SAND2011-7397P

Internal Short Circuit Methods for Lithium Ion Cells

220th ECS Meeting
Boston, MA
Oct. 9 – 14, 2011

Kyle Fenton, Ganesan Nagasubramanian, Chris Orendorff

Sandia National Laboratories
Advance Power Sources R & D

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Battery Hazards and Incidents

Cell Failure – higher damage potential as scale increases

EV and HEV Application

- Implication of shift from Wh to kWh
- Increasing cell number – reliability issues

Pack Propagation

- Understanding transition from several cell systems to thousand cell systems
- Understanding and replication – potential mitigation strategies

Cell Failure & Testing

Numerous causes

Fabrication

- Debris during fabrication
- Equipment drift
- Internal shifting / improper winding

Operational Hazards

- Cell management failure – overcharge
- Mechanical damage
- Temperature abuse
- Accidents – short circuit situations, cell integrity failure, etc.

Abuse Testing

Mechanical

- Crush
- Nail Penetration

Electrical

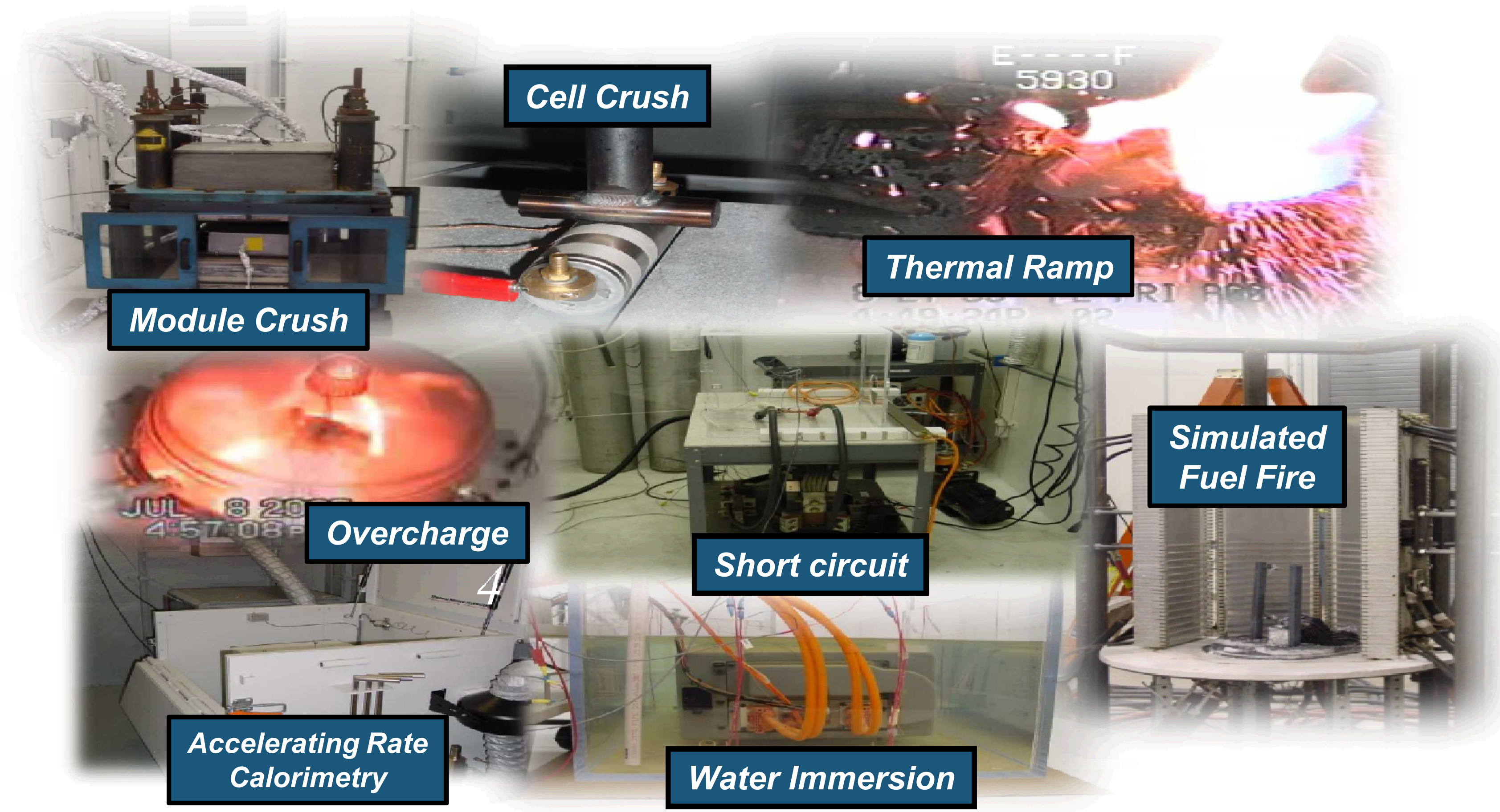
- External Short Circuit
- Overcharge
- Overdischarge

