UL 9540A DATA UTILIZATION GUIDE FOR NYC: FLOW CHARTS

Introduction

The Smart Distributed Generation (DG) Hub, established by Sustainable CUNY of the City University of New York in 2013, is a comprehensive effort to develop a strategic pathway to safe and effective solar and solar+storage installations in New York City. The work of the Smart DG Hub is supported by the U.S. Department of Energy, the New York State Energy Research & Development Authority (NYSERDA), the New York Power Authority (NYPA), and the City of New York.

The DG Hub is engaged in efforts to remove barriers and open the market for solar and energy storage systems (ESS) in NYC through partnerships with technical advisors that include DNV GL, Underwriters Laboratory (UL), subject matter experts (SME) from industry, academia, and utilities, and city agencies. These efforts focus on facilitating development of clear permitting processes for ESS in NYC, sharing best practices, helping to reduce the learning curve for Authorities Having Jurisdiction (AHJ) and vendors, and providing clarity on the safe installation of ESS. To this end, the DG Hub published the ***Energy Storage Permitting and Interconnection Process Guide for New York City: Lithium-Ion Outdoor Systems*** to provide building owners, project developers and other industry participants a comprehensive document outlining the requirements and approval processes for deploying outdoor Lithium-Ion based ESS in NYC.

This ***UL 9540A Data Utilization Guide for NYC: Flow Charts*** document is intended as a supplement to the Outdoor Permitting Guide. It provides high-level guidance on the utilization of data obtained from ***UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems***,, which is a key component of all lithium-ion based energy storage permitting applications under consideration by NYC AHJs. This document is built around the generic analysis flow charts included in the 4th Edition of the UL 9540A Test Method, annotating the critical data points, input assumptions, and analysis and documentation processes required to submit a compliant application specific to NYC. Future iterations are expected to provide additional guidance that delves into the details of the engineering analysis and AHJ acceptance criteria.

For questions about this Guide or general technical assistance regarding energy storage permitting in NYC please contact the CUNY Smart DG Hub:

www.smartdghub.com

smartdghub@cuny.edu

(812) 302-2735

UL 9540A and Flow Charts

UL 9540A, 4th Edition, is an ANSI-accredited standard developed and published by Underwriters Laboratory (UL), entitled *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*. It is available for free digital viewing or purchase at [UL's Standards Shop](). This standard test method does not provide a pass/fail certification, but rather creates data critical to the design of right-sized safety measures for energy storage systems. Included as part of the standard are three flow charts which outline basic testing decision points and how the data produced in the tests may be leveraged in support of safety system designs. The flow charts include baseline development in the initial tests (Figure 1); assessment of fire spread at a system level (Figure 2); and assessment of explosion mitigation measures (Figure 3).

