Performance of AEA 80 Ah Battery Under GEO Profile

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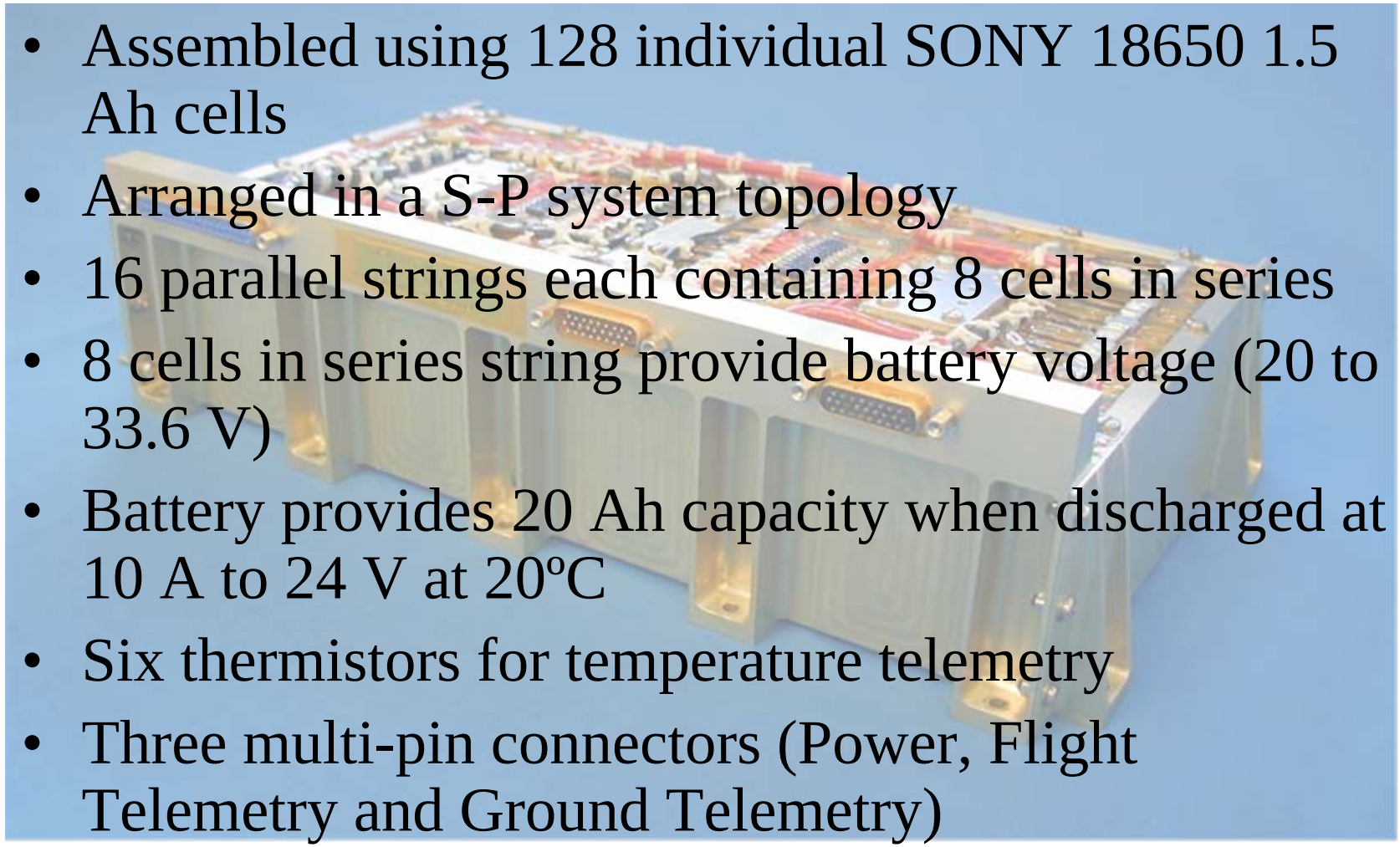
AEA GEO Life Testing

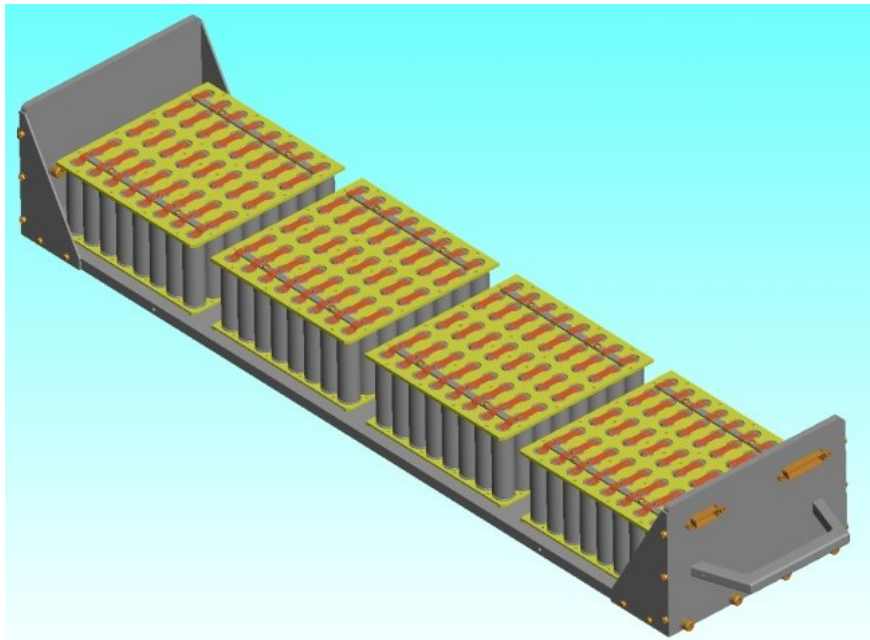
- AEA initiated cycling and calendar life tests over 6 years ago
  - Accelerated GEO cycling tests with no solstice period
- GSFC directed a real-time life test at battery level at AEA
- Battery design based on an existing module previously qualified for GSFC

AEA/GSFC 20 Ah Battery

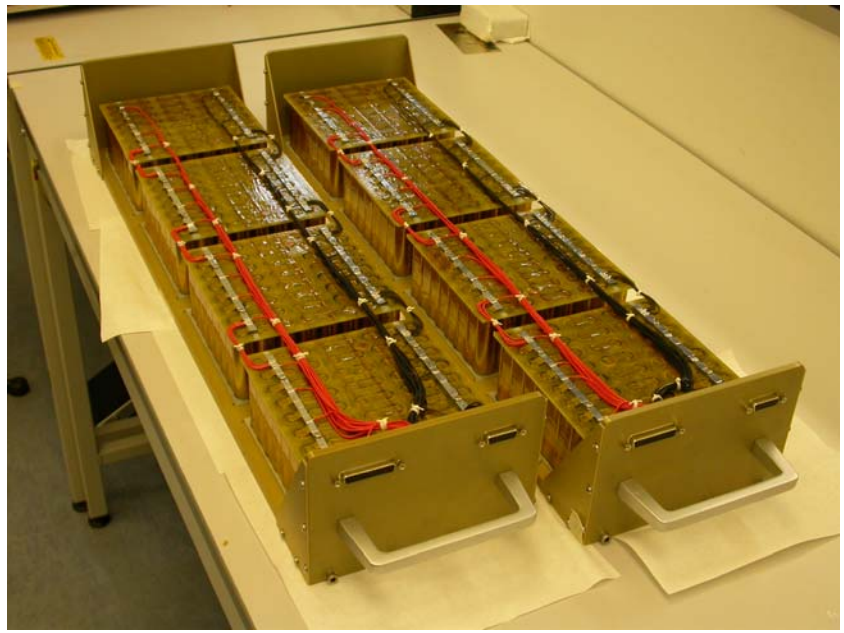


- Assembled using 128 individual SONY 18650 1.5 Ah cells
- Arranged in a S-P system topology
- 16 parallel strings each containing 8 cells in series
- 8 cells in series string provide battery voltage (20 to 33.6 V)
- Battery provides 20 Ah capacity when discharged at 10 A to 24 V at 20ºC
- Six thermistors for temperature telemetry
- Three multi-pin connectors (Power, Flight Telemetry and Ground Telemetry)

