Panasonic Small Cell Testing For AHPS

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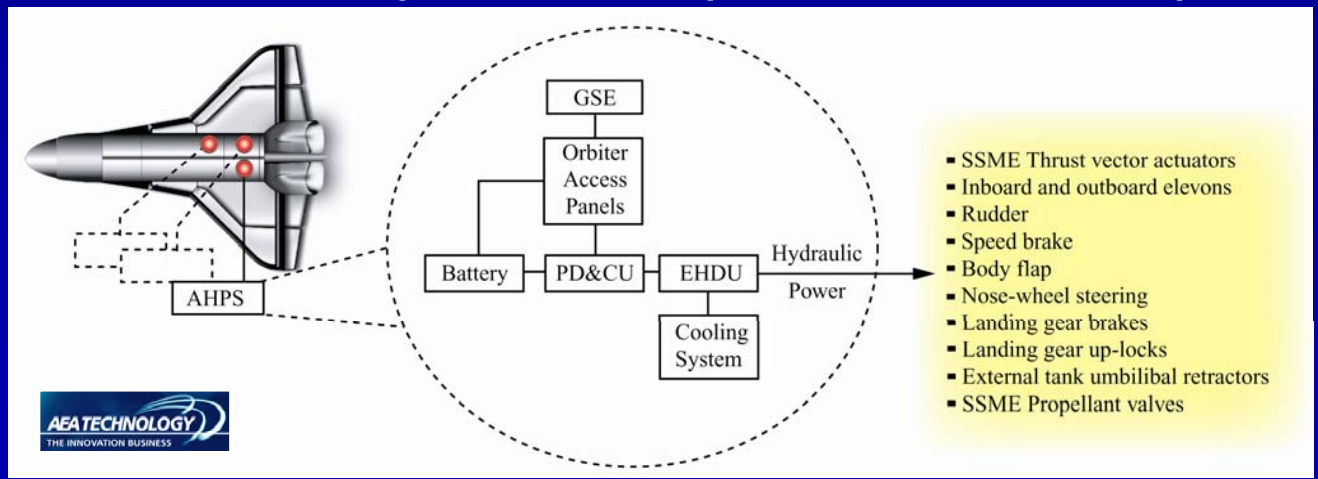
Contents

- Background
  - AHPS Battery
  - Motivation
- Test Overview
- Conclusions

AHPS Battery System Overview

- AEA selected in May 2004 to develop the Lithium-ion battery system for the NASA Space Shuttle Advanced Hydraulic Propulsion (System)
- AEA received contract from NASA JSC in Dec 03 to test the Panasonic CGR18650C cell for the AHPS application
- Battery system to provide high voltage electrical power to the Electro-hydraulic Unit (EHDU)
- Battery system: 3 Battery Assemblies
- Battery Assemblies: 2 Battery Modules (series connected)



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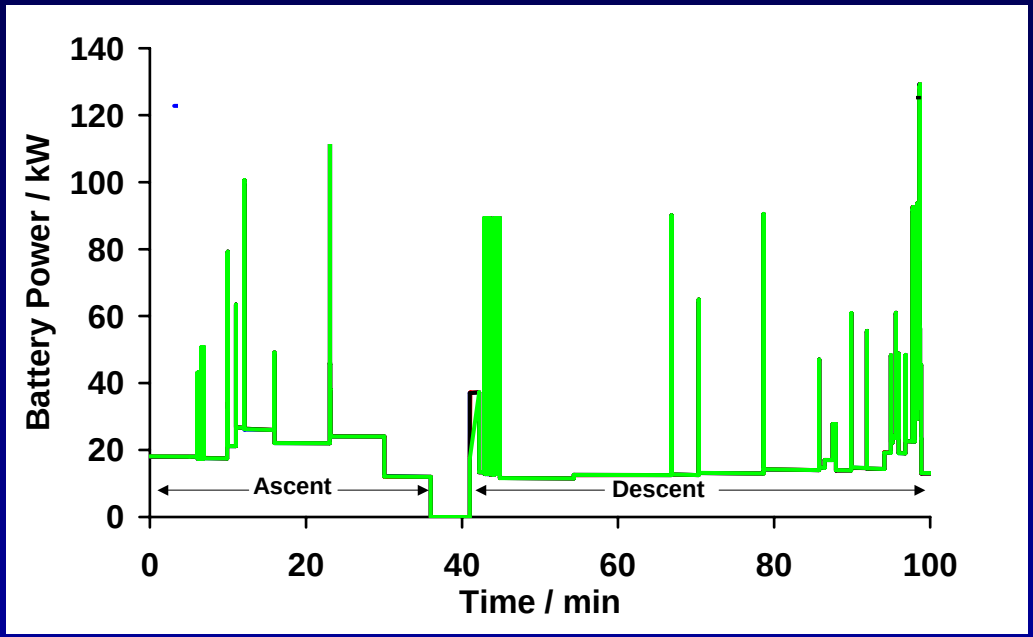
AHPS Battery Requirements

- Output Voltage : 360V – 230V
- Discharge Capacity : 28 kWh
- Maximum Load : 130kW (565A @ min V)
- Low cycle life
- High pulse load

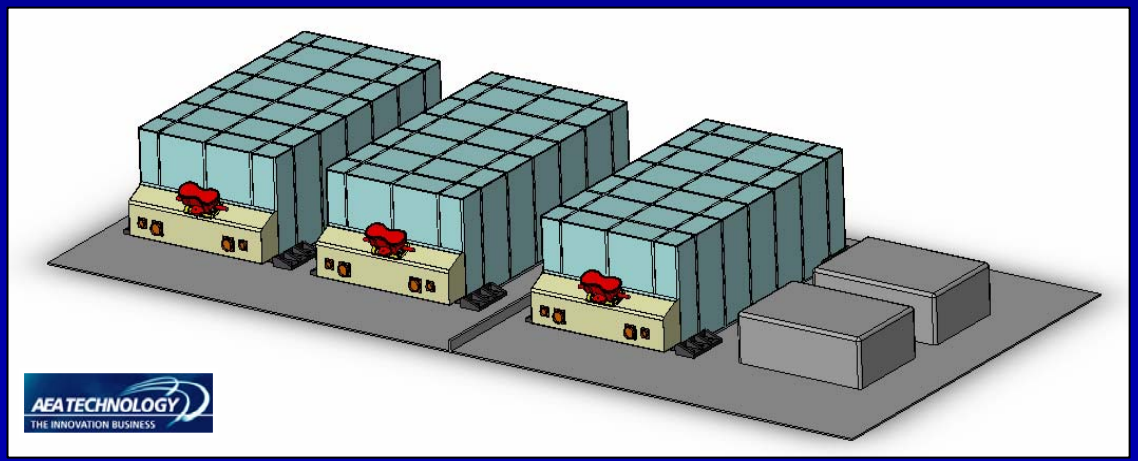


DRIVERS

- Safety and reliability
- Mass
- Cost
- Increase hydraulic flow
- Increase redundancy

MODULE CONFIGURATION

- 43s92p – SONY 18650HC
- Assembly 2s modules



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Background: AHPS Battery Challenges

- Large range in battery interface temperature
  - Cold temperature <10°C
  - Hot temperature ~60°C
- Cold temperature
  - Increased internal resistance
  - Low EOD voltage for same load
- Hot temperature
  - Internal protection device (PTC) operates ~70°C
  - PTC operation dependent in temperature and cell load
  - Upon PTC operation, cell internal resistance rises significantly
- Battery electrical design driven by understanding both cases