Thermal

- Thermal Ramp
- Simulated Fire

Numerous standards and tests – UL, IEC, NEMA, SAE, UN, IEEE, JIS, BATSO …

Sandia Battery Abuse Testing Lab



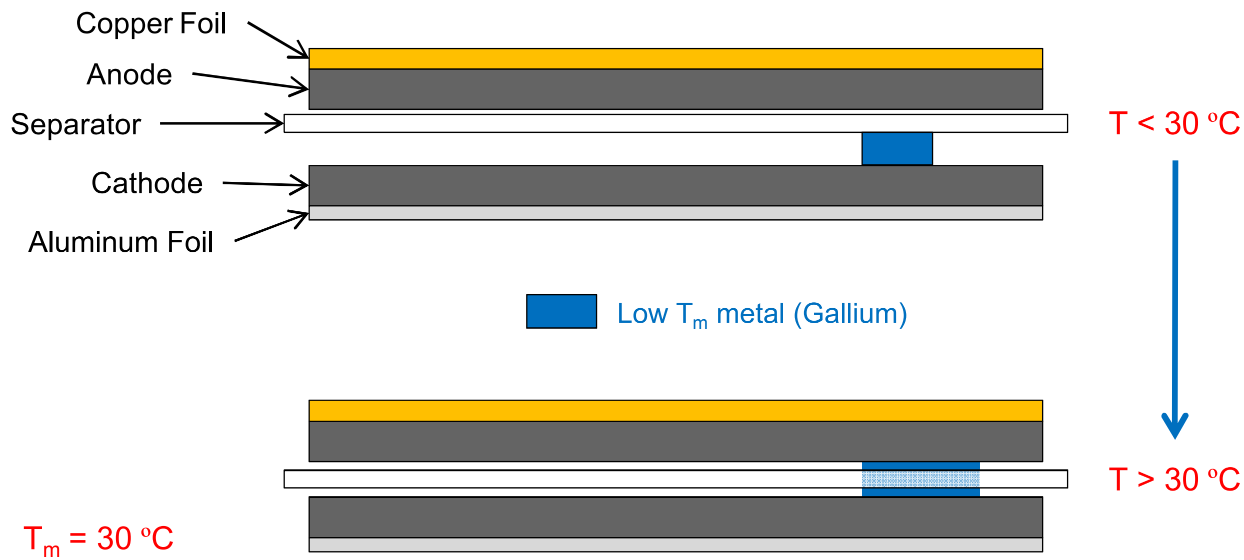
Possible to induce short circuit with minimal external interference?

Internal Short Circuit Testing Objectives

- Develop methodology to trigger internal short circuits in normally operating cells
- Have trigger be minimally invasive for cell function and environment
- Have methodology be applicable for many cell chemistries and form factors (pack level testing applicability)
  - Difficult due to size limitations for small form factors
- Methodology that is flexible enough to allow for various short scenarios (Al-Cu, Al-C, Oxide-Cu, etc)

Design for Liquid Metal Internal Short Circuits

- **Low melting point metals**
  - **Fabricated into cell (multiple short scenarios possible)**
  - **Allows for normal operation**
  - **Allows for low temperature scenarios**
  - **No external connections (retains can wall integrity)**
  - **Available with numerous T_m**

