WHEN TRUST MATTERS

Safety Testing of Batteries Beyond UL9540A

ESS Safety & Reliability Forum – June 6, 2023

Martin Plass – Director – Energy Storage Testing
BEST Test & Commercialization Center (BTCC), Rochester, NY

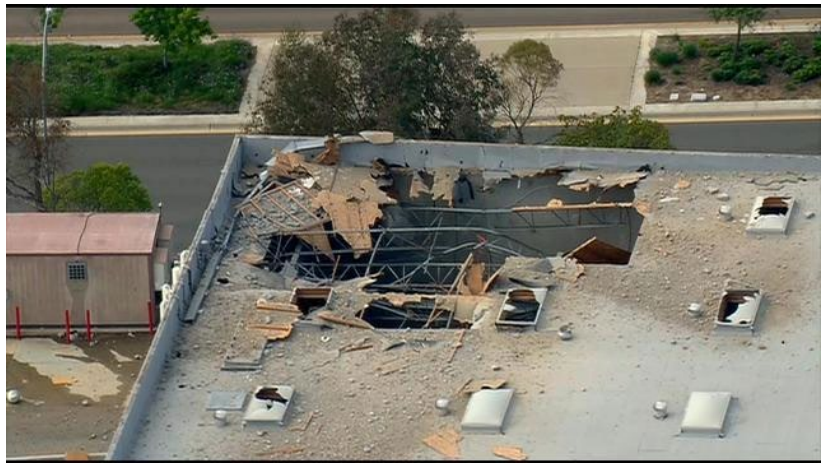
06 June 2023

Catastrophic failures of energy storage systems

Fact: Energy storage systems have high energy densities

Risk: Uncontrolled release of this energy

Flooding of Pumped Hydro station



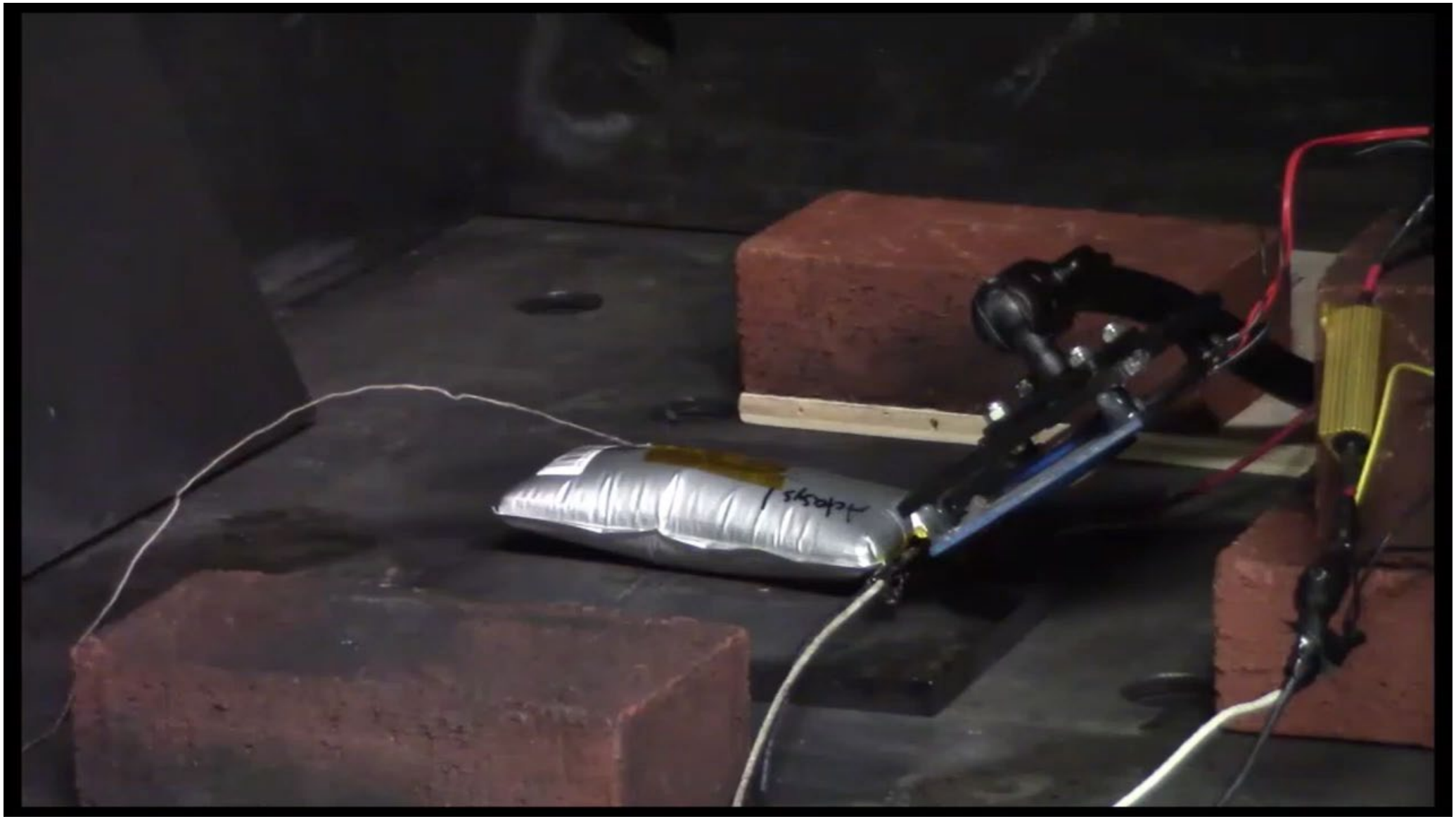
Industrial explosion with flywheel

http://www.cbs8.com/story/29289445/industrial-explosion-at-a-poway-business

Thermal runaway of Li-ion batteries

Recommended Practices for the Safe Design and Operation of Flywheels (sandia.gov)

10Ah Pouch Cell Overcharge



Nail Pen – Pouch Cell

Lithium-Metal Cell Nail Pen Test

UL 9540 and UL 9540A

- UL 9540A is a testing method used for evaluating thermal runaway impacts in a BESS
  - Not a pass/fail test
  - 4 levels of the test: cell, module, unit, and installation*
    - *Installation level tests are not typically required for lithium-ion batteries
  - Each level has performance criteria that must be met in order for the test to stop at that level
  - Currently in its 4th edition
    - Notable difference between 3rd and 4th editions: 4th edition required cell-to-cell propagation in the module-level test

- UL 9540 is the Standard for Safety for Energy Storage Systems and Equipment
- There are currently 2 version of UL 9540: the 2016 version and the 2020 version
  - Notable difference between versions: The 2nd edition (2020 version) requires the 4th edition UL 9540A testing