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Background: Motivation

- AEA employs Panasonic cell in terrestrial packs

	Panasonic CGR18650C	SONY 18650 HC
Dimensions	18650	18650
Mass (g)	43	42
Capacity (Ah)	2.15	1.5
Energy (Wh)	7.74	5.2

- Test program completed recently
- Test report submitted to NASA
- Main drivers for program
  - Increased performance suggested by capacity
  - Understand Hot case, seen as driving SONY cell battery size

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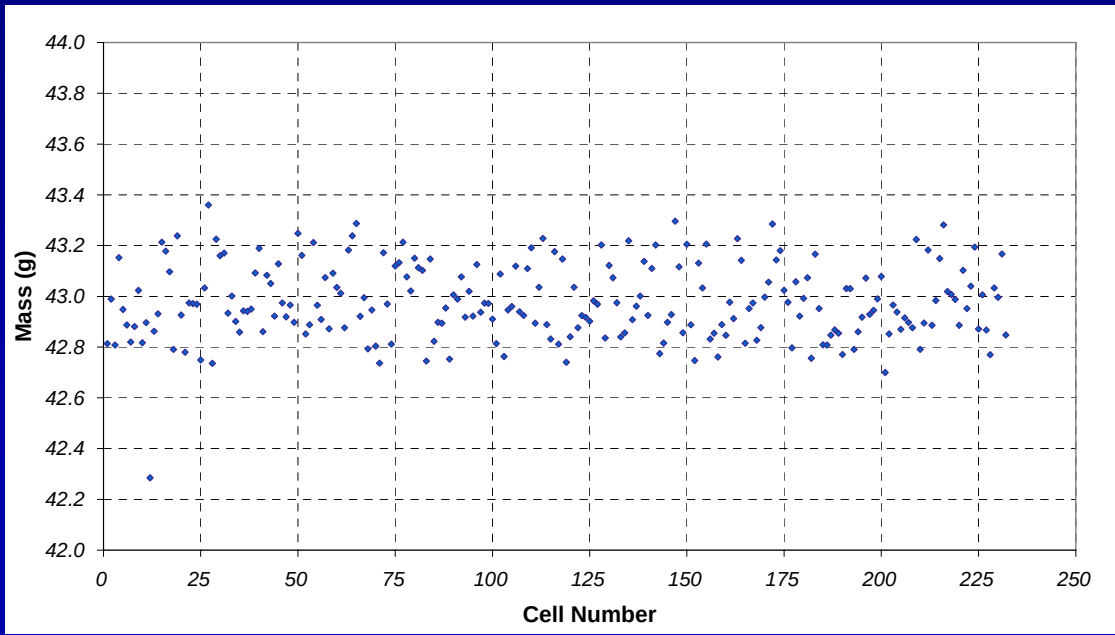
Initial Inspection

Receiving inspection & test (232 cells)

- Mass, volume
- PTC cold resistance
- Stabilisation Cycling



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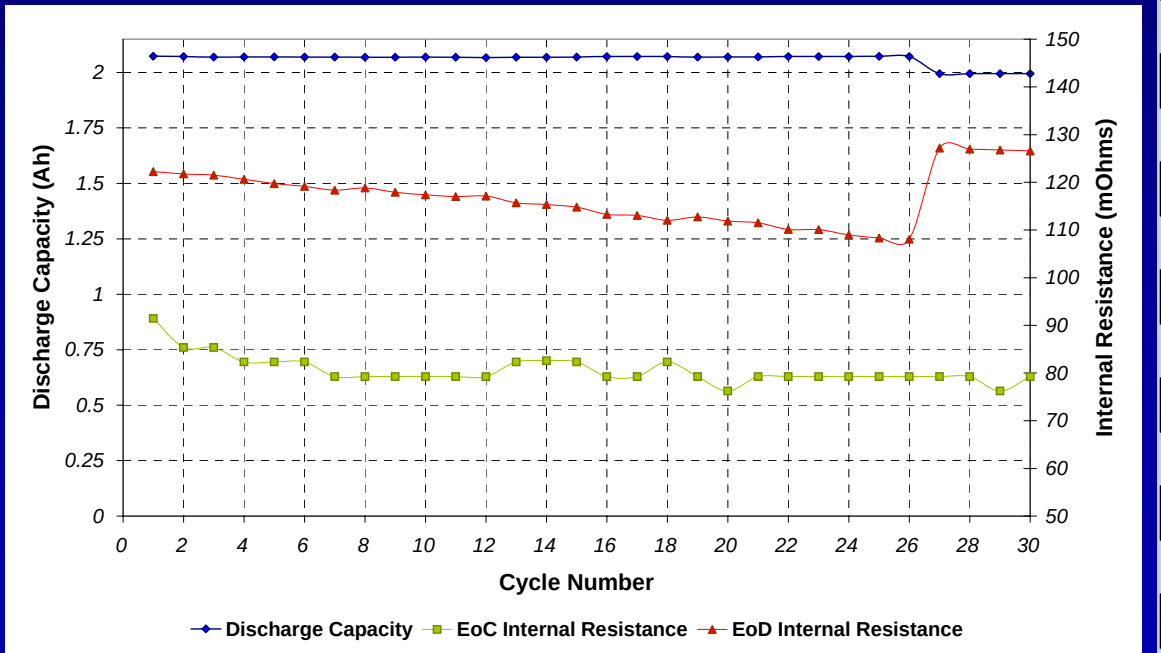
TEST 13: Cell Internal Short Circuit

TEST 14: Cell Destructive Parts Analysis

Capacity under Cycling

- 22°C cycle repeated 30 times
  - 2.59W discharge, 20W pulses (3s/6min)
  - 2.5V voltage limit
  - 1 less pulse cycle 26 onwards