AEA/GSFC 80 Ah Battery



- 40 Ah Test module assembled using four of the standard 8 x 8 battery blocks
- Battery block uses qualified design from 20 Ah units



- Each block contains 64 cells
- Total of 256 cells per test module

SDO Life Test: Overview

- Real time GEO life testing including solstice and eclipse seasons
- Capacity measurements performed only at the start of each eclipse season
  - Before first eclipse season each year both AEA* and GSFC** capacity measurements performed
  - Before second eclipse season each year an extra AEA capacity measurement is performed

* C/10 charge to 33.6V and C/10 discharge to 20.0V

**C/10 charge to 33.6V clamp with a taper current to C/100 and C/2 discharge to 24.0V

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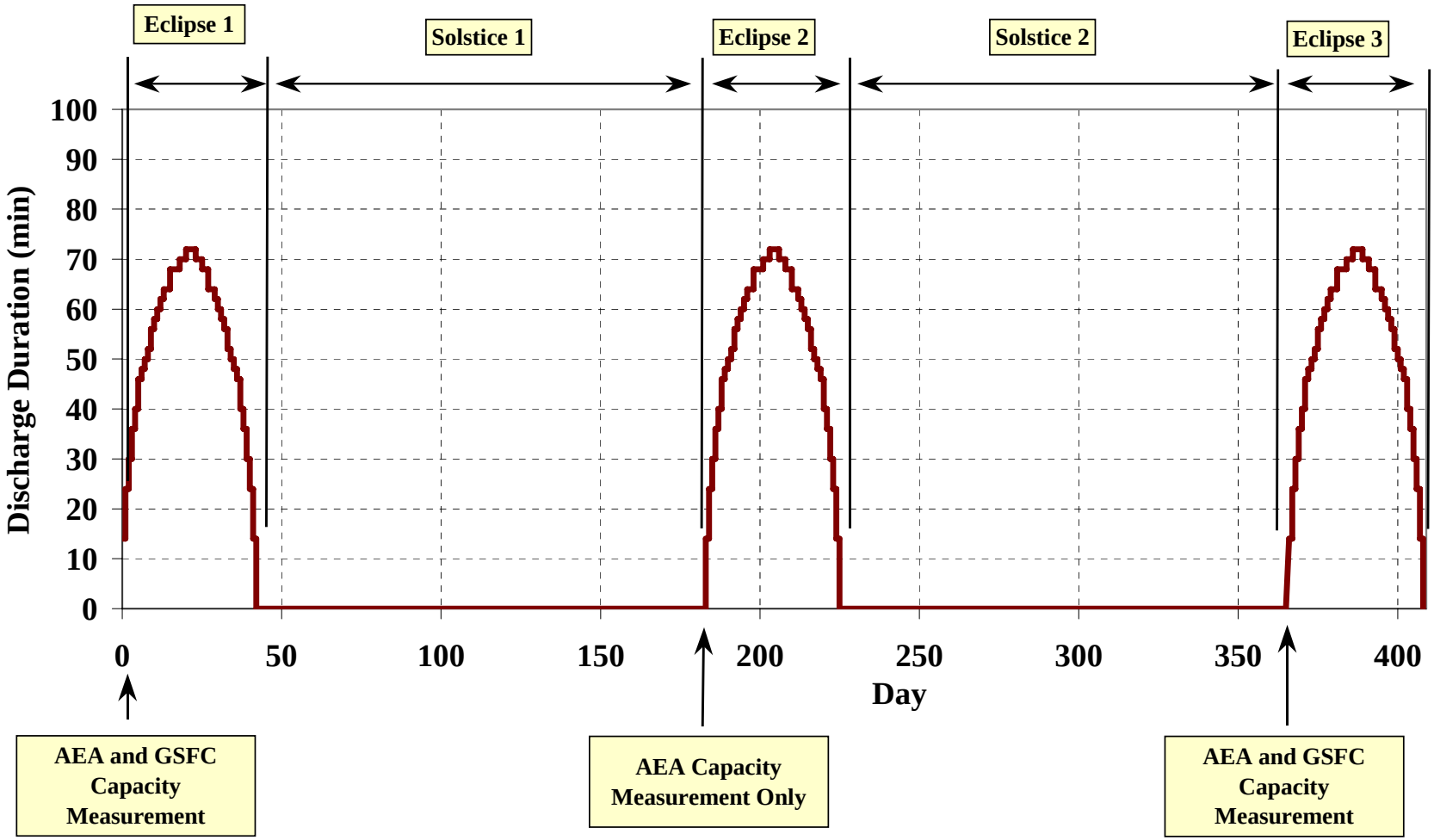
SDO Life Test: Overview – cont'd

- Eclipse Regime
  - Charge at 4A to 33.35V clamp with a taper to 0.1 A, followed by 0.1A constant current until end of the charge period
  - Maximum State-of-Charge (SOC) 98% day 1 and day 42
  - Minimum SOC 28% days 21-23
  - Discharge current 48A
- Solstice Regime
  - 140 days
  - Voltage clamp at 32.3V (72% SOC)
  - Fully charged before prior to commencement of eclipse season

