INTERNATIONAL ASSOCIATION OF FIRE FIGHTERS

Energy Storage Systems and Fire Fighter Response Safety

Sean DeCrane, Director
Health and Safety Operational Services

June 6, 2023

Agenda

1. Background
2. Arizona Incident Review
3. Project 1 of 3: UL 9540A Installation Level Testing
    1. Objectives
    2. Results
    3. Fire Fighter Considerations
4. Chandler, AZ Incident Review
5. Teaser: Project 2 of 3: “A Safe Response to Renewable Energy Hazards” (DOE-IAFF-UL)
6. Teaser: Project 3 of 3: “Explosion Hazards from Li-ion Battery Thermal Runaways in Residential Garages”
7. Reality check

Background

2 MW/2.16 MWh lithium-ion battery ESS

- Average home in Arizona consumes 1 MWh/month
- ESS owned by local electric utility (APS)
- Batteries manufactured by LG Chem
- ESS designed by the integrator (Fluence)
- ESS maintained by contractors to the integrator (Sturgeon)

Four firefighters (Peoria HAZMAT team) seriously injured

Four firefighters (Surprise E304) held overnight for suspected exposure to HCN

Courtesy of APS

Timeline

16:54:30 — Minimum battery cell voltage in Rack 15 began to decrease.

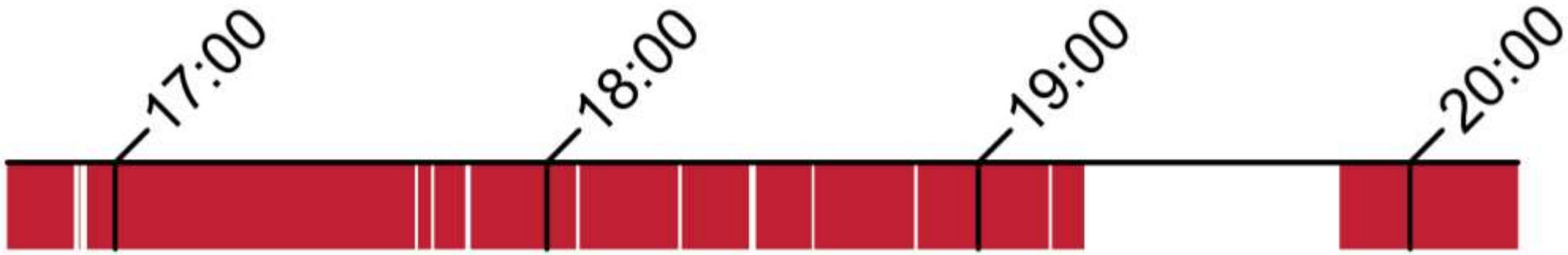
16:54:44 — Air temperature measurements started to rapidly increase.

16:55:20 — VESDA smoke detector registered an alarm condition; all breakers and contactors opened.

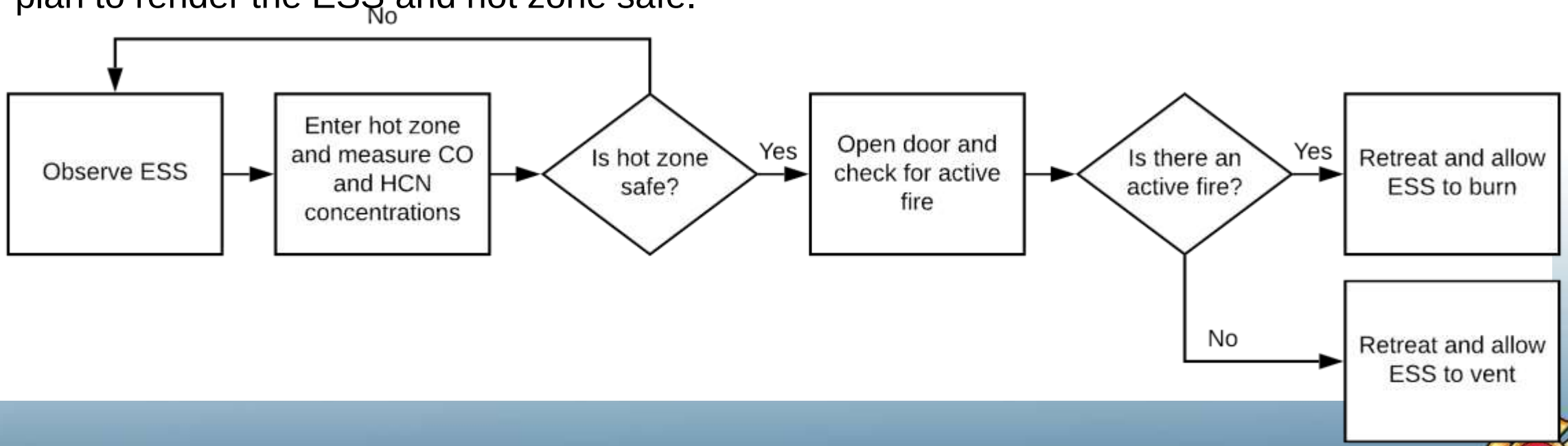
16:55:38 — Air temperature measurements peaked at 121.6 F.

16:55:50 — Suppression system discharged.

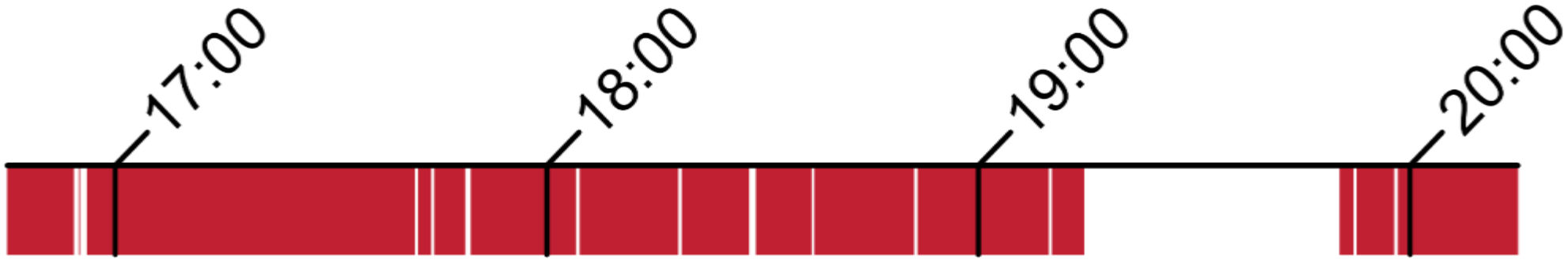
Timeline



19:15-19:50 — HAZMAT team conferenced with senior fire department officers and developed a plan to render the ESS and hot zone safe.



Timeline



19:50 — The visible gas/vapor mixture was no longer leaking out of the ESS.

19:52:24 — HAZMAT team made final entry into the fenced area around the ESS.