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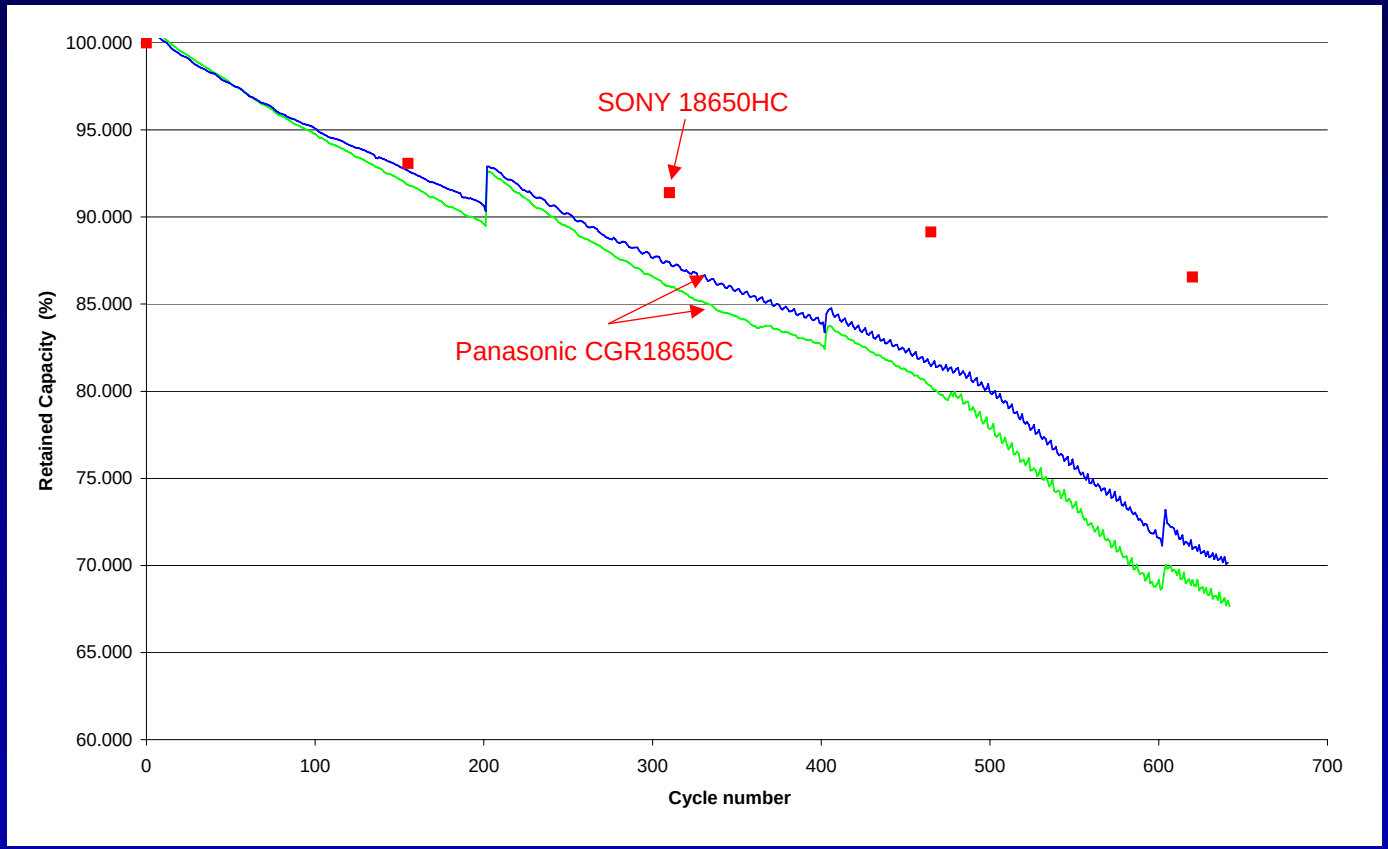
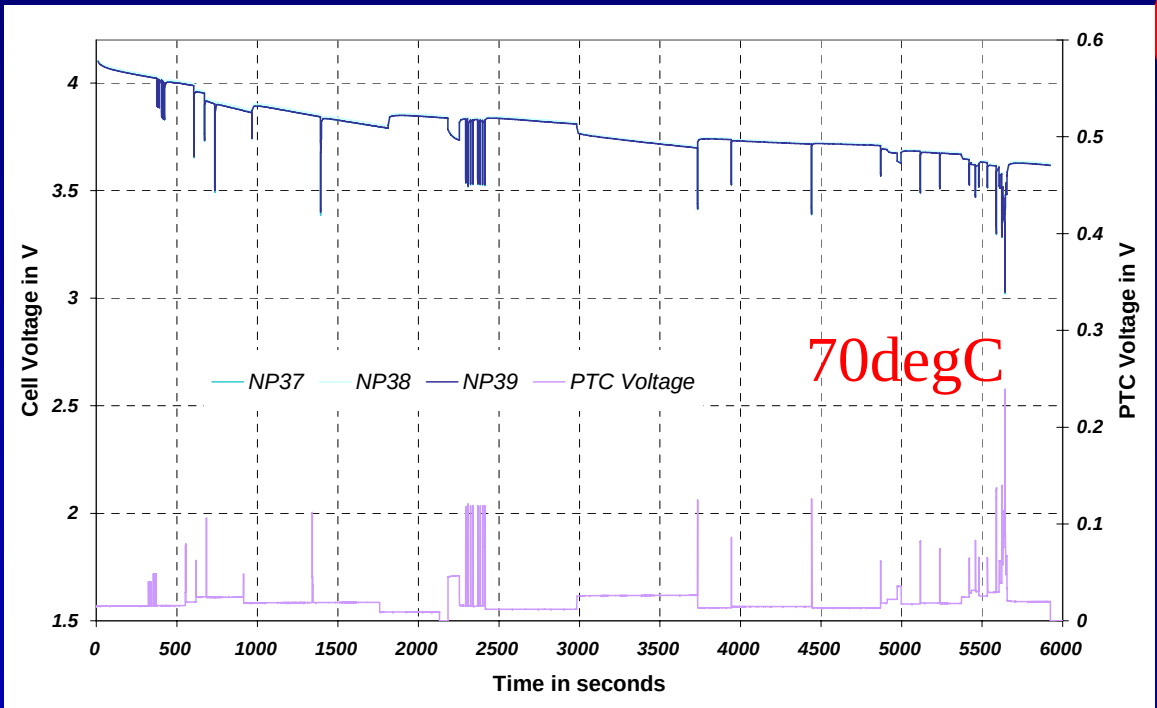
Cycling Comparison



- AEA Internal tests
- 100%DOD
- Ambient temperature

PTC Trip Temperature Evaluation

- Mission profile test – 86s50p
  - 3 cells tested
  - 24°C, 70°C



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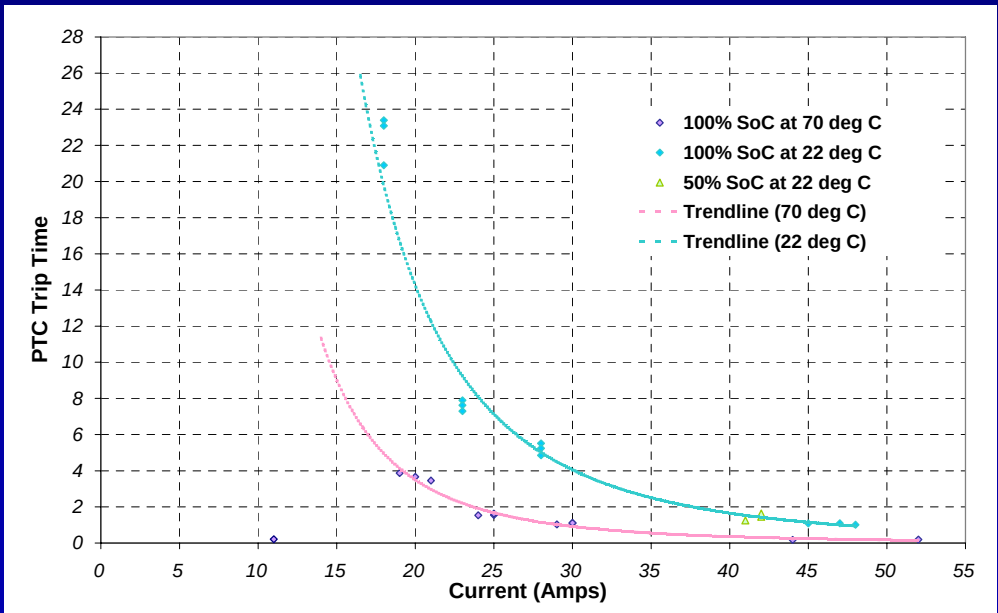
PTC: Predicting Hot Performance

- PTC characterisation
  - Trip time measured
  - 22 and 70°C
  - PTC trip time is function of current and temperature