SDO Life Test: Real-Time Profile



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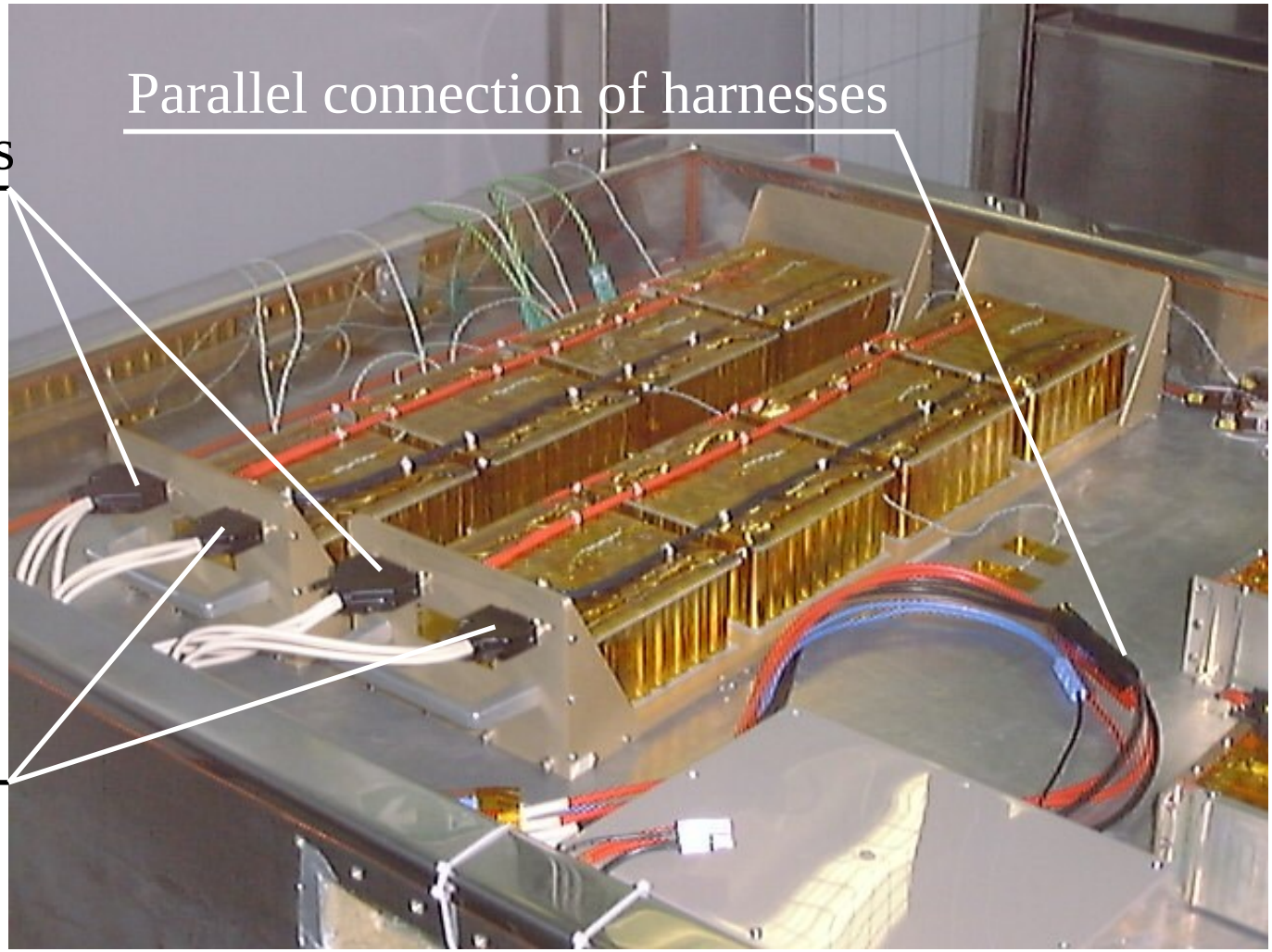
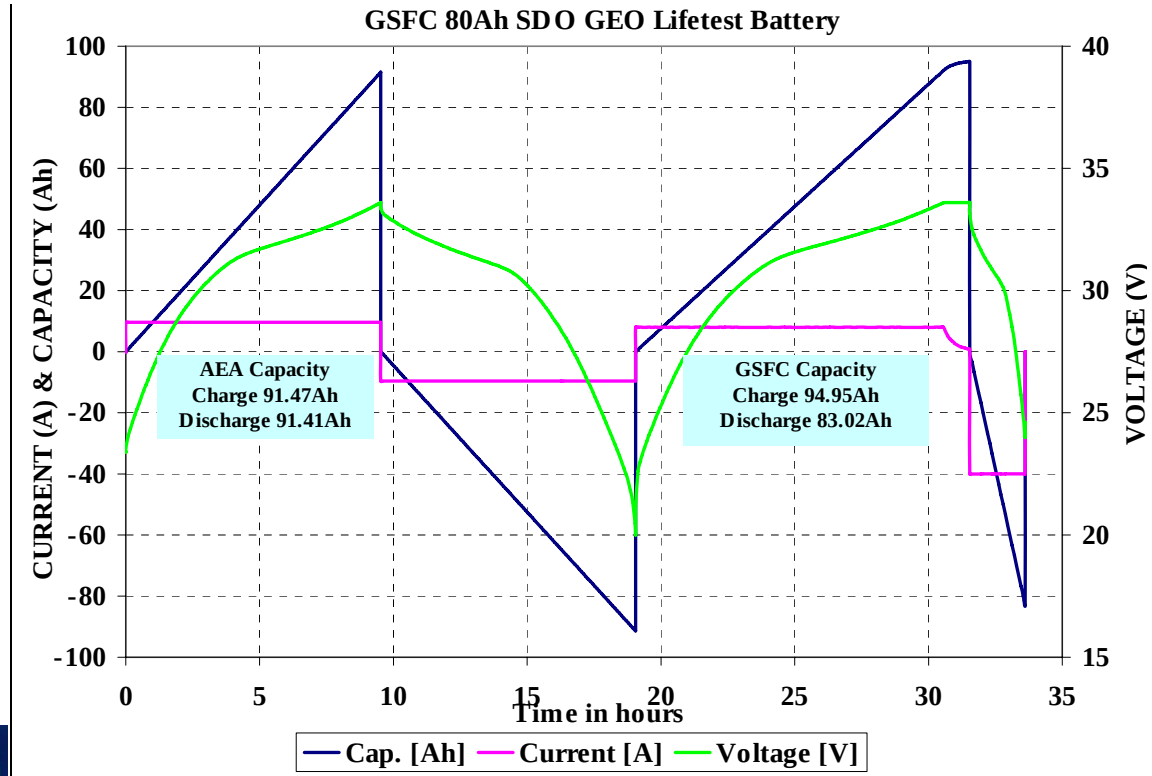
SDO Life Test Setup



Test Results

- AEA Standard Capacity Measurement (SCM) (C/10 charge and discharge) = 91.41 Ah
- C_{GSFC} (C/10 charge & taper to C/100, C/2 discharge) = 83.02 Ah
- C_{TOTAL} = 97.76 Ah