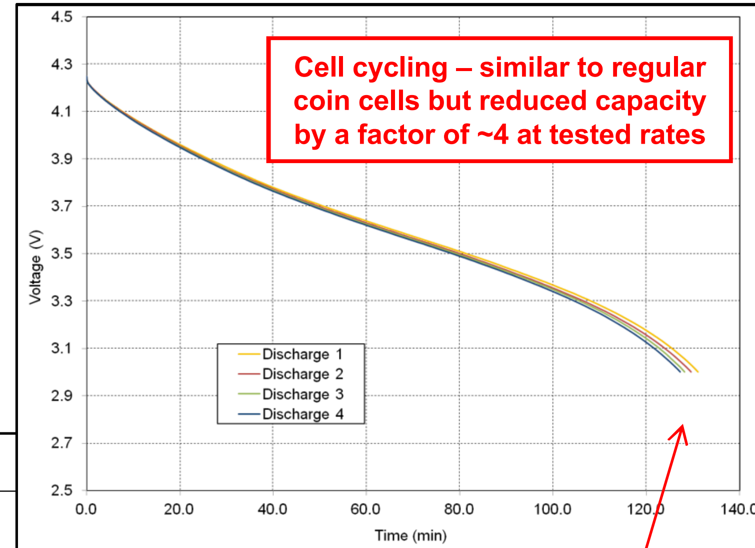


T_m = 30 °C

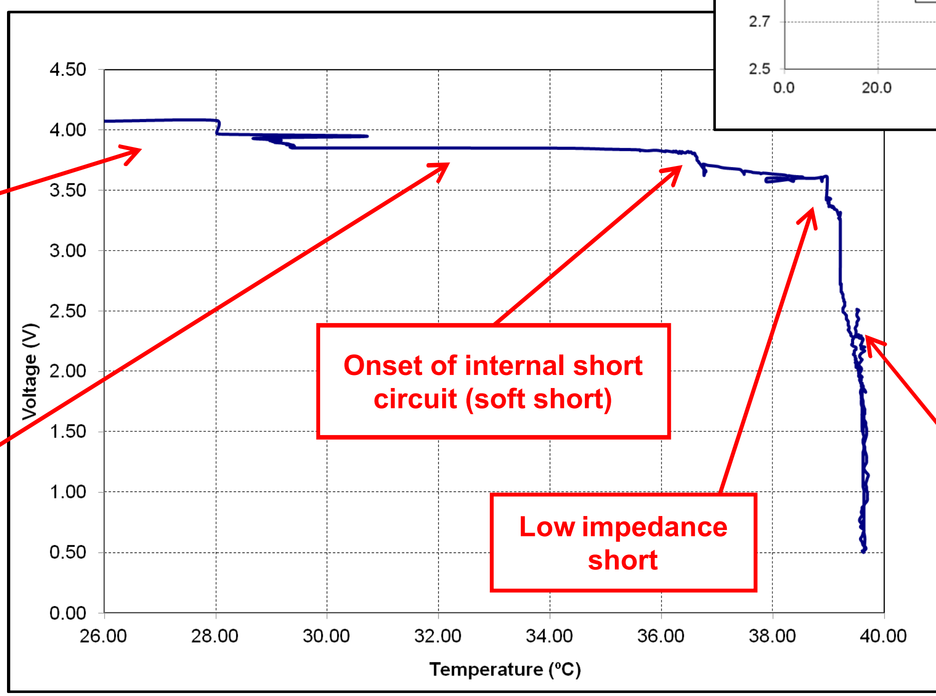
Melting of metal ⟶ contact between electrodes

Gallium – ISC evaluation

- 2032 coin cell fabrication
  - After electrode balance
  - Built onto cathode side current collector (short to anode)
  - $LiCoO_2$ and $LiMn_{1/3}Ni_{1/3}Co_{1/3}O_2$ (MNC) cathodes vs. carbon anode
  - Gallium insert ~350 µm thick



