

Reliability Through Life of Internal Protection Devices in Small-Cell ABSL Batteries



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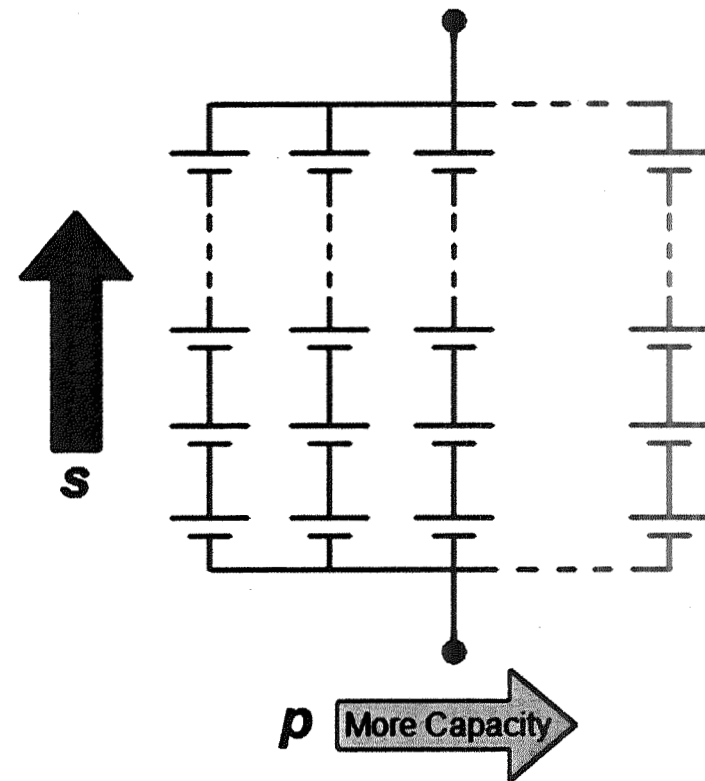
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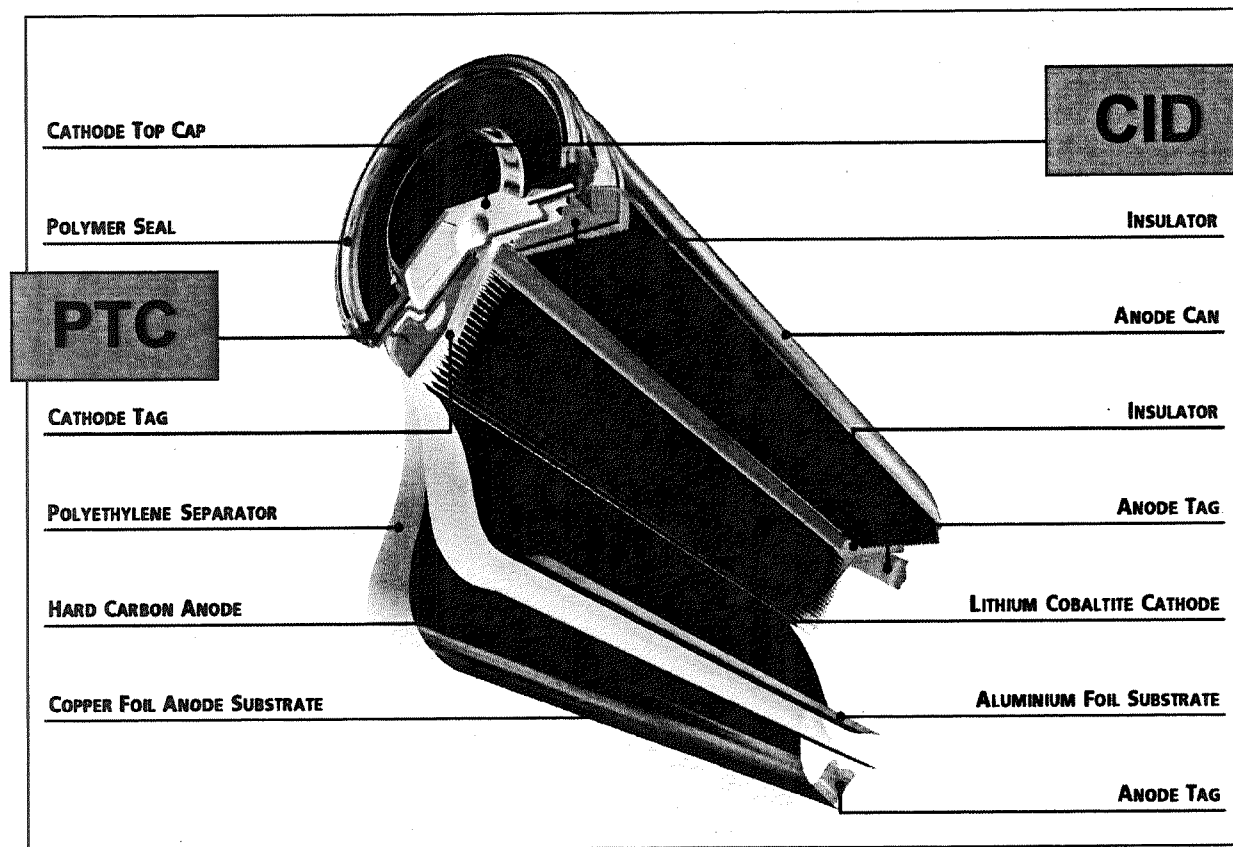
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- The s-p Topology
- Cell Level Protection Devices
- Battery Level Fault Protection
- Large Cell Comparison
- Battery Level Testing & Results
- Conclusions

