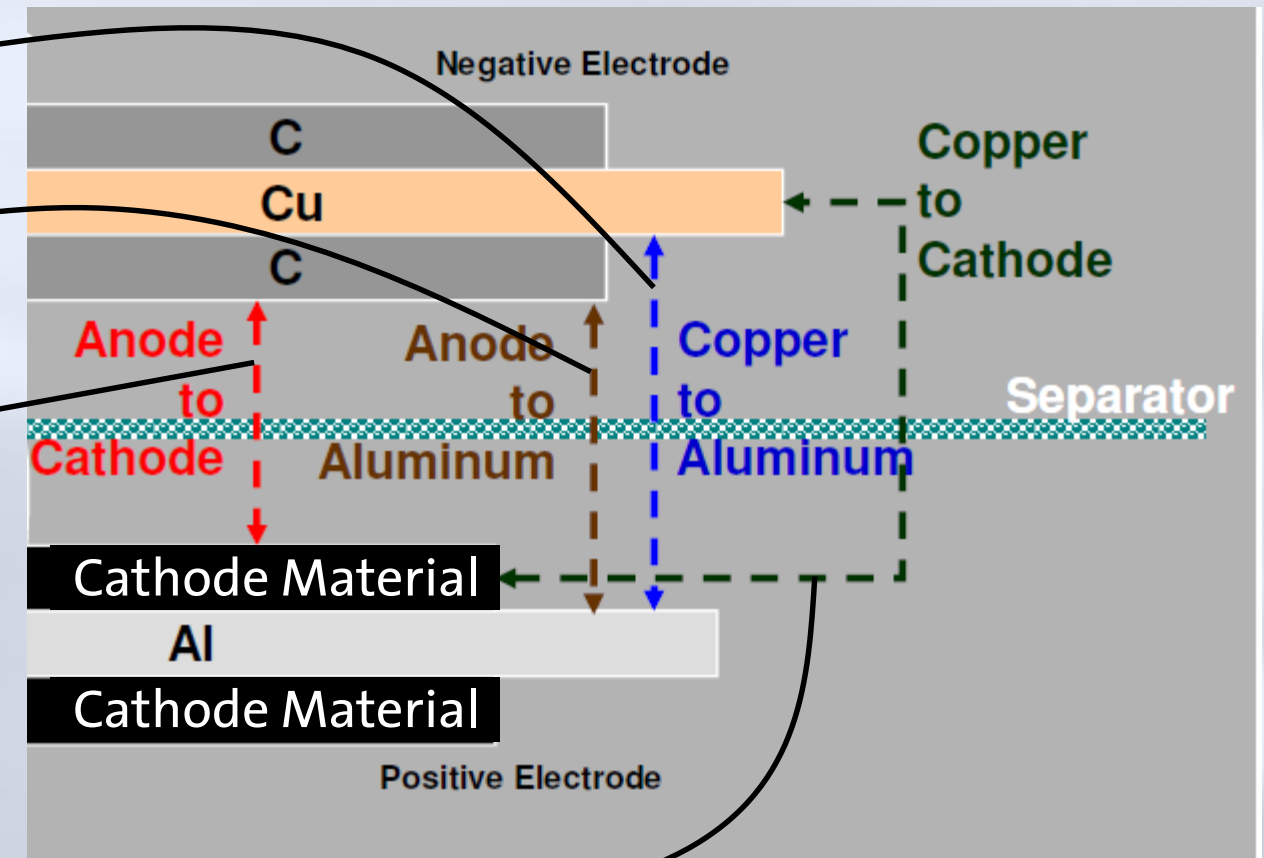
