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AUSSAT BATTERY LIFE TEST PROGRAM

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ABSTRACT

AUSSAT Pty Ltd, the Australian National Satellite organization, has contracted with the Hughes Aircraft Company (HAC) for the construction of 3 satellites based on the now familiar HS-376 product line. As part of the AUSSAT contract, HAC is conducting an extensive NiCd battery life test program. This paper describes the life test program, its objectives and test results to date. Particular emphasis is given to the evaluation of the FS2117 separator as a future replacement for the Pellon 2505 separator of which only a very limited quantity remains.

BACKGROUND

The AUSSAT spacecraft design shown in Figure 1 is based on the standard HS-376 product line. However the unique payload requirements of the AUSSAT mission have pushed the mass and power design limits of the HS-376 bus, particularly in the power subsystem. The major features of the power subsystem are summarised on Table 1.

The spacecraft employs two 27 A-hr. NiCd batteries. Each battery contains 32 cells configured as 4 separate packs, each pack holding 8 cells. The cells themselves are a scaled up version of those previously used by HAC on the HS-376 product line, and manufactured by General Electric (GE). The major cell design parameters are listed in Table 2.

For thermal control each pack employs a radiator fin and packs are evenly located around the spun shelf. A battery heater controller actively maintains the packs above 5°C. A battery charge and reconditioning unit (BCRU) provides four selectable charge rates and two selectable reconditioning rates.

Due to power limitations it was not possible to size the medium charge string to allow parallel high rate charging of both batteries. Hence the sequential post-eclipse charging scheme illustrated in Figure 1 was proposed. In this scheme one battery would be fully charged at the high 2M+T rate, while the other battery is trickle charged at the T-rate. The charging rates would then be reversed to enable charging on the latter battery to be completed at the high rate. In order to limit any possible side effects from the long trickle charge applied to this battery before high rate charging can be applied, it was further decided to rotate the battery initially placed on trickle charge after each eclipse.

Virtually all space flight NiCd batteries have been built using the Pellon Corporations 2505 non-woven nylon fabric as the separator. Unfortunately production of the material was discontinued in 1976 and recent attempts to commercially reproduce the separator have failed. GE expects their supply of the 2505 separator to be committed by early 1985. As such it was proposed by HAC to use the opportunity presented by the AUSSAT life test program to evaluate the FS2117 material as a replacement for the Pellon 2505.

The US government agencies have also been alerted to the limited amount of Pellon 2505 available. A joint USAF/NASA evaluation program for qualifying a replacement separator is pending. USAF/NASA are negotiating with Pellon in the USA to produce a new separator similar to the FS2117. This is not a reflection on the FS2117 but a desire to have a domestic rather than a foreign source. According to reference 2, life testing on cells with the new domestic separator is scheduled to commence during May/1985 with preliminary results available a year later.

LIFE TEST OBJECTIVES

The objectives of the life test program are seen as follows:

- To adequately qualify the scaling of the Hughes third generation NiCd battery to the AUSSAT A-hr. name plate rating. The previously testing cells were 21.6 A-hr. as opposed to the 27.5 A-hr. nameplate capacity required for AUSSAT.
- To provide a check on the manufacturing processes and materials at the cell vendor (G.E.) at a point just prior to the production of the fight cells.
- To provide BOL and EOL indications of the performance to be expected from the battery.
- To verify the new sequential battery post-eclipse charging scheme proposed by HAC.
- To evaluate the performance of the FS2117 separator.

In addition the test program must provide at least a preliminary indication of flight battery performance as early in the program as possible and certainly prior to launch.

LIFE TEST DESCRIPTION

In order to meet the objectives defined above, a continuous 900 cycle throughput test and a 20 season real time GEO eclipse shortened solstice test were selected.

The throughput test is a continuous cycling test in which a 10 cell engineering pack is discharged at 14 amperes (C/2) for 1 hour to give a nominal 50% depth of discharge, and then charged at 2.8 amperes (C/10) for 7 hours to a 140% recharge return. The engineering pack is maintained at 10°C. Testing at 3 discharge/charge cycles per day is only interrupted for reconditioning and environmental chamber maintenance. Individual cell reconditioning is performed when the cell voltage on discharge falls below 1.14 volts. The test has been included in order to verify the cycle life capability of the flight batteries prior to launch, but will also enable test results to be correlated with previous testing performed on similar battery designs at HAC.