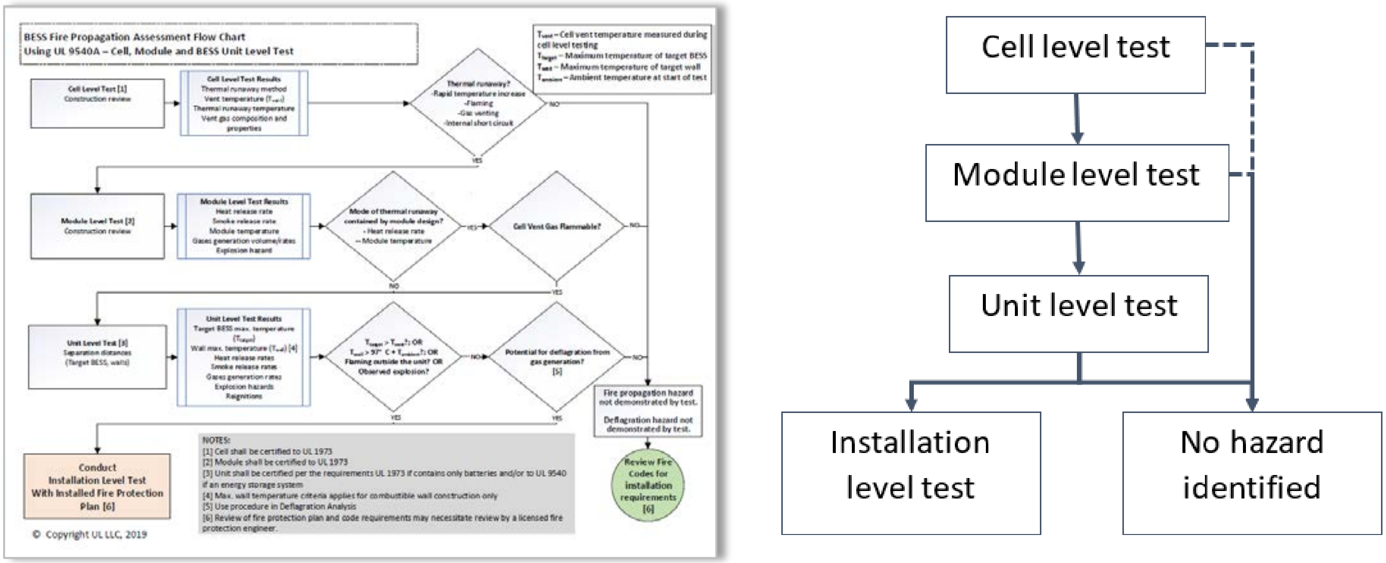


Figure 1 Using UL 9540A: Cell, Module, and BESS Unit Level Test; (left: full chart, right: simplified chart)

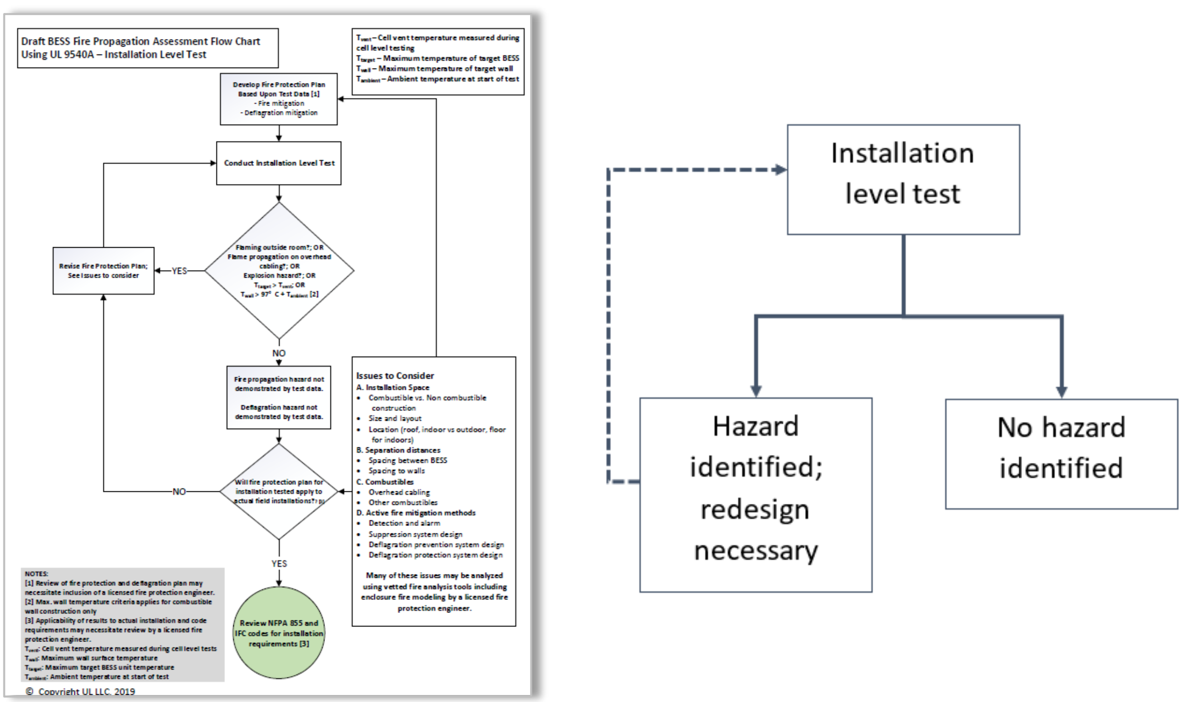


Figure 2 Fire propagation assessment: Installation level analysis (left: full chart, right: simplified chart)