Similar capacity loss per cycle as normal cell

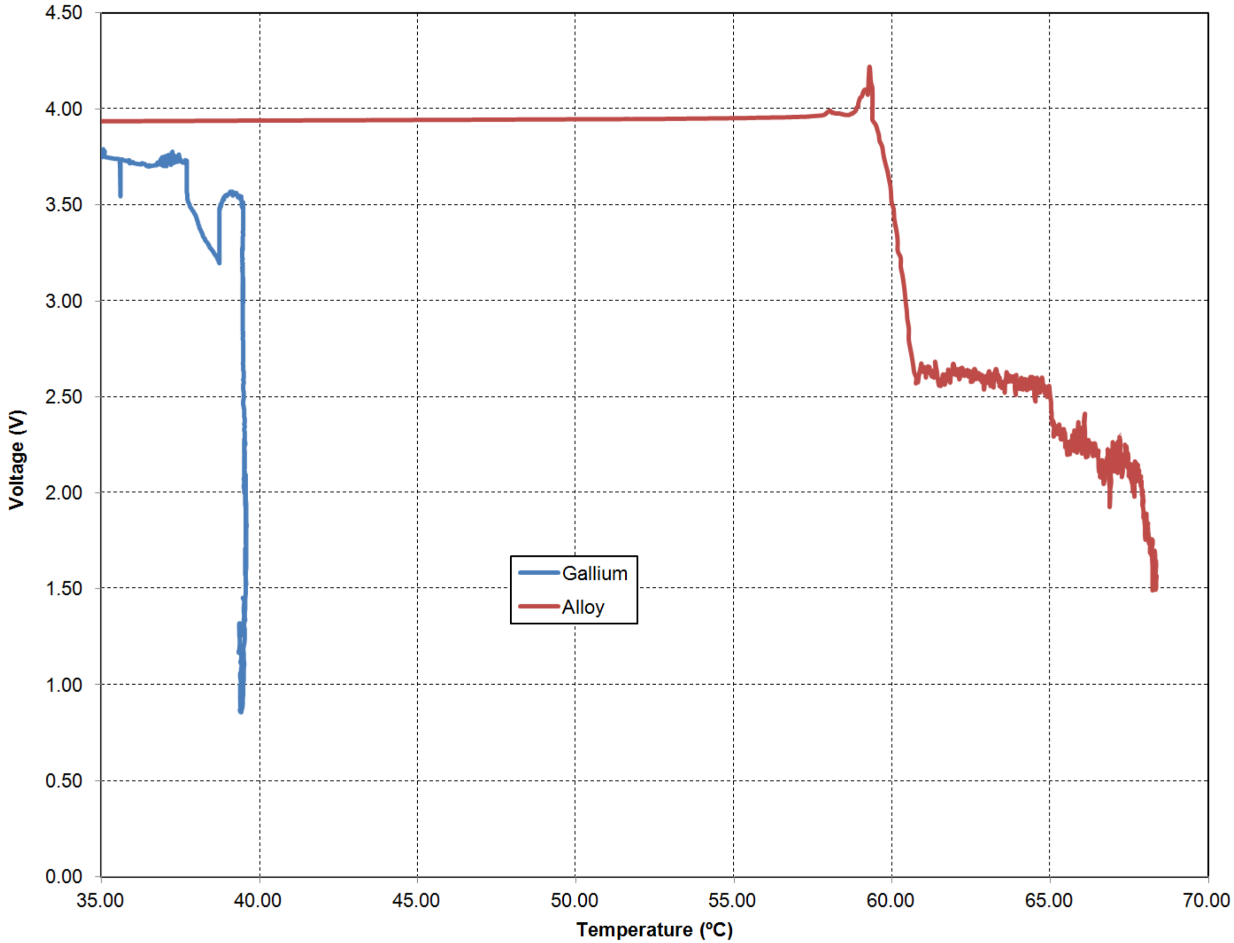


Initial ramp and hold at ~28 ºC

Thermal ramp to melt gallium metal and initiate short circuit

1C rate applied to evaluate voltage recovery with short in place

Liquid Metal Alloy – ISC Evaluation



- **Alloy #60 – Bismuth/Tin/Indium (32.5% / 16.5% / 51%)**
- **T_m = 60 ºC**
- **Liquid metal alloy selection – tailor short to application**
- **Short circuits typical between ~ 60 - 65 ºC**

Orendorff, C.J., Roth, E.P., Nagasubramanian, G.
J Power Sources 196(2011), 6554 – 6558.

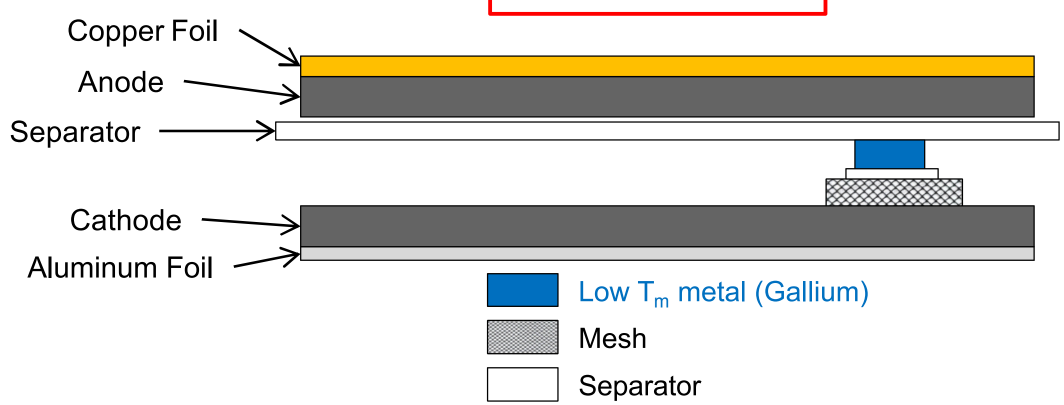
Alloy selection – ability to select T range for short to occur

Modified Methods for Liquid Metal Shorts

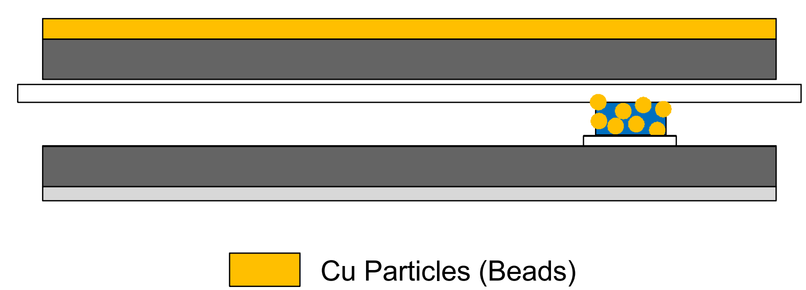
Ideal Outcomes

- **Increase degree of shorting**
- **Decrease time required for full short**
- **Decrease interfacial impedance (liquid metal to foil or electrode)**
- **Control liquid metal flow towards short location**
- **Use of more rigid metals (rupture of separator and increased short)**
- **Copper beads used (0.4 mm average diameter, 33% w%)**