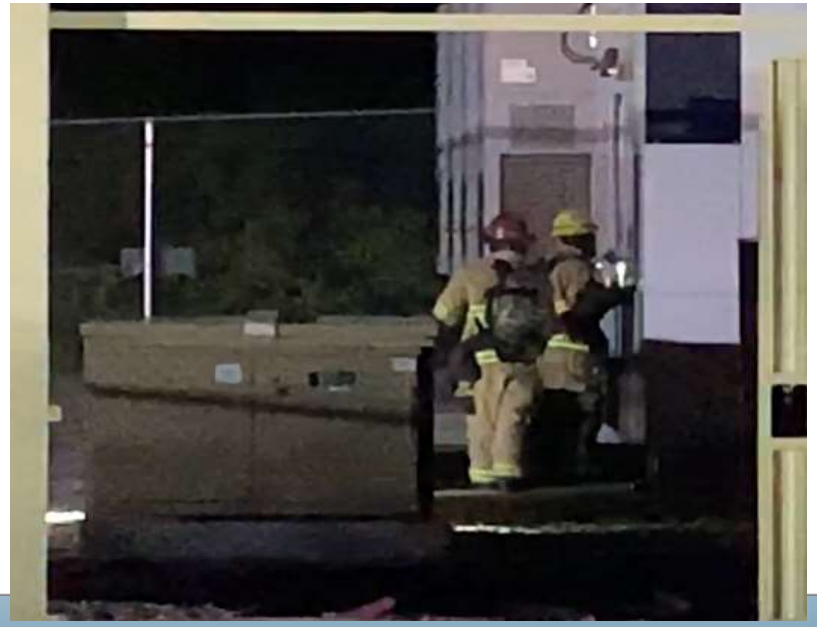
19:58:03 — HAZMAT team pulled hose line to ESS to prepare to open door.

Photos courtesy of APS

Timeline

20:00:54 — HAZMAT team opened the door to the ESS.

20:03:49 — Mayday call



Photos courtesy of APS

Photos courtesy of Peoria Fire Department

Contributing Factors

- Core HAZMAT training curricula for first responder and technician levels do not yet cover basic ESS hazards.
- Extra-curricular ESS-specific training opportunities do not comprehensively address ESS hazards.

Recommendations

- Basic firefighter, officer and HAZMAT training should emphasize ESS safety, the potential explosion hazard from lithium-ion batteries, vapor cloud formation and dispersion and the dynamics of deflagrations.
- Research that includes full-scale testing should be conducted to understand the most effective and safest tactics for the fire service in response to lithium-ion battery ESS incidents.
- Until definitive tactics can be established, it is recommended that fire service personnel define a conservative blast radius to remain outside of while treating the gas/vapor mixture in the ESS as if it is above the LEL until proven otherwise.
- An online education tool should be developed to proliferate the appropriate base knowledge about lithium-ion battery ESS hazards and fire service tactical considerations.

Contributing Factors

- The ESS did not include sensors that provided information about the presence of flammable gases.
- There was no way for the HAZMAT team to monitor toxic gas concentrations, LEL or any other conditions inside the ESS from a physically secure location.

Recommendations

- Lithium-ion ESSs should incorporate gas monitoring that may be accessed remotely.
- Research that includes multi-scale testing should be conducted to evaluate the effectiveness and limitations of stationary gas monitoring systems for lithium-ion battery ESSs.

Contributing Factors

- The emergency plan was not provided to the responding fire service personnel prior to the incident.
- The emergency response plan that was provided was inadequate.

Recommendations

- Owners and operators of ESSs should develop an emergency operations plan in conjunction with local fire service personnel and the code authorities and command a comprehensive understanding of the hazards associated with lithium-ion battery technology.
- Signage that identifies the contents of an ESS should be required on all ESS installations to alert fire responders to the potential hazards associated with the installation.

Contributing Factors

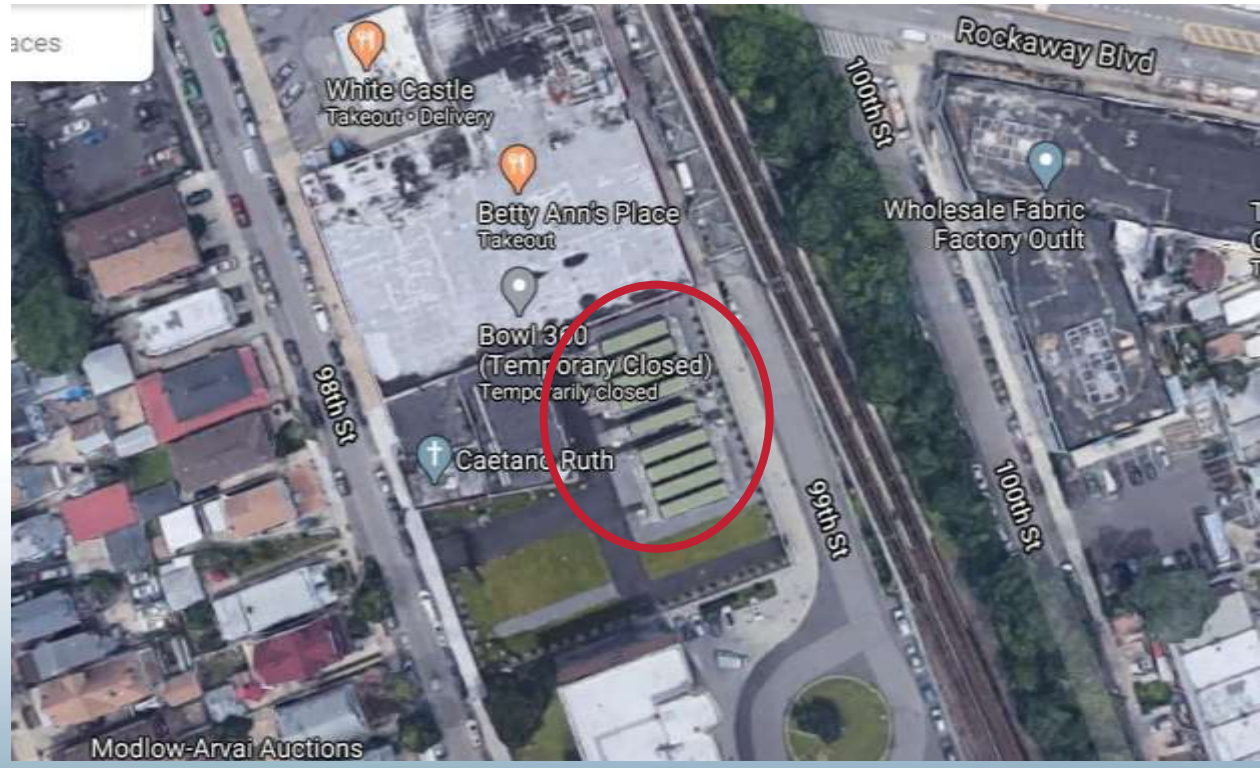
- The ESS did not have deflagration venting panels (NFPA 68) or adequate ventilation to prevent the accumulation of flammable gases (NFPA 69).
- The total flooding clean agent suppression system likely contributed to the deflagration.

Recommendations

- Lithium-ion battery ESSs should incorporate adequate explosion prevention protection as required by consensus standards in coordination with the emergency operations plan.
- Research that includes full-scale testing should be conducted to determine the most effective fire suppression and explosion prevention systems for lithium-ion battery ESSs.

Additional Recommendations

Conduct research focused on emergency decommissioning best practices and the fire service's role in an emergency situation.



