

Lithium-Ion Small Cell Battery Shorting Study

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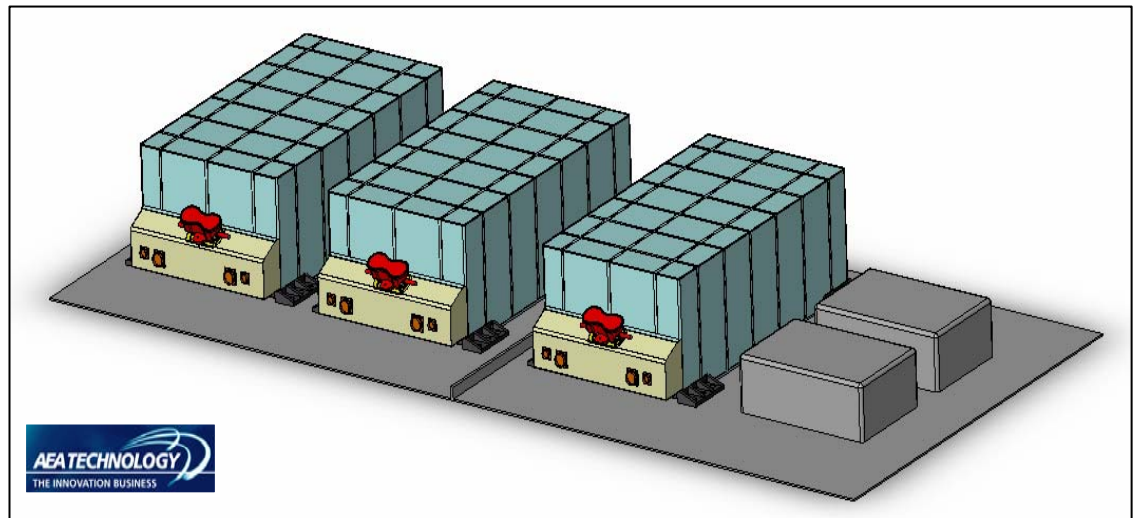
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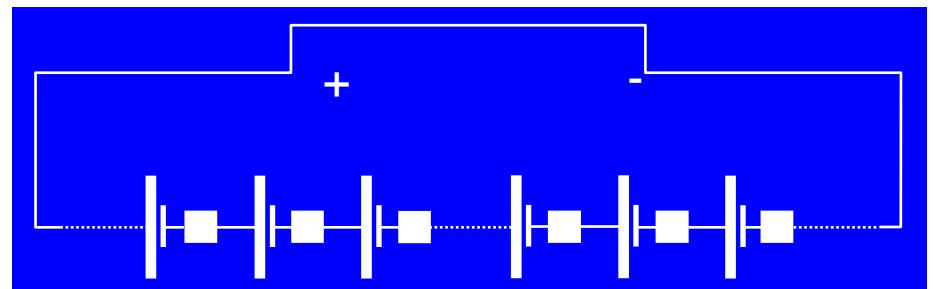
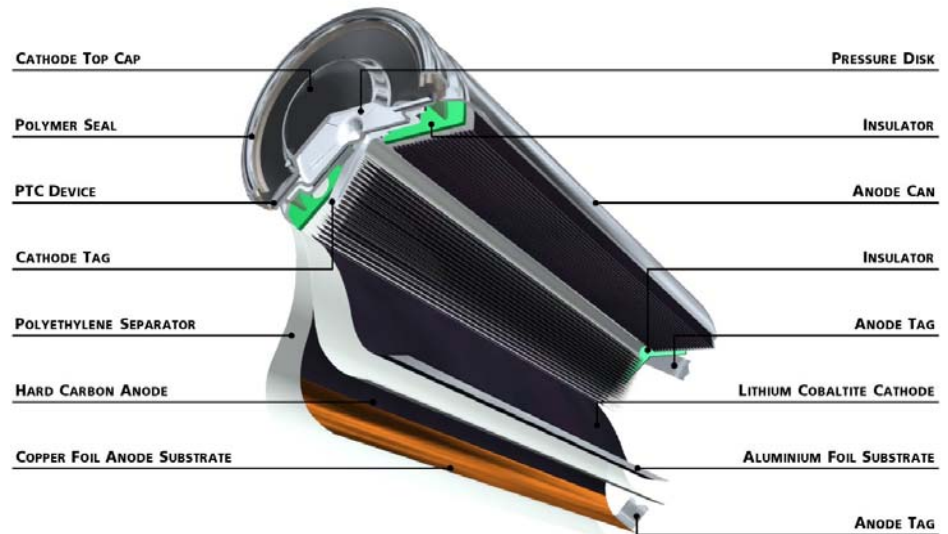
Background: History

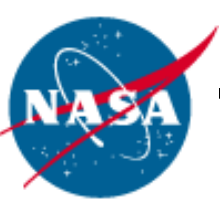
- NASA/Johnson Space Center (JSC) identified Battery hard short issue during Electric Auxiliary Power Unit (EAPU) project
- NASA/Goddard Space Flight Center (GSFC) encouraged AEA to understand process and mitigation strategy for unmanned work
- AEA conducted hard short study under internal funding
- Understanding Positive Temperature Coefficient (PTC) limitation was critical to AEA winning the Advanced Hydraulic Power System (AHPS) contract
- Diode scheme implemented for AHPS (86s) battery passing safety segment of Interim Design Review



