UL 9540A

Large Scale Testing of Energy Storage Systems: Fire Protection and Response Considerations

March 6, 2019

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AGENDA

1. Protecting Against Failure Events
2. Fire Safety Approach
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

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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)

- Enables the development of fire protection strategies based on measurement data
  - Fire hazards
  - Explosion hazards
  - Tenability hazards

Fire Service Strategy and Tactics

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

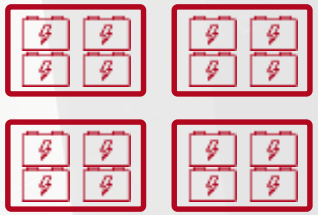
UL 9540A

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

Energy Storage System

UL 9540A Test Method

Fire Test Report

Manufacturer/
Integrator/Sponsor

Fire Protection
Consultant

Insurance Industry

Building Owner

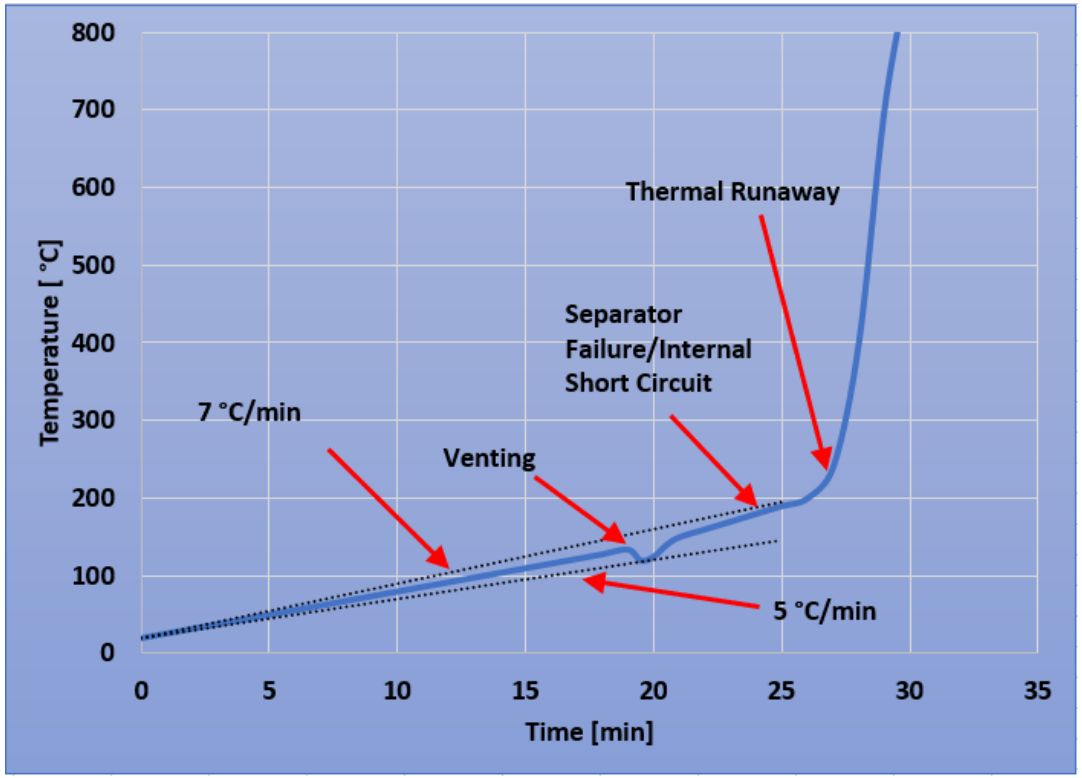
Other AHJ

Fire Department

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)



