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Technical Memorandum 83991

USE OF THE CHARGE/DISCHARGE (C/D) RATIO TO AUGMENT VOLTAGE LIMIT (V_T) CHARGE CONTROL IN THE ERBS SPACECRAFT

Gerald Halpert

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National Aeronautics and
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Goddard Space Flight Center
Greenbelt, Maryland 20771

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Gerald Halpert
Space Technology Division

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GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

All measurement values are expressed in the International System of Units (SI) in accordance with NASA Policy Directive 2220.4, paragraph 4.

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ABSTRACT

A 50-ampere hour nickel cadmium cell test pack was operated in a power profile simulating the orbit of the Earth Radiation Budget Satellite (ERBS). The objective was to determine the ability of the temperature compensated voltage limit (V_T) charge control system to maintain energy balance in the half sine wave-type current profile expected of this mission. The four-cell pack (50 E) was tested at the Naval Weapons Support Center (NWSC) at Crane, Indiana.

The ERBS evaluation test consisted of two distinct operating sequences, each having a specific purpose. The first phase was a parametric test involving the effect of V_T level (GSFC Standard Levels, 5 through 7), temperature (-5 to 25°C), and Beta angle (90-, 65-, and 10-degree angles between the normal to the orbital plane and Earth sunline) on the charge/discharge (C/D) ratio--an indicator of the amount of overcharge.

As expected, the C/D ratio was quite sensitive to the V_T level at all parametric operating conditions, making charge control with V_T limit operation questionable.

The second phase of testing made use of the C/D ratio limit to augment the V_T charge limit control. When the C/D limit was reached, the current was switched from the taper mode to a C/67 (0.75 A) trickle charge. Ampere hours of charge and discharge were integrated by the microprocessor which switched the current to trickle charge when the predetermined C/D ratio was achieved. The result was a consistent end-of-discharge voltage and minimum overcharge heating. The procedure was followed for 500 simulated orbits at the depth-of-discharge conditions expected in the ERBS projected mission.

The use of an ampere hour integrator limiting the overcharge to a C/67 rate provided a fine tuning of the charge control technique which eliminated the sensitivity problems noted in the initial operating sequence.

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ACKNOWLEDGMENTS

The efforts of those at the Naval Weapons Support Center (Crane, Indiana), specifically those of Jim Harkness, were greatly appreciated. The concept and implementation of a microprocessor to control and operate the test pack in a simulated Earth Radiation Budget Satellite (ERBS) orbit, and the rapid response to the program needs were instrumental in the success of this test.

The recognition of the problem and support of the ERBS project office, as well as the able assistance of Harry Culver of the Space Power Applications Branch is also acknowledged.

The author also wishes to acknowledge the excellent work of Darryl Smith of Bowie State College, whose proficiency in the use of the Hewlett Packard (HP) 9845 computer during his GSFC summer apprenticeship program provided a clear presentation of the data in the form of tables and curves for this report.

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USE OF THE CHARGE/DISCHARGE (C/D) RATIO TO AUGMENT VOLTAGE LIMIT (V_T) CHARGE CONTROL IN THE ERBS SPACECRAFT

1. INTRODUCTION

The Earth Radiation Budget Satellite (ERBS) is projected to be in a 610-kilometer circular orbit with an inclination of 46 to 57 degrees with respect to the Equator. Its solar array is fixed with respect to the spacecraft. The resulting orbital power profile differs considerably from the Solar Maximum Mission (SMM) or Landsat-D spacecraft operating in a Low Earth Orbit with a sun-pointing solar array.

The orbital power profile of SMM, operating in space since 1980, and the Landsat-D power profile provide maximum power and therefore, current when the spacecraft emerges from the Earth's shadow. The maximum power is available throughout the daylight period. Thus, the batteries are charged quickly and at a preset temperature compensated voltage (V_T) limit allowed to current taper until the end of the daylight period (thus, controlling the amount of overcharge).

The ERBS profile is such that when the spacecraft emerges from shadow, the solar array angle to the Sun is minimal. Thus, the current available for charging the batteries is minimal. As the spacecraft continues in orbit, the solar array points more directly at the Sun which increases the available charge current to a maximum at midday. The charge current then decreases as the solar array points away from the Sun through the remainder of the daylight period. Further, with a fixed solar array, the spacecraft (in different orbital planes around the Earth) assumes different angles (Beta angles) between the normal to orbital plane and the sunline. The power profile indicating the current available, for each of the two batteries, under three different Beta angle conditions in the ERBS orbit (90, 65, and 10°) are given in Figure 1-1. There has been only limited cell and battery testing in this type of orbital profile to date.

The objective of this effort was to determine whether the V_T charge control method and levels[1] used in the SMM/ Landsat-D operation were acceptable for controlling charge and maintaining energy balance over the ERBS projected mission profile and life. To this end, the initial (Phase 1) test sequence involved a parametric test to evaluate the effect of V_T level, temperature, and Beta angle on the C/D ratio (a measure of the overcharge and cell condition). The C/D

[1]Appearing in the specification for a NASA Standard Nickel Cadmium 20- and 50-Ah Spacecraft Battery S-711-16, Revision B.

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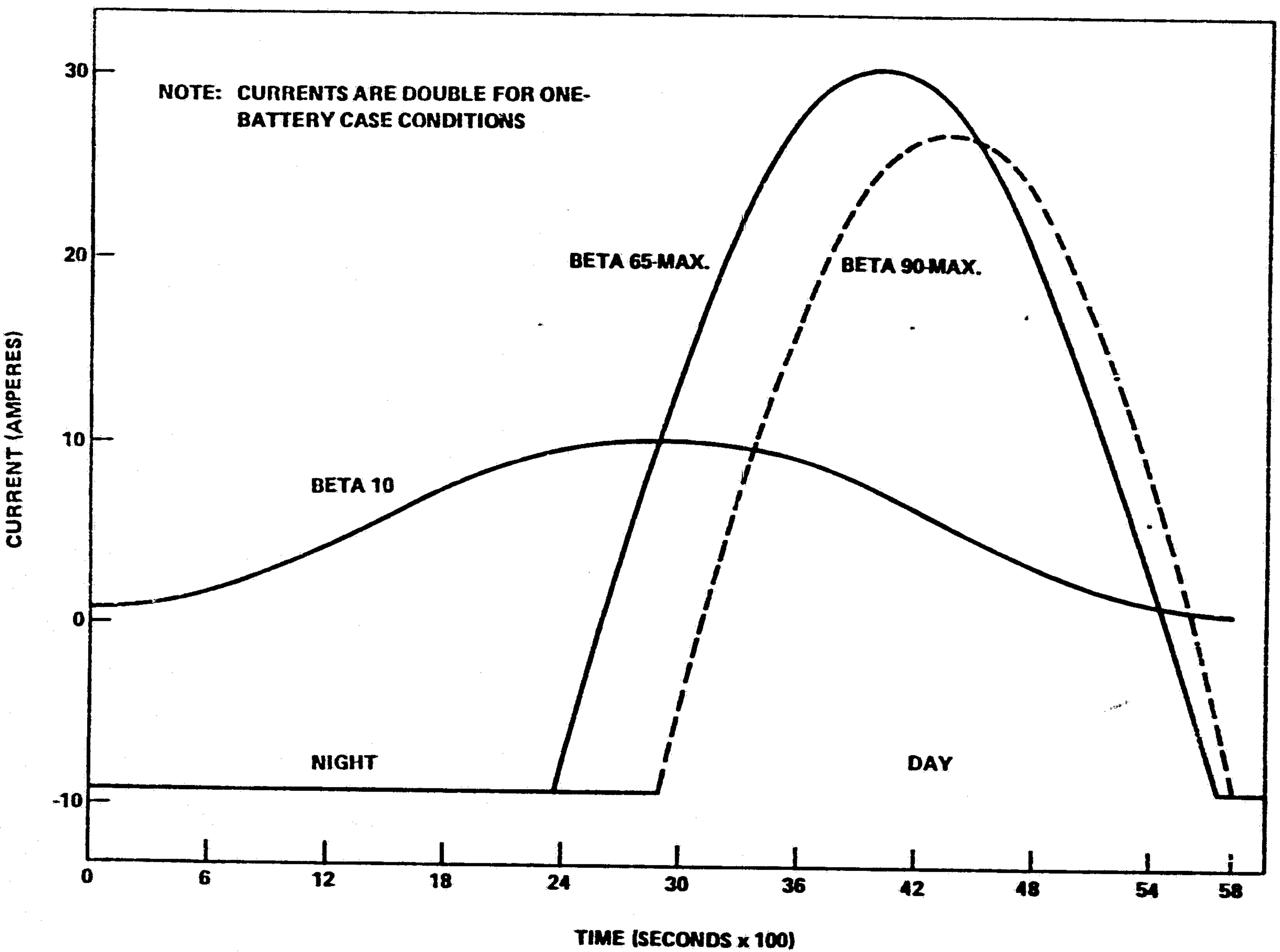

Figure 1-1. Current Profiles for Two-Battery Case Conditions.

ratios achieved during this parametric test were compared to the Goddard Space Flight Center (GSFC) recommended levels. Because of the high sensitivity of C/D ratio to V_T level found in the Phase 1 tests, a second sequence of tests (Phase 2) were performed using control of the C/D ratio in addition to the V_T level charge control method to minimize sensitivity.

These tests were conducted at the Naval Weapons Support Center (NWSC) at Crane, Indiana under GSFC Contract S-57075 AG. The effort involved subjecting the cells to the initial evaluation test and performing baseline SMM/Landsat-D simulated orbital cycling before initiating the first parametric test sequence. The baseline tests were repeated after the parametric sequence but prior to the second sequence of tests described for comparison with available data. NWSC, for the first time, utilized a microprocessor to simulate the ERBS orbit profile, program the current, and control the test. Each 97-minute orbit was simulated using 256 steps in the microprocessor. Application of the microprocessor for this purpose, worked quite well and could be used for improved simulation of mission power profiles for other spacecraft cell and battery testing.

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2. CELL DESCRIPTION AND HISTORY

The 50-Ah nickel cadmium cells used in this test program were manufactured by General Electric to the G.E. Manufacturing Control Document (MCD) 232A2222AA-84, (GSFC approved process) Revision 11 and are designated catalog number 42B050AB20.[2]

These cells were designated serial numbers 041, 070, 050, and 034 and were from the Lot 2 cells used in the Landsat-D test batteries (numbers 2 through 5). They were also from the same lot as Pack 50 C and 50 D cycling in the SMM-simulated orbits at 25- and 40-percent DOD* at 20 degrees Celsius.

The cells were activated with electrolyte during the 28th week of 1978. They were subjected to GE Preacceptance Test Procedure P24B-PB-261 and met the requirements of GSFC Acceptance Test Procedure P24A-PB-277.

Pertinent plate and cell manufacturing data are given in Table 2-1.

Table 2-1
Plate and Cell Lot Data

Item	Positive Plates	Negative Plates
Post No.	06084	06032
Flooded Capacity Ah	64.66	143.29
Theoretical Capacity Ah	82.39	170.52
Utilization (%)	78	84
No. of Plates	16	17
Area of Plate dm^2	1.422	1.422
Avg. Thickness (inches)	0.027	0.031
Loading (hydrate) g/dm^2	12.53	16.19
Volume of Electrolyte cc	170 of 31% KOH*	
Separators	bags of Pellon 2505 nylon around positive plate	
Precharge Ah	25	

*potassium hydroxide

The cells had been stored and shorted at room temperature until this test effort.

[2]The design is based on GSFC 74-15000, "Specification for the Manufacturing of Aero-Space Nickel-Cadmium Storage Cells," Goddard Space Flight Center, January 1974.

*depth of discharge

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3. INITIAL EVALUATION TESTS

The cells were subjected to GSFC-required initial evaluation tests at NWSC to verify that the cells were in an acceptable condition and consistent with Pack 50 C and 50 D results. The cells were subjected to a conditioning, and the capacity and overcharge tests required in NWSC Test Procedure 3053-TP-324, Change 7 (April 2, 1974). The test results are summarized in Table 3-1.