The real time eclipse shortened solstice test is a much more representative test of in-orbit conditions and, in particular, the post-eclipse sequential charging scheme. Three 8-cell qualification battery packs and a 6-cell engineering pack are subjected to 20 GEO eclipse seasons in real time, with the intermediate solstice trickle charge period shortened to 14 days. Reconditioning is performed prior to each eclipse season. The discharge and charge profiles used to simulate each GEO eclipse season are shown in Table 3. The profiles reflect the actual eclipse daily levels in terms of charge and discharge times, charge and discharge rates, and the sequential battery charging scheme.

The engineering packs have been utilized to allow gauge cells to be included for cell pressure monitoring and to enable easy addition, and removal of cells for destructive physical and chemical analysis.

For the purposes of evaluating the performance of the new separator, 2 cells with the new separator were included in each of the engineering packs, while one of the real time qualification packs was assembled totally from cells using the new separator. Two different plate lots have been used in preparing the life test cells. Half the FS2117 separator cells were assembled from each plate lot.

THE NEW SEPARATOR

A comparison of the physical and chemical properties of the 2505 and FS2117 separator is summarized in Table 4. The 2505 data is taken from the Sealed-Cell Nickel-Cadmium Battery Applications Manual (ref. 1), while the FS2117 data has been supplied by the General Electric Battery Business Department. In general, the property values quoted are typical rather than specification.

Significant property differences between the separators and the impact these may have on cell performance and design parameters are discussed below.

PHYSICAL/CHEMICAL PROPERTY DIFFERENCES

The FS2117 separator is denser as a joint result of the use of Nylon 66 and the calendaring process. The calendaring process has been used to bond and reduce the thickness of the separator. No specific data on the tensile strength and elongation was available; however these properties should be comparable.

Electrolyte absorption and air permeability are lower, as expected for the FS2117 separator. The 35% increase in density matches well with the 30% decrease in electrolyte retension and air permeability.

Impurities in the form of anti-static coatings are present on both the FS2117 materials. No information is available on these coatings however the FS2117 separator is subjected to the same wash treatments to remove these as the 2505 material. The effectiveness of the treatment is checked by a foam test. The above, while lacking any degree of technical sophisication, appears to work. The only concern here is that some residual impurities may be different and have a significant impact on cell performance; this has occured in the past where different and apparently acceptable separators have been substituted.

No specific data is available on hydrolysis reaction rates for the FS2117 separator. However, with the use of Nylon 66, the FS2117 materials breakdown rate in KOH electrolyte should be significantly less. The reaction rate is also affected by the bonding method and exposed surface area.

EXPECTED CELL PERFORMANCE DIFFERENCES

A number of flight performance differences can be expected as a result of the above physical and chemical differences in the separators. The differences in performance are expected to be minor, but they can easily be corrected in future flight battery applications of the separator. The correction would include only slight changes in the present cell design and activation procedures in order to fine tune the cell for the 2117 separator.

Precharge to overcharge levels: Second generation NiCd cells typically specified a 35 - 40% precharge level on the negative Cd plate in order to prevent voltage fading of the cell during discharge especially at beginning of life. Hydrolysis of the separator and subsequent oxidation of the products increases the precharge level at the expense of overcharge protection as the separator breaks down over life. Hence the present generation of NiCd cells now specify only 30 - 35% precharge in order to maintain a higher overcharge protection level at end of life. The lower hydrolysis rate of the 2117 separator will result in a lower overall precharge levels and will be somewhat more prone to voltage fading problems at beginning of life and, in particular, at low temperature. This has in fact been observed with initial 0°C capacity tests. However after a 30 cycle burn-in test, no significant differences at normal operating temperatures have been recorded.

Electrolyte Retension & Redistribution: One of the major life limiting factor for NiCd cells is drying of the separator. This occurs over life as the plates swell and the electrolyte migrates out of the separator and into the plate. The lower electrolyte retension capability of the 2117 separator would have aggravated the problem on older cells. However the use of teflonated negatives and increased electrolyte quantitites (3 to 4 cm^3/A-hr) should obviate the problem at least for 7 year applications. Electrolyte redistribution will be less noticeable over short periods of time, the effect of this has already been demonstrated in the qualification cell capacity differences observed between the 2117 and 2505 separators after a 20 day stand period.

