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QUALIFICATION TESTING OF GENERAL ELECTRIC 50 Ah NICKEL-CADMIUM CELLS WITH PELLON 2536 SEPARATOR AND PASSIVATED POSITIVE PLATES

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SUMMARY

Forty-two 50 Ah nickel-cadmium cells were delivered to the Goddard Space Flight Center (GSFC) by General Electric (GE) in February, 1985 for the purpose of evaluating and qualifying a new nonwoven nylon separator material, Pellon 2536, and the new GE positive plate nickel attack control gas passivation process. Testing began in May, 1985 at the Naval Weapons Support Center (NWSC) in Crane, Indiana with GSFC standard initial evaluation tests. Life cycling in both Low Earth Orbit (LEO) and Geosynchronous Orbit (GEO) began in July, 1985 with approximately 6500 LEO cycles and three GEO eclipse seasons complete at this writing. After early problems in maintaining test pack temperature control, all packs are performing well but are exhibiting higher than normal charge voltage characteristics.

INTRODUCTION

In the early 1980's, Pellon Corporation announced that it would discontinue the manufacture of areospace nickel-cadmium nonwoven nylon separator material, Pellon 2505 ml. That announcement meant that a new separator material would have to be developed and qualified for aerospace use.

Pellon 2536, very similar to 2505 ml, was chosen in 1984 as the new separator material. In the meantime, GE had developed a new positive plate process to reduce the amount of attack on the nickel sinter structure during active material impregnation. This process, therefore, also needed to be tested to determine the effect, if any, it would have on the well defined performance characteristics and life of the space cells. Therefore, a test program was put together by the GSFC to evaluate and qualify both the separator and positive plate process. Cell fabrication for this program was initiated in early 1984 at GE and the cells were delivered in February, 1985.

CELL DESCRIPTION

The 50 Ah nickel-cadmium cells being tested in this program were activated with electrolyte during the 37th week of 1984. All cells have dual, nickel braze, ceramic-to-metal terminal seals and welded prismatic cases with a nominal case wall thickness of 0.0265 inch. Cells undergoing test are made up of 4 designs: 1) NASA standard with Pellon 2505 ml separator, old positive plate processing, and teflonated negative plates (42BO50AB20); 2) Pellon 2536 separator, old positive plate processing, and teflonated negative plates (42BO50AB25); 3) Pellon 2505 ml separator, gas passivated positive plate processing, and teflonated negative plates (42BO50AB26); and 4) Pellon 2536 separator, gas passivated positive plate processing, and teflonated negative plates (42BO50AB27). Cell design data is presented in Table 1. The cells were manufactured to GE Manufacturing Control Document (MCD) 232A2222AA-84 and acceptance tested at GE to Acceptance Test Procedure P24A-PB-222 prior to delivery.

TEST OBJECTIVES

The objectives of this test program are: 1) to evaluate the effects of Pellon 2536 separator material and the new GE positive plate nickel attack control gas passivation process on cell performance and life and 2) to qualify these changes for use in NASA/GSFC spacecraft applications.

INITIAL EVALUATION TEST RESULTS

The standard initial evaluation test used by the GSFC is outlined in Figure 1. Results of the initial evaluation tests were reported at the 1985 NASA/GSFC Battery Workshop and, therefore, will only be summarized here.

First, packs with the GE gas passivated positive plates exhibited higher peak and end-of-charge voltages during capacity and overcharge tests. Peak voltages were as much as 20 mV higher than other packs. Second, capacity test results for all packs compared well. Capacities ranged between 58.7 Ah and 63.2 Ah. Third, packs with the GE gas passivated positive plates recovered to a lower voltage during voltage recovery tests following 16 hour resistive short down. Voltage differential between packs was as much as 35 mV. Fourth, internal resistance, charge retention, and pressure versus capacity returned test results compared well between all packs.

LIFE CYCLE EVALUATION TEST DESCRIPTION

The identification of each test pack and the test matrix outlined is detailed in Table 2. There were initially 3 cycling regimes in this test: LEO 40% DOD and 20°C (L4020), LEO 40% DOD and 0°C (L4000), GEO 80% DOD and 20°C (G8020). All four cell designs are being tested in the the L4020 regime (packs 150A-150D) while only the old positive, 2536 separator and passivated positive, 2536 separator designs are tested in the G8020 regime (packs 150H and 150I) and only the passivated positive, 2536 separator design is tested under the L4000 regime (pack 150G). Because of problems encountered with maintaining 0°C and cell divergence in the pack, the L4000 pack temperature was raised to coincide with the L4020 packs at cycle 2920.

In the L4020 regime, the cells are discharged at a 0.8C rate (40 amperes) for 30 minutes and charged at a 0.8C rate to a voltage clamp at which point the current is allowed to taper for the remainder of the 60 minute charge period. The voltage clamp was initially selected to assure a percent recharge (C/D) of

112 ± 2 percent. All LEO packs undergo a capacity check at the normal cycling discharge rate to 0.75 volts/cell every six months.

The G8020 regime is a real-time GEO regime with a 42-day eclipse period occurring twice per year. During shadow periods the cells are discharged at a 0.667C rate (33 amperes). Following each shadow, the packs are charged at a 0.1C rate (5 amperes) to 115 percent recharge (C/D) or 1.48 volts any cell, whichever occurs first. At that time, the rate is reduced to a 0.017C rate (0.83 ampere). During periods of continuous charge (full sun periods), the packs are trickle charged at the 0.017C rate. The packs are reconditioned to 0.75 volt/cell before each eclipse season. All test packs contain 5 cells.

LIFE CYCLE EVALUATION TEST RESULTS

At this time, the L4020 packs have experienced approximately 6500 cycles while the L4000 pack has seen 3600 cycles. The G8020 packs have gone through 3 eclipse seasons. Problems were encountered early in the cycle life test in controlling the internal cell temperatures in the L4020 packs. Temperatures at various locations in the packs rose to as high as 28°C and temperature imbalance between the cells caused severe cell voltage divergence. Because the capability of providing active cooling to the individual packs was not available, it was decided that the environmental chamber temperature be lowered to 10°C in order to maintain a 15°C internal pack temperature at the hottest point. This was done at cycle 2900. Since that time, cycling has continued without anomaly.

Current cycling endpoint data is presented in Table 3. This data shows that packs 150A through 150D compare very well in performance with all end-of-discharge (EOD) voltages between 1.03 and 1.10 volts/cell and charge/discharge ratios between 1.03 and 1.05. These EOD voltages are in the range expected from previous tests run on NASA standard 50 Ah cells at 40% DOD. All packs are operating at the same voltage clamp. Figures 2 through 5 are typical cycle plots for packs 150A through 150D. These plots correspond to the cycle prior to the scheduled 1 year capacity check. Figures 6 through 9 are the discharge curves for the 1 year capacity check. The second plateau characteristic is very noticeable at the normal cycling DOD. The capacities of all packs compare fairly well and range between 43 and 50 Ah.

Problems related to temperature were also experienced with the L4000 pack (150G). At 0°C, cell divergence within the pack occurred at approximately cycle 2833. In the next 50 cycles, the voltage clamp was adjusted numerous times without avail. At cycle 2920, the environmental chamber temperature was raised to 10°C to maintain a pack temperature of 15°C at the hottest point. Cycling has continued since that time without anomaly. It appears, therefore, that differences in charge efficiency between the cells at cold temperatures caused pack imbalance. This is being investigated and will be reported on at a later date.

Through 3 eclipse seasons, the G8020 packs (150H and 150I) have performed without anomaly. Reconditioning discharges prior to eclipse season 2 for packs 150H and 150I are presented in Figures 10 and 11 respectively. These curves show that there has been no loss of capacity and that both packs are performing comparably. A measure of the number of ampere-hours in and out for each day during eclipse season 2 is presented in Figures 12 and 13. These figures show the discharge profile for each day in the eclipse season and show the capacity returned during each charge at both the high rate and low rate. End-of-charge and end-of-discharge voltages are shown in Figures 14 and 15 for both packs. Both packs are performing well with minimum EOD voltages of approximately 1.15 volts/cell at 80% DOD. A slight divergence in cell EOC voltages at the high rate charge is apparent from Figure 14. These voltages come back together during the subsequent low rate charge period.

CONCLUSIONS

Slightly higher charge voltages as well as increased voltage divergence has been observed in all gas passivated positive plate test packs. This is most clearly seen in overcharge tests and LEO cycling test voltage clamp settings. Performance at low temperatures has also been a problem with pack 150G.

This problem is being investigated and may prove to be associated with low temperature charge efficiency.

Overall, performance of all cell designs has been acceptable with no extreme differences observed with Pellon 2536 separator or the GE gas passivated positive plates. Life cycle testing will continue to failure.

REFERENCES

1. Morrow, G. W., "Qualification Testing of General Electric 50 Ah Nickel-Cadmium Cells with New Separator and New Positive Plate Processing," The 1985 Goddard Space Flight Center Battery Workshop, NASA CP 2382, pages 159-168.
2. Morrow, G. W., "Qualification Testing of General Electric 50 Ah Nickel-Cadmium Cells with New Separator and New Positive Plate Processing," Journal of Power Sources, vol. 18, nos. 2 and 3, September 1986, pages 135-144.