Table 3-1
Initial Evaluation Test Data

	20°C Capacity		Charge Retention (20°C)		
	EODV	CAP	EOCV	E 1 Wk.	CAP
041	1.469	61.14	1.468	1.278	50.80
070	1.469	61.65	1.467	1.284	54.08
050	1.468	63.16	1.466	1.285	55.59
034	1.469	63.91	1.466	1.286	56.60
				class averaged 10% Loss	

	Charge EFF[1]		0°C Capacity[2]		30°C Capacity[3]	
	EOCV	CAP	EOCV	CAP	EOCV	CAP
041	1.376	18.14	1.503	6.066	1.406	63.31
070	1.377	18.65	1.504	62.93	1.417	62.81
050	1.37/	18.14	1.500	62.17	1.416	64.57
034	1.376	18.65	1.499	63.93	1.418	65.58
	Efficiency 76%					

(based on 25 Ah of charge)

[1] Charge 20 hours at 1.25 A
[2] Charge 60 hours at 2.5 A
[3] Charge 24 hours at 5 A

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4. LANDSAT-D BASELINE TESTING

In order to assure that Pack 50 E was operating in a manner consistent with previous experience, it was cycled in the typical Landsat-D power profile and the results compared with Pack 50 C and 50 D on test at NWSC. The two Landsat-D test packs containing cells from the same manufacturing lot as those in Pack 50 E are designated Pack 50 C (25-percent DOD, 20°C) and Pack 50 D (40-percent DOD, 20°C). Pack 50 C was considered the baseline test condition. The ERBS test pack (50 E) was operated under the same conditions both before and after the Phase 1 parametric test sequence for baseline comparison.

After completion of the initial evaluation tests, the four cells were subjected to a capacity cycle (C/10* charge for 24 hours, discharge at C/2 to 1 volt) and then, a voltage limit capacity (VLC) cycle (C/2 charge to V_T-6, current taper to 75.9-Ah, discharge at C/2 to 1 volt) at 20 degrees Celsius. After a VLC recharge, the Pack 50 C baseline testing profile was initiated. It consisted of a 60-minute charge (C/2 to V_T-6) followed by a taper charge. The 30-minute discharge was at C/2 providing 25-percent DOD.

The results of the first 250 cycles of Pack 50 E and 50 C are given in Figures 4-1 through 4-3 together with cycles 1500 through 2500. Figure 4-1 provides end-of-charge current (EOCI), Figure 4-2, end-of-discharge voltage (EODV), and Figure 4-3, the charge-to-discharge (C/D) ratio versus cycle.

During the first 250 cycles, the EOCI increased from 2.75 to 3 amperes; the EODV decreased from 1.230 to 1.215V/cell, and the C/D increased from 1.05 to 1.09. As seen in the figures, the Pack 50 E trends were consistent with those of the Pack 50 C initial 250 cycles which operated in an identical manner.

*The value for C is the nominal cell capacity--in this case 50. Therefore, the current for a C/10 rate is 5 amperes.

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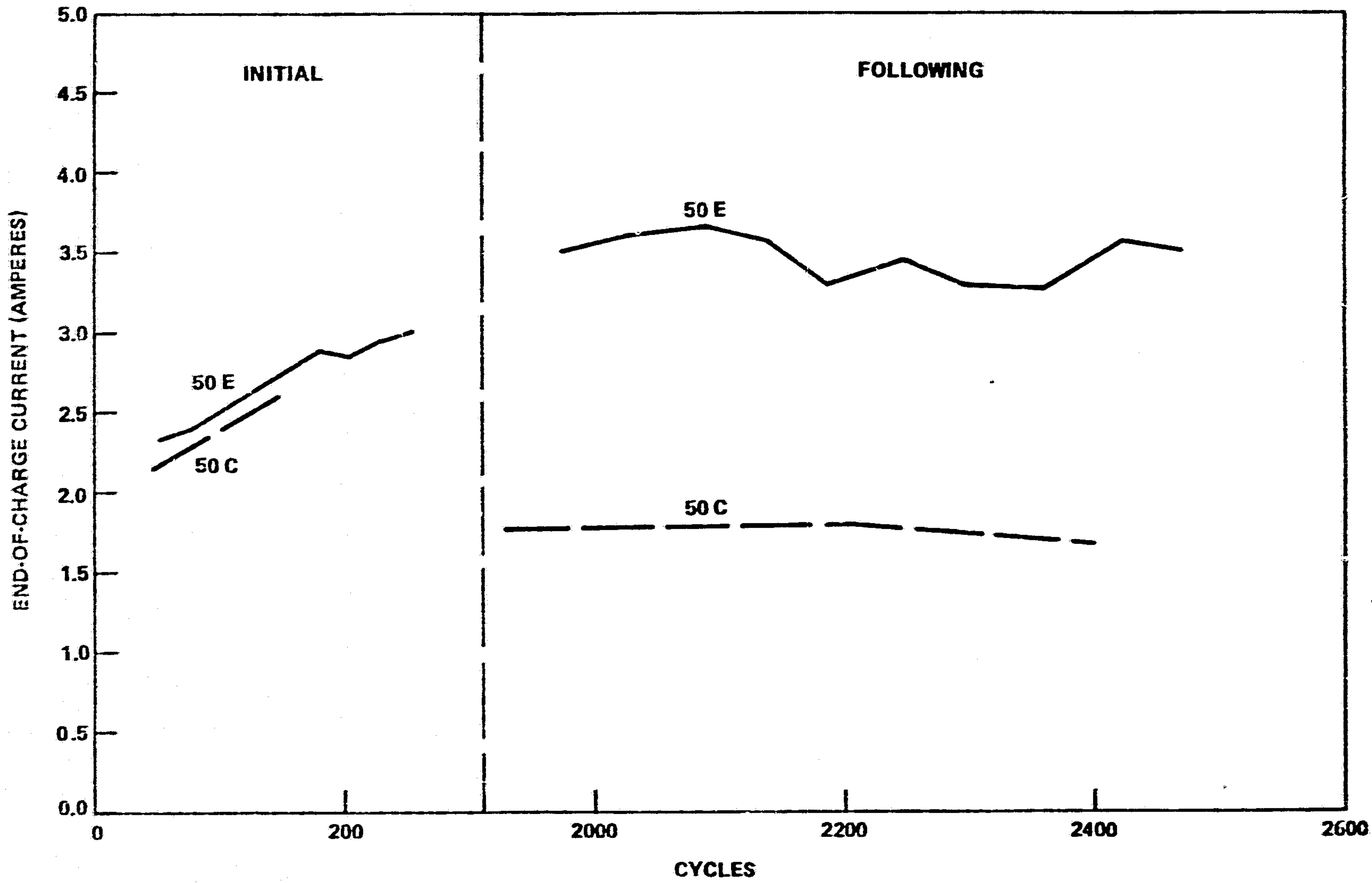

Figure 4-1. End-of-Charge Current Versus Cycle (ERBS 50 Ah)

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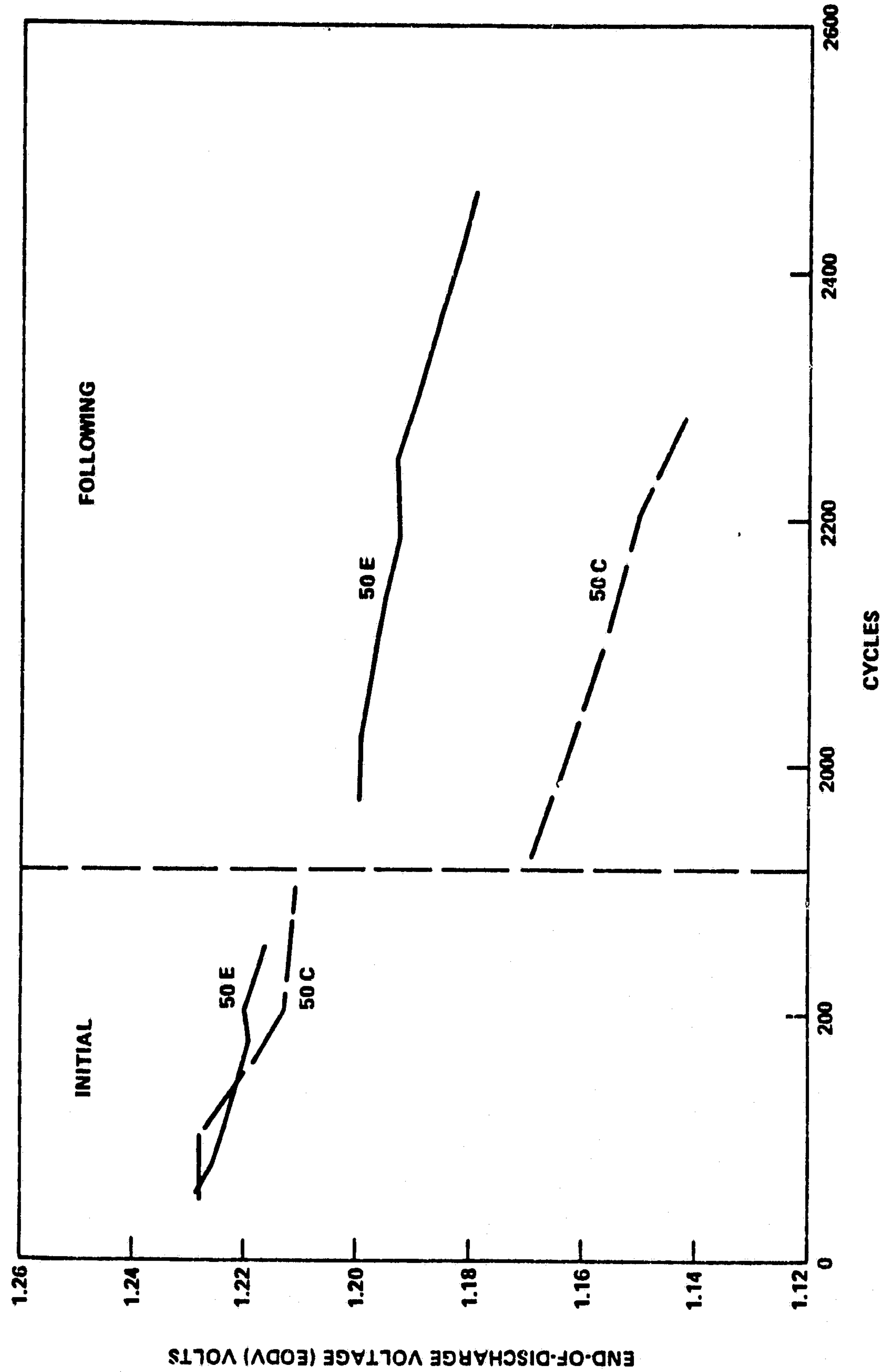

Figure 4-2. End-of-Discharge Voltage Versus Cycle (ERBS 50 Ah)

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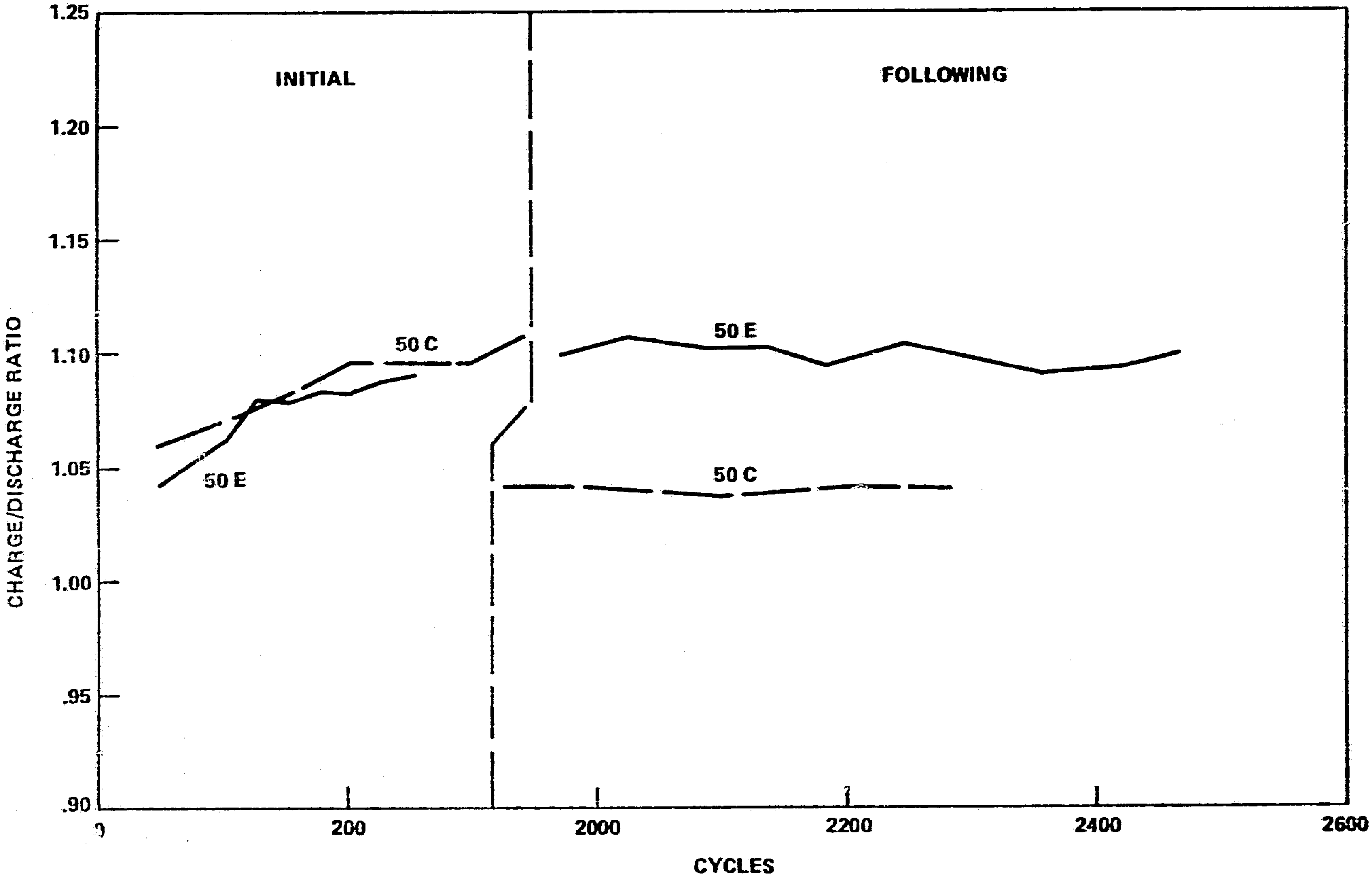