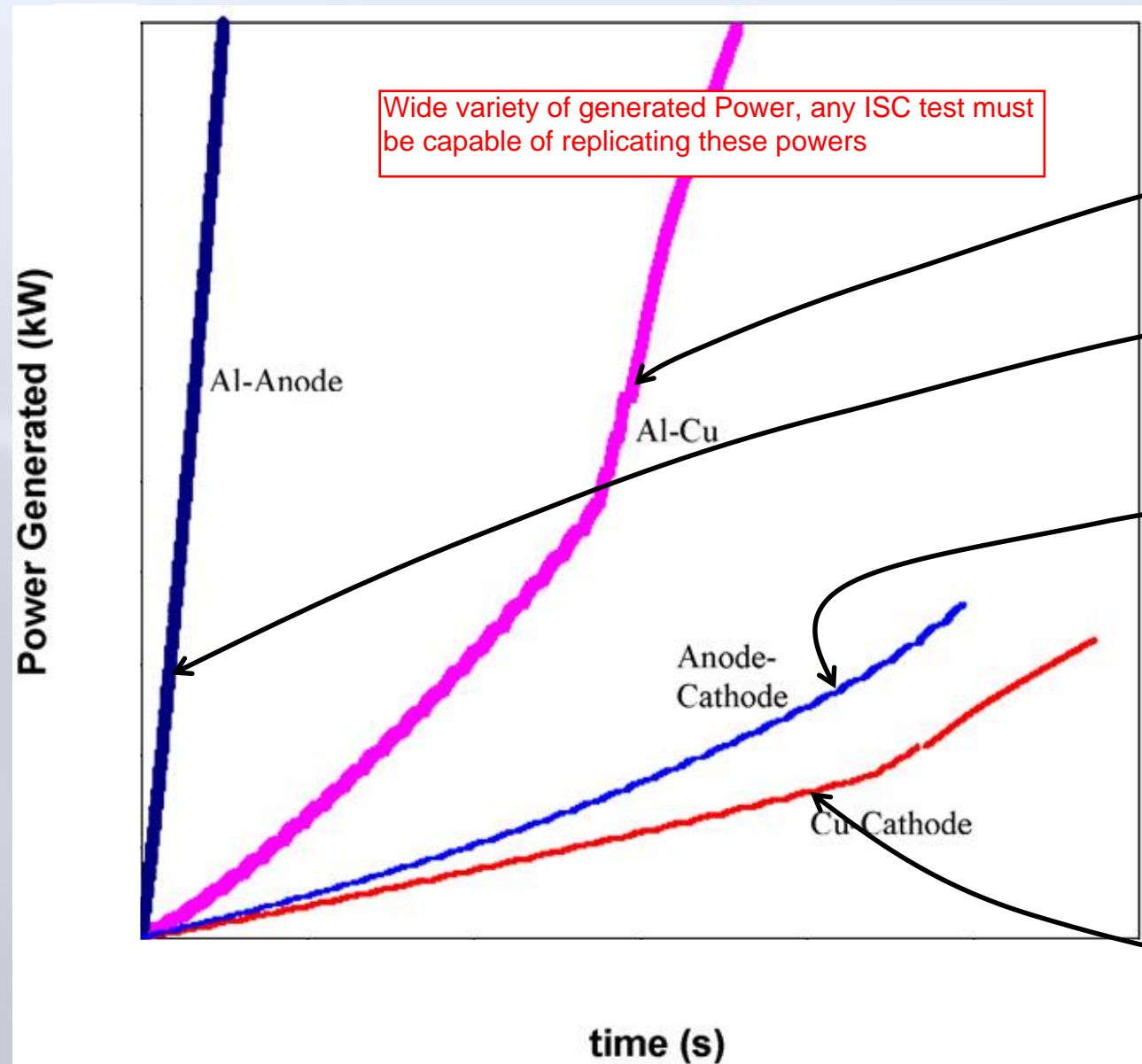


