ACCELERATED AND REAL-TIME GEOSYNCHRONOUS LIFE CYCLING TEST PERFORMANCE OF NICKEL-HYDROGEN BATTERIES

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ABSTRACT

RCA Astro-Electronics currently has four nickel-hydrogen storage battery modules (11 cells each) on test in simulated geosynchronous life cycle regimes. These battery modules are of identical design to those used on the GSTAR (GTE Satellite Corp.) and Spacenet (GTE Spacenet Corp.) communications satellites as previously reported.[1]

The batteries are being tested using an automated test station equipped with computer-controlled environmental chambers and recording equipment. The two battery types, 30 ampere-hours and 40 ampere-hours (GSTAR and Spacenet, respectively), are being electrically cycled using identical 44-day eclipse sequences at 5°C and vary with respect to depth of discharge, recharge ratio, duration of accumulated suntime, and the use of a reconditioning sequence. This paper outlines the test parameters and presents the preliminary test data and results.

INTRODUCTION

As part of RCA Astro-Electronics development and qualification of the nickel-hydrogen energy storage system for the GSTAR and Spacenet communications satellite programs, three 30 AH nameplate battery modules (GSTAR type) and one 40 AH nameplate battery module (Spacenet type) are currently being tested in a simulated geosynchronous life cycle, both real-time and accelerated (reduced suntime) regimes. This test sequence is being performed to demonstrate satisfactory performance of the batteries over the mission life of their respective spacecrafts. All depth-of-discharge (DOD) values are given as a function of actual measured capacity at 10°C unless otherwise noted. The C/2, C/20, and C/60 rates are based on nameplate capacity values.

EXPERIMENTAL

TEST EQUIPMENT

All electrical performance testing of nickel-hydrogen batteries at RCA is performed using an automated battery test system. This test system consists of three major units:

1. Test Station - Combining environmental control chamber, charge power supply, and discharge load

2. Computer System - Providing parameter control, monitoring, and data acquisition

3. Operator CRT and printer for command-control and programming

ELECTRICAL

44-day Eclipse Season

All four battery modules are operating using the same 44-day geosynchronous eclipse simulation, as shown in Table 1. The 30 AH GSTAR modules 005, 006, and 007 are represented as test modules A, B, C, and the 40 AH Spacenet module is represented in test as module D. Note here that the charge time at C/20 is directly proportional to the recharge ratio selected, and that the C/60 charge rate is used to "top-off" and maintain the battery at full state-of-charge.

Suntime: Real-Time vs. Accelerated

The suntime is defined as that period of time when the spacecraft is not in eclipse. One battery in test (Module C) is operating in real-time, that is, there are approximately 3200 hours between eclipse seasons. Because stationkeeping maneuvers use the batteries and are performed every 3 to 4 weeks during this period, this module is operating as detailed in Table 2A.

The three remaining modules (A, B, D) are operating in a reduced suntime test. Here the suntime has been reduced to approximately 5% of real-time (Tables 2B and 2C). The simulated stationkeeping discharges have been reduced to 1 per season, and are placed at the beginning of the suntime.

Reconditioning vs. Non-Reconditioning

Reconditioning is that sequence of events when the battery cells are all discharged and drained of all their capacity, immediately followed by a full charge. This usually occurs 1 to 3 weeks prior to beginning a new eclipse season.

The NiH_2 batteries on board the GSTAR and Spacenet spacecraft have the capabilities of being reconditioned[1] should the need arise. Of the four battery units in test, only module A is being reconditioned. This started at the commencement of eclipse season 5.

Depth-of-Discharge and Recharge Ratio

When the full load on the GSTAR and Spacenet spacecraft is applied to the batteries, a depth of discharge of approximately 52% of actual capacity is expected. This being the case, three of the modules (A, C, and D) are operating in constant current discharge mode to 52% DOD (60% of nameplate capacity). In addition, these three modules have a 1.2 recharge ratio at the C/20 rate followed by C/60 for the duration of the daily charge time.