Figure 4-3. Charge/Discharge Ratio Versus Cycle (ERBS 50 Ah)

5. SIMULATED ERBS CYCLING - PHASE 1: PARAMETRIC V_T LEVEL/TEMPERATURE TEST

This Phase 1 effort was a parametric test at three V_T levels, three temperatures, and three Beta angles predicted from mission profiles. This test was to determine the battery characteristics over the range of available operating conditions. The test matrix* is given in the following list. The test included cycling at each condition for 24 hours following an initial activation cycle. The profiles given in Figure 1-1 were used.

- Beta-90 max. - Two-Battery Case (48.6M - charge/48.6M - discharge) V_T5, 6, 7 at -5, 5, 15°C
- Beta-65 max. - Two-Battery Case (59M - charge/38M - discharge) V_T4, 5, 6 at 5, 15, 25°C
- Beta-10 max. - Two-Battery Case (continuous charge) V_T3, 4, 5 at 5, 15, 25°C
- Beta-90 max. - One-Battery Case (48.6M - charge/48.6 - discharge) V_T5, 6, 7 at -5, 5, 15°C
- Beta-65 max. - One-Battery Case (59M - charge/38M - discharge) V_T4, 5, 6, at 4, 15, 25°C
- Beta-90 min. - Two-Battery Case (48.6M - charge/48.6M - discharge) V_T5, 6, 7 at -5, 5, 15°C
- Beta-90 min. - One-Battery Case (48.6M charge/48.6M - discharge) V_T5, 6, 7 at -5, 5, 15°C
- Beta-90 max. - Two-Battery Case (48.6M charge/48.6M - discharge) V_T5, 6, 7 at 5, 5, 15°C

In addition to the three Beta angles, the ERBS profile testing also included a single battery operation (simulating failure of a battery in orbit), average load conditions (maximum available current), and maximum load conditions (minimum available current).

Examples of how the cell pack operated under the different Beta profile conditions are given in the next few figures. The specifics of the operating conditions and parameters are discharge time, rate, percent DOD, and available peak current. They are given in Table 5-1.

Examples of the cell voltage and current profiles (solid lines) for the different Beta conditions overlayed on the projected power profile (dotted lines) are given in Figure 5-1 (Beta 90 Two-Battery

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*Test procedure is given in TP711.2-81-1.

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Table 5-1
Summary of Parametric Test Operating Conditions

Condition	No. of Batteries	Discharge Current (a)	Capacity Removed (Ah)	DOD (%)	Discharge Time (min.)	Available Peak Curr. Chg. (A)	Reference Figure No.
B90 Max.	2	8.24	6.94	13.9	48.3	26.8	4
B65 Max.	2	8.10	6.17	12.3	37.6	30.4	5
B10 Max.	2	-	-	-	0	10.4	6
B90 Max.	1	16.47	12.94	24.6	48.8	53.8	7
B65 Max.	1	16.47	12.37	20.7	37.6	53.7	-
B90 Min.	2	8.24	6.66	13.3	48.7	23.3	-
B90 Min.	1	16.47	13.13	26.2	48.3	47.4	-

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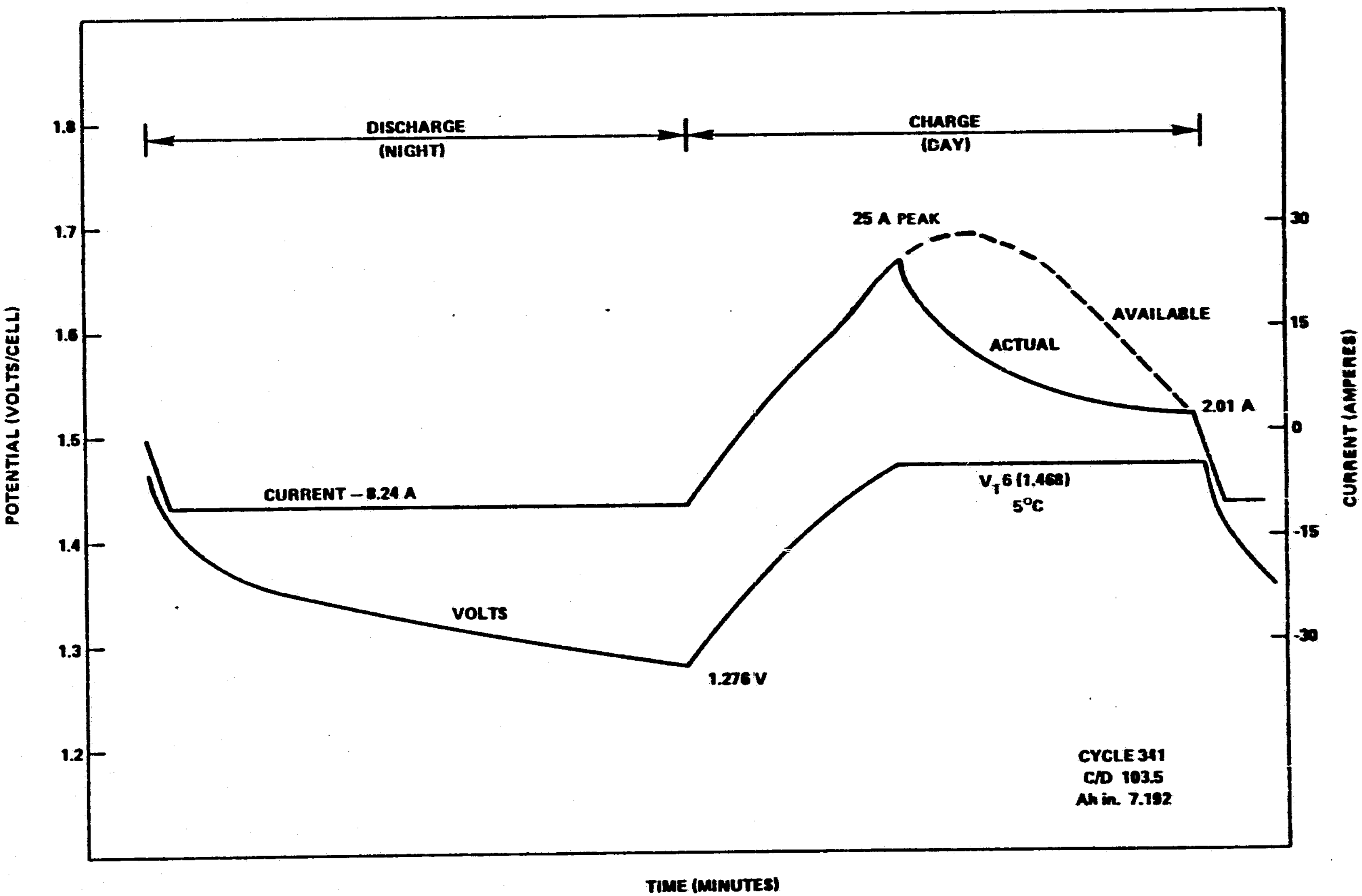

Figure 5-1. Beta-90 Maximum, Two-Battery Case

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Case), Figure 5-2 (Beta 65 Two-Battery Case), and Figure 5-3 (Beta 10 Two-Battery Case). The profile for the Beta 90 One-Battery Case is given in Figure 5-4. The point of divergence between the solid and dotted line is where the voltage limit was reached and current taper initiated. The Beta-90 and Beta-65 discharge were both at constant current for fixed periods. The Beta-10 operation did not include a discharge.

Each parametric condition started with a VLC type activation, which was complete when the taper current, and dropped to 3.75 A (C/15). The pack was then cycled in the specified condition for 24 hours (approximately 16 cycles).

The results are given in Figures 5-5 through 5-7 in which the C/D ratio versus temperature is given for the different test conditions. In each figure, the ampere hours returned on charge are given for each parametric test condition. A measure of reproducibility is indicated in Figure 5-5, which compares the results of using the same test conditions from the beginning and 1300 cycles later. Figure 5-6 compares the results of the Beta-90 and Beta-65 Two-Battery-maximum test condition. The GSFC recommended C/D range is also provided. The results indicate that Level 6 may be inadequate for charging in an ERBS profile at Beta 90. Yet V_T7 is obviously excessive because it would result in too much overcharge. For Beta 65, V_T6 is above the guideline at temperatures greater than 10 degrees Celsius. However, V_T5 would be totally inadequate. This sensitivity to V_T level is not experienced in the SMM type of orbit and is evidently related to the sine wave-shaped charge profile projected for the ERBS mission.

For the Beta 90 and 65 One-Battery-maximum case (Figure 5-7 simulating one battery disconnected from the bus) both V_T7 at Beta 90 and V_T6 at Beta 65 are well below the accepted level. Charge at the highest available, V_T-8, for Beta 90 or V_T7 at Beta 65 levels were obviously excessive and would result in a significant thermal problem.

There was little difference between the C/D versus temperature curves for the Beta 90-maximum and Beta 90-minimum case. This is expected considering that the capacity removed was similar and peak current between the two differed by only 10 percent.

Figure 5-8 contains the same information as Figure 5-9 except that C/D is plotted versus V_T level.

The results of the Beta-10 case are given in Figure 5-9 in which end-of-charge current and ampere hours input are plotted versus temperature of operation. The entire 97 minutes of orbit are spent in the charge conditions; consequently, there is a significant amount of overcharge. It should be realized this is only one charge profile of an almost infinite number of charge profiles which is dependent on the operational mode and operational sequencing of the ERBS.