Table 1: CELL DESIGN DATA

	NASA STANDARD		OLD POSITIVE NEW SEPARATOR		NEW POSITIVE OLD SEPARATOR		NEW POSITIVE NEW SEPARATOR	
	Pos.	Neg.	Pos.	Neg.	Pos.	Neg.	Pos.	Neg.
Post No.	31069	45008	31069	45008	45046	45008	45046	45008
Flooded Cap. Ah	59.23	130.06	59.23	130.06	60.62	130.06	60.62	130.06
Theoretical Cap Ah	78.50	149.71	78.50	149.71	74.86	149.71	74.86	149.71
Utilization %	76	87	76	87	81	87	81	87
No. of Plates	16	17	16	17	16	17	16	17
Plate Area (dm^2)	1.422	1.422	1.422	1.422	1.422	1.422	1.422	1.422
Plate Thickness (in.)	0.027	0.031	0.027	0.031	0.027	0.031	0.027	0.031
Loading Hydrate (g/dm^2)	12.21	15.86	12.21	15.86	12.12	15.86	12.12	15.86
Electrolyte (cc)	166		157		162		155	
Separator	Pellon 2505		Pellon 2536		Pellon 2505		Pellon 2536	
Precharge Ah	20.83		21.25		21.40		20.97	

TABLE 2:

LIFE CYCLING TEST MATRIX

ORBIT	DOD	TEMP (^oC)	NASA STD. CELLS	OLD POS. NEW SEP.	NEW POS. OLD SEP.	NEW POS. NEW SEP.
LEO	40	20	PACK 150A 42B050AB20 S/N 2-7	PACK 150B 42B050AB25 S/N 2-7	PACK 150C 42B060AB26 S/N 2-8	PACK 150D 42B060AB27 S/N 3-6,11,12
GEO	80	20		PACK 150H 42B050AB25 S/N 1,8-12		PACK 150I 42B050AB27 S/N 1,7-10
LEO	40	0				PACK 150G 42B050AB27 S/N 2,13-16

TABLE 3: CURRENT CYCLING AND ENDPOINT DATA

PACK	VT LIMIT (V/CELL)	EOD V (V/CELL)	EOC I (AMPS)	C/D	CAPACITY 1 YR. (AH)
150A	1.468	1.05	3.25	1.05	50.3
150B	1.468	1.06	3.50	1.05	45.3
150C	1.468	1.03	2.75	1.03	43.8
150D	1.468	1.10	3.05	1.04	43.1

- PHENOLPHTHALEIN LEAK TEST
- THREE CAPACITY TESTS
- INTERNAL RESISTANCE TEST
- CHARGE RETENTION TEST, 20°C
- INTERNAL SHORT TEST
- CHARGE EFFICIENCY TEST, 20°C
- OVERCHARGE TESTS, 0° AND 35°C
- PRESSURE VERSUS CAPACITY TEST
- PHENOLPHTHALEIN LEAK TEST

Figure 1. Initial Evaluation Test Regime.

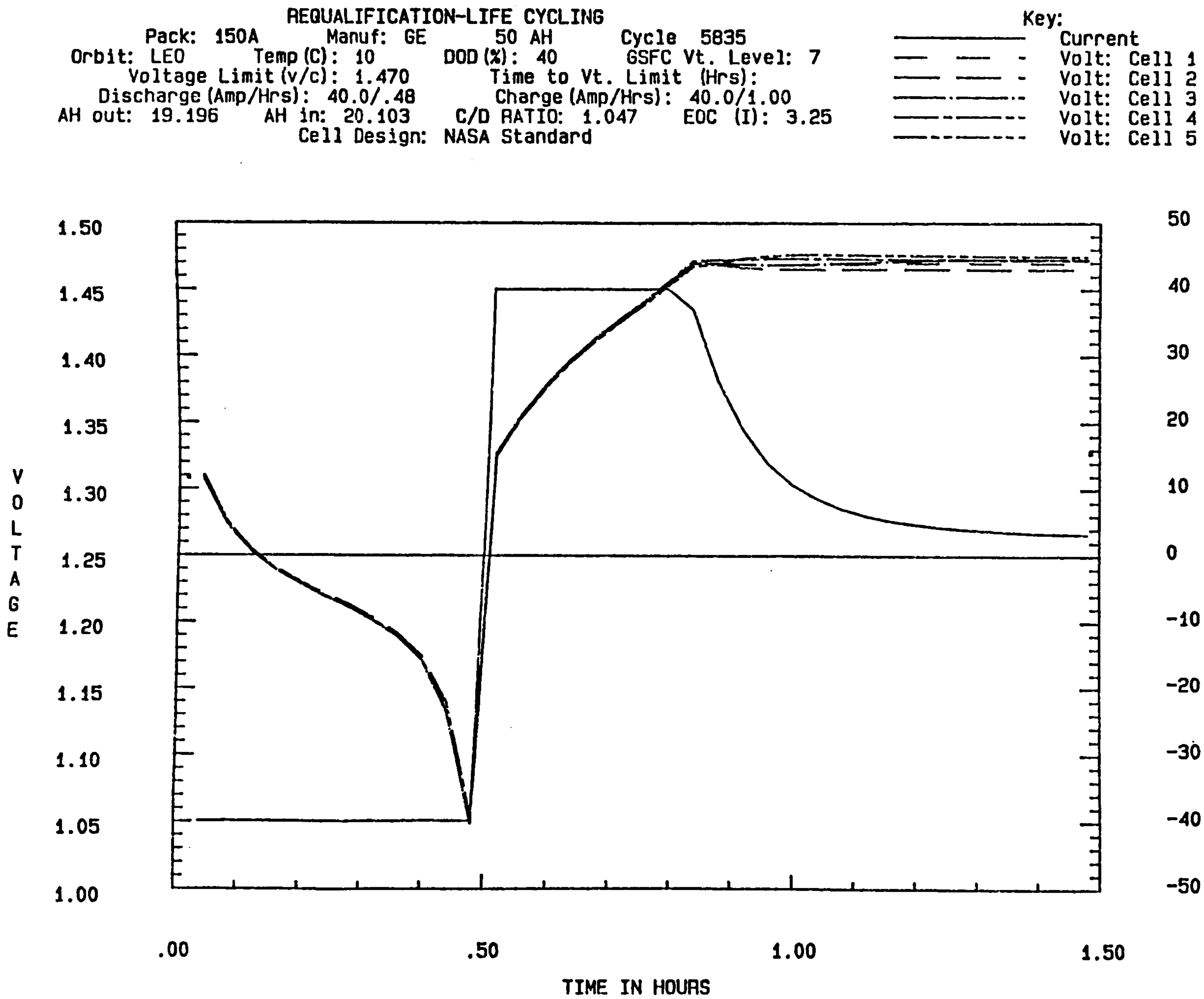

REQUALIFICATION-LIFE CYCLING
Pack: 150A Manuf: GE 50 AH Cycle 5835
Orbit: LEO Temp (C): 10 DOD (%): 40 GSFC Vt. Level: 7
Voltage Limit (v/c): 1.470 Time to Vt. Limit (Hrs):
Discharge (Amp/Hrs): 40.0/.48 Charge (Amp/Hrs): 40.0/1.00
AH out: 19.196 AH in: 20.103 C/D RATIO: 1.047 EOC (I): 3.25
Cell Design: NASA Standard
Key:
Current
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
VOLTAGE
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
CURRENT
50
40
30
20
10
0
-10
-20
-30
-40
-50
.00
.50
1.00
1.50
TIME IN HOURS

Figure 2.