Table 1. 44-DAY ECLIPSE SEASON DAY-BY-DAY ECLIPSE DURATION, RECHARGE TIMES

Day No.	Day No.	Discharge Time (hours)*	Total Charge Time (hours)
1	44	0.200	23.800
2	43	0.367	23.633
3	42	0.483	23.517
4	41	0.583	23.417
5	40	0.667	23.333
6	39	0.773	23.227
7	38	0.800	23.200
8	37	0.867	23.133
9	36	0.933	23.067
10	35	0.983	23.017
11	34	1.033	22.967
12	33	1.067	22.933
13	32	1.110	22.890
14	31	1.133	22.867
15	30	1.150	22.850
16	29	1.167	22.833
17	28	1.167	22.833
18	27	1.167	22.833
19	26	1.183	22.817
20	25	1.183	22.817
21	24	1.183	22.817
22	23	1.183	22.817

NOTE: The total charge time is divided into charge time at nominal C/20 rate and charge time at the nominal C/60 rate. The duration of the C/20 charge is dependent upon the recharge ratio selected, and the remaining time is used to trickle charge the battery at C/60 rate.

*Discharge current determined from average spacecraft load, nominal C/2 rate.

Table 2A. REAL-TIME SUNTIME, MODULE C

Mode	Current	Time	
1. Discharge	11 Amperes	1.5 Hours	(Stationkeeping)
2. Charge	C/20 (1.5A)	13.2 Hours	
3. Charge	C/60 (0.5A)	307 Hours	

Repeat Step 1-3 10 times, totaling 3217 hours of suntime.

Table 2B. ACCELERATED SUNTIME*, MODULES A AND B

Mode	Current	Time	
1. Discharge	11 Amperes	1.5 Hours	(Stationkeeping)
2. Charge	C/20 (1.5A)	13.2 Hours	
3. Charge	C/60 (0.5A)	166 Hours	

*Approximately 5% of real-time

Table 2C. ACCELERATED SUNTIME*, MODULE D

Mode	Current	Time	
1. Discharge	16.5 Amperes	1.5 Hours	(Stationkeeping)
2. Charge	C/20 (2.0A)	14.9 Hours	
3. Charge	C/60 (0.67A)	166 Hours	

*Approximately 5% of real-time

Battery module B was originally operating at 70% DOD (80% of nameplate capacity) with a 1.2 recharge ratio. Although no test difficulty was encountered (e.g., cell reversal), the DOD was reduced to 65% (approximately 75% nameplate), because the minimum voltage requirement of 25.0 volts was being exceeded at the higher DOD. The recharge ratio was increased to 1.4 to overcome charge inefficiency and maintain uniform end-of-charge pressures at the relatively high DOD.

ENVIRONMENTAL

All four test units are each in an environmentally controlled chamber. The chamber is temperature controlled to 5° ±2°C using dry nitrogen. The real-time test, Module C, operates at 10°C (increasing 1°C every year) during the long suntime operation. There is, in addition, a hydrogen sensor in the chamber monitoring for the lower explosion limits of hydrogen, and can abort the test and alert the operator of a potential hazard.