Background: PTC Functionality

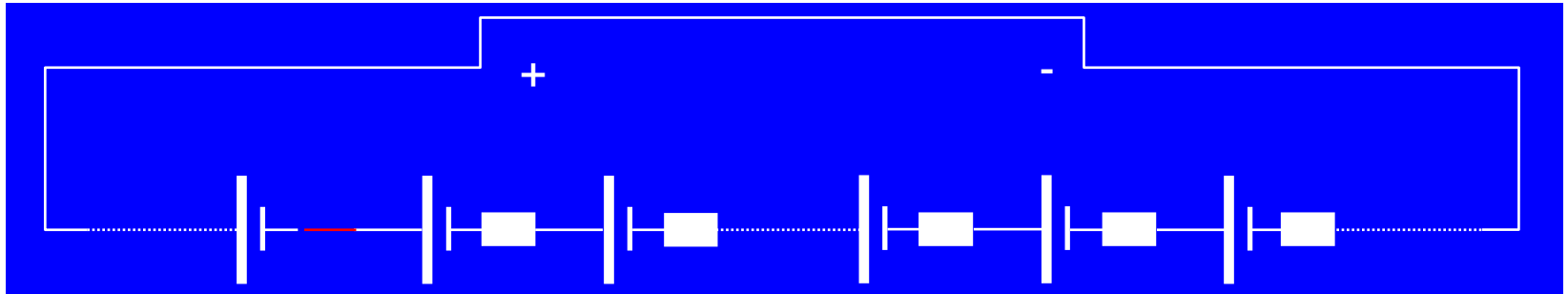
- PTC is a standard safety feature in the SONY 1.5 Ah 18650HC Lithium-Ion small cell
- PTC is a temperature dependent resistor in series with cell
- At high current, temperature rise triggers resistance rise in PTC stopping current flow
- PTC mitigates high energy events associated with short circuit
- Key safety benefit of the small cell approach



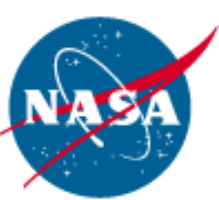


Background: PTC Limitations

- Series-PTC can fail short circuit if sufficiently high voltage is applied

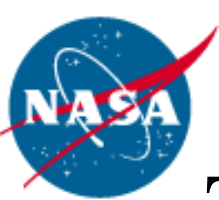


- In event of sustain low impedance hard short across battery terminals, no protection if voltage is higher than rating
- Cells become increasingly hot, venting can occur
 - However, much less energetic event than in a large cell
- Possible safety issues
 - ground handling
 - manned space applications



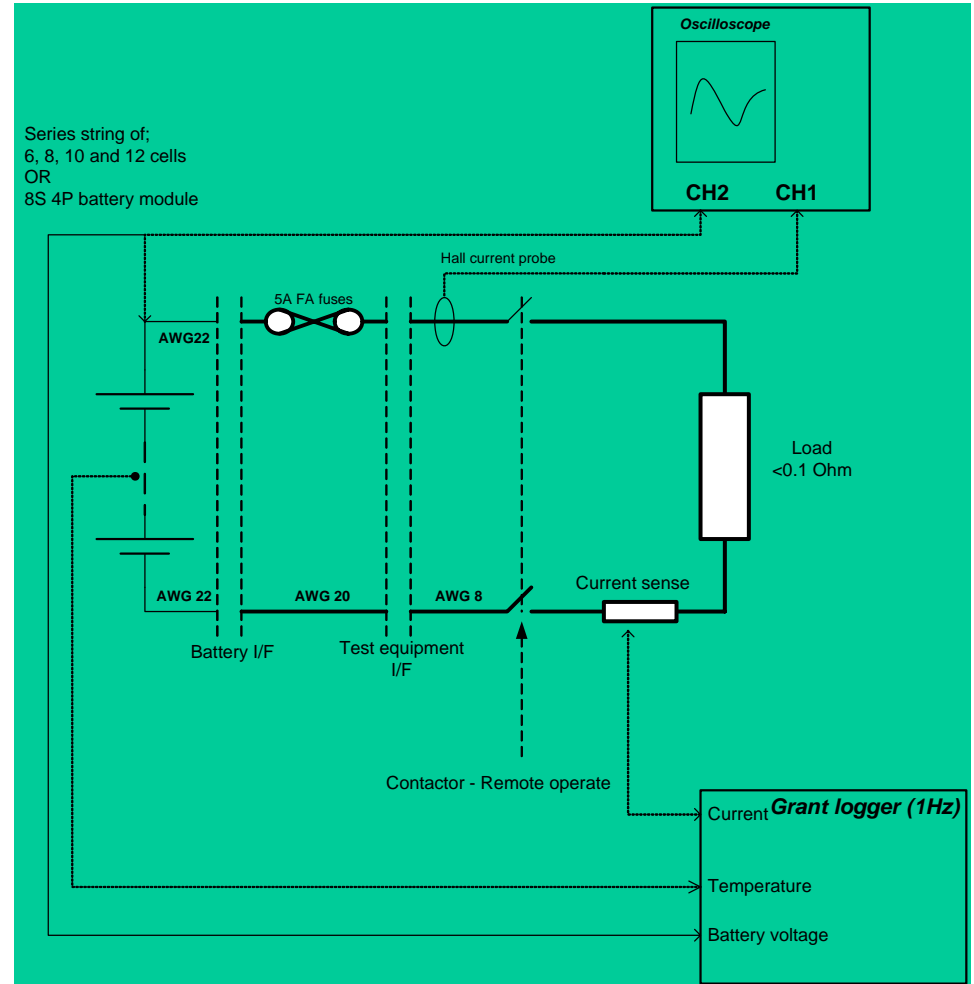
Test Plan

- Hard Short Single (1p) String Tests
 - 6s
 - 8s
 - 10s
 - 12s
- Battery Module (8s4p) Tests
 - 2C discharge test
 - Hard short with fused saver
 - Hard short without fused saver