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 Testing Apparatus

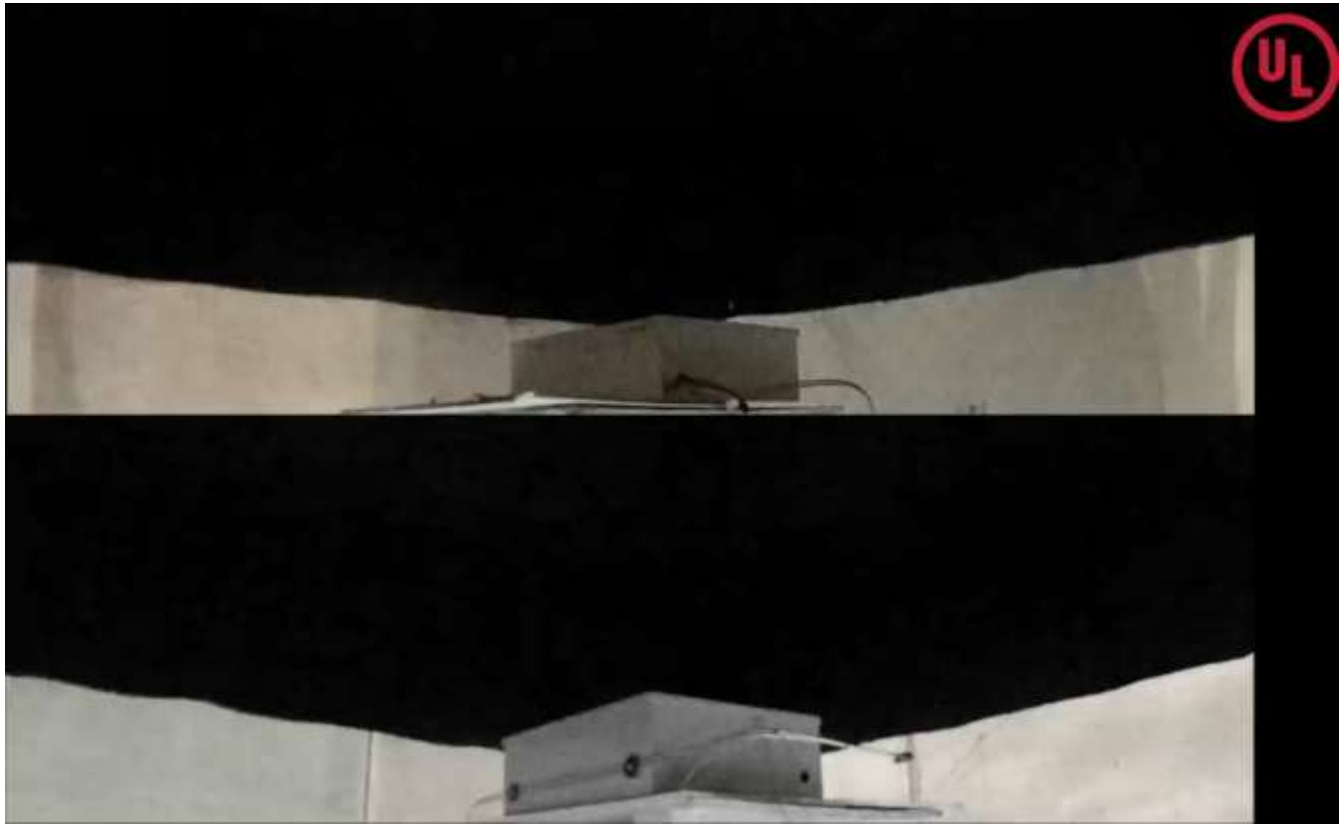
Gas	Composition (Vol %)
CO	36.2
CO_2	22.1
H_2	31.7
Hydrocarbons	~10%

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.

