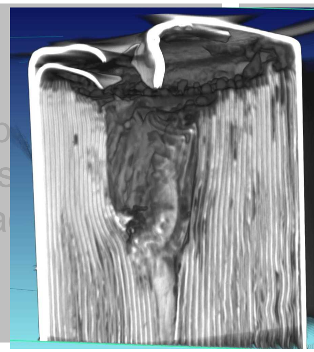
SAND2017-5745C



Alternative Battery Failure Initiation

Joshua Lamb, Leigh Anna Steele, Loraine Torres-Castro, June Stanley, Chris Grosso, Jerry Quintana and Chris Orendorff

May 22, 2017

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Power Sources Technology Group

Sandia National Laboratories

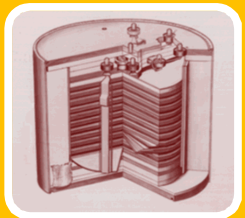
Power Sources Technology Group (PSTG)

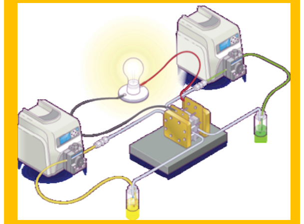

Enterprise Integration


SNL External Production


PS Production


PS Design & Development


PS Component Development


PS Research & Development

NW | **Grid Storage** | **Transportation** | **Fundamental Science**

- Thermal batteries
- Reserve batteries
- Lithium primary batteries

- Thermoelectrics
- Radioisotope power sources
- Lithium-ion batteries

- Sodium batteries
- Flow batteries
- Battery safety and reliability

- Electrolyte development
- Solid-state electrolytes
- Beyond lithium chemistries

- DOE National Nuclear Security Administration
- Other Government Agencies
- Department of Defense
- Strategic Partnership Programs

- DOE Office of Electricity
- DOE Vehicle Technologies Office
- DOE Basic Energy Sciences
- Department of Transportation

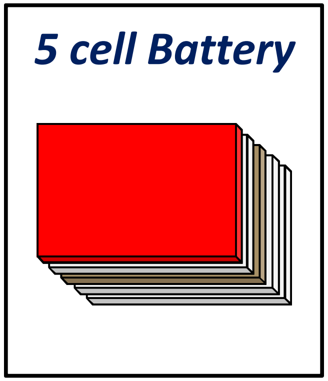
Capabilities of Power Source R&D Group

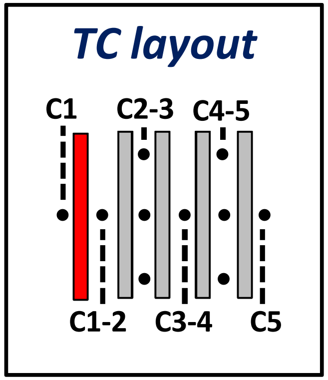
- 10,000 sq. ft. dry room space
- Synthesis of battery materials
- Prototyping for thermal batteries, Li primary, and Li-ion cells and batteries
- Battery design & development
- Performance and abuse testing
- Battery calorimetry facilities
- Forensics and analysis
- Fundamental electrochemistry
- Modeling and simulation*
- Environmental testing*
- High hazard test facilities (Burn Site)*

*Facilities leveraged from our Partners in SNL Experimental Sciences Center

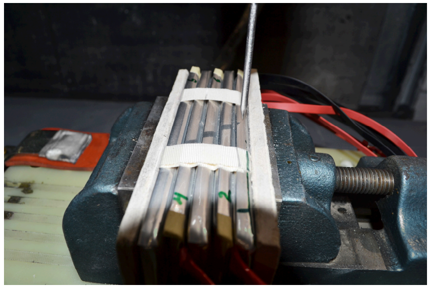
Failure Propagation: How to initiate failure?

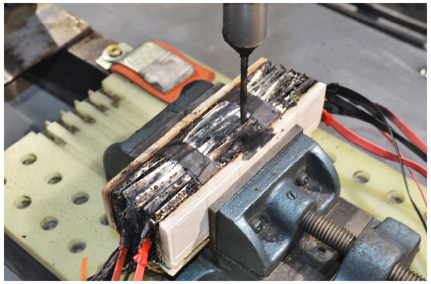
Failures initiated by mechanical insult to edge cell of COTS $LiCoO_2$ packs (3Ah cells)

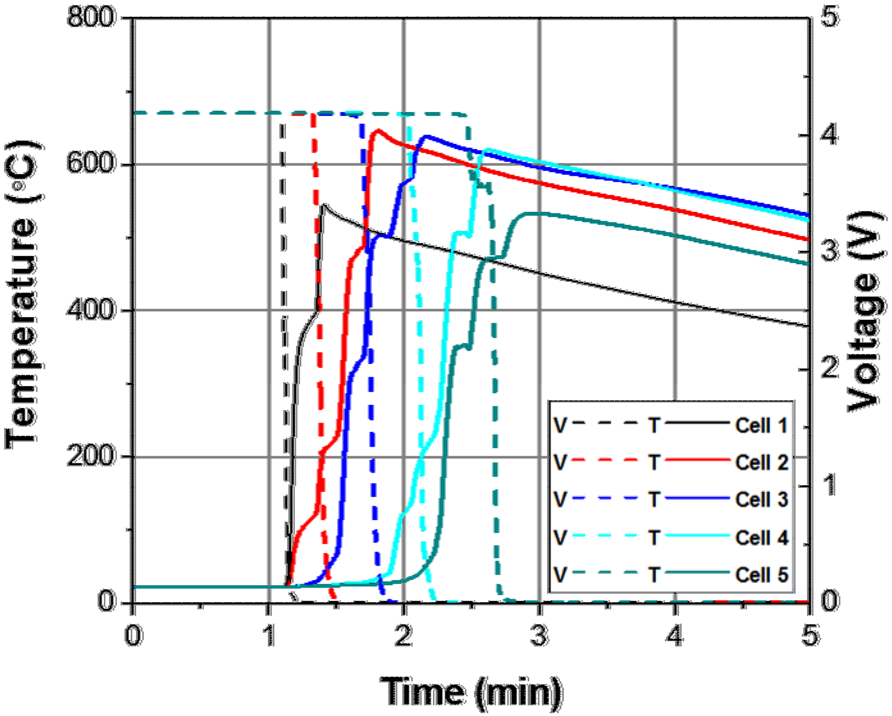




- Propagation testing requires initiation or simulation of a thermal runaway of a single cell in a pack
- Initiation is typically achieved with abusive battery tests that inject significant energy into a system