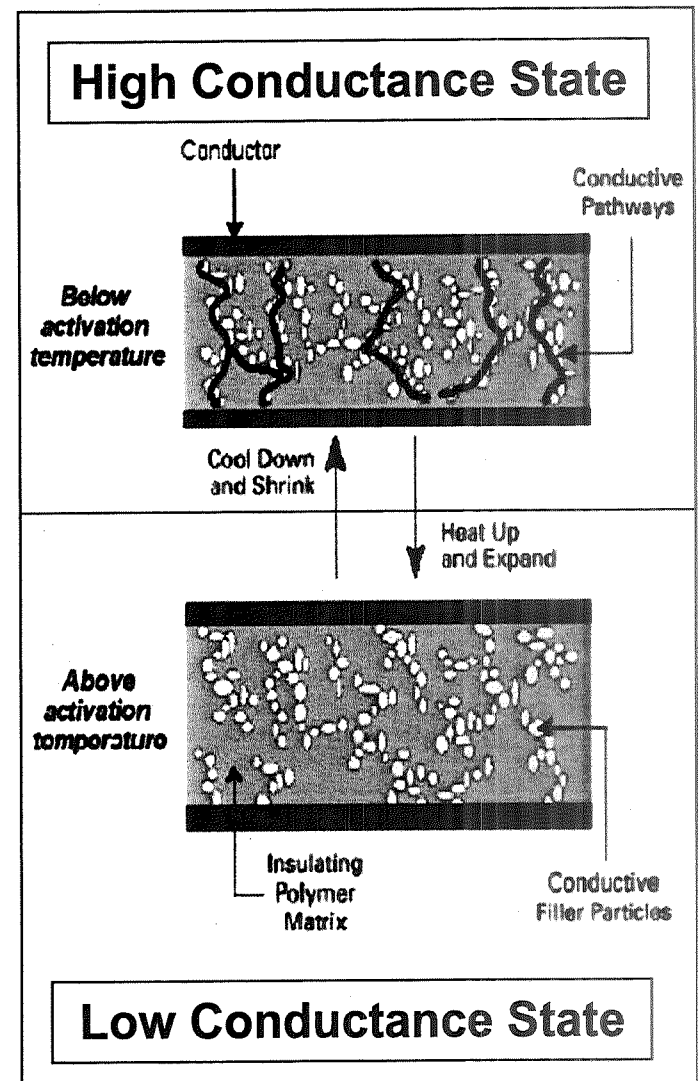
- S = number of cells in series (per string); principally determines battery voltage.
- P = number of strings in parallel; principally determines battery capacity.
- No external cell protection electronics necessary



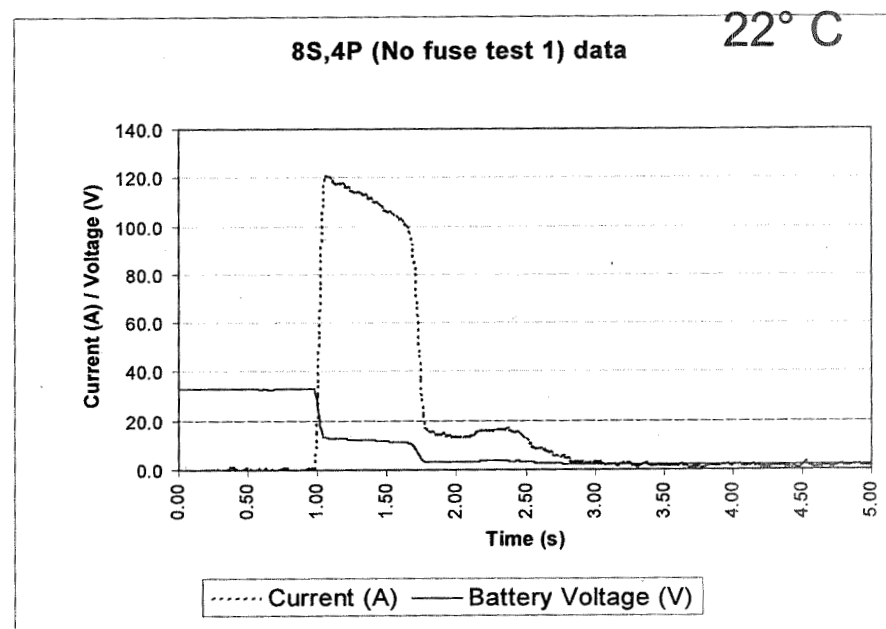
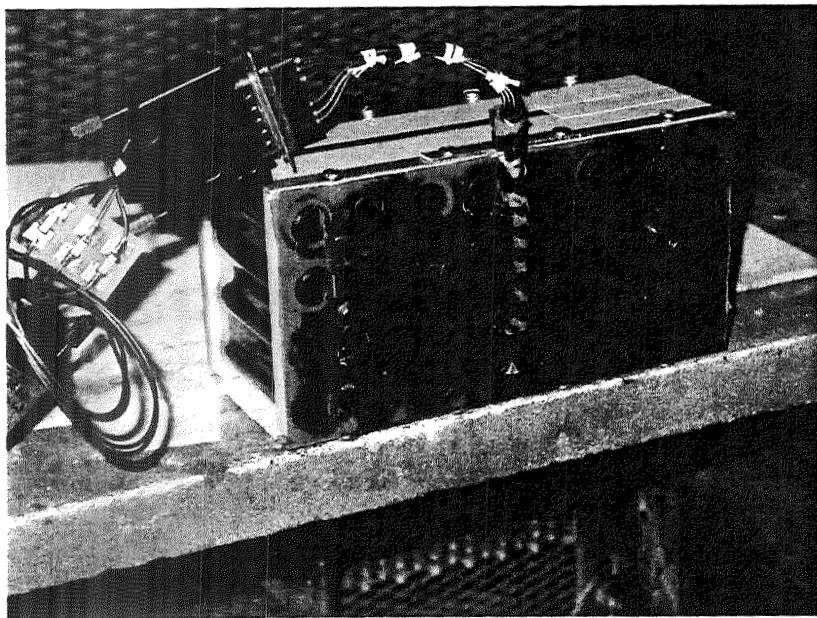
- PTC: Positive Temperature Coefficient Polyswitch
- CID: Current Interrupt Device