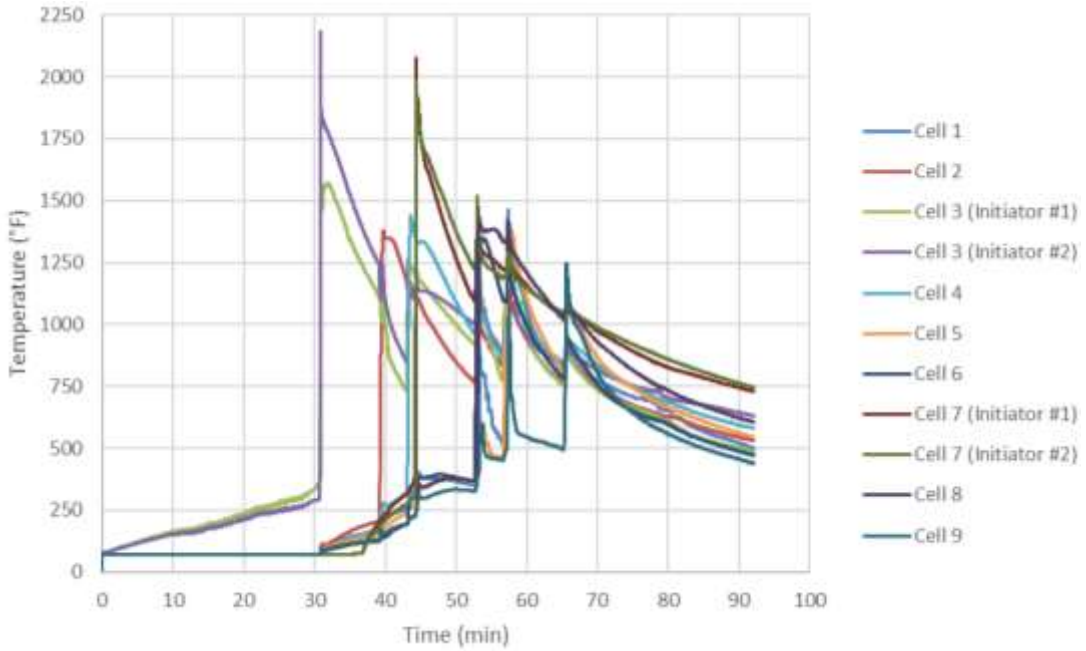


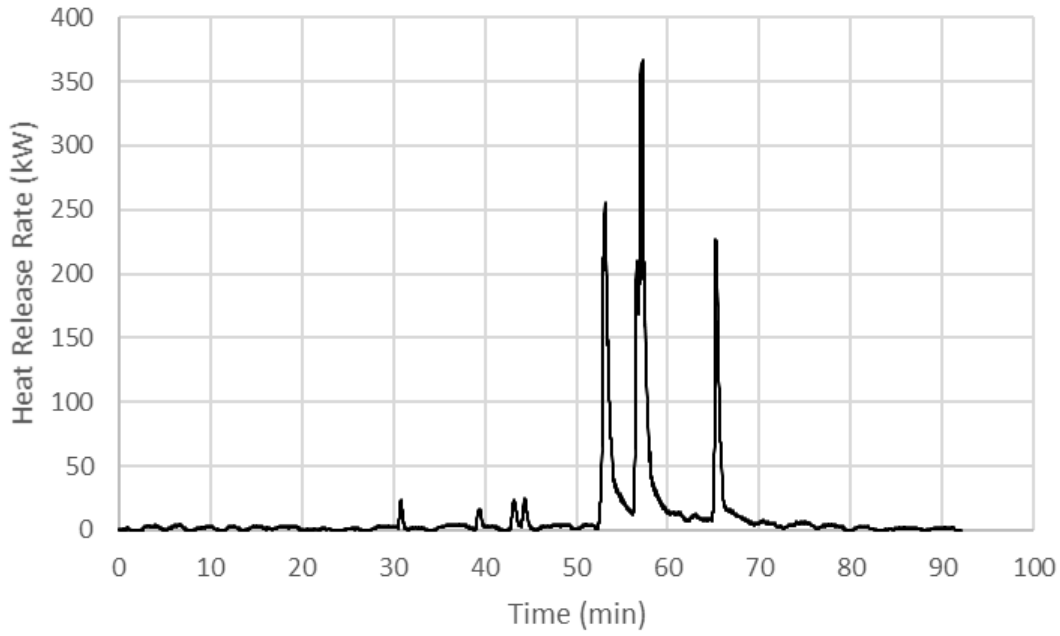
Important Data

- 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

Example of generic li-ion propagation of thermal runaway.