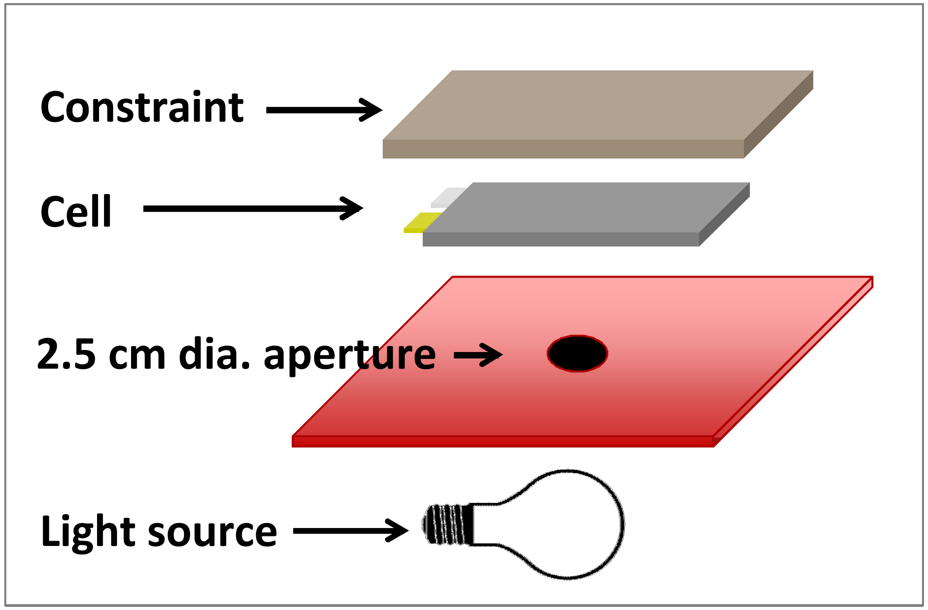


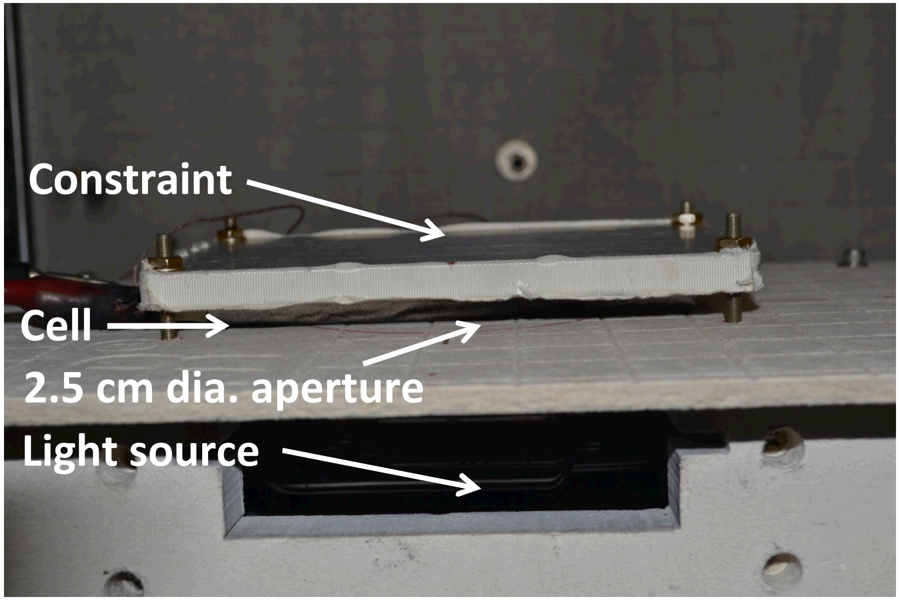




- Traditional abuse tests either inject a significant amount of energy into a pack or cause significant damage to a cell
- Can we more closely mimic and internal short within a cell?