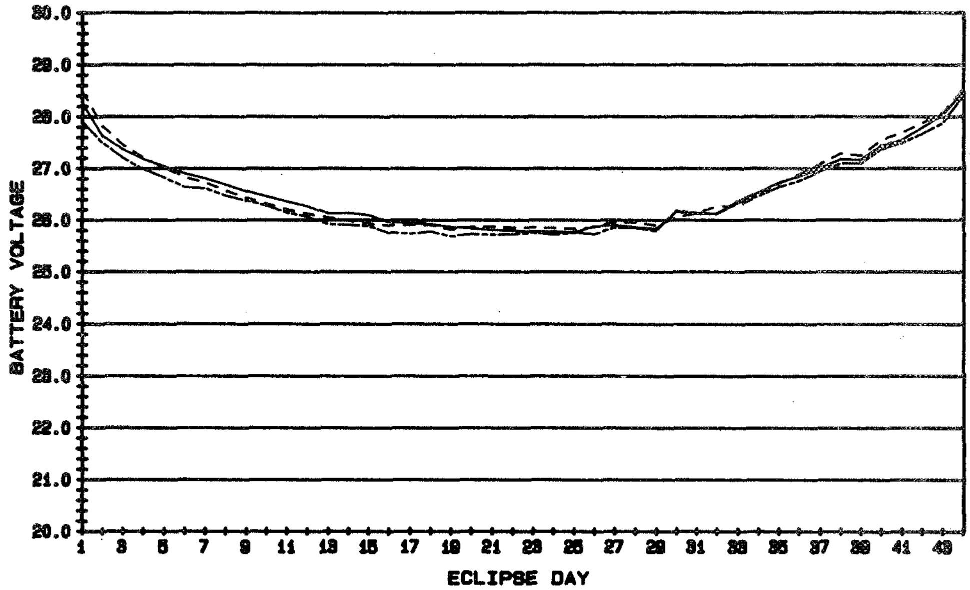
DATA

Module A (GSTAR 005) is operating in an accelerated test regime with a reconditioning sequence prior to each eclipse season (beginning with season 5) at 5°C. The end-of-discharge voltage versus eclipse day for seasons 1, 3, and 5 are shown in Figure 1. At 52% DOD for the 72-minute maximum eclipse period, no degradation has been observed to date. The addition of a reconditioning sequence at the beginning of season 5 appears to have no appreciable effect at this time. The relative uniformity of the end of charge voltages for seasons 1, 3, and 5 can be observed from Figure 2.

Module B (GSTAR 006) is currently being tested in an accelerated test regime at a high depth of discharge at 5°C. During the first two simulated eclipse seasons, this battery was discharged at 70% maximum DOD during the longest days. The charge return for the first half of season 1 was 120% and was increased on day 20 to 130%. Season 2 operated with 140% charge return. The end-of-discharge voltages for seasons 1 and 2 are shown in Figure 3. An increase in end-of-discharge voltage was observed with a 140% charge return in season 2.

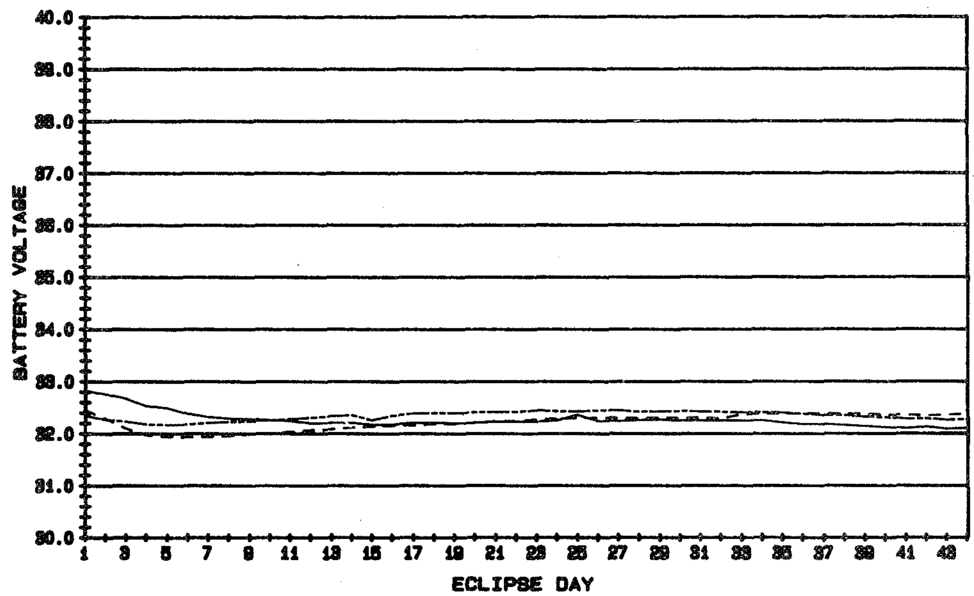
Beginning with day 20 of season 3, the depth of discharge was lowered to 65% (for programmatic reasons), and a 1.4 recharge ratio maintained. Figure 4 shows significant voltage increase of approximately 0.7 volt for season 3 when the DOD was reduced from 70% to 65%. Note here the relatively uniform EOD voltages for seasons 4, 5, and the latter half of season 3. Uniform end-of-charge voltages were observed regardless of DOD and recharge ratios, as seen in Figure 5.