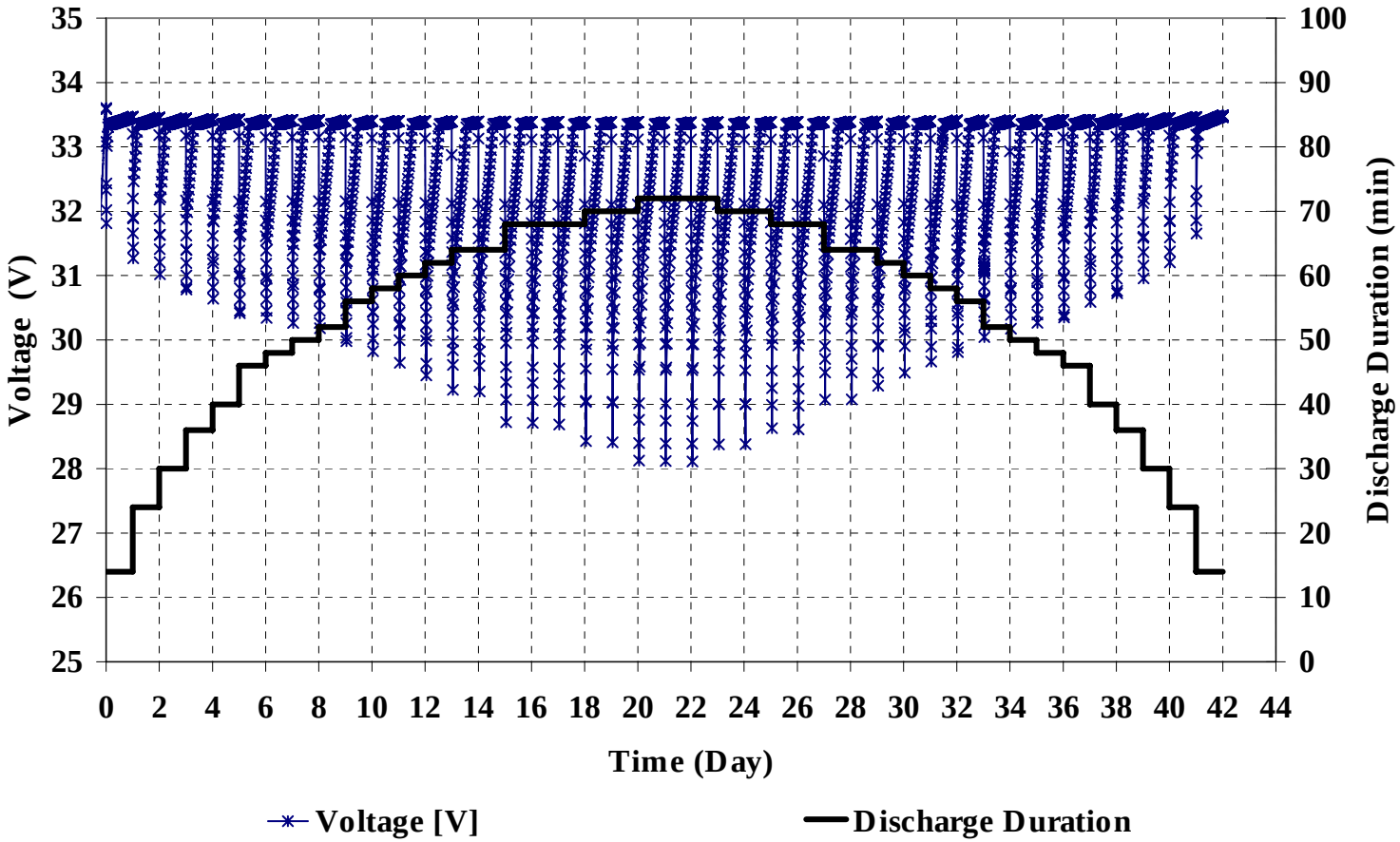


Test Results: Voltage

- Completed to date nominal three seasons
- Note rising voltage towards end of charge
  - –True taper charge to very low current not possible with test equipment used
  - –Min current without a specific ‘rest’ mode is 0.1 A
  - –Therefore battery charged to 33.35 V then held at 0.1 A current for remaining duration
  - –33.35 V calculated to ensure battery remains below 33.6 V at end of charge for worst case (minimum discharge)

Test Results: Voltage

First Eclipse Season Profile



Test Results: Voltage

Profiles for Maximum Depth-of-Discharge (DOD), 72%, for the Three Seasons

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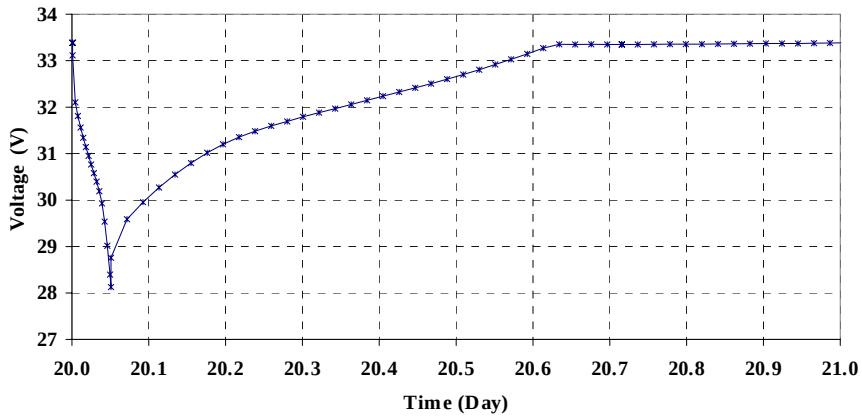
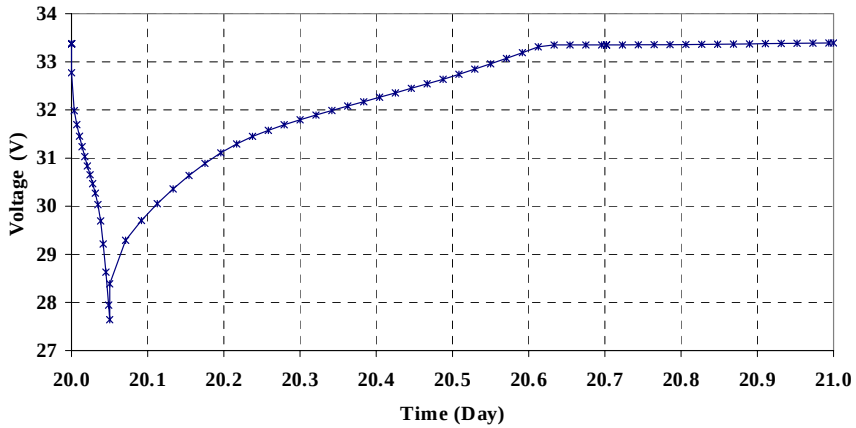
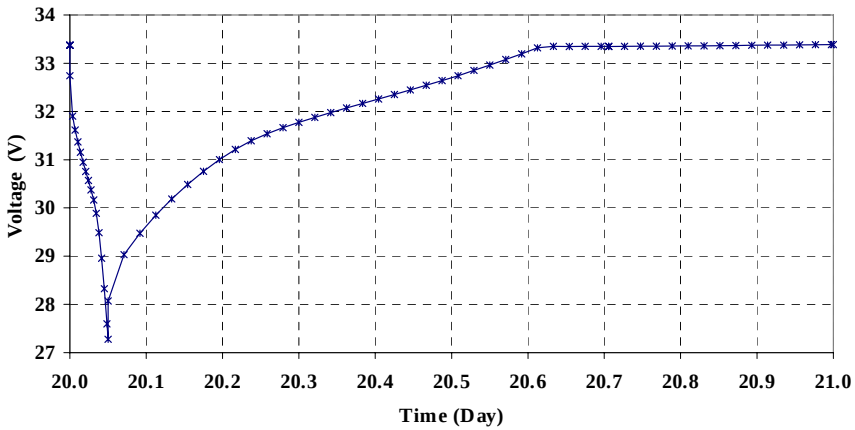
First Eclipse (72 min)



Second Eclipse (72 min)



Third Eclipse (72 min)



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Test Results: Current

- Logged current shows four stages per orbit:
- Main constant current charge at 4 A
- Taper region when voltage clamped at 33.35 V
- Limiting 0.1 A current for remaining duration of charge
- 48 A discharge current results in a peak of 57.6 Ah (equivalent to 72% DOD of C_{GSFC})