UL9540A

- Standardized method to evaluate battery fire safety (Cell, Module, Unit, Install Level)
- Required for NFPA-855 BESS Installation Standards
- Referenced in international Battery Safety Standards (IEC 62933)
- **Provides good input data for fire safety engineering & simulations:**
  - **Vent & TR Temperatures**
  - **Volume of vent gas**
  - **Gas composition**
  - **Flammability**

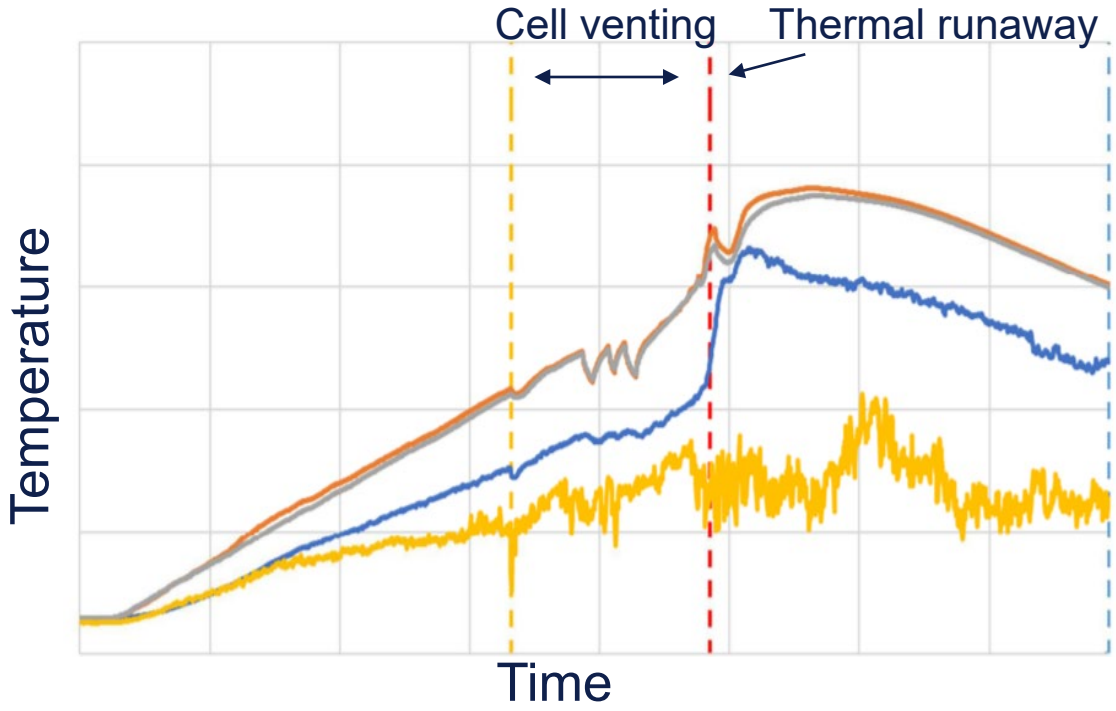
UL 9540A: Test method for evaluating thermal runaway fire propagation in BESS

Purpose: Evaluate potential dangers from battery fires

Important data considerations:

1. Cell level
   - Venting and thermal runaway temperatures
   - Off-gas volume and composition
2. Module level
   - Level of thermal runaway propagation between cells*
   - Flammability of off-gas
3. Unit level
   - Effect of thermal runaway on adjacent exposures (target BESS, walls, means of egress)

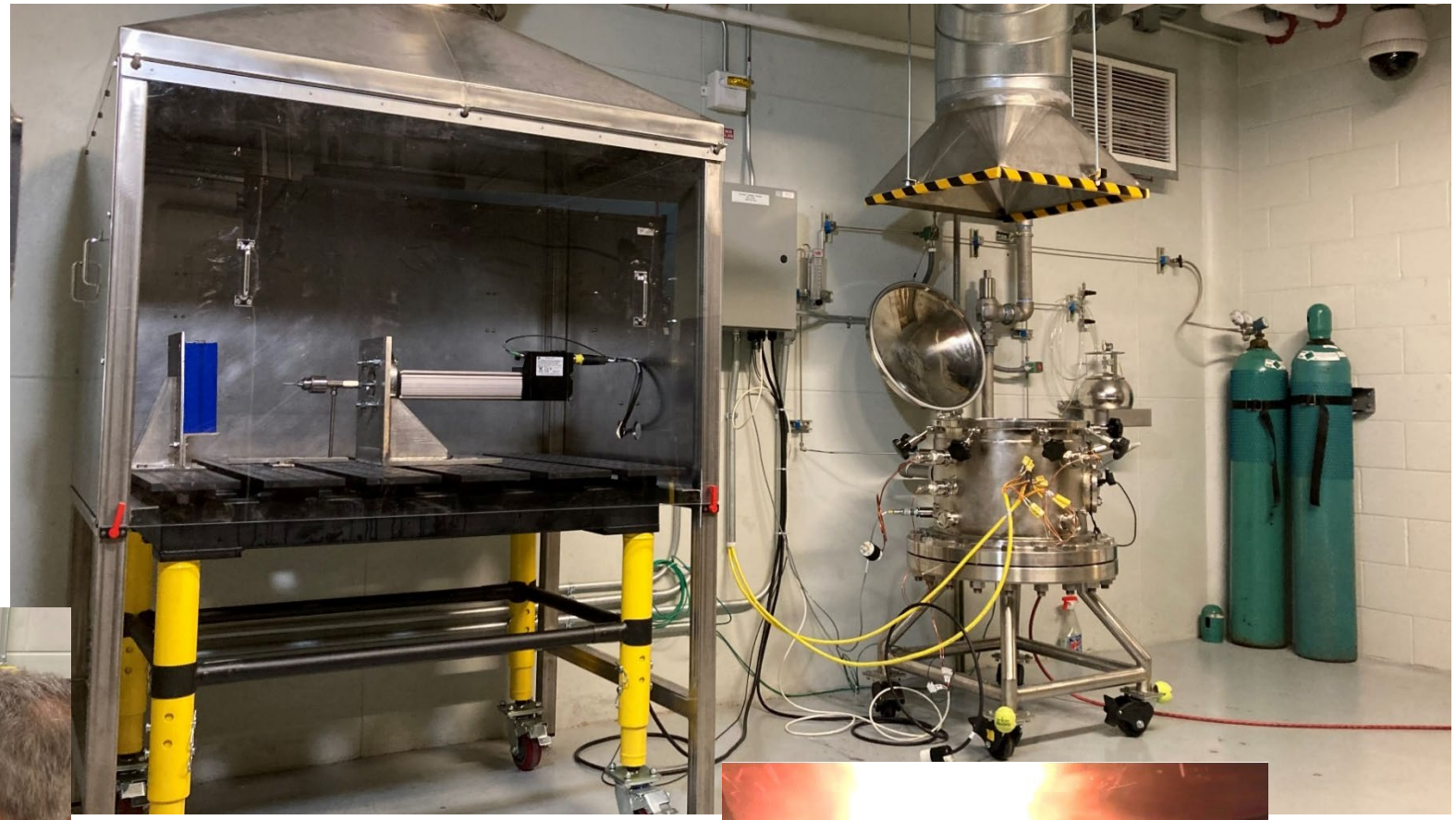
*4th edition requires cell-to-cell propagation