Overcharge Pressure: The higher density of the FS2117 separator will reduce the amount of free void volume for gas expansion in the cell and thus increase cell overcharge pressure unless the electrolyte level or cell free volume is suitably increased. In addition, the lower gas permeability of the 2117 separator may decrease the oxygen recombination rate and this also increase cell overcharge pressure.

LIFE TEST STATUS AND RESULTS

Life testing commenced in July 1984. The throughput test will require 10 months to complete 900 discharge/charge cycles, while the real-time eclipse shortened solstice test will need 3.5 years to complete 20 seasons. At the time of writing, 115 cycles and one eclipse season have been completed on the respective tests.

The 2505 and FS2117 separator cell end of charge and end of discharge voltages from the through-put and real-time eclipse test are shown in Figure 3 through 6. FS2117 separator cell performance, at the present early stage of testing, matches well with the 2505 separator cell performance. FS2117 separator cell voltages are, in general, bounded by the upper and lower voltage ranges observed on the 2505 separator cells.

The through-put and real-time eclipse test behaviour of the 2505 separator cells is also normal. In particular the sequential charging scheme has had no short term affect on the real-time eclipse test performance of the cells.

REFERENCES

1. Sealed-Cell Nickel-Cadmium Battery Applications Manual. NASA reference Publication 1052, December, 1979.

2. M. J. Milden; J. Harkness: Separator Qualification for Aerospace Nickel-Cadmium Cells. 1984 IECE Conference, Paper 849037.

Table 1. POWER SUBSYSTEM CHARACTERISTICS AND PERFORMANCE

Parameter/Unit	Characteristics/Performance		
Main bus voltage range	Sunlight	Eclipse	Posteclipse Transient
Spinning	30.0±0.5V	29.1±0.1V	29.0 to 42.5V
Despun	29.5±0.5V	28.5±0.1V	28.5 to 42.5V
Minimum at loads	28.15V	28.15V	-
Minimum transient (squib firing)	26.5V	-	-
Solar arrays			
Expected main array power at 29.3V		BOL	EOL
21 June solstice		1047.1W	860.0W
21 September equinox		1163.5W	943.4W
Charge array current at 50.6V			
Trickle (21 June)		0.421A	0.343A
Trickle (21 September)		0.471A	0.394A
Medium (21 September)		0.848A	0.708A
Batteries			
Number per spacecraft	2		
Cells per battery	32		
Capacity per battery	27.0A-hr		
Average eclipse voltage, BOL	39.68V		
Discharge controller	One unit with two redundant, constant power, pulse width modulated controllers.		
Input voltage	31 to 45V		
Output voltage	29.1 ±0.1V		
Charge and reconditioning unit	Configures four solar panel trickle (T) and medium (M) boost arrays and selects two reconditioning loads.		
Charge configurations	T, M, 2M, T + M, T + 2M		
Reconditioning loads	186ohm, 93ohm.		
Bus limiters	Redundant units with four individually commandable limiters per unit.		
Set and tap points			
Limiter A	29.62V at cell 23 of 69 total (aft)		
Limiter B	29.86V at cell 23 to 69 total (aft)		
Limiter C	30.10V at cell 19 to 66 total (fwd below radiator)		
Limiter D	30.34V at cell 18 to 66 total (fwd above radiator)		
Battery cell voltage monitor	One unit per battery measures cell voltage with 4 mV accuracy.		
Battery Heater Controllers	Two units, each with redundant controllers, maintain minimum battery temperature of 5°C (41°F) Nominal setpoint is 6.4°C (43.5°F).		

Table 2. AUSSAT NiCd BATTERY CELL DESIGN PARAMETERS

- 27 A-hr capacity at 10°C.
- 1.09 aspect ratio.
- 9.31 x 8.57 x 0.0647 cm coined plates.
- 15 positive/16 negative plates.
- 0.2mm inter-electrode spacing.
- 304L stainless steel case.
- GE butt geometry for positive terminal.
- Common case to negative terminal.
- Pellon 2505 separator.
- 10.2 g/dm^2 positive plate loading.
- 13.9 g/dm^2 negative plate loading.
- 5mA/cm^2 nominal current density.
- 80% nominal sinter void volume.
- 30-35% pre-charge.
- 50% excess negative overcharge protection.
- TFE negatives.
- 3.2 cc/A-hr electrolyte (31% KOH).
- Less than 3 g/l carbonate.
- -18°C to 40°C survival temperature.
- 8°C average case temperature.