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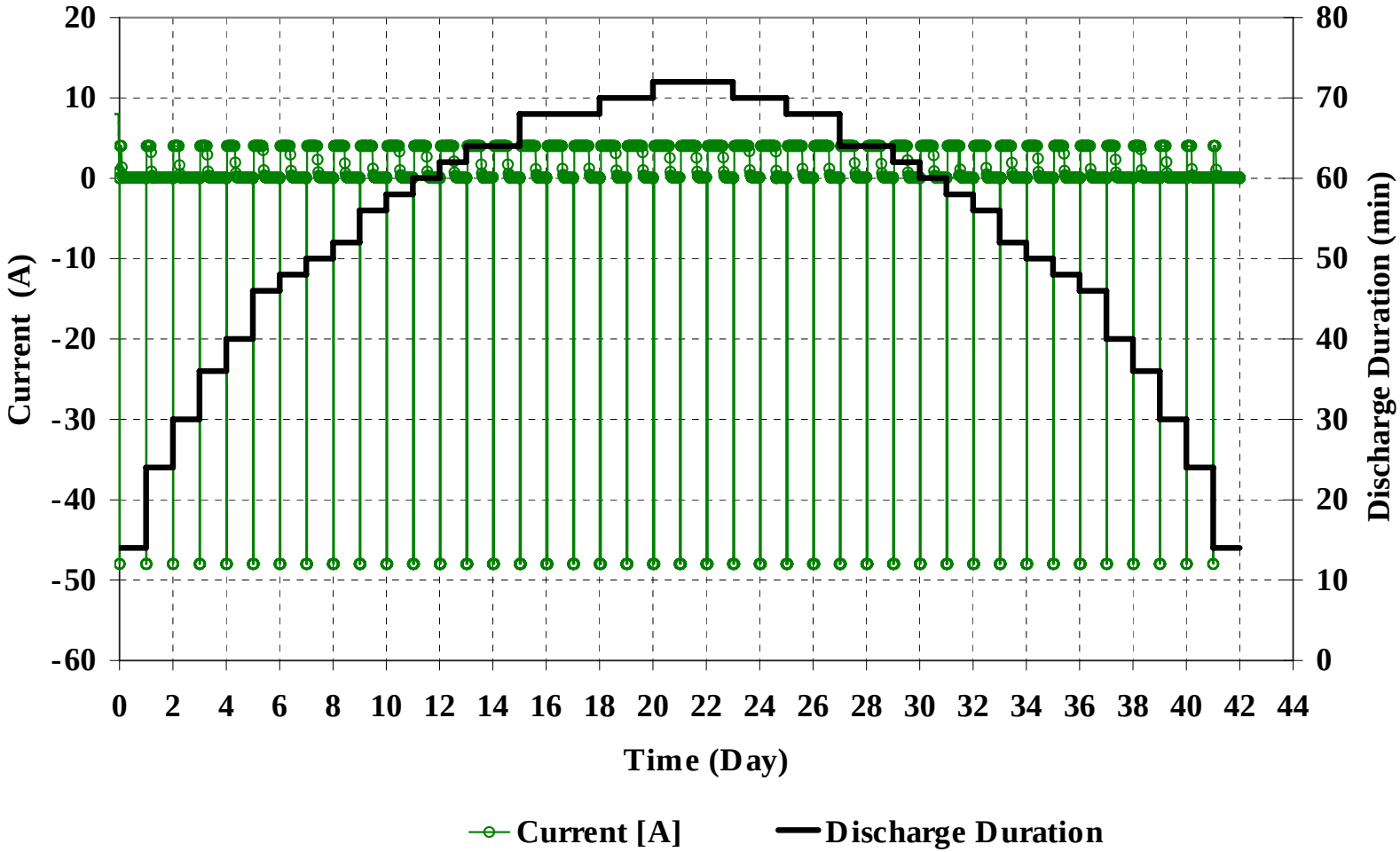
Test Results: Current

Profile for the Eclipse Season



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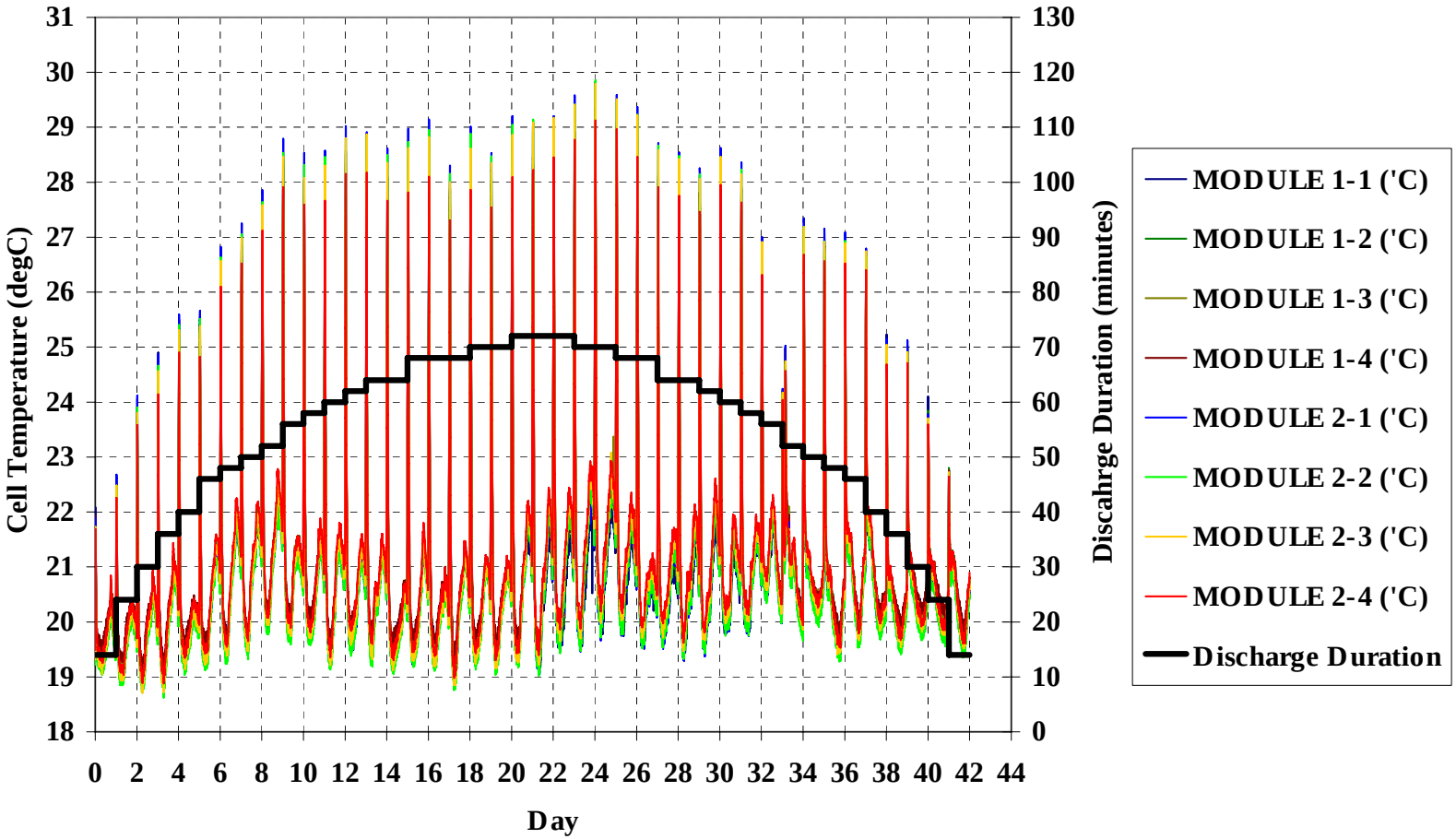
Test Results: Temperature