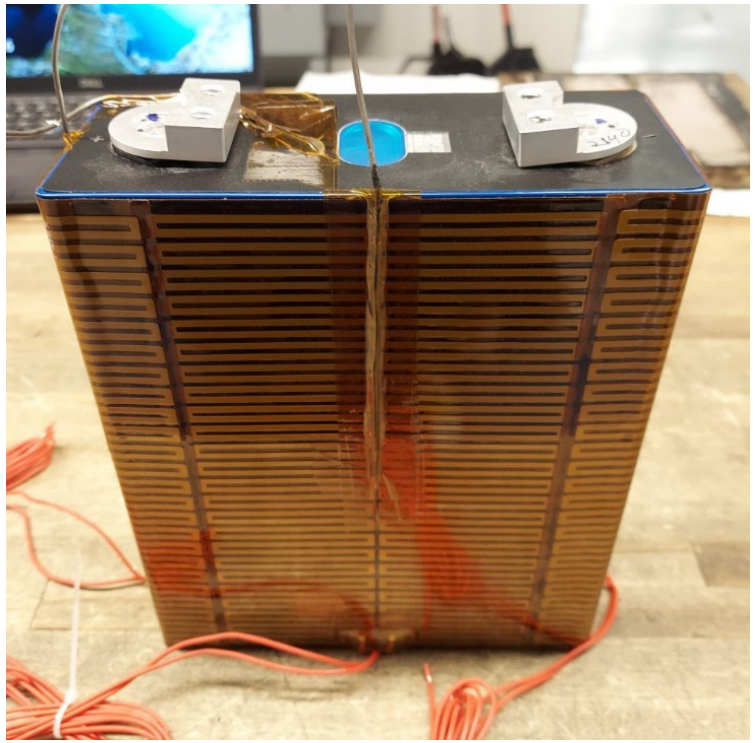
Note: colored lines indicate different thermocouples.

Cell Safety & Abuse Tests at BEST Test Center

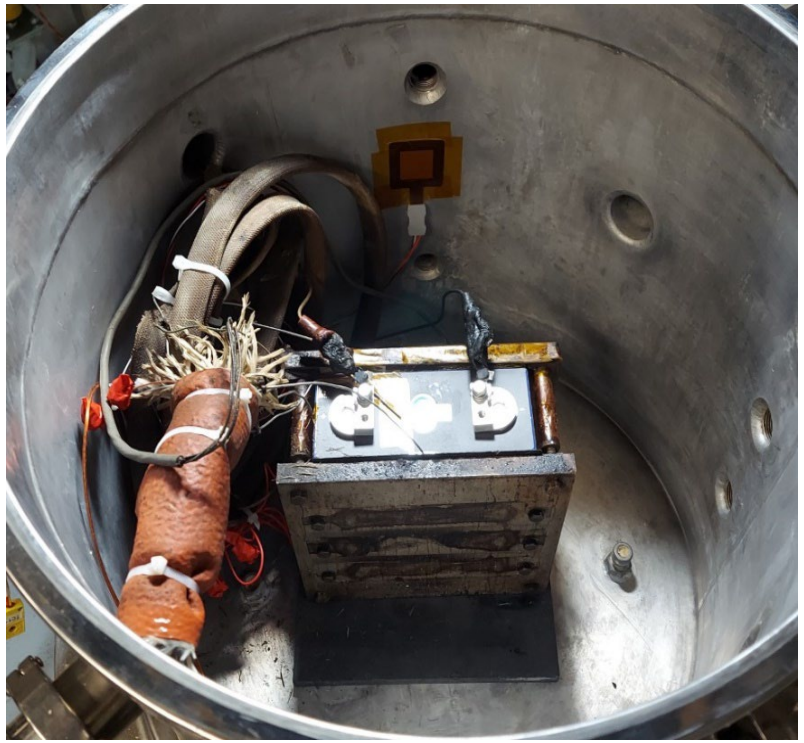
- UL9540A Thermal Runaway Tests
- Abuse Tests:
  - Overheat
  - Overcharge, Short-Circuit
  - Nail Penetration
- Gas Capture and Analysis
- Customized Safety Tests
- UL9540A Module & Unit Tests at partner lab



Example of UL 9540A cell testing at BTCC: high-power prismatic cell



Prismatic lithium cell with thin film heaters attached to surface



Cell fixtured in vessel

Pressure Vessel (Filled with Inert Gas)