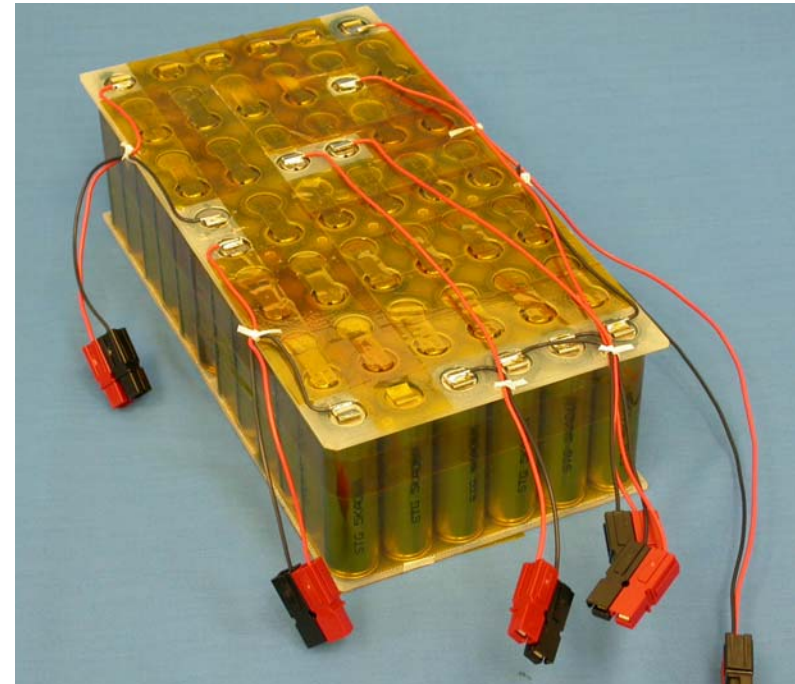
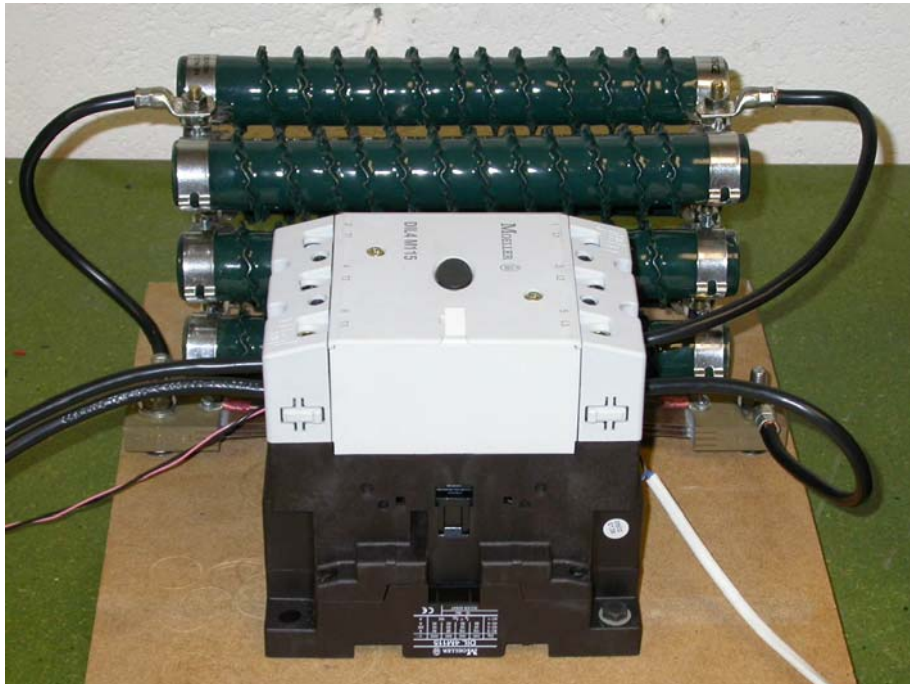


Test Results: Single String Test Set Up

- Test set up for controlled short circuit
- Recorder to log temperature, voltage and current during short circuit
- Oscilloscope to capture fast transients
- Remote operation



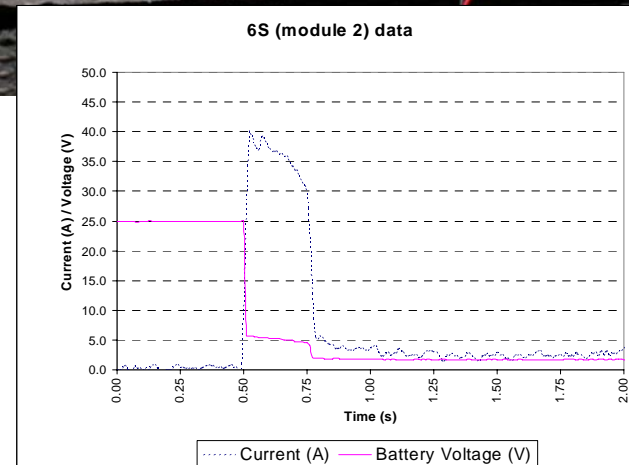
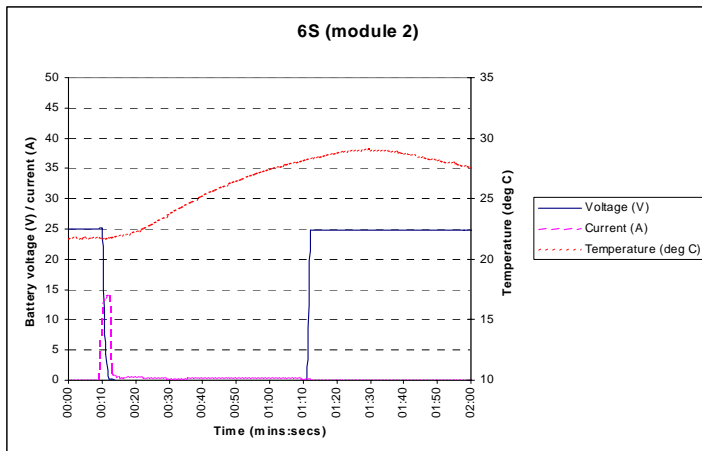
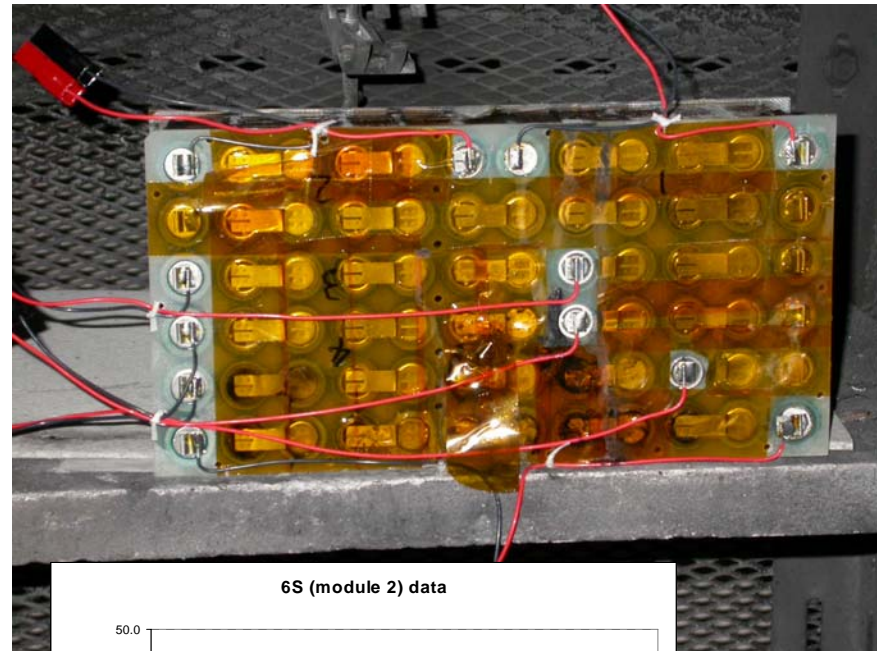
Test Results: Single String Test Hardware