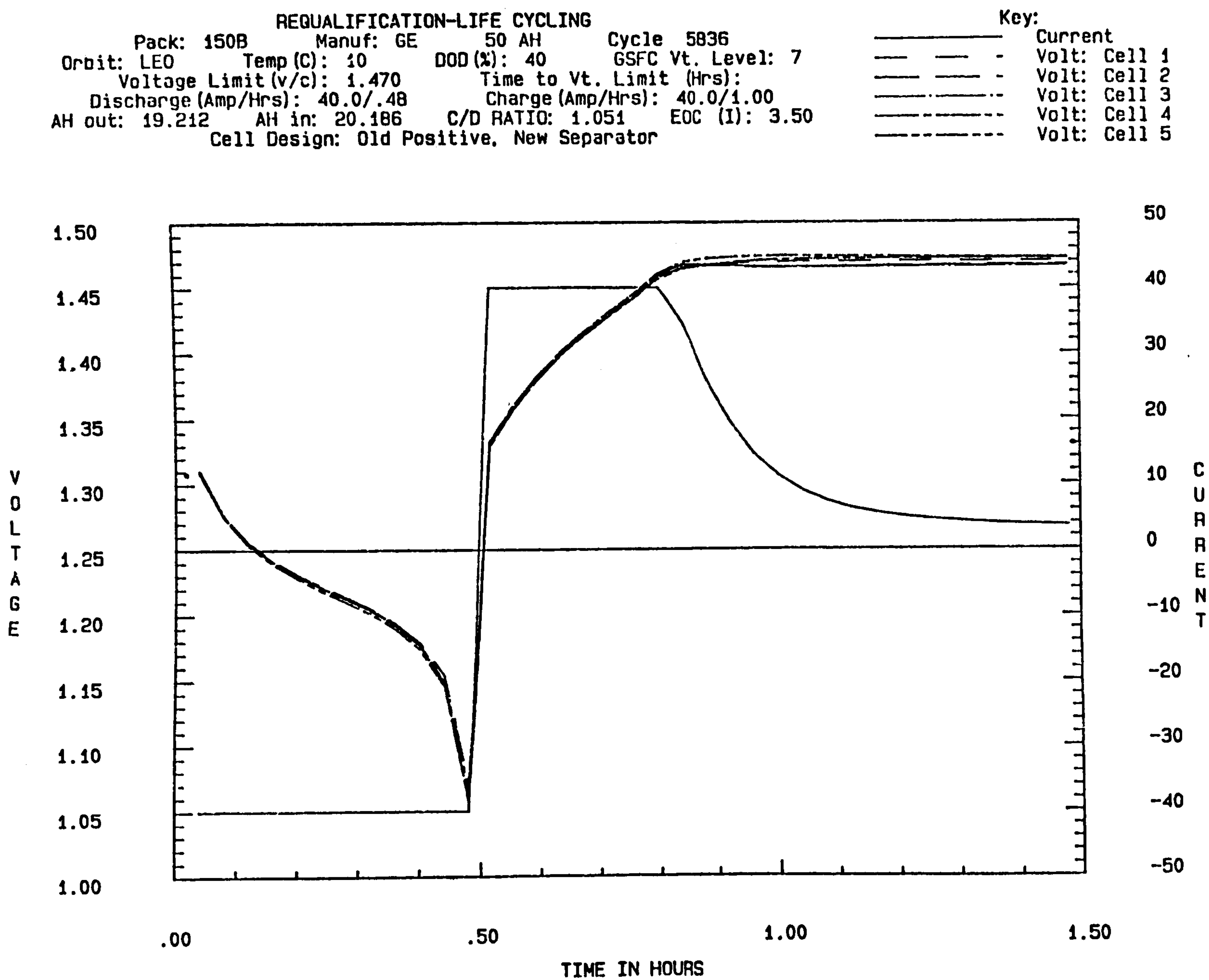

REQUALIFICATION-LIFE CYCLING
Pack: 150B Manuf: GE 50 AH Cycle 5836
Orbit: LEO Temp (C): 10 DOD (%): 40 GSFC Vt. Level: 7
Voltage Limit (v/c): 1.470 Time to Vt. Limit (Hrs):
Discharge (Amp/Hrs): 40.0/.48 Charge (Amp/Hrs): 40.0/1.00
AH out: 19.212 AH in: 20.186 C/D RATIO: 1.051 EOC (I): 3.50
Cell Design: Old Positive, New Separator
Key:
Current
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
VOLTAGE
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
CURRENT
50
40
30
20
10
0
-10
-20
-30
-40
-50
.00
.50
1.00
1.50
TIME IN HOURS

Figure 3.

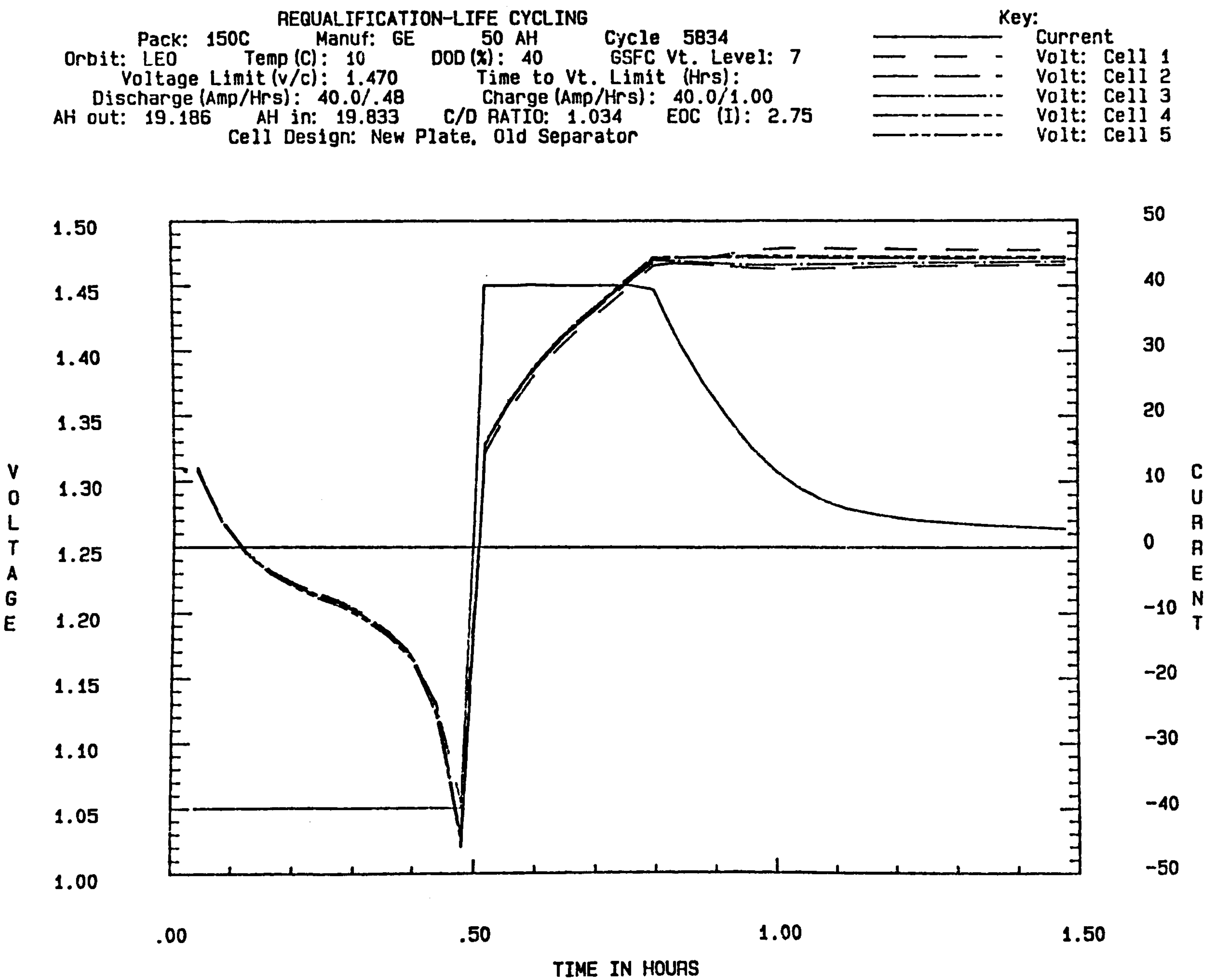

REQUALIFICATION-LIFE CYCLING
Pack: 150C Manuf: GE 50 AH Cycle 5834
Orbit: LEO Temp (C): 10 DOD (%): 40 GSFC Vt. Level: 7
Voltage Limit (v/c): 1.470 Time to Vt. Limit (Hrs):
Discharge (Amp/Hrs): 40.0/.48 Charge (Amp/Hrs): 40.0/1.00
AH out: 19.186 AH in: 19.833 C/D RATIO: 1.034 EOC (I): 2.75
Cell Design: New Plate, Old Separator
Key:
Current
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
VOLTAGE
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
CURRENT
50
40
30
20
10
0
-10
-20
-30
-40
-50
.00
.50
1.00
1.50
TIME IN HOURS

Figure 4.

