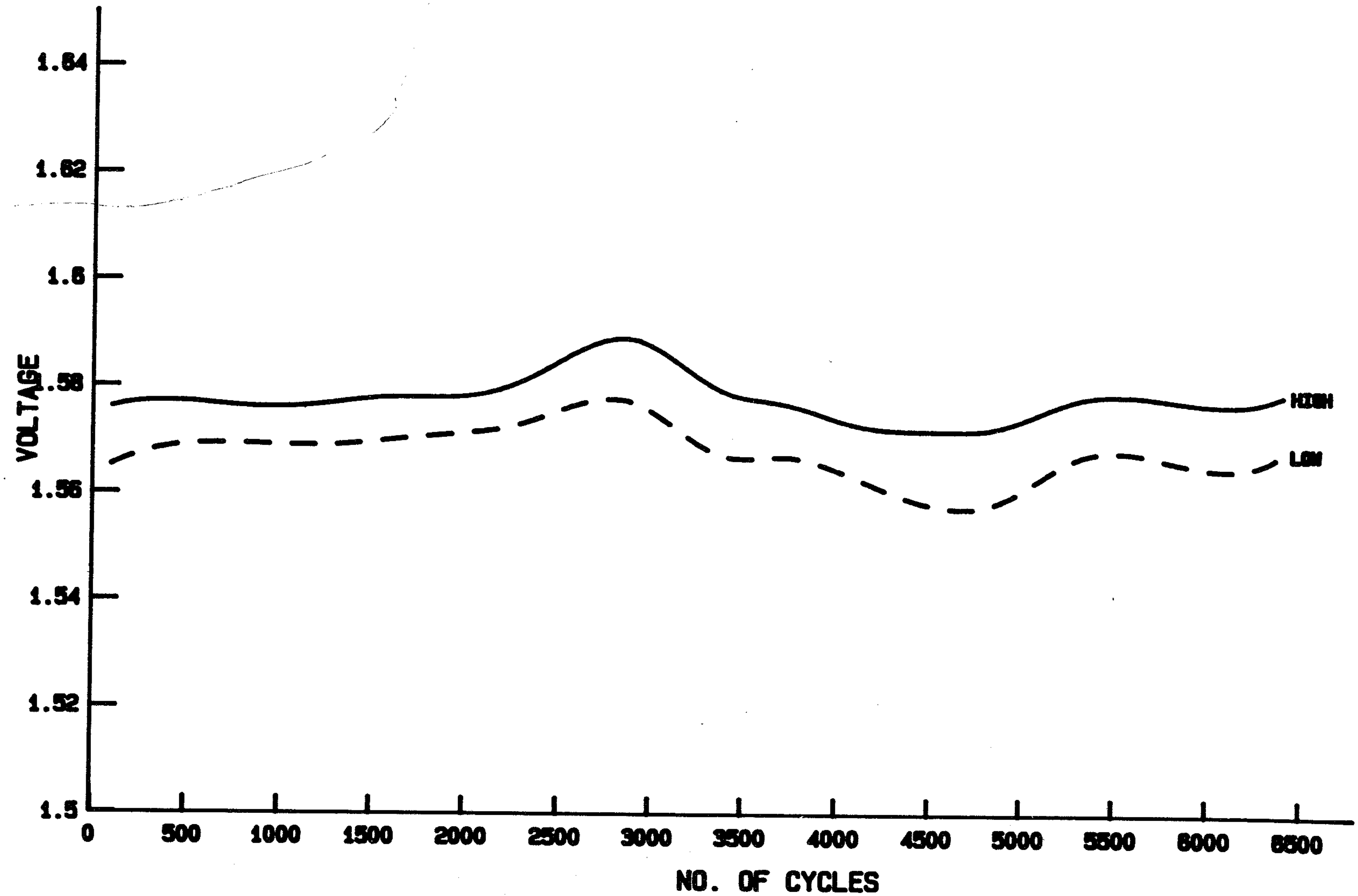

Figure 4. End-of-Charge Voltages

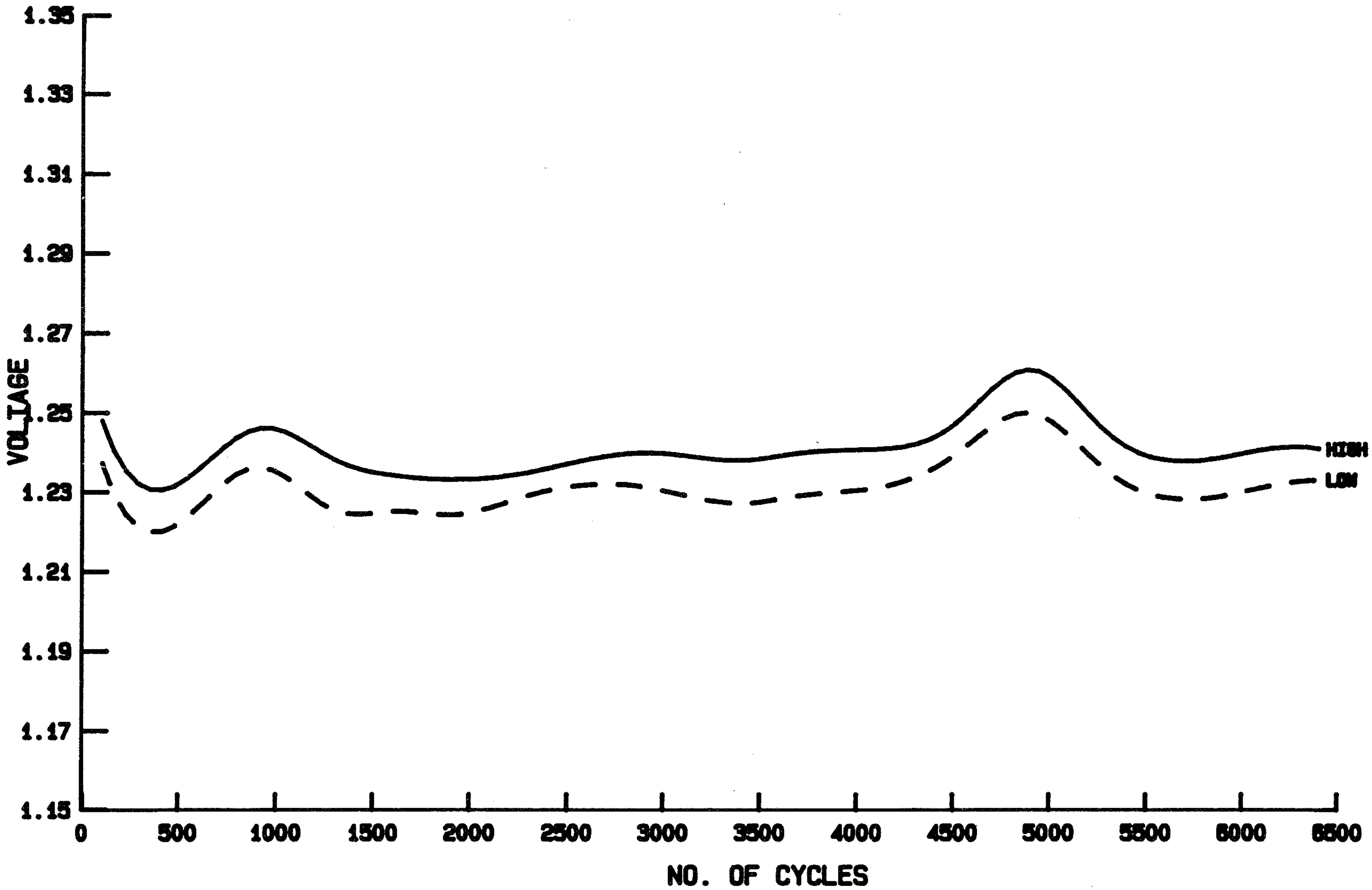

Figure 5. End-of-Discharge Voltages

S/N	INITIAL	CYCLE #2300	CYCLE #4200 (1)	CYCLE #4200 (2)	CYCLE #4400 (3)
01	36.0	36.0	37.0	40.0	34.6
02	35.4	30.8	32.3	35.1	30.8
03	36.0	36.0	37.5	40.0	35.7
04	35.6	35.4	36.7	39.8	34.4
05	35.0	32.3	33.6	38.0	33.1
06	35.8	32.1	34.1	38.0	33.1
07	35.3	32.6	34.1	38.2	33.1
08	36.0	32.3	34.4	38.2	33.1
09	35.8	32.6	34.4	38.2	32.3
10	35.8	32.9	35.4	38.5	33.6
11	35.3	32.3	33.9	38.2	32.9
12	35.3	32.3	33.9	38.2	33.1
AVG:	35.6	33.1	34.8	38.4	33.3
S.D:	0.87	1.69	1.56	1.30	1.22

(1) IMMEDIATELY PRIOR TO REVERSAL

(2) AFTER REVERSAL TO -0.25V

(3) AFTER 96 HR. OPEN CIRCUIT STAND

Figure 6. Discharge Capacities (Ampere Hours) RNH-30-1 Life Test

S/N	CYCLE #70 96 HOUR STAND BEGIN OCV	CYCLE #70 96 HOUR STAND END OCV	CYCLE #1000 120 HOUR STAND BEGIN OCV	CYCLE #1000 120 HOUR STAND END OCV	CYCLE #2200 288 HOUR STAND BEGIN OCV	CYCLE #2200 288 HOUR STAND END OCV
01	1.532	1.369	1.528	1.352	1.392	1.339
02	1.534	1.369	1.529	1.354	1.394	1.340
03	1.530	1.371	1.526	1.353	1.397	1.339
04	1.529	1.368	1.526	1.352	1.395	1.338
05	1.526	1.371	1.521	1.353	1.400	1.338