- AEA built low resistance relay block
- Single battery block split into strings

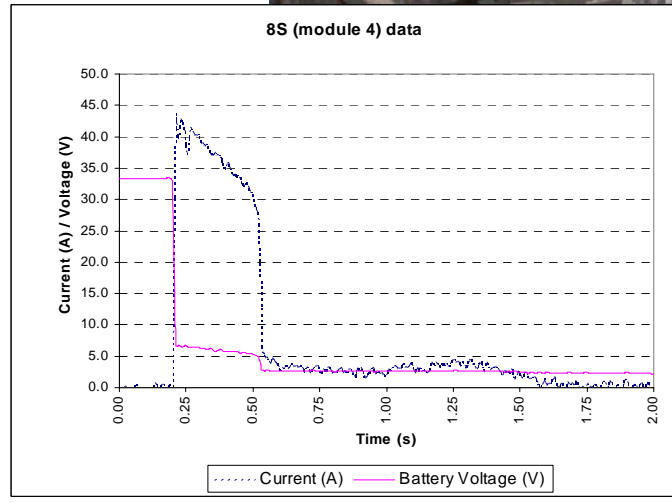
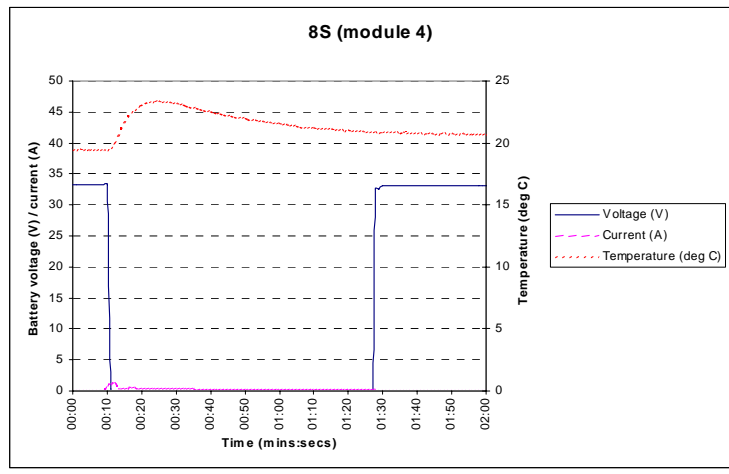
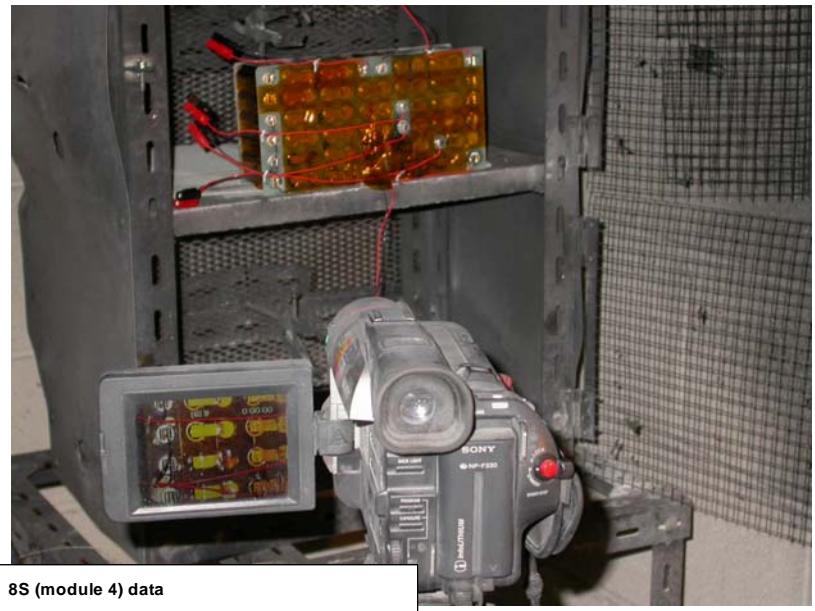
Test Results: Single String 6s1p Sustained Short