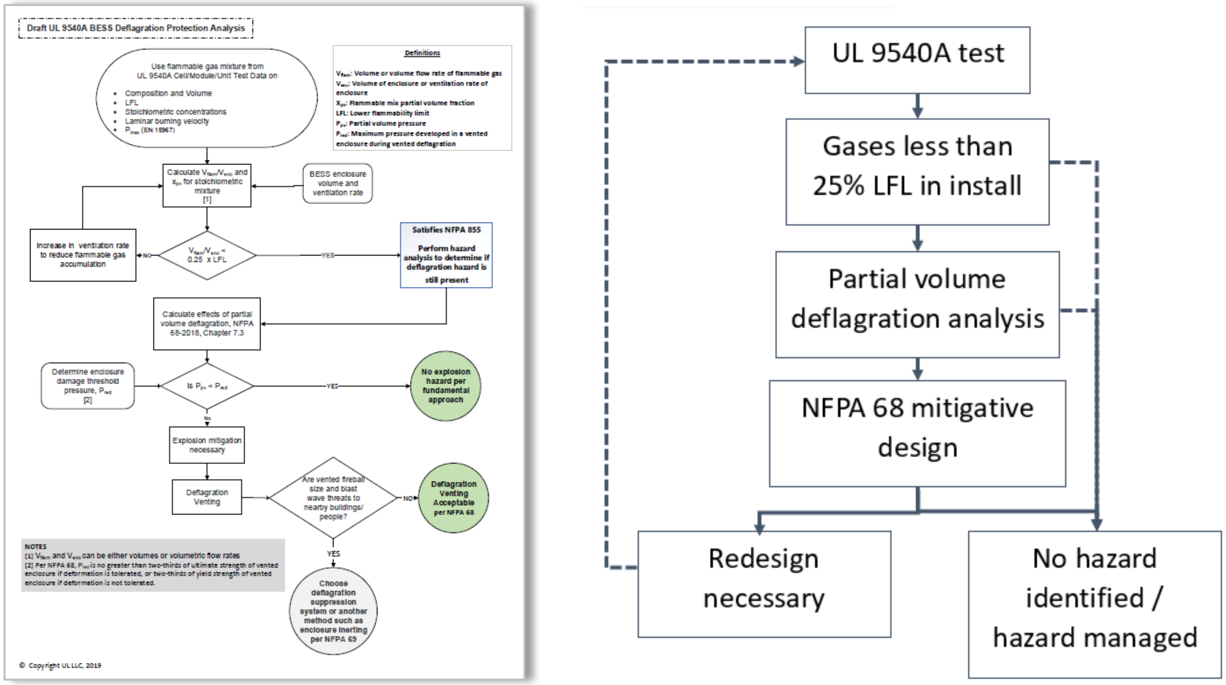


Figure 3 Deflagration Protection Analysis (left: full chart, right: simplified chart)

NYC Interpretation and Requirements

The methodologies outlined in the flow charts within UL 9540A, 4th Edition, are generic, rooted in widely accepted standards across multiple fields. While this provides a strong basis for assessment, it does leave open energy storage- and jurisdiction-specific decision points that would require interpretation by system designers, engineers, and NYC Agencies. In order to provide guidance on acceptable interpretations, assumptions, and formats, annotated versions of these flow charts were developed in collaboration with NYC Agencies and subject matter experts. Each annotation is tied to a standard, department policy, or subject matter expert interpretation, and have been determined as acceptable by the Agencies. If these methodologies are leveraged in the system design of submitted applications, they will be accepted by Agencies; this is not intended to imply that the project as a whole will be found to be acceptable, but that the methodology will not require further validation upon submission. While there remain areas where acceptance criteria are still under development, these methodologies will ensure submittals are clear, consistent, and compliant, and technical discussions can be focused on a reduced subset of topic areas. Critical among these are an understanding of site specific risk analysis, and how it is interpreted by the Agencies. This will be detailed in other materials.