Table 3. REAL TIME ECLIPSE TEST PROFILES

Eclipse Day	Discharge Time (min.)	High Rate Charge Charge Time (min.)	Total Trickle Charge Time (hours)
1-2	10	61	22.82
3-8	20	121	21.65
9-13	40	242	19.30
14-18	60	363	16.95
19-28	70 (52% dod)	423	15.78
29-33	60	363	16.95
34-38	40	242	19.30
39-44	20	121	21.65
45-46	10	61	22.82

Notes:
1. Sequential recharge scheme used.
2. High rate charge time sized to give a 100% A-hr. return.
3. Discharge rate is fixed at C/2.25 (12.0 Amperes).
4. High rate charge is fixed at C/13.5 (2.0 Amperes).
5. Trickle charge rate is fixed at C/67.5 (0.4 Amperes).

Table 4. COMPARISON OF 2505 and 2117 SEPARATOR PROPERTIES

Property	2505 Separator[1]	2117 Separator[2]
Filament Type	Nylon 6	2/3 Nylon 66 1/3 Nylon 6
Weight (gm/m^2)	60 ± 8	74
Thickness (mm)[6]	0.38 ± 0.07	0.30
Breaking Strength (kg)		
Parallel to machine direction	2.3	NA[5]
Across machine direction	3.2	NA
Electrolyte absorption (wt-%)	800(min)	580
Air Permeability (cfm ft^2 at 0.5 in. H_2O)	200(min)	142
Bonding method	Chemical[3]	Heat [4]
Calendaring	No	Yes[4]
Residual Impurities	Anti-static coating; both materials are treated by GE to remove these.	
Hydrolysis Reaction Rates	No quantitative data however Nylon 66 oxidation rate is less than Nylon 6.	
Shrinkage (31% KOH, 70°C, 200 hrs)	1% (max)	1% (max)
Wetability (minutes in 31% KOH)	5 (min)	5 (min)

Notes:
1. Typical measured values taken from reference -1.
2. From data supplied by G.E.
3. Stabilized zinc chloride bonded nylon.
4. Hot inert gas (argon) bonded nylon.
5. No data available.
6. Cady gauge.