Module C (GSTAR 007) is proceeding through test in a real-time test regime, 52% DOD. The approximately 3200 hours of suntime are broken up into ten test portions, each beginning with a simulated stationkeeping maneuver that discharges the battery at approximately a C/3 rate to a DOD of approximately 47%. The 1.2 recharge ratio is maintained for all discharges in this battery.



———— VTOTAL. SEASON 1. 12/22/83–2/5/84 (BATT. VOLTAGE = 2 x MODULE V.)
—·—·—·— VTOTAL. SEASON 3. 3/31/84–5/25/84
– – – – – – VTOTAL. SEASON 5. 7/30/84–9/18/84 RECONDITIONING

Figure 1. GSTAR Module 005, Accelerated Life Test, End-of-Discharge Voltage vs. Eclipse Day



———— VTOTAL. SEASON 1. 12/22/83–2/5/84 (BATT. VOLTAGE = 2 x MODULE V.)
—·—·—·— VTOTAL. SEASON 3. 3/31/84–5/25/84
– – – – – – VTOTAL. SEASON 5. 7/30/84–9/18/84 RECONDITIONING

Figure 2. GSTAR Module 005, Accelerated Life Test, End-of-Charge Voltage vs. Eclipse Day

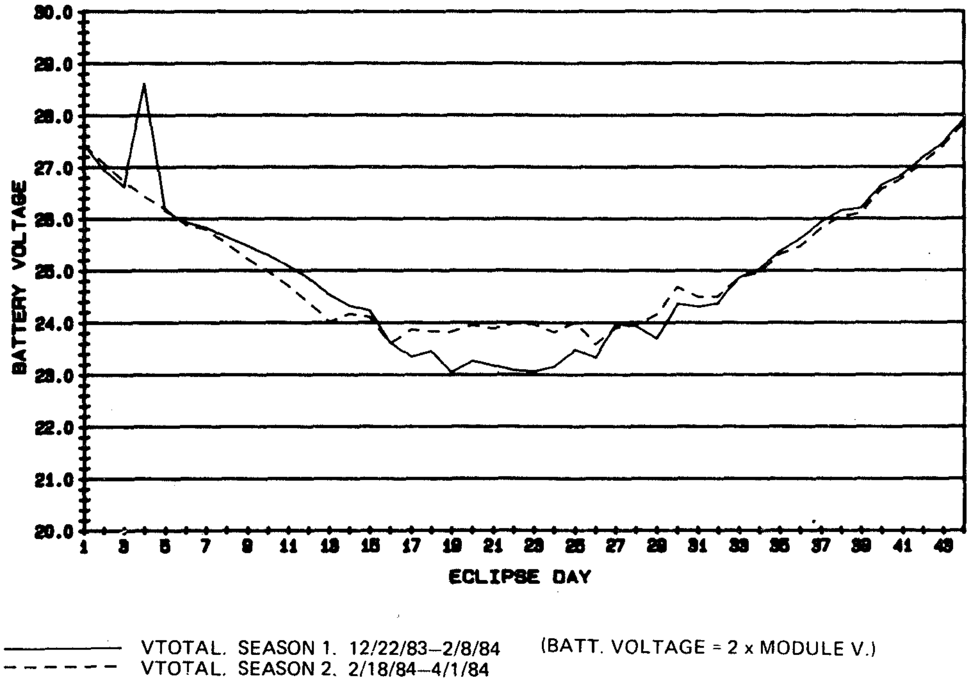


Figure 3. GSTAR Module 006, Accelerated Life Test, 70% DOD, End-of-Discharge Voltage vs. Eclipse Day