Google Earth photos

Fire Service Considerations with Li-ion battery ESS

A new online training module
for the fire service is available from FSRI.

training.fsri.org

Chandler, AZ Incident


Evacuation Area
Road Closes at 6 pm
W Frye Rd
E Frye Rd
N 56th St
ARIZONA
202
INTERSTATE
10
E Fairview St
W Morelos Pl
S 54th St
S 56th St


SECT #1
SECT #2
SECT #3
Main Breaker
SECT #4
SECT #5


FIRE
ALARM
PANEL
2
1


FIRE
ALARM
2
2
1

Near-Miss Research: Surprise, Arizona, ESS incident

JOINT CANADA-UNITED STATES
NATIONAL STANDARD

ANSI/CAN/UL
9540A:2019

STANDARD FOR SAFETY

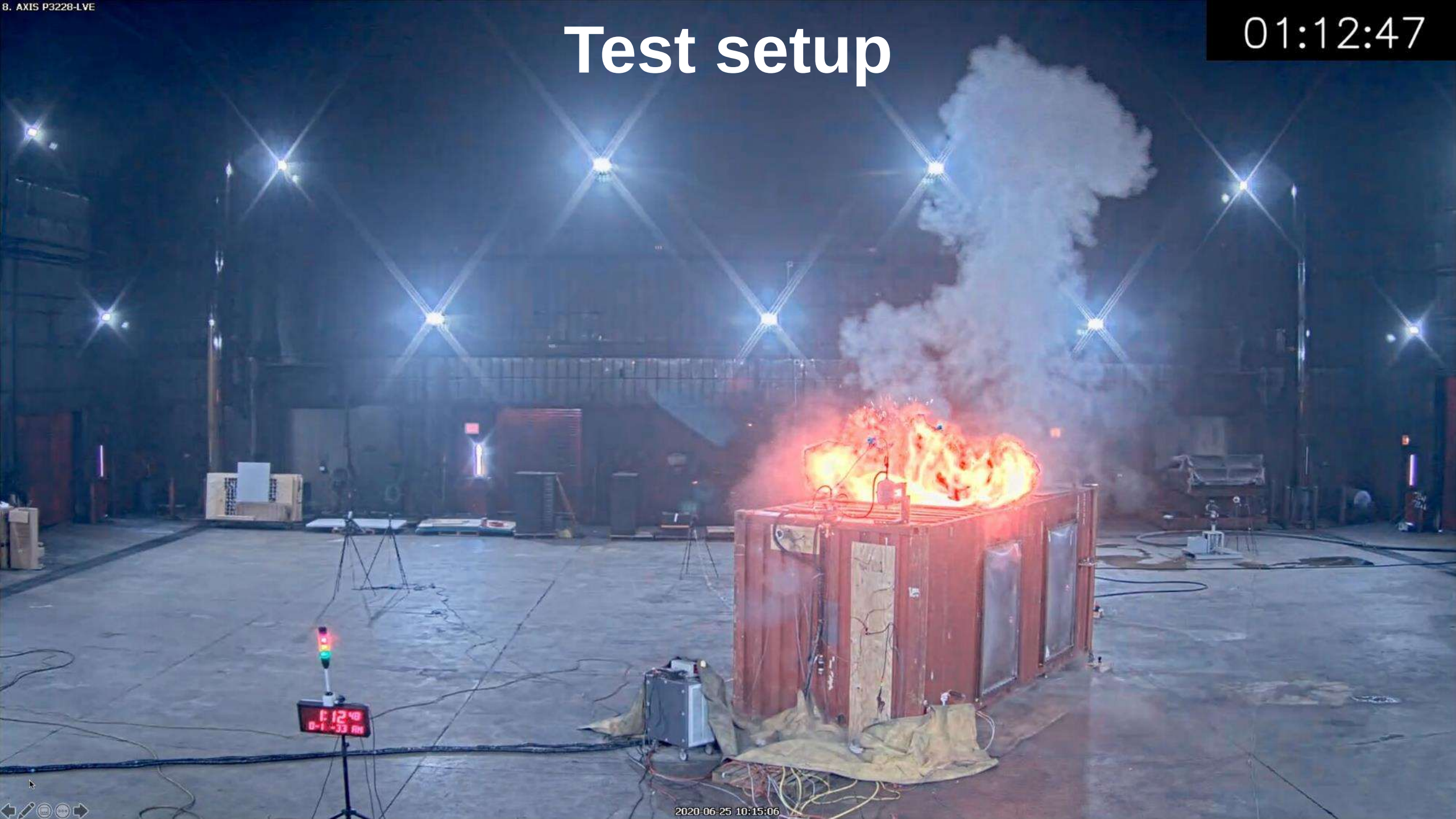
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

ANSI

ANSI/UL 9540A-2019

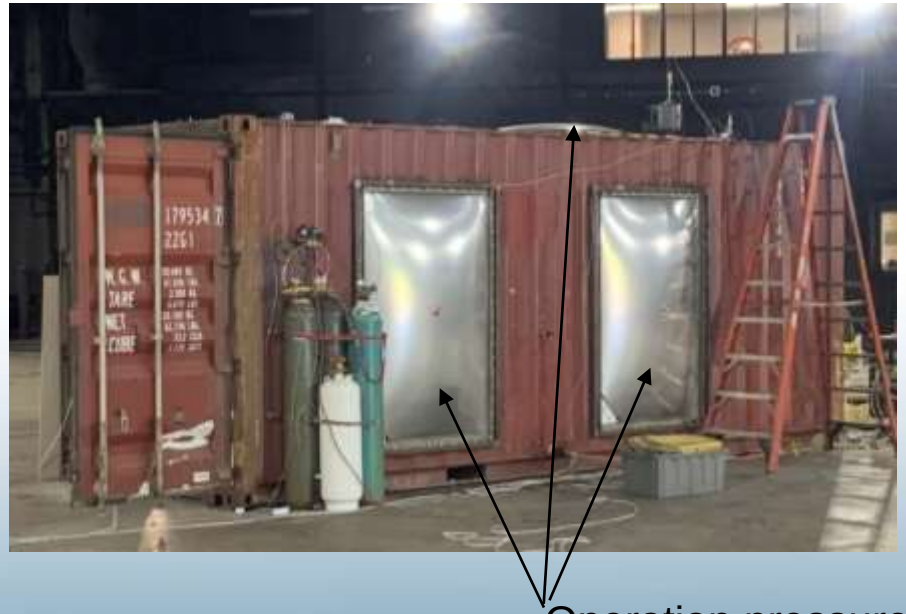
Standards Council of Canada
Conseil canadien des normes