RELATIVE RESISTANCE OF ISC TYPE

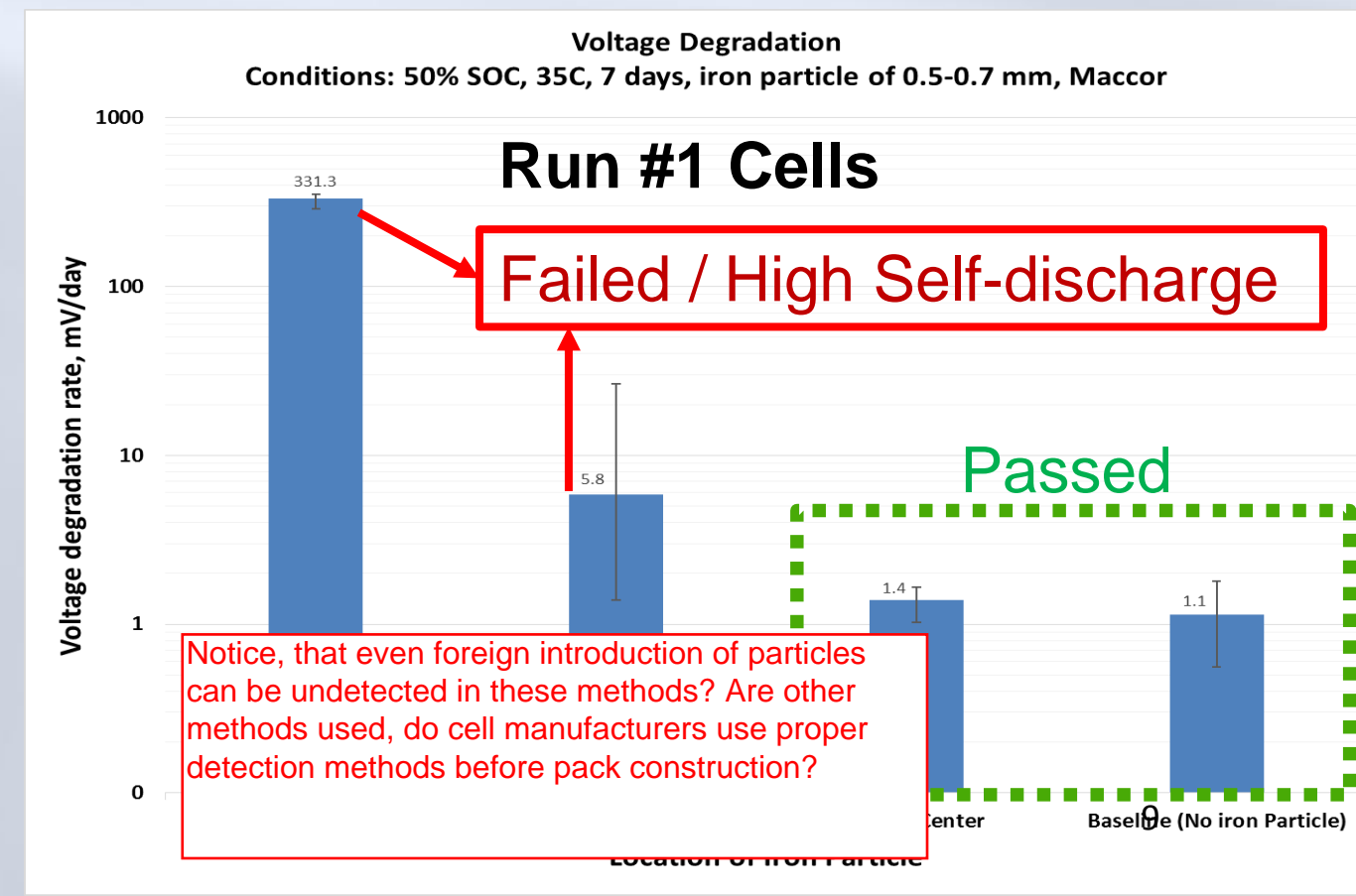


Shriram Santhanagopalan, Premanand Ramadass, John (Zhengming) Zhang,
 Analysis of internal short-circuit in a lithium ion cell,
 Journal of Power Sources, Volume 194, Issue 1, 2009, Pages 550-557.

CELL MANUFACTURING QUALITY CHECKS

- All cells passed the Hi-Pot test after electrode stack assembly
- Only cells with large particles located on the cathode surface showed higher than normal self-discharge rates