- PTC activates in 0.5 sec.
- Temperature rise 8°C
- PTC ensures safe shutdown



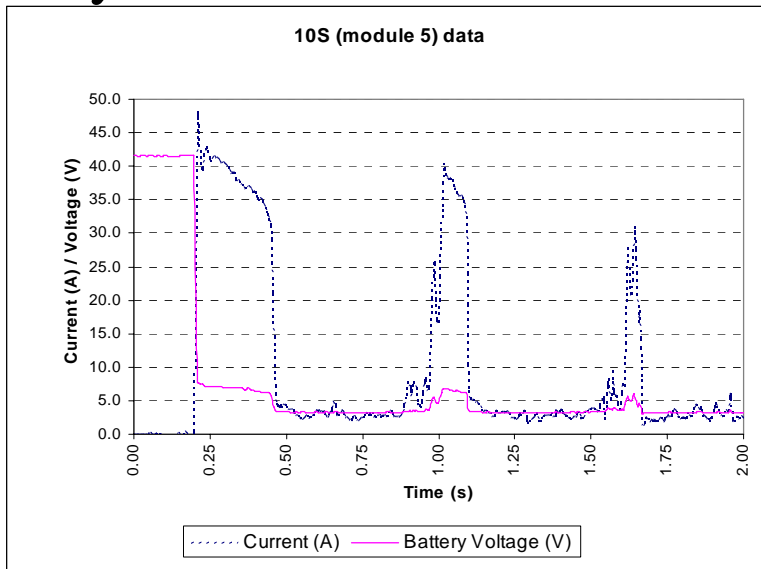
Test Results: Single String 8s1p Sustained Short

- PTC activates in 0.3 sec.
- Temperature rise 2°C
- Maximum current 42 A



Test Results: Single String 10s1p Sustained Short

- PTC initially activates in similar manner to 6s & 8s test
- 1st PTC breaks down after 0.5 sec.
- Succession of PTC activation followed by breakdown

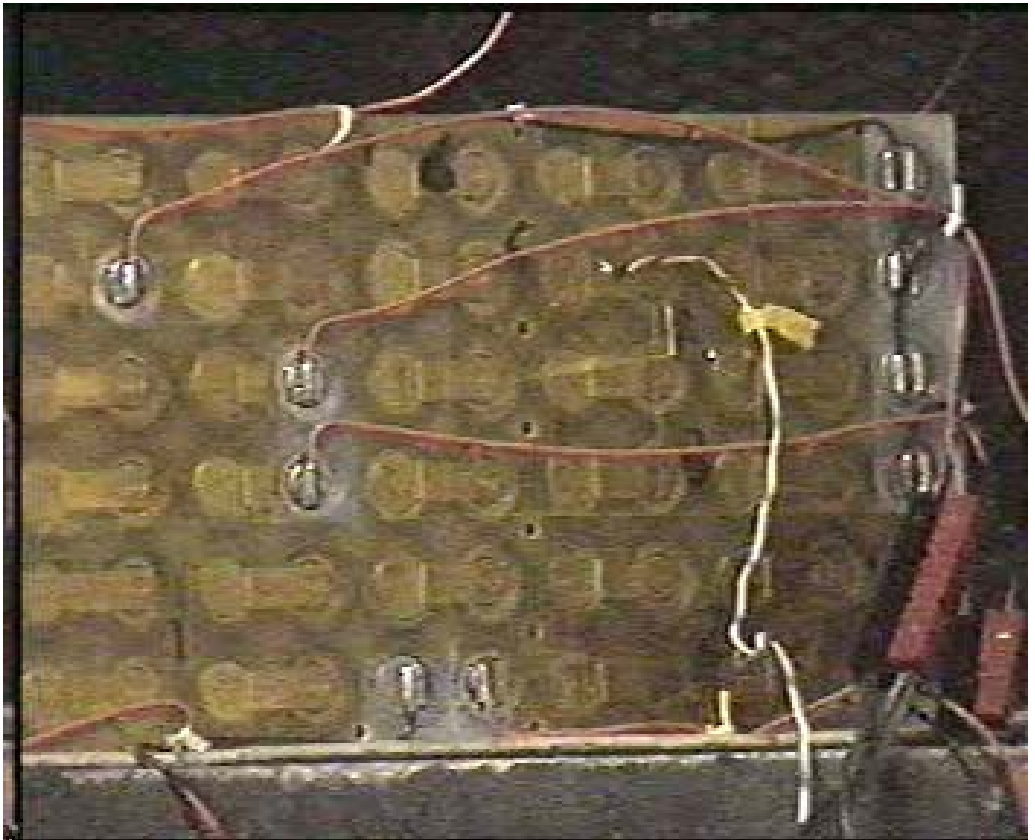


- Temp rises to 28°C after 40 sec.



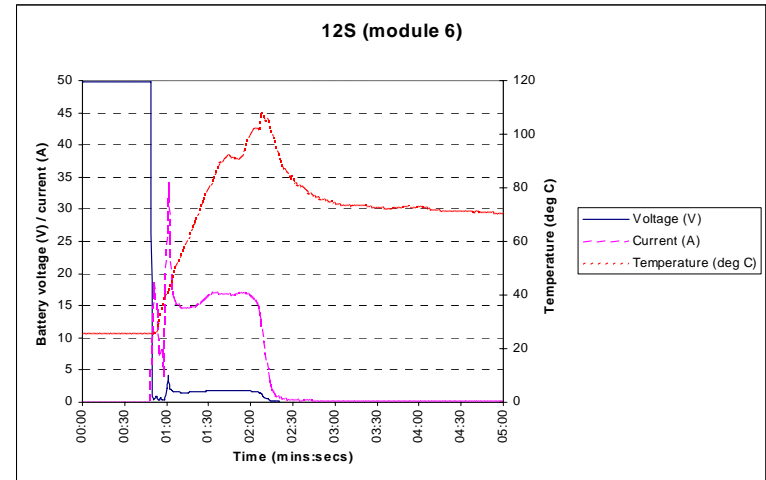
Test Results: Single String 10s1p Sustained Short