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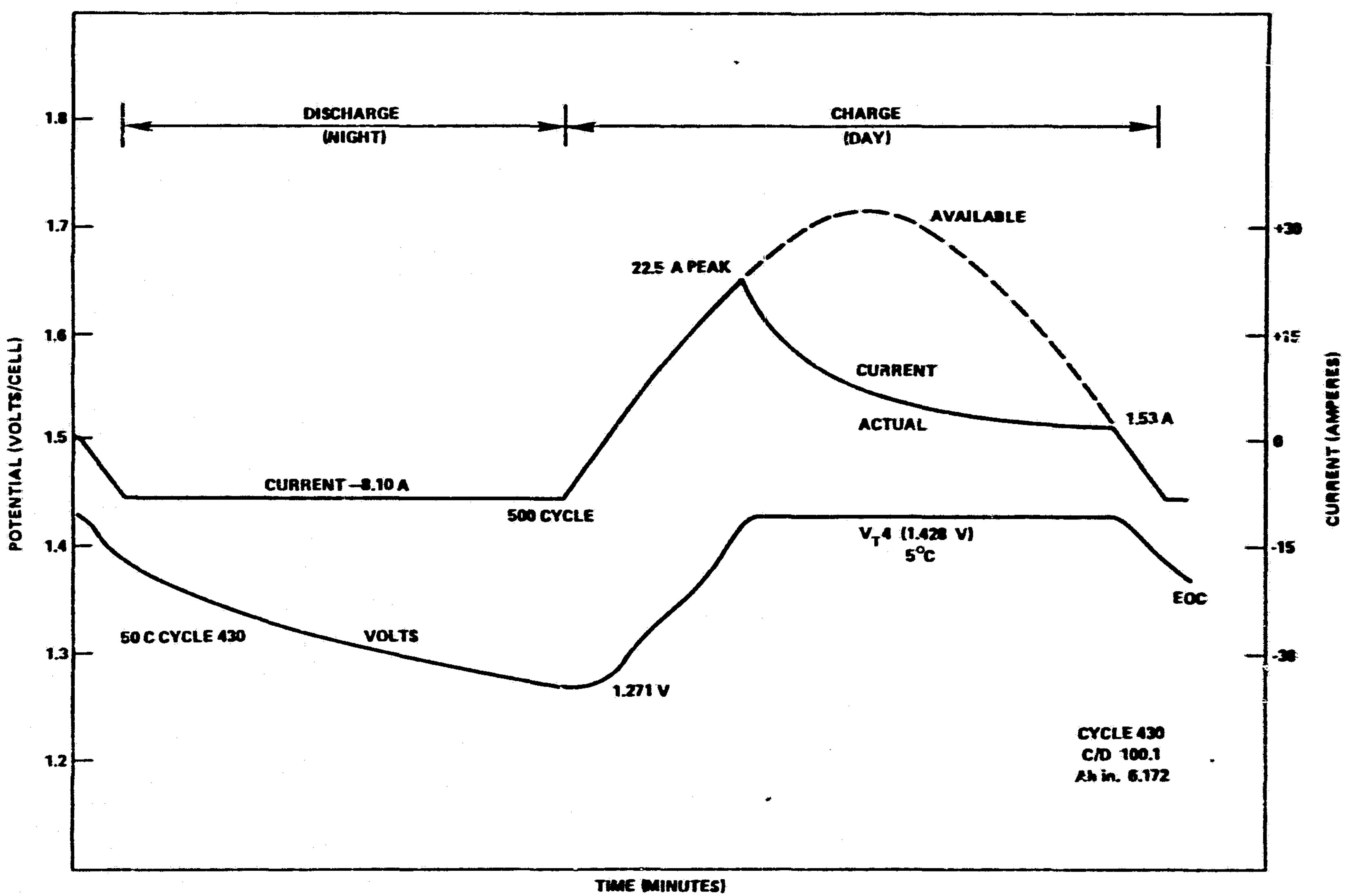

Figure 5-2. Beta-65 Maximum, Two-Battery Case

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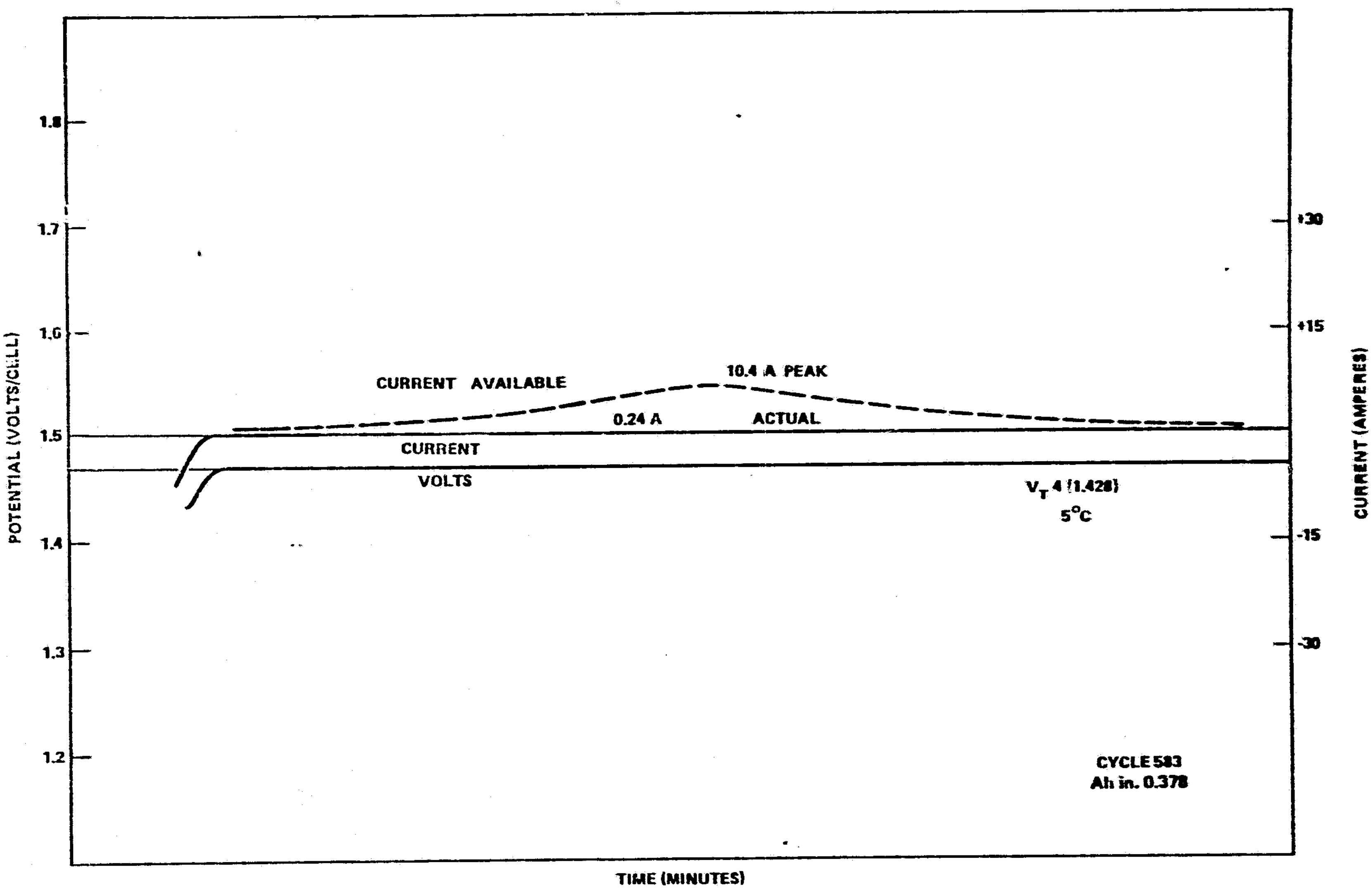

Figure 5-3. Beta-10 Maximum, Two-Battery Case

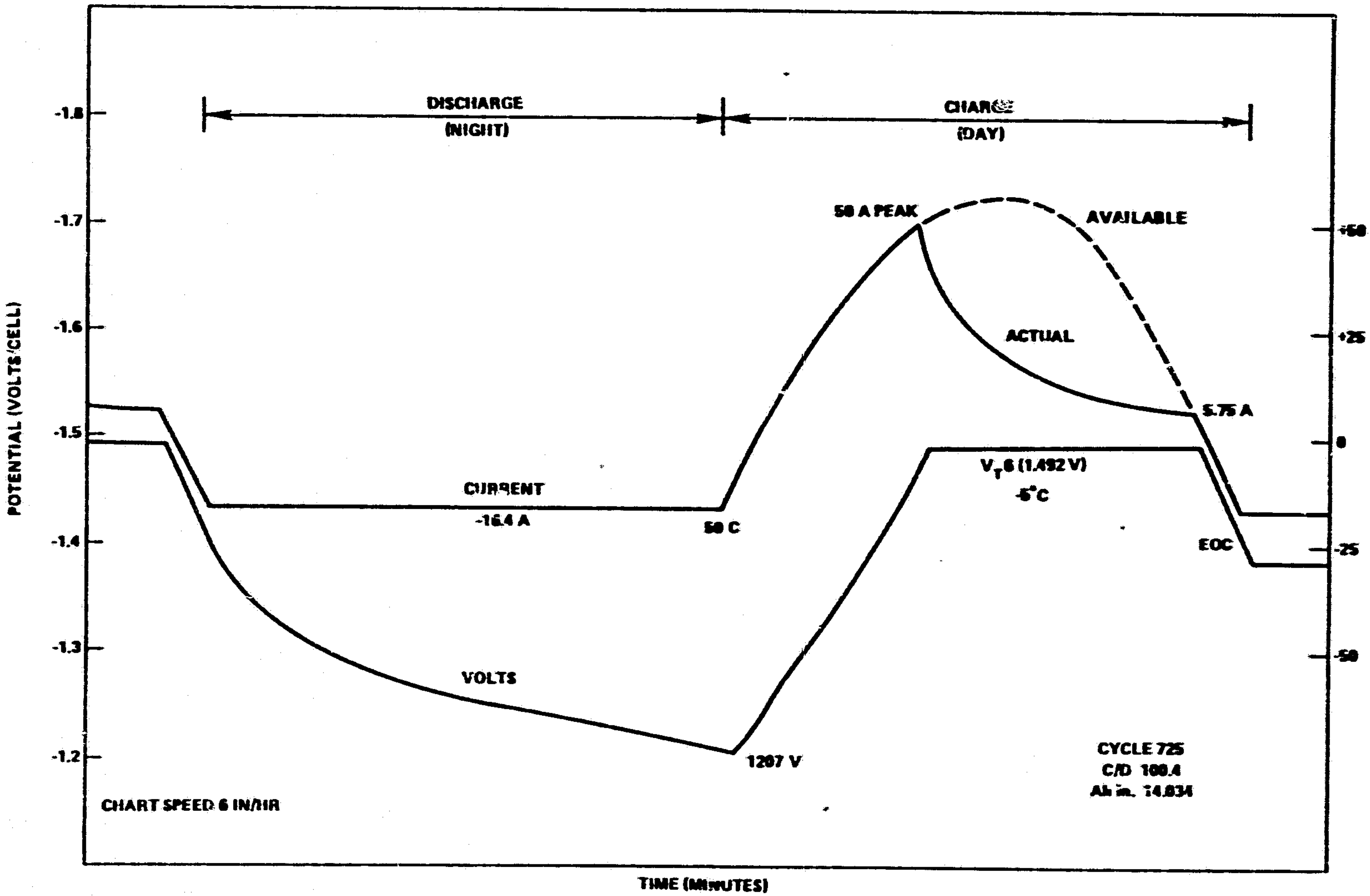

Figure 5-4. Beta-90 Maximum, One-Battery Case

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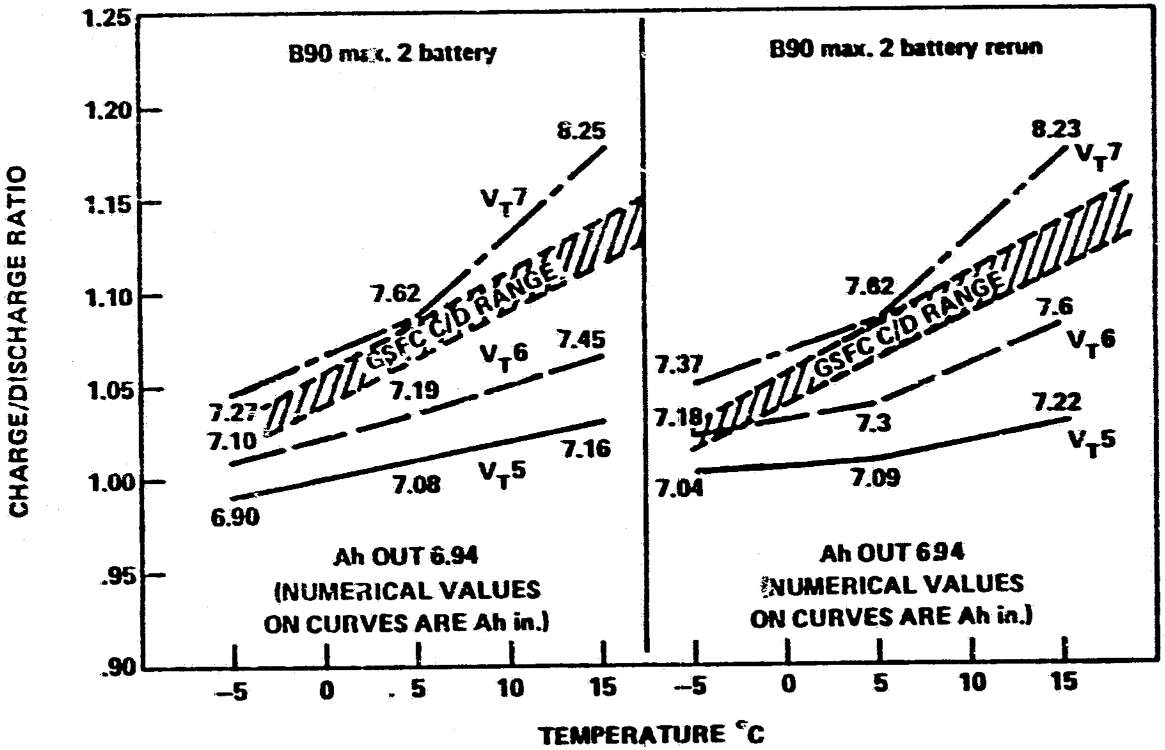

Figure 5-5. Charge/Discharge Ratio Versus Temperature (Beta-90 max. - Beta-90 max.)