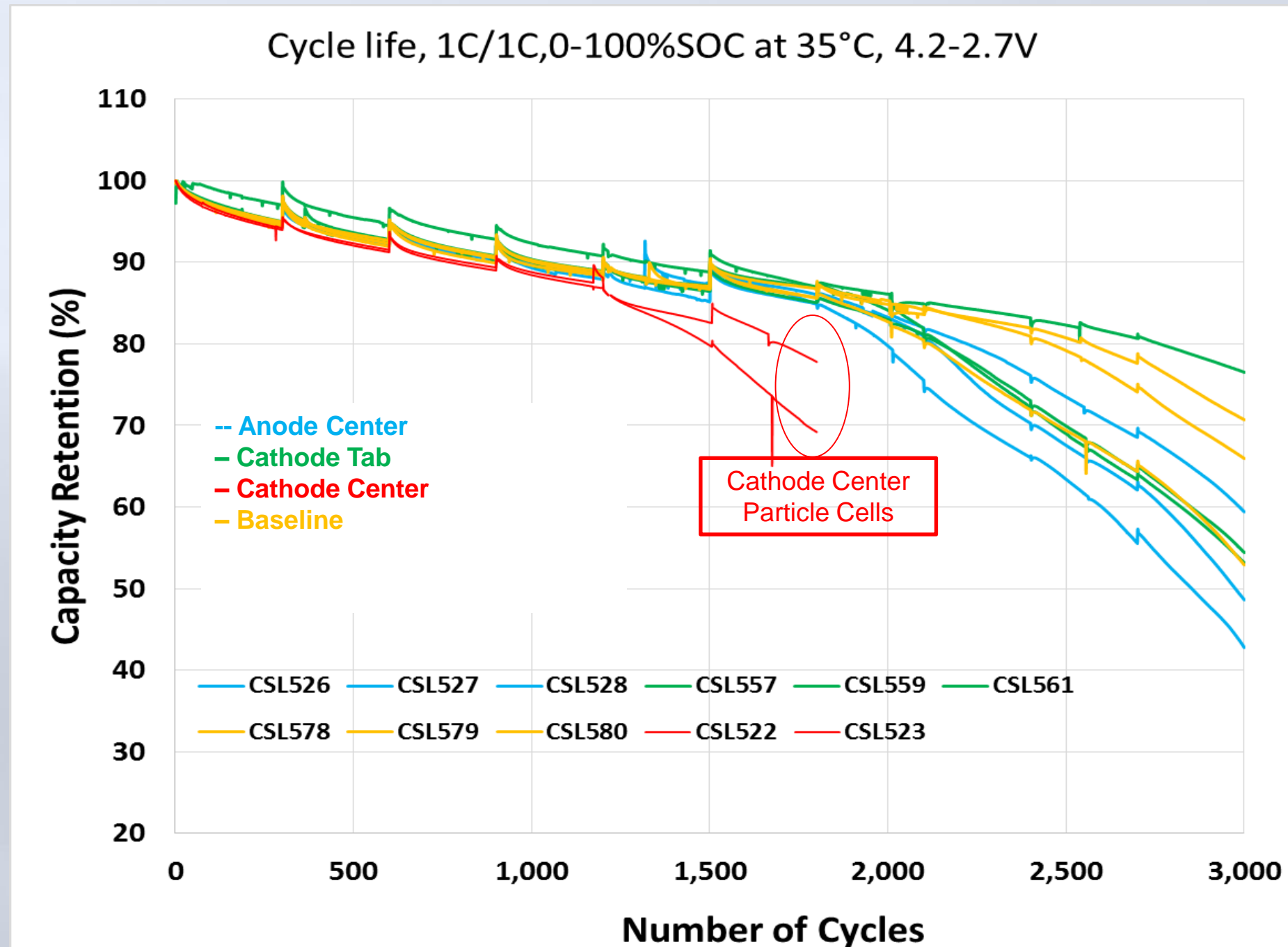
Run	Iron Particle Size	Anode Center	Cathode Tab	Cathode Center	Baseline Cells
Run #1	> 500 μm	Pass Hi-Pot Pass self-discharge	Pass Hi-Pot Failed self-discharge	Pass Hi-Pot Failed self-discharge	Pass Hi-Pot Pass self-discharge
Run #2	100-150 μm			Pass Hi-Pot Pass self-discharge	Pass Hi-Pot Pass self-discharge
	50-100 μm			Pass Hi-Pot Pass self-discharge	Pass Hi-Pot Pass self-discharge



RUN #1 CELLS – CYCLE LIFE TEST

- Cathode Center particle cells showed a more rapid Ah capacity decline.
- Anode Center and Cathode Tab particle cells showed no significant difference compared to the Baseline cells.
- No cell venting occurred.

Notice again how a foreign particle introduction can last for many high rate cycles (1C/1C) without failure compared to baseline. When will failure occur?