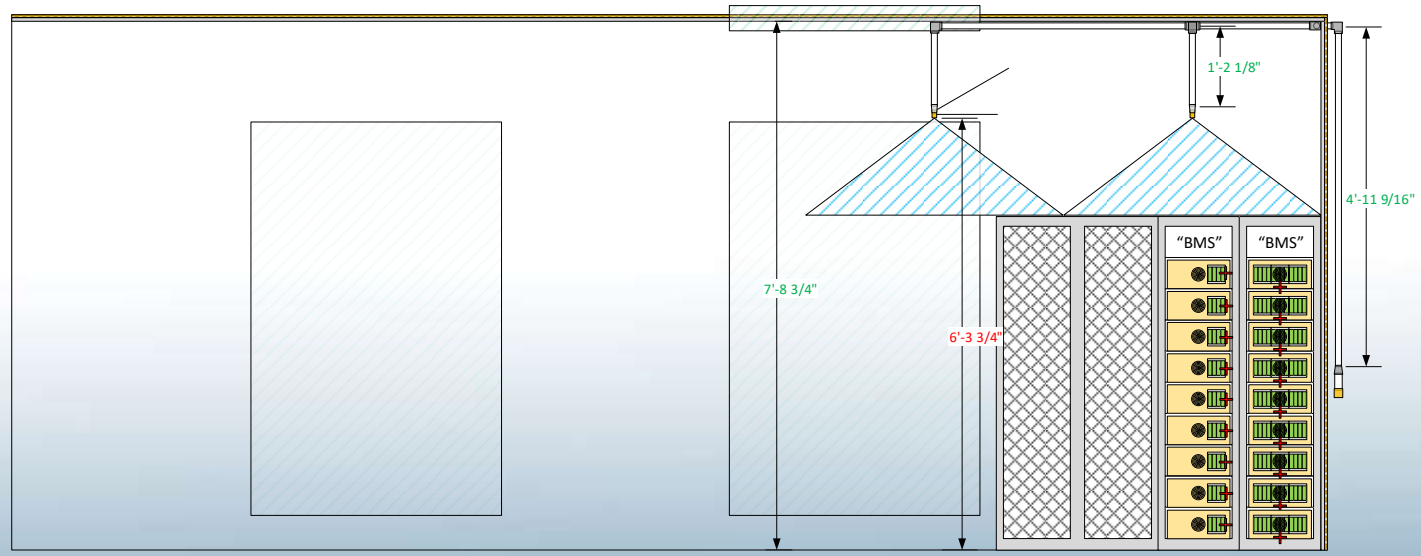
UL 9540 A Testing


8. AXIS P3228-LVE
Test setup
01:12:47
2020-06-25 10:15:06

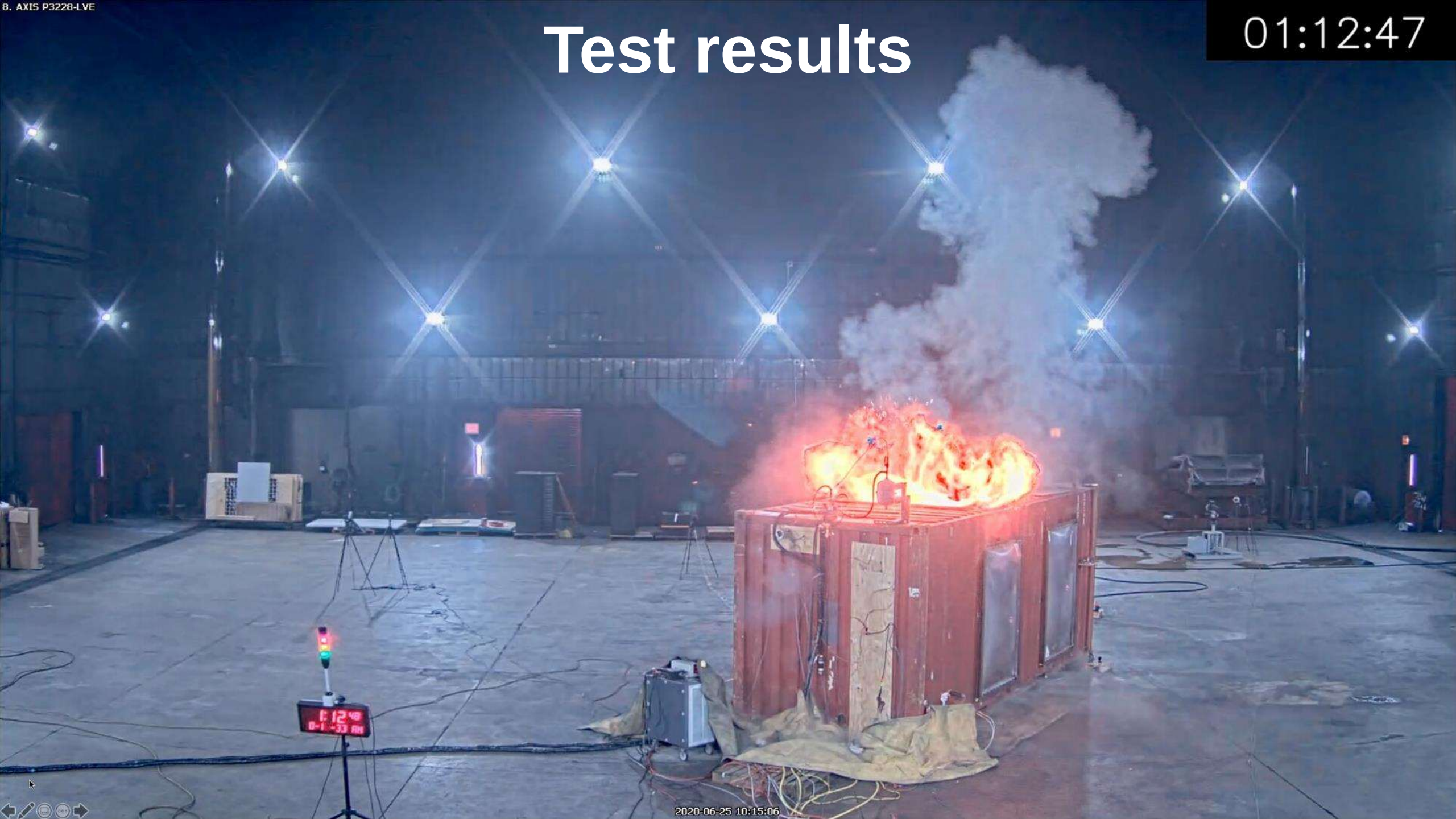
Test setup — UL 9540A installation level test

- Test 1 –Without any provision for fire protection
- Test 2 – With Novec 1230 total flooding clean agent system (8 v% concentration)
- Test 3 – With 0.5 gpm/ft^2 (20.4 lpm/m^2) density water spray system (from ceiling)





Operation pressure 0.5 psig (3.4 kPa); vent area calculation based on NFPA 68, Standard on Explosion Protection by Deflagration Venting


8. AXIS P3228-LVE
Test results
01:12:47
2020-06-25 10:15:06

Results — Test 1, timeline of major events

Smoke accumulation
[TR + 00:00:31]

Ignition
[TR + 00:00:31]

TR propagation for 3 hours
[TR + 00:11:54]

Flaming outside container
[TR + 00:47:18]

Partial volume deflagration
[TR + 00:00:31]
TR notes the time of the first cell thermal runaway.

Results — Test 2, timeline of major events

Novec 1230 discharge
[TR + 00:00:58]

Smoke stratification before ignition [TR + 00:26:51]

Ignition
[TR + 00:28:32]

Flashover conditions and flaming from open door
[TR + 02:09:48]

Deflagration
[TR + 00:44:39]

TR notes the time of the first cell thermal runaway.

Results — Test 3, timeline of major events

Ignition, sustained flaming
[TR + 00:08:49]

Waterflow @ 0.5 gpm/ft^2
[TR + 00:10:13]

Deflagration
[TR + 00:42:02]