06	1.530	1.371	1.524	1.355	1.400	1.337
07	1.524	1.371	1.520	1.354	1.401	1.338
08	1.528	1.370	1.522	1.354	1.400	1.337
09	1.527	1.371	1.522	1.355	1.400	1.338
10	1.531	1.372	1.526	1.356	1.403	1.339
11	1.522	1.369	1.518	1.353	1.401	1.338
12	1.520	1.369	1.516	1.353	1.400	1.339

S/N	CYCLE #2500 288 HOUR STAND BEGIN OCV	CYCLE #2500 288 HOUR STAND END OCV	CYCLE #4200 96 HOUR STAND BEGIN OCV	CYCLE #4200 96 HOUR STAND END OCV	CYCLE #4500 96 HOUR STAND BEGIN OCV	CYCLE #4500 96 HOUR STAND END OCV
01	1.523	1.339	1.515	1.358	1.472	1.353
02	1.527	1.339	1.518	1.364	1.472	1.357
03	1.523	1.339	1.515	1.362	1.474	1.356
04	1.523	1.339	1.514	1.360	1.472	1.354
05	1.518	1.341	1.514	1.358	1.467	1.352
06	1.521	1.340	1.513	1.361	1.471	1.355
07	1.515	1.342	1.510	1.360	1.465	1.351
08	1.519	1.341	1.511	1.361	1.469	1.354
09	1.518	1.341	1.511	1.361	1.469	1.354
10	1.518	1.340	1.511	1.362	1.470	1.356
11	1.514	1.341	1.509	1.359	1.467	1.351
12	1.514	1.341	1.509	1.358	1.468	1.350

Figure 7. Charge Retention, RNH-30-1 Life Test

CYCLE	CELL A	CELL B	LOT AVG. (80 CELLS)	SIGMA
$30^{o}C$ Capacity	35.5	35.3	27.0	1.4
$20^{o}C$ Capacity	35.4	35.4	31.7	.8
$10^{o}C$ Capacity	36.8	36.9	34.2	.5
$0^{o}C$ Capacity	37.0	38.4	37.3	.2
$10^{o}C$ Chg. Ret.	33.6	33.6	29.8	.7