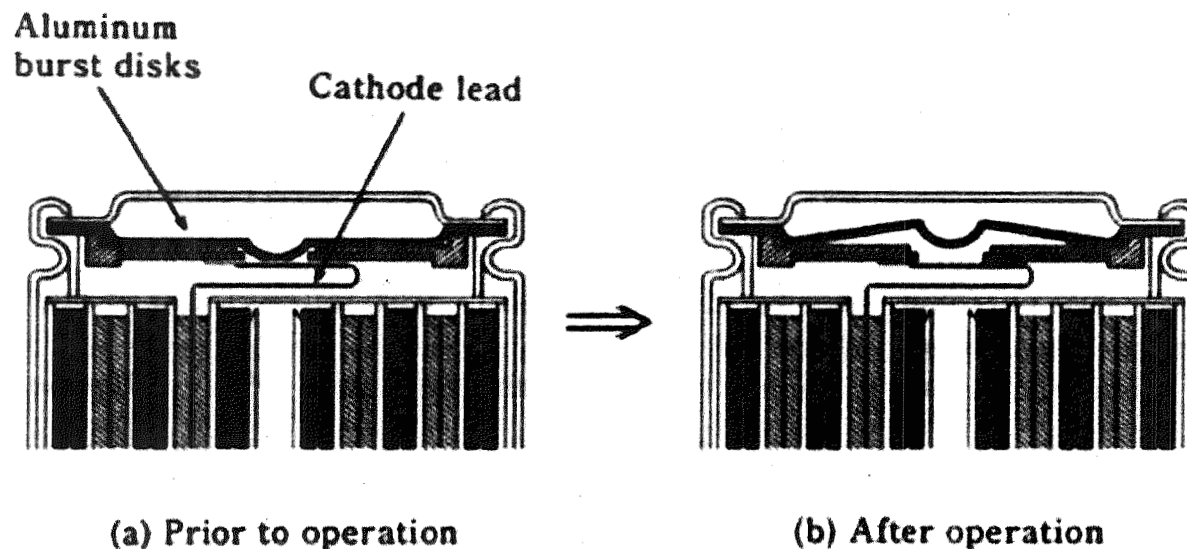
- The PTC circuit is a composite of low conductance semi-crystalline polymer and high conductance filler particles.
- In normal operation, the PTC is high conductance (low resistance)
- At high temperature, PTC conductance decreases by 3 orders of magnitude.
- Acts as a current limiter.



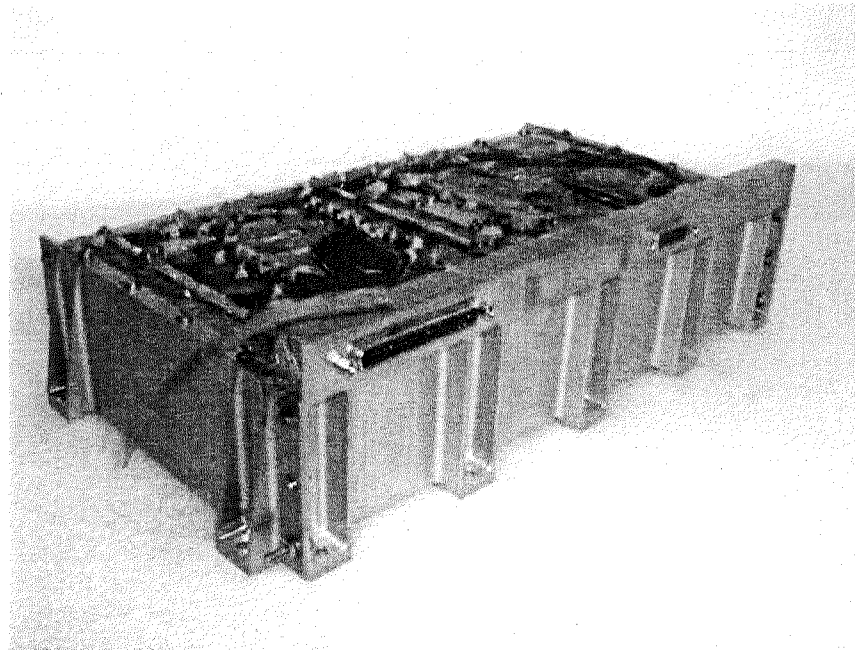
- PTC's proven at battery level:
 - “Lithium Ion Small Cell Battery Shorting Study,” 2004 NASA Aerospace Battery Workshop, C. Pearson, et. al.
 - Qualified up to 8s
 - Engineered solution for >8s



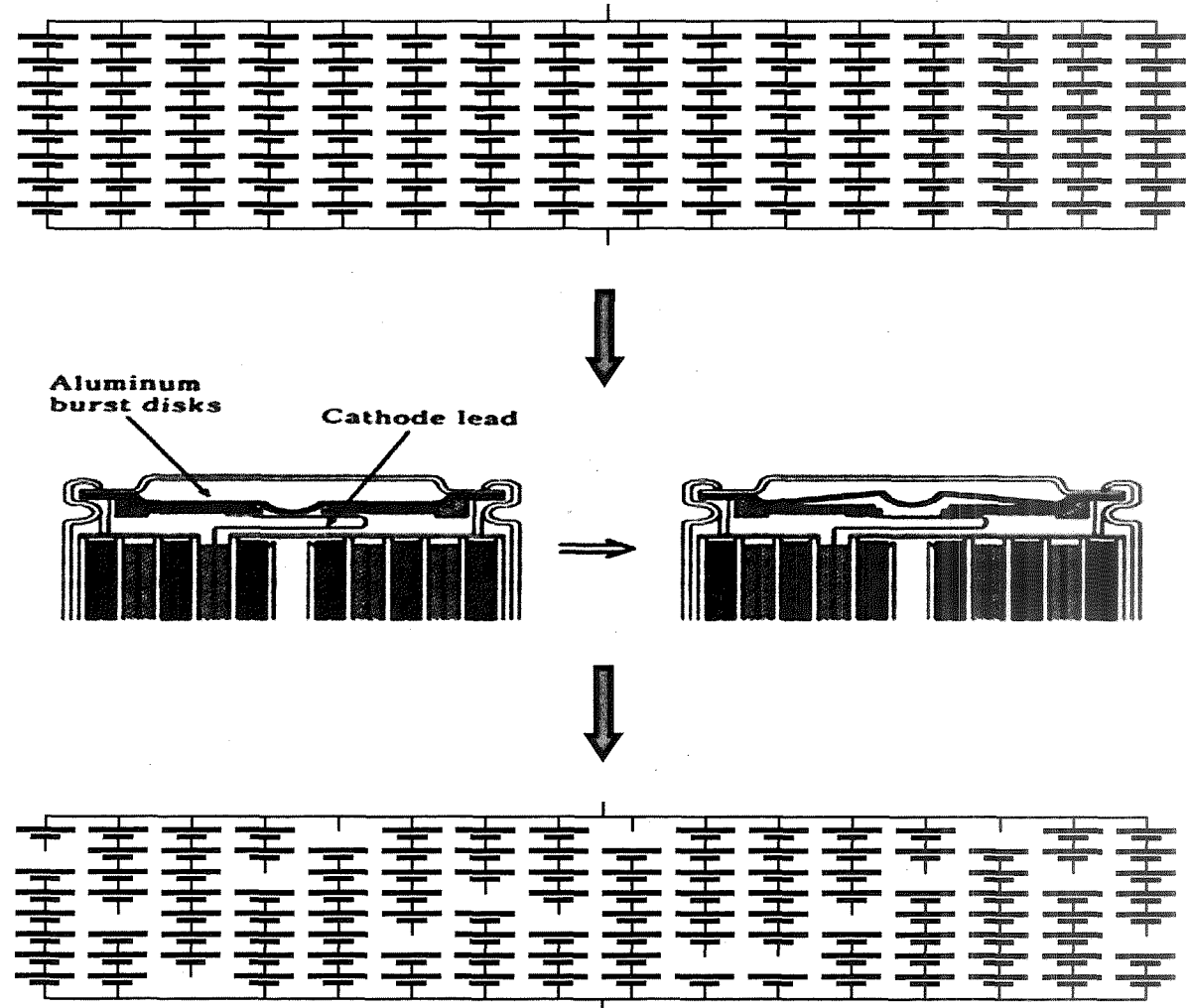
- As the Electromotive Force (EMF) exceeds 4.8V, a chemical reaction takes place emitting CO₂.
- The CO₂ generation raises internal cell pressure until the burst disk distorts, disconnecting the cell open circuit (OC).
- As gas pressure increases further, the burst disk ruptures to safely vent the gas.