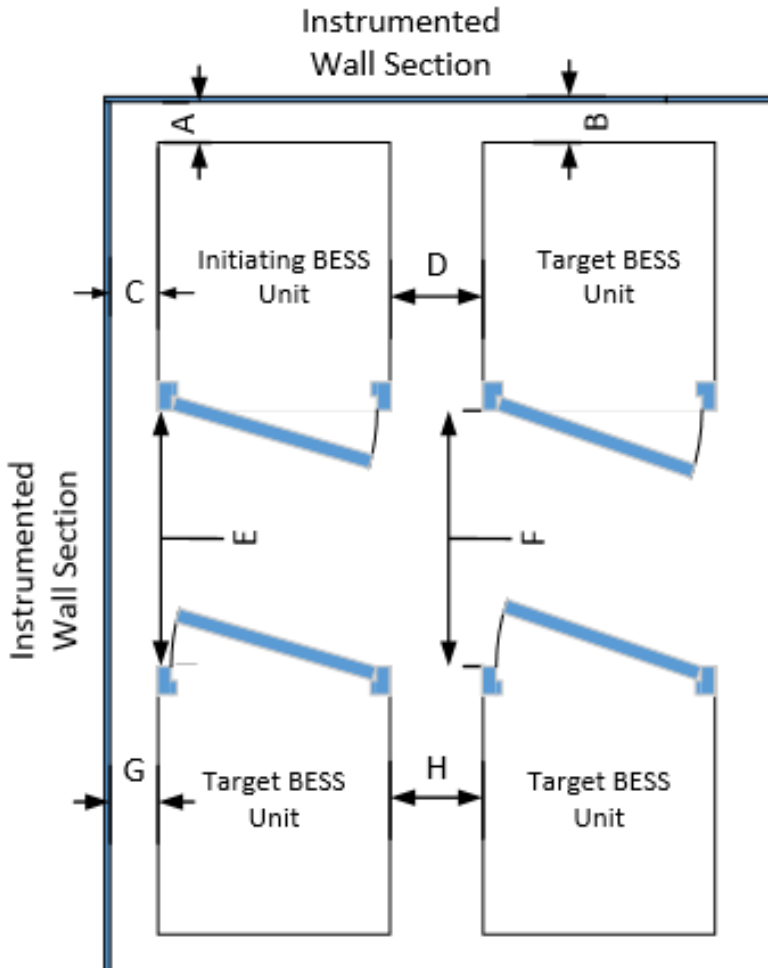
MODULE LEVEL MOCKUP TEST

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	Hydrocarbons	2.6	0.1
Total Hydrocarbons (% Propane)	Hydrocarbons	276.4	82.3
Hydrogen	-	-	-
Carbon Dioxide	Carbon Containing	197.4	2312.0
Carbon Monoxide	Carbon Containing	513.6	254.8
Hydrogen Bromide	Hydrogen Halides	0.0	0.4
Hydrogen Chloride	Hydrogen Halides	0.0	0.8
Hydrogen Fluoride	Hydrogen Halides	0.0	0.0
Ammonia	Nitrogen Containing	0.0	0.0
Hydrogen Cyanide	Nitrogen Containing	1.3	2.6

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.