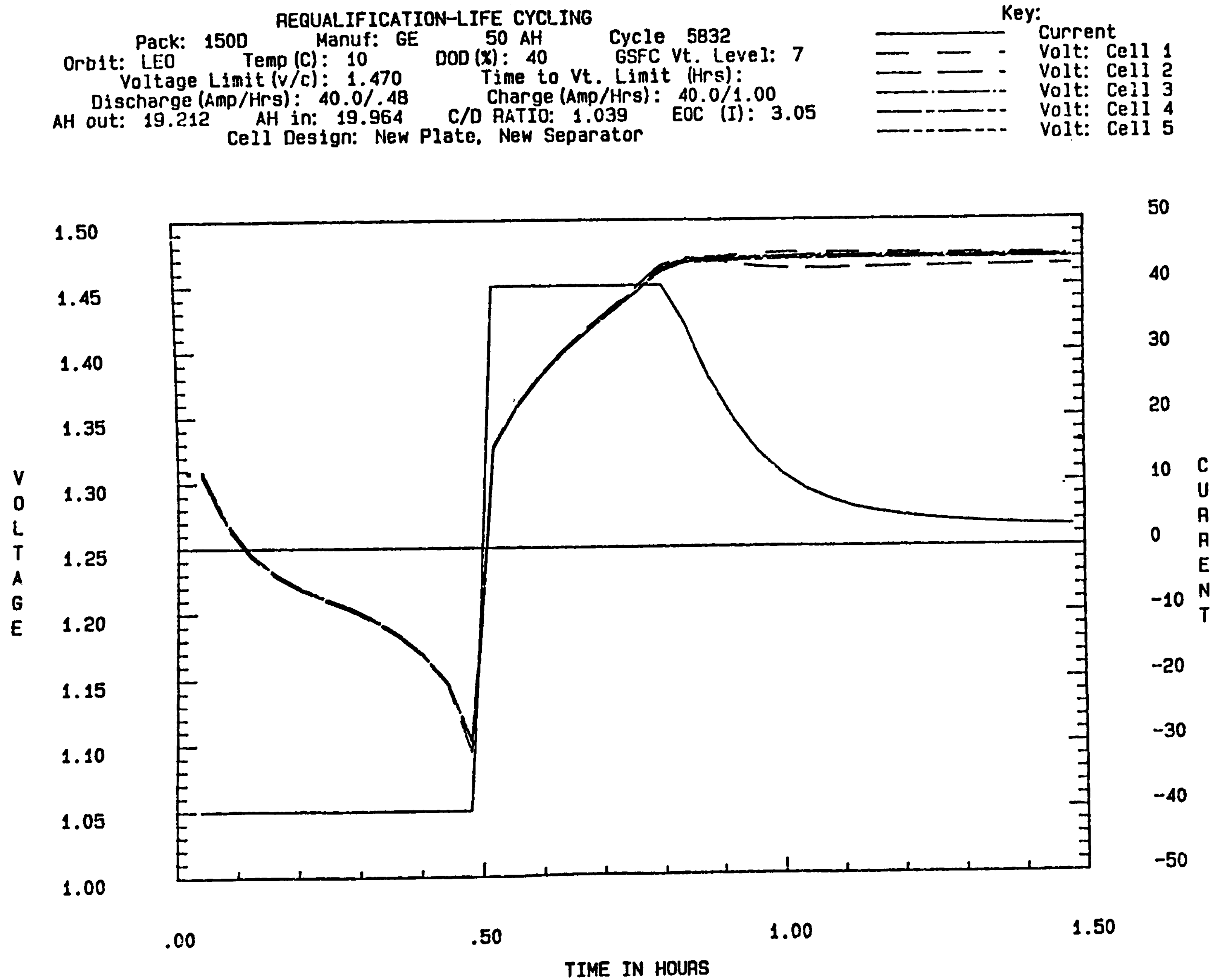

REQUALIFICATION-LIFE CYCLING
Pack: 150D Manuf: GE 50 AH Cycle 5832
Orbit: LEO Temp (C): 10 DOD (%): 40 GSFC Vt. Level: 7
Voltage Limit (v/c): 1.470 Time to Vt. Limit (Hrs):
Discharge (Amp/Hrs): 40.0/.48 Charge (Amp/Hrs): 40.0/1.00
AH out: 19.212 AH in: 19.964 C/D RATIO: 1.039 EOC (I): 3.05
Cell Design: New Plate, New Separator
Key:
Current
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
VOLTAGE
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
CURRENT
50
40
30
20
10
0
-10
-20
-30
-40
-50
.00
.50
1.00
1.50
TIME IN HOURS

Figure 5.

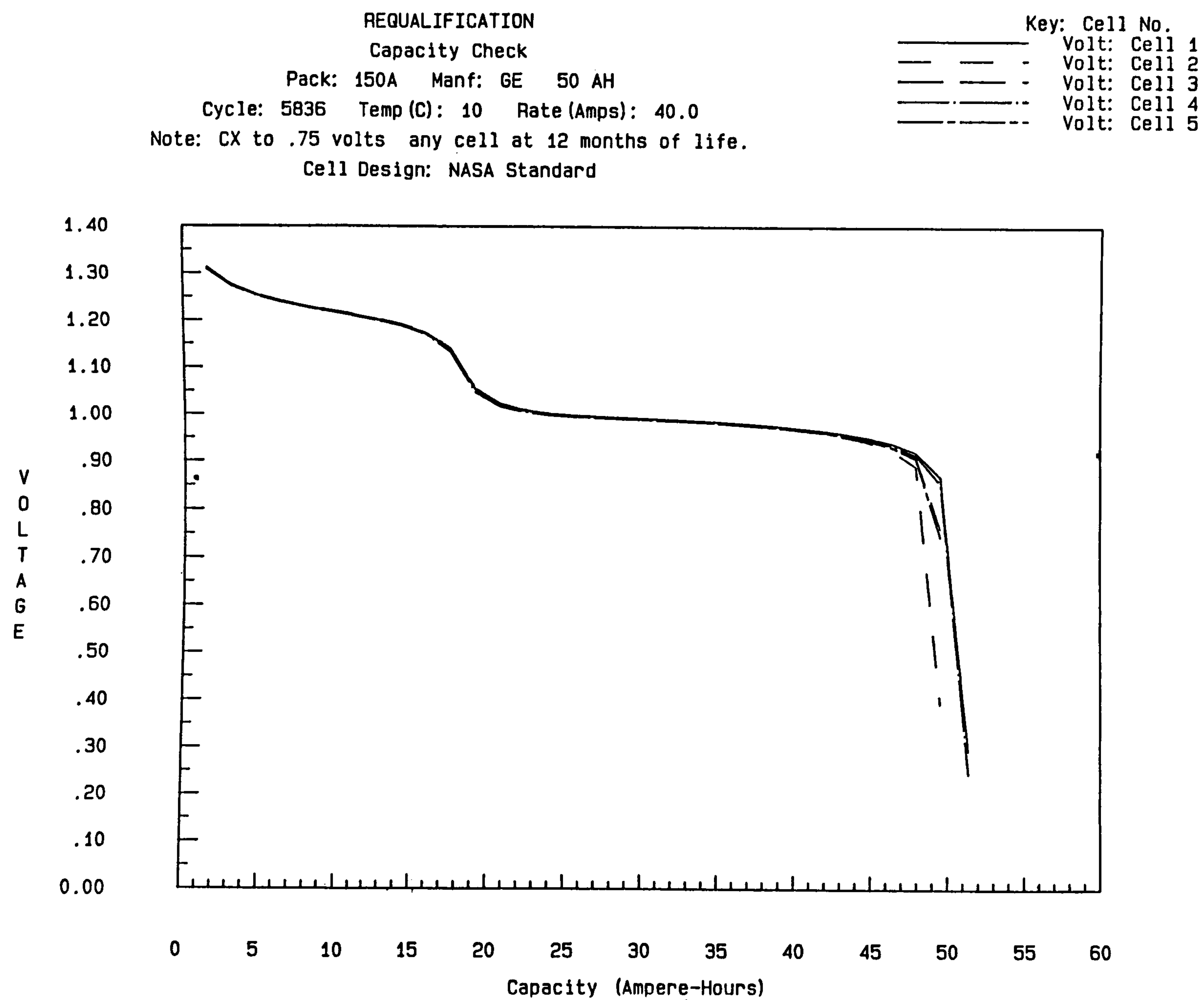
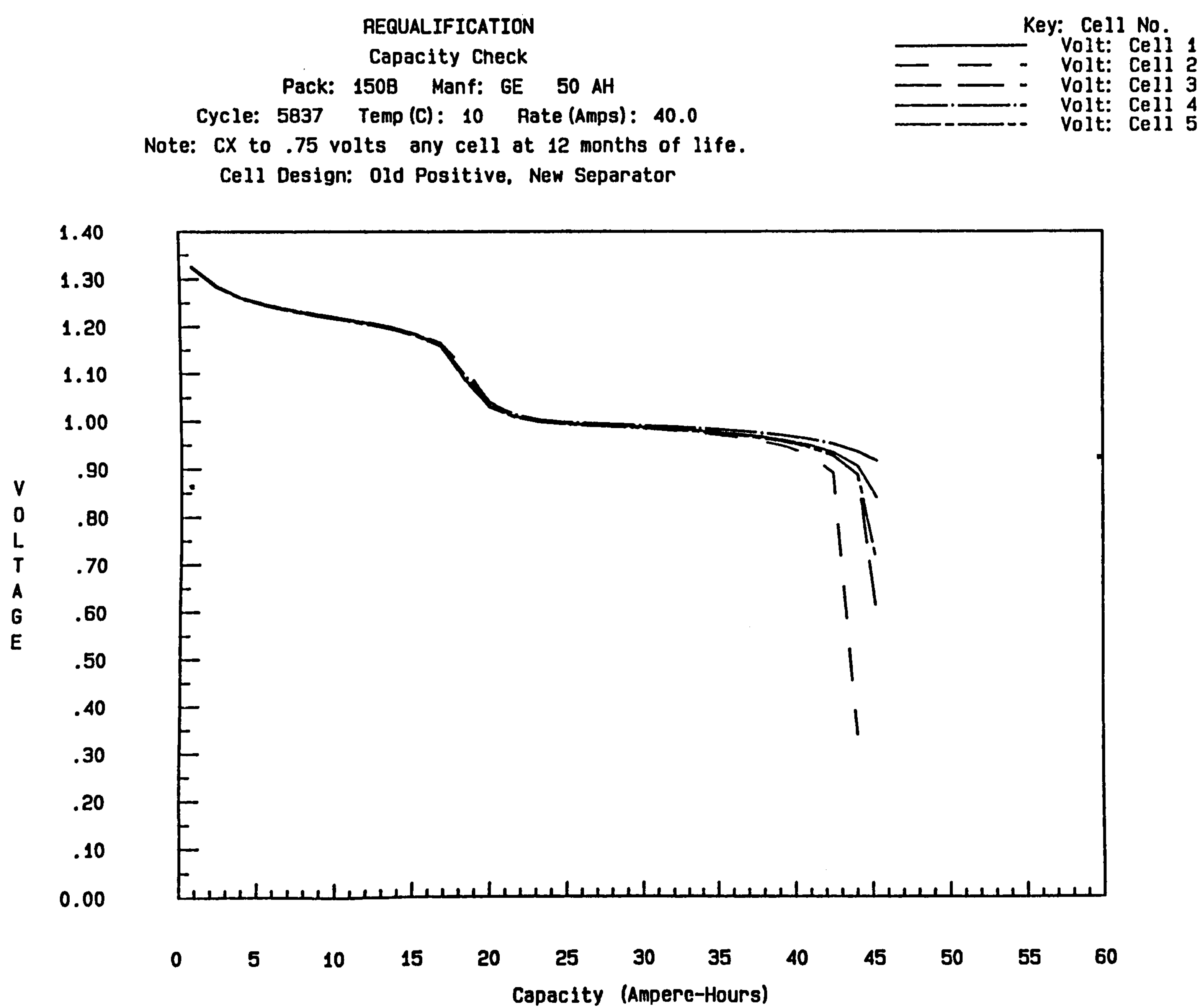