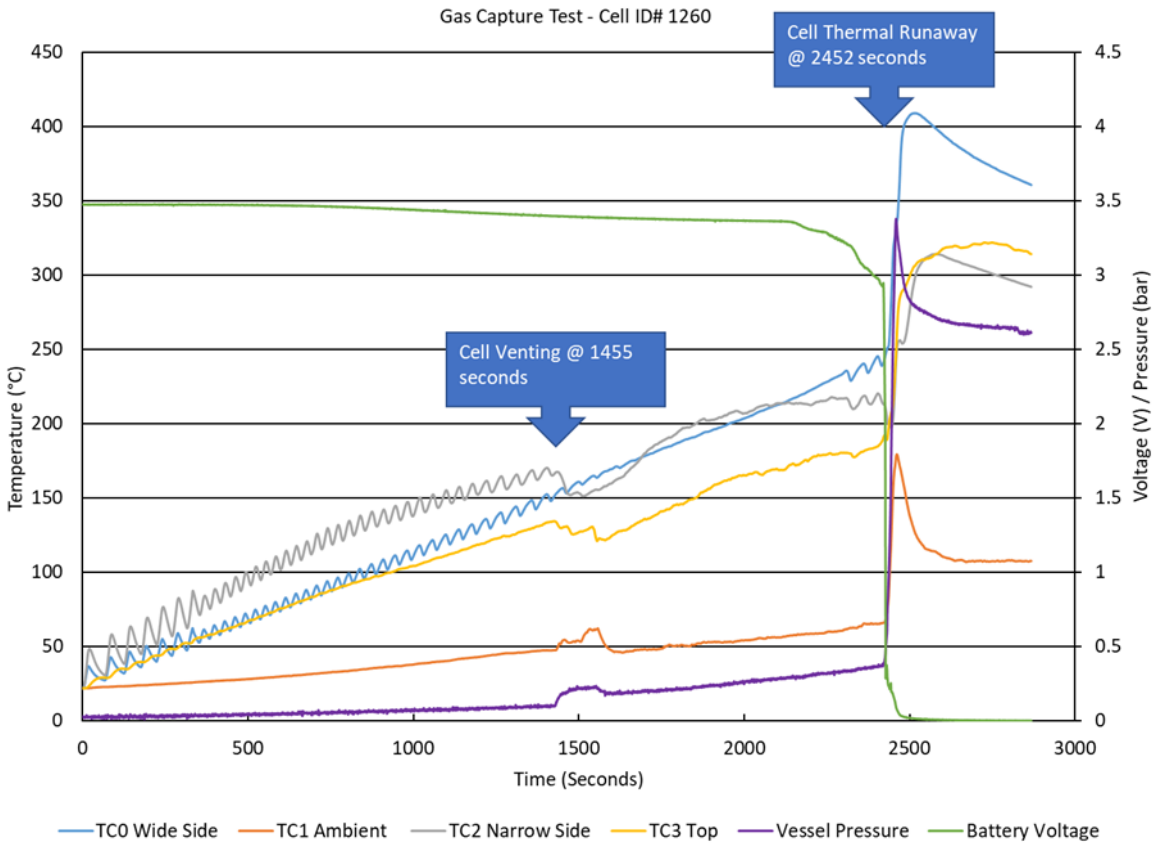
~100L Vessel backfilled with Nitrogen

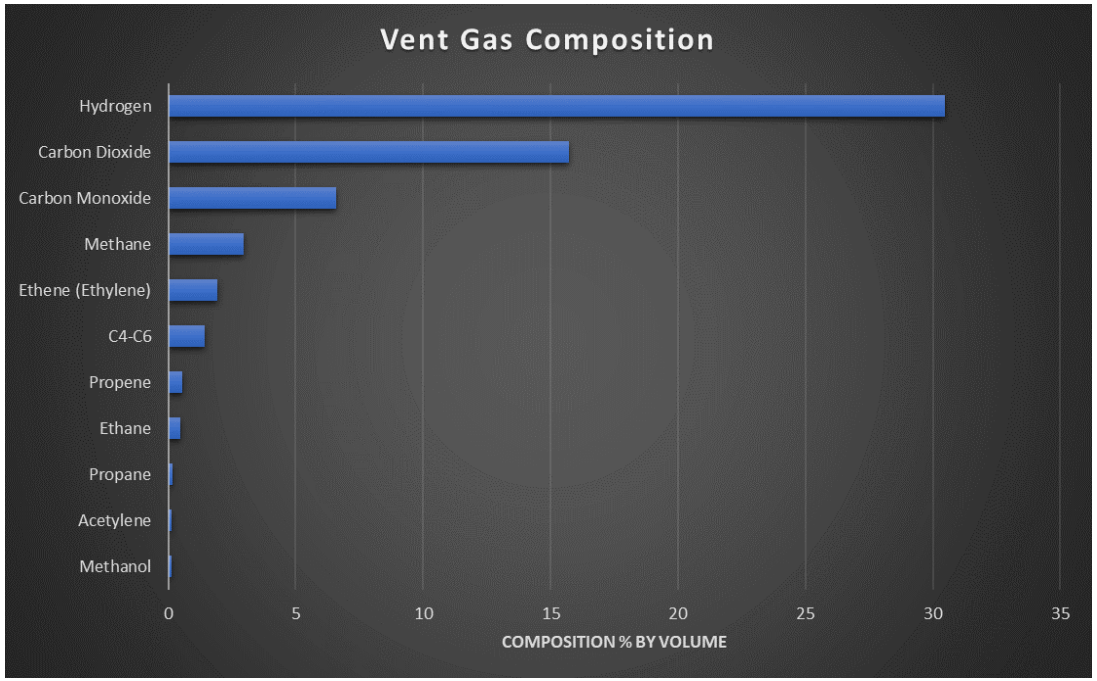
UL 9540A cell test

View of cell in vessel as cell vents