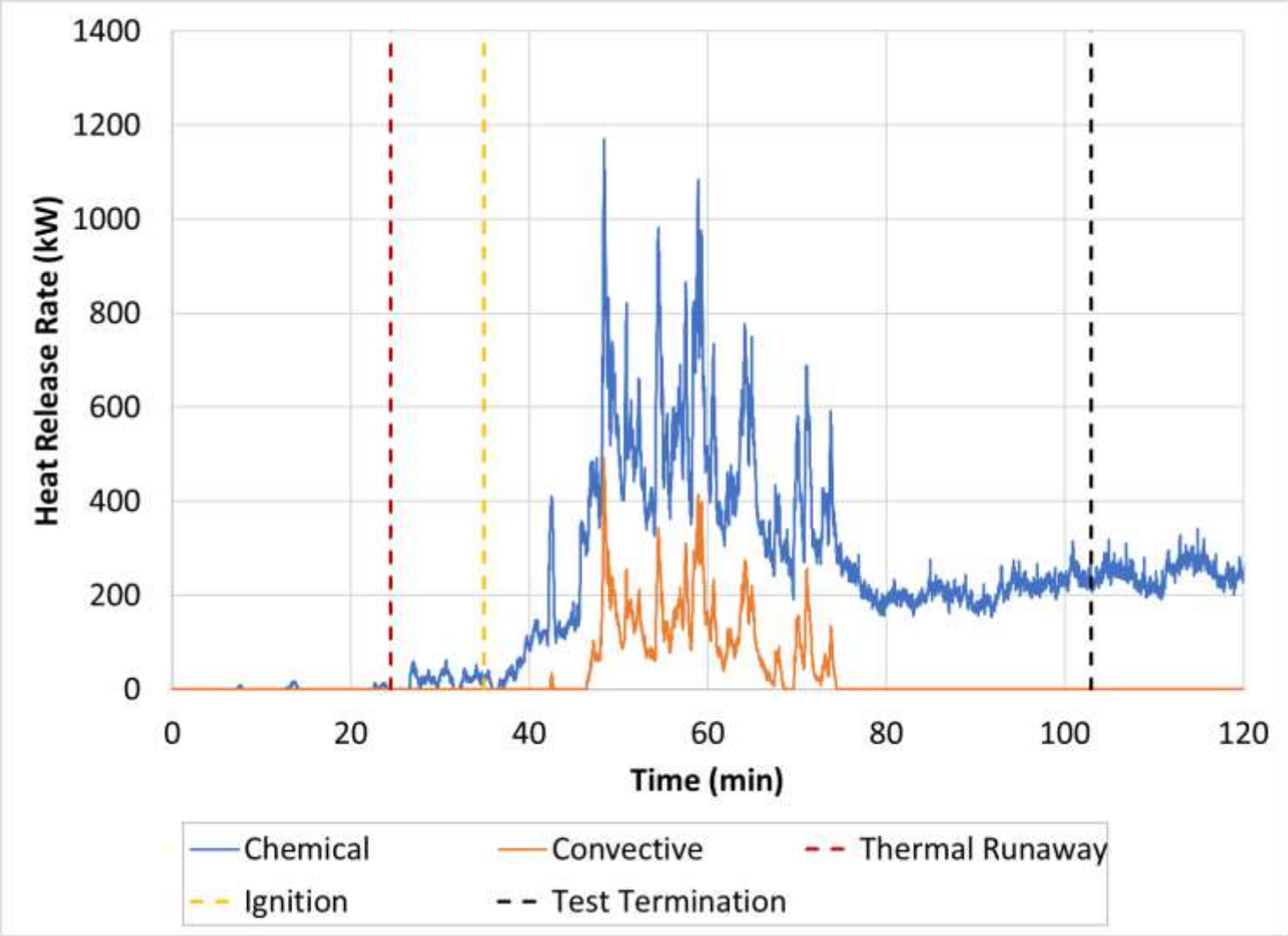


Important Data

- 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)

UNIT LEVEL MOCKUP TEST

UNIT LEVEL MOCKUP TEST – Heat Release Rate



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

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)