REQUALIFICATION
Capacity Check
Pack: 150A Manf: GE 50 AH
Cycle: 5836 Temp (C): 10 Rate (Amps): 40.0
Note: CX to .75 volts any cell at 12 months of life.
Cell Design: NASA Standard
Key: Cell No.
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
VOLTAGE
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0.00
0 5 10 15 20 25 30 35 40 45 50 55 60
Capacity (Ampere-Hours)

Figure 6.



REQUALIFICATION
Capacity Check
Pack: 150B Manf: GE 50 AH
Cycle: 5837 Temp (C): 10 Rate (Amps): 40.0
Note: CX to .75 volts any cell at 12 months of life.
Cell Design: Old Positive, New Separator
Key: Cell No.
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
VOLTAGE
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0.00
0 5 10 15 20 25 30 35 40 45 50 55 60
Capacity (Ampere-Hours)

Figure 7.

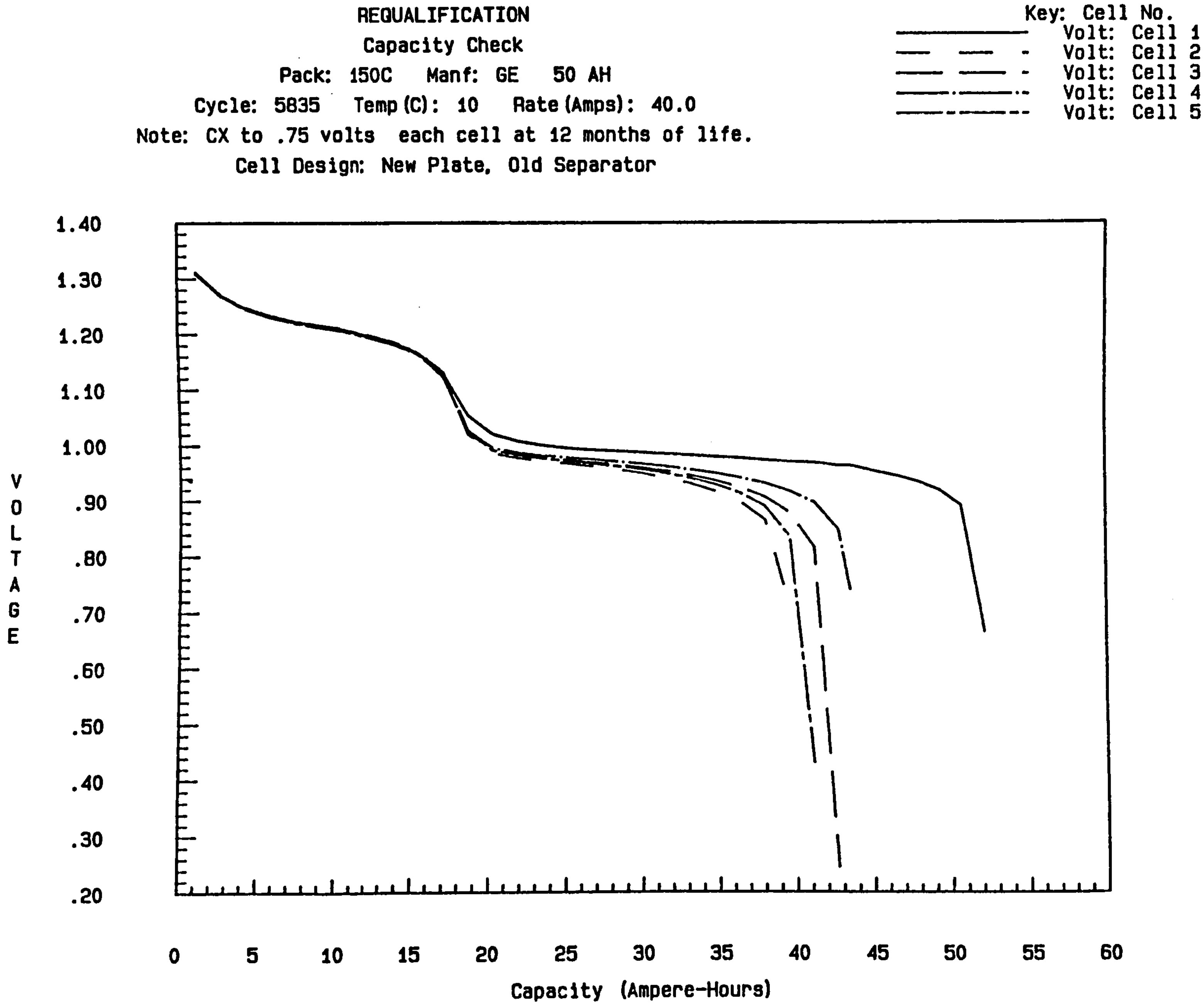

REQUALIFICATION
Capacity Check
Pack: 150C Manf: GE 50 AH
Cycle: 5835 Temp (C): 10 Rate (Amps): 40.0
Note: CX to .75 volts each cell at 12 months of life.
Cell Design: New Plate, Old Separator
Key: Cell No.
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
VOLTAGE
0
5
10
15
20
25
30
35
40
45
50
55
60
Capacity (Ampere-Hours)

Figure 8.