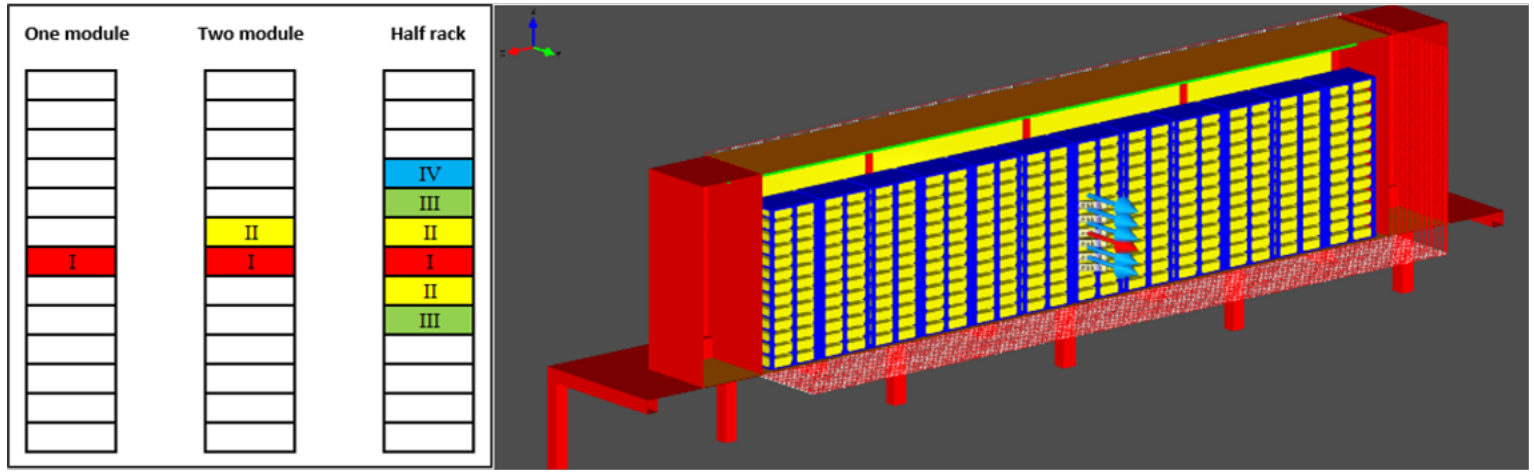
View of cell post test

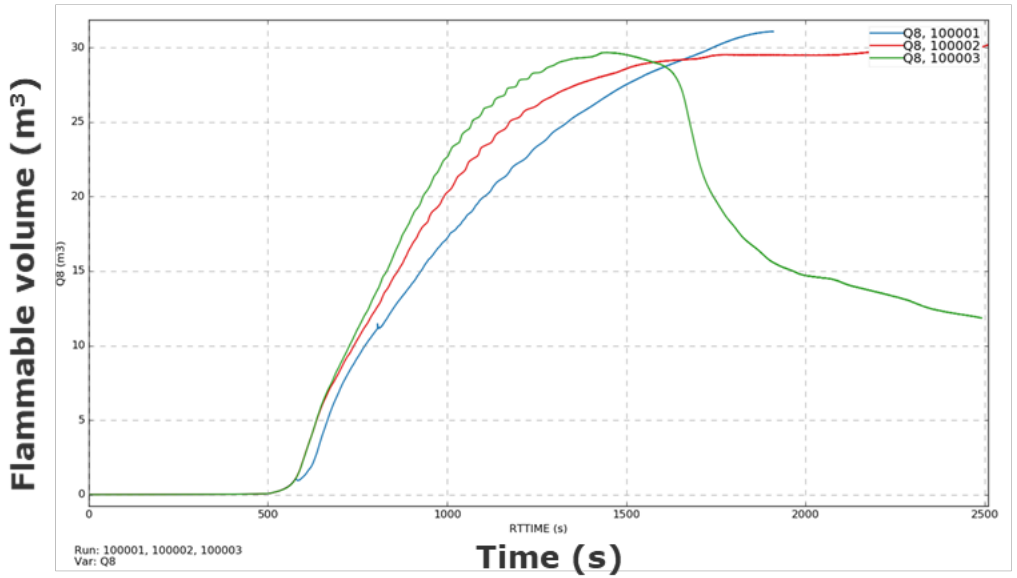
UL 9540A – Cell Gas Capture

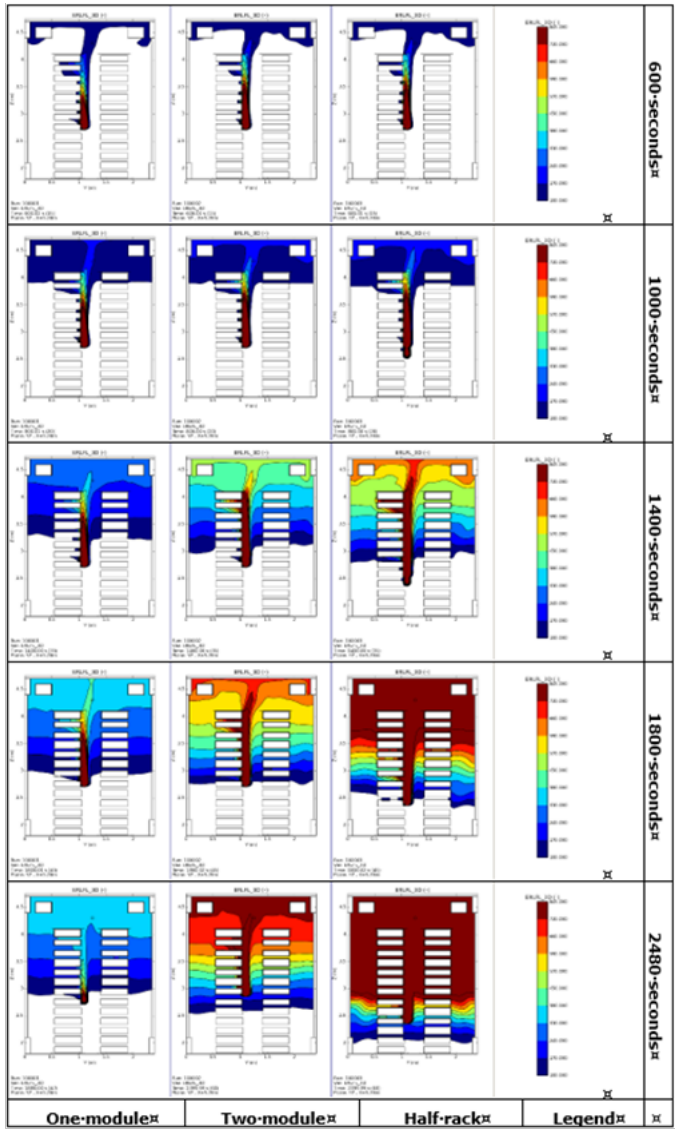