Following this, the same three UL 9540A flow charts are provided with annotations, in Figure 4 (with a focus on test data outputs and acceptable ways in which that data is reported), Figure 5 (reporting, criteria, and assumptions for fire suppression/protection of the system, to protect people and structures), and Figure 6 (reporting, criteria, and assumptions for acceptable explosion mitigation to protect people and structures).

FIGURE 4

3, 5. Reporting requirements
Any submitted UL 9540A test report must include the following:
- Executive summary
- Laboratory
- Date of test
- Edition of test method
- Description of energy storage equipment
- Description of layout and mitigative systems
- Description of test set up
- Summary of results, in numeric and graphic format

Although not required as part of the test report submission, if during the course of the Authority's review additional information is needed, the full set of raw test data must be provided.

8. Toxicity analysis/modeling is not required for outdoor sites. Appropriate PPE should be identified for first responders, and prescriptive egress requirements must be followed. Indoor sites may require gas detection.

1. No exceptions will be granted for this test. A cell's ability to resist thermal runaway is not an acceptable reason to not perform the test, as external factors may impact the system which are not possible for internal controls to manage. As such, it is critical to understand if failure of the cell does occur, what the impact is.

4. As such, **all projects must be submitted with a full UL 9540 test report and associated analysis** OR submitted within a year of issuance of LONO/conditional acceptance letter.

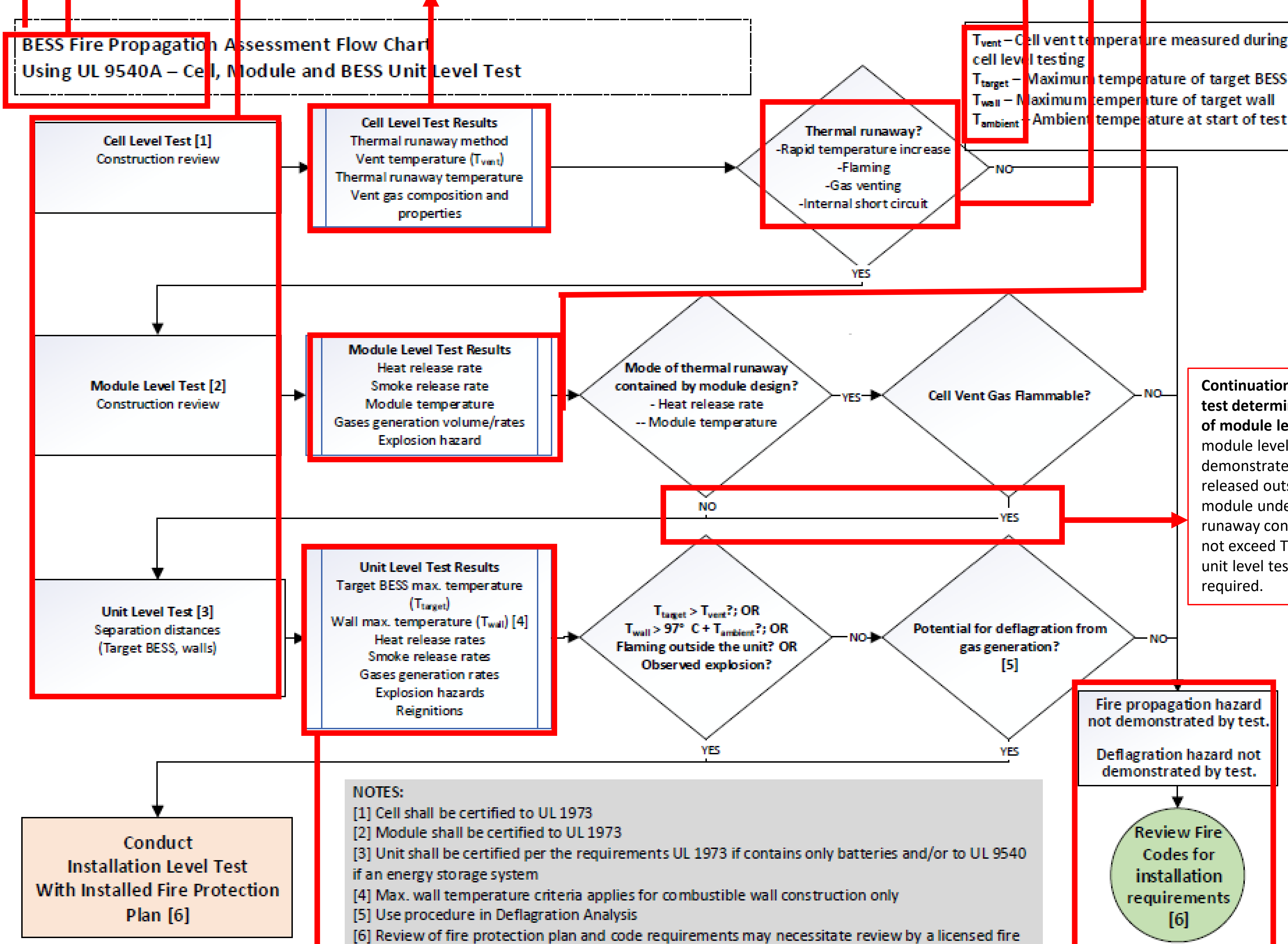
2. **FDNY and DOB will accept test results from any lab which is accredited to conduct UL 9540 or UL 1973.** This is a temporary measure, as no laboratory can currently be accredited for the test method. This requirement is intended to prevent unqualified labs from performing a complex and dangerous test, and expect otherwise qualified labs to self-select based on the necessary skill sets. Considering a six month limitation on this period (mid-2020).