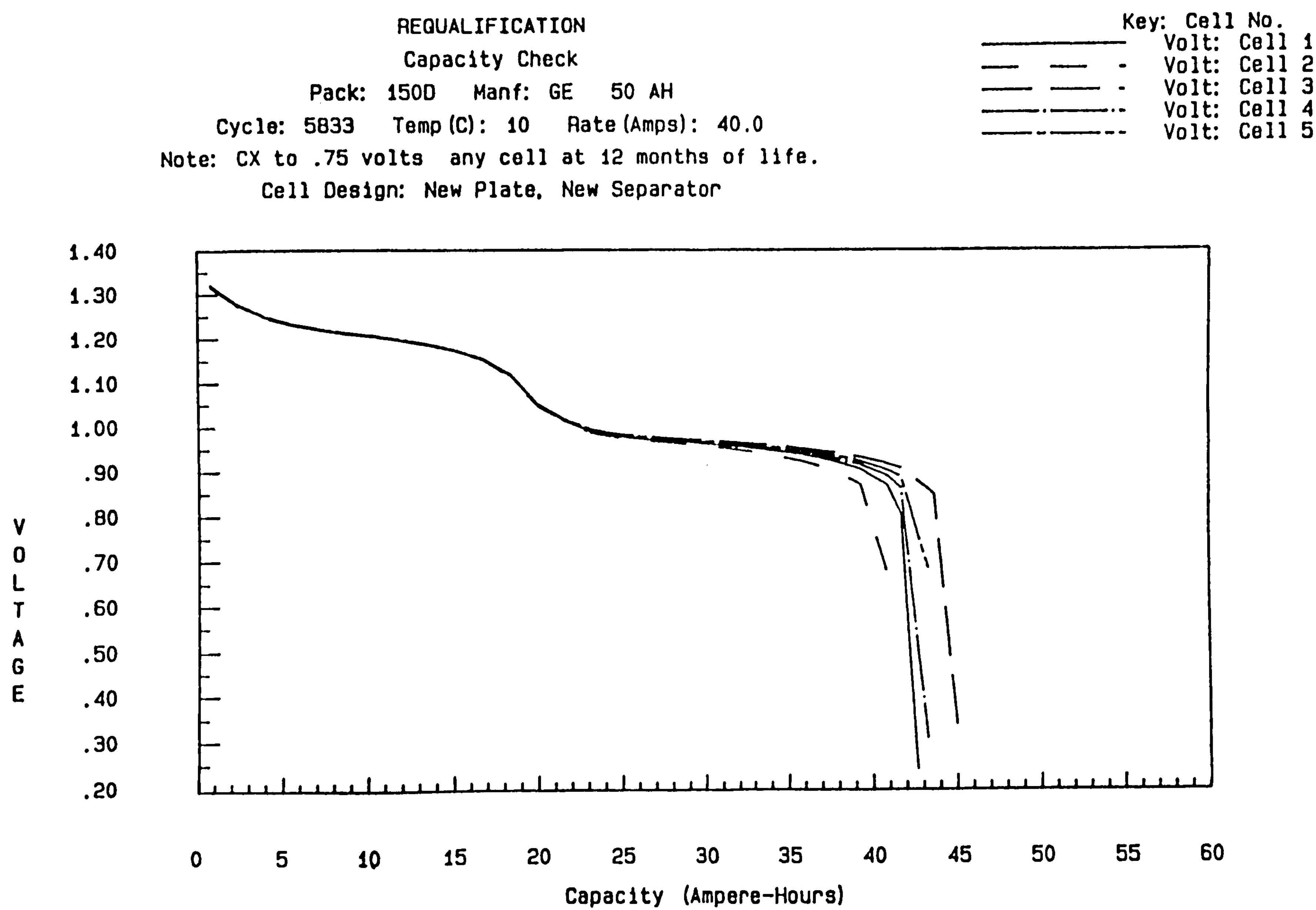

REQUALIFICATION
Capacity Check
Pack: 150D Manf: GE 50 AH
Cycle: 5833 Temp (C): 10 Rate (Amps): 40.0
Note: CX to .75 volts any cell at 12 months of life.
Cell Design: New Plate, New Separator
Key: Cell No.
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
VOLTAGE
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
0
5
10
15
20
25
30
35
40
45
50
55
60
Capacity (Ampere-Hours)

Figure 9.

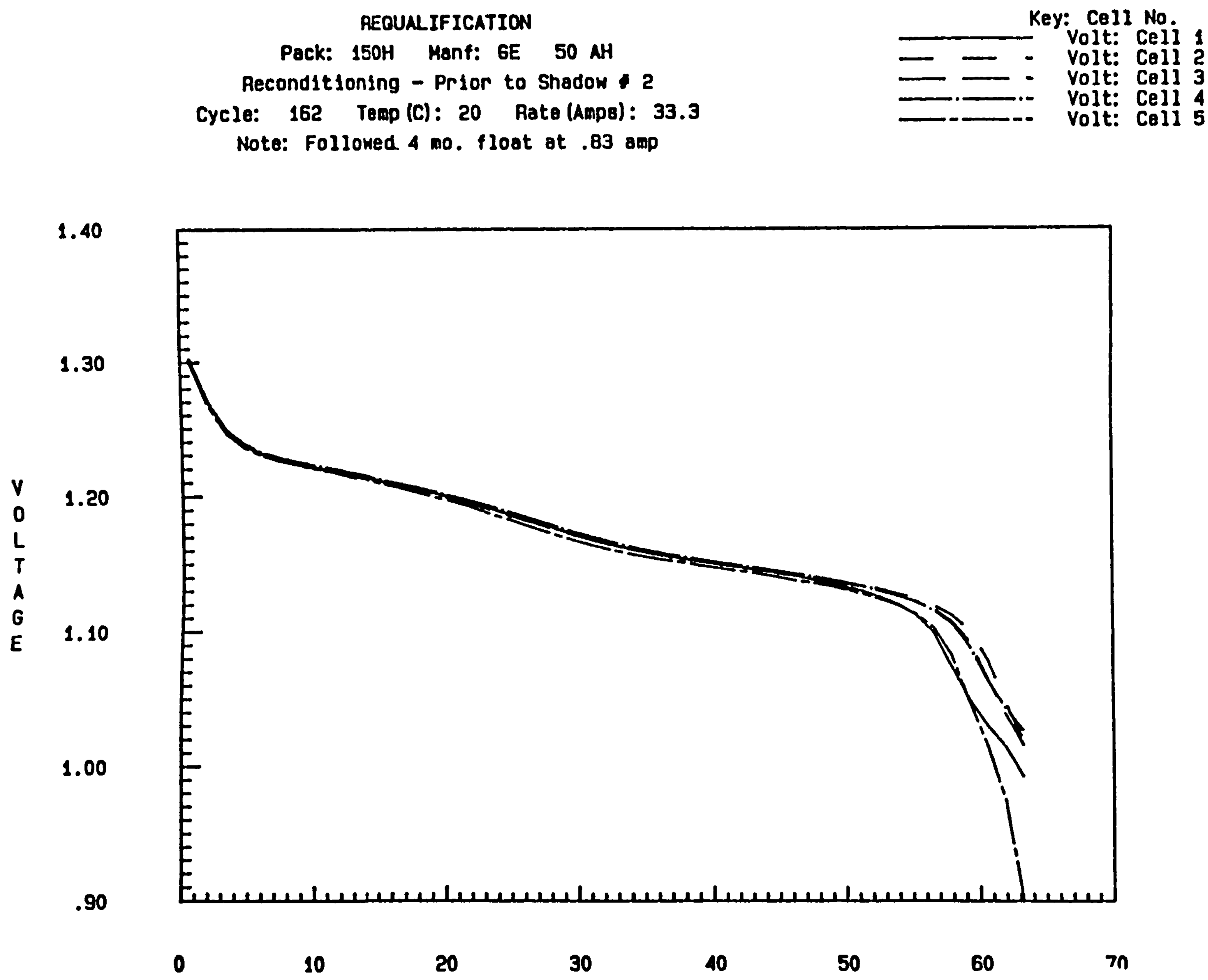
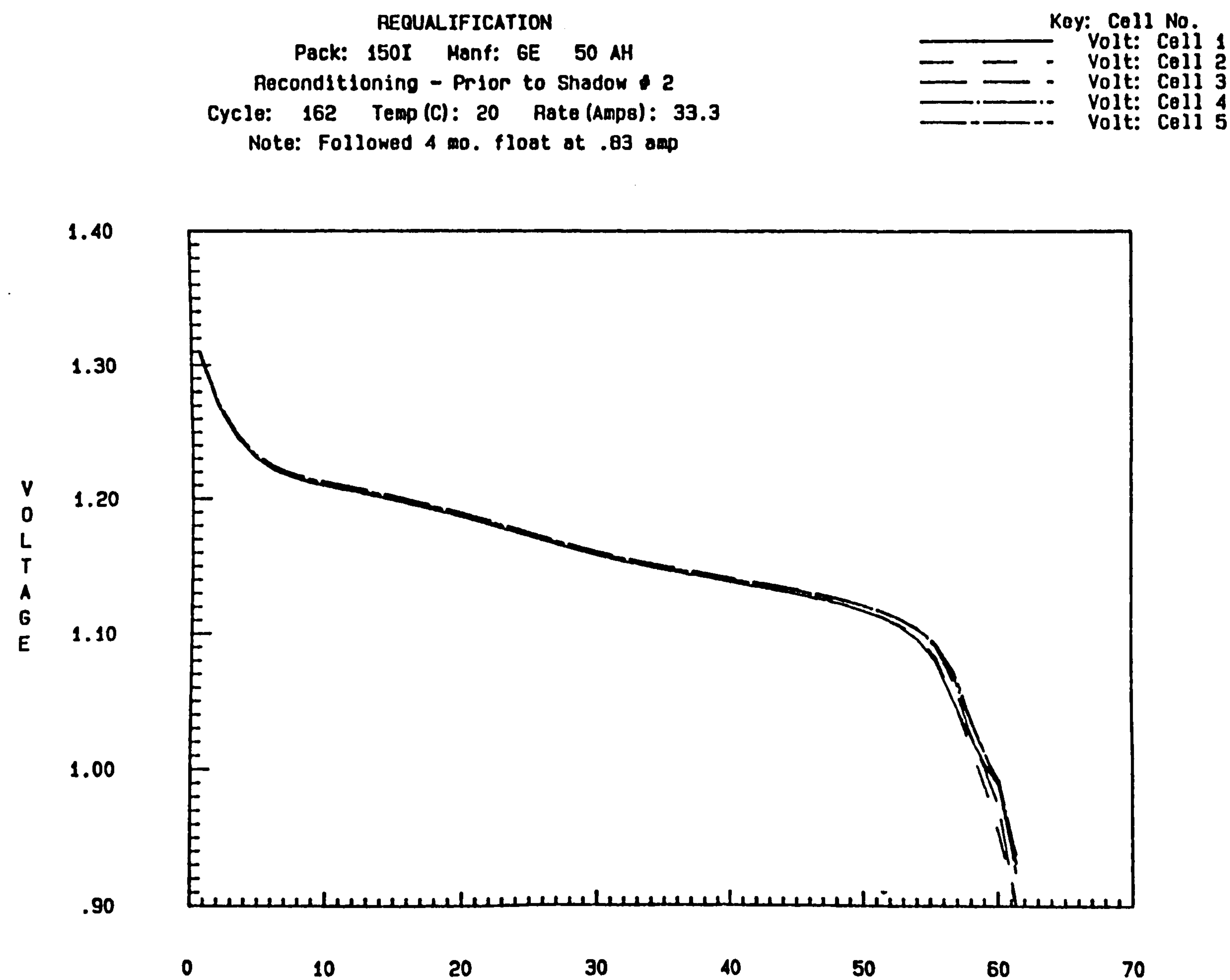

REQUALIFICATION
Pack: 150H Manf: GE 50 AH
Reconditioning - Prior to Shadow # 2
Cycle: 162 Temp (C): 20 Rate (Amps): 33.3
Note: Followed 4 mo. float at .83 amp
Key: Cell No.
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
VOLTAGE
1.40
1.30
1.20
1.10
1.00
.90
0
10
20
30
40
50
60
70

Figure 10.