Figure 8. Performance of Additive Cells, Capacities in Ampere-hours

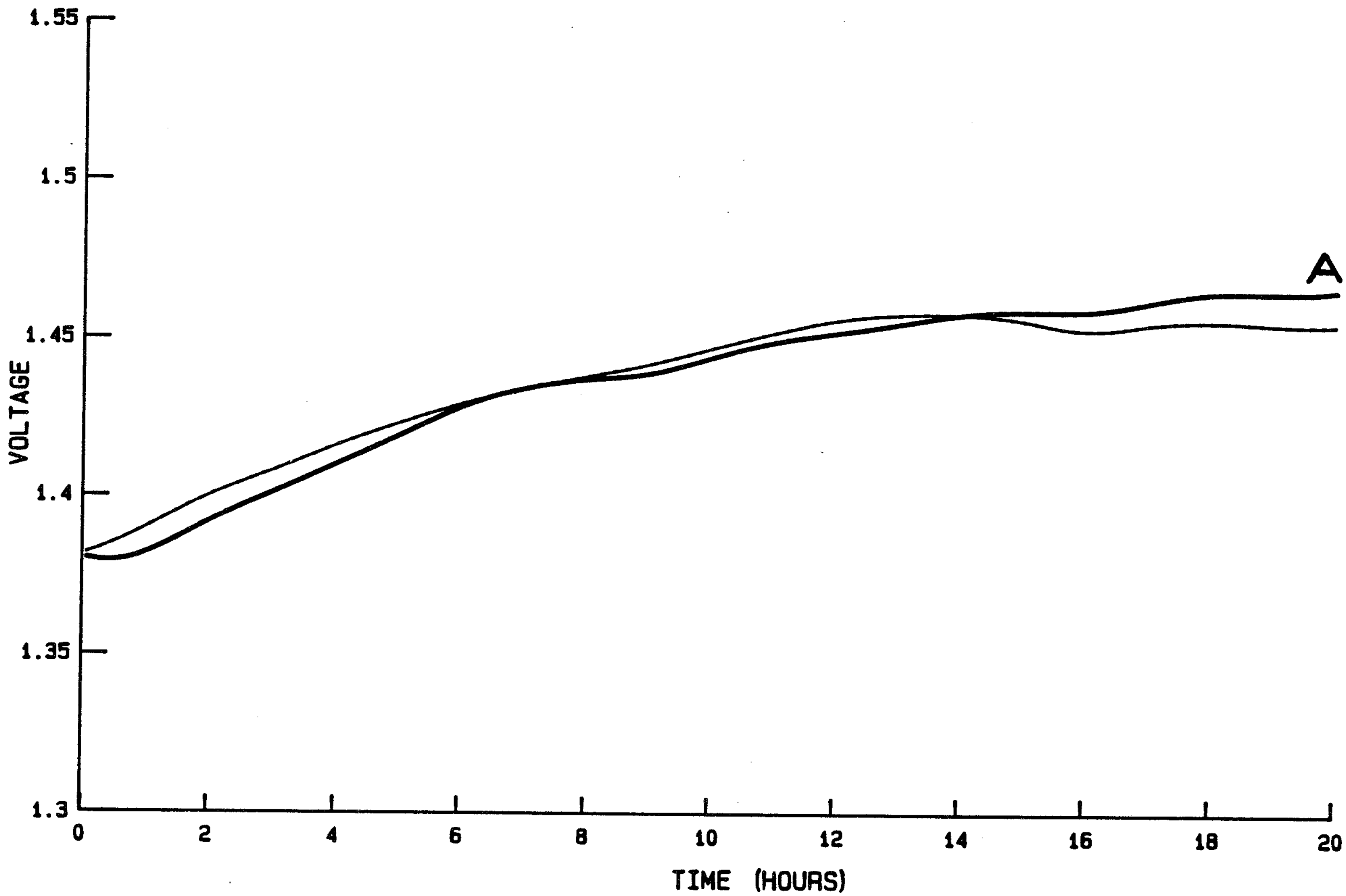

Figure 9. 30 Degree Charge

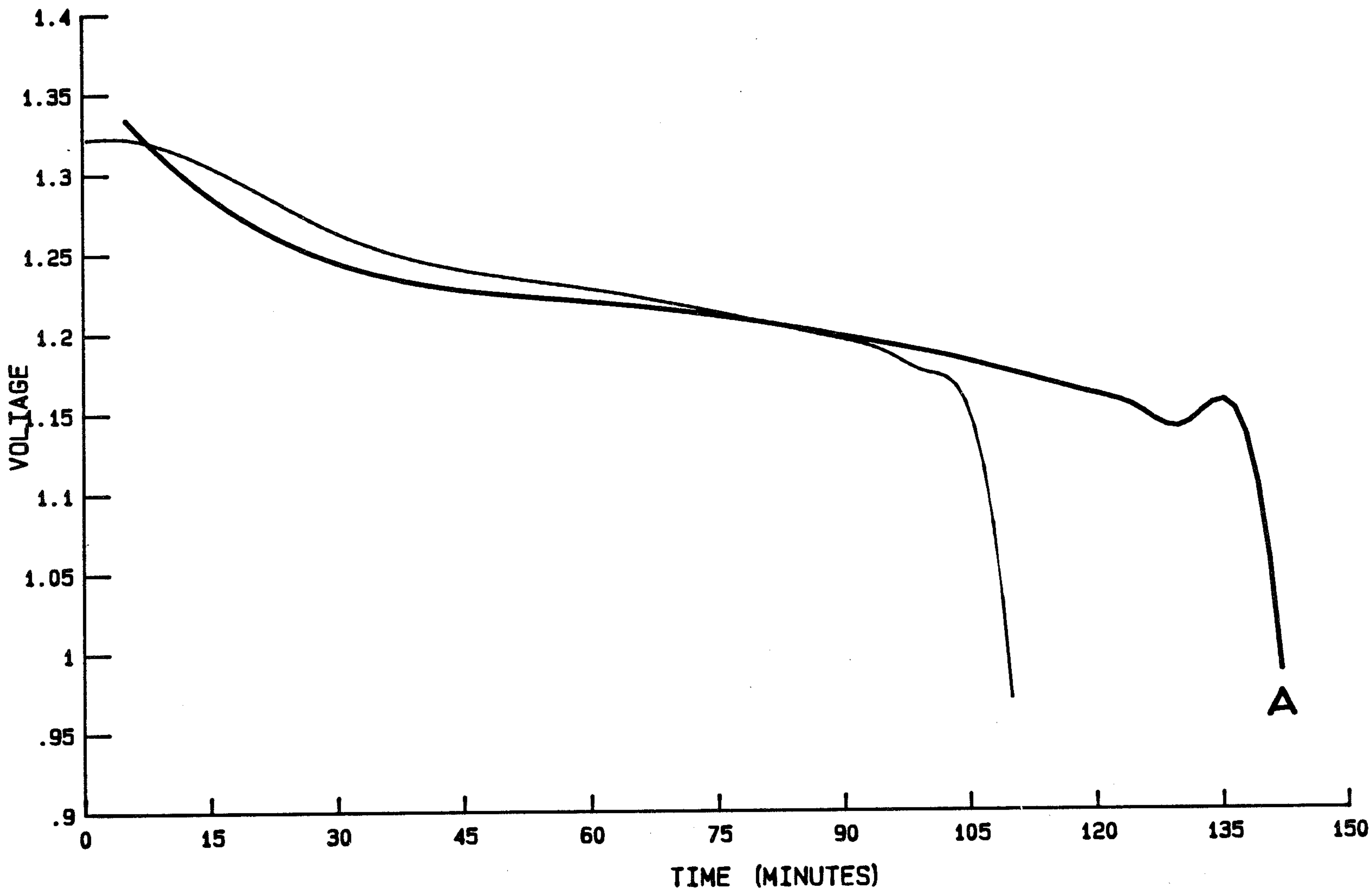

Figure 10. 30 Degree Discharge