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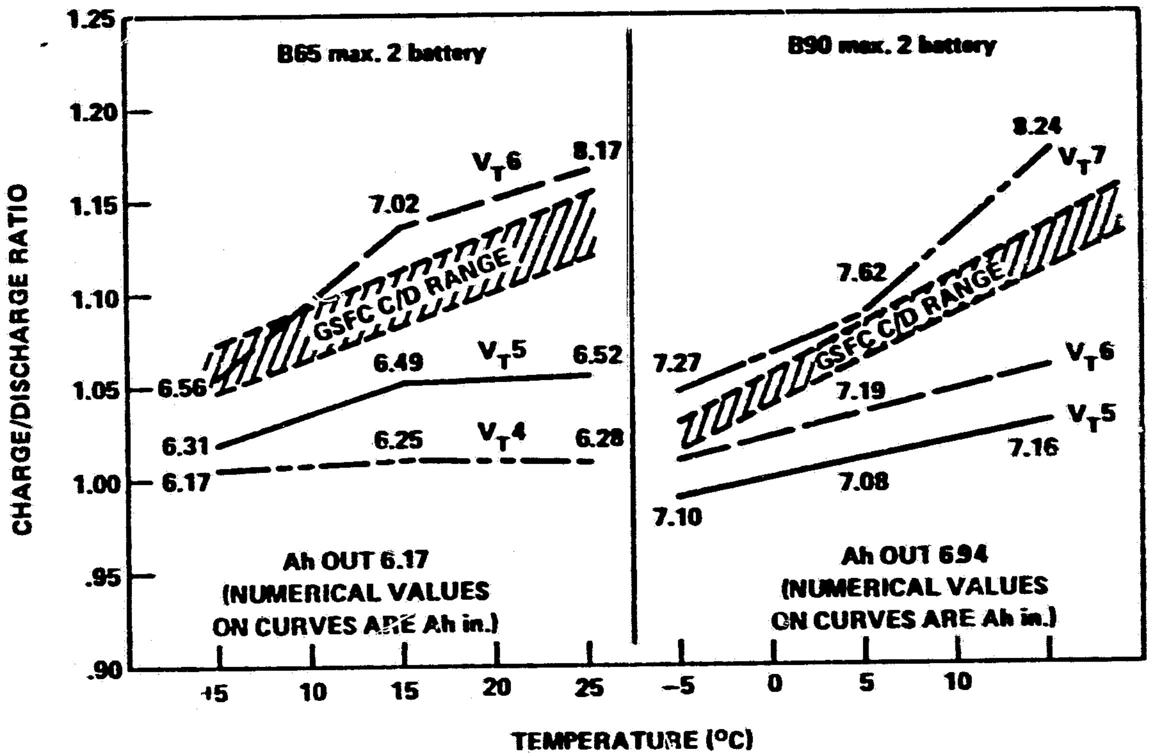

Figure 5-6. Charge/Discharge Ratio Versus Temperature (Beta-90 max. - Beta-65 max.)

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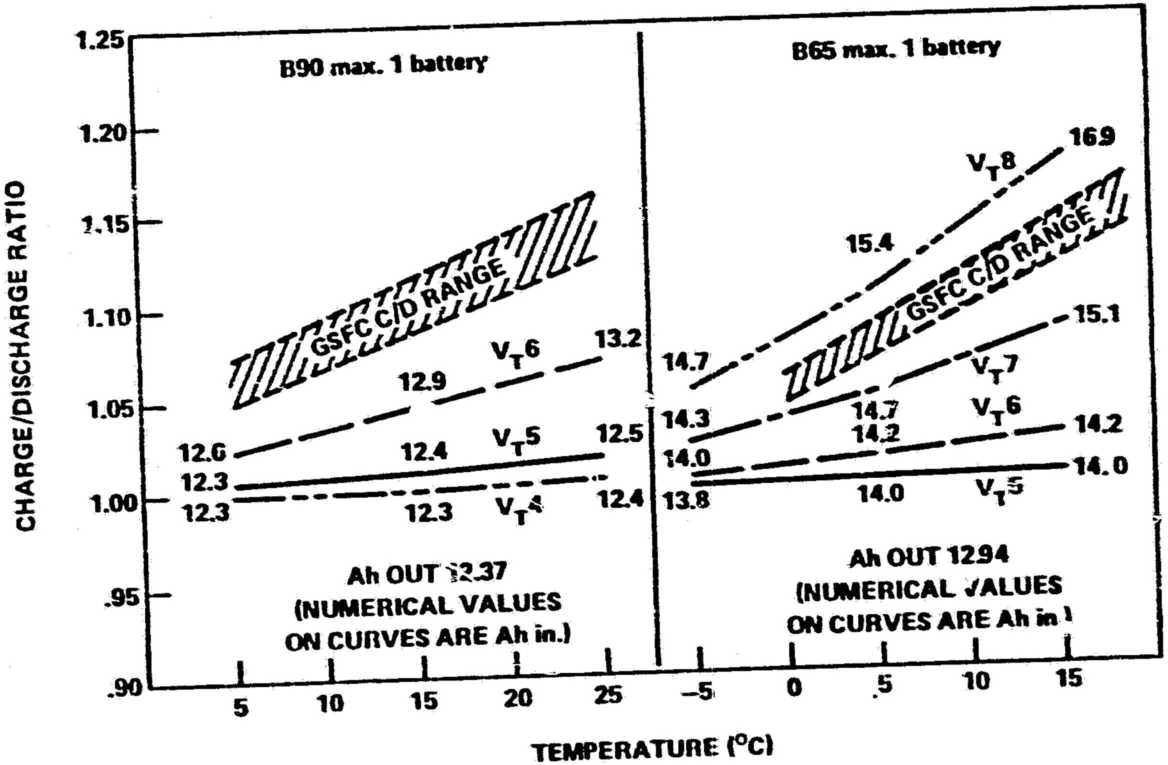

Figure 5-7. Charge/Discharge Ratio Versus Temperature (Beta-90 max. – Beta-65 max., One-Battery Case)

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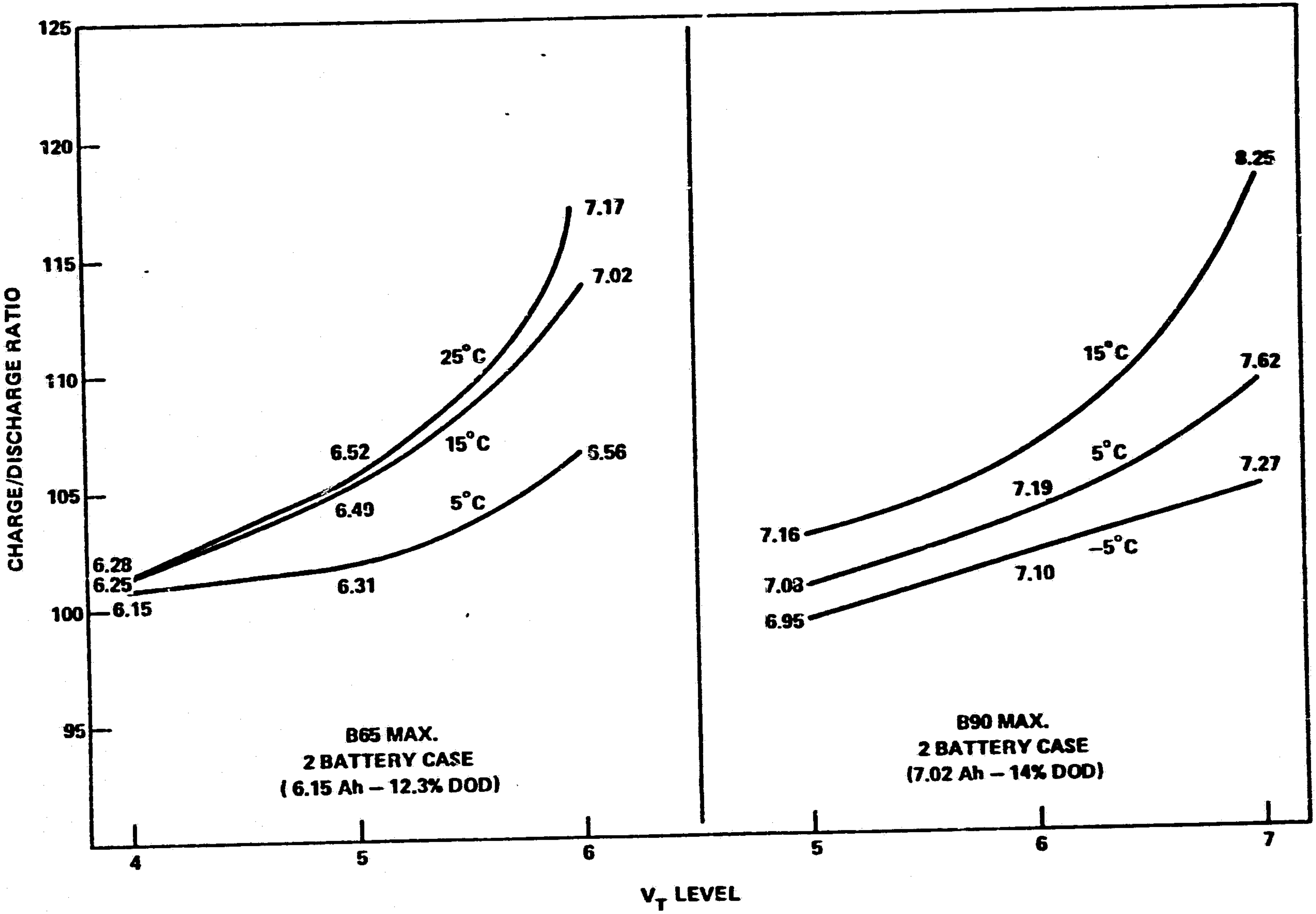

Figure 5-8. Charge/Discharge Ratio Versus V_T for Beta 90 - Beta 65, Two-Battery Case