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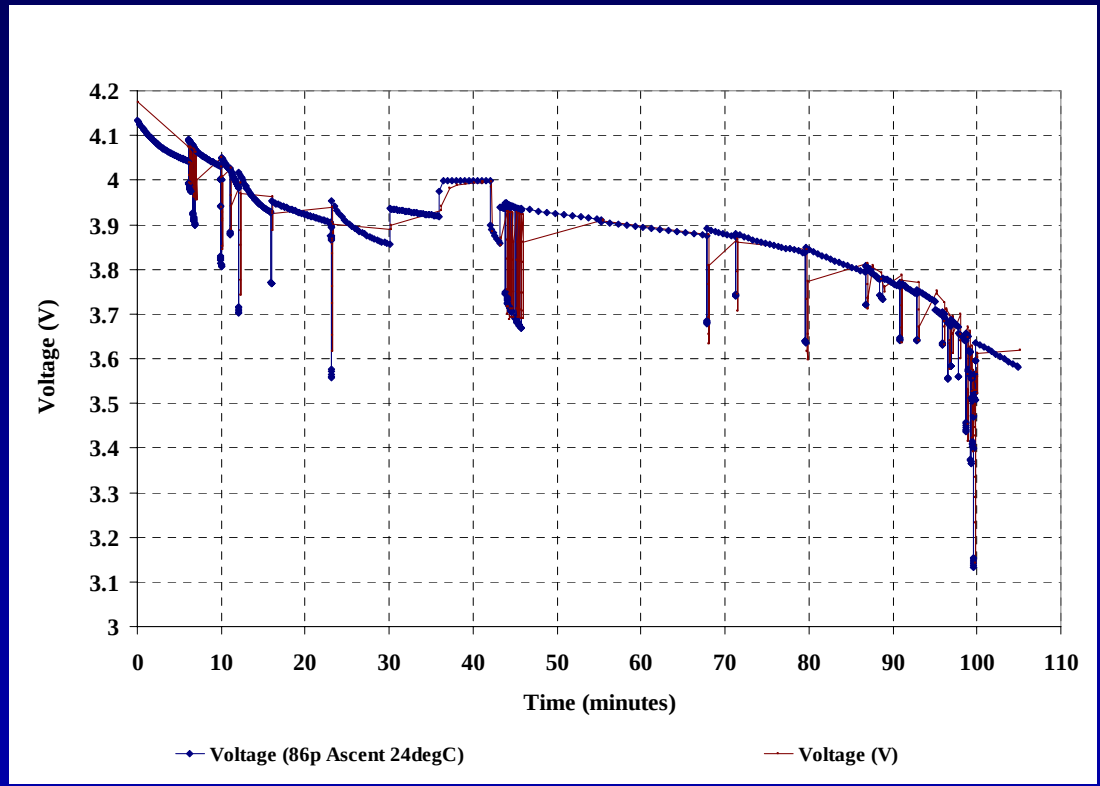
AHPS Performance Prediction: SONY

- Success modelling SONY 18650HC for AHPS profile
- Key factor for AHPS selection
- Iterative tests to find minimum configuration with Panasonic cell
  - Time consuming tests finding minimum configuration PTC trips
- AEA attempted to modify basic BEAST algorithm for Panasonic cell



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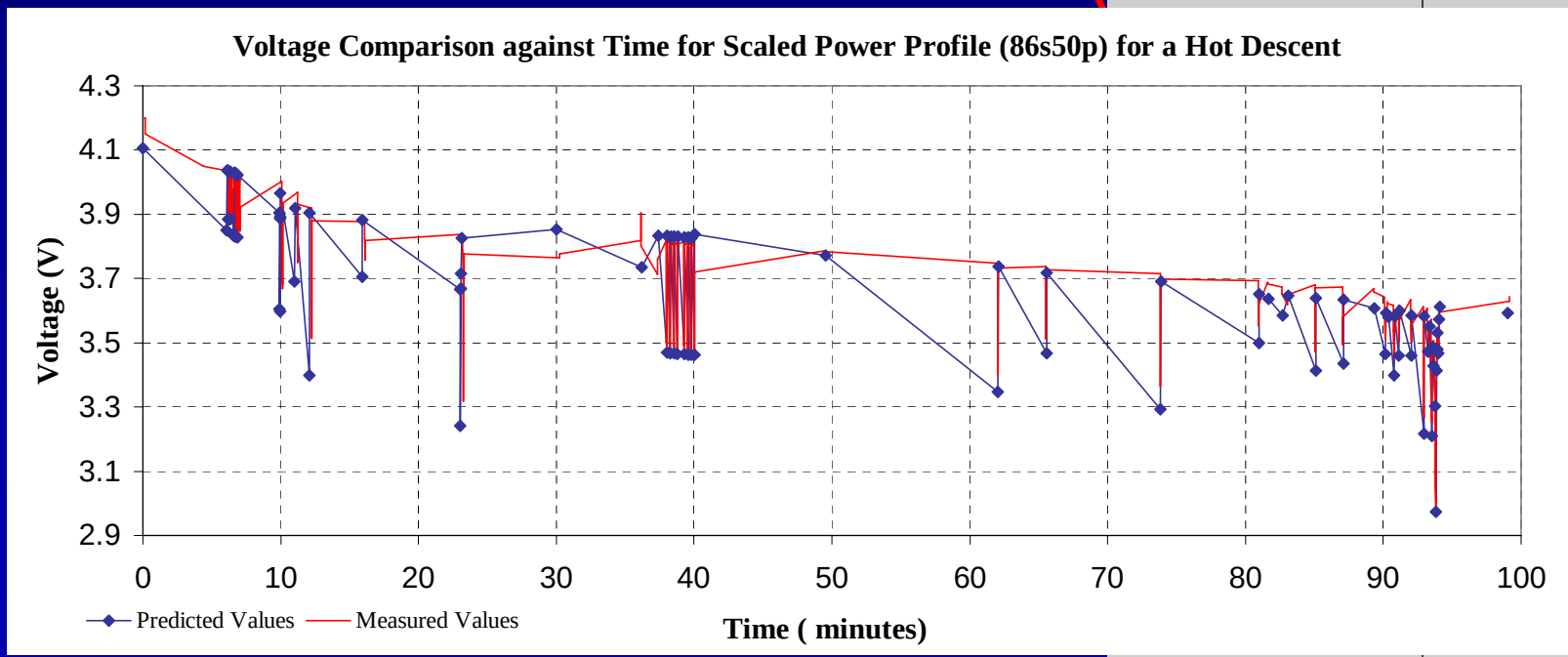
Performance Prediction: Panasonic

- Panasonic measured electrical parameters entered into model
- Performance predictions indicated cold case would drive battery sizing



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Battery Sizing

Voltage

Seal Leakage

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TEST 14: Cell Destructive Parts Analysis