REQUALIFICATION
Pack: 150I Manf: GE 50 AH
Reconditioning - Prior to Shadow # 2
Cycle: 162 Temp(C): 20 Rate(Amps): 33.3
Note: Followed 4 mo. float at .83 amp
Key: Cell No.
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
VOLTAGE
1.40
1.30
1.20
1.10
1.00
.90
0
10
20
30
40
50
60
70

Figure 11.

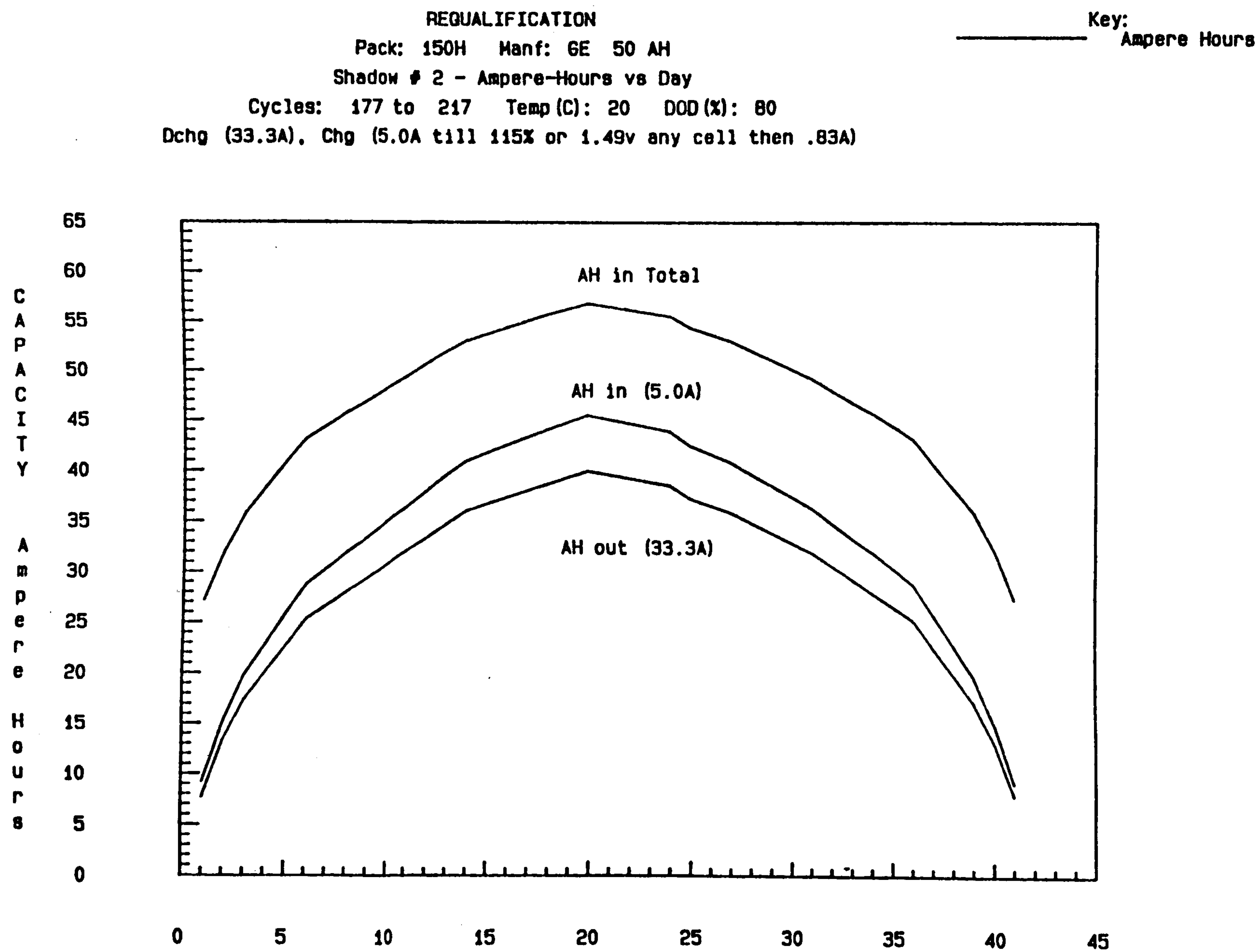

REQUALIFICATION
Pack: 150H Manf: GE 50 AH
Shadow # 2 - Ampere-Hours vs Day
Cycles: 177 to 217 Temp (C): 20 DOD (%): 80
Dchg (33.3A), Chg (5.0A till 115% or 1.49v any cell then .83A)
Key:
Ampere Hours
CAPACITY Ampere Hours
65
60
55
50
45
40
35
30
25
20
15
10
5
0
AH in Total
AH in (5.0A)
AH out (33.3A)
0
5
10
15
20
25
30
35
40
45

Figure 12.

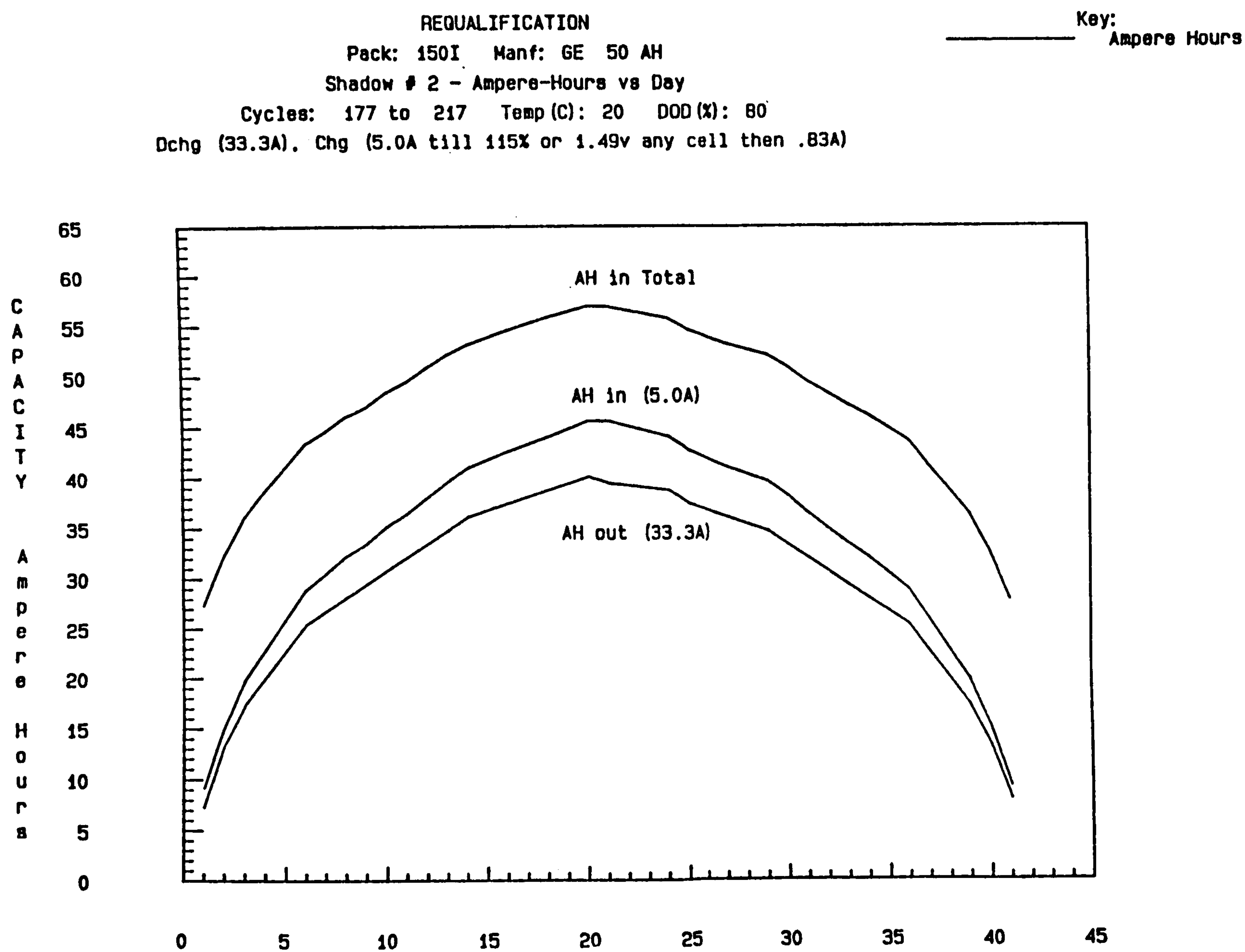
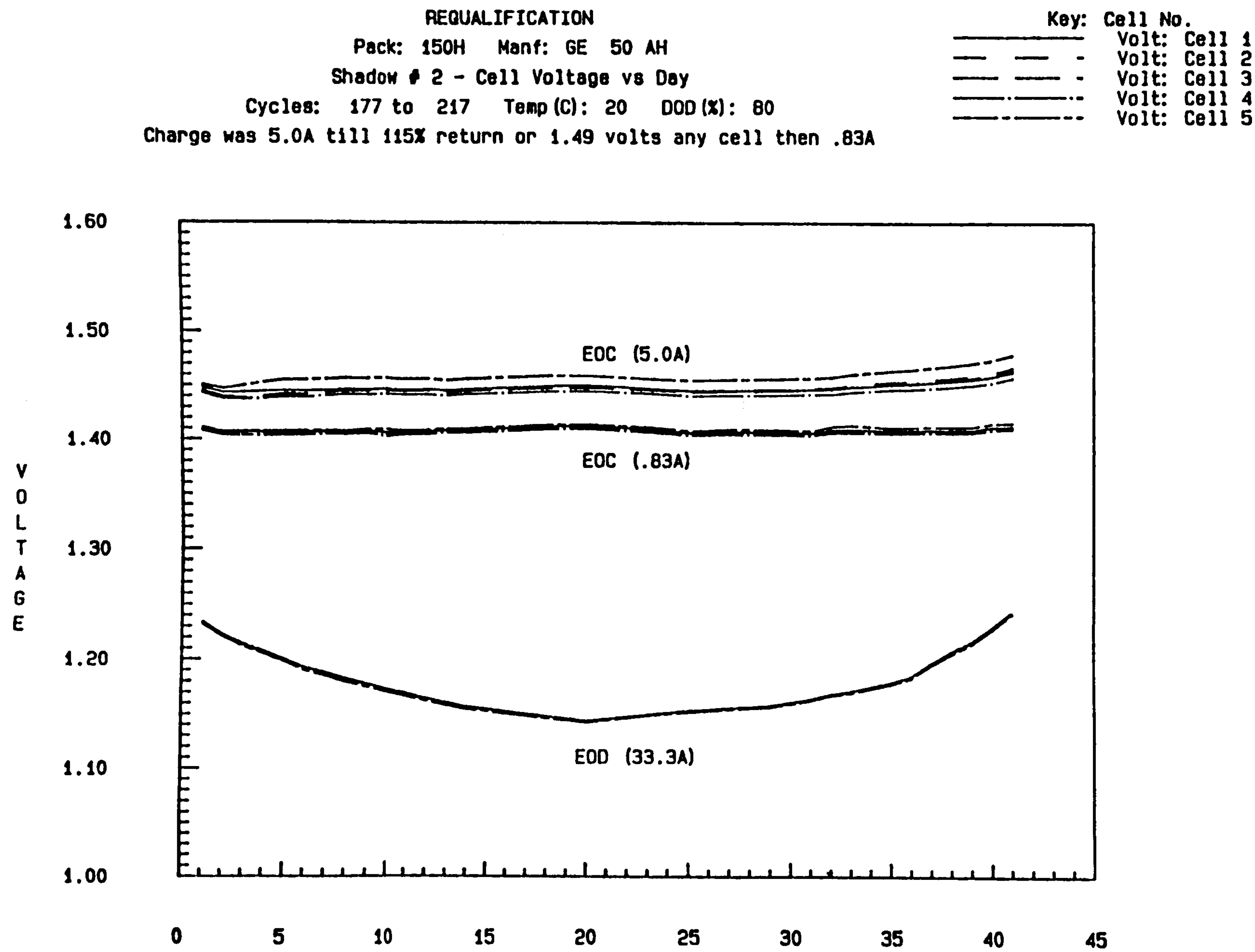