Metallic Mesh



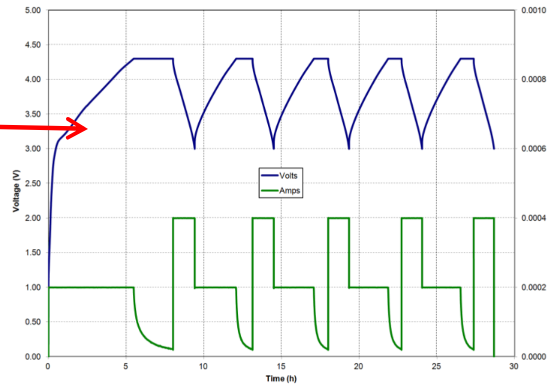
Metallic Beads

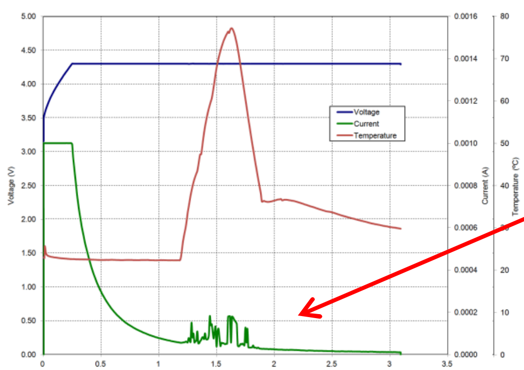


Modified Methods for Liquid Metals Summary

Metallic Beads

Formation – similar to normal cell



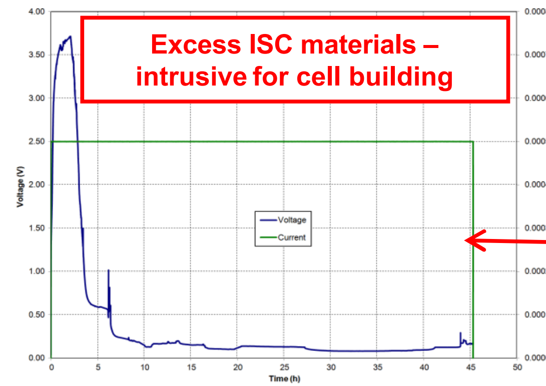


Slight response with T – minimal shorting with bead inclusion

Wetting behavior – noticeable difference with Cu bead

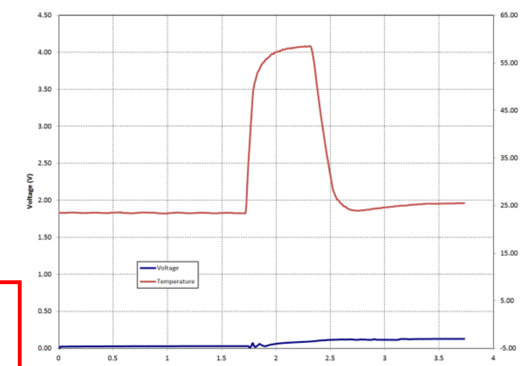
Metallic Mesh

Excess ISC materials – intrusive for cell building



Formation – very difficult

Slight response with T – mesh driving short



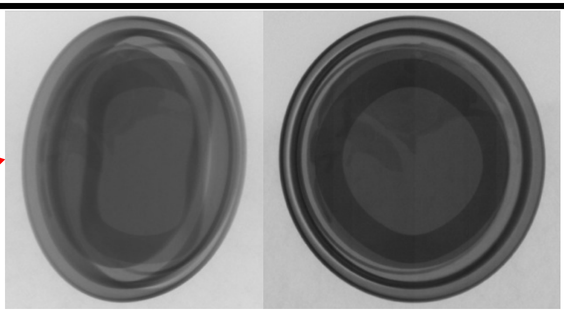
Mesh control of liquid metal – increased cathode contact

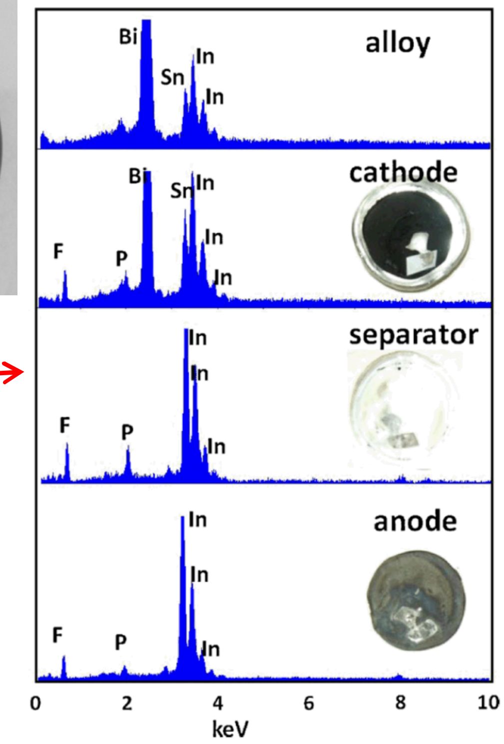
National Nuclear Security Administration

Sandia National Laboratories

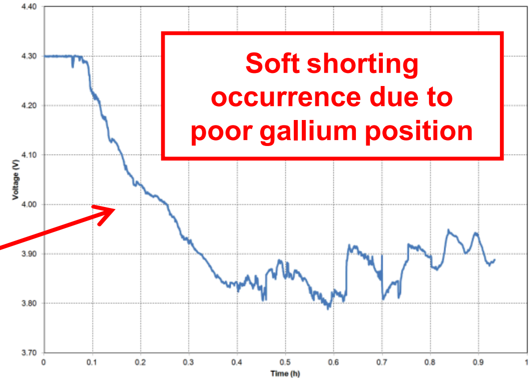
Liquid Metal Short Circuits – Challenges

- **Gallium movement within cell**
  - **Control is difficult**
  - **Care to not impede in assembly / formation**
- **Alloy movement within cell**
  - **Alloy phase separation**
- **Wetting**
- **Assembly**





Variations in extent of short circuit
- **Liquid metal placement after T ramp**
- **Contact with electrode / current collector**