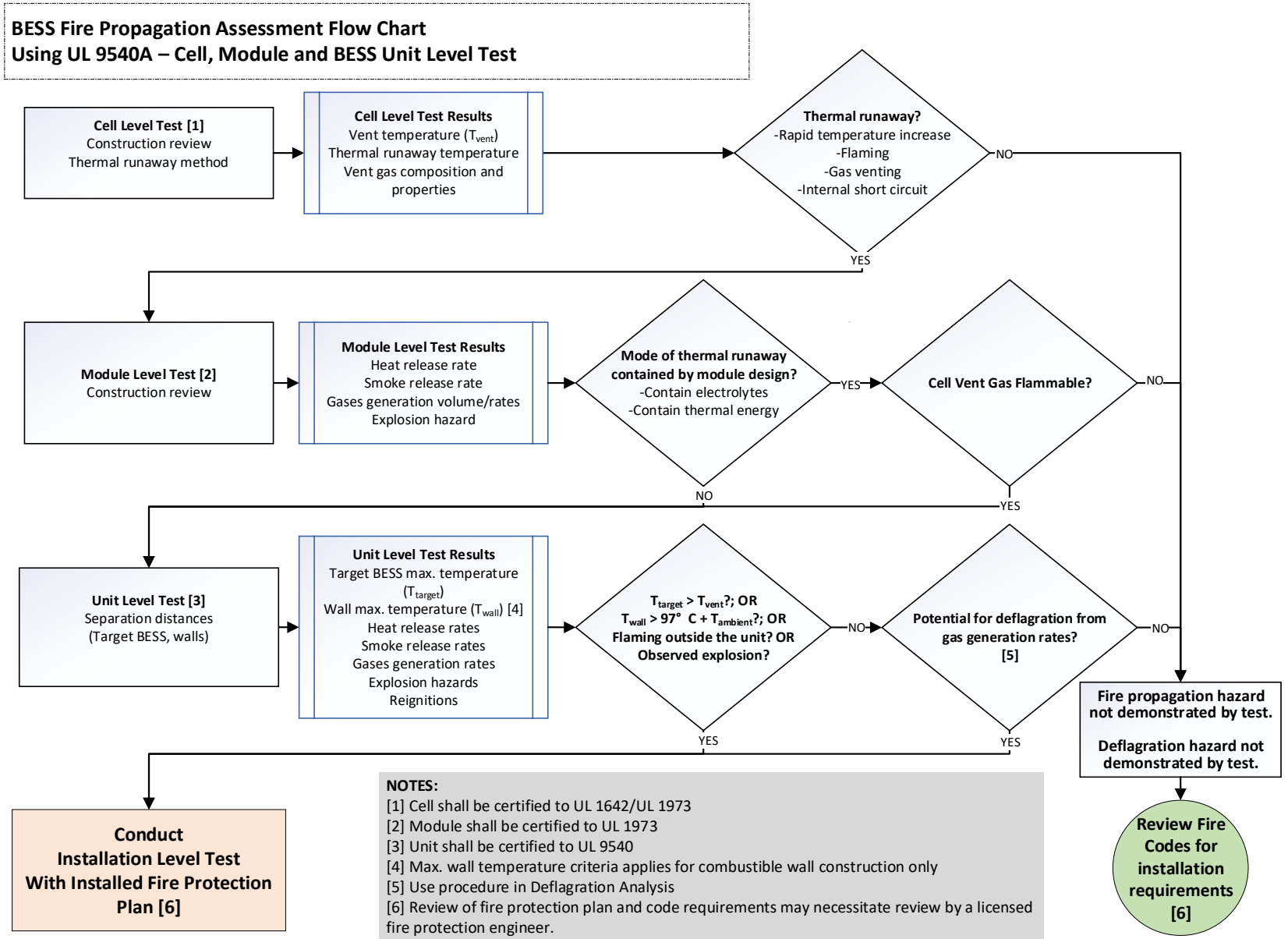
(3, 4, 5) Observations with regard to explosion hazard(s);