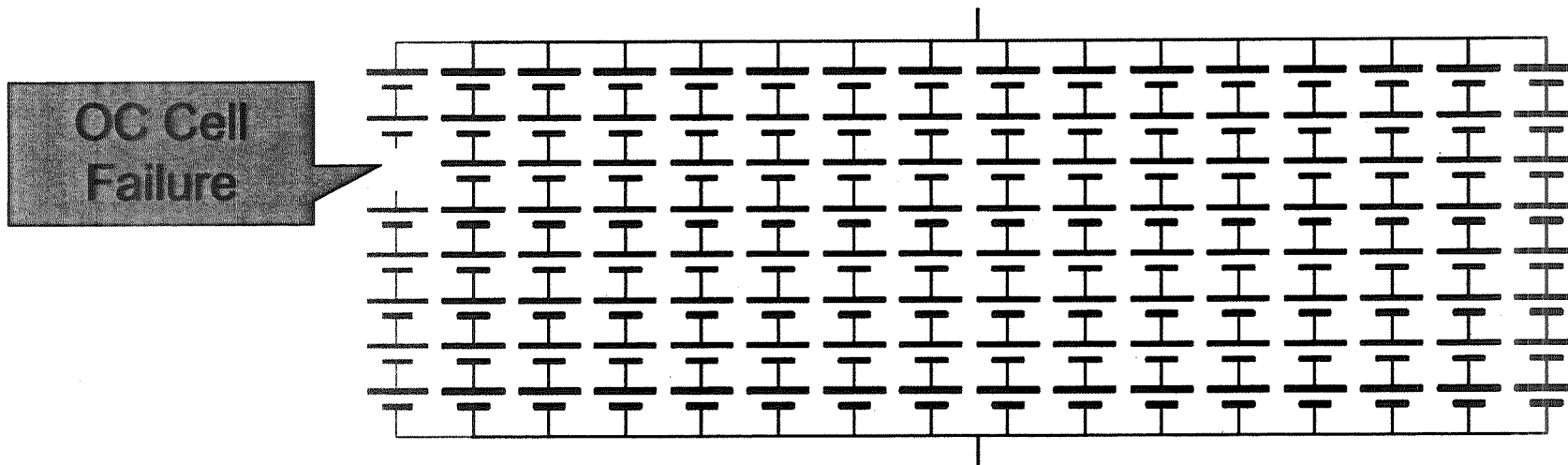
- “Range Safety Considerations for Small Cell Batteries,”
2006 Space Power Workshop, C. Pearson, et. al.
 - 8s16p flight-like battery
 - Overcharged at C/5



- CIDs activated in a cell(s) in each string, safely shutting down the battery.
- No thermal runaway or venting



Highly Tolerant to Cell Failures w/o External Cell Protection Electronics



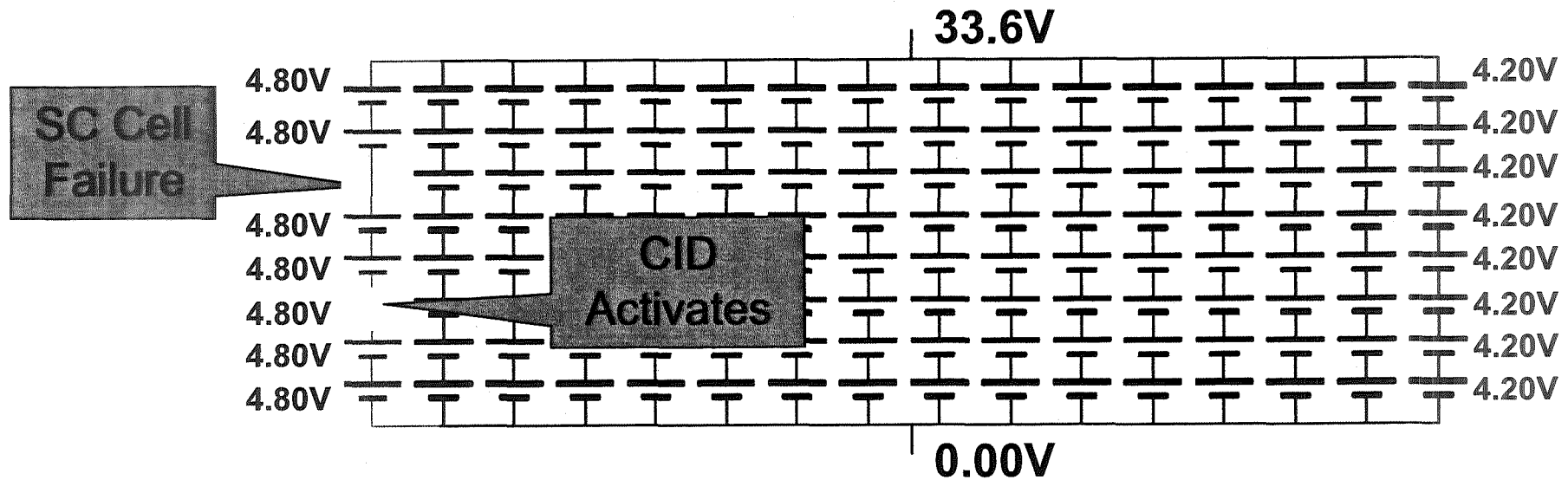
- OC Cell Failure:
 - Corresponding string rendered open circuit
 - Small reduction in capacity, energy
 - Negligible effect on voltage