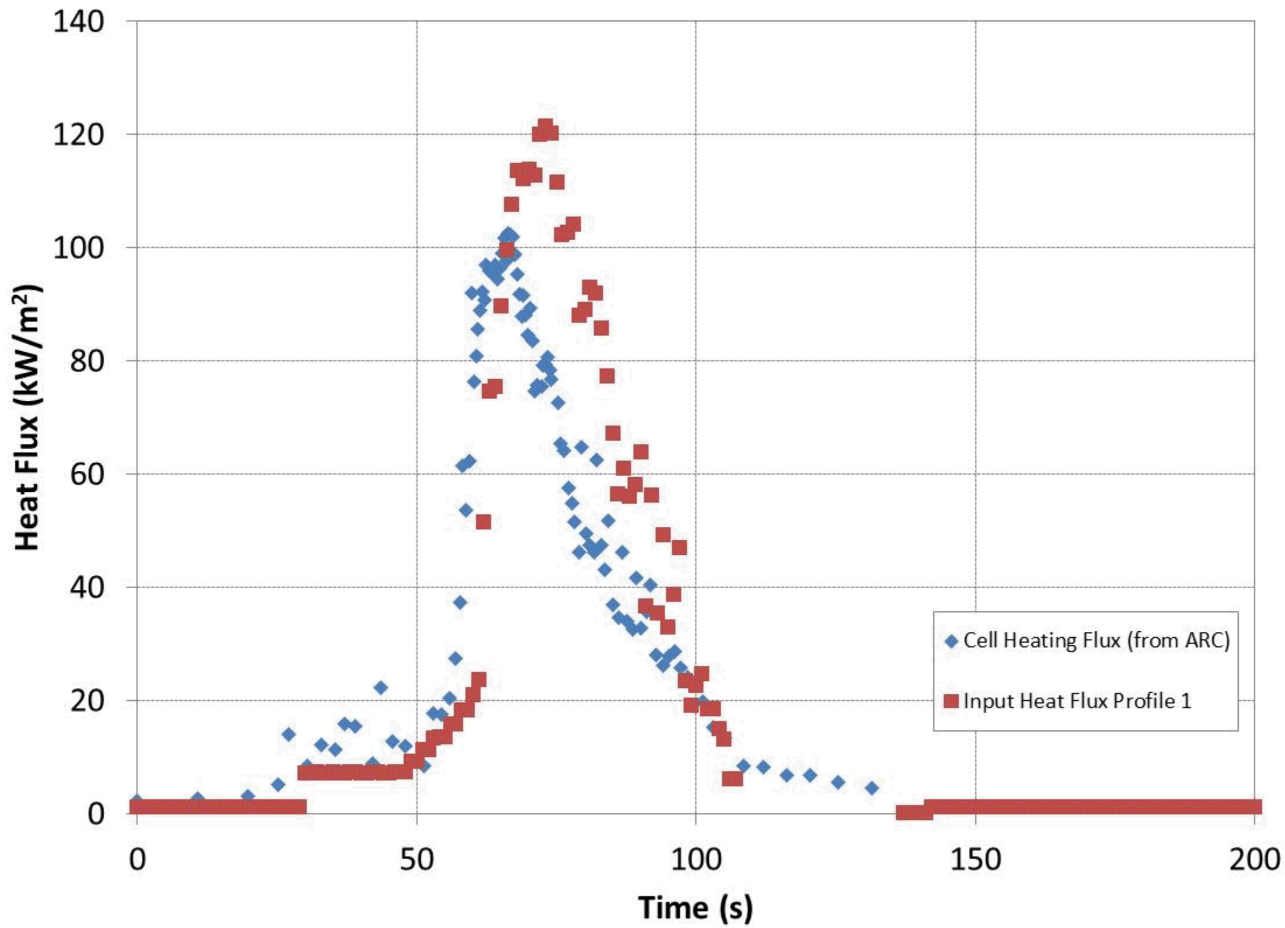
Quartz Lamp Initiation





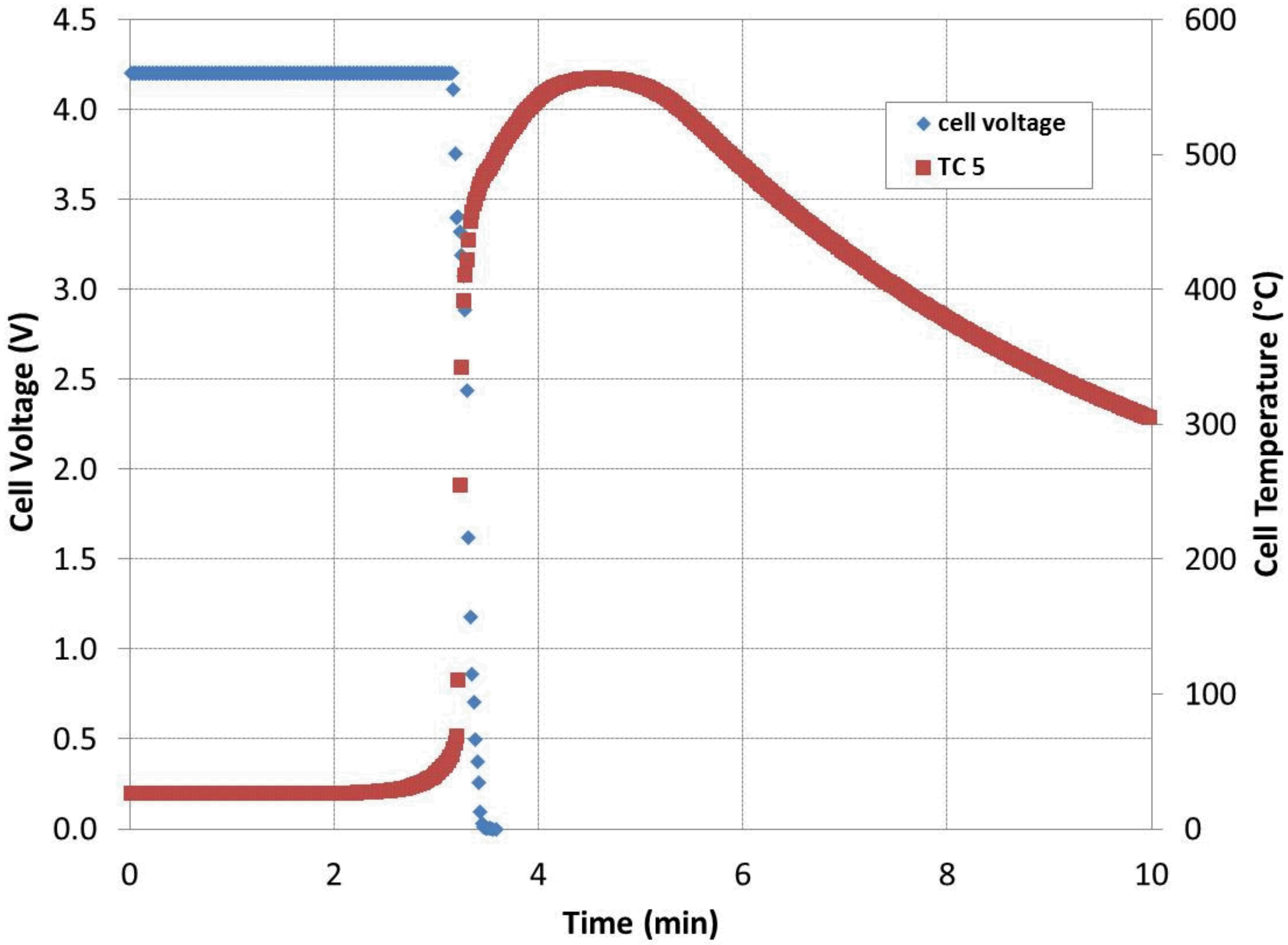
Experimental set up for lamp initiated runaway experiments
Flux measured through aperture prior to testing using radiometer
The goal is to recreate the heat flux from a nearby cell runaway using the high intensity light source

Heating Profiles



Comparison of heating profile of a single cell determine from ARC testing to the tuned input heat flux