Simulation – Off-gas Accumulation

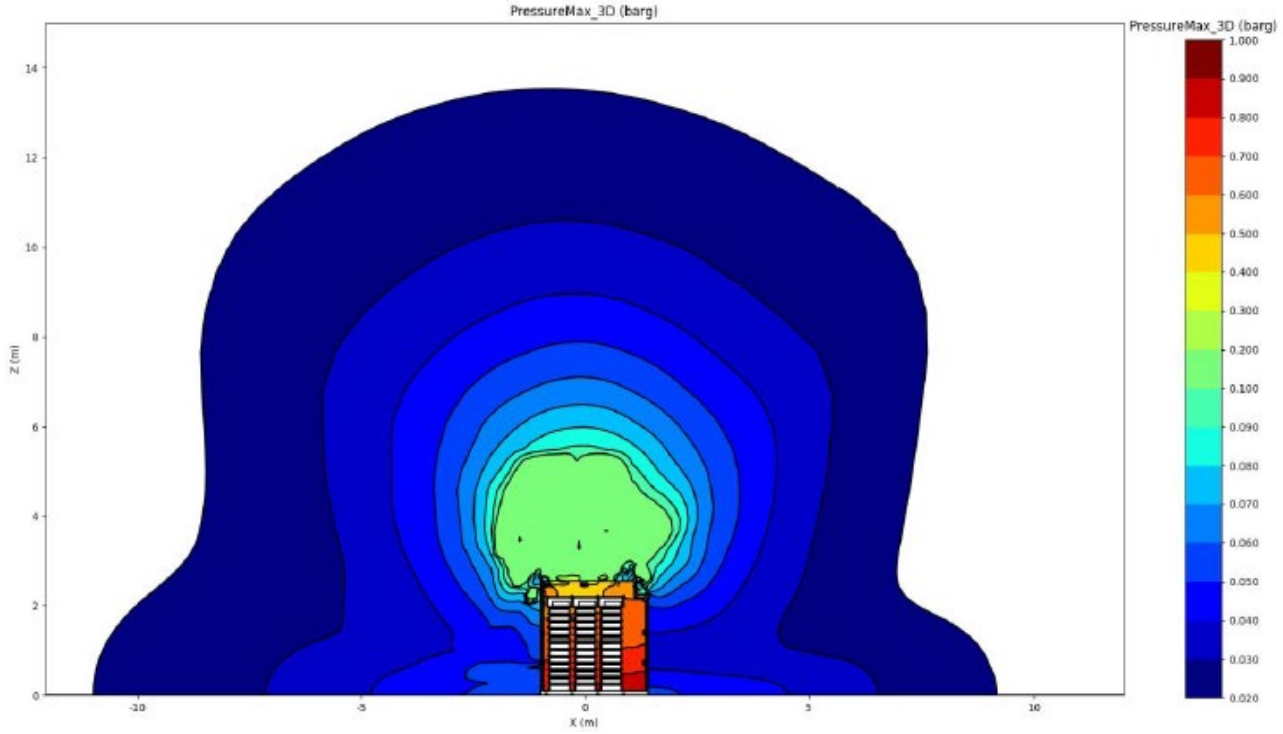






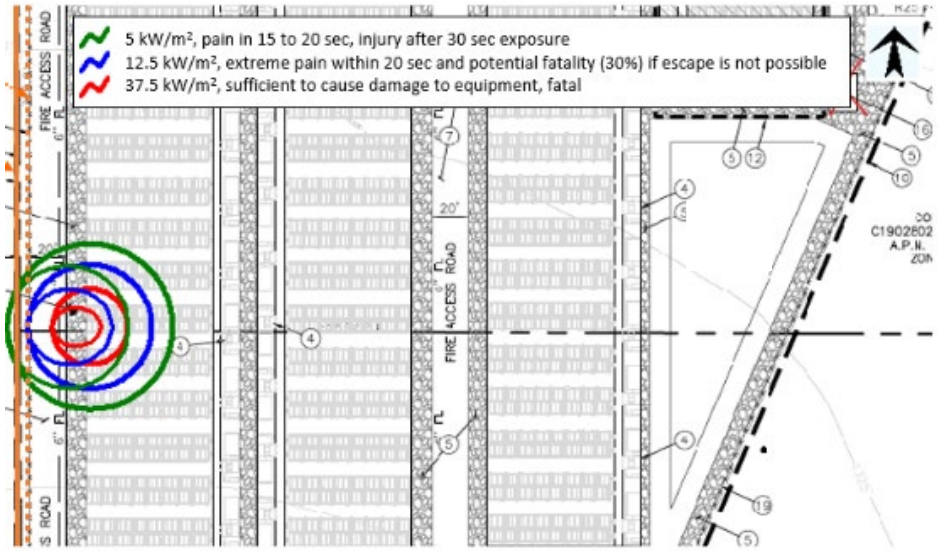
Modeling BESS hazards (CFD)