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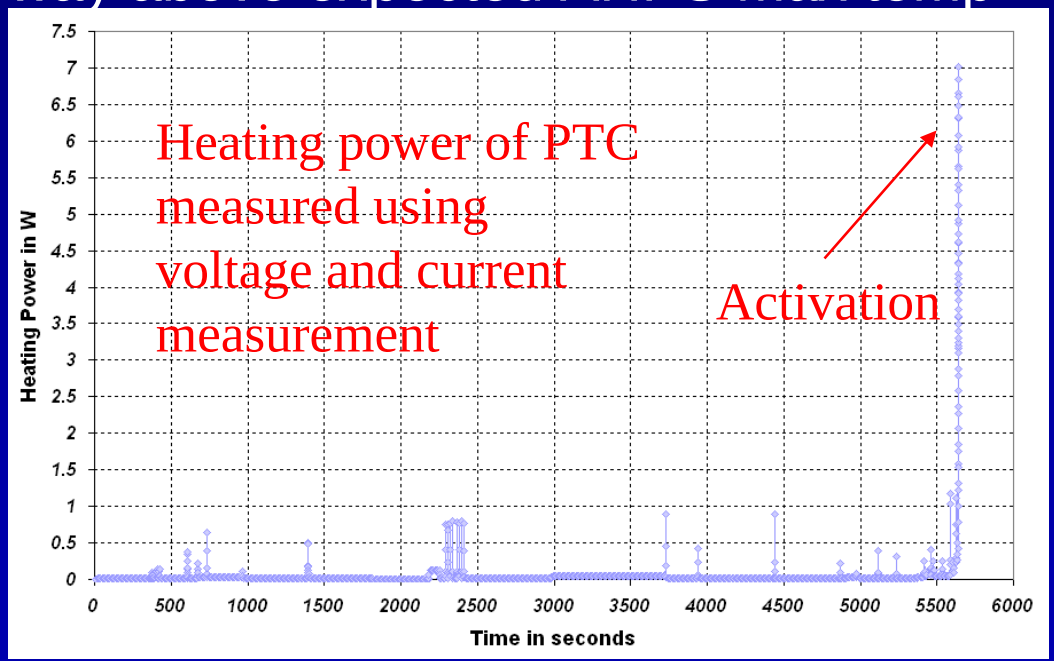
Mission Profile Tests: Hot Case

- Scaled 86s50p mission tests performed:
  - 75°C, 80°C, 85°C, 90°C
- All tests performed on 3 cells
- PTC only begins to activate at 90°C, way above expected AHPS max temp



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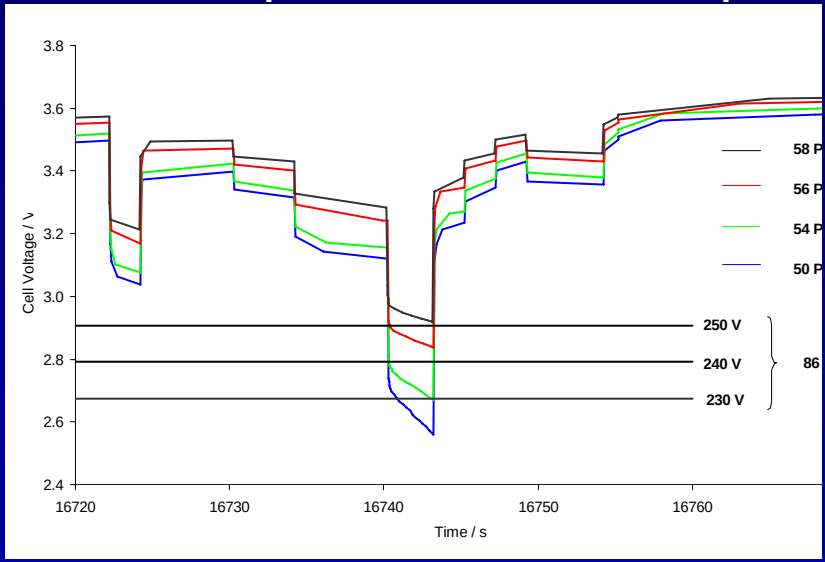
Mission Profile Tests: Cold Case

- 20degC test
  - 86s: 50p, 54p, 58p, 60p
- Confirmed 54p limit at cold temperature



- HOT CASE: 86s50p, 90degC limit
- COLD CASE: 86s54p, 20degC limit

⇓

COLD CASE IS DRIVER

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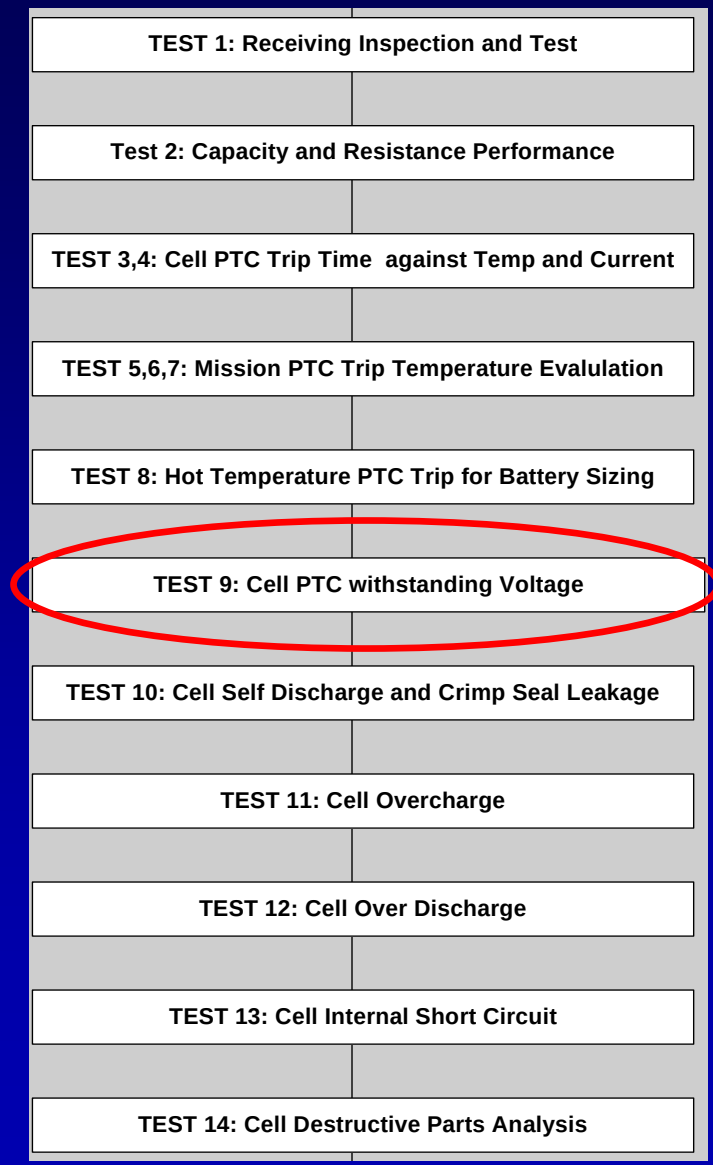
PTC Withstanding Voltage

- Attempt to measure robustness of PTC to failure under high voltage
- 22degC, placed in series with 15A DC supply
- Results indicated maximum voltage was around 38V – similar to SONY cell
- More representative testing performed at string level on SONY 18650HC
  - Thermal effects from other cells