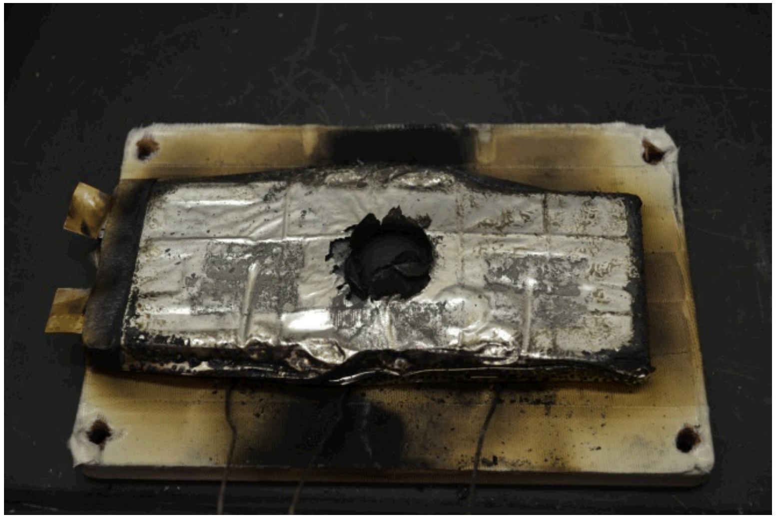
Initial thermal runaway tests



Successful thermal runaway initiation with modified profile
Peak cell skin temperature ~550 °C, ignition, sustained fire

Thermal runaway results

Post-mortem of cell failure

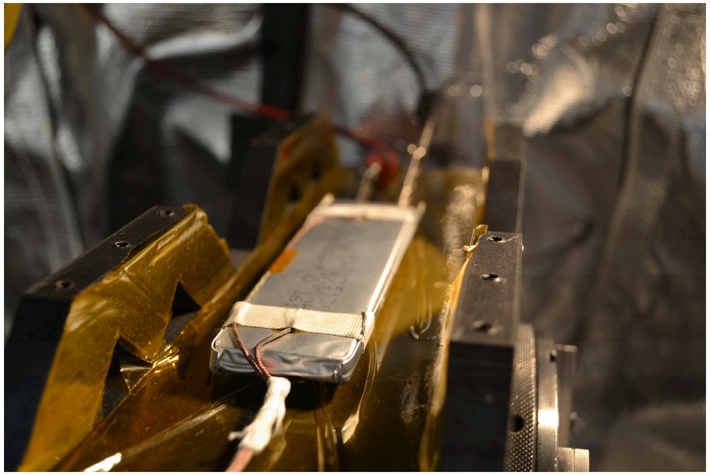


High heat flux through the surface of the cell provided thermal runaway initiation

Relatively deep penetration of the created "hot spot" was observed during post mortem – physical damage was observed 7 electrode layers deep

Laser battery failure initiation

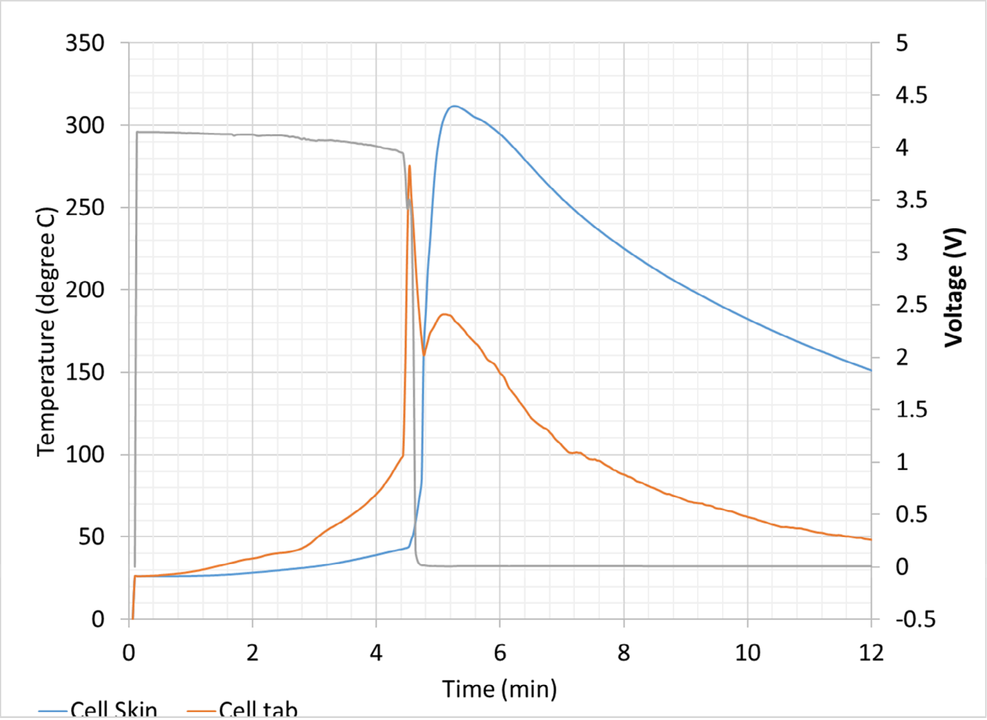
- Quartz lamp initiator while effective has some limitations
- It is difficult to fully direct the flux generated by the quartz lamp
- Similarly, it is difficult to focus the energy to a limited area



Other needs also exist for the development of internal short circuit tests

- Currently, testing of off-the-shelf cells relies on nail penetration
- This is problematic as the damage caused by nail penetration is much more severe than would be expected from an internal short
- Can we generate a small, localized point of failure on an unmodified off-the-shelf cell?