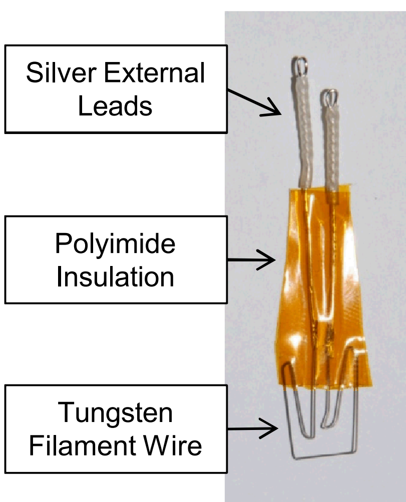
Inability to form or short
- **ISC assembly interference**
- **Liquid metal interface with electrode**

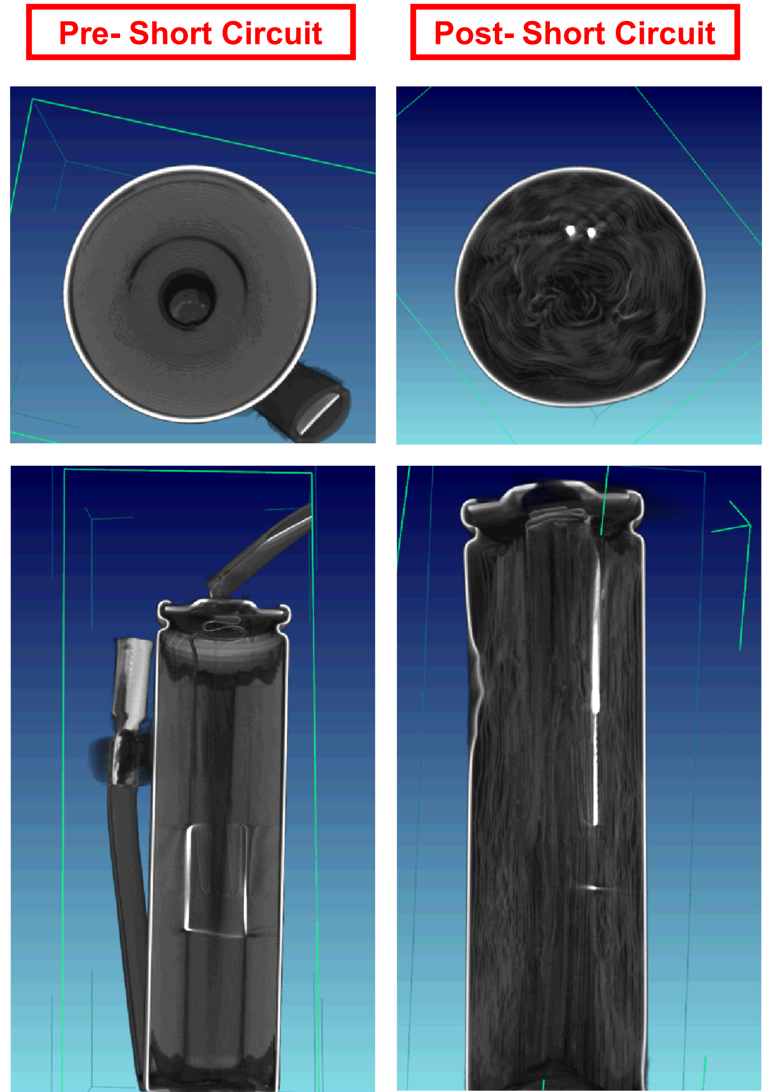
Winding tension in 18650 – difficulty with liquid metal
Technique has been demonstrated

Internal Heater Wire Shorting (Developed at SAFT)