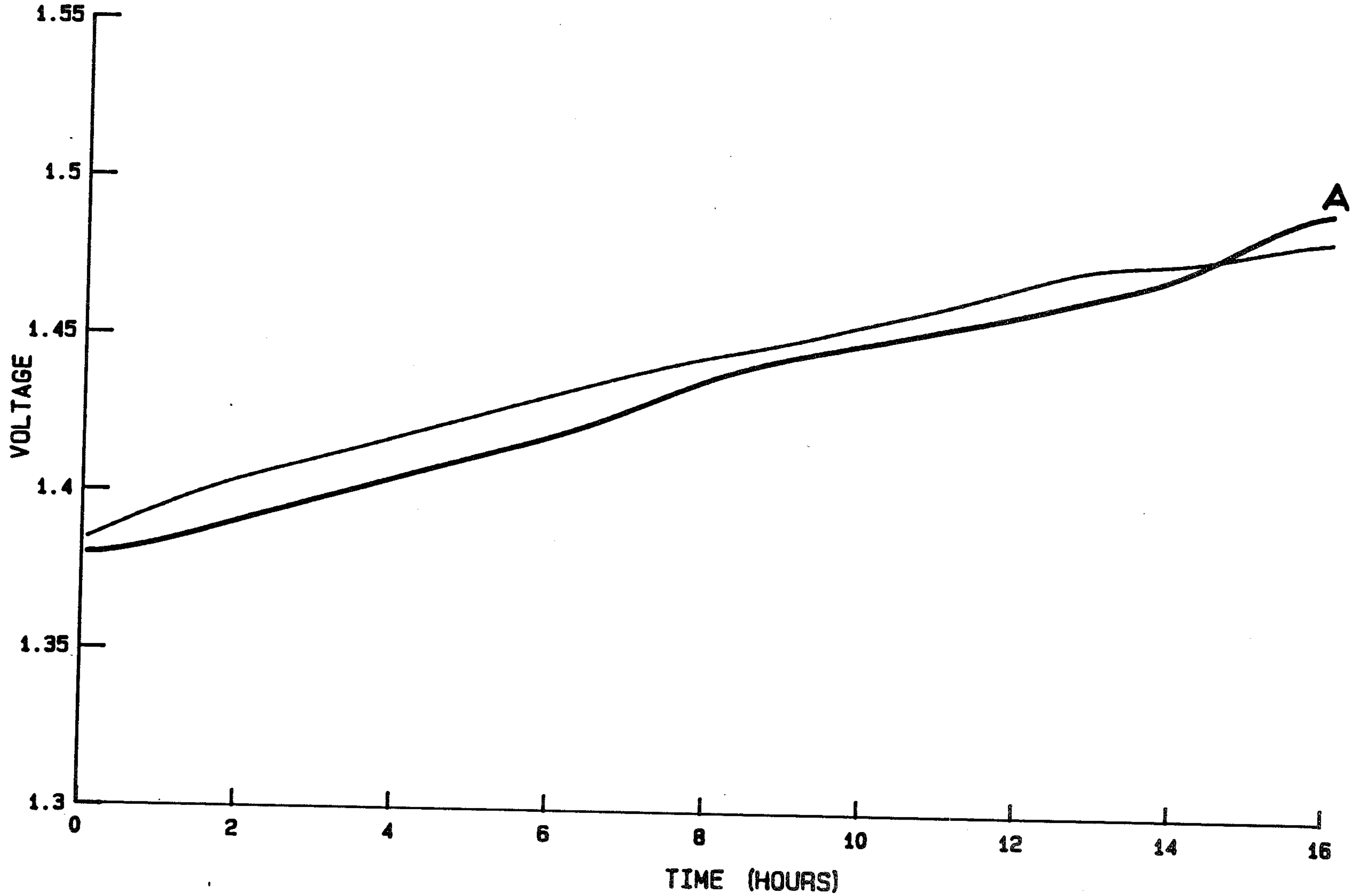

Figure 11. 20 Degree Charge

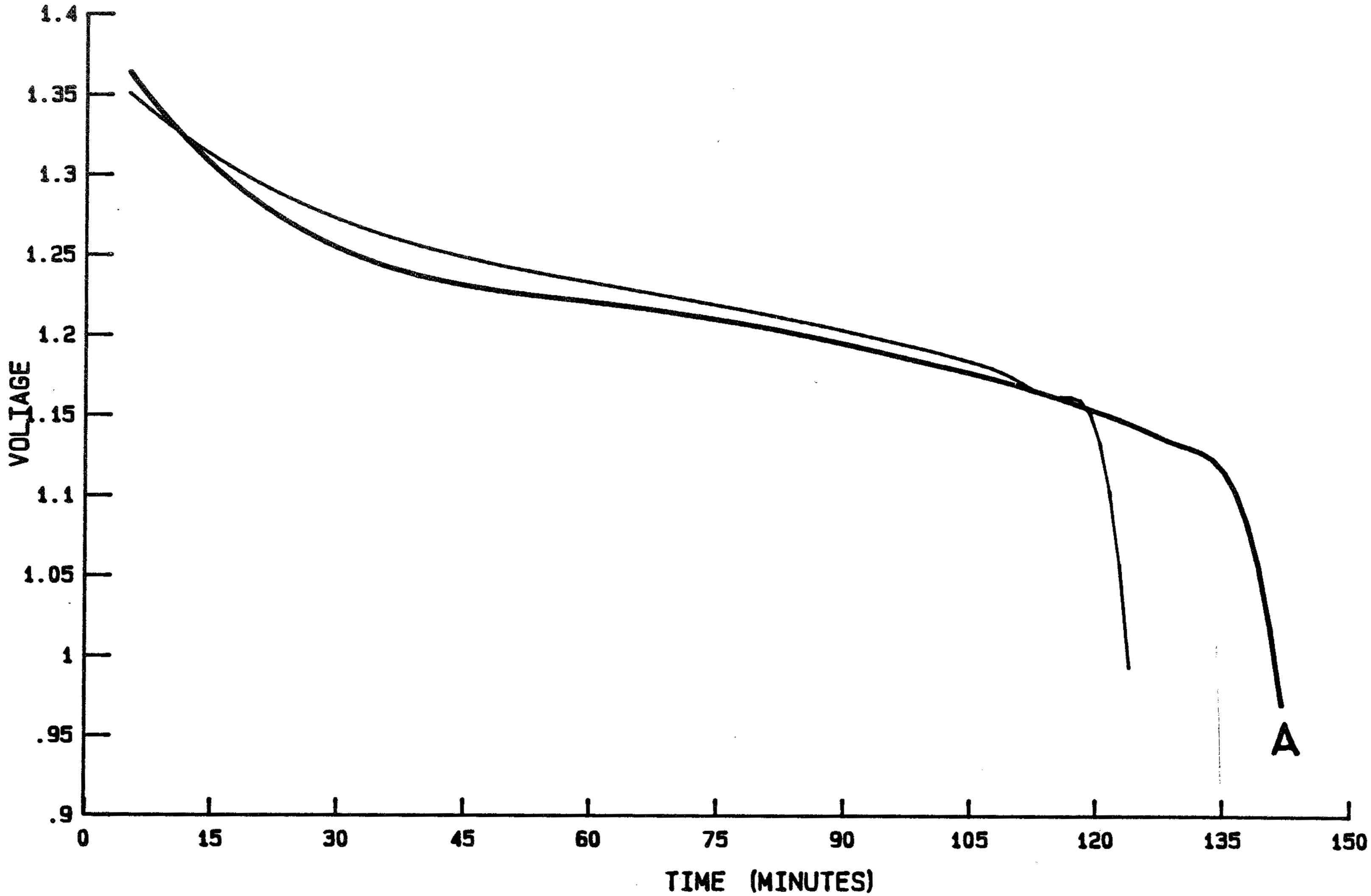

Figure 12. 20 Degree Discharge

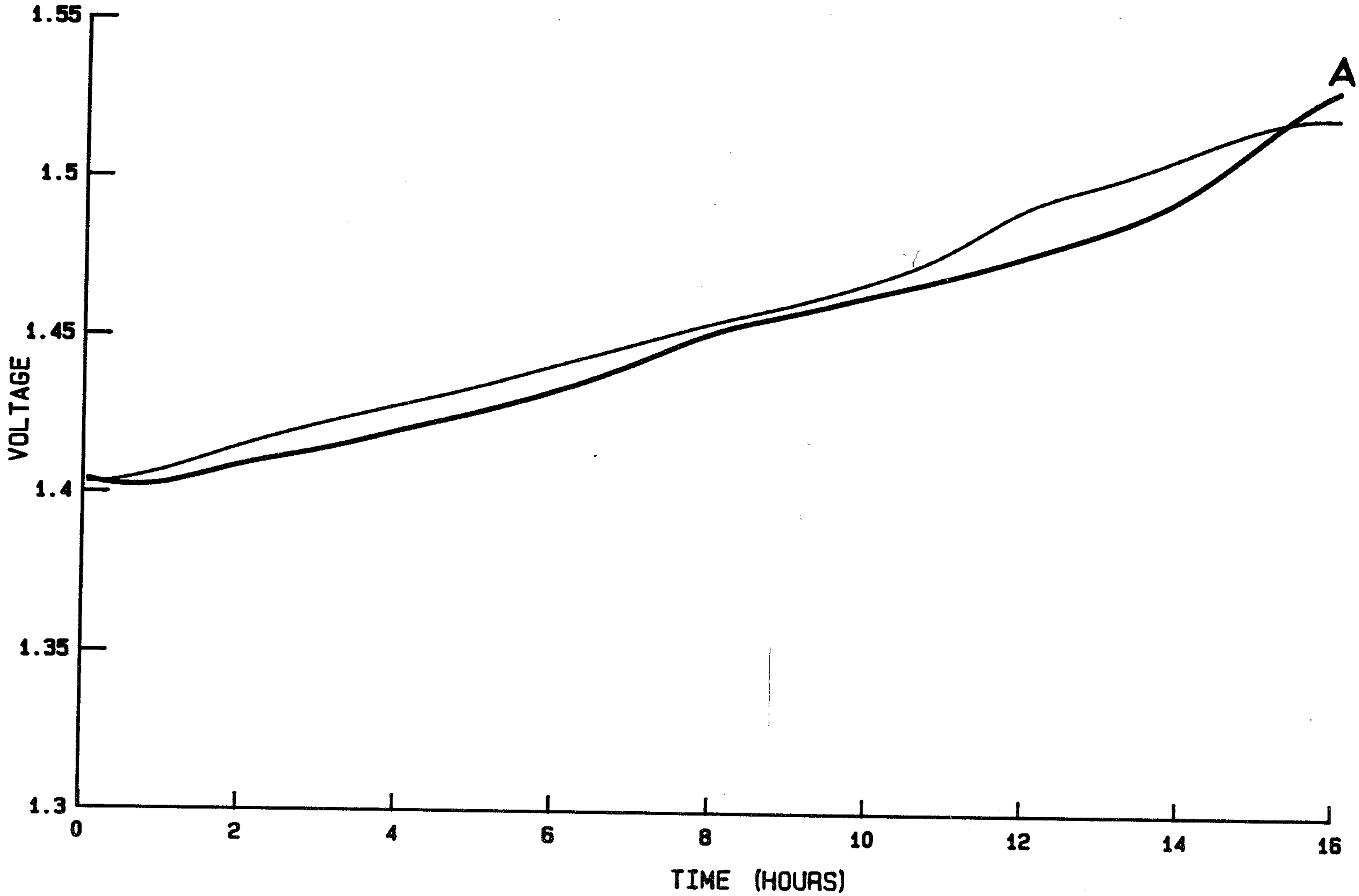

Figure 13. 10 Degree Charge