Laser Battery Failure Initiation

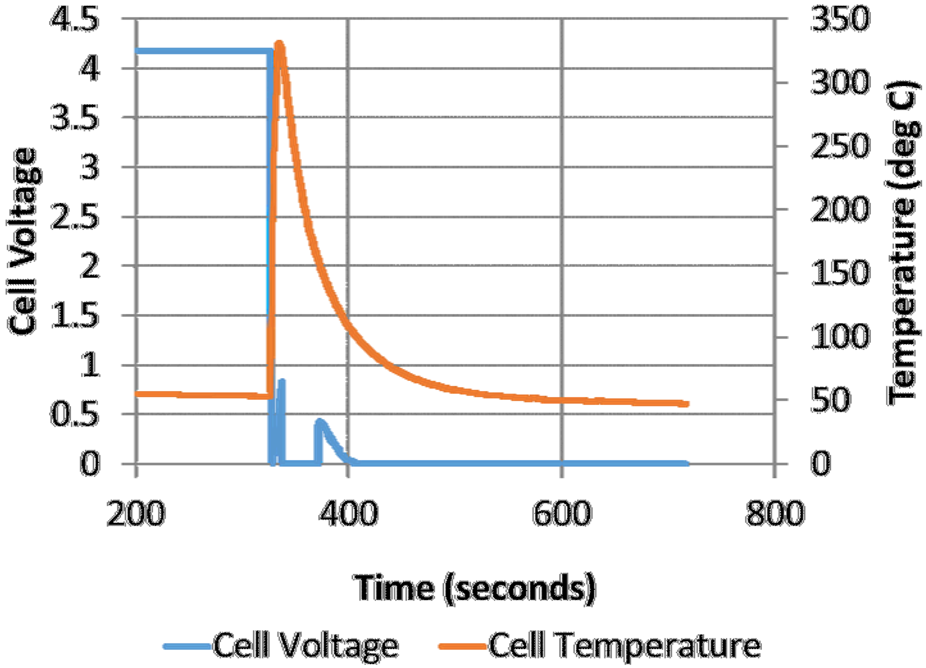


Single cell failure initiated using 40W pulse laser
~38 J total energy needed for failure (20 1.9J pulses)

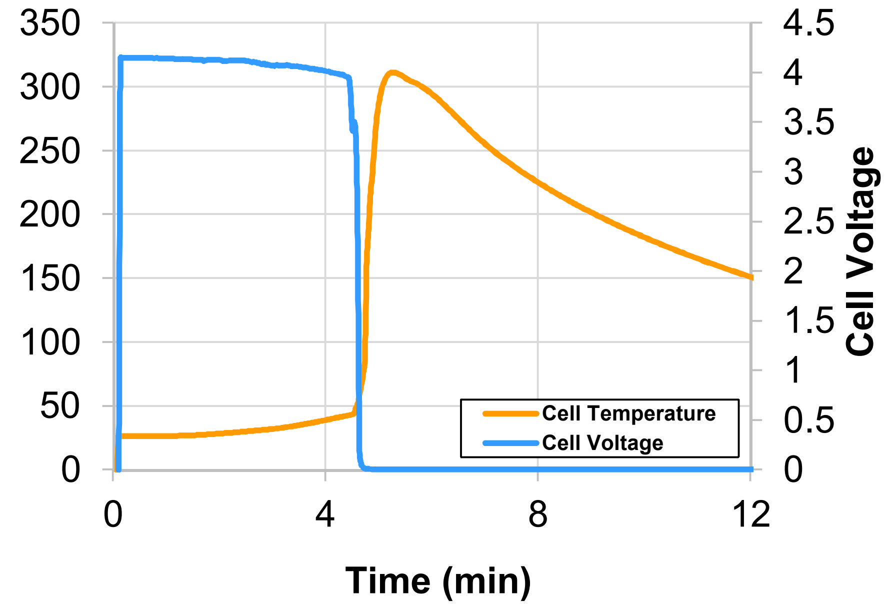
Comparison to Mechanical Data

Sandia National Laboratories

Nail Penetration Failure

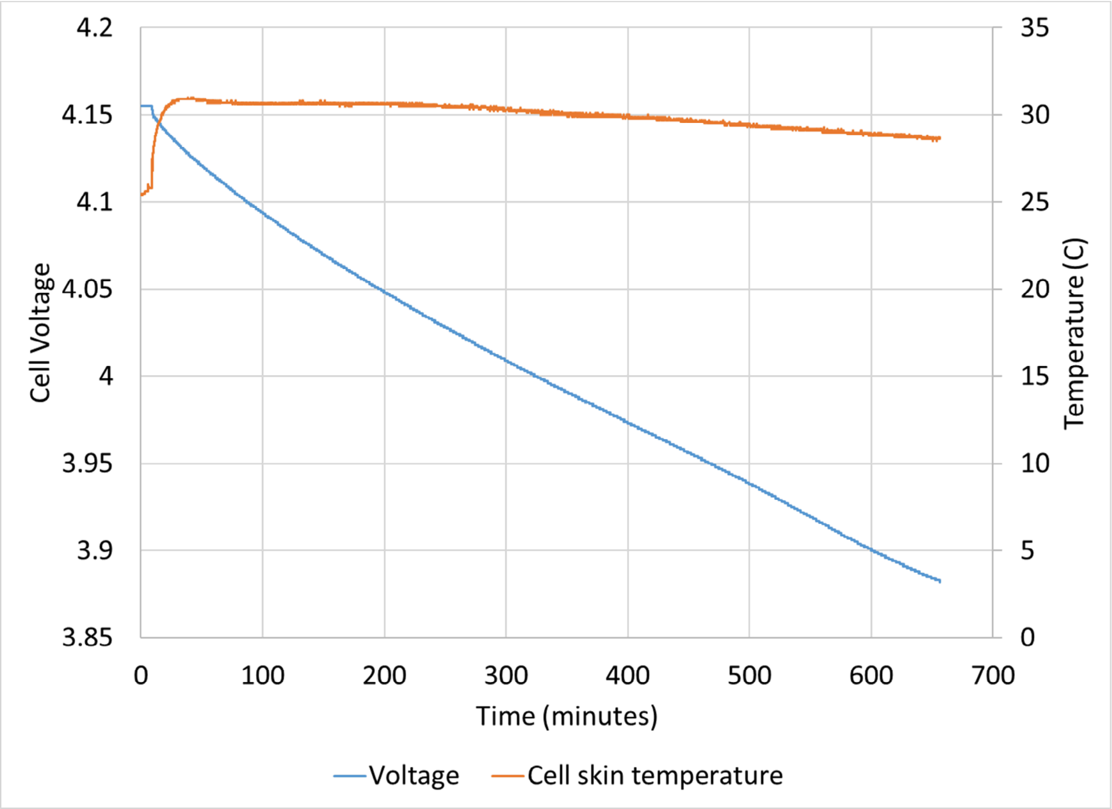


Low Impedance Laser Induced Failure



- Comparison of failure to nail penetration of same model of cell.
- Peak temperatures observed are similar, however the nail penetration shows much higher rate of failure after onset

Induced high impedance failure



High impedance failure induced with 4 (7.6 J) pulses

Slow discharge observed over several hours, no high rate runaway observed within 24 hours of initiation