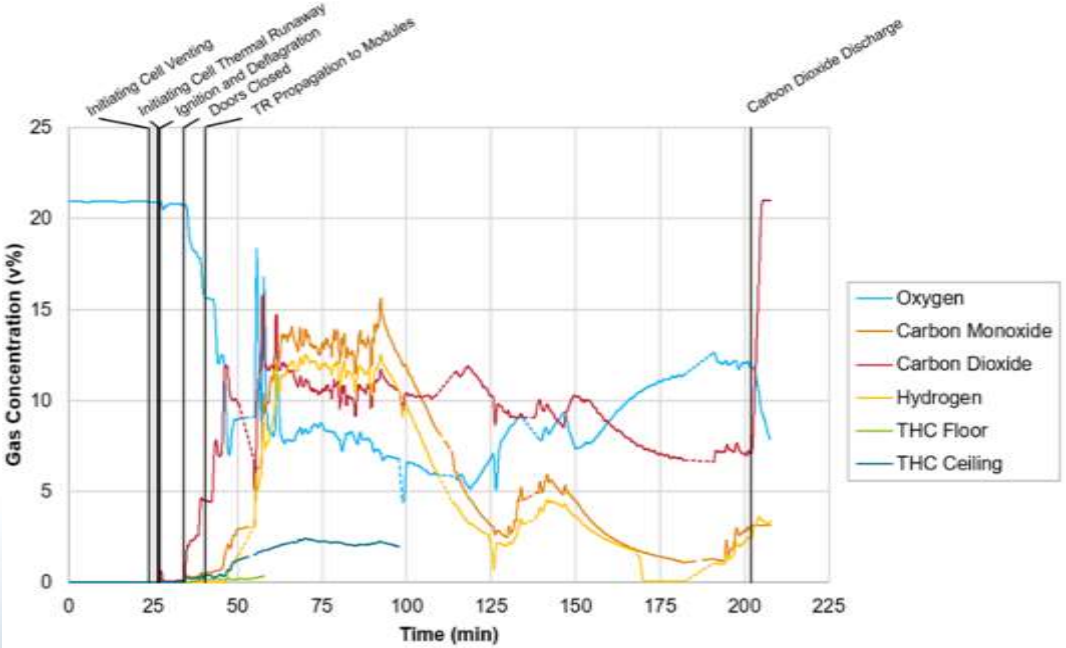
TR notes the time of the first cell thermal runaway.

TR propagation after water flow off
[TR + 01:13:05]

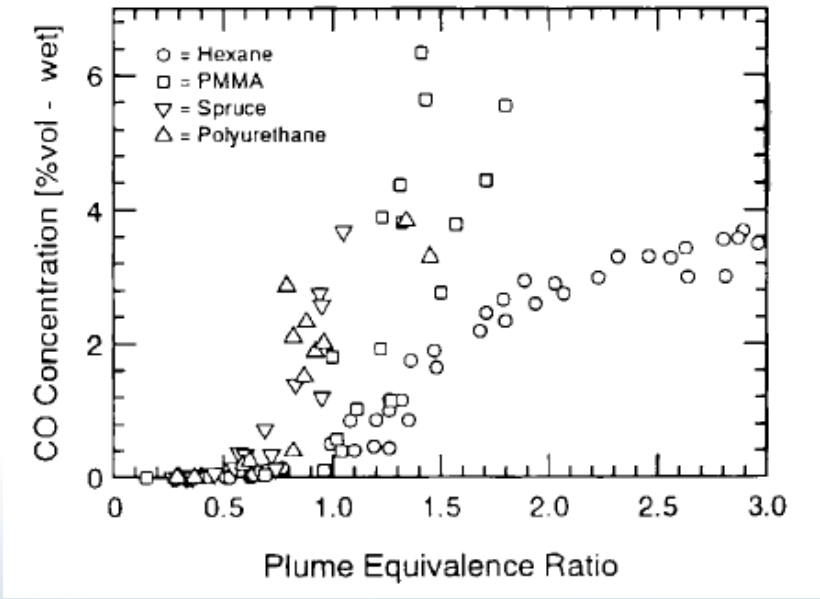
TR propagation continues after water flow restart [TR + 01:49:54]

Key Findings: Comparison to Room and Content Fires

Propagating thermal runaway events generate more severe flammability and toxicity hazards than typical room and content fires.



- H_2: > 10 v%
- CO: 12 v% - 15 v%
- CO_2: ~10%



- H_2 = 0 v%
- CO: ~6 v%
- CO_2: ~10%

D. Gottuk, et al. J. of Fire Prot Eng. 4, 4, 1992

Key Findings: Gas Detection

Common combustible gas, carbon monoxide and hydrogen detectors were:

Effective for thermal runaway gas detection

- All detectors responded in <5 seconds when exposed to gas.
- Nuisance sources are unlikely, given measurands (H2, CO, LEL).
- Proximity to ESS units is critical for detection time.

Not reliable for ongoing hazard assessment

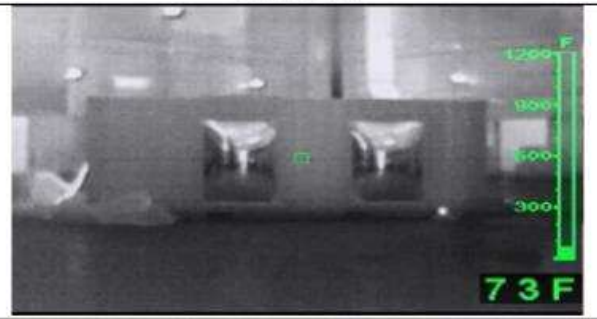
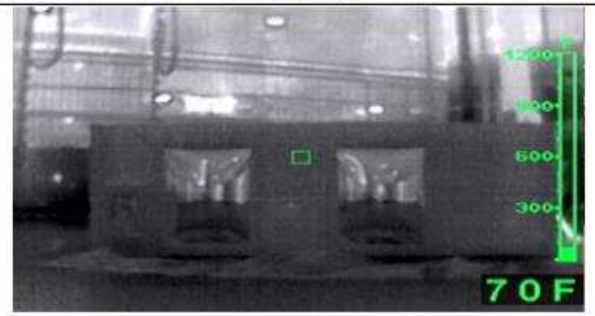
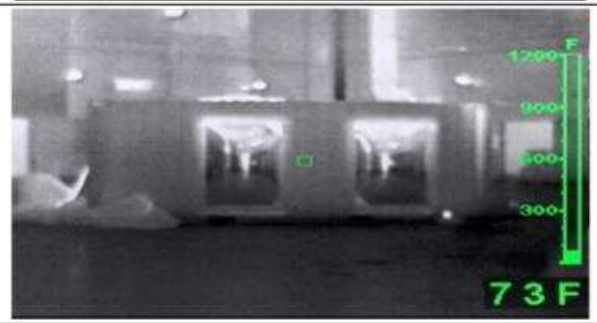
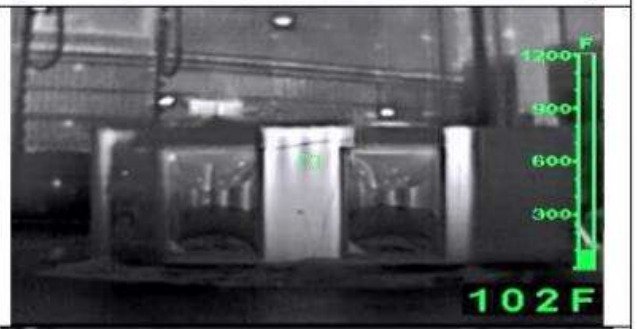
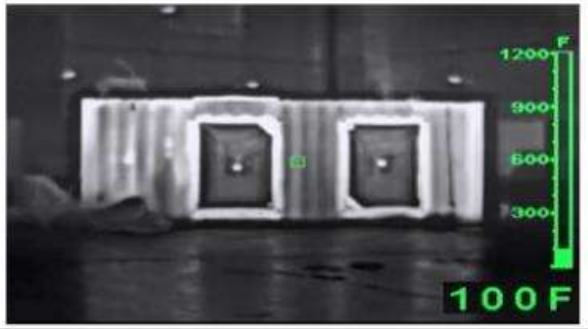
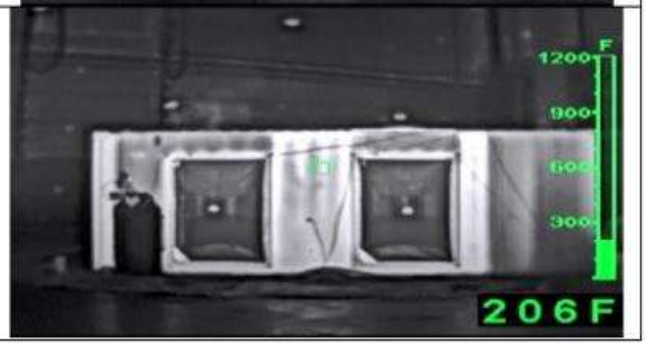
- Cross-sensitivity diminishes sensor accuracy.
- Thermal, chemical and particulate stresses damage sensors.

