Evaluating the Safety of Energy Storage Systems: UL9540A

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AGENDA

1 Protecting Against Failure Events

2 ESS Requirements in Codes and Standards

3 UL 9540A

- Objectives of 9450A – What does it do?
- Cell Level Testing
- Module Level Testing
- Unit Level Testing
- Installation Level Testing

PROTECTING AGAINST FAILURE EVENTS

- Mitsubishi Materials Corporation (Japan 2011)
  – 2 MW Sodium Sulfur system, thermal runaway
- Kahuku Wind farm (USA, 2012)
  – 15 MW, Advanced lead acid battery
- The Landing Mall (USA, 2013)
  – 50 kW Li-ion ESS system in a shopping mall, thermal runaway
- Boeing 787 Dreamliner (USA, 2013)
  – Li-ion battery, thermal runaway
- Engie Electrabel (Belgium, 2017)
  – 20 MW Li-ion facility, thermal runaway

FIRE SAFETY APPROACH

Installation Codes

NEC: National Electric Code (NFPA 70)

NFPA 855: Standard for the Installation of Stationary Energy Storage Systems

ICC: The International Fire Code, International Residential Code

Battery Safety Certification

UL 1642: Lithium Batteries

UL 1973: Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications

UL 9540: Energy Storage Systems and Equipment

Testing for Performance

UL 9540A: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

LAYERS OF FIRE PROTECTION

Prevention

Mitigation

Layers of Protection → Preventative Measures | Fire Growth Control | Life Safety and Property Protection | Fire Mitigation

Precipitating Hazard

- Internal short circuit
- Mechanical abuse
- External fire

Internal Heating

Separator Failure
Chemical Reactions

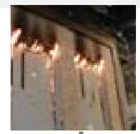
- Cathode
- Anode
- Electrolyte

Cell Failure

Thermal Runaway

Hazard Propagation

- Other ESS units in proximity
- Cabling other ESS components
- Additional combustible materials



Hazard Containment

- Fire spread to adjoining rooms
- Deflagration, detonation

Fire Impact

- Re-ignition
- Injuries/fatalities
- Property loss

Mitigation Methods →

- Tested and certified components

- Integrated fire protection system
- Smoke and fire detection

- Automatic sprinklers
- Fire containment
- Fire resistance
- Designed safe zones

- Evacuation
- Emergency service response

LAYERS OF FIRE PROTECTION

Prevention

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Layers of Protection →

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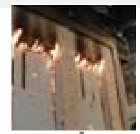


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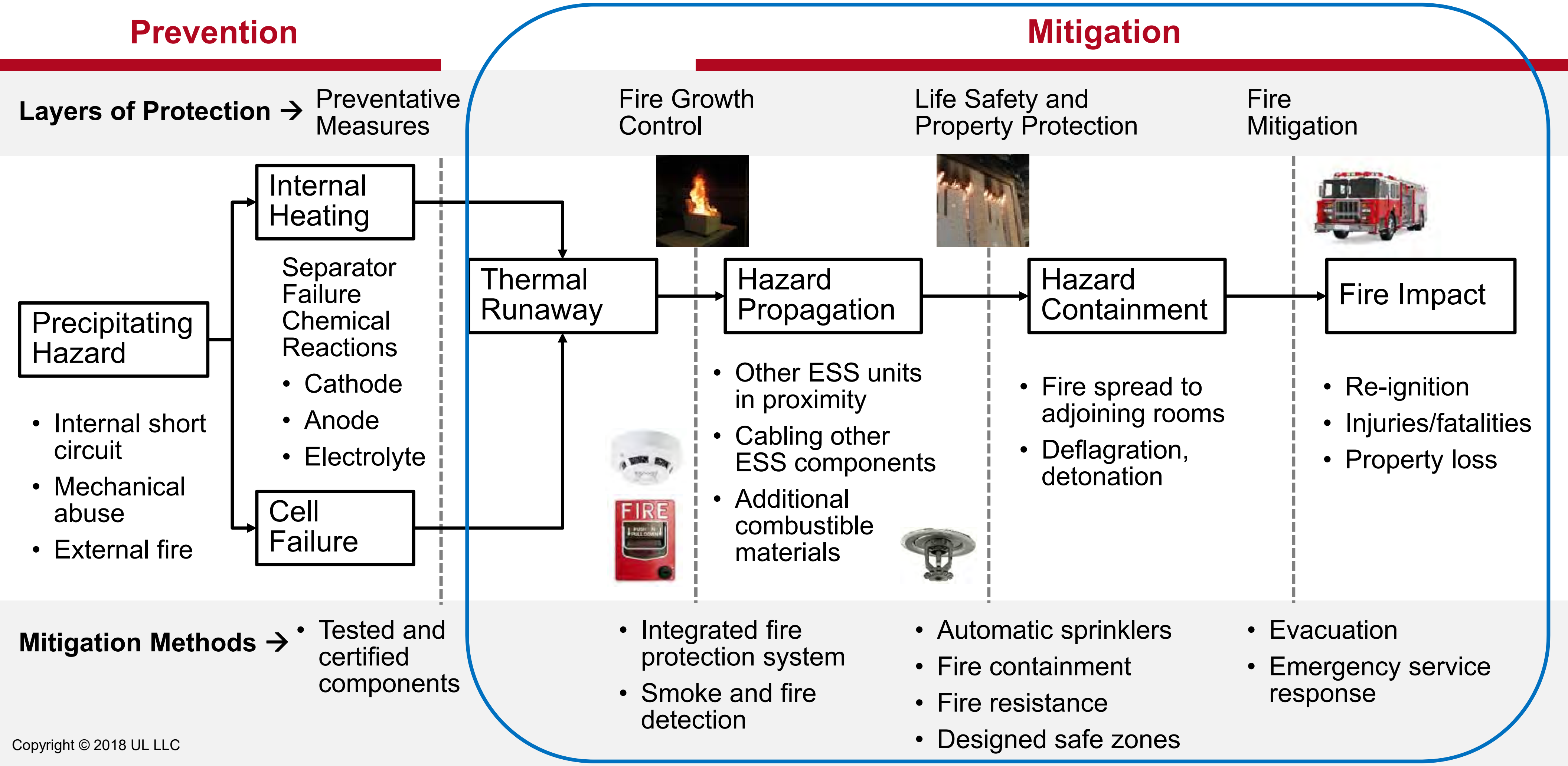