Energy Injection Comparison

Test	Energy Source	Conditions	Estimated Energy
20 Pulse laser	IR Laser	20 1.9 J pulses	38 J
Nail Penetration	Mechanical	20 mm penetration ~200 lb peak load	1.8 J
Undirected light	Quartz lamp	Exposure to light source through aperture	6000 J*
Thermal Ramp	Thermal	Heat to 200 °C	6300 J**
Overcharge	Electrical	1C to 200% SOC	43200 J***

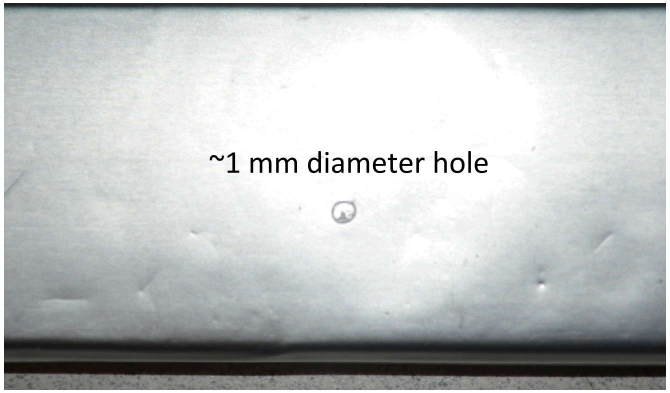
* Based on radiometer measured flux through aperture
** Calculated for hypothetical 40g cell – larger cells will require more energy
*** Calculated for a hypothetical overcharge at 3 A and 4 V at a 1C rate