Key Findings: Deflagration Protection System

- Deflagrations occurred in all three tests.
- The deflagrations were all mitigated with an engineered deflagration protection system designed per NFPA 68.
- Deflagration intensity varied based on the gas conditions at the time of ignition.

Tactical Consideration: Thermal Imager Use

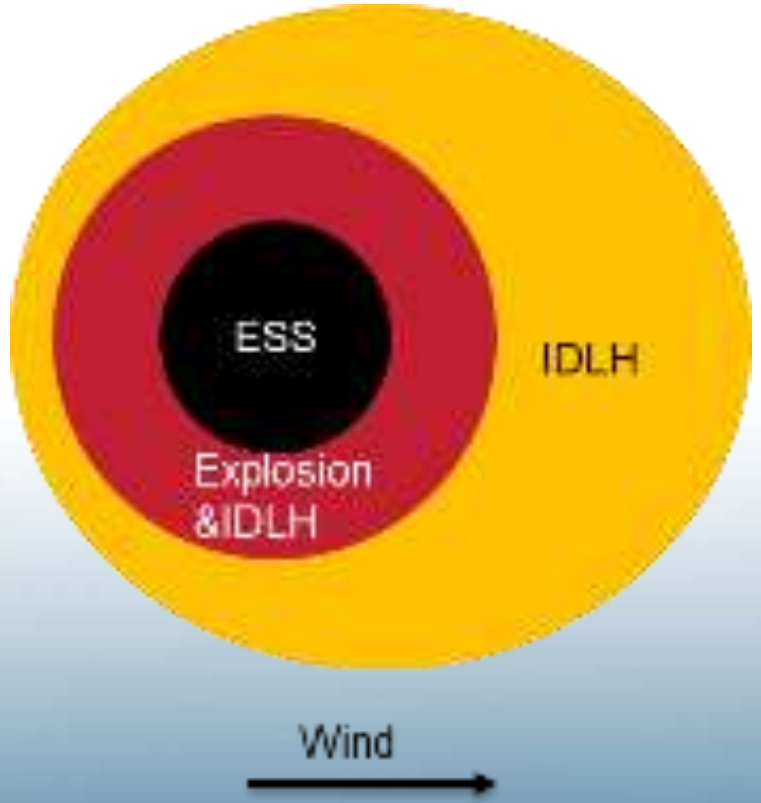
- Thermal imaging cameras (TIC) do not enable evaluation of the number or location of ESS units in thermal runaway.
- TICs provide a limited ability to determine whether a suppression system has operated or is operating.
- TICs are not a viable tool for determining the nature of visible vapors (e.g., battery gas, steam, Novec 1230).

	Side B	Side D
Thermal Runaway – Initiating Module		
Thermal Runaway – Additional Modules		
120 minutes after test start		

Tactical Consideration: Size-up and Gas Monitoring

A deflagration event is hard to predict, even with good-quality gas concentration data.

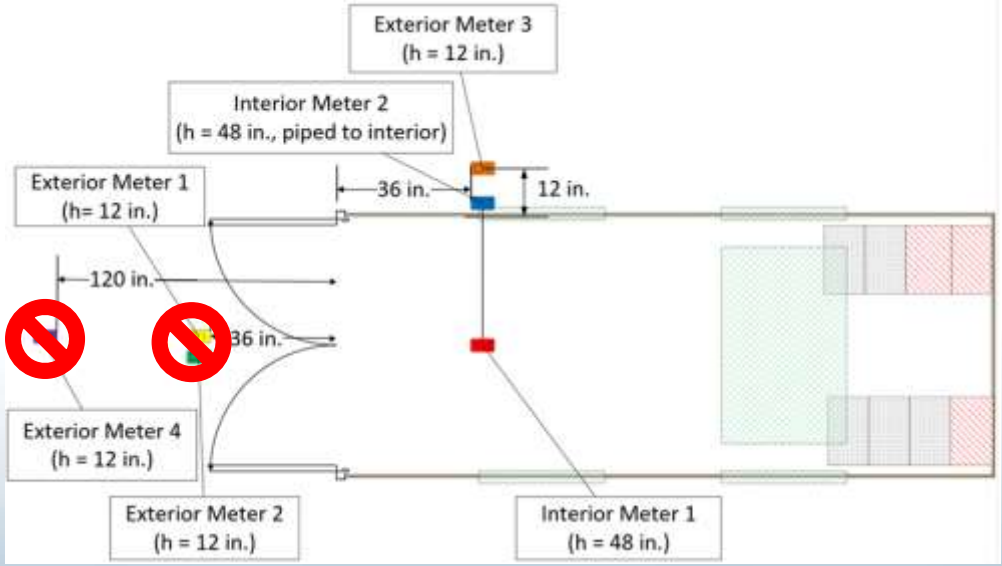
Responding firefighters should consider using portable gas meters and visual observations to define an exclusion zone while wearing full structural PPE (Level D Ensemble) with full SCBA.



Tactical Consideration: Portable Gas Meters

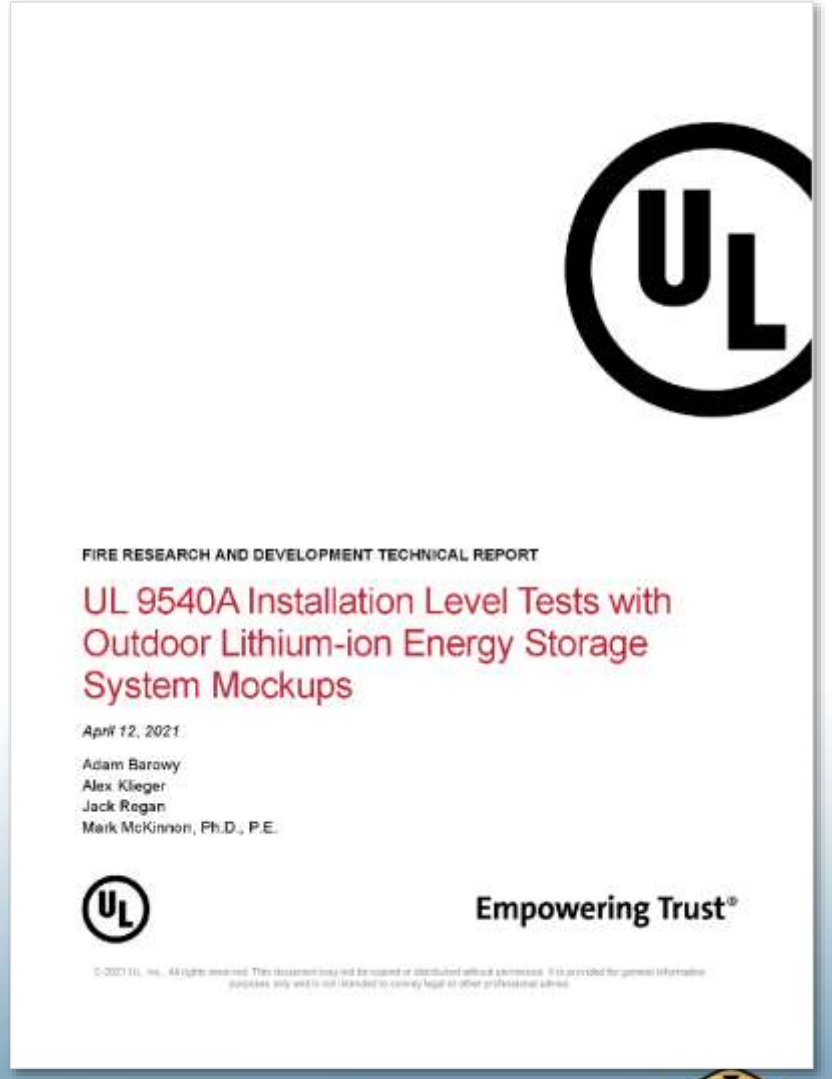
Portable gas meters have limited effectiveness to evaluate the potential for explosive atmosphere within the ESS container.