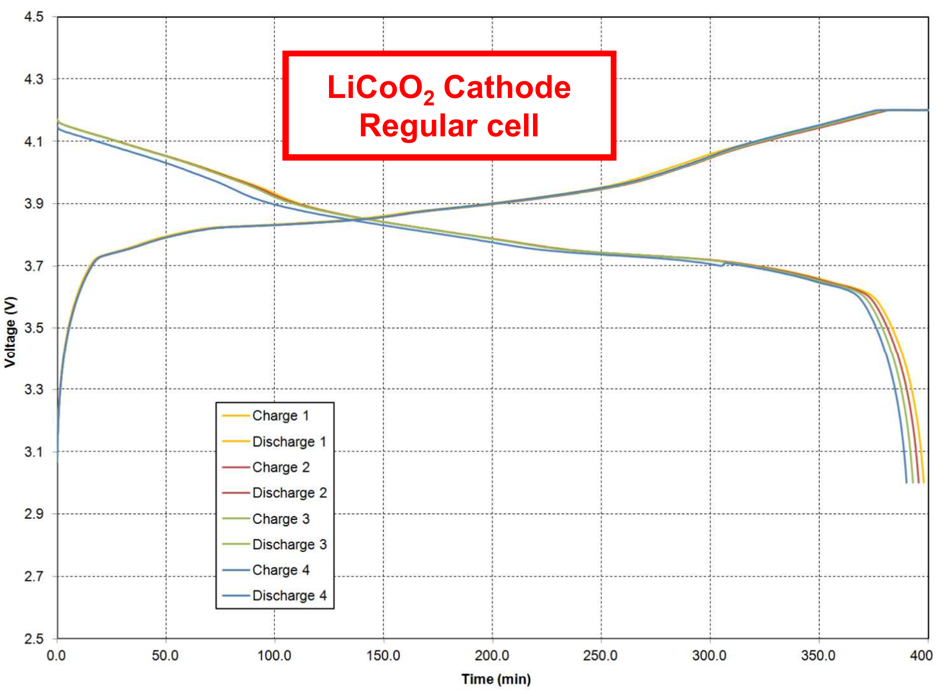
Internal Wire within the cell

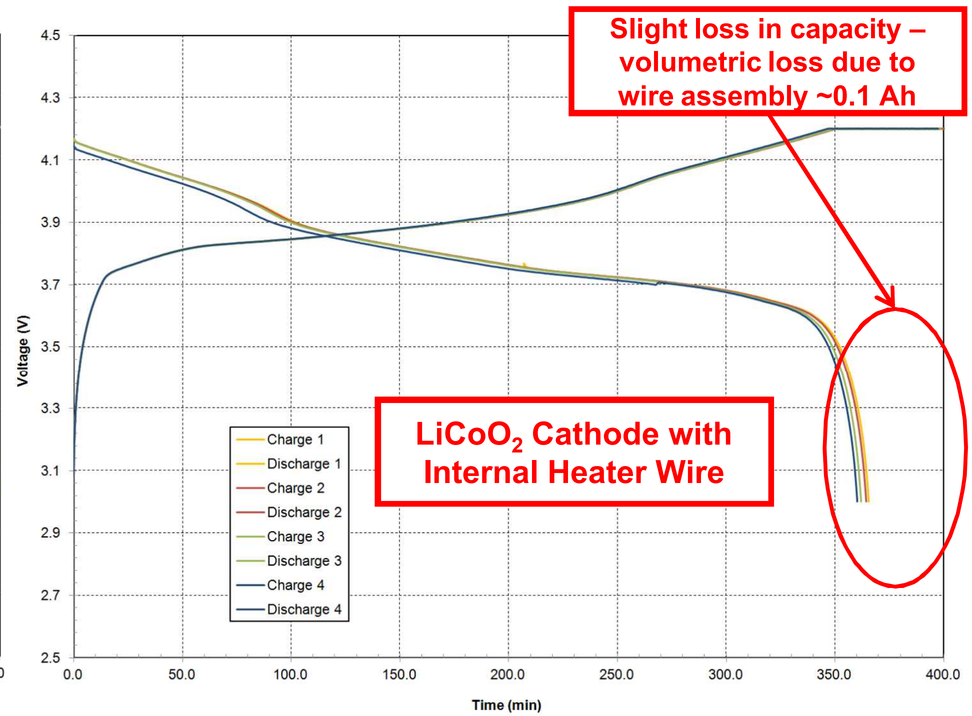
- Fabricated through the header
- Current applied to wire externally
- Wire heats resistively
- Separator melts
- Short occurs





Formation Cycling with Internal Wire Cells



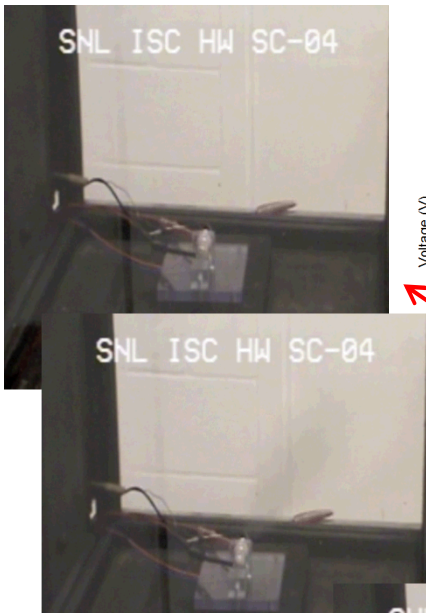


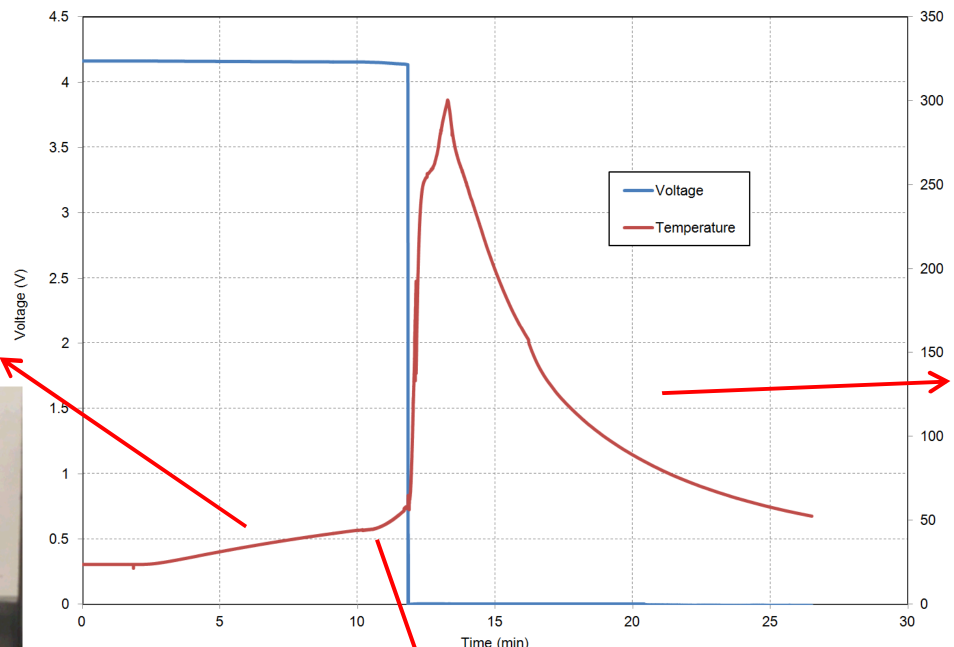
- **18650 cells made using $LiCoO_2$ cathodes vs. carbon anodes**
- **Cells with internal wires cycle similar to normal cells but have slightly less capacity (active material loss from volume of wire)**
- **Electrode loss is ~ 1 inch per electrode for internal heater wire**