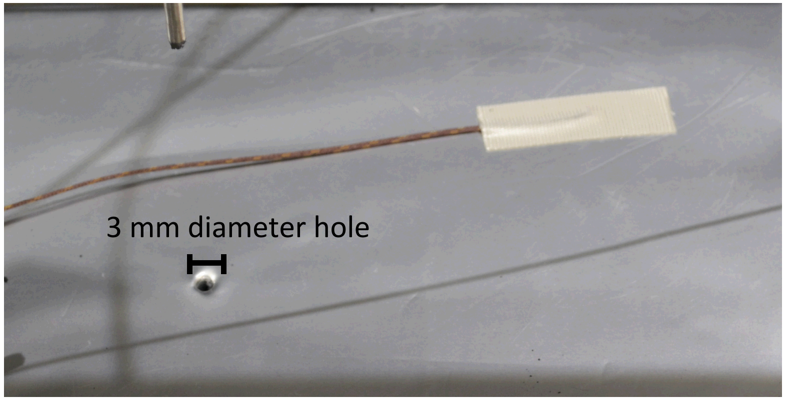
Damage comparison: Laser vs. Nail

20 Pulse Laser

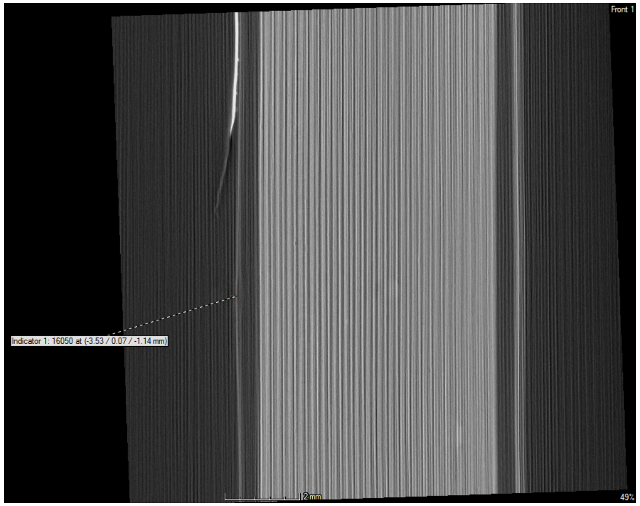
Blunt Rod

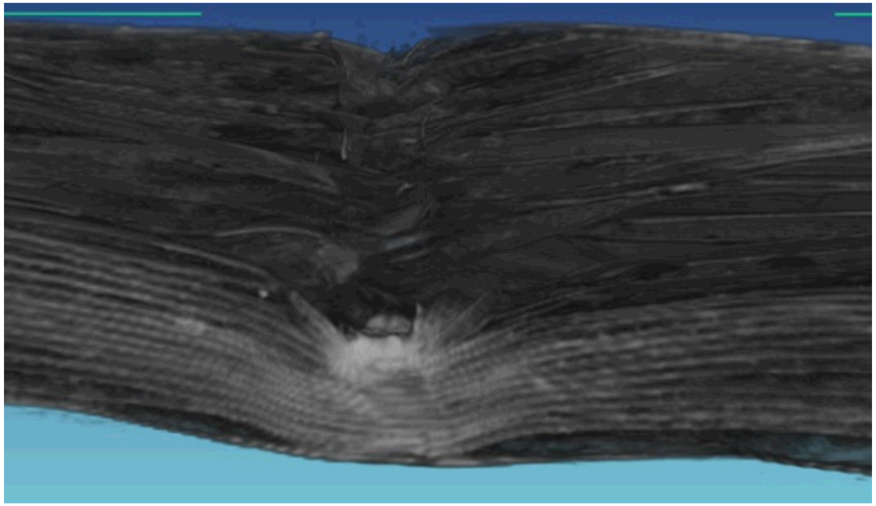
External





Internal

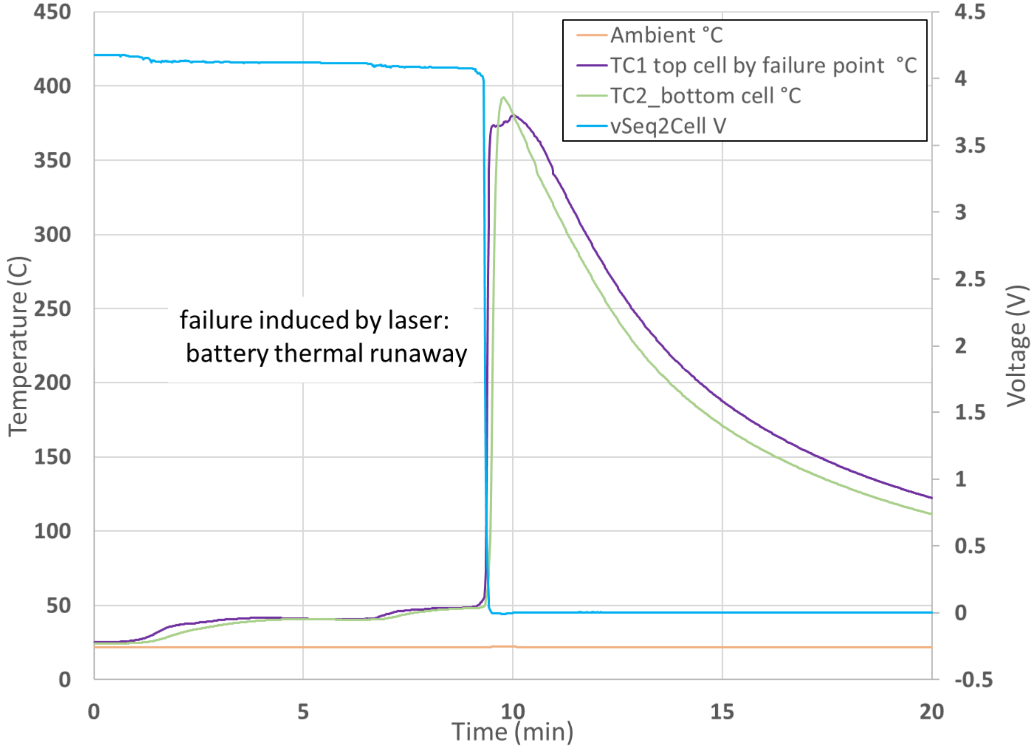


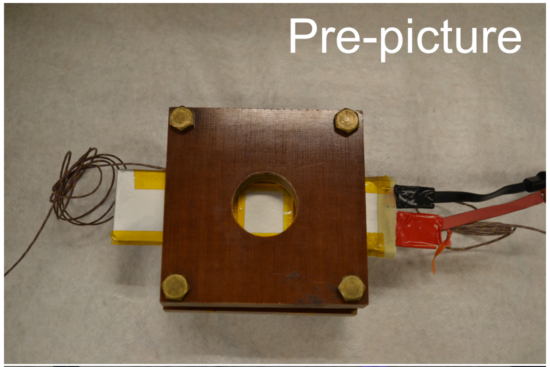


- Nail penetration shows significantly more internal damage.
- Internal damage done by laser initiation is very limited to surface layers.

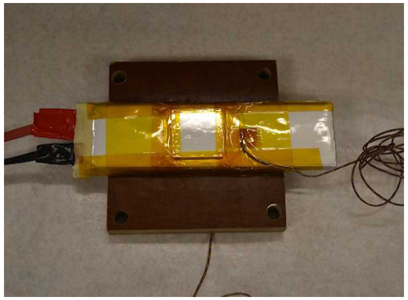
Laser initiated failure through fused silica slide (2mm)

In hopes to reduce the oxygen exposure to hole being produced from laser, an IR transparent slide was used as barrier during testing



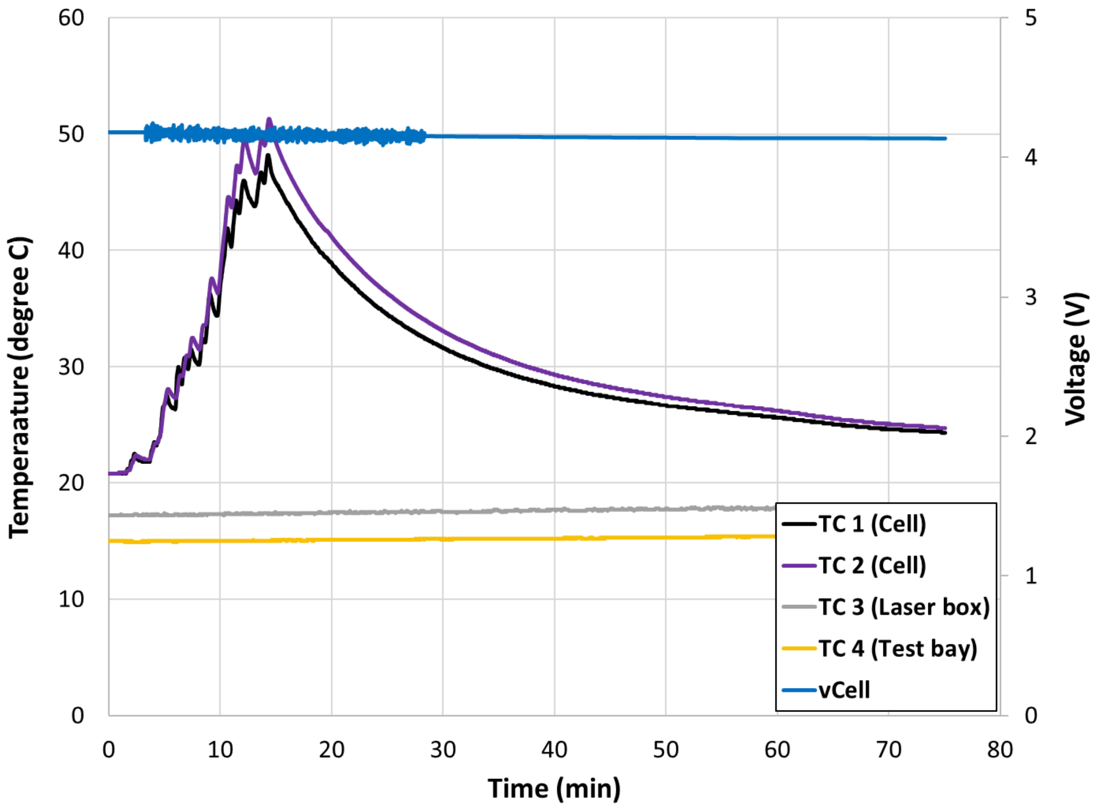


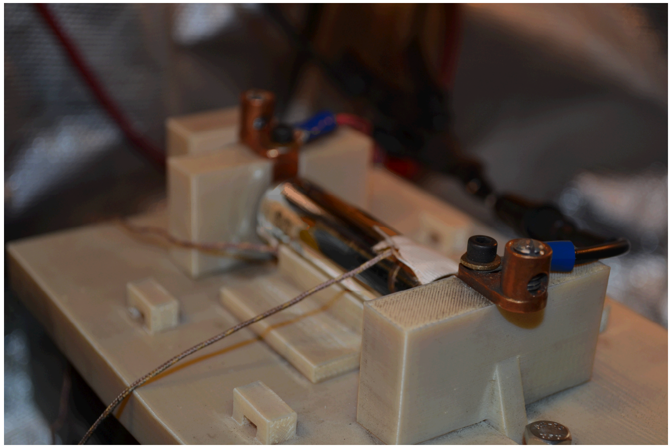
- Able to induce failure using laser through silica slide
- Final power setting of 350V, 20ms, 1Hz to induce thermal runaway
  - More energy needed to induce runaway through silica slide
- Maintained seal between silica and pouch cell until full runaway