- Small sparks
- Cell vent
- Electrolyte leak
- No smoke
- No fire

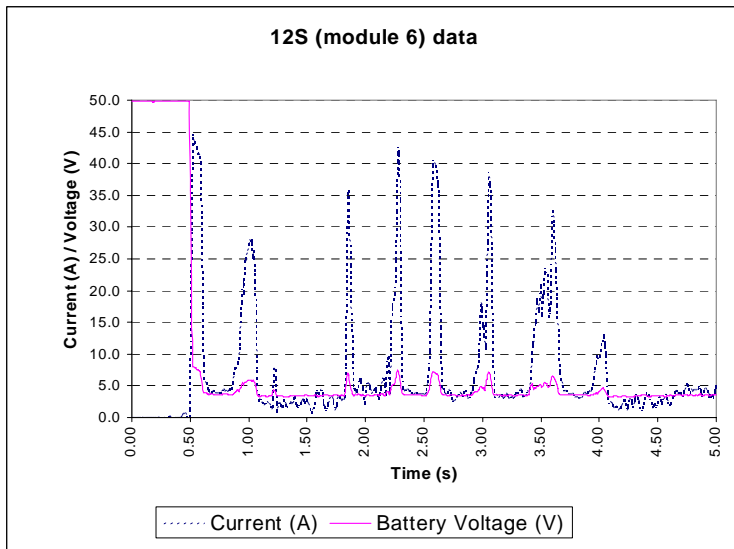


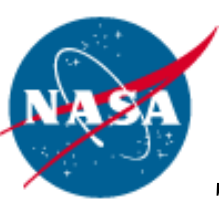
Test Results: Single String 12s1p Sustained Short

- PTC initially activates in similar manner to 6s & 8s test
- 1st PTC breaks down after 0.5 sec.
- Succession of PTC activation followed by breakdown



- 17 A sustained for 2 min. causes temperature to rise to 110°C





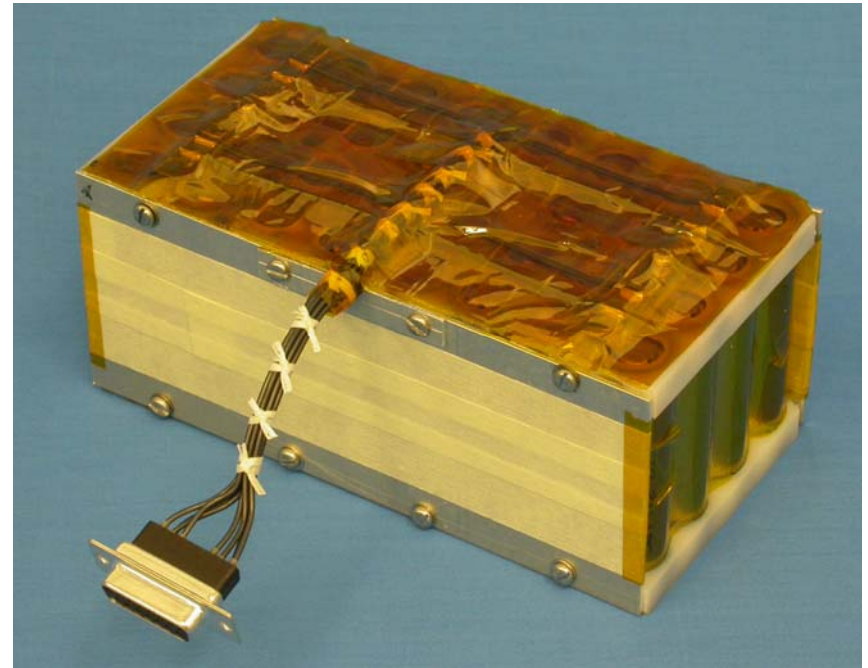
Test Results: Single String 12s1p Sustained Short

- Small sparks
- Cell vent
- Electrolyte leak
- No smoke
- No fire



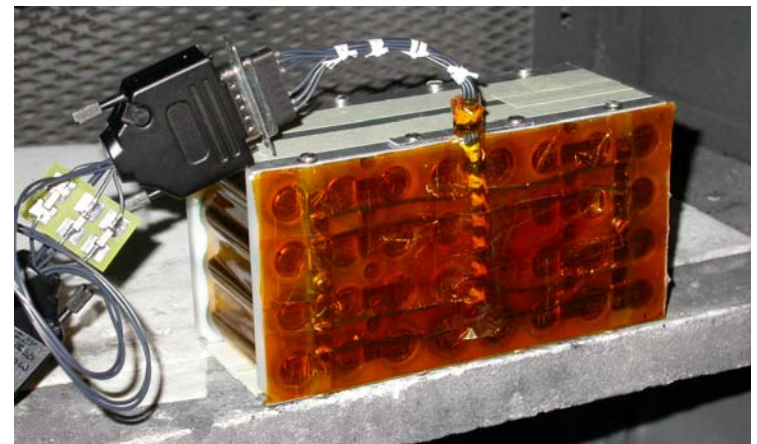
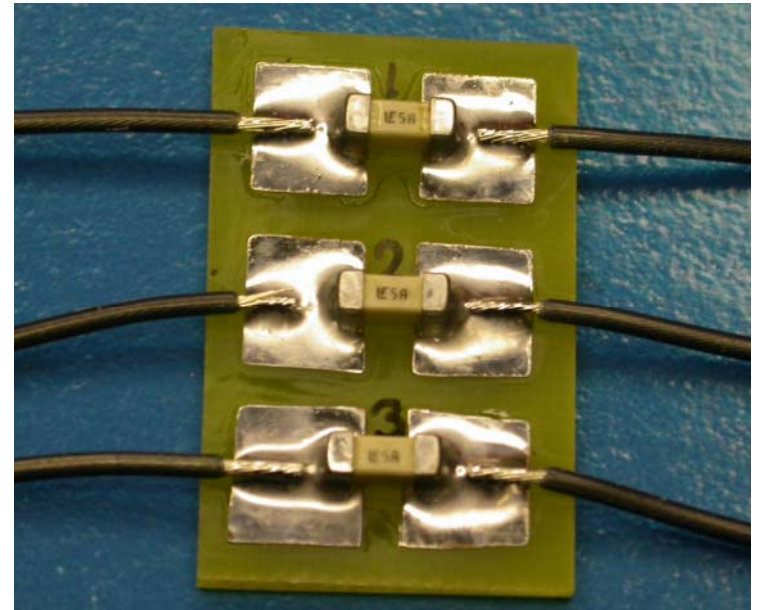
Test Results: Battery Module Test Hardware