Battery Level Fault Protection - Continued

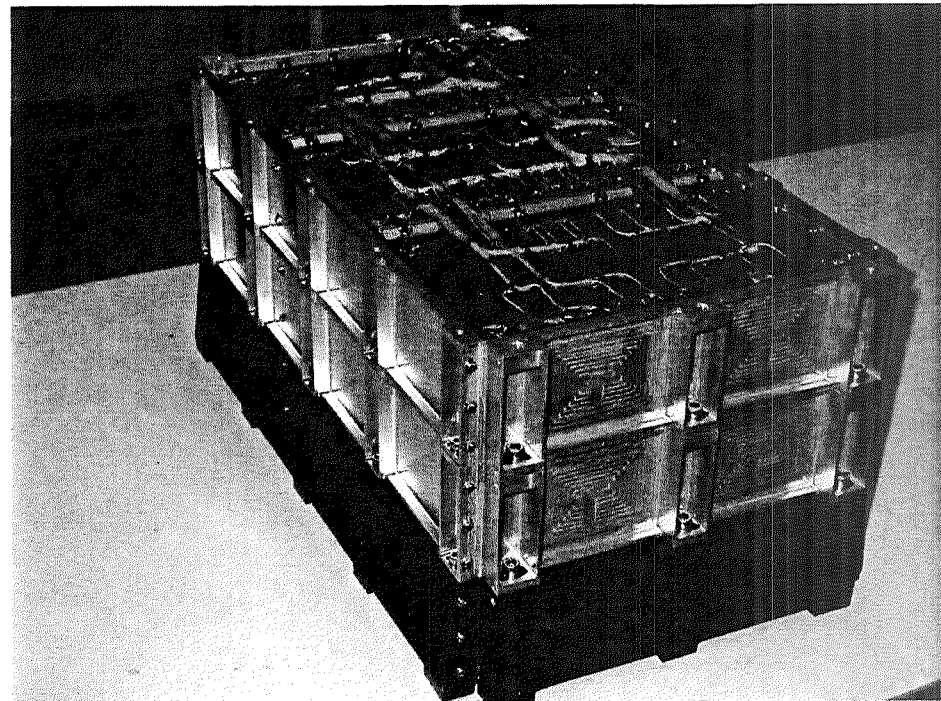


Highly Tolerant to Cell Failures w/o External Cell Protection Electronics



- Short Circuit (SC) Cell Failure:
 - Remaining cells in string over-charged
 - CID activates on an over-charged cell in the string
 - String rendered open circuit

- These safety features can be less effective in larger batteries, but solutions have been engineered to maintain safety and fault tolerance.
- 2004 Space Power Workshop, E. Darcy



- ABSL battery performance is highly tolerant of cell failures.

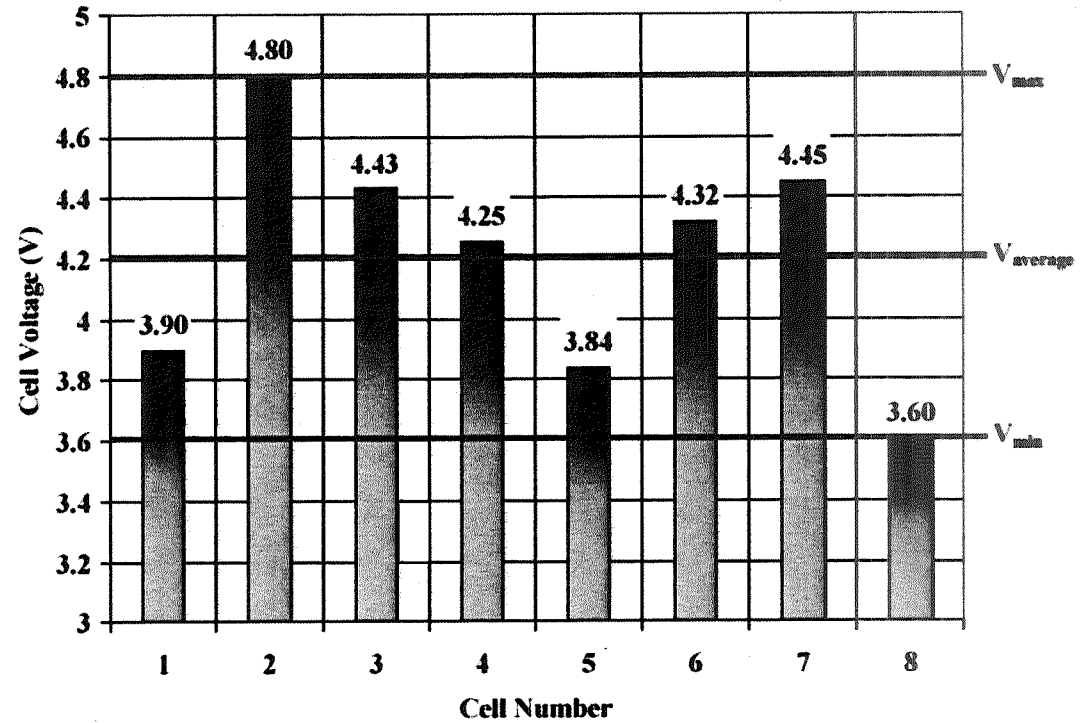
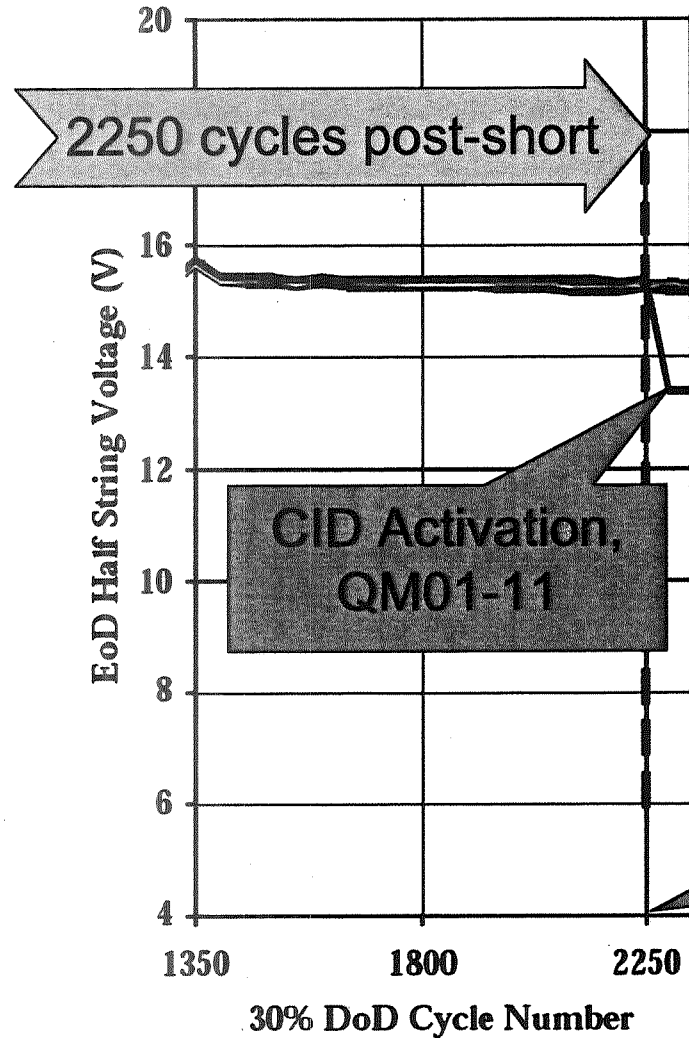
Effects of SC & OC Cell Failures