Post test –detail

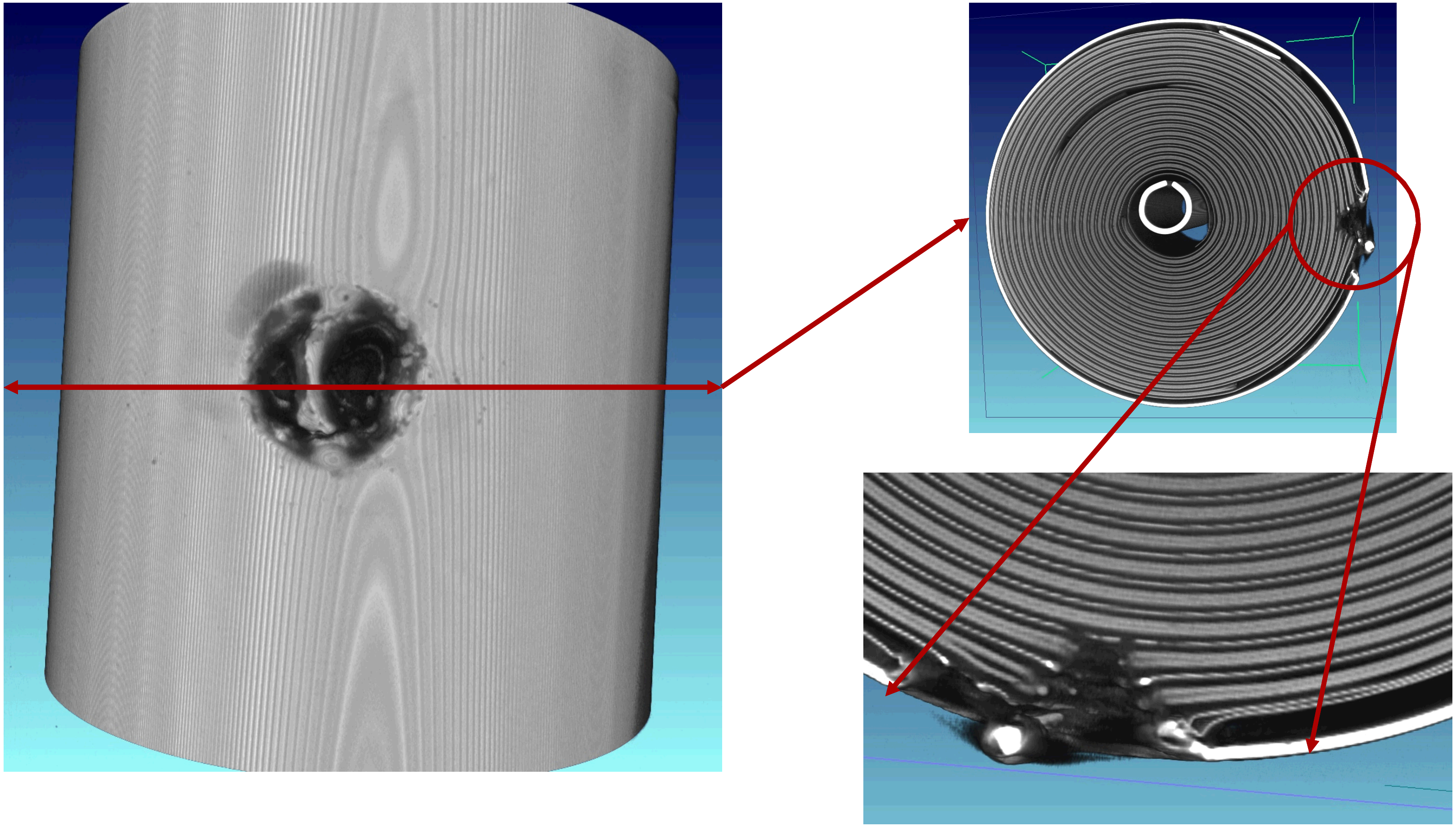
Cylindrical cell tests





- Some cell heating and voltage drop observed
- No thermal runaway initiated
- Visible damage caused to can surface and evaluated with CT

CT of 18650 damage



Discussions on Laser Battery Initiation

- Failure initiated with IR laser pulse
  - ~38 J total energy required to create enough damage to lead to high rate runaway
  - High impedance/low rate discharge with ~3.6 J total energy
- Energy comparisons show significantly less energy required for failure compared to overcharge/thermal ramp initiation, however more energy is required when compared to nail penetration
- Nail penetration shows significantly more internal damage. Internal damage done by laser initiation is very limited to surface layers.

Discussions on Laser Battery Initiation

- Failure initiated on pouch cell with quartz slide sealing area of failure
  - Larger failure energy needed to initiate failure
  - ~50 C cell temperature observed prior to runaway
- No runaway observed on initial cell can tests
- Inspection of initial damage shows penetration into cell may be excessive, lower energy levels may be key to initiating failure in cylindrical cells. This testing is in progress to initiate failure in cylindrical cells.
  - This provides some information for further technique development – increased laser energy may not necessarily have increased likelihood of creating a cell failure

Acknowledgements

- DOE Vehicle Technologies Program
  - Dave Howell
  - Brian Cunningham
  - Samm Gillard
- DOT NHTSA
  - Phil Gorney
  - Steve Summers
- June Langendorf
- Kyle Fenton
- Summer Ferreira
- John Hewson