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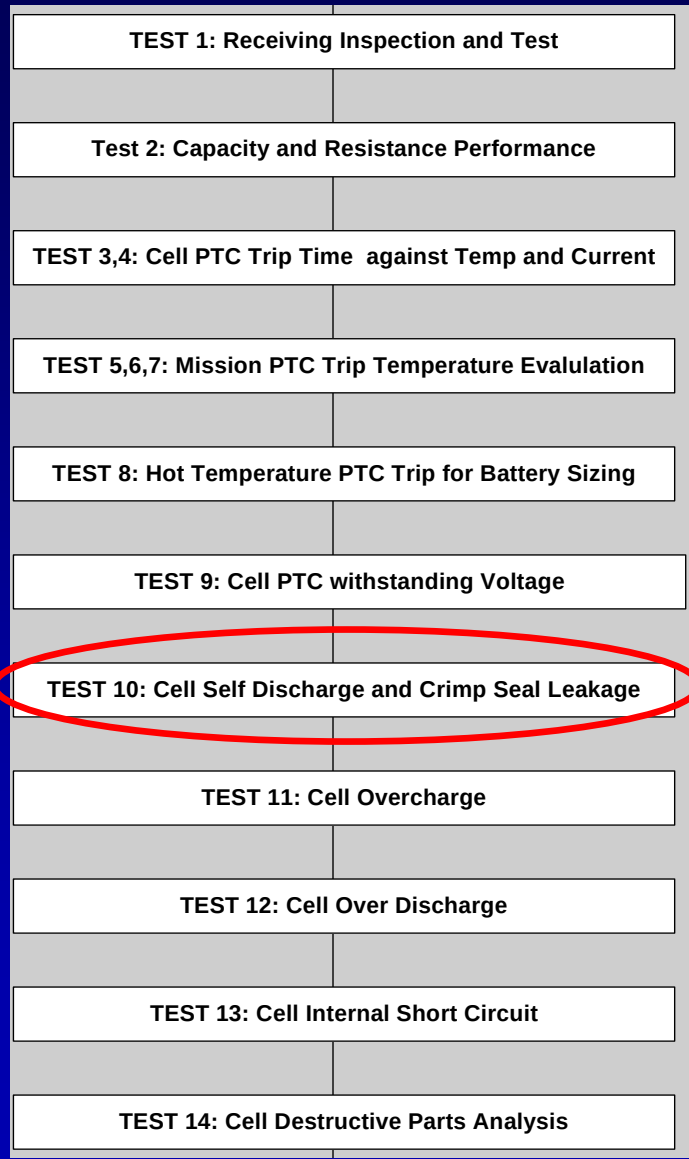
Self Discharge and Leakage Test

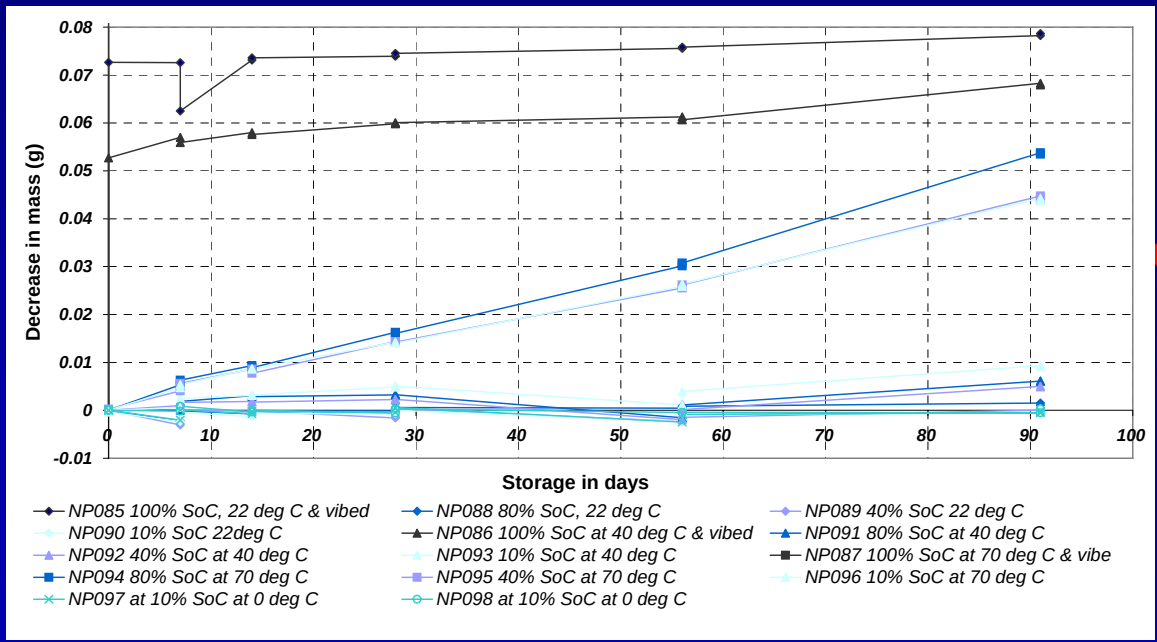
Temp (°C)	100% SOC	80% SOC	40% SOC	10% SOC
0°C	-	-	-	NP 097, 98, 99
22°C	NP085	NP088	NP089	NP090
40°C	NP086	NP091	NP092	NP093
70°C	NP087	NP094	NP095	NP096

Thermal cycle + Vibration



Self Discharge and Leakage Test

- Cell NP087 damaged during removal from vibe jig
- Thought leakage in NP085 and 086 could be due to similar problem
- High temp mass loss thought to be due from chemical dissociation and gas release



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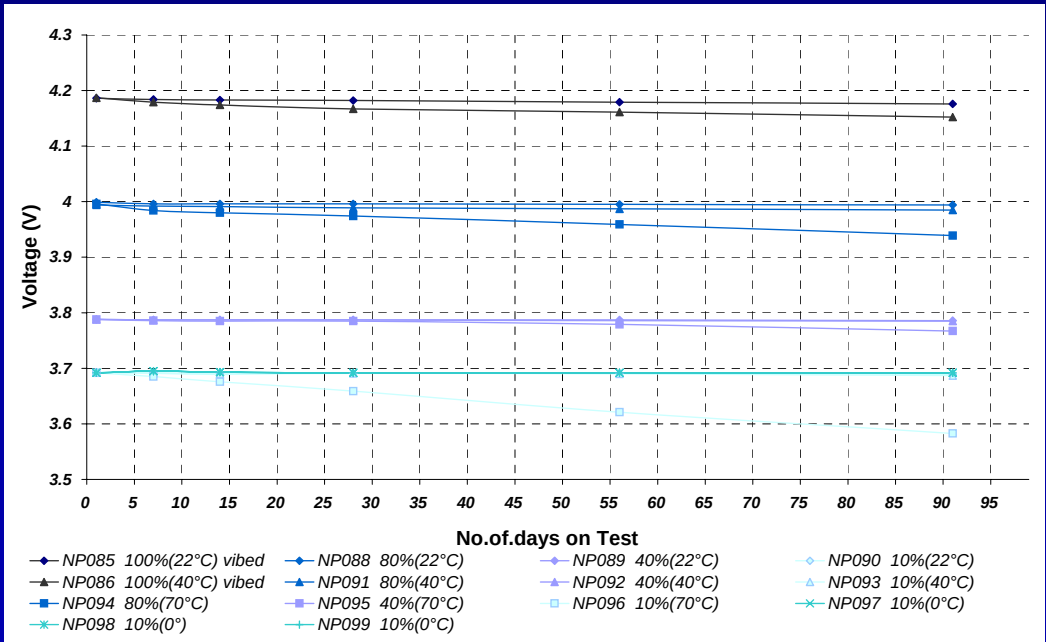
Self Discharge and Leakage Test

- Low voltage drop due to self-discharge
- Self discharge increase with temperature evident in 10%SOC plot
- Test error meant capacity loss from self-discharge could not be differentiated from irreversible capacity loss