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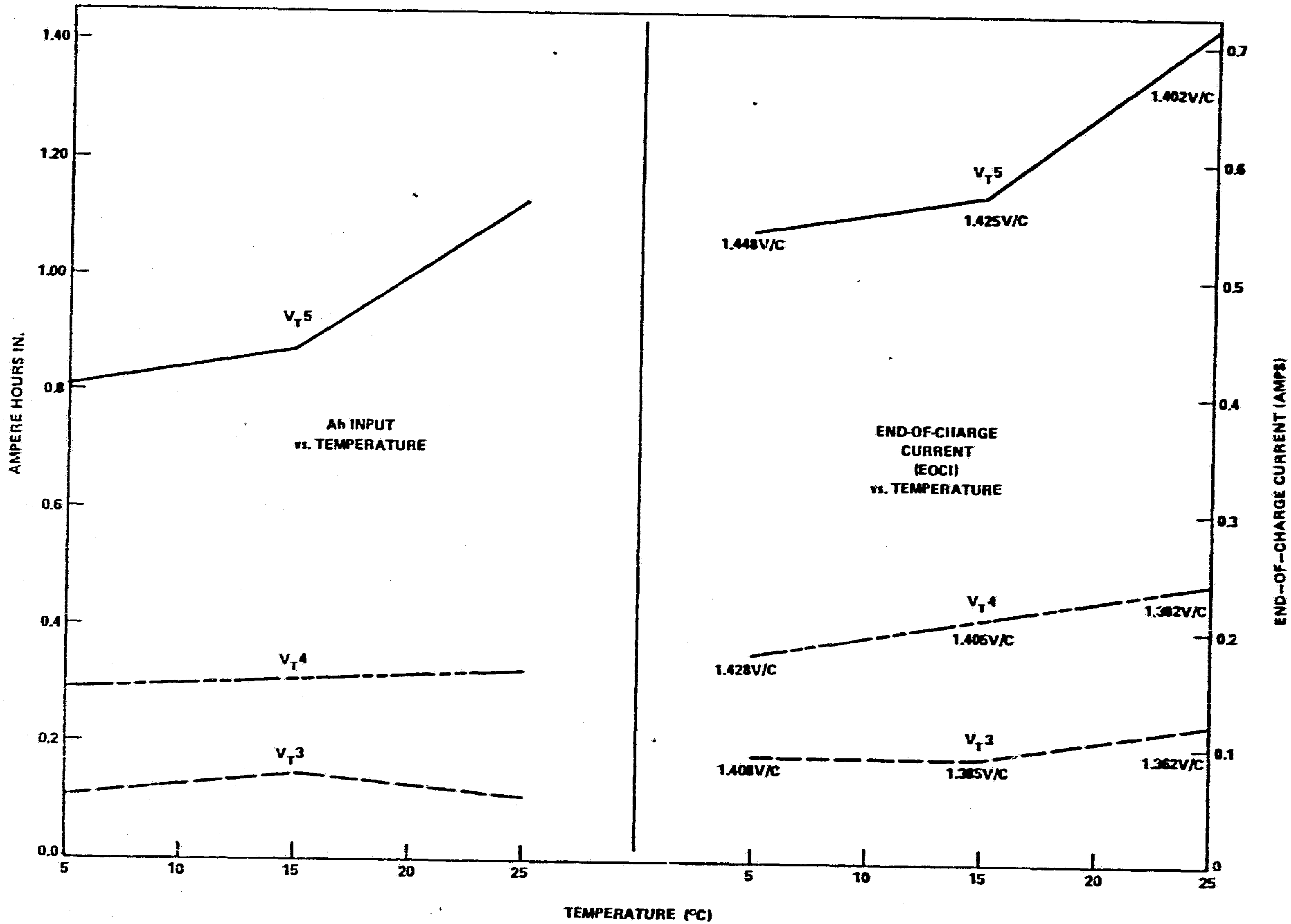

Figure 5-9. Beta 10, Two-Battery Case

Heat is dissipated by the battery during discharge and overcharge. Both are a function of current. On discharge, 16 to 18 percent of the instantaneous watts are dissipated as heat. During charge, and until the battery is fully charged, the balance between the Joule heating and entrophy heating provide a very small net absorption of heat by the battery (thus, providing a minimal lowering of temperature at the base of the battery). When the battery is fully charged (greater than GSFC recommended C/D levels) and charging continues, the result is a net instantaneous heating approximately equivalent to the voltage times the current. Therefore, the higher the current and the greater the overcharge, the greater the heat dissipation. Hence, it is desired that the overcharge be terminated at the recommended C/D ratio, or overcharge current be minimized. Operating at too high a V_T limit will result in a high taper charge current during the overcharge, resulting in a significant amount of heat to contend with (in addition to that during discharge).

V_T-4 would be an adequate operating voltage level for the Beta-10 condition. It represents 0.3 watts/cell or 6.5 watts for a 22-cell battery at a C/250 charge rate. At V_T5 and 15 degrees Celsius, the heat generation rate is 0.87 watts/cell or 19.1 watts/battery at a charge rate of C/88. This test was performed under voltage limit control so that the cell was in the taper current mode throughout the charge.

In summary, Phase 1 tests provided insight into the V_T operation in an ERBS profile. It indicated that the batteries could be charged using the V_T method. However, there was a significant degree of concern about the recharge or overcharge at the given V_T levels. The high sensitivity of C/D to V_T level resulted in either insufficient charge or considerable overcharge. This situation suggested that an additional charge control method was required in addition to the V_T level in order to control the amount of overcharge.

Use of an ampere hour integration was suggested. It was utilized to control the overcharge by reducing current to a trickle charge when a preset C/D ratio was reached. The technique was tested in the Phase 2 test sequence.

6. LANDSAT-D BASELINE TESTING - REPEAT

After the Phase 1 ERBS testing, the cells were returned to the 25-percent DOD LEO life cycling performed during the first 250 cycles. The EOCI, end-of-discharge voltage (EODV), and C/D ratios for the repeat (following) test are potted versus cycle number in Figures 4-1 through 4-3 with the initial test data.

Data for the Pack 50 E (ERBS pack) for orbits 1640 to 2200 are compared with that of Pack 50 C (SMM type) for the same orbits. Both packs had consistent but differing in EOCI, decreasing EODV, and constant C/D ratios. The improved values for the Pack 50 E may be due to the activation cycle prior to each parametric test, or more likely to the difference between DOD between the packs. The fact that Pack 50 E operation was changed often while Pack 50 C operation was consistent may also have had an effect.

7. SIMULATED ERBS CYCLING - PHASE 2: BEGINNING OF LIFE (BOL) AND END OF LIFE (EOL) TESTING

After completion of the 500-cycle repeat baseline cycling, testing was initiated on Pack 50 E which approximated the expected ERBS orbit more exactly. It used similar profiles as the Phase 1 testing except that (at a prescribed C/D ratio) a microprocessor simulating an ampere hour integrator reduced the current to trickle charge (0.75 A) to avoid excessive overcharge. This allowed the operation of the battery to be performed at a higher V_T level than would be selected from the earlier parametric test. It also overcame the problem of sensitivity experienced in the Phase 1 tests.

The sequence of testing appears in Table 7-1.

Table 7-1
BOL/EOL Test Sequence and Parameters

Test Condition	Beta	Temp.	Profile	Initiate Trickle Charge at C/D	V_T
1	90	1°C	BOL	1.03 (Level 2)	6
2	65	3°C	BOL	1.03 (Level 2)	6
3	40	9°C	BOL	1.06 (Level 2)	6
4	15	16°C	BOL	1.08 (Level 2)	6
5	90	1°C	EOL	1.03 (Level 2)	6
6	65	3°C	EOL	1.03 (Level 2)	6
7	40	9°C	EOL	1.06 (Level 2)	6
8	15	16°C	EOL	1.08 (Level 2)	6

Each test condition was performed for a 5-day period (approximately 70 cycles). In addition to the Beta's 90 and 65 test simulations in the initial phase, Beta's of 40 and 15 (replacing 10) were used. Also, beginning of life (BOL) and end of life (EOL) power profile simulations were used. Predicted battery environmental temperatures were incorporated into the test conditions. A V_T6 charge level was utilized for each condition. Further, when a C/D ratio reached a preset temperature compensated level (Curve 2) suggested by BASD* (given in Figure 7-1), the charge current was reduced to 0.75 A

*Ball Aerospace Division - prime contractor to ERBS.

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until the daylight (charge) period was completed. Note that the Curve 2 C/D ratio displayed in Figure 7-1 is at the lower limit of the GSFC C/D ratio guidelines.

The charge/discharge profiles for the four BOL conditions are given in Figures 7-2 through 7-5. They follow an expected characteristic; for the Beta-90 case, the current nearly reached the peak and taper followed when the V_T level was reached. However, trickle charge was not initiated in this condition because the C/D Curve 2 value is not achieved during the charge period. In Beta's 65, 40, and 10, the taper charge is switched to trickle charge before the end of the simulated daylight period. The EOL profiles are quite similar to these.

The quantitative results are given in Table 7-2. As indicated, time at the V_T level decreases with decreasing Beta angle and DOD. Consequently, trickle charge time increases. The effect of using the ampere hour integrator can be seen in the column "C/D BTC," which is a computation of total ampere hours of charge to the end-of-the-taper charge (Ah of trickle charge not included). The second to the last column comprises the C/D ratio, including the trickle charge, which reflects the extended charge period at the low-trickle charge current. The most important data appear in the final column. It is the calculated C/D ratio if the taper charge were to continue without trickle charge. The advantage of the requirement for the C/D control using an ampere hour integrator is obvious.

Perhaps the most important proof that the system is working is shown in Figures 7-6 and 7-7. The EODV in the four BOL and EOL conditions are given over a 500-orbit period without activation (~70 cycles at each condition). The EODV is remarkably level compared with the earlier Phase 1 ERBS profile tests and the SMM LED life tests, but there is a slight decrease for the Beta-90 condition with cycling. It may be that trickle charge is desired in this orbital condition. Operation in the Beta-90 condition may be improved by operating at V_T-7, but this remains to be proven.

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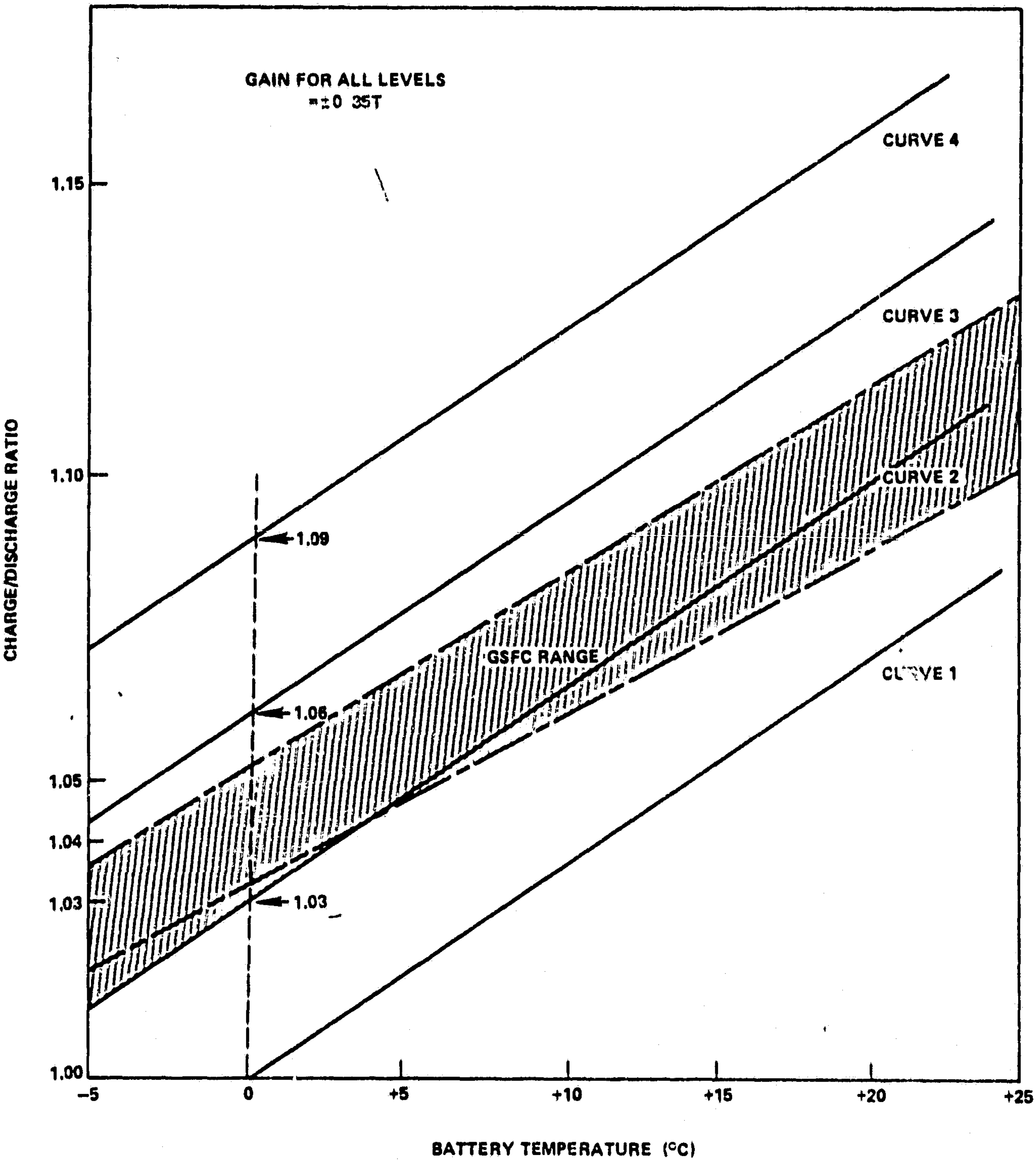