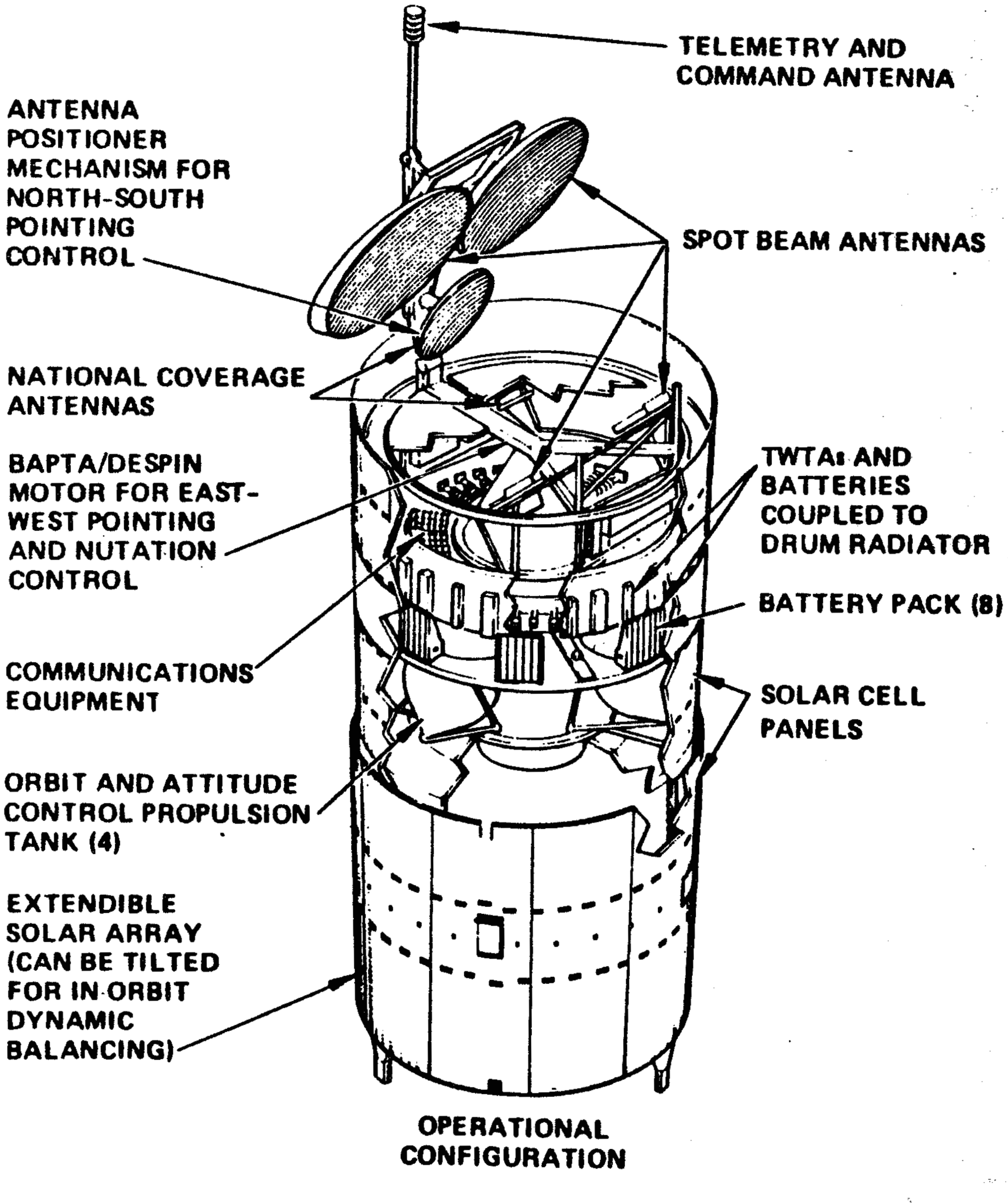

Figure 1. Aussat Spacecraft Configuration

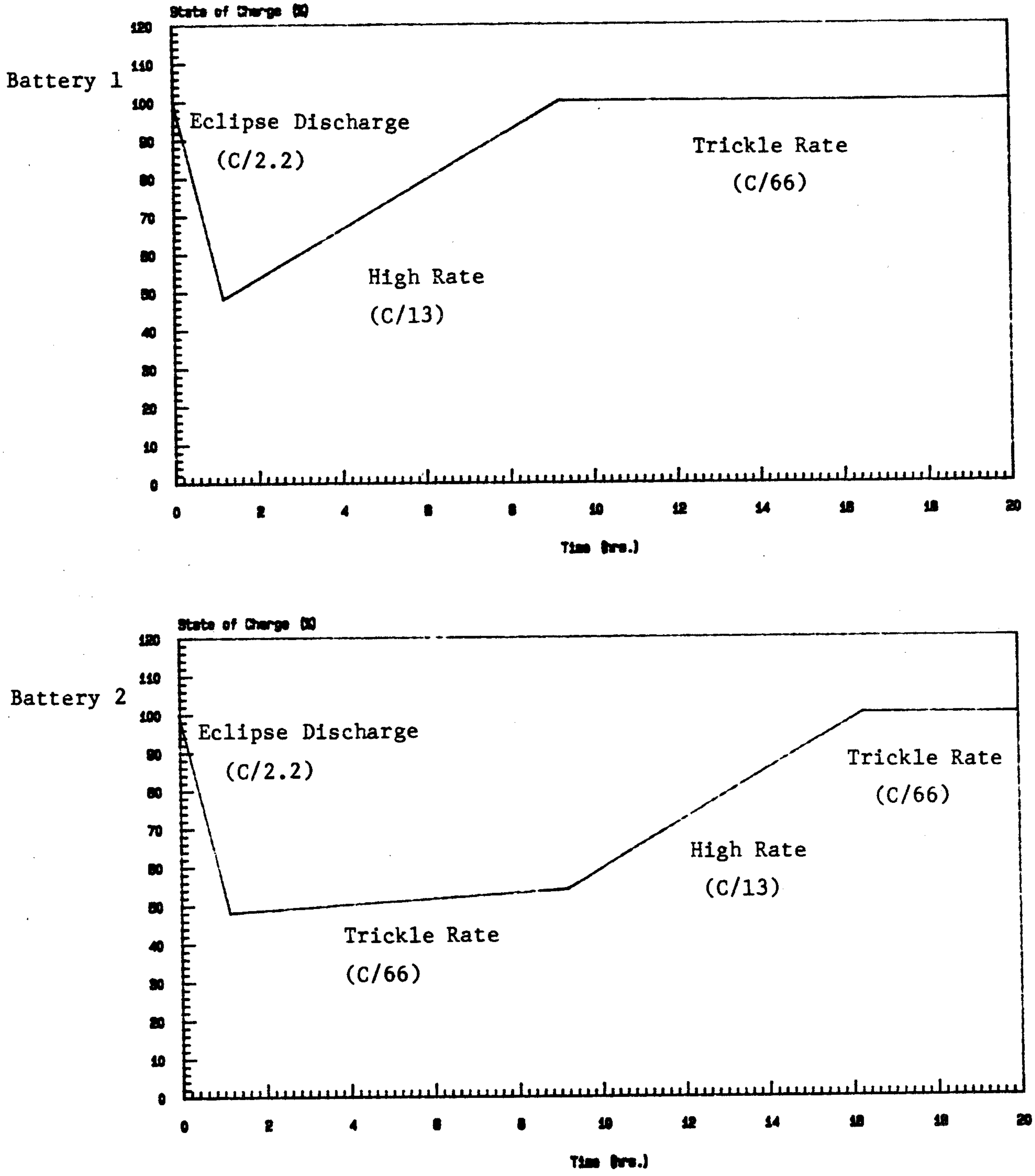