UL 9540A TEST STANDARD

Scope

Evaluate fire characteristics of a battery energy storage system that undergoes thermal runaway.

Data generated will be used to determine the fire and explosion protection required for an installation of a battery energy storage system.

Match Fire Protection of Installation to Performance of BESS

UL 9540A ADDRESSES KEY FIRE SAFETY CONCERNS

BESS Installation Parameters

- Enables determination of separation distances between units to minimize unit-to-unit fire propagation
- Enables determination of separation distances between units and enclosure walls
- Enables determination of potential of fire spread to overhead cabling

Installation Ventilation Requirements

- Quantifies deflagration potential
- Quantifies heat generation

Fire Protection (Integral or External)

- Evaluates fire protection strategies

Fire Service Strategy and Tactics

- Characterizes magnitude of potential fire event
- Documents re-ignitions within a BESS unit under test
- Documents gases generated

UL 9540A

Cell Level Test

- Whether cell can exhibit thermal runaway
- Thermal runaway characteristics
- Gas composition (flammability)

Module Level Test

- Propensity for propagation of thermal runaway
- Heat and gas release rates (severity/duration)
- Flaming/deflagration hazards

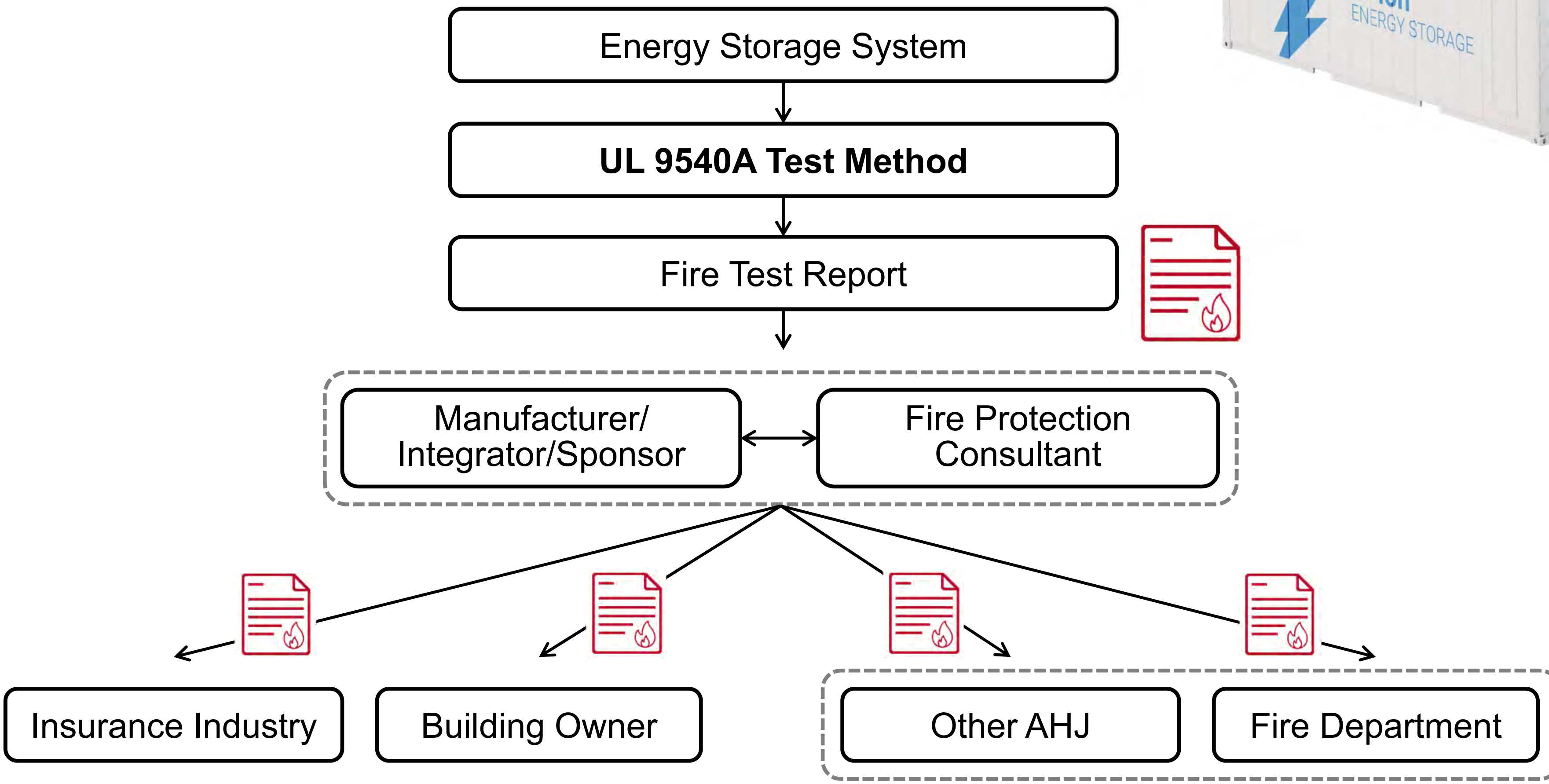
Unit Level Test

- Evaluation of fire spread
- Heat and gas release rates (severity/duration)
- Deflagration hazards
- Re-ignition hazards

Installation Level Test

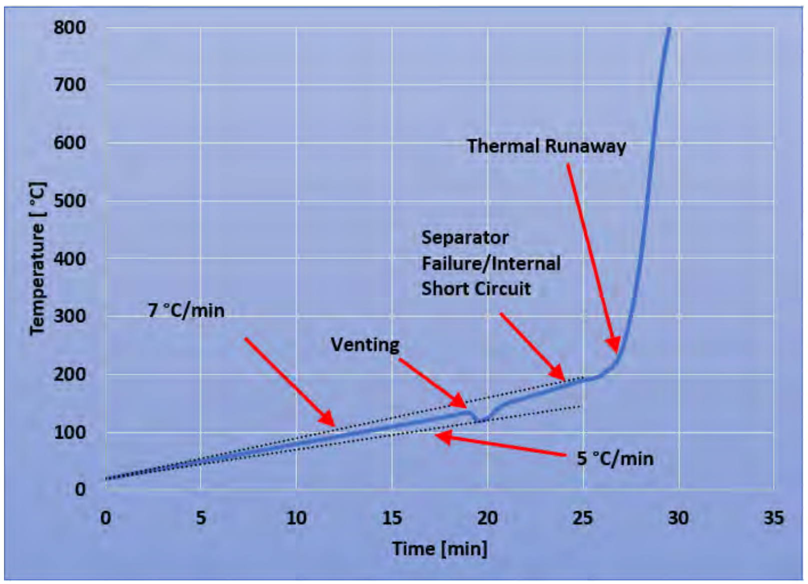
- Effectiveness of fire protection system(s)
- Heat and gas release rates (severity/duration)
- Deflagration hazards
- Re-ignition hazards

UL 9540A – USE IN INDUSTRY



CELL LEVEL TESTING

Purpose:
1. Cell thermal runaway methodology, instrumentation
2. Thermal runaway test parameters
3. Cell surface temp at venting and thermal runaway
4. Gas generation/composition; characterize gas flammability hazards (LFL)