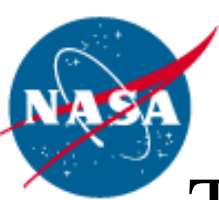
- Dedicated battery module
 - 8 cells in series
 - 4 strings in parallel



Test Results: Battery Module Test Hardware

- Fused connector
 - Ensures protection against short during Integration and Testing
- Standard AEA equipment
- Fuses sized
 - To ensure nominal battery performance is unaffected
 - Rating of wiring is not exceeded
- Inexpensive item
- Removed prior to final spacecraft integration





Test Results: Battery Module Test Procedure

TEST 1:

- 2C discharge for 15 min. with the fused connector

TEST 2:

- Hard short with fused connector

TEST 3:

- Hard short without fused connector

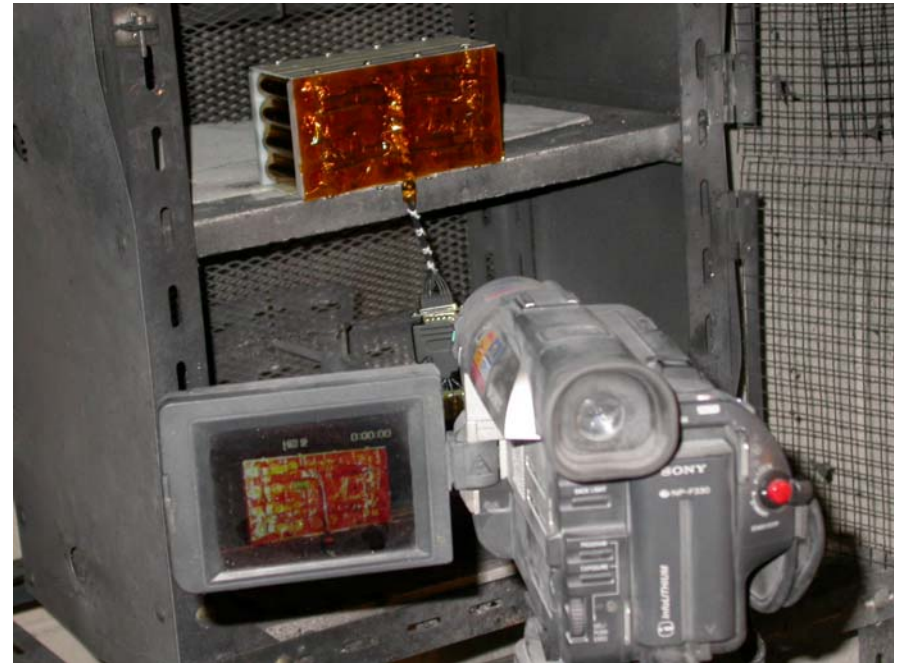
During All Tests:

- Battery Voltage/ Current monitored
- Visual observation for any smoke, sparks or vent

Test Results: Battery Module Test 1

2C discharge test

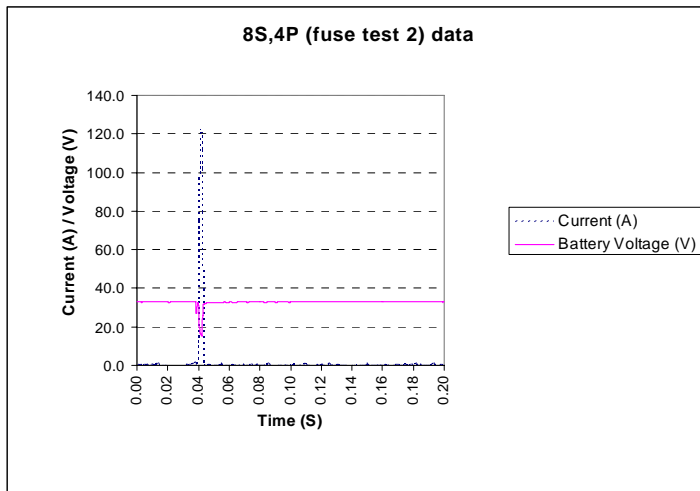
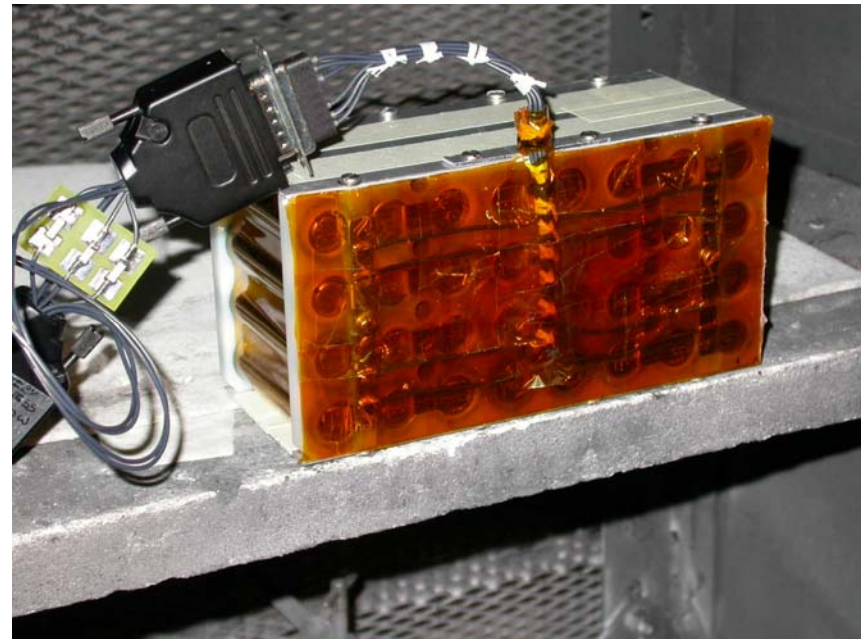
- Battery delivers 2C for 15 min.
- Slight rise in temperature
- Fused connector not activated
- PTC not activated
- Post test AEA Standard Capacity Measurement (SCM) confirmed battery health