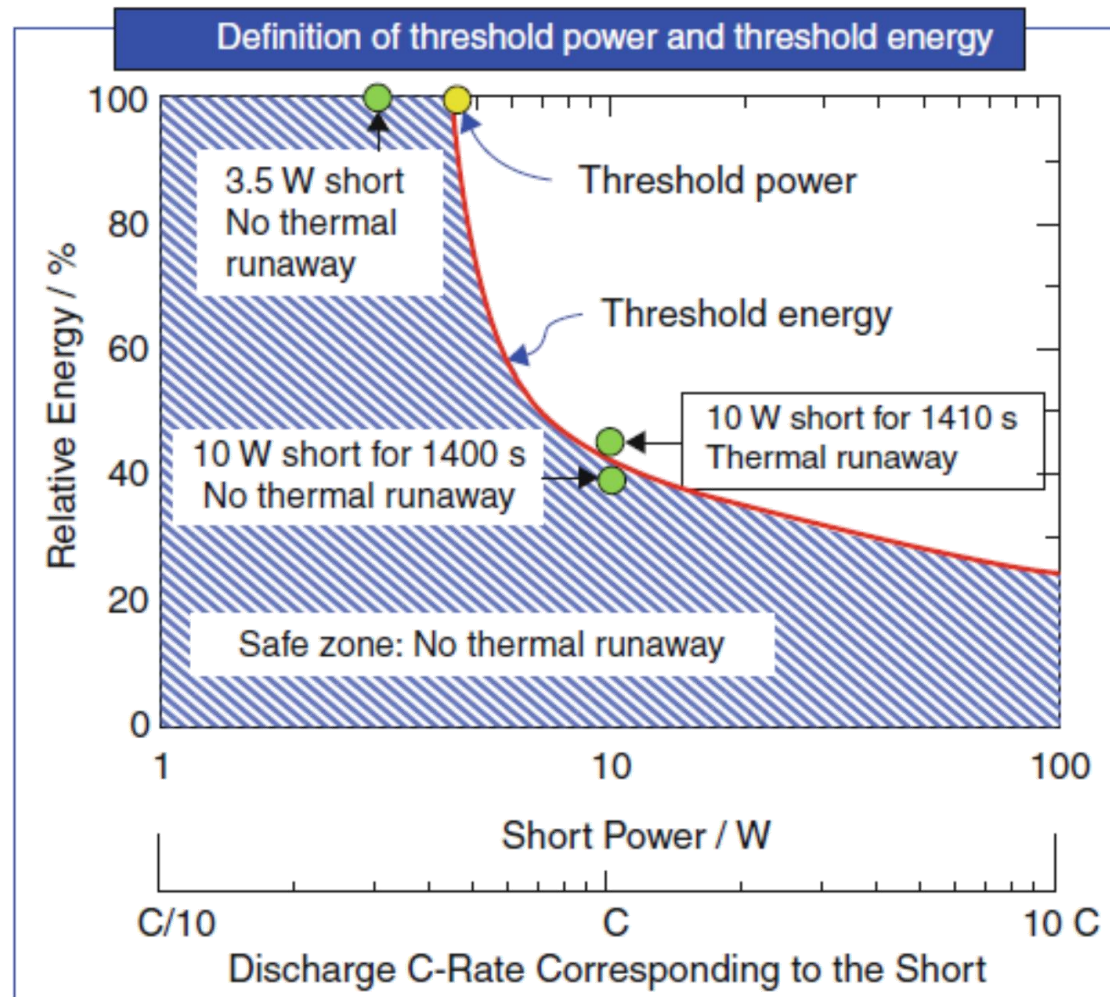


CONCLUSIONS:

- Particles much larger than the separator's thickness (20-28 times) did not push through to create an internal short, even after cycling under pressure.
- Metal particles on the negative electrode (anode) did not cause internal cell shorting.
- Only metal particles initially located on the positive electrode, if of sufficient size and mass, caused internal cell shorting.
- Large metal particles are detectable by self-discharge and capacity loss in the manufacturer's Aging/Storage process step.
- Particles below 100 μm have limited or no effect, while particles near 150 μm did cause pre-mature cycle life failure.

Were cells under pressure similar to pack designs?
or no pressure?
Your cycling was at 1C rates with no CV at top of
charge (different than vehicles), Did you verify other
rates or CV charging?

Critical Internal Short Resistance



- Depending on cell chemistry, cell design, and application, there exists a threshold between thermal runaway and no thermal runaway

Please expand on this graph? where are chemistry/design and application shown? If just illustrative ok, but not clear. In my view this will be different for every cell. The axes are misleading. Safe zones for 18650s are not the same as for EV cells.

Fig. 9.9 The Safe Zone construct

Barnett B., Ofer D., Sriramulu S., Stringfellow R. (2013) Lithium-Ion Batteries, Safety. In: Brodd R. (eds) Batteries for Sustainability. Springer, New York, NY

Key Messages

- Industry has extensive field experience with lithium ion cells
- There have been no known incidents of internal short circuits resulting in cell thermal runaway

Many thermal runaways have occur in numerous applications with no attributed cause or source . In-situ detection of internal short circuits is a concept only, not applied in practice. Tear-down analysis of failures will never conclusively prove the cause was an internal short circuit. There could be no known incidents simply because there are no mechanisms to identify them as the root cause.

Known Internal Short Induced Thermal Events

- NONE

How do you define or characterize an ISC event from a thermal event in the field? You mentioned V drop previously

Similar to page 28, there are no reliable mechanisms in place to detect them, during or after a thermal event have occurred, so although they are not "known", it does not confirm they do not happen.

Possible internal short frequency

- Varies somewhat by cell type and manufacturer
- Overall GM experience shows ~2-5 events per million cells for detected cell internal short in customer vehicles

Very interesting, so GM has detected 100 to 250 ISC based on slide 32. It would be great to more details on these (how they were detected, the range of self-discharge rates observed, etc.).. How were they quantified?