Cell Level Testing Apparatus

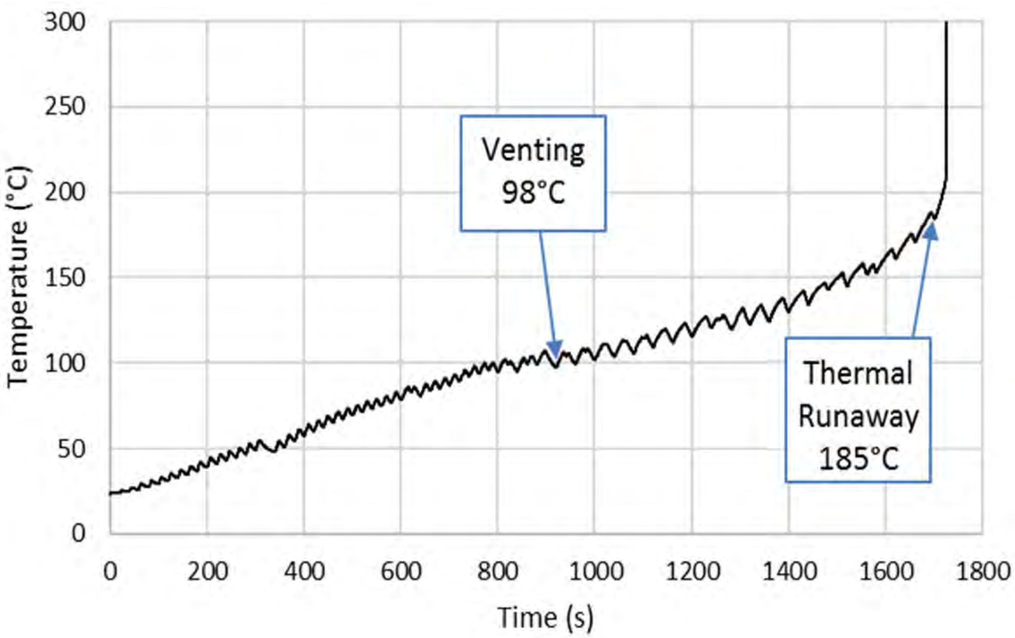
Important Data

- Thermal runaway method and parameters
- Temperature at venting
- Temperature at thermal runaway initiation
- Cell vent gas measurements:
  - Composition
  - Volume
  - Lower Flammability Limit
  - Burning Velocity
  - P_{max}

CELL LEVEL MOCKUP TEST

CELL LEVEL MOCKUP TEST

Example of generic Li-ion cell heated to thermal runaway.
Cell venting and thermal runaway temperature are documented.



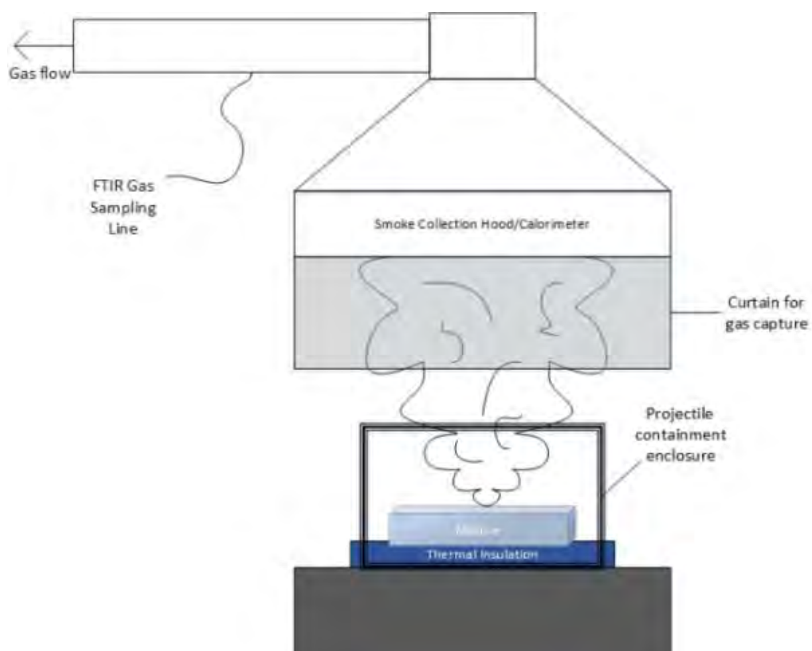
Gas	Composition (Vol %)
CO	36.2
CO_2	22.1
H_2	31.7
Hydrocarbons	~10%

Lower Flammability Limit (LFL) = 8.5%
Burning Velocity (S_u): 35 cm/sec
Volume = 70 L
P_{max}= 91 psig

MODULE LEVEL TESTING

Purpose:

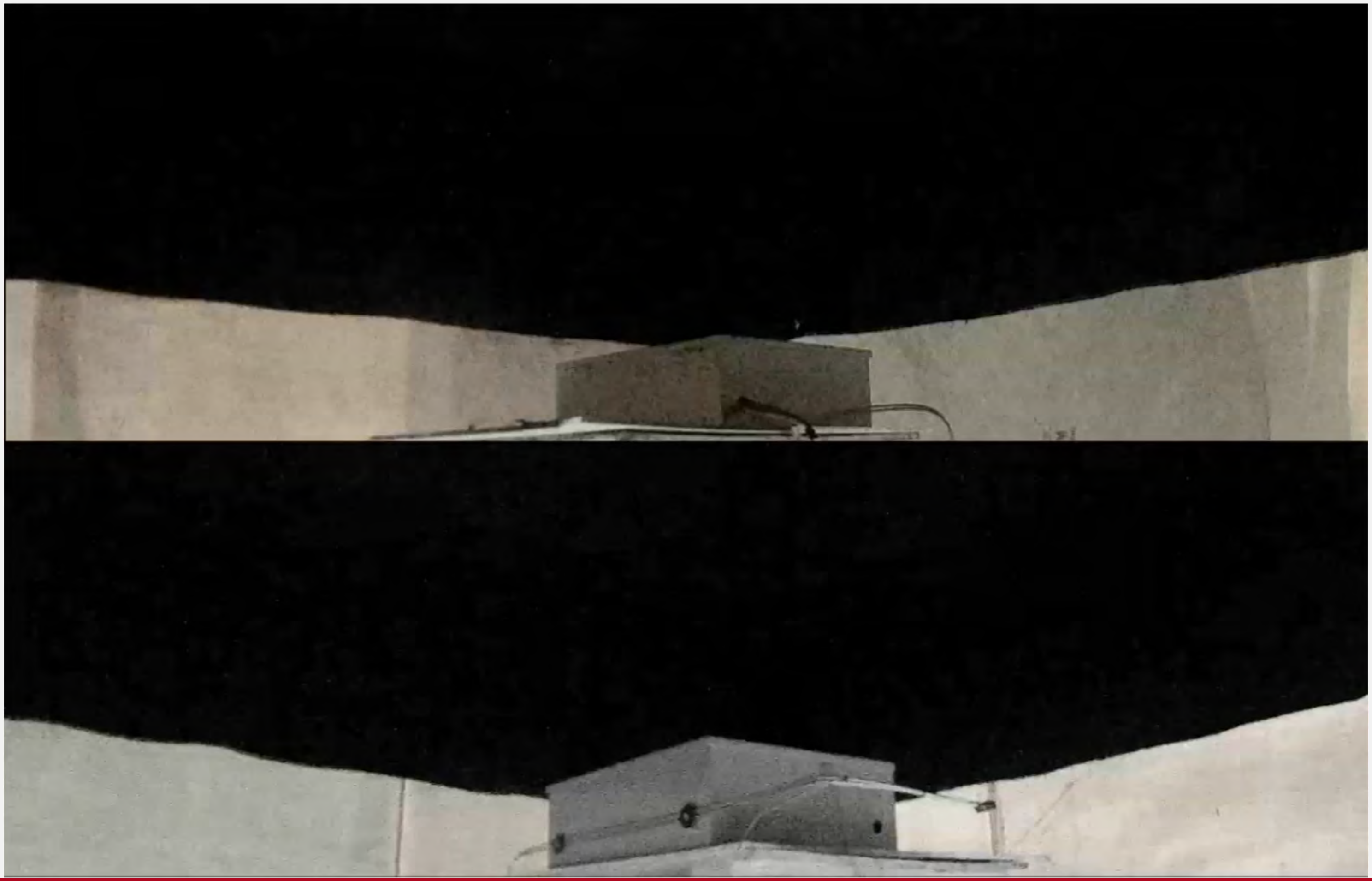
- Demonstrate the propensity for cascading thermal runaway propagation within a module
- Develop data on heat release rate and cell vent gas composition
- Document fire and deflagration hazards.



Important Data

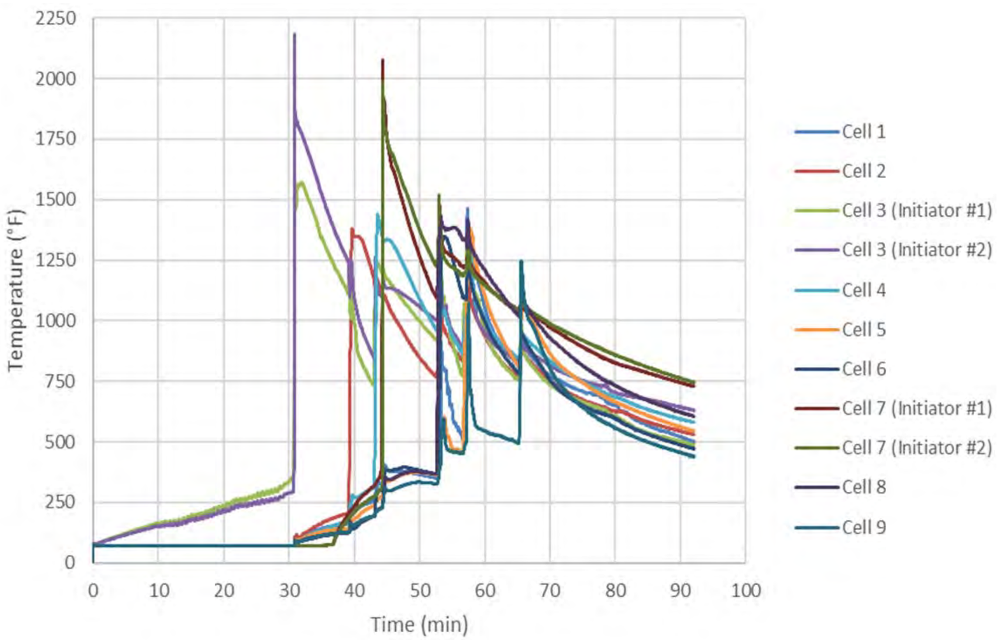
- Thermal runaway propagation
- Heat release rate
- Deflagration hazards
- Cell vent gas measurements:
  - Gas composition and volumes
    - Hydrocarbons, H_2, THC, CO/CO_2, O_2, Halogens, etc.