(6) Gas generation and composition data;

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

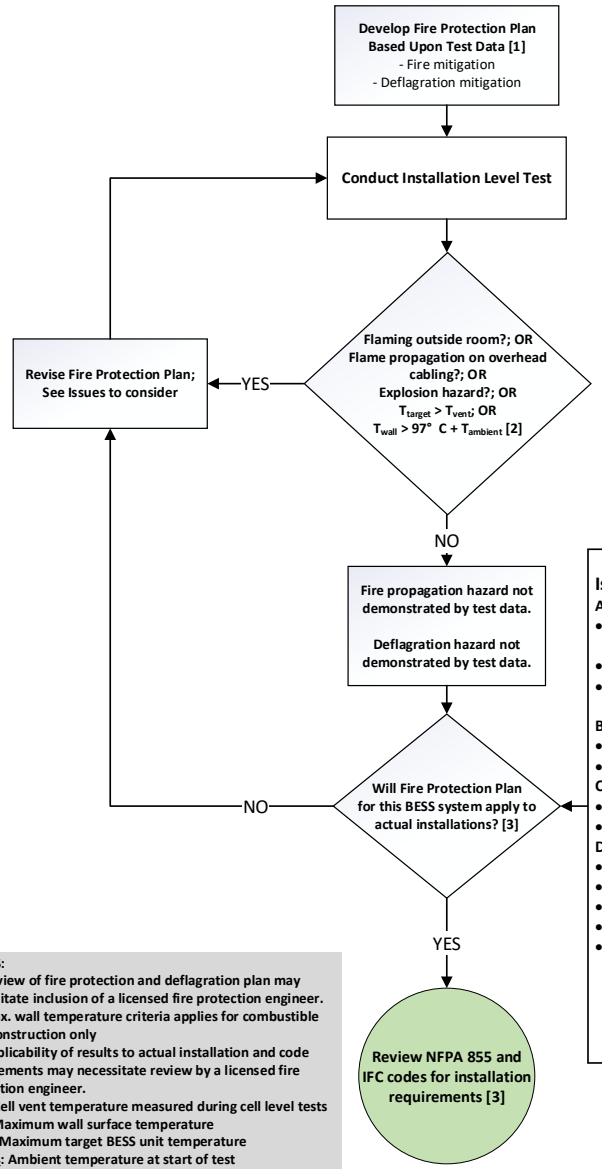
(3, 7) Observation of flaming outside the test room (Installation Level)

BESS FIRE PROPAGATION ASSESSMENT PROCESS



BESS FIRE PROPAGATION ASSESSMENT PROCESS

Draft BESS Fire Propagation Assessment Flow Chart
Using UL 9540A – Installation Level Test



Issues to Consider

A. Installation Space
- Combustible vs. Non combustible construction
- Size and layout
- Location (roof, indoor vs outdoor, floor for indoors)

B. Separation distances
- Spacing between BESS
- Spacing to walls

C. Combustibles
- Overhead cabling
- Other combustibles

D. Active fire mitigation methods
- Detection and alarm
- Suppression system design
- Deflagration prevention system design
- Deflagration protection system design

Many of these issues may be analyzed using vetted fire analysis tools including enclosure fire modeling by a licensed fire protection engineer.