Figure 2. Aussat Battery Sequential Charging Scheme

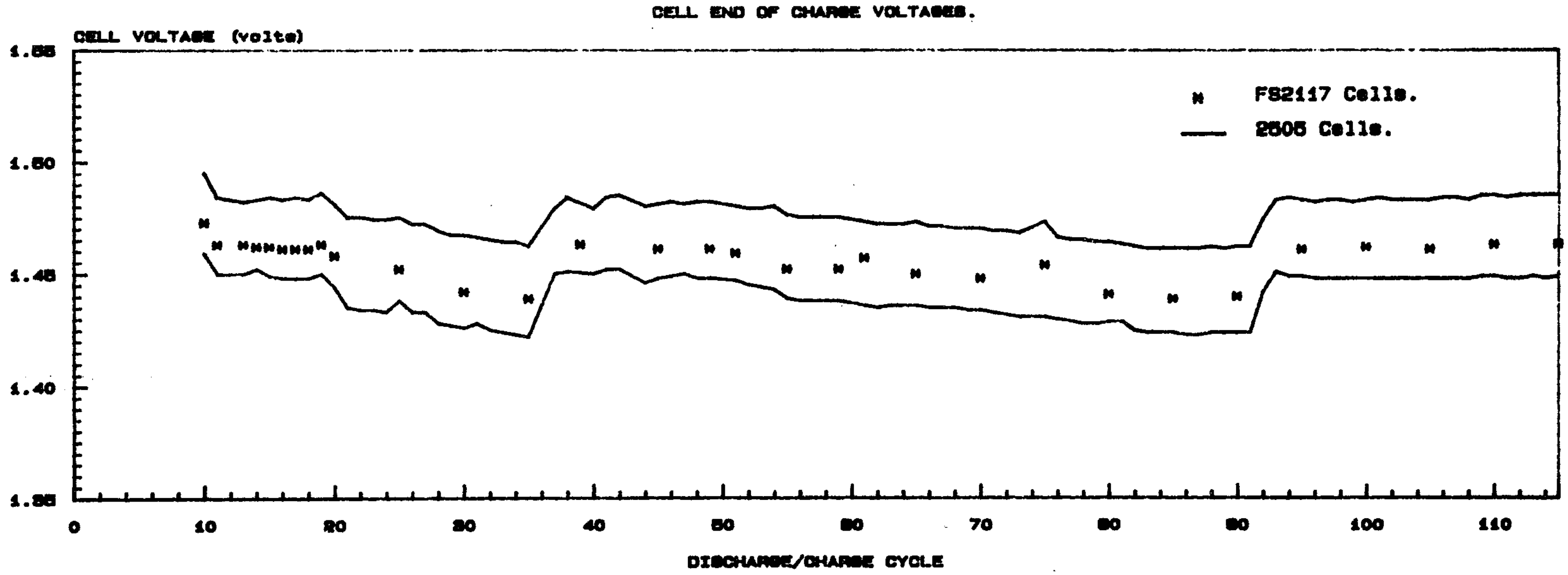

Figure 3. Through-put Test Results