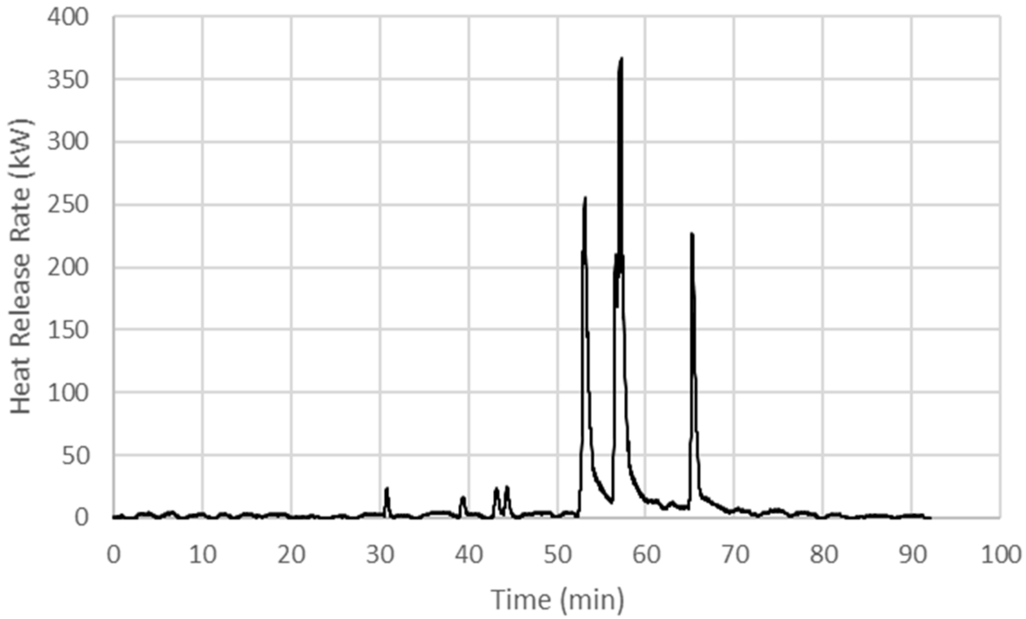
MODULE LEVEL MOCKUP TEST



MODULE LEVEL MOCKUP TEST

Example of generic li-ion propagation of thermal runaway.