	ABSL 8s16p	Large Cell 1p8s
Nominal Voltage	-0.00%	-12.50%
Energy	-6.25%	-12.50%

- Three 8s16p modules in parallel
- 1800 cycles at 40% DOD
- Reconfigured for individual module capacity measurements and 30% DOD GPM Mission Profile cycling
- 3994 cycles at 30% DOD

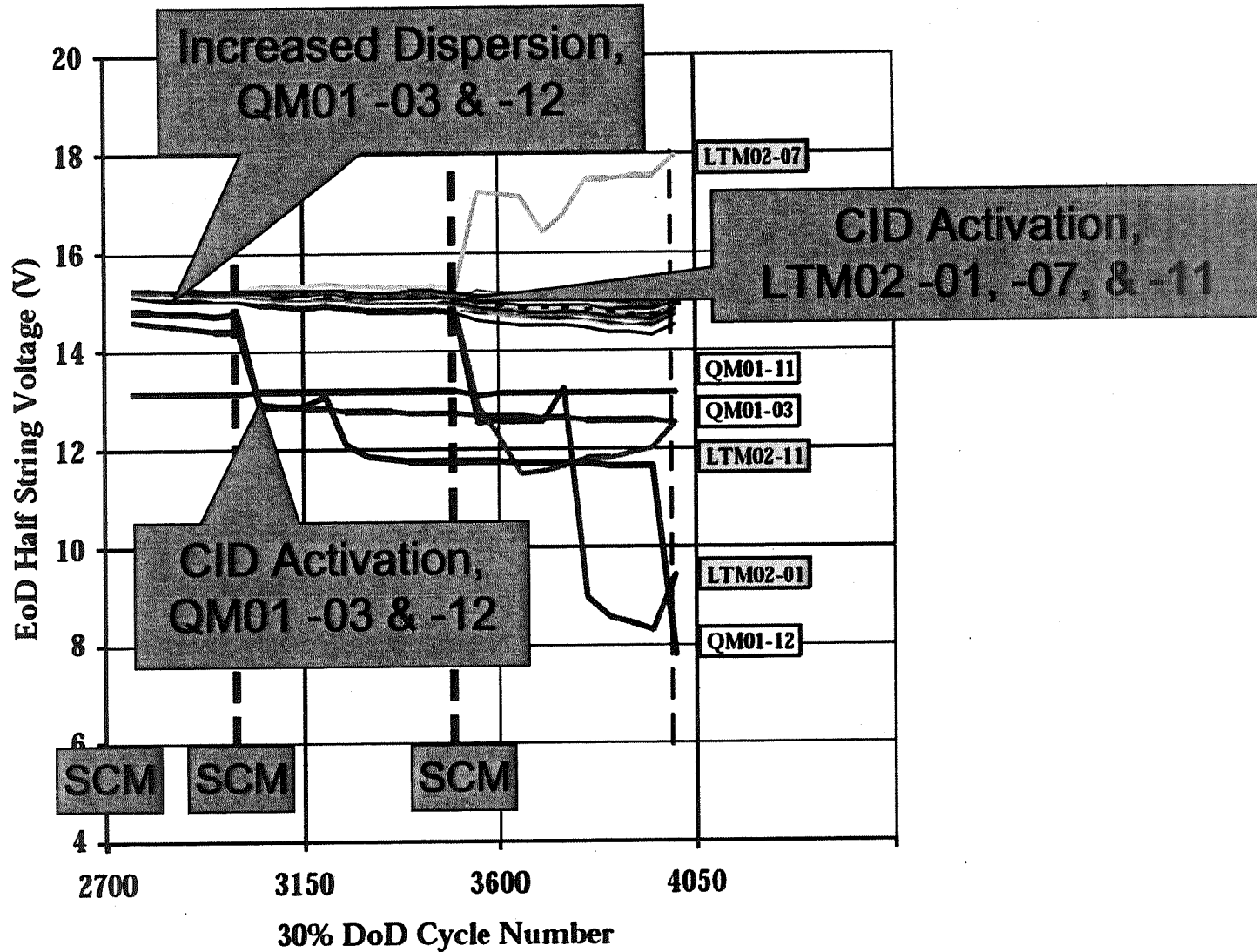
QM01 and LTM02 short-circuited during reconfiguration