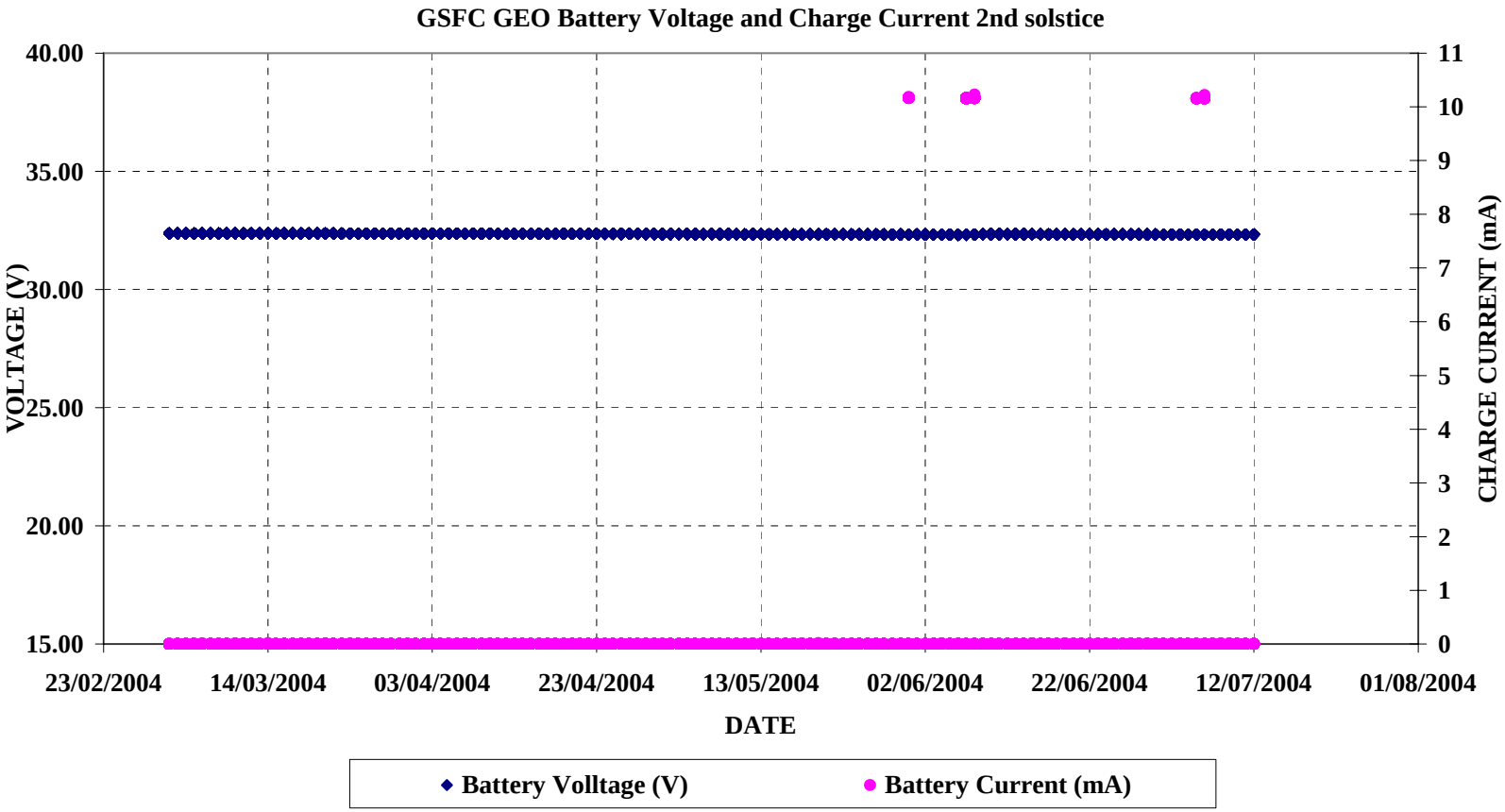
- 1 thermistor at the centre of each block
  - represents maximum cell temperature
- On following plot ‘spike’ temperature rises during the discharge periods
  - Peak cell temperature approx 30°C
- Variation in temperature during charge follows repeating pattern:
  - Initially endothermic (temp falls below interface (I/F))
  - Then exothermic (temperature rises 1 to 2°C)
  - Then cells cool back towards I/F temperature near end of charge when current tapers and dissipation reduces
  - Small variation in I/F temperature due to thermal control limits