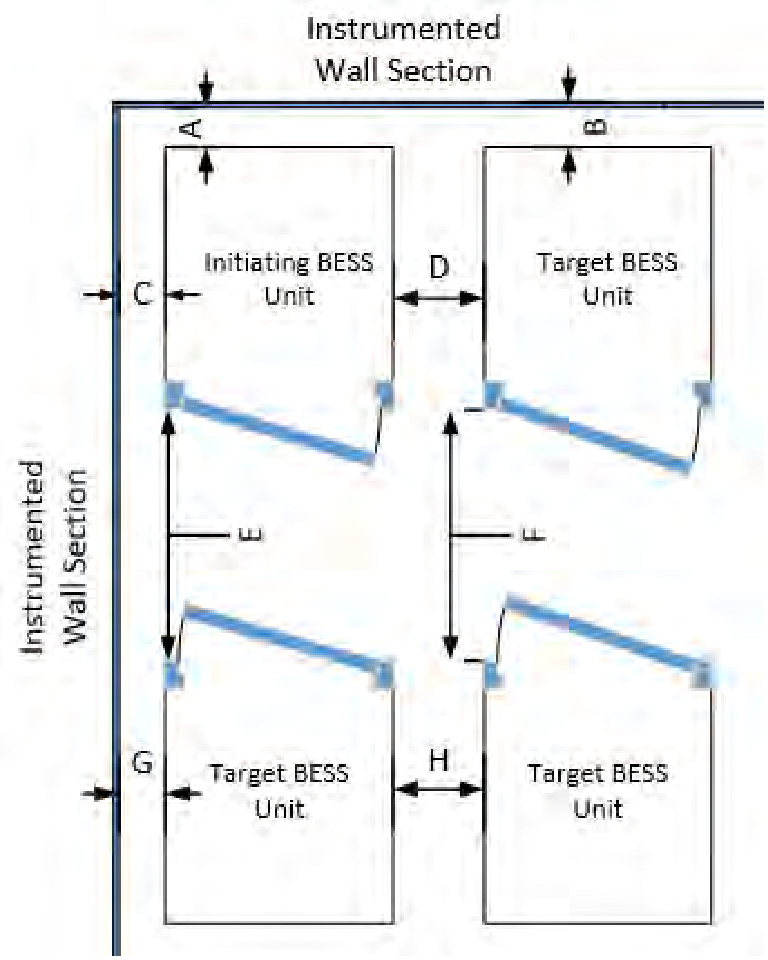
MODULE LEVEL MOCKUP TEST

Gas Component	Gas Type	Volume Released Pre-Flaming (Liters)	Volume Released Flaming (Liters)
Acetylene	Hydrocarbons	3.3	1.6
Ethylene	Hydrocarbons	39.4	10.5
Methane	Hydrocarbons	72.4	48.7
Methanol	Hydrocarbons	1.6	0.9
Propane	Hydrocarbons	39.2	21.3
Formaldehyde	Aldehydes	2.6	0.1
Hydrogen Bromide	Hydrogen Halides	0.0	0.4
Hydrogen Chloride	Hydrogen Halides	0.0	0.8
Hydrogen Fluoride	Hydrogen Halides	0.0	0.0
Carbon Dioxide	Carbon Containing	197.4	2312.0
Carbon Monoxide	Carbon Containing	513.6	254.8
Ammonia	Nitrogen Containing	0.0	0.0
Hydrogen Cyanide	Nitrogen Containing	1.3	2.6
Hydrogen	-	0.0	0.0
Total Hydrocarbons (% Propane)	Hydrocarbons	276.4	82.3

UNIT LEVEL TESTING

Purpose:

1. Document thermal runaway progression within a BESS unit;
2. Document if flaming occurs outside the BESS unit;
3. Measure heat and gas generation rates;
4. Measure surface temperatures and heat fluxes in target BESS units; and
5. Measure surface temperatures and heat fluxes on surrounding walls.



Important Data

- Module to module thermal runaway propagation in Initiating BESS
- Heat release rate
- Gas composition and volume
- Wall temperatures and heat fluxes
- Target BESS temperatures and heat fluxes
- Deflagration hazards
- Re-ignition (on-going thermal runaway)

INSTALLATION LEVEL TESTING (IF REQUIRED)

Methods:

1. Ceiling mounted automatic sprinklers; or
2. Designed Fire Protection Plan (open to manufacturer's design).

UNIT/INSTALLATION LEVEL PERFORMANCE ASSESSMENT

NFPA 855

3.3.11 Large-Scale Fire Testing.

Testing of an energy storage system unit that induces a significant fire into the unit under test and evaluates whether the fire will spread to adjacent energy storage system units, surrounding equipment, or through an adjacent fire-resistance-rated barrier.

IFC 2018

1206.2.8.3 Stationary battery arrays.

Storage batteries, prepackaged stationary storage battery systems and preengineered stationary storage battery systems shall be segregated into stationary battery arrays not exceeding 50 kWh (180 megajoules) each. Each stationary battery array shall be spaced not less than 3 feet (914 mm) from other stationary battery arrays and from walls in the storage room or area. The storage arrangements shall comply with Chapter 10.

Exceptions:

1. Lead acid and nickel cadmium storage battery arrays.
2. Listed preengineered stationary storage battery systems and prepackaged stationary storage battery systems shall not exceed 250 kWh (900 megajoules) each.
3. The fire code official is authorized to approve listed, preengineered and prepackaged battery arrays with larger capacities or smaller battery array spacing if large-scale fire and fault condition testing conducted or witnessed and reported by an approved testing laboratory is provided showing that a fire involving one array will not propagate to an adjacent array, and be contained within the room for a duration equal to the fire-resistance rating of the room separation specified in Table 509 of the *International Building Code*.

UNIT/INSTALLATION LEVEL PERFORMANCE ASSESSMENT

IFC Large Scale Testing Analysis Guidelines

1206.2.3.2 Analysis approval.

The *fire code official* is authorized to approve the hazardous mitigation analysis provided that the hazard mitigation analysis demonstrates all of the following:

1. Fires or explosions will be contained within unoccupied battery storage rooms for the minimum duration of the fire-resistance-rated walls identified in Table 509.1 of the *International Building Code*.
2. Fires and explosions in battery cabinets in occupied work centers will be detected in time to allow occupants within the room to evacuate safely.
3. Toxic and highly toxic gases released during fires and other fault conditions shall not reach concentrations in excess of Immediately Dangerous to Life or Health (IDLH) levels in the building or adjacent means of egress routes during the time deemed necessary to evacuate from that area.
4. Flammable gases released from batteries during charging, discharging and normal operation shall not exceed 25 percent of their lower flammability limit (LFL).
5. Flammable gases released from batteries during fire, overcharging and other abnormal conditions shall not create an explosion hazard that will injure occupants or emergency responders.