Figure 7-1. Charge/Discharge Ratio Versus Temperature Limit Curves

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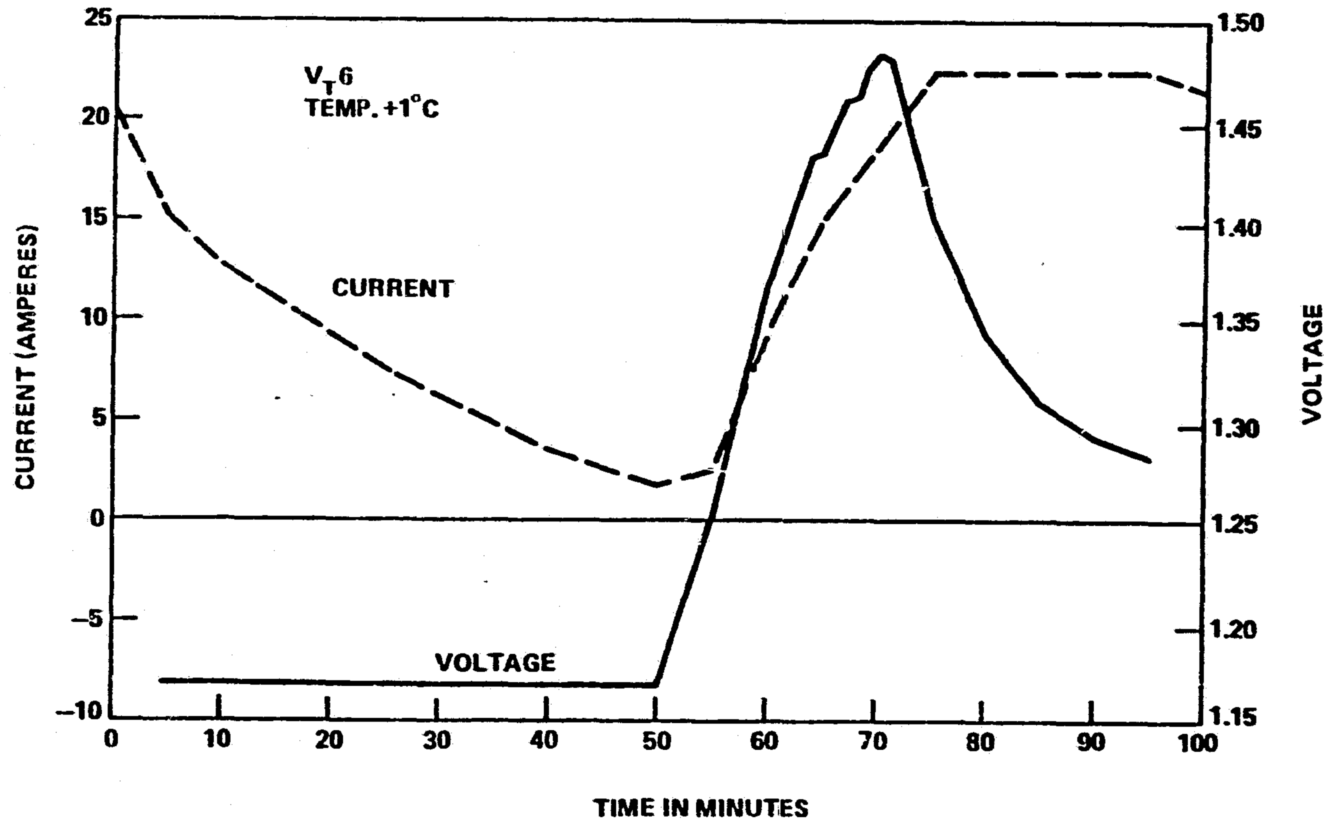

Figure 7-2. Beta-90 Beginning-of-Life Profile (Pack 50 E)

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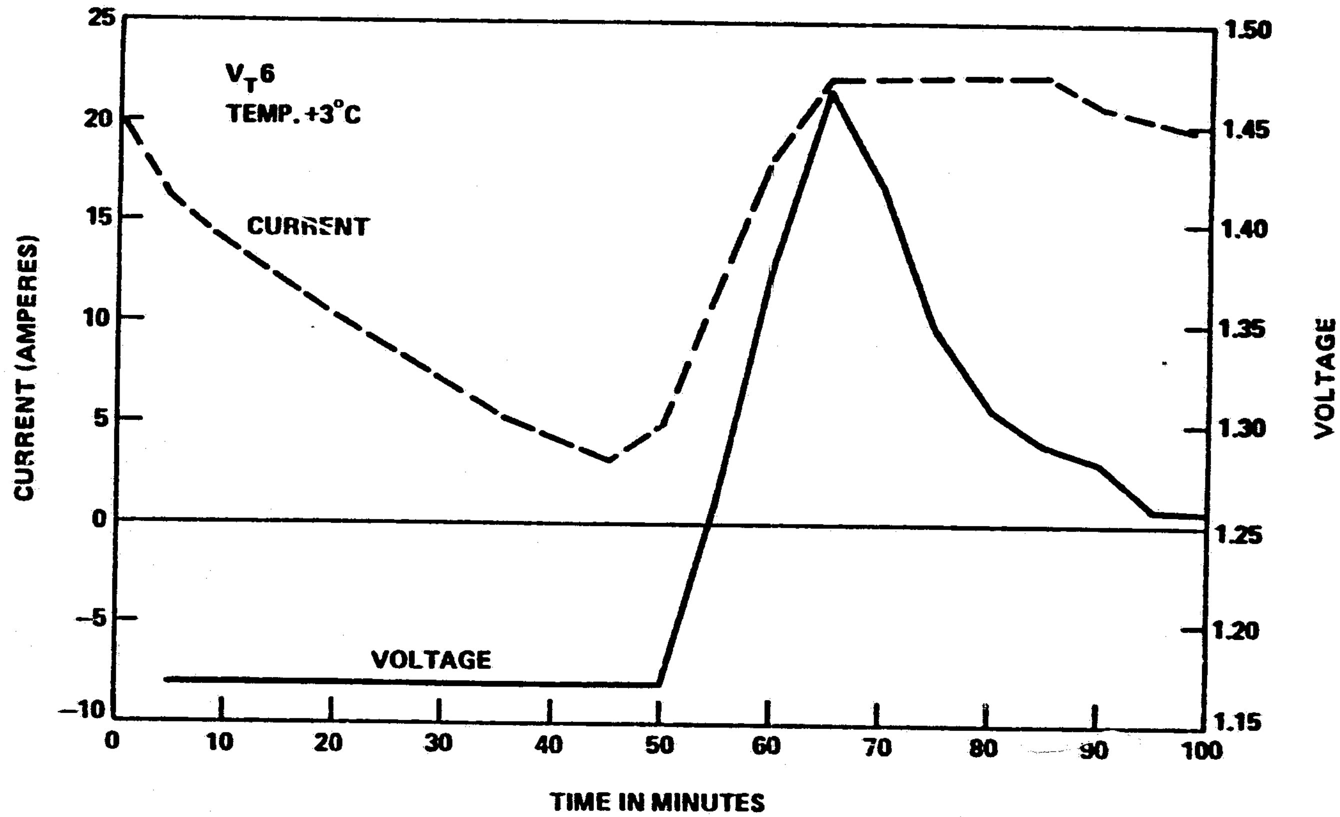

Figure 7-3. Beta-65 Beginning-of-Life Profile (Pack 50 E)

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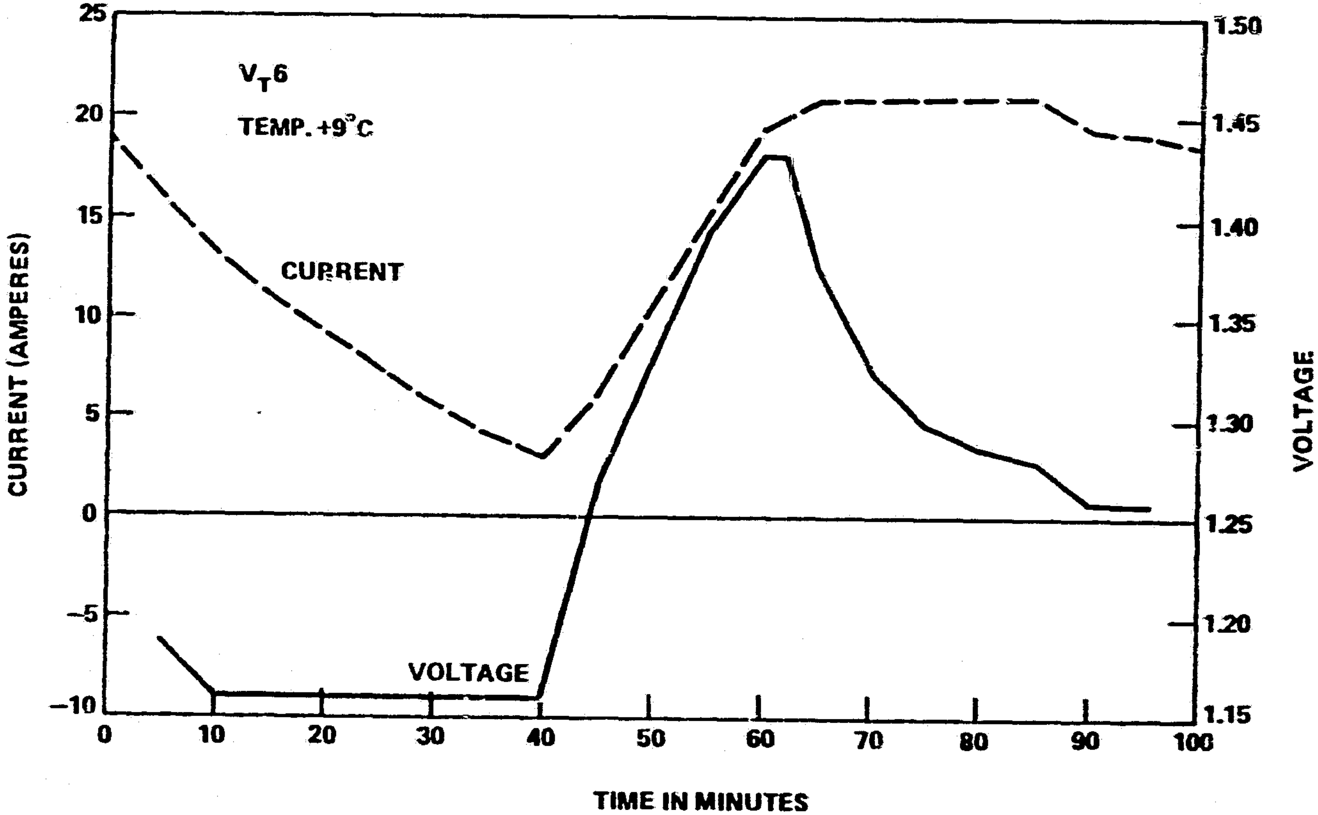

Figure 7-4. Beta-40 Beginning-of-Life Profile (Pack 50 E)

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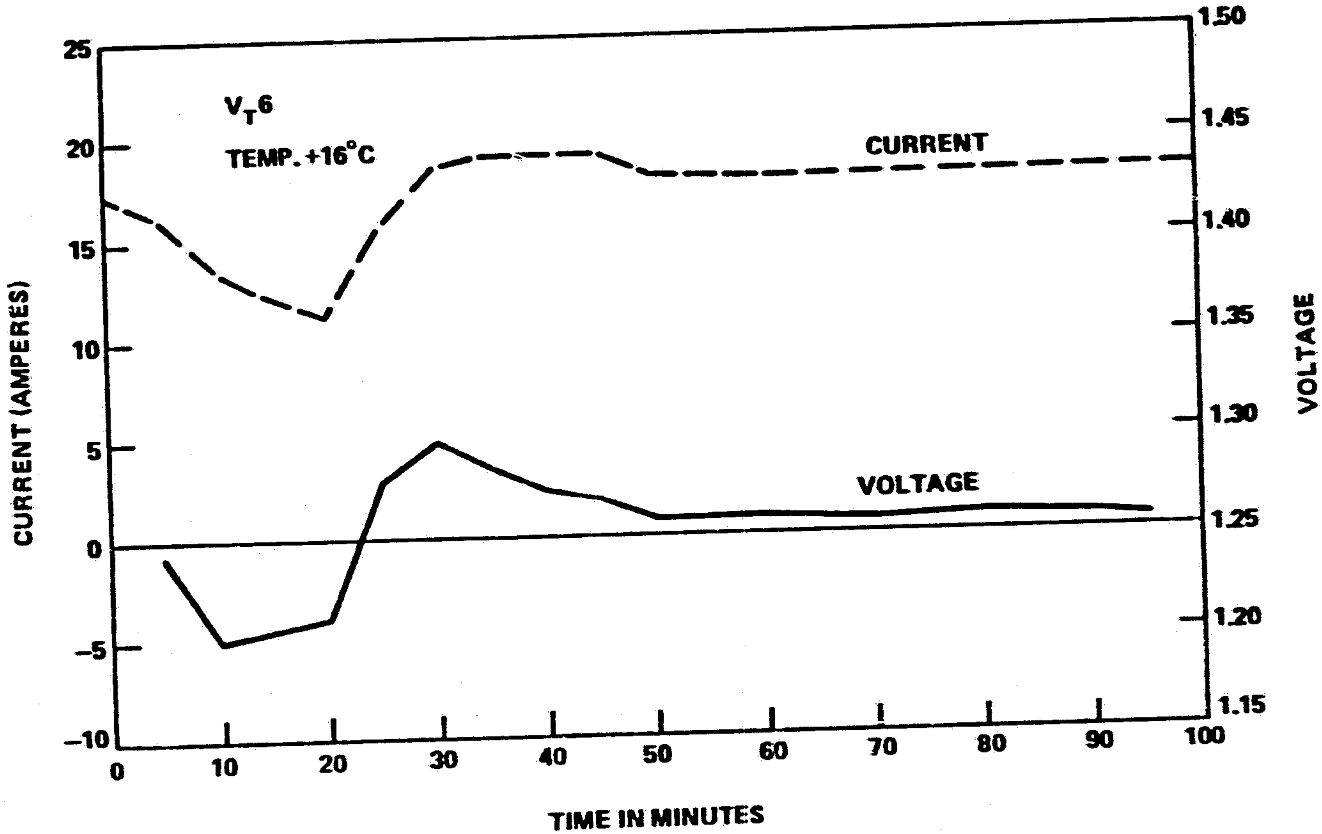