Test Results: Temperature

Profile for the Eclipse Season



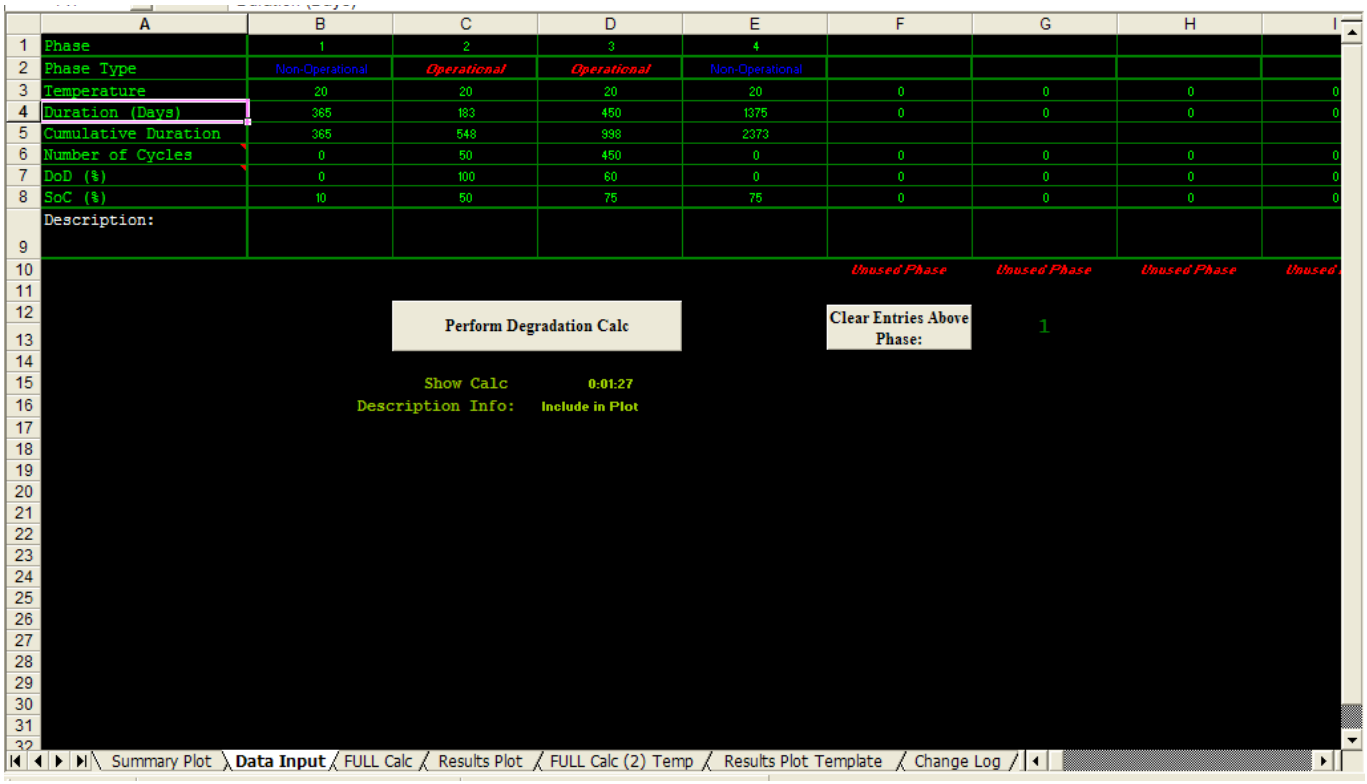
Test Results: Solstice



Correlation: AEA Fade Tool

- AEA life test program has accumulated over 40 million cell hours including 6 years calendar life
- Intended to simulate Low Earth Orbit (LEO), Geosynchronous (GEO), Medium Earth Orbit (MEO), Geosynchronous Transfer Orbit (GTO), Interplanetary and Planetary Lander scenarios
- This data, combined with understanding of cell level chemical processes has been incorporated into AEA fade tool

Correlation: AEA Fade Tool - cont'd

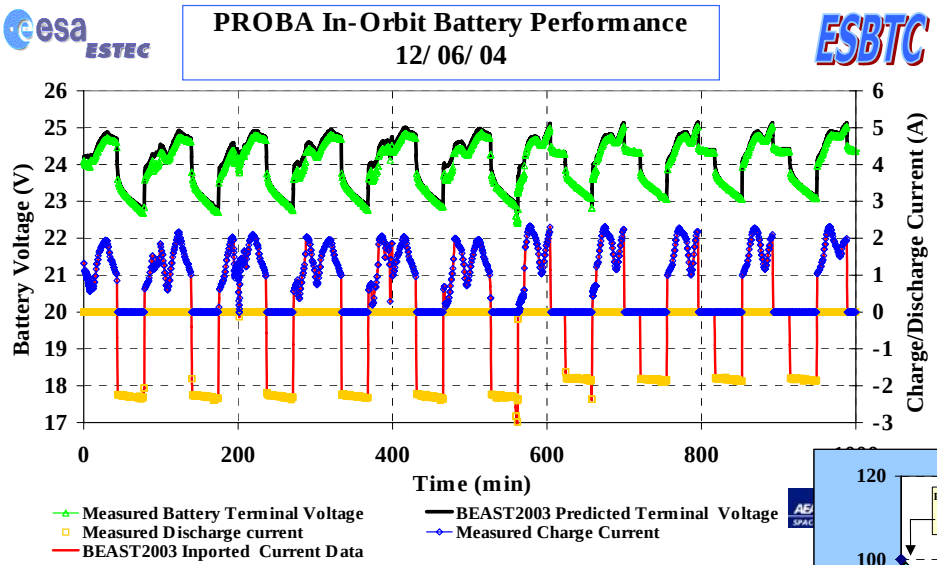


	A	B	C	D	E	F	G	H	I
1	Phase	1	2	3	4				
2	Phase Type	Non-Operational	Operational	Operational	Non-Operational				
3	Temperature	20	20	20	20	0	0	0	0
4	Duration (Days)	365	183	450	1375	0	0	0	0
5	Cumulative Duration	365	548	998	2373				
6	Number of Cycles	0	50	450	0	0	0	0	0
7	DoD (%)	0	100	60	0	0	0	0	0
8	SoC (%)	10	50	75	75	0	0	0	0
9	Description:								
10						Unused Phase	Unused Phase	Unused Phase	Unused
11									
12			Perform Degradation Calc			Clear Entries Above Phase:	1		
13									
14			Show Calc	0:01:27					
15			Description Info:	Include in Plot					

Summary Plot | Data Input | FULL Calc | Results Plot | FULL Calc (2) Temp | Results Plot Template | Change Log

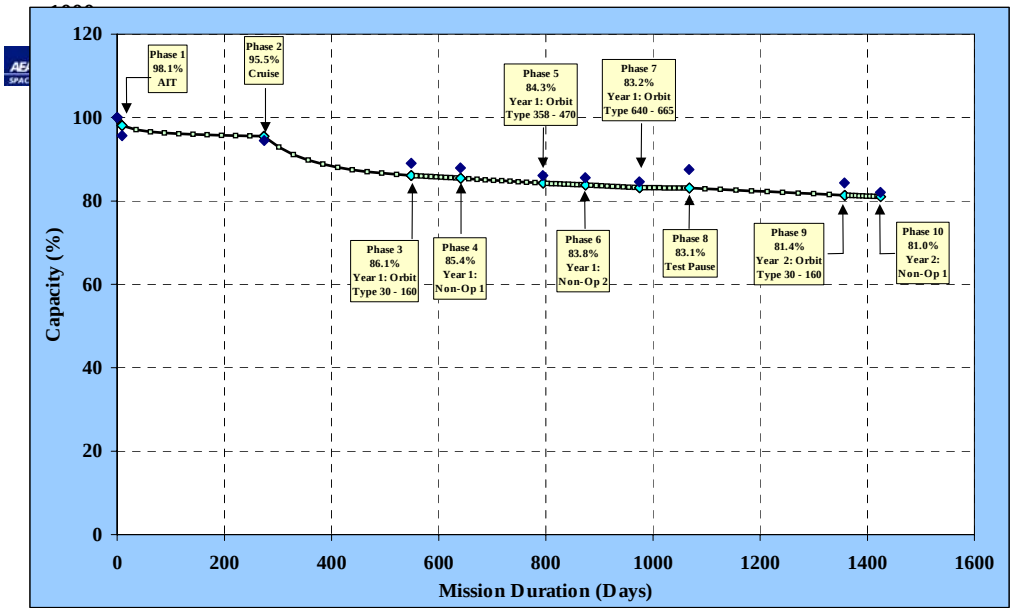
- Simple Excel based user interface
- Each phase defined by temperature, duration, number of cycles, DOD, state of charge