1. FLACS explosion analysis
2. PHAST plume studies



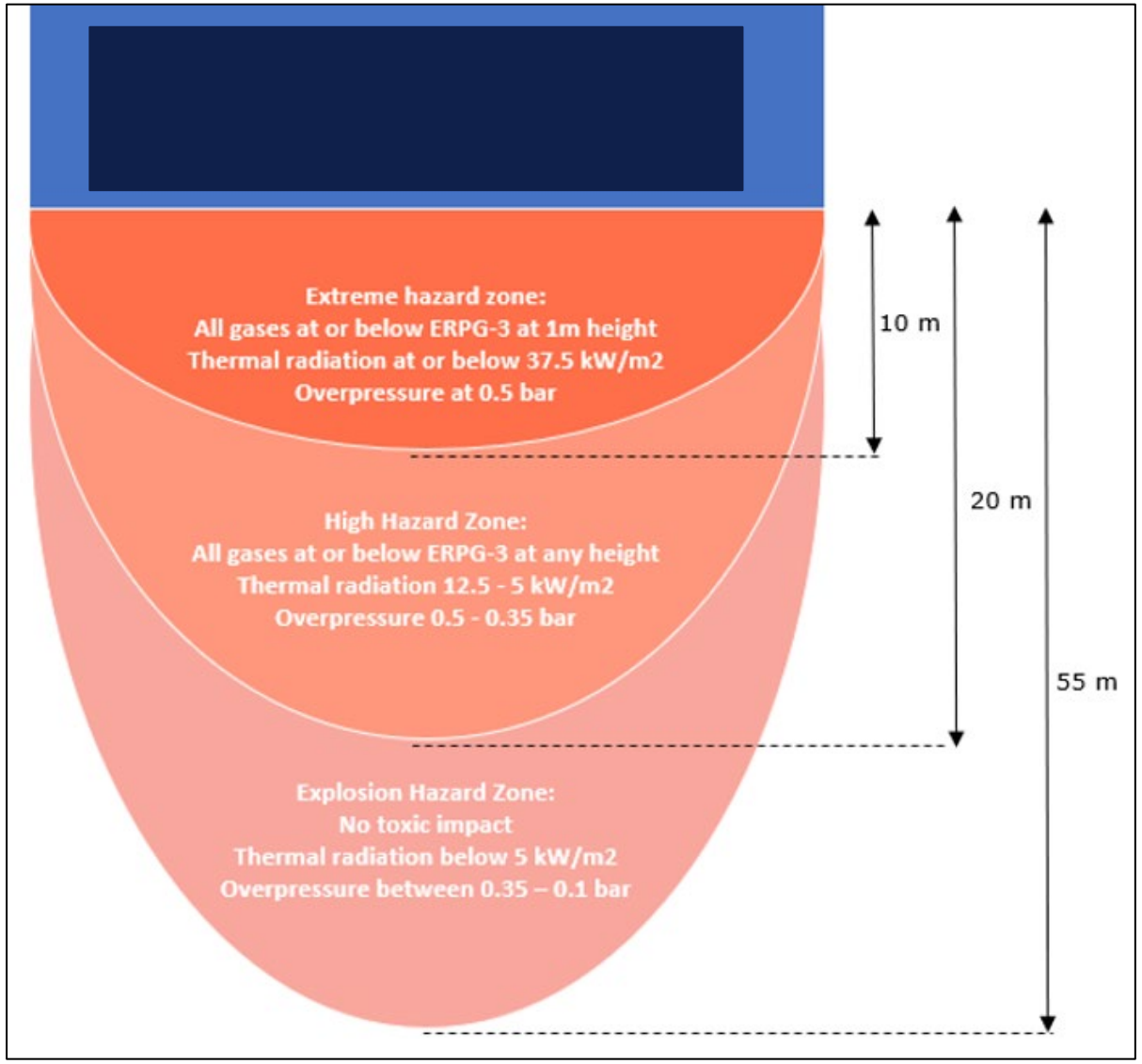
Overpressure

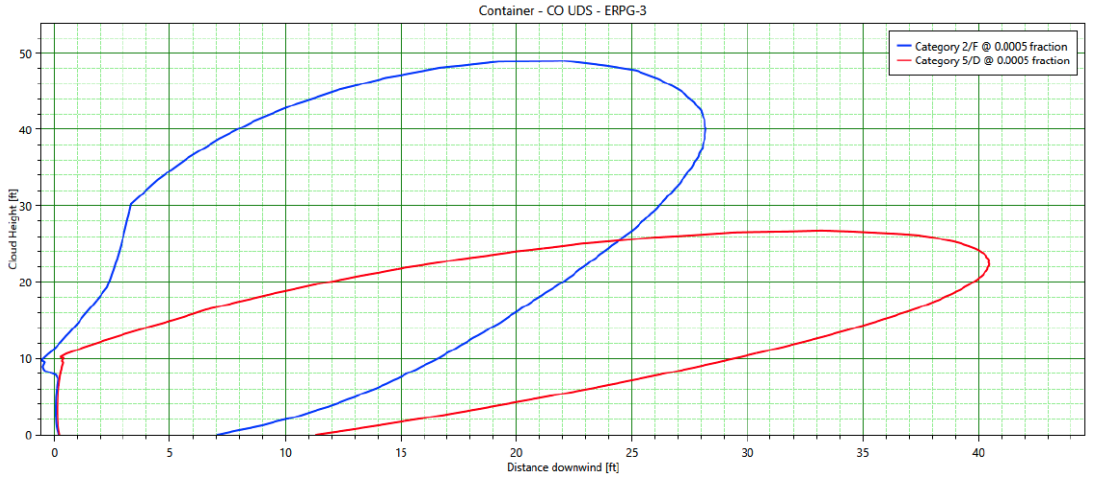
Toxic gas

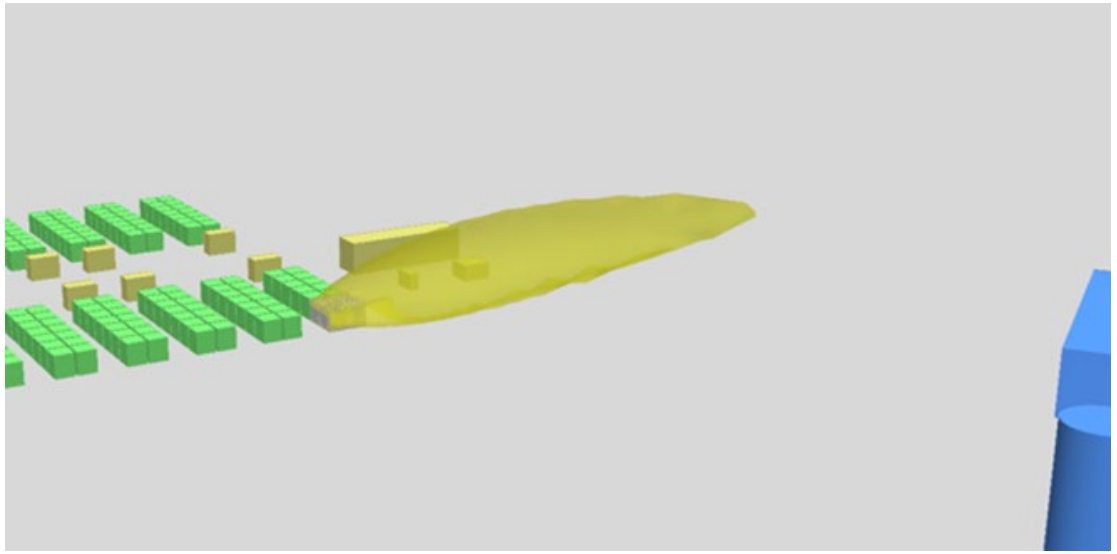


Thermal radiation

Plume Analysis







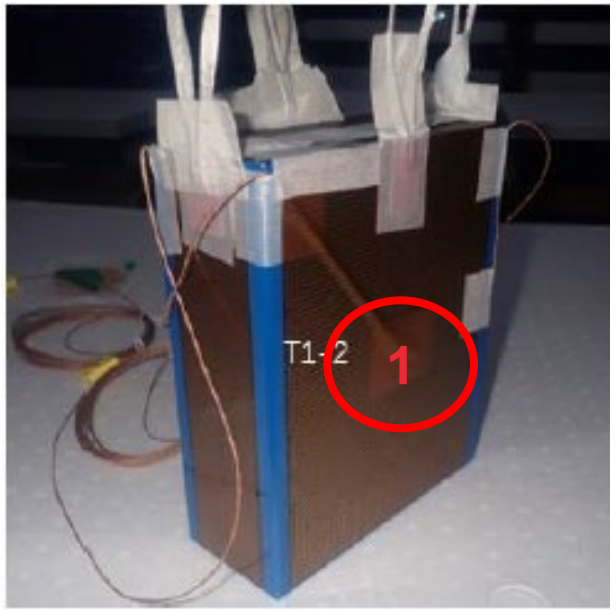
Challenges of UL9540A

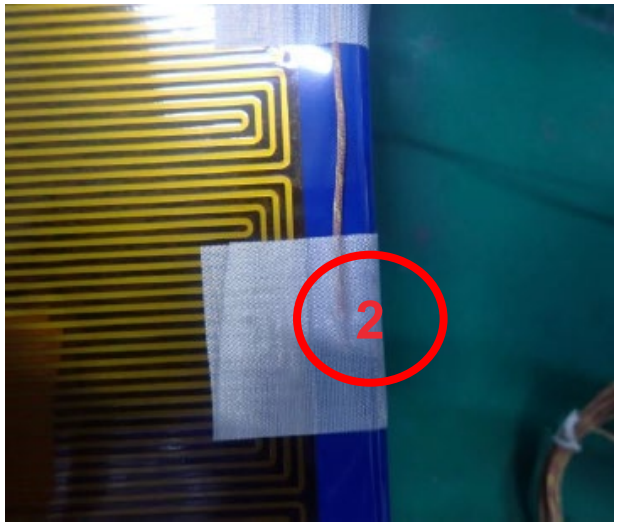
1. Temperature measurement point not well defined