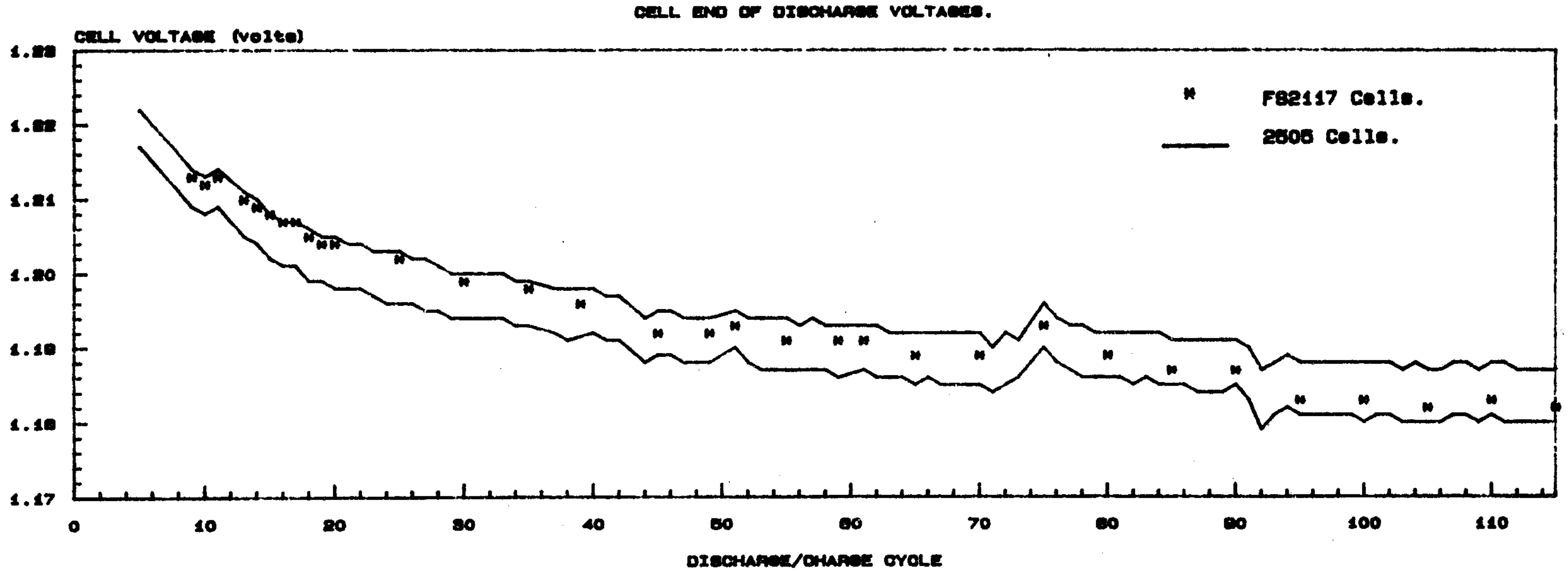

Figure 4. Through-Put Test Results

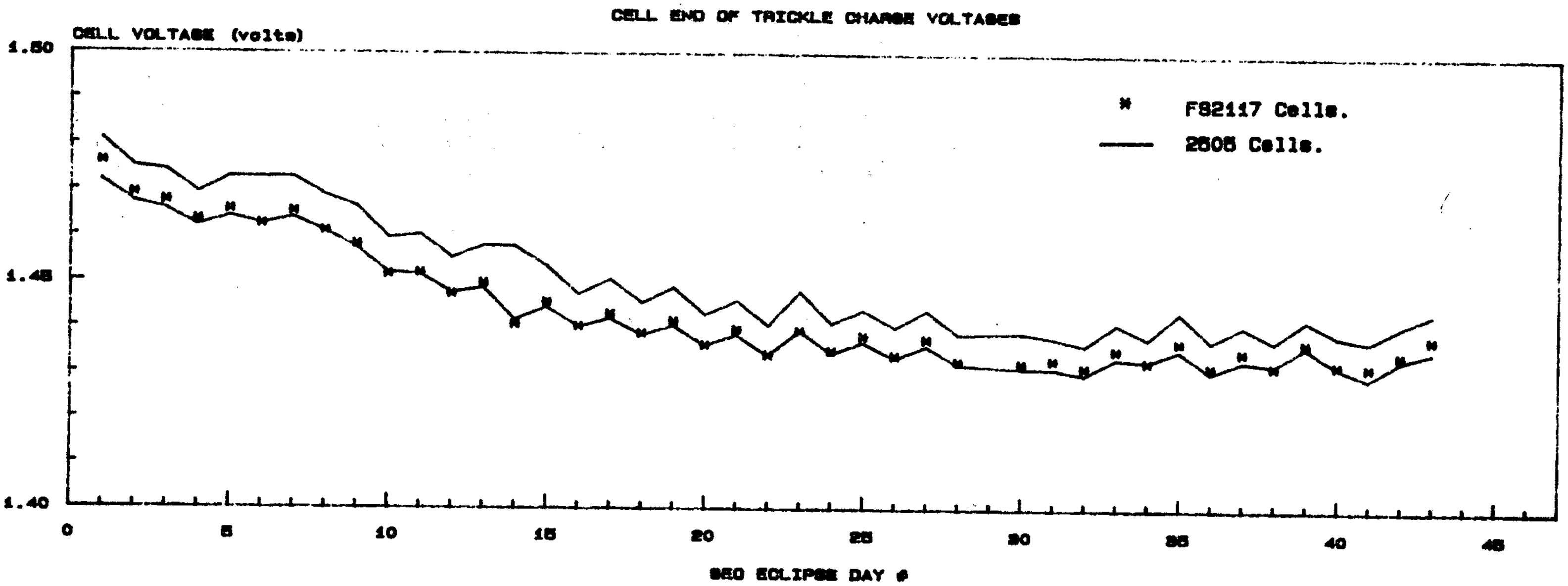