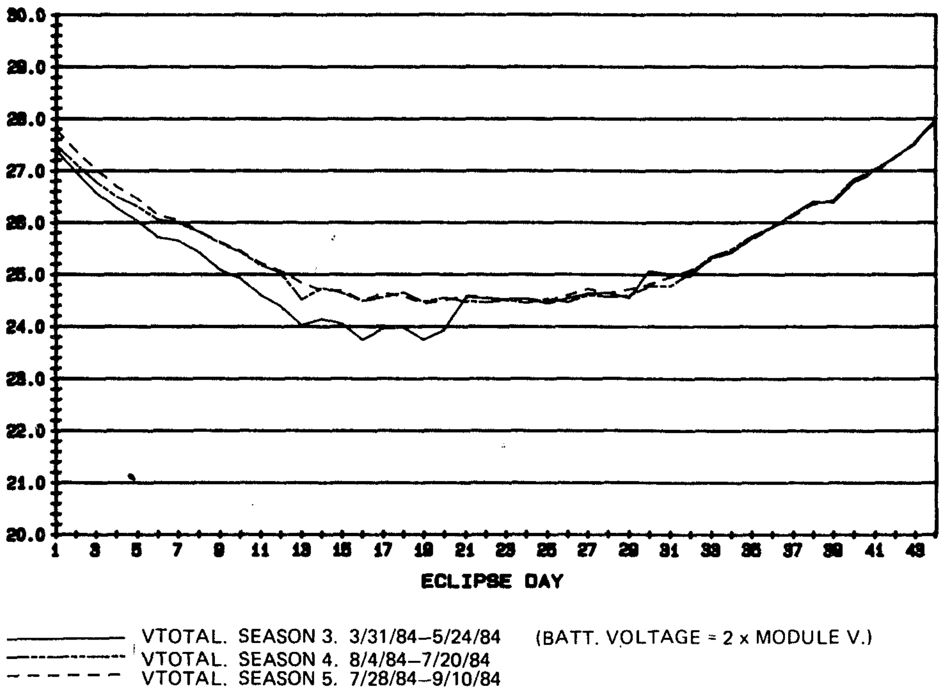
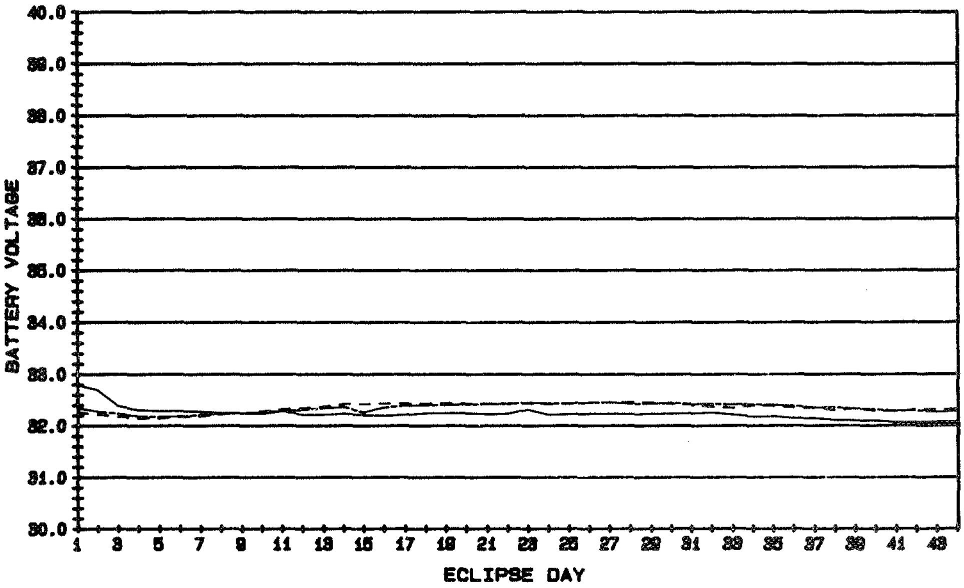