Figure 7-5. Beta-15 Beginning-of-Life Profile (Pack 50 E)

Table 7-2
Quantitative Results of Phase 2 Test

Test Condition	Beta	Temp (°C)	A	Discharge Ah Out	DOD	V_T[6]	TTVL[1]	Charge TIVL[2]	TIVC[3]	C/D DTC[4]	C/D WTC[5]	C/D WOAHI[6]
1	90	1	8.23	7.41	14.8	1.477	15	26	–	1.01	1.014	1.014
2	65	3	8.00	6.14	12.3	1.473	13	25	10	1.03	1.055	1.108
3	40	9	8.93	5.66	11.3	1.459	17	25	11	1.06	1.083	1.147
4	15	16	5.00	1.13	2.3	1.443	11	17	50	1.10	1.589	2.321
Beginning-of-Life Simulation												
5	90	1	7.90	7.03	14.1	1.447	18	20	1	1.02	1.025	1.025
6	65	3	8.25	6.40	12.8	1.473	16	24	7	1.03	1.042	1.082
7	40	9	8.58	5.55	11.1	1.459	20	19	11	1.06	1.083	1.175
8	15	16	5.50	2.16	4.3	1.443	20	12	30	1.08	1.236	1.275
End-of-Life Simulation												

[1] Time to the Voltage Limit
[2] Time in Voltage Limit
[3] Time in Trickle Charge
[4] Before Trickle Charge
[5] With Trickle Charge
[6] Without Amp. Hour Integration

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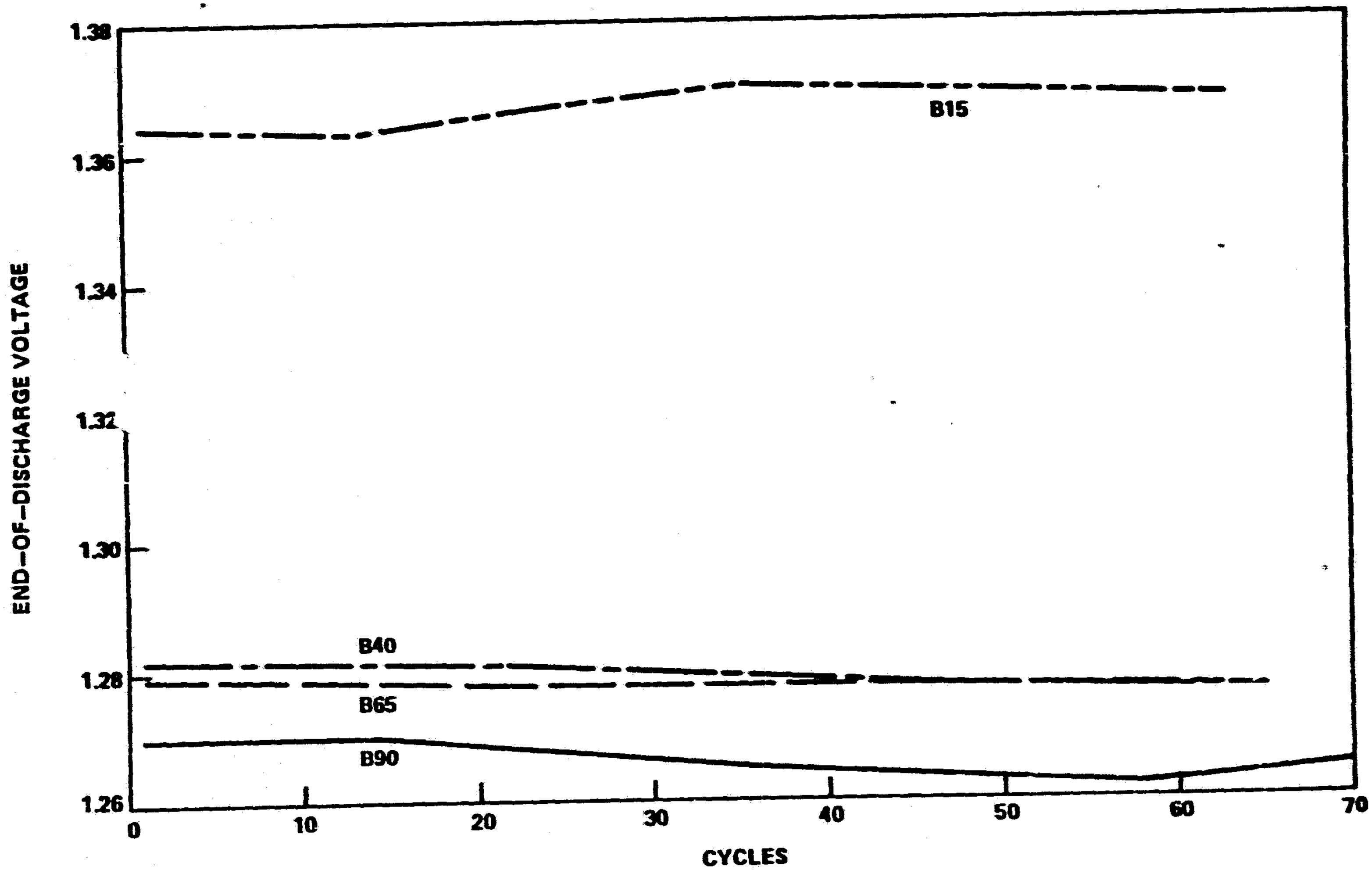

Figure 7-6. End-of-Discharge Voltage Versus Cycles (Beginning of Life)

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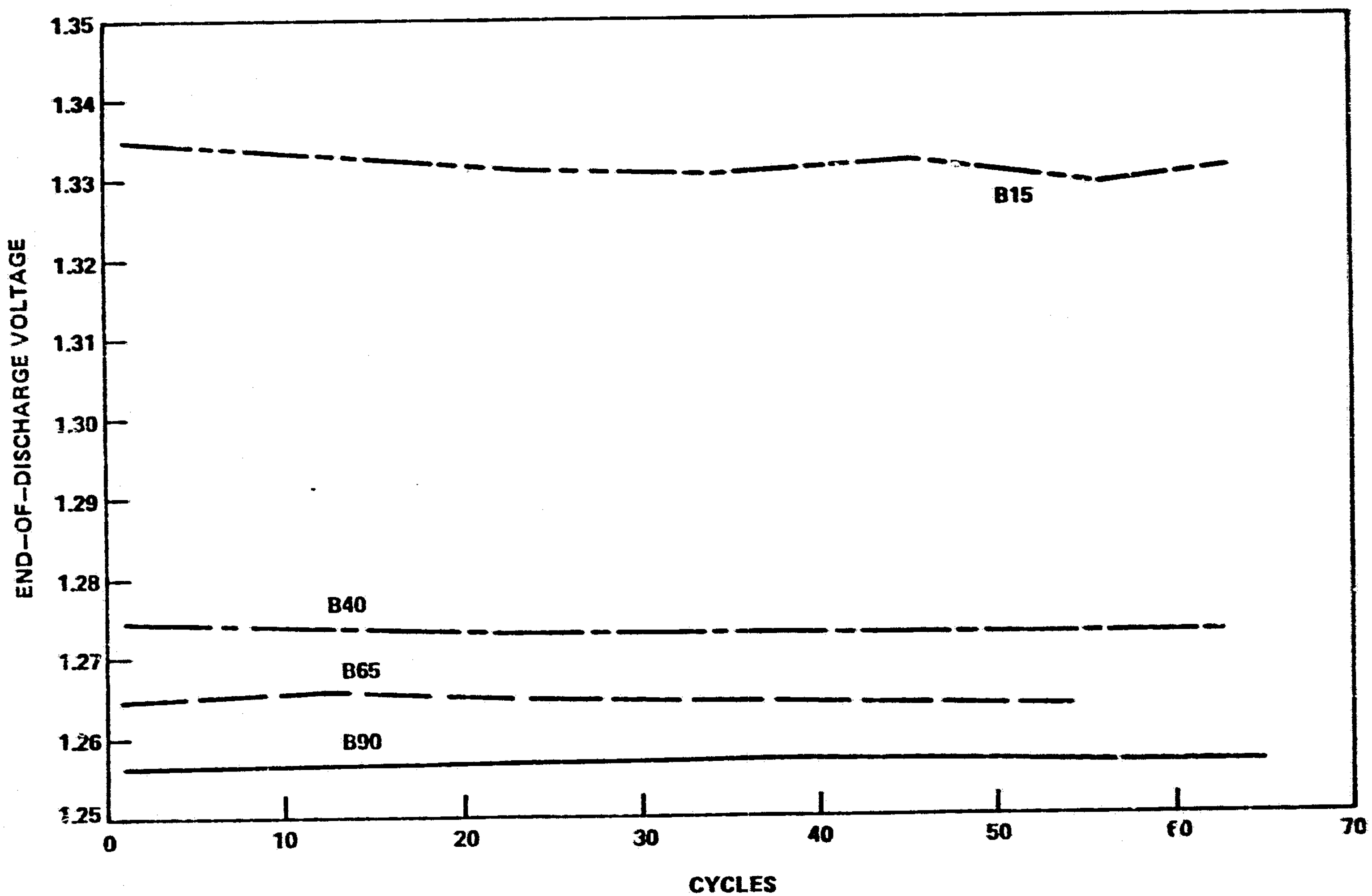

Figure 7-7. End-of-Discharge Voltage Versus Cycles (End of Life)

8. SUMMARY AND CONCLUSIONS

The short-term ERBS simulated battery test has been completed using flight quality 50-Ah cells from the Landsat-D lot in a 4-cell pack (50 E) at NWSC at Crane, Indiana. The results have indicated that a battery can be successfully operated (at least for the short term) in this type of profile using the V_T charge control technique, together with a C/D ratio limit and trickle charge to control overcharge.

Use of the V_T limit, alone, as a charge control device resulted in C/D ratios which were, generally, well above or below the acceptable operating values. Operating at the higher V_T level, and reducing the charge current to 0.75 A when the acceptable C/D limit was reached minimized the battery overcharge. A microprocessor was used to control the test and served as an ampere hour integrator providing the signal to switch to the trickle-charge mode.

The advantage of this technique for charge control is that overcharge and heat dissipation are minimized. In addition, the battery is charged at V_T levels that were found to be successful in the past. Use of the microprocessor for this function was a first for NWSC.

The test covered four Beta angles (90, 65, 40, and 15) at the projected temperatures and used the temperature compensated voltage (V_T) levels proven in the SMM and Landsat-D missions.

9. RECOMMENDATIONS

The requirement for performing a life test still exists. Obtaining flight cells, and subjecting them to the most realistic test scheme possible for projection would provide additional confidence in the method and charge system. Among the items to consider for the life test are the Beta angles, temperature, the projected sequence of operation, DOD, and V_T level.

This effort can be initiated upon cell delivery in early 1983.