UNIT/INSTALLATION LEVEL PERFORMANCE ASSESSMENT

IFC and NFPA 855 Large Scale Test Requirements

1. No fire spread to surrounding equipment
2. No array to array propagation
3. No fire spread through fire resistance rated barrier
4. Explosions are contained
5. Explosions cannot injure occupants/first responders
6. Toxic gases shall not exceed IDLH
7. Gas released will not exceed 25% of LFL in installation

UL 9540A Performance Data

(1,2) Observations of flaming outside the initiating BESS unit (if flaming observed, proceed with installation level test);

(2) Report whether maximum temperatures in target BESS units are less than the vent temperature measured in the cell level test;

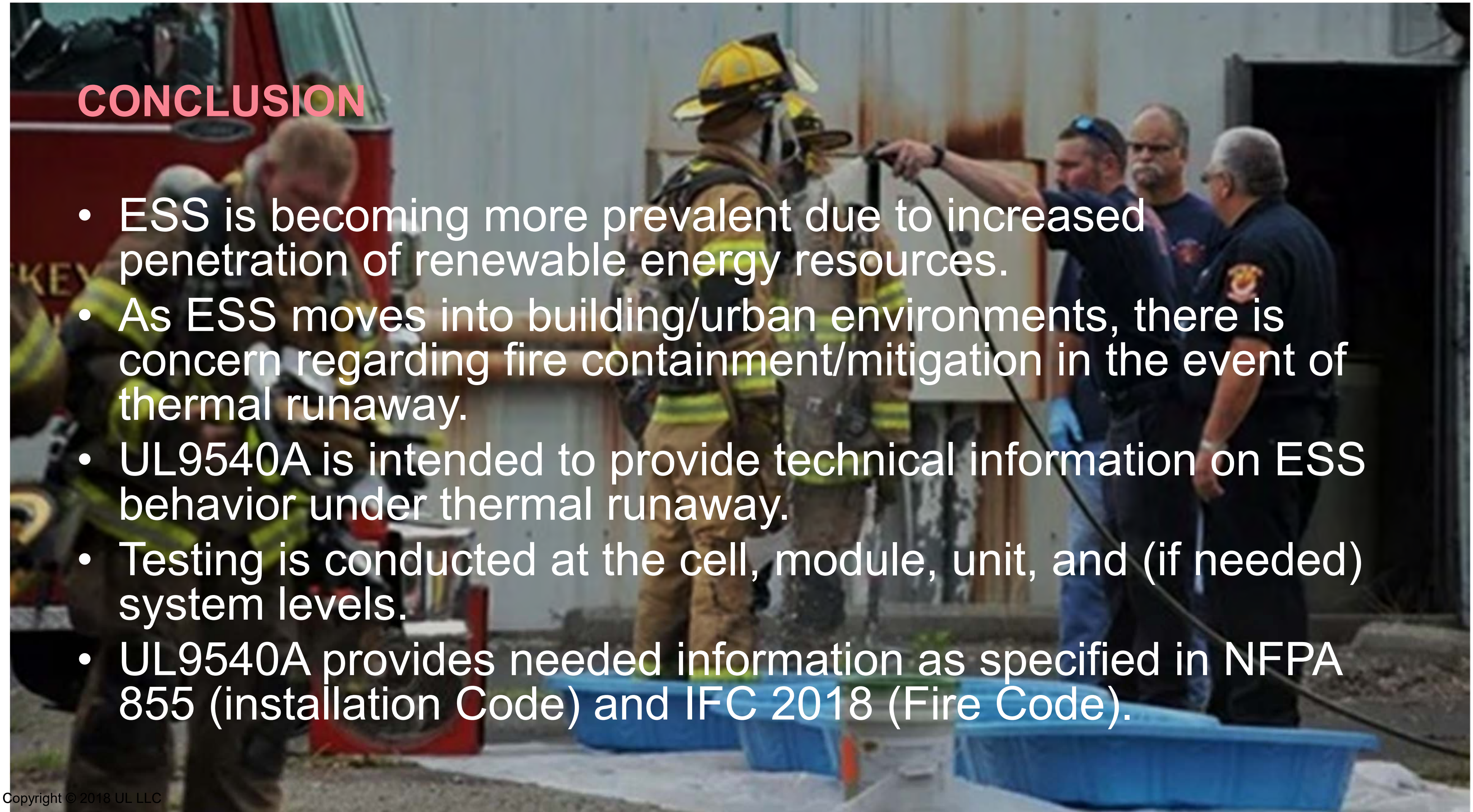
(1,3) With regard to combustible wall construction, report whether surface wall temperature rise above ambient is more than 97 °C (175 °F); (UL 103, UL 1978, UL 8782)

(3, 4, 5) Observations with regard to explosion hazard(s);

(6) Gas generation and composition data;

(1) Observation of fire spread in the flame indicator; (Installation Level);

(3, 7) Observation of flaming outside the test room (Installation Level)



CONCLUSION

- ESS is becoming more prevalent due to increased penetration of renewable energy resources.
- As ESS moves into building/urban environments, there is concern regarding fire containment/mitigation in the event of thermal runaway.
- UL9540A is intended to provide technical information on ESS behavior under thermal runaway.
- Testing is conducted at the cell, module, unit, and (if needed) system levels.
- UL9540A provides needed information as specified in NFPA 855 (installation Code) and IFC 2018 (Fire Code).