Figure 4. GSTAR Module 006, Accelerated Life Test, High DOD, End-of-Discharge Voltage vs. Eclipse Day



VTOTAL. SEASON 1. 12/22/83–2/6/84 (BATT. VOLTAGE = 2 x MODULE V.)
VTOTAL. SEASON 3. 3/31/84–5/24/84
VTOTAL. SEASON 5. 7/28/84–9/10/84

Figure 5. GSTAR Module 006, Accelerated Life Test, High DOD, End-of-Charge Voltage vs. Eclipse Day

The test temperature is 10°C for suntime (increase 1°C/year) and 5°C during eclipse simulation. Figures 6 and 7 are the EOD and EOC voltages versus eclipse day for seasons 1 and 2, respectively.

The fourth nickel-hydrogen battery in this test is Module D (Spacenet 005), a 40-AH qualification unit identical to that launched in the Spacenet F1 spacecraft.[1] Operating in a 52% maximum eclipse day DOD accelerated test mode employing a 1.2 recharge ratio, two simulated eclipse seasons have been witnessed to date. The uniformity of both the EOD voltages and the EOC voltages during the simulated eclipse seasons can be seen in Figures 8 and 9, respectively.

DISCUSSION

All three modules being evaluated at 52% DOD are operating normally. End-of-charge voltages are as expected, above 32 volts/battery (1.46 volt/cell) at the trickle rate of C/60, and the end of discharge voltages are above 25 volts/battery (1.18V/cell) at the C/2 rate for 72-minute discharge.

The nickel-hydrogen energy storage system is clearly capable of being discharged to a 70% DOD on the maximum eclipse day at the C/2 rate. The end-of-discharge voltage is above 23.1 volts/battery (1.05V/cell) without any test difficulty.

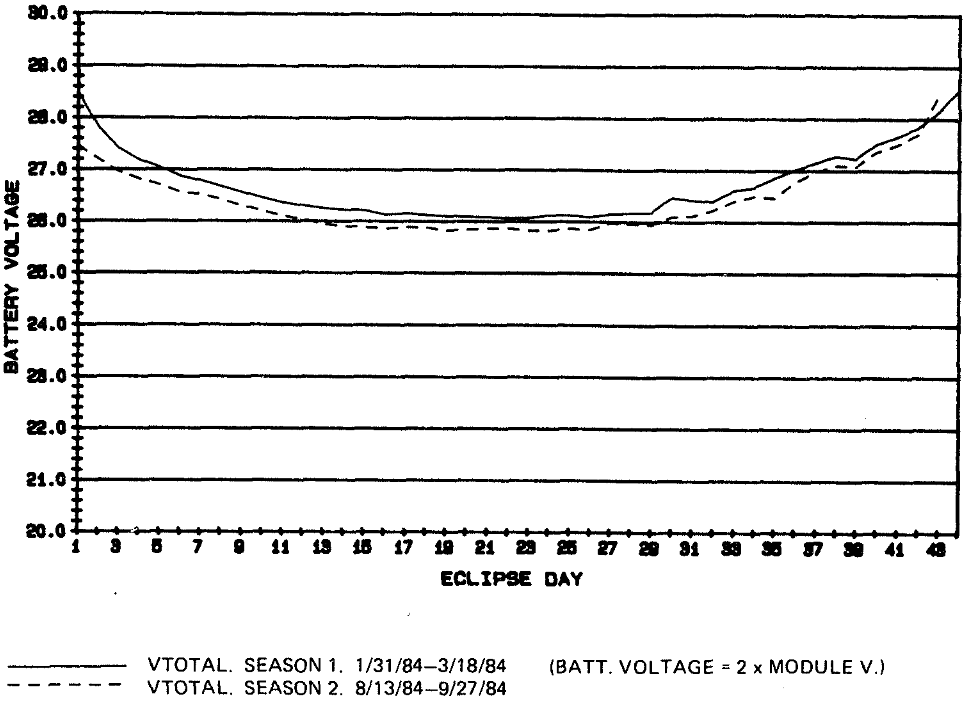


Figure 6. GSTAR Module 007, Real-Time Life Test, End-of-Discharge Voltage vs. Eclipse Day