- No explosion, fire, or smoke
- No measurable effect on capacity, though half string dispersions were increased
- Verified cell safety features in unexpected incidence

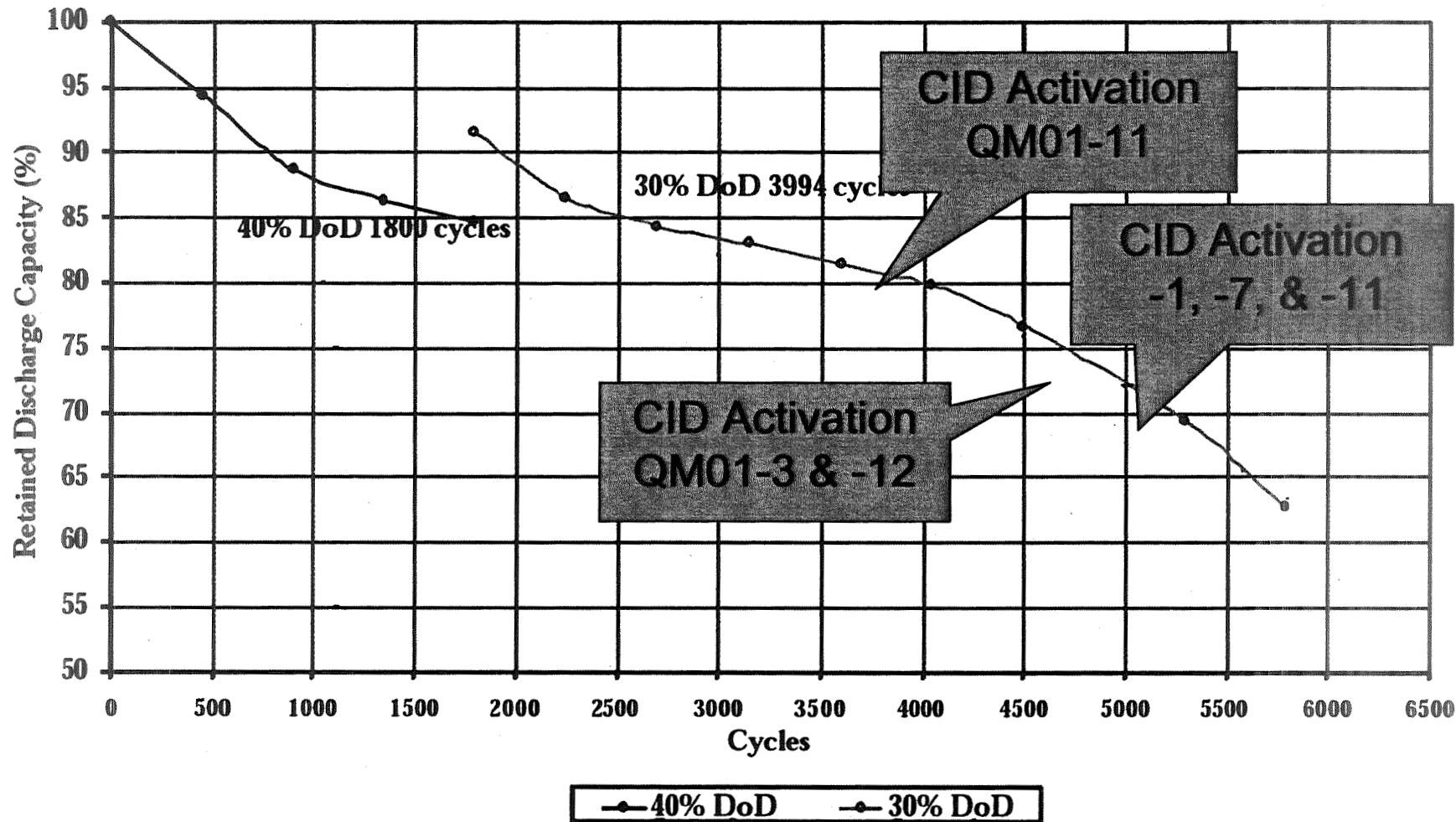


Standard Capacity Measurement (SCM)
4.2V to 2.5V @ C/10

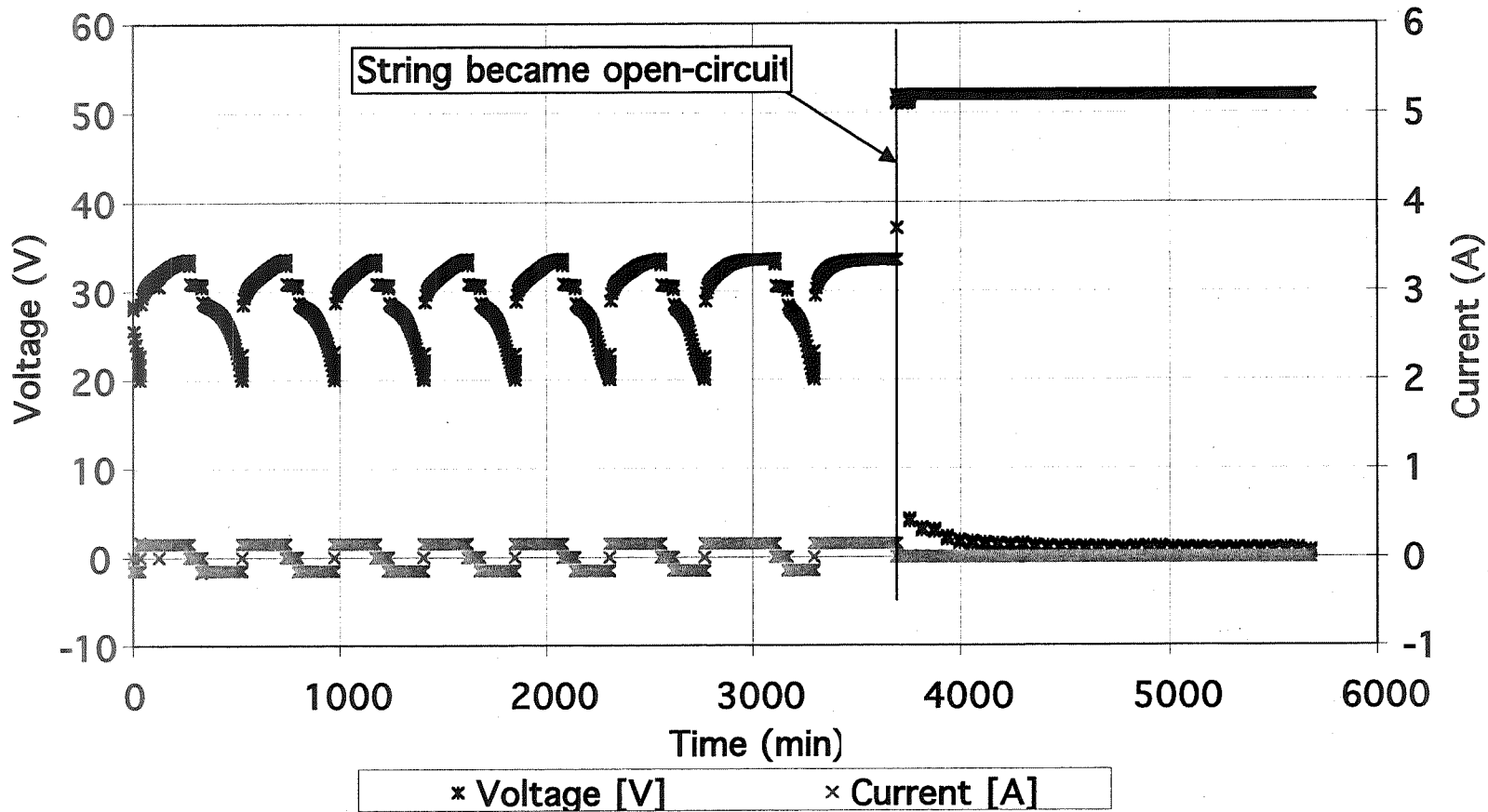
Post-Short Cycling- Continued



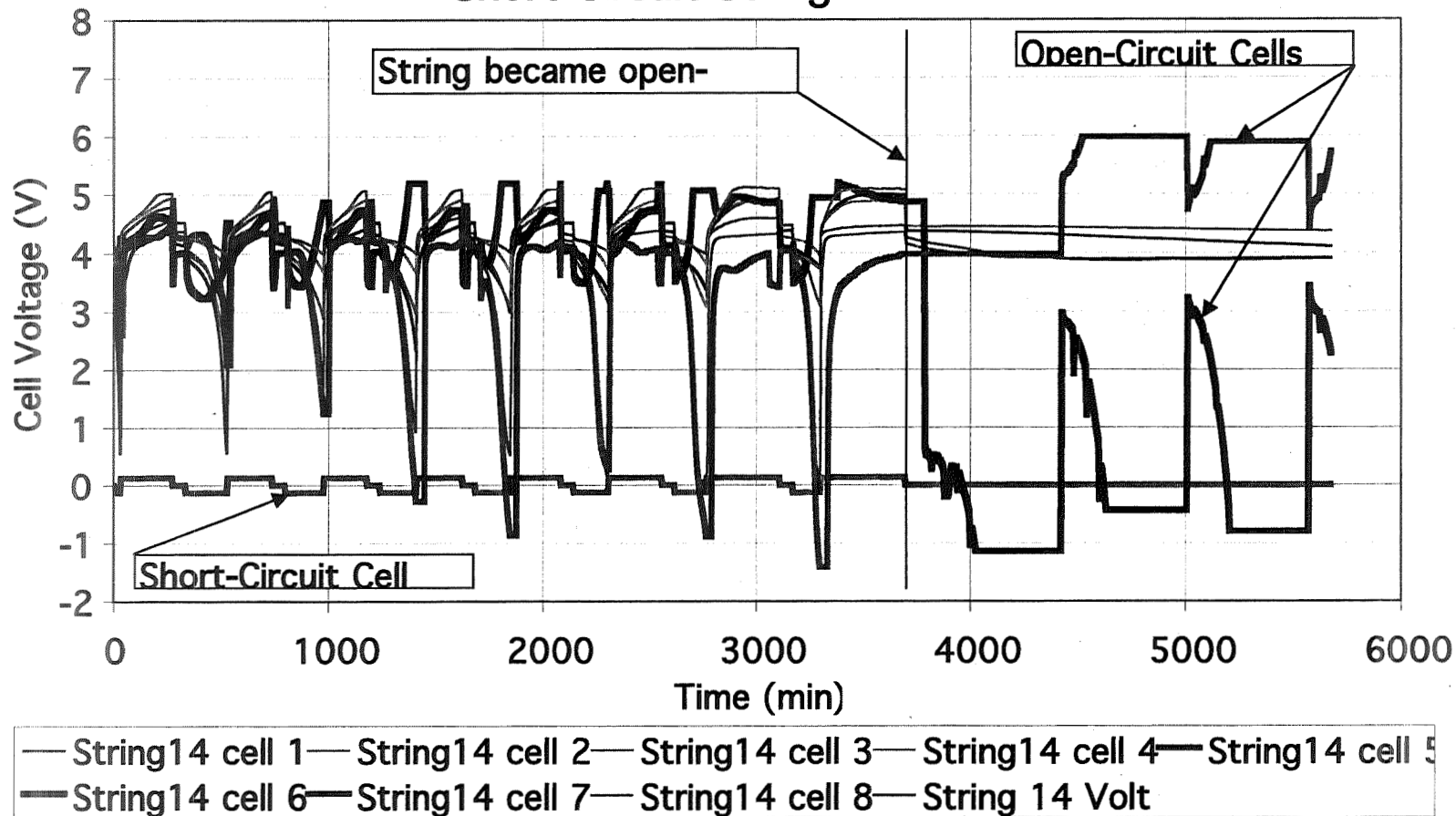
GSCF LEO Lifetest Capacity Fade Profile



Short-Circuit String Lifetest



Short-Circuit String Lifetest



- **Cell level safety devices and the s-p topology provide an extremely simple and effective battery protection architecture**
 - Both PTCs and CIDs proven through life, operating properly after thousands of cycles and severe abuse conditions!
 - Short-circuited cells are safely handled without complex external cell protection electronics
 - Large step changes in capacity, energy, and voltage are avoided
 - Batteries are tolerant to single cell failures, unlike large cell batteries.

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Acknowledgements

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