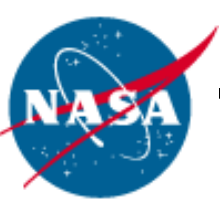
Test Results: Battery Module Test 2

Hard Short Test With Fused Connector

- Protective fused connector instantaneously activates
- No rise in temperature
- PTC not activated



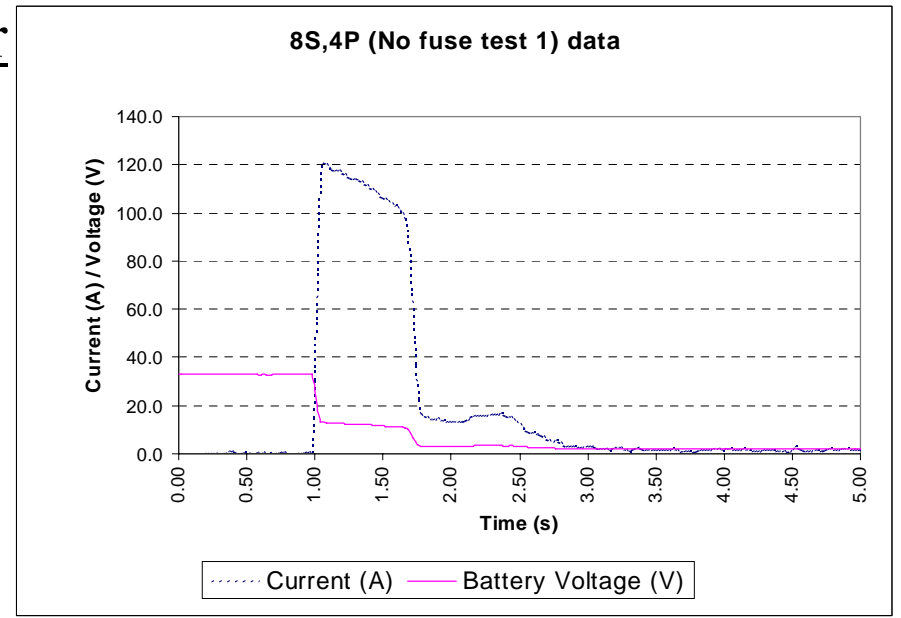
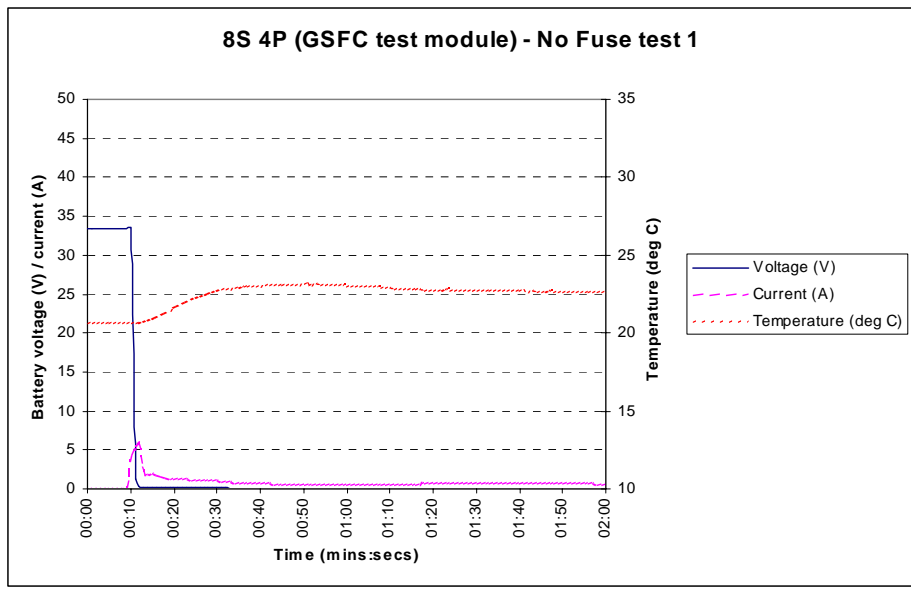
- Post test SCM shows no affect on battery
- Fuse activates within 0.05 sec.
- High current transient around 120 A



Test Results: Battery Module Test 3

Hard Short – No Fused Connector

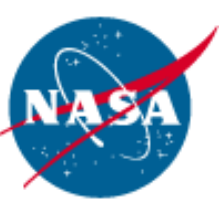
- PTC operated nominally
- Safe shutdown
- No visual events





Test Results: Summary

Cell Configuration	Result
6s1p	PTC Activates Nominally – safe shutdown
8s1p	PTC Activates Nominally – safe shutdown
8s4p	PTC Activates Nominally – safe shutdown
10s1p	PTC breakdown – short circuit
12s1p	PTC breakdown – short circuit



Conclusions

- PTC provides adequate sustained hard short protection for AEA batteries with up to 8 cells in series
- PTC cannot protect against sustained hard short in AEA batteries with 10 cells or more in series
- Protective fused connector is a proven way to protect larger batteries from hard short damage
 - Hard short not credible in unmanned missions
 - However, recommended during ground handling
 - Inexpensive item
- Preliminary diode protection scheme has passed manned space safety requirements for high voltage batteries
- SCM confirmed fused connector did not affect battery health
 - However, this affect of hard short on the its long calendar and cycle life performance needs to be verified.



Acknowledgements

- Dr. Eric Darcy, NASA/JSC
- Don Lester, ASTRIUM