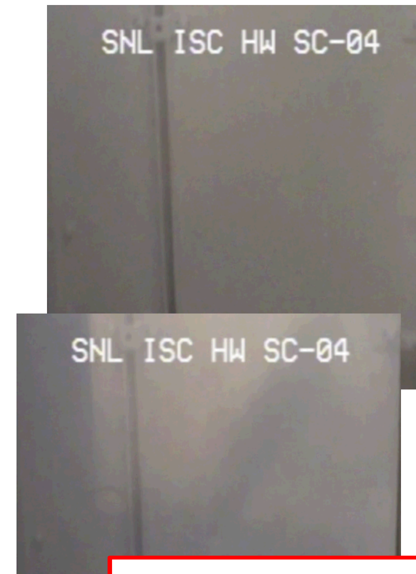
NNSA National Nuclear Security Administration

Sandia National Laboratories

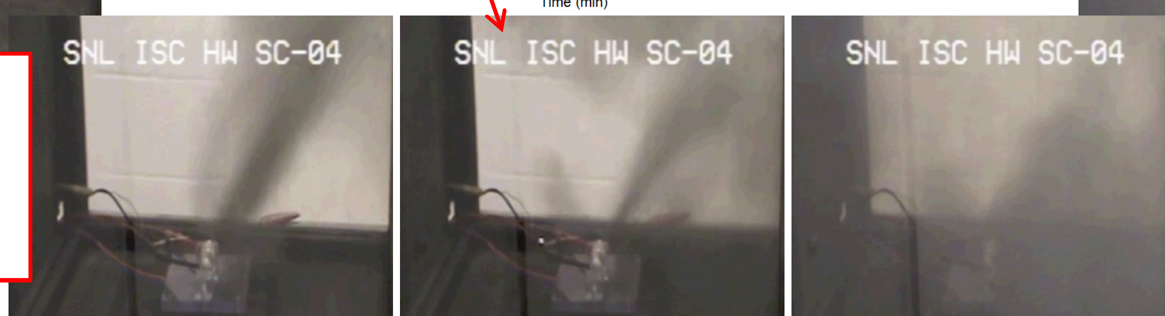
Short Circuit Event with Internal Wire Cells







Local heating – separator breakdown and internal short



Complete loss of materials and energy

Decomposition occurs – rapid heating and breakdown (electrolyte, anode, cathode) results in cell disassembly and venting

NNSA National Nuclear Security Administration

Sandia National Laboratories

Summary

Internal short circuit development – liquid metal techniques

- Demonstrated ability to internally short using minimal initiation temperature
- Alloy inclusion:
  - Small form factors – reduces cell capacity, but allows for cell operation
  - Larger form factors – minimal impact on electrochemical performance
- Use of alloys – allows for short to be application specific (can be just outside of operational window)
- Methodology allows for various shorting scenarios
- External trigger allows for use in any pack geometry

Internal short circuit development – modified liquid metal techniques

- Inclusion of copper beads – allows for electrochemical cycling but short circuit is difficult (wetting behavior)
- Wire mesh – ISC materials can potentially interfere with formation of cell. Liquid metal appears to wick well to cathode (minimization of interference ideal)

Internal heater wire demonstration

- Demonstrated ability to build and form 18650 cells with included wire
- Short circuit induced at low temperature (~50 ^{o}C) resulting in cell component breakdown and runaway

Future Work

Internal short circuit development – liquid metal and modified techniques

- Evaluation of new methods – liquid metal flow control and contact resistance
- Evaluation of new alloy materials – understanding of alloy separation and alloy conductivity on internal short circuit
- Modification of materials – allow for more reliable application of modified methods (thinner materials or particle loading)

Internal heater wire

- Modification of materials set and procedure – include a wider range of form factors (ideally much smaller)

Acknowledgements

- Dave Howell (DOE/OVT)
- Tom Wunsch
- Josh Lamb
- Lorie Davis
- Mike Russell
- Jill Langendorf
- Dave Johnson

NNSA National Nuclear Security Administration

Sandia National Laboratories