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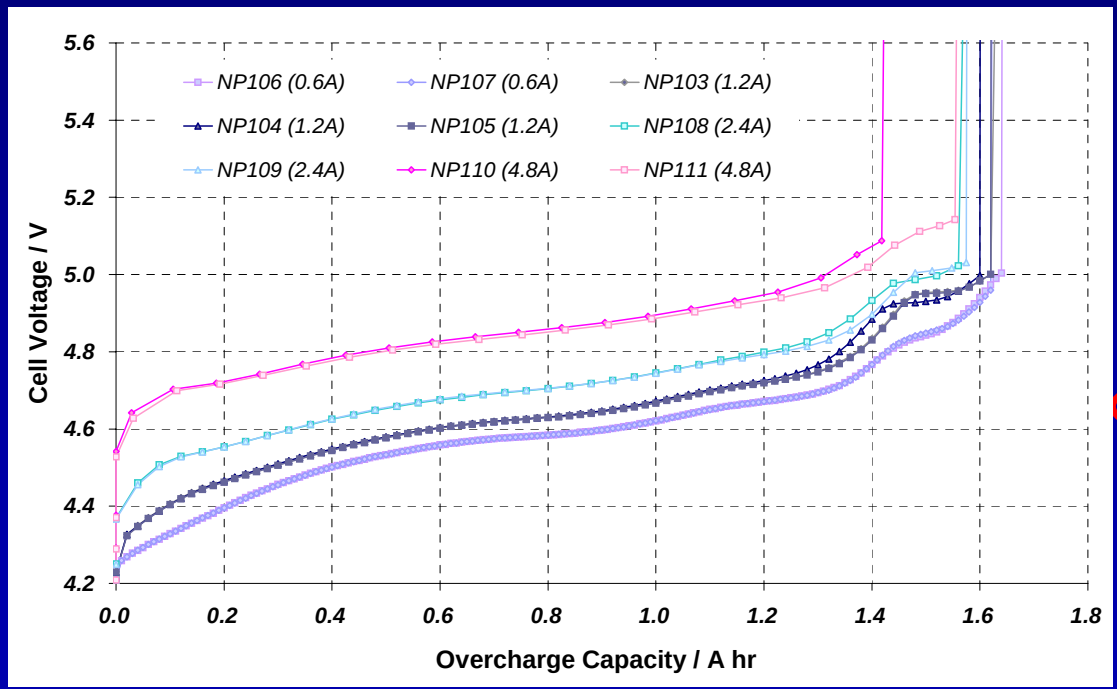
Cell Overcharge

- Charged to 12V, fixed currents
  - 0.6A, 1.2A, 4.8A
- All 6 cells disconnect close to 5V
- Matched other dedicated testing at 1.2A



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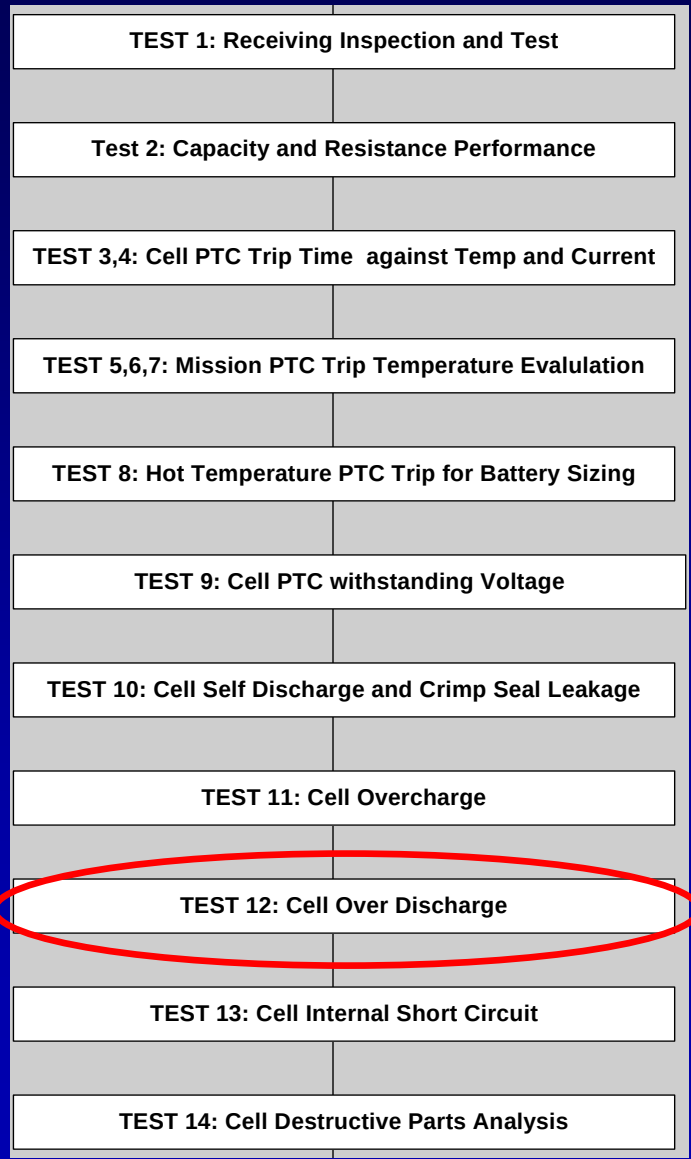
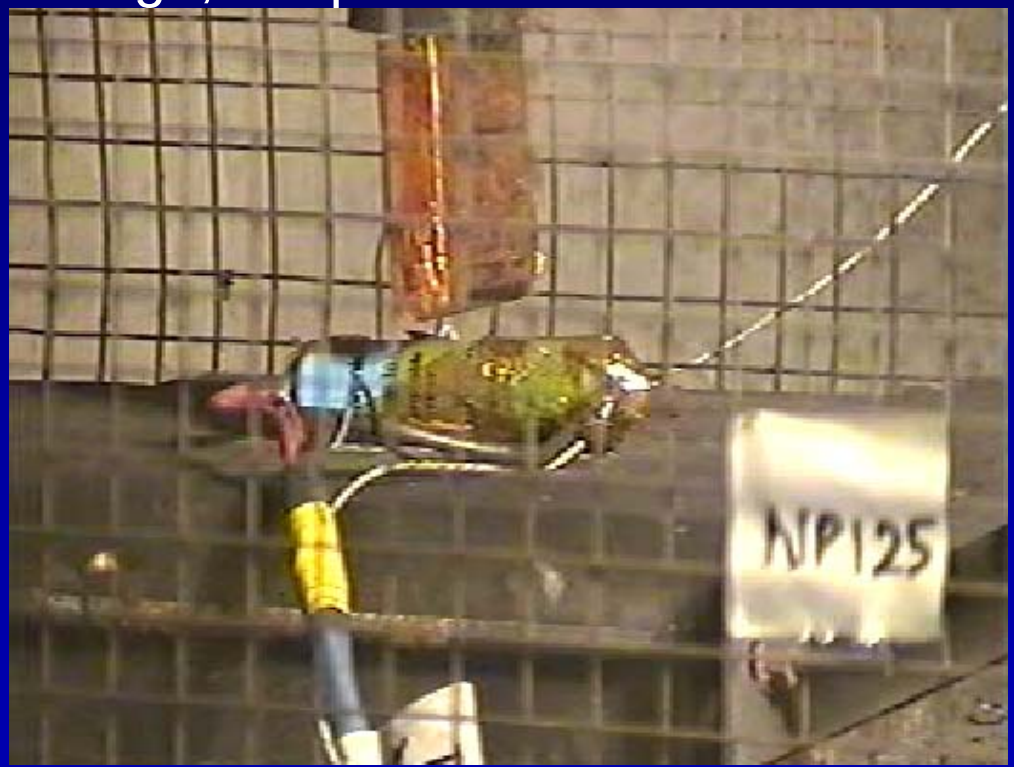
Cell Overdischarge

- Fully charged cells discharged
  - to 2.5V held for 60mins (@XAmps)
  - to 2.0V held for 60mins (@XAmps)
  - to 1.0V held for 60mins (@XAmps)
  - Charged back to 4.2V (@0.43A)
  - Discharged to 2.8V (@0.43A)
  - Discharged to 0V (@XAmps)
  - Discharged at 1.2A to 150% of 1C
- 3 cells each at X=1.2A, 2.4A, 4.8A
- At negative voltages, all cells soft short and act as resistors