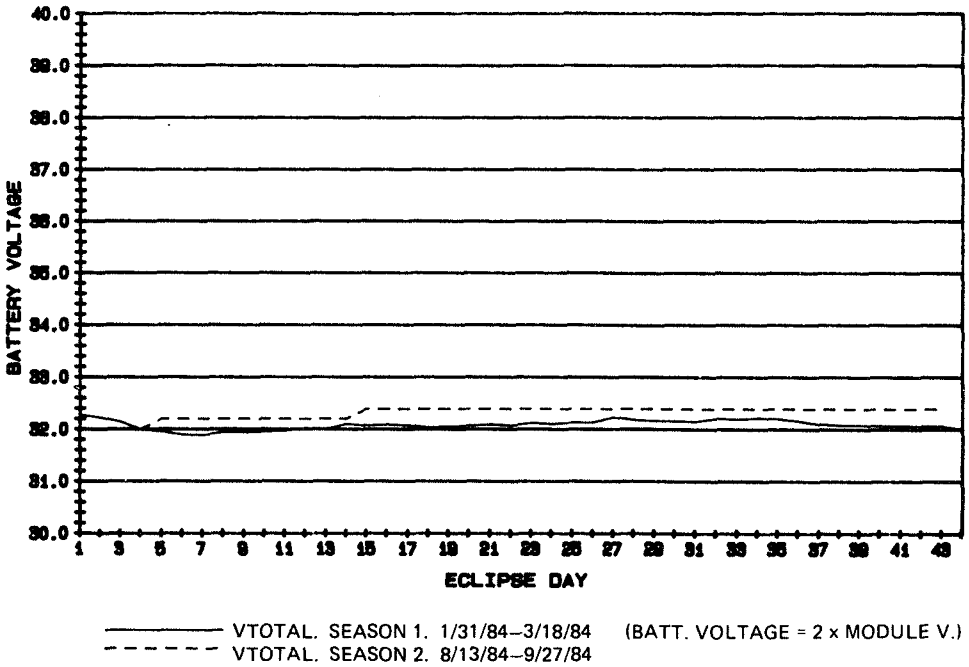


Figure 7. GSTAR Module 007, Real-Time Life Test, End-of-Charge Voltage vs. Eclipse Day