Correlation: AEA Fade Tool - cont'd

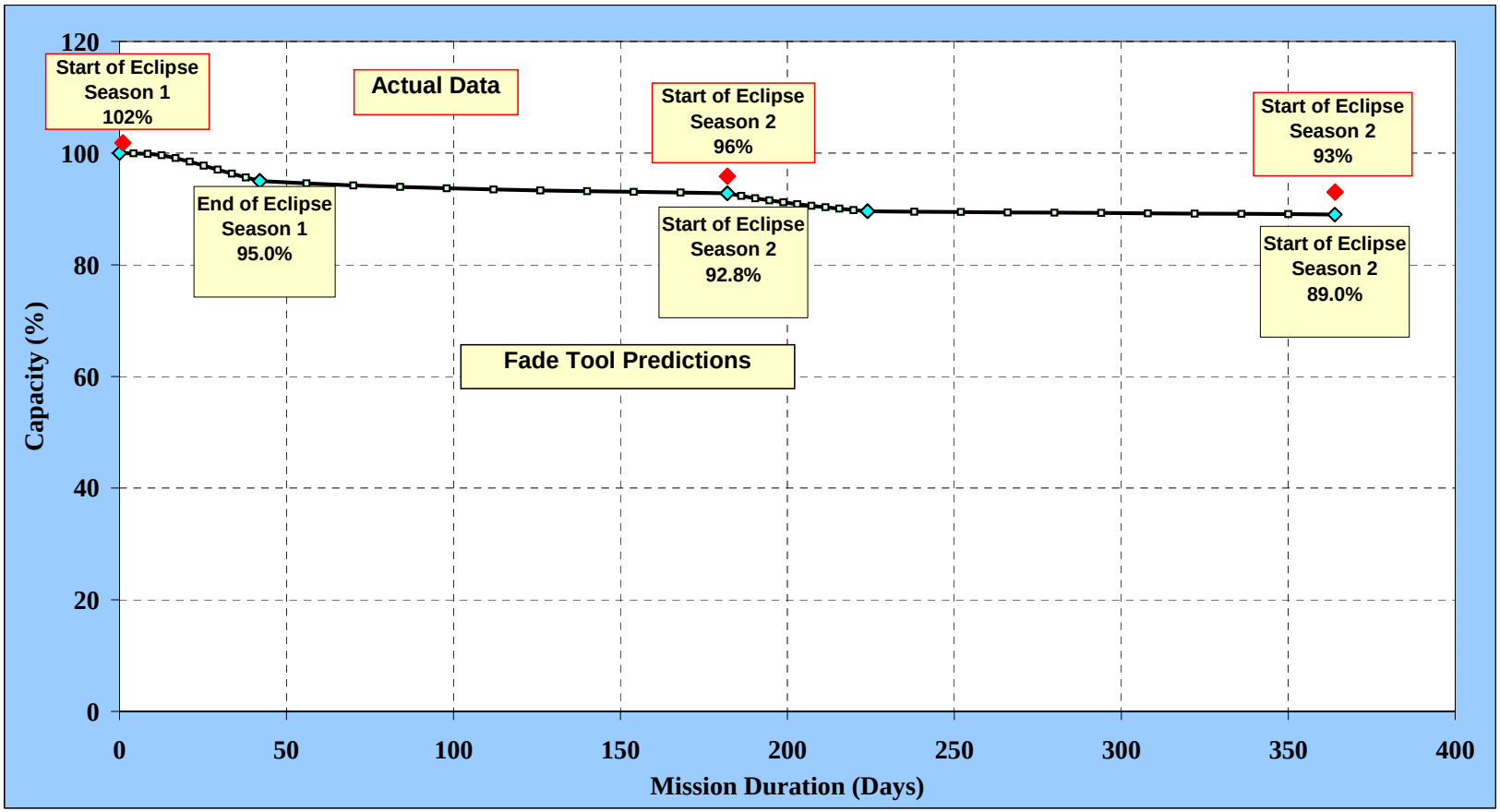


Proba Mission Data

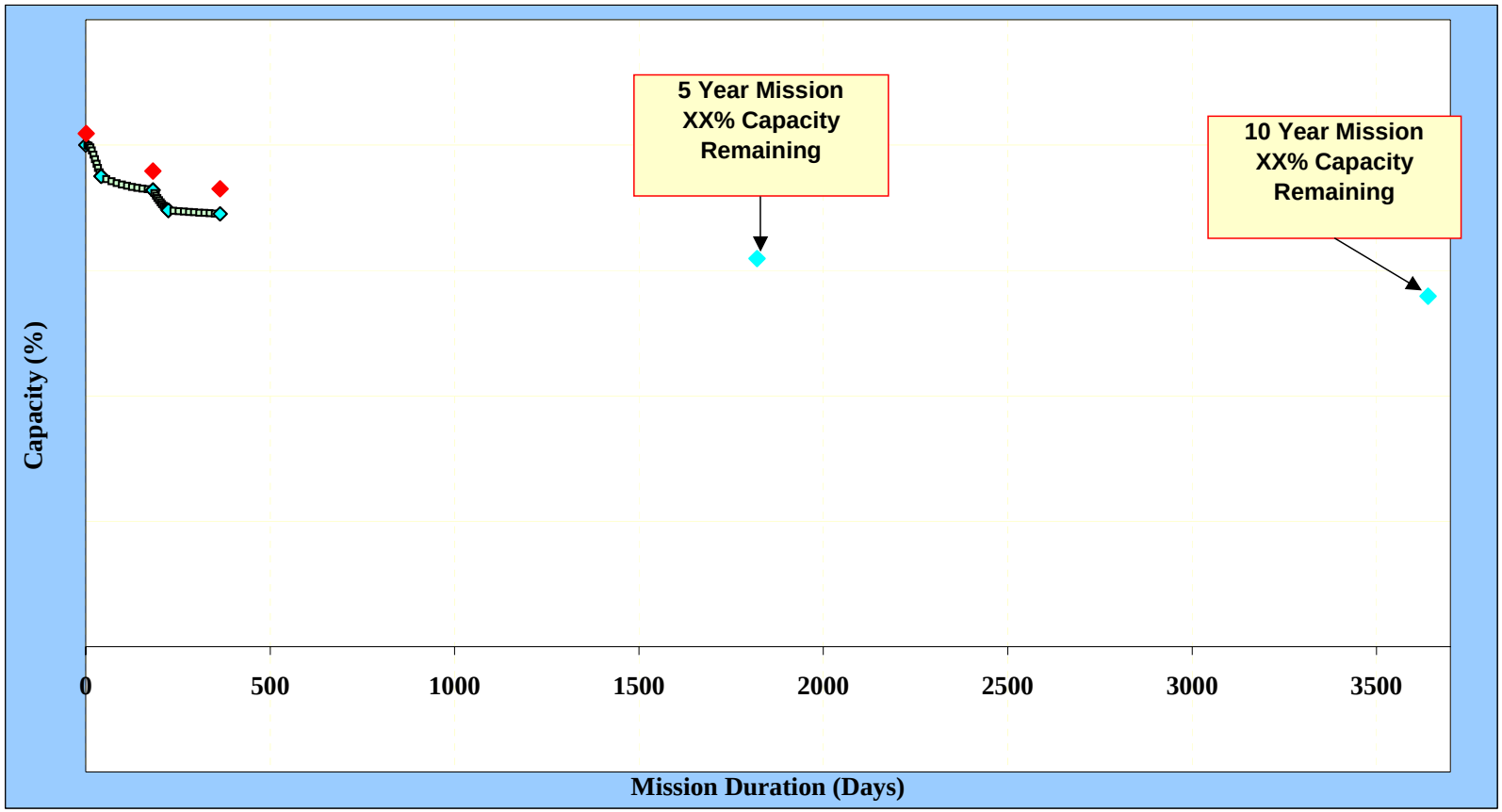
Mars Express Real Time Lifetest Data



Correlation: AEA Fade Tool - cont'd



Correlation: Long Term Prediction



Conclusions

- To date completed three SDO real-time eclipse seasons
- Sony 18650HC has a low rate of capacity fade under GEO cycling regime
- Real time test results correlate with accelerated GEO lifetest data and AEA capacity fade prediction tool
- This data, together with other AEA test data, justify the SDO Project decision to baseline Lithium-Ion chemistry for the spacecraft battery.

Acknowledgements