Figure 5. Real Time Eclipse Test Results

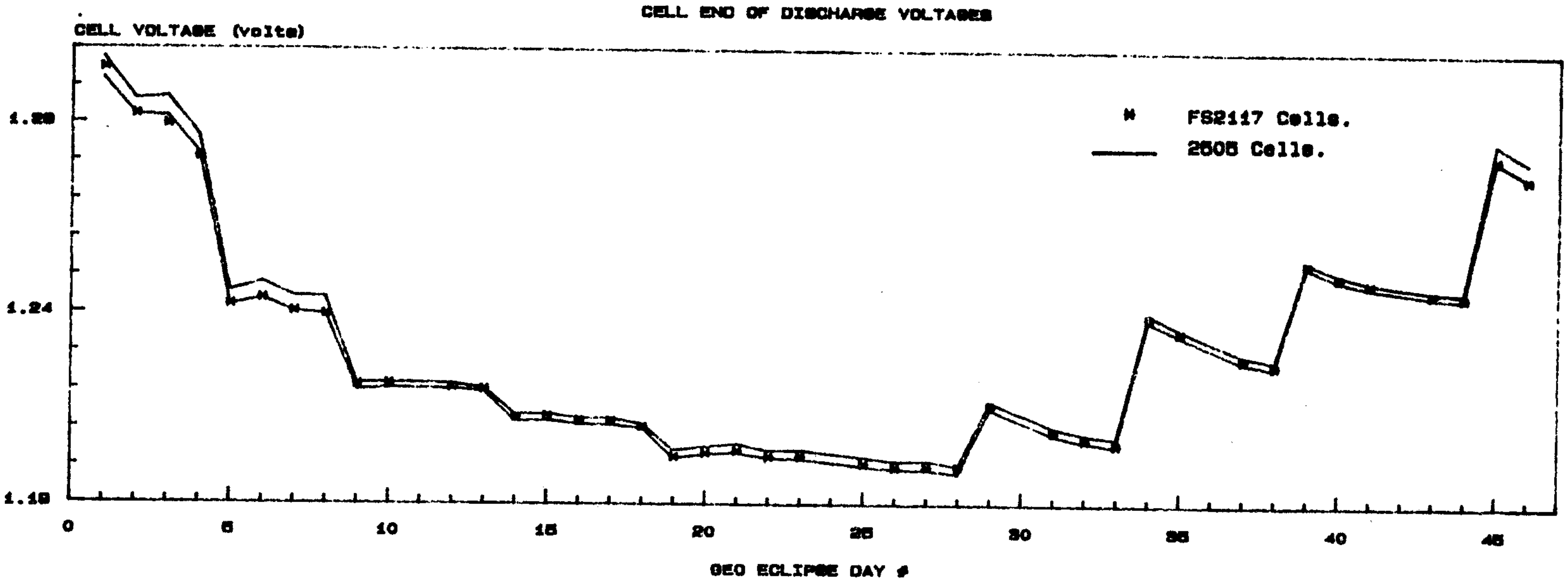

Figure 6. Real Time Eclipse Test Results