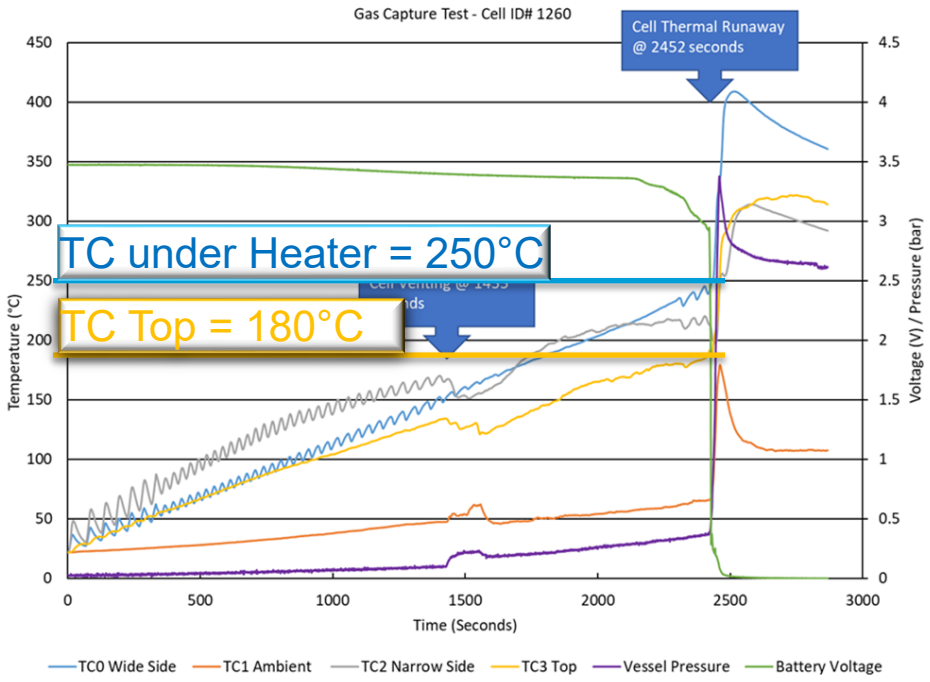
- 1 - Between Heater and Cell (Specified in Standard, e.g. 250°C)
- 2 - Cell Surface next to Heater (Often used: e.g. 180°C)

>>> Safe temperatures for cells in applications could be misinterpreted

Examples of UL tests from different test labs show vastly different temperatures

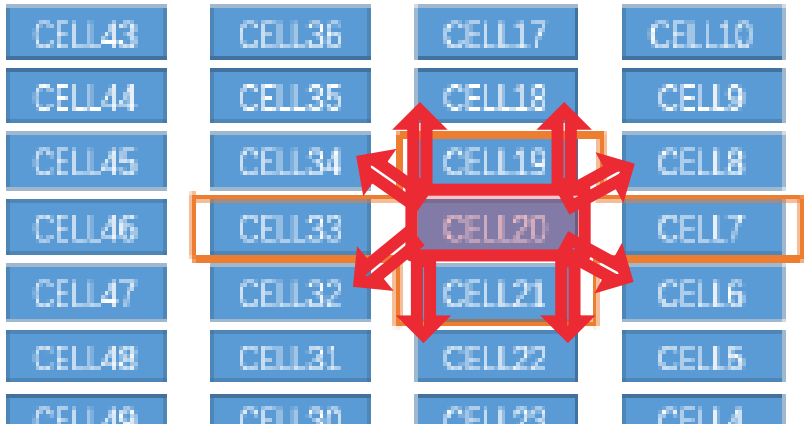






2. Module Test - Propagation Requirement

- Standard requires cell-to-cell propagation, i.e. one cell triggered in a module should propagate to other cells that are not heated.



Example:

- Cell 20 = Trigger Cell - Heated
- Cell 19, 21, 7, 33 = Heated from one side
- Standard requires non-adjacent cells to go into T.R. (i.e. 6, 8, 18, 22, 32 or 34)

>>> Cells that do not easily propagate need to be triggered with more heat or multiple heated cells

>>> Anti-propagation devices or insulation prevent tests from being successful (opposite of desired outcome)

3. Unit Test does not represent worst case

- Only one cell is typically triggered (heated)
- TR propagation often is benign
- No significant fire or gas release

However:

- Battery fires in the field are often much larger with explosions and serious hazards for people
- Customer and AHJ's want to see worst case scenarios, i.e. a whole container burning

> Need for a more extreme/realistic fire/ explosion test beyond UL9540A:

- Show that losses of large fire events are limited to initiating units and do not consume the entire BESS

> Test level of danger to people and buildings:

- Heat exposure
- Explosion pressure
- **Toxicity of vent gases** (currently only flammable gases are considered in UL test, not toxic gases like HF, HCl, HCN)

UL Test

Extreme Fire Test

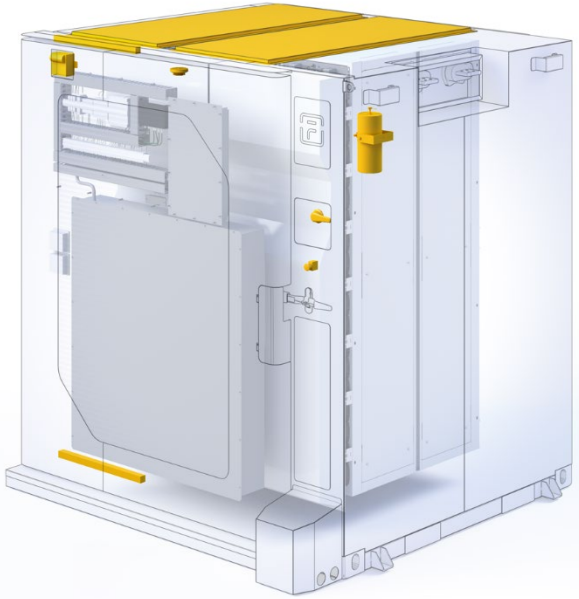
Extreme Module Fire Test (LFP)

Extreme Container Fire Test (LFP)

Additional fire safety

There are a range of additional measures that can be added to improve upon the basic product offering:

- Plume gas analysis specific to the chemistry / construction
- Gas detection
- Water sprinkler system
- Water mist system
- Forced ventilation
- Deflagration panels
- Dry risers within containers
- Fire propagation testing



Thank You

Martin Plass
Director Energy Storage Testing

Martin.Plass@dnv.com
617-484-1237

www.dnv.com