NOTES:
[1] Review of fire protection and deflagration plan may necessitate inclusion of a licensed fire protection engineer.
[2] Max. wall temperature criteria applies for combustible wall construction only
[3] Applicability of results to actual installation and code requirements may necessitate review by a licensed fire protection engineer.
T_{vent}: Cell vent temperature measured during cell level tests
T_{wall}: Maximum wall surface temperature
T_{target}: Maximum target BESS unit temperature
$T_{ambient}$: Ambient temperature at start of test

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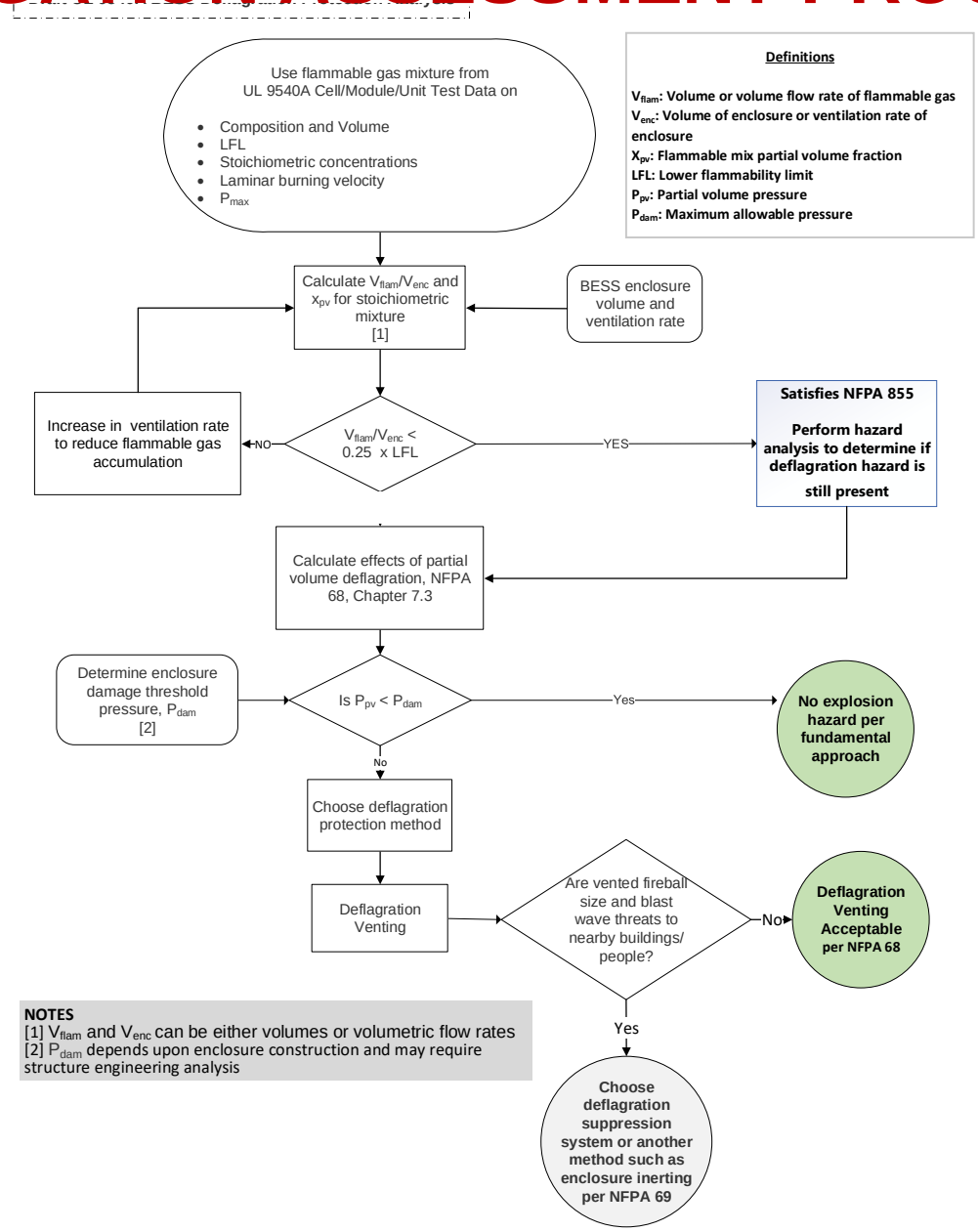

CONTACT US

Technical Questions
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