- Deflagration may occur before flammable gas is detectable at the exterior of the container for measurement.
- Flammable gas only detected/measured one foot from container – FF may be dangerously close to the container before an explosion hazard via LEL measurement is identified.
- Exterior gas concentrations approximately equal to interior gas concentrations – Remotely monitored gas meters may safely provide insight into continued or halted thermal runaway activity but are subject to factors like wind, terrain, etc.



Technical Report Available

- UL 9540A Installation Level Tests with Outdoor Lithium-ion Energy Storage System Mockups
- Published April 12, 2021
- Available for download at:
  - ULFirefighterSafety.org/Research-Projects/Firefighter-Line-of-Duty-Injuries-and-Near-Misses.html
  - UL.com/services/UL-9540A-Test-Method


FIRE RESEARCH AND DEVELOPMENT TECHNICAL REPORT

UL 9540A Installation Level Tests with Outdoor Lithium-ion Energy Storage System Mockups

April 12, 2021

Adam Barowy
Alex Klieger
Jack Regan
Mark McKinnon, Ph.D., P.E.

Empowering Trust®

A Safe Response to Renewable Energy Hazards

June-July 2022

Explosion Hazards

Aug-Oct 2022

Ignition and Explosion Hazard

Explosions: Partial volume deflagrations

Hazard scenarios – immediate ignition

Fire hazards

Thermal runaway propagation in an ESS Unit

Immediate/ Delayed Ignition?

Immediate Ignition

Delayed Ignition

Measurements:

ESS unit enclosure fire containment & HRR
+
Thermal exposure to adjacent surfaces

Hazard Scenario: Flaming ESS Unit

Either performance is nonhazardous or installation test is run with fire protection system(s)

AHJ determination:

1) No array-array fire hazard
2) No loss of fire containment
OR
3) UL 9540A Installation test data demonstrates fire protection system(s) provide conditions 1 and 2

UL 9540A performance criteria provided to aid analysis

Hazard scenarios – delayed ignition in installation

Thermal runaway propagation in an ESS Unit

Immediate/ Delayed Ignition?

Delayed Ignition

Ignition inside/ outside unit enclosure?

Outside

Inside

Ignition leads to flaming

Measurements:

Gas explosibility, volume, volume rate
+
Installation enclosure parameters

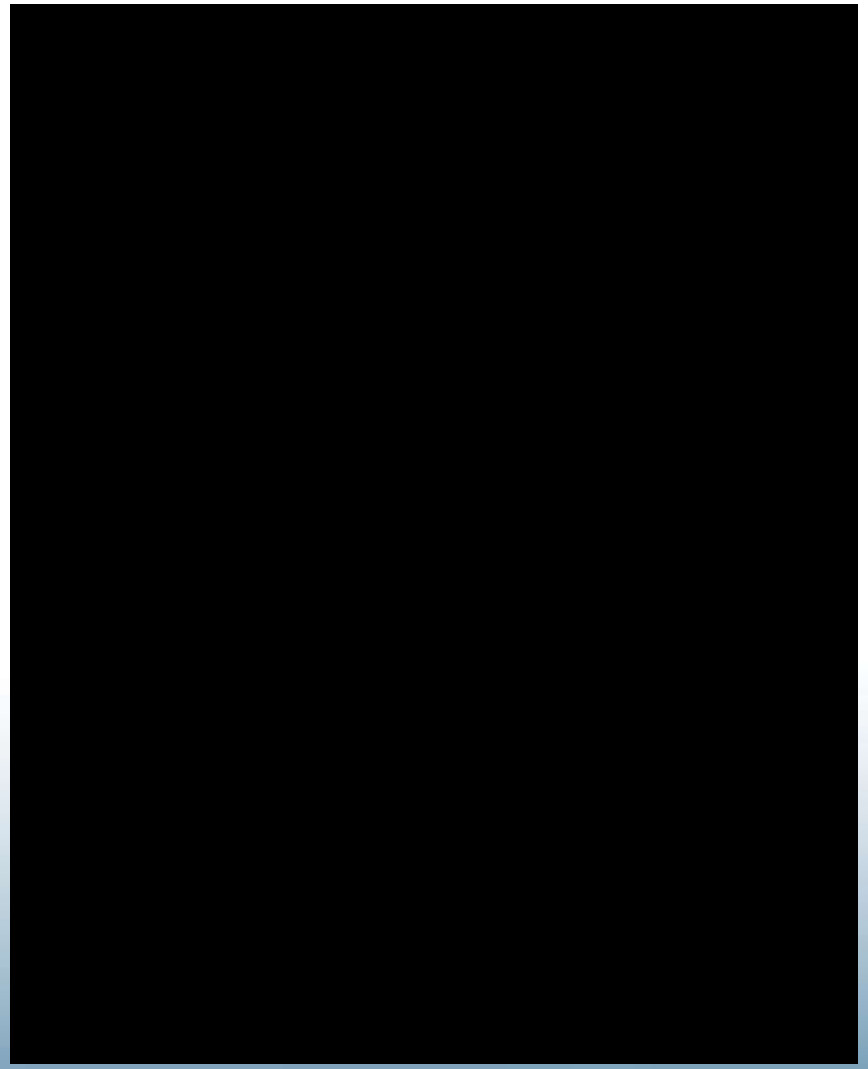
Hazard Scenario:
Occupiable Volume Deflagration Hazard