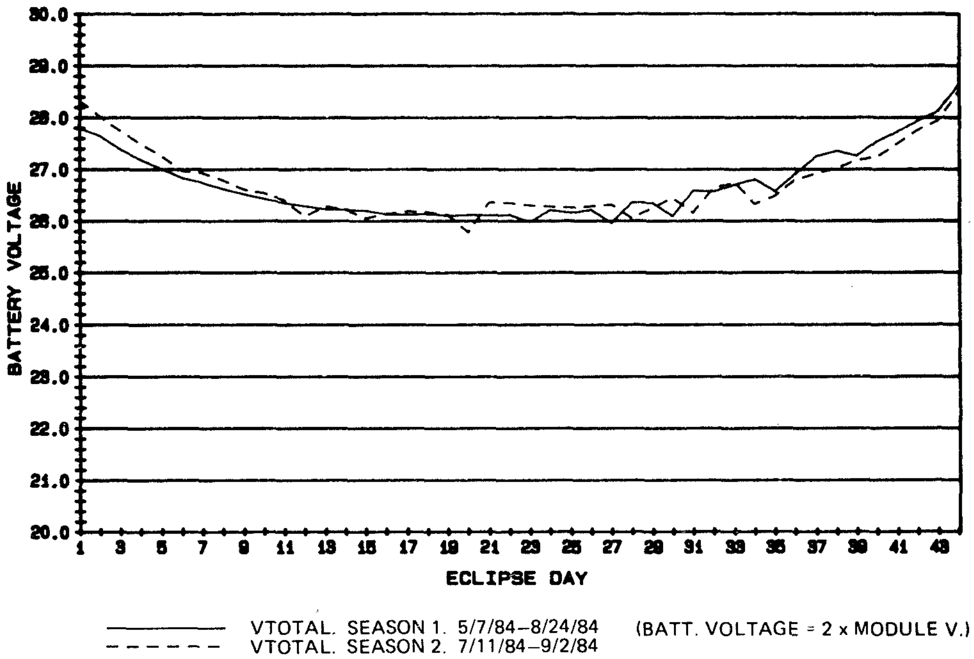


Figure 8. Spacenet Module 005, Accelerated Life Test, End-of-Discharge Voltage vs. Eclipse Day

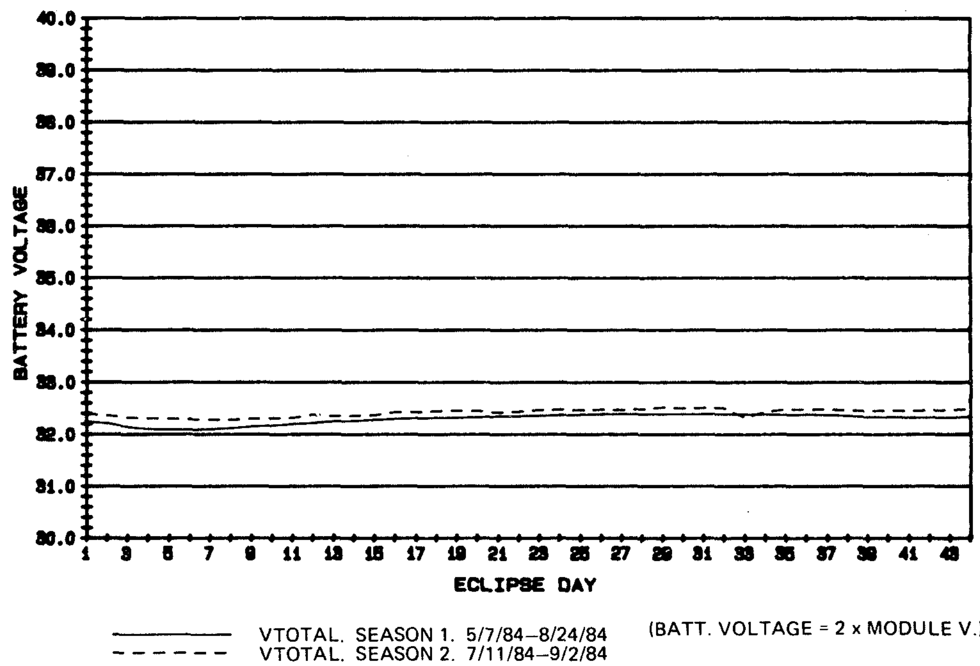


Figure 9. Spacenet Module 005, Accelerated Life Test, End-of-Charge Voltage vs. Eclipse Day

CONCLUSION

The database for the terrestrial testing of nickel-hydrogen batteries in terms of expected life in geosynchronous orbit is still quite small (compared to nickel-cadmium battery technology), and the in-orbit data even smaller. With the successful launch and deployment of the Spacenet F1 spacecraft and the launch of other NiH_2-equipped GSTAR and Spacenet spacecraft in the near future, in-orbit data will be obtained to increase this database. Demonstration of these nickel-hydrogen batteries to perform satisfactorily over their respective mission lives is well under way, and further data and results will be presented periodically.

REFERENCE

1. S. J. Gaston, "The GSTAR and Spacenet Nickel-Hydrogen Batteries for Geosynchronous Orbit Applications," Proc. 19th Intersociety Energy Conversion Engineering Conference, 1984, pp. 257-263.

ACKNOWLEDGEMENTS

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