REQUALIFICATION
Pack: 150I Manf: GE 50 AH
Shadow # 2 - Ampere-Hours vs Day
Cycles: 177 to 217 Temp (C): 20 DOD (%): 80
Dchg (33.3A). Chg (5.0A till 115% or 1.49v any cell then .83A)
Key:
Ampere Hours
AH in Total
AH in (5.0A)
AH out (33.3A)
CAPACITY Ampere Hours
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 5 10 15 20 25 30 35 40 45

Figure 13.



REQUALIFICATION
Pack: 150H Manf: GE 50 AH
Shadow # 2 - Cell Voltage vs Day
Cycles: 177 to 217 Temp(C): 20 DOD(%): 80
Charge was 5.0A till 115% return or 1.49 volts any cell then .83A
Key: Cell No.
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
1.60
1.50
1.40
1.30
1.20
1.10
1.00
VOLTAGE
EOC (5.0A)
EOC (.83A)
EOD (33.3A)
0
5
10
15
20
25
30
35
40
45

Figure 14.

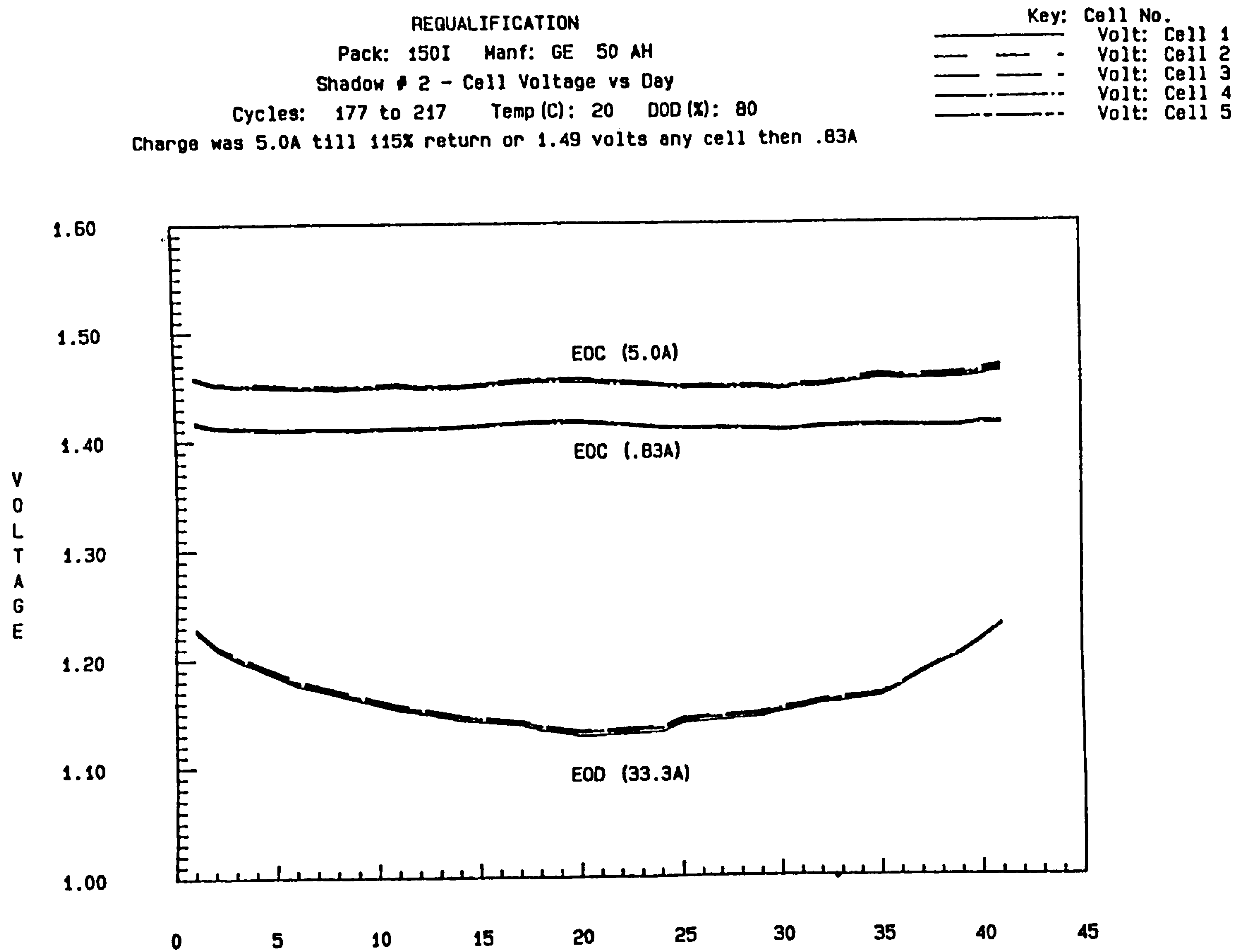

REQUALIFICATION
Pack: 150I Manf: GE 50 AH
Shadow # 2 - Cell Voltage vs Day
Cycles: 177 to 217 Temp (C): 20 DOD (%): 80
Charge was 5.0A till 115% return or 1.49 volts any cell then .83A
Key: Cell No.
Volt: Cell 1
Volt: Cell 2
Volt: Cell 3
Volt: Cell 4
Volt: Cell 5
VOLTAGE
1.60
1.50
1.40
1.30
1.20
1.10
1.00
EOC (5.0A)
EOC (.83A)
EOD (33.3A)
0
5
10
15
20
25
30
35
40
45

Figure 15.