Cell Internal Short Circuit

- 3 fully charged cells
- 25°C±5°C
- Non-metallic crush rod through cell centre
- Voltage, temperature monitored



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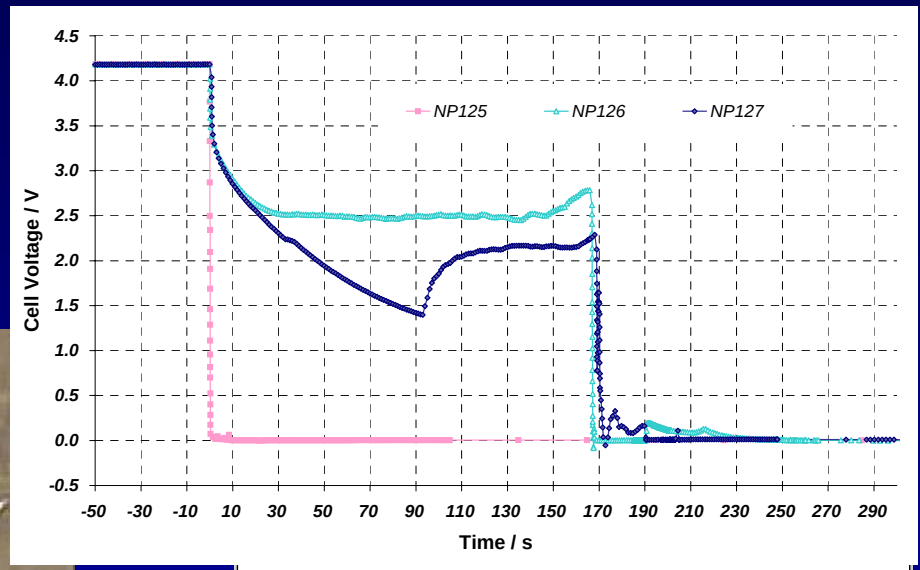
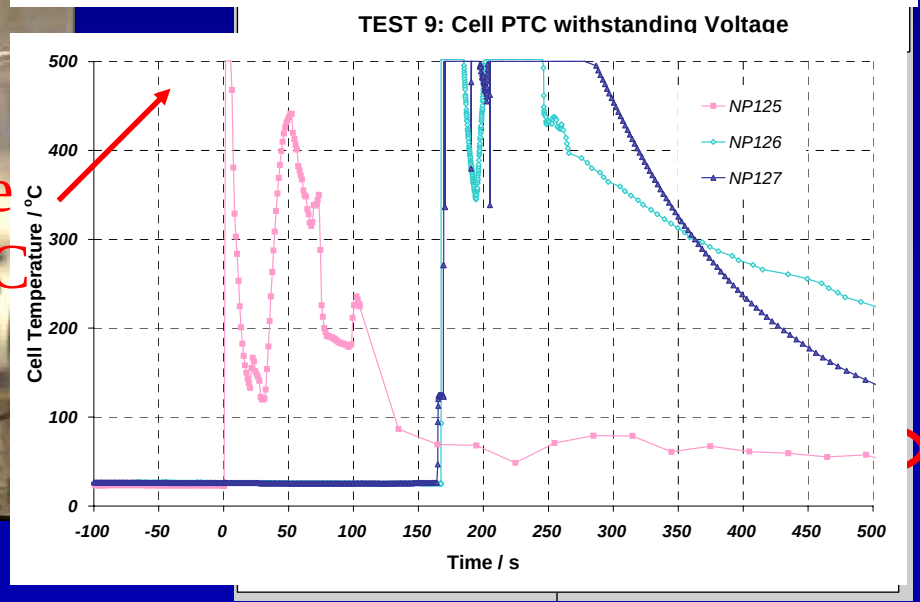
Cell Internal Short Circuit

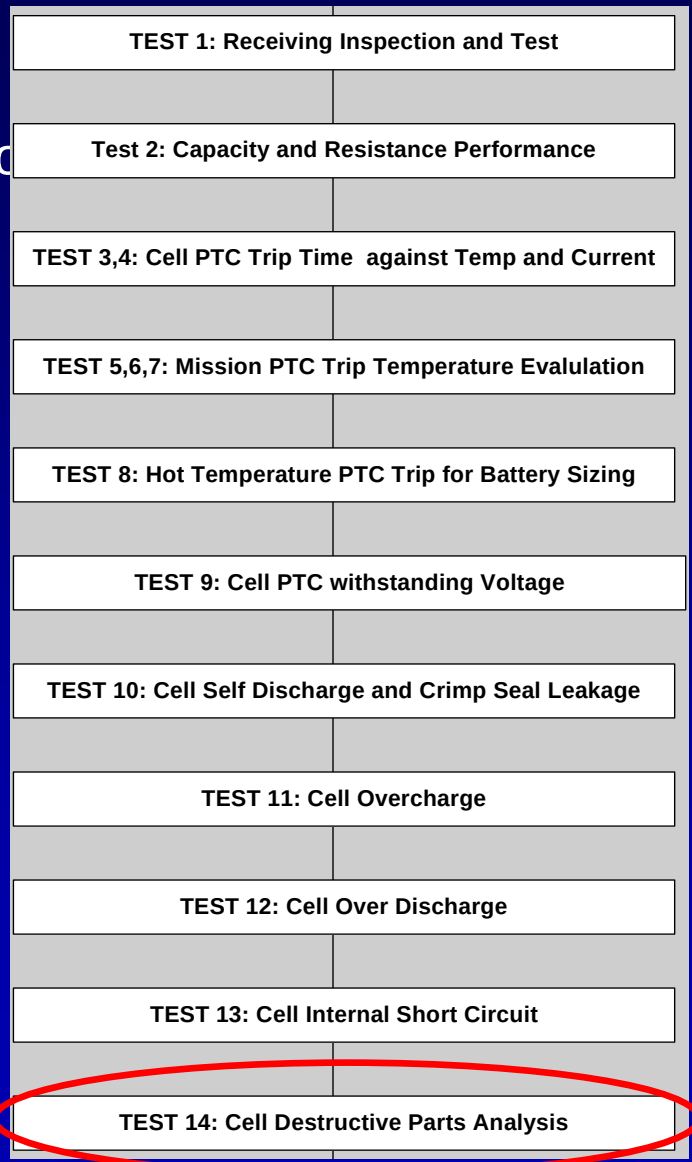
- All 3 cells caught fire as cells cleave in 2
- Screw action test may leave soft short





Cell DPA

- 2 cells disassembled, chemical composition analysed
- Electrolyte extracted with anhydrous methanc
  - Organic analysis
  - Inorganic analysis
  - Karl Fischer test (water content)
- SEM and EDAX examination
  - Anode
  - Cathode
- Separator analysis
  - IR spectroscopy
- Cell Construction inspection
  - Similar to all other 18650s encountered
- Cell burst and vent pressure measured
  - Burst ~47bar max Vent ~18bar max
  - Above 2.5 safety ratio



Conclusions

- AEA selection and successful Interim Design Review for AHPS proves maturity of small cell approach for very large batteries
- Cells show excellent opportunity for battery mass reduction for AHPS and other low cycle applications
- Lack of cycle and extended calendar life make EOL battery performance difficult (AHPS 8 year mission)
- Preliminary design, AEA retained SONY 18650HC cell as baseline
  - Well characterised performance
  - Wealth of safety test data