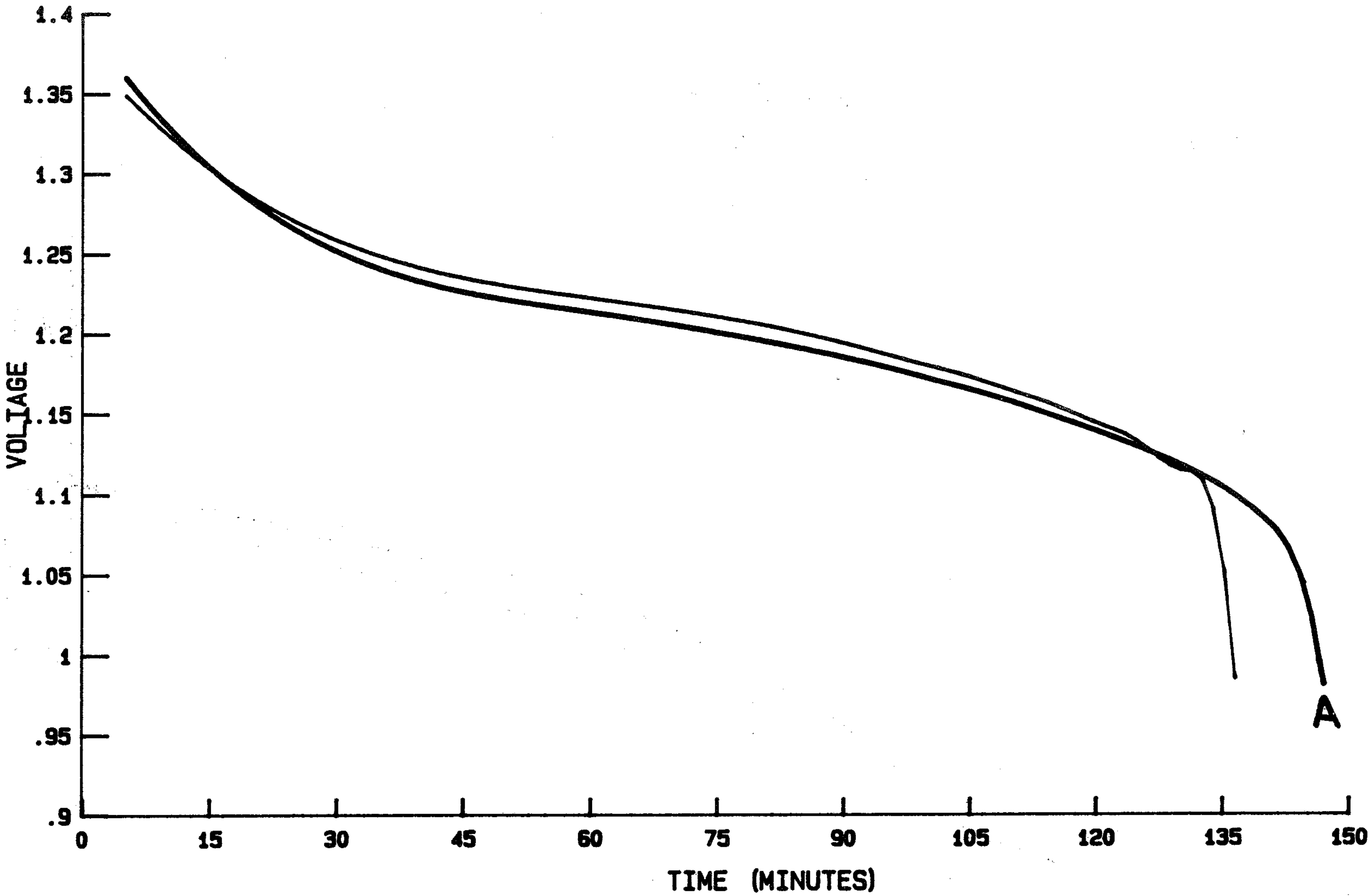

Figure 14. 10 Degree Discharge

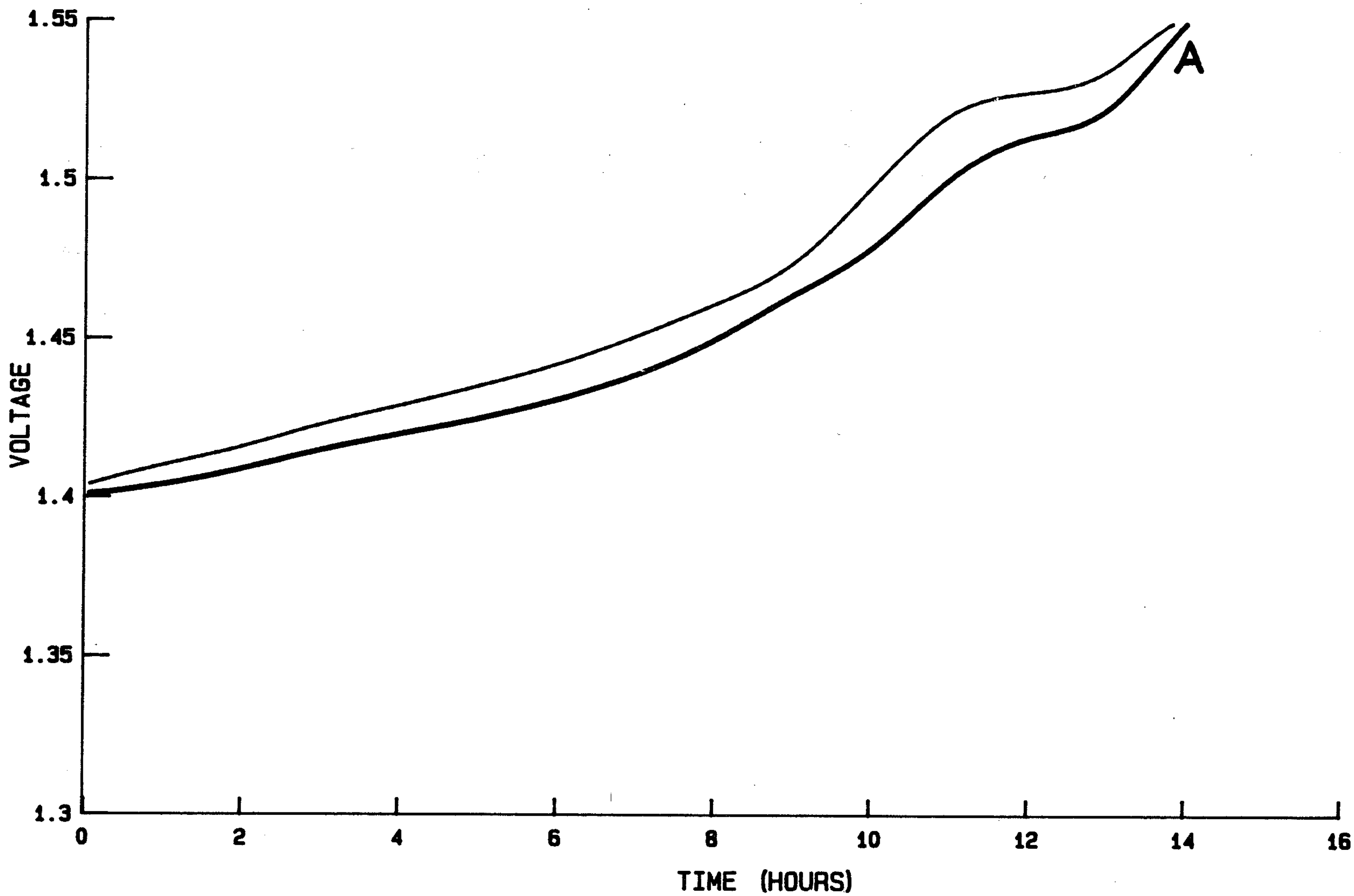

Figure 15. 0 Degree Charge

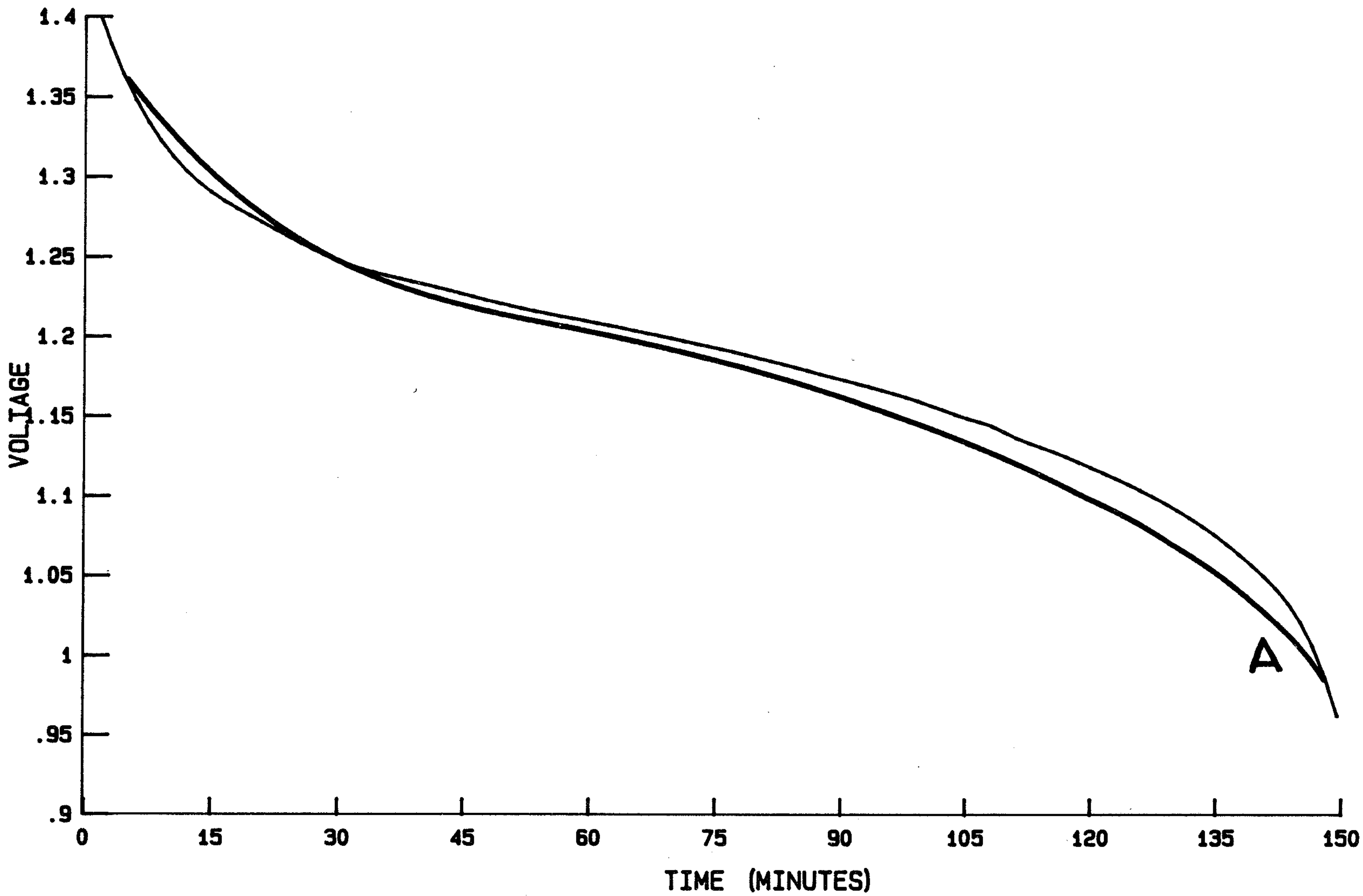

Figure 16. 0 Degree Discharge

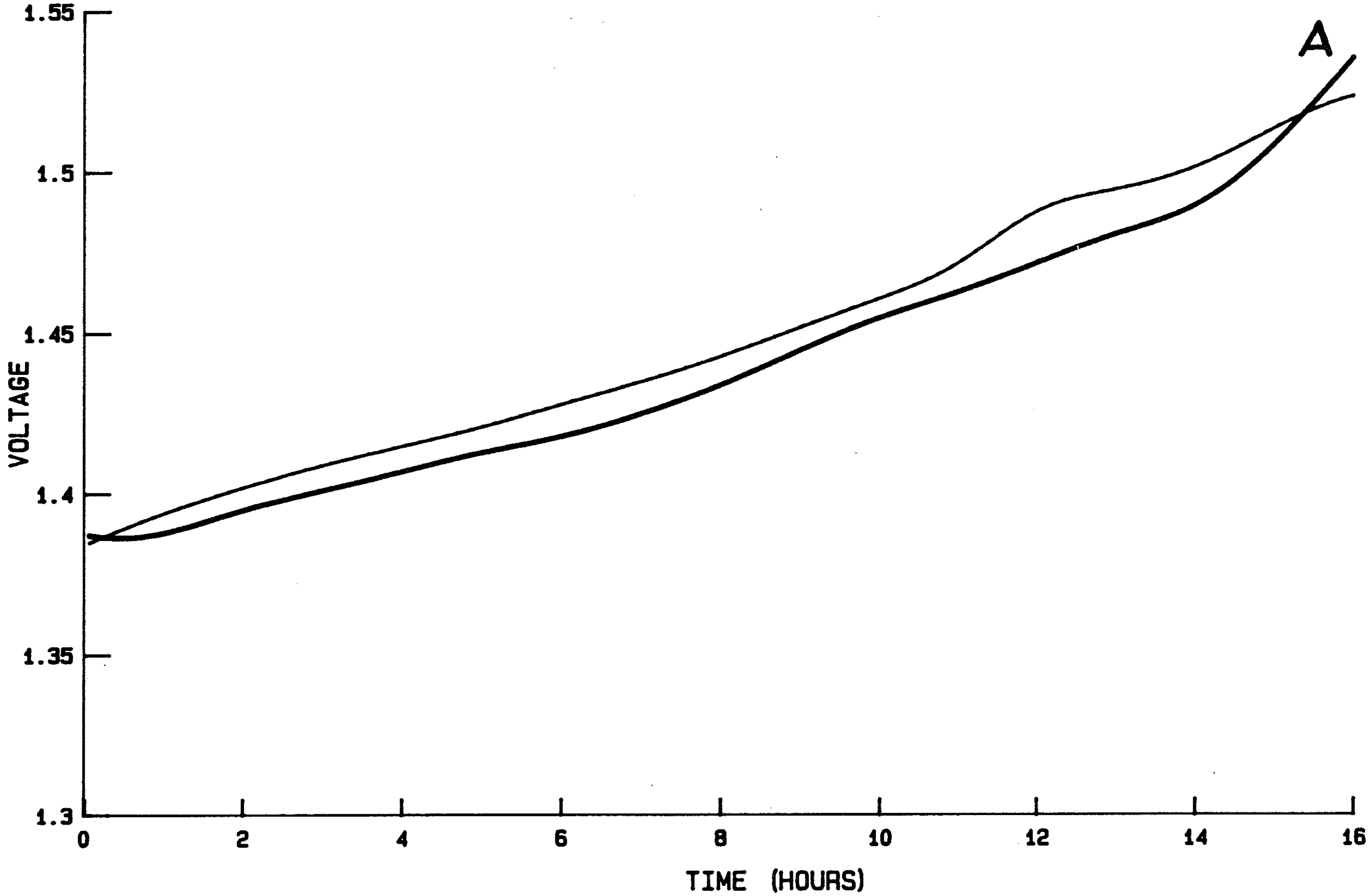