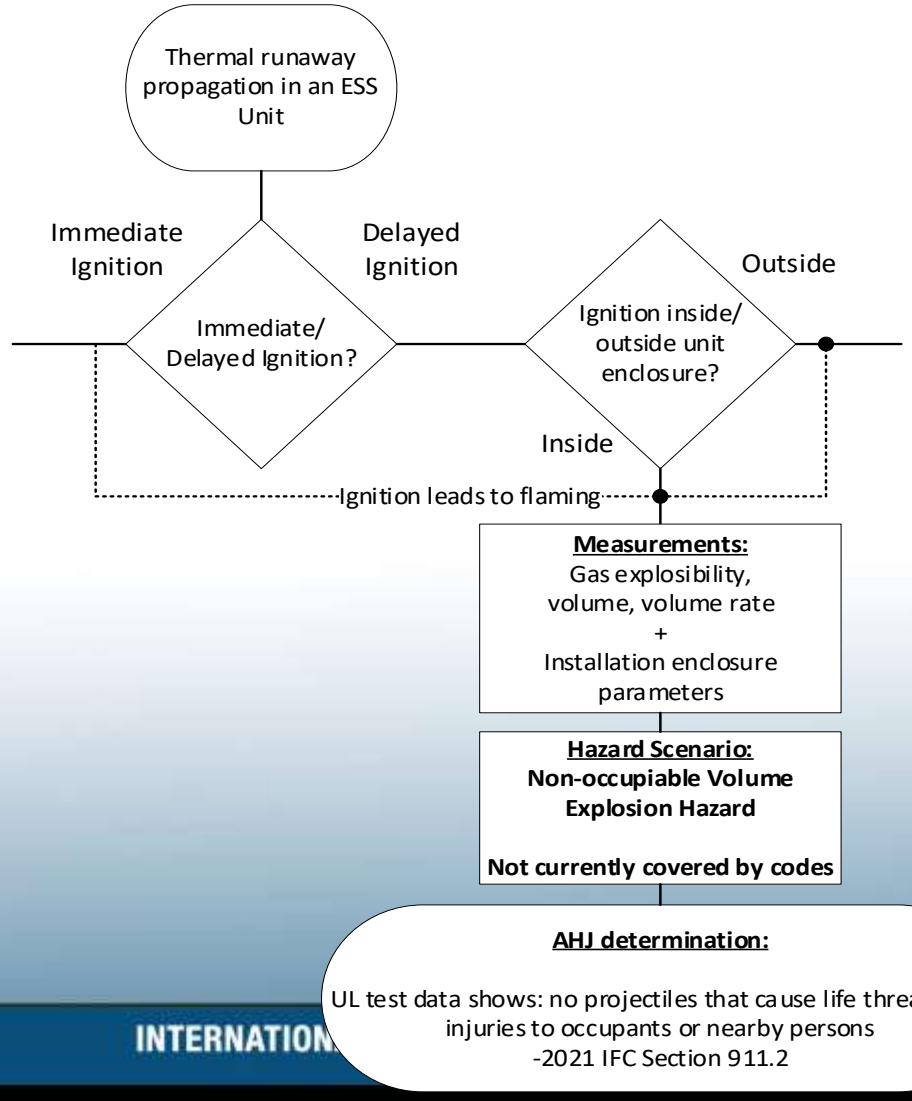
FPE design of explosion safety system if v% gas > 25% LFL

AHJ determination:

1) No explosion hazard. <25% of LFL per UL 9540A test data and FPE analysis
OR
2) NFPA 68 and/or NFPA 69 system mitigates explosion hazard

Hazard scenarios – delayed ignition in unit enclosure





Hazard scenarios – delayed ignition in unit enclosure

- Deflagration venting systems cannot be evaluated unless a deflagration occurs during test.
- Deflagration severity during a UL 9540A test is dependent on gas conditions at the time of ignition.

Fire Service Size-up and Tactical Considerations

D. Additional indicators for battery involvement should be considered beyond smoke appearance.

- Response area – Know your running district
- Presence of Photovoltaic System
- Meter altering – Additional connections
- Labeling
- Presence of EV
- Sounds and Smells

Project Webpage

RESEARCH

Reality Check

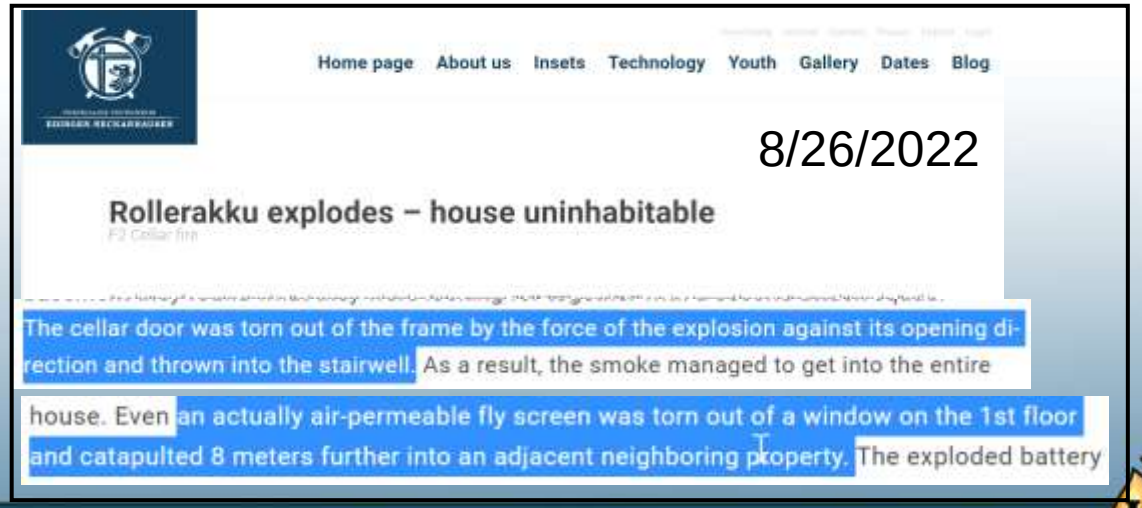
Involvement of LiB in fires and confinement of unburned battery gas create new hazards for home occupants and the fire service.

Potential sources of battery gas:

1. E-mobility devices
2. Electric vehicles
3. Energy storage systems, stationary and portable
4. Battery storage cabinets

Electric Vehicle

Scooter



Hybrid Jeep

Mountain View Fire Rescue crews responded to reports of a structure fire in the Morgan Hill neighborhood of Erie at 8:16 this morning. Upon arrival nothing was showing from the outside of the home on Marlowe Circle.

When firefighters entered the home, they searched both the first floor and the basement looking for the source of the light smoke which turned out to be in the secondary garage.

A Jeep Wrangler 4XE hybrid was smoking and when crews started putting water on the vehicle, there was a small explosion. As the garage door was blown off its tracks, it just missed a Mountain View Fire Rescue Captain as it flew about 30 feet into the yard. No firefighters were injured in the blast.

Remarkably the home sustained only very minor damage as a result of the vehicle fire and minor explosion.

Investigators are working the case and will be inspecting the electrical system and the vehicle in full detail. More information will be released as it becomes available.

Dekra vs Mountainview

Reality Check

RESEARCH

https://fsri.org/research/examining-fire-safety-hazards-lithium-ion-battery-powered-e-mobility-devices-homes

Reality Check

UL 1487 (under development, input welcome)

Released January 2023

https://fsri.org/

A training program to assist first responders, AHJs and the general public better understand the development and hazards of li-ion battery thermal runaways.

E-Bike in Bedroom

E-Bike in Living Room

This experiment was designed to intentionally drive a lithium-ion battery into failure to examine the potential hazards of storing and charging e-mobility devices, which have been known to catch on fire and cause explosions.

Potential Future LIB Hazard Research Topics

1 grant proposal?

1. EV fire suppression methodologies (equipment & tactics)
2. Battery fire suppression runoff contaminant ID
3. Stranded energy mitigation (effectiveness & duration)
4. Damaged battery re-ignitions
5. EV fire impact on parking garage safety & fire protection equipment effectiveness
6. First responder exposure to battery fire effluent
7. Consumer product thermal runaway mitigation (e.g., micro-mobility)
   a) Gases released from this process
   b) Characterization of waste generated
8. Evaluation/development of sensor technology for reliable ongoing measurement of gas composition during thermal runaway events
9. Impact of ventilation on battery fires
10. Others?

Thank you

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IAFF Health and Safety Operational Services

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