Figure 17. 10 Deg Charge Ret Charge

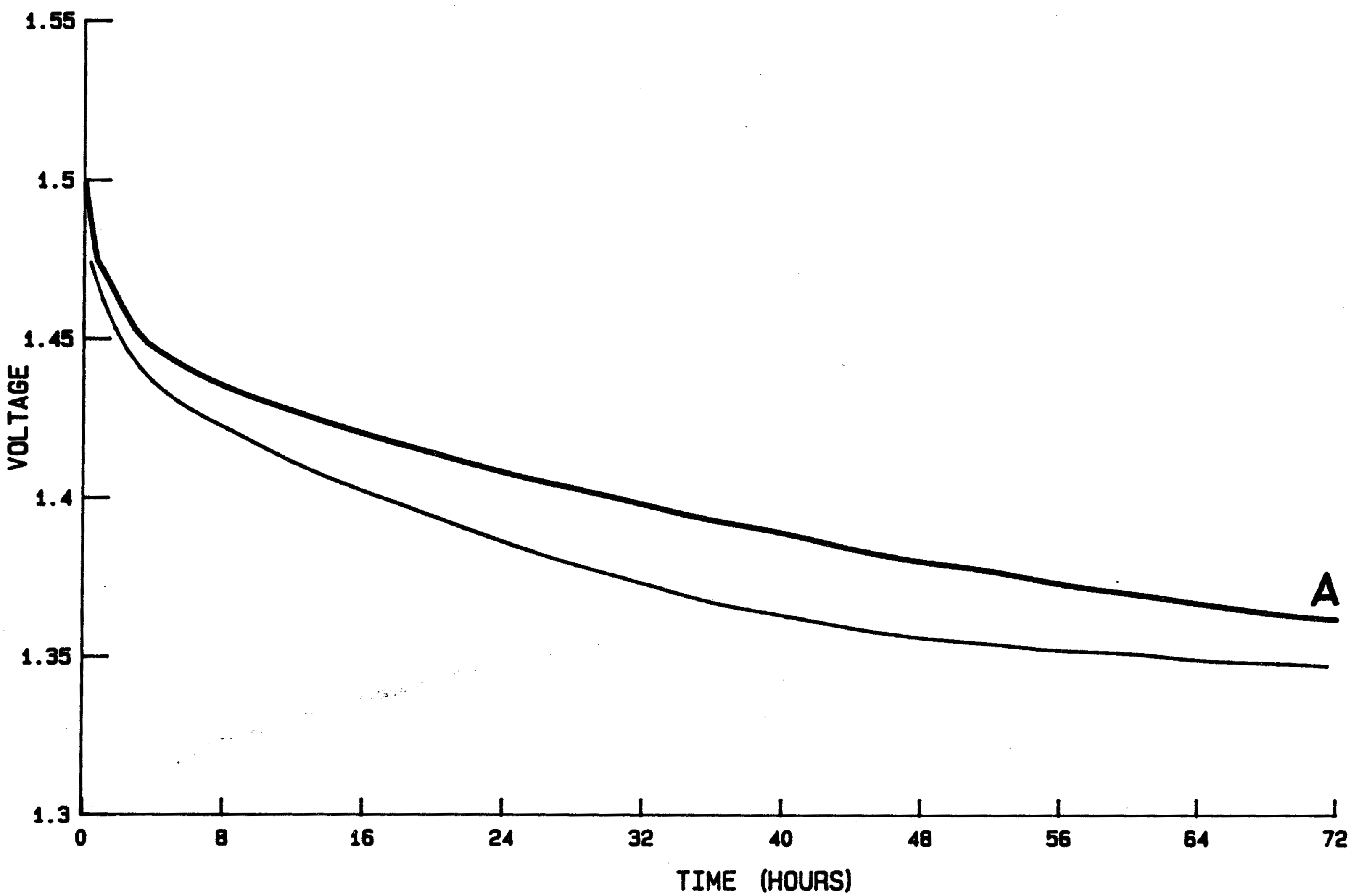

Figure 18. 10 Deg Charge Ret 72 hr. OCV

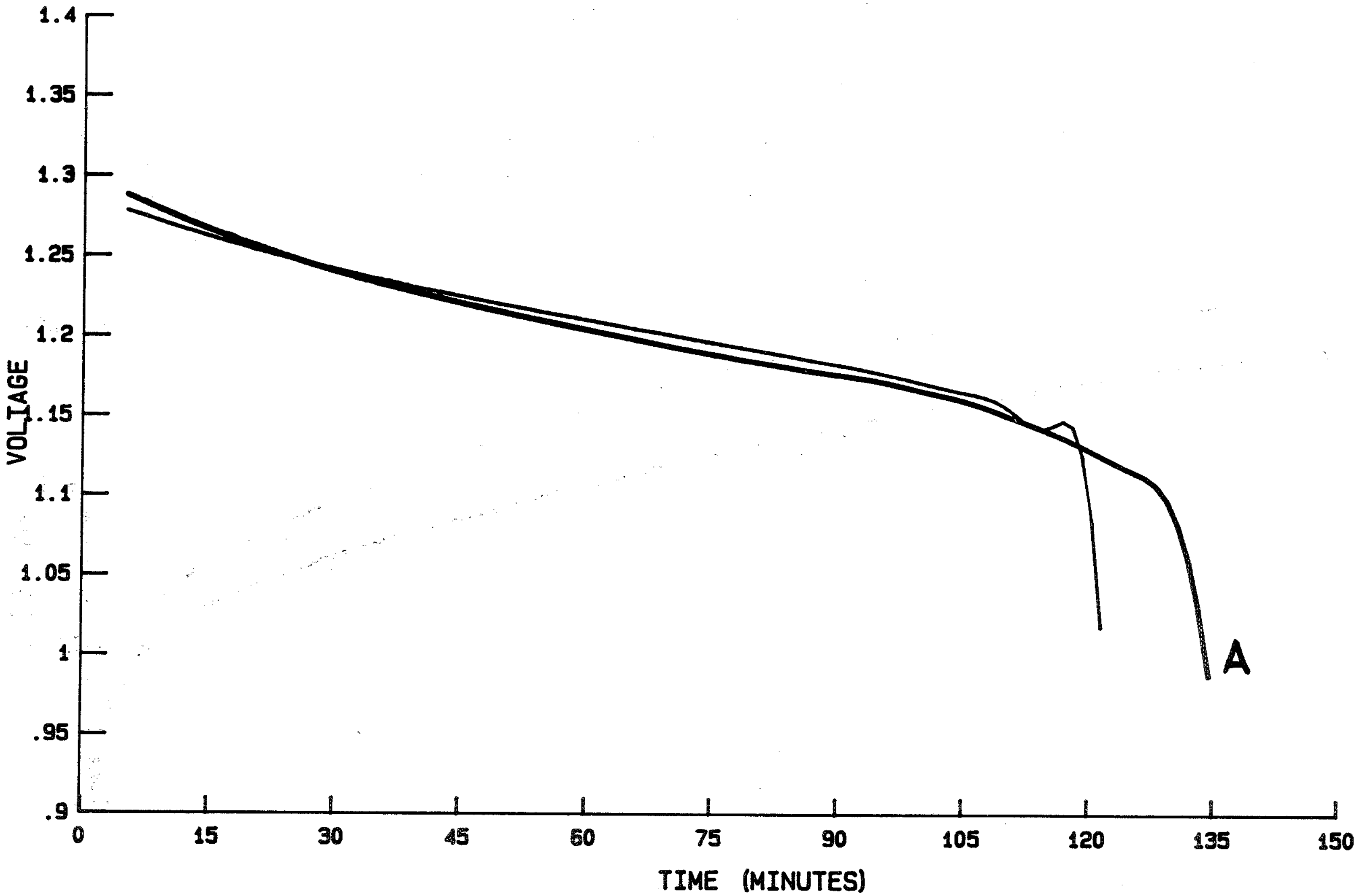

Figure 19. 10 Deg Charge Ret Discharge

NORMAL KOH	CYCLE - 0	55	160	240	320
	THICKNESS (IN.) AT:				
1	.031	.031	.031	.035	.035
2	.031	.031	.031	.036	.036
3	.030	.030	.030	.037	.037
4	.031	.031	.031	.039	.039
5	.031	.031	.031	.036	.036
6	.031	.031	.031	.035	.036
ADDITIVE KOH					
1	.031	.031	.031	.034	.035
2	.030	.030	.030	.031	.032
3	.030	.030	.030	.031	.032
4	.030	.030	.030	.031	.031
5	.029	.029	.029	.029	.030
6	.030	.030	.030	.031	.031

Figure 20. Thickness of Positive Plates During Stress