9. **UL 9540A 3rd edition is considered by FDNY and DOB to be applicable to all system types, sizes, and installation locations.** It is understood that newer UL 9540A editions or related publications may more directly address such installations. Until that point, the data gathered in the 3rd edition methodology will still be required, and may be analyzed as appropriate to each installation.

31. **Conservative criteria are assessed in order to account for edge cases.** It is recognized that the temperature at which the cell vents is not the same as the thermal runaway temperature; however, as an early part of the thermal runaway event, if no mitigative actions are taken, it is taken as a conservative initiating temperature.

13. Module level measurements:
- Propagation of thermal runaway
- External flaming
- Locations of flame venting
- Flying debris
- Peak heat release rate (HRR)
- Re-ignitions
- Gas composition pre-flaming
- Gas composition post-flaming

14, 15, 16. Cell test measurements:
- Thermal runaway initiation method
- Cell surface temperature at gas venting
- Cell surface temperature at thermal runaway
- Gas volume
- Gas composition (CO, CO2, H2, total hydrocarbons)
- Lower flammability limit (LFL)
  - Determined through secondary test, via the method outlined in ASTM 918 or ASTM E681
- Deflagration pressure (Pmax)
  - Determined through secondary test, via the method outlined in EN 15967
- Burning velocity (cm/s)
  - Determined through secondary test, via the method outlined in ASHRAE 34 or ISO 817



Continuation to unit level test determined by results of module level test. If the module level test demonstrates the heat released outside of the module under thermal runaway conditions does not exceed Tvent, then the unit level test is not required.

13. Unit level test measurements:
- Test configuration
- Fire protection systems within unit
- Thermal runaway propagation
- External flaming
- Locations of flame venting
- Flying debris
- Peak HRR
- Re-ignitions
- Max. target BESS temperature
- Max. wall surface temperature
- Gas composition pre-flaming
- Gas composition post-flaming

11. Construction review requirements:
- Use of identical data to the system installed is not mandatory, as long as the 'worst case scenario' system is tested and used.
- Approved test lab may conduct a formal construction review, per its own internal standards, comparing and contrasting the tested and untested technologies. This report must be provided with the permitting submission.
- If the approved test lab determines that the technology under test is considered, comparatively, to represent the 'worst case design', i.e., that its energy density, construction, or components represent a greater threat than the compared technology, it may provide test data from the tested technology instead for use in design of mitigative systems.
- "Scaling down" results from the worst-case scenario data, rather than directly using the worst-case scenario data, must be demonstrated as appropriate through testing by an approved lab. Models and assumptions are not currently acceptable.

12. **A site specific risk analysis is necessary,** signed and stamped by a NYS PE, including:
- Identification of hazards
- Severity and likelihood assessment
- Modes and mitigations analysis
- Gap analysis

(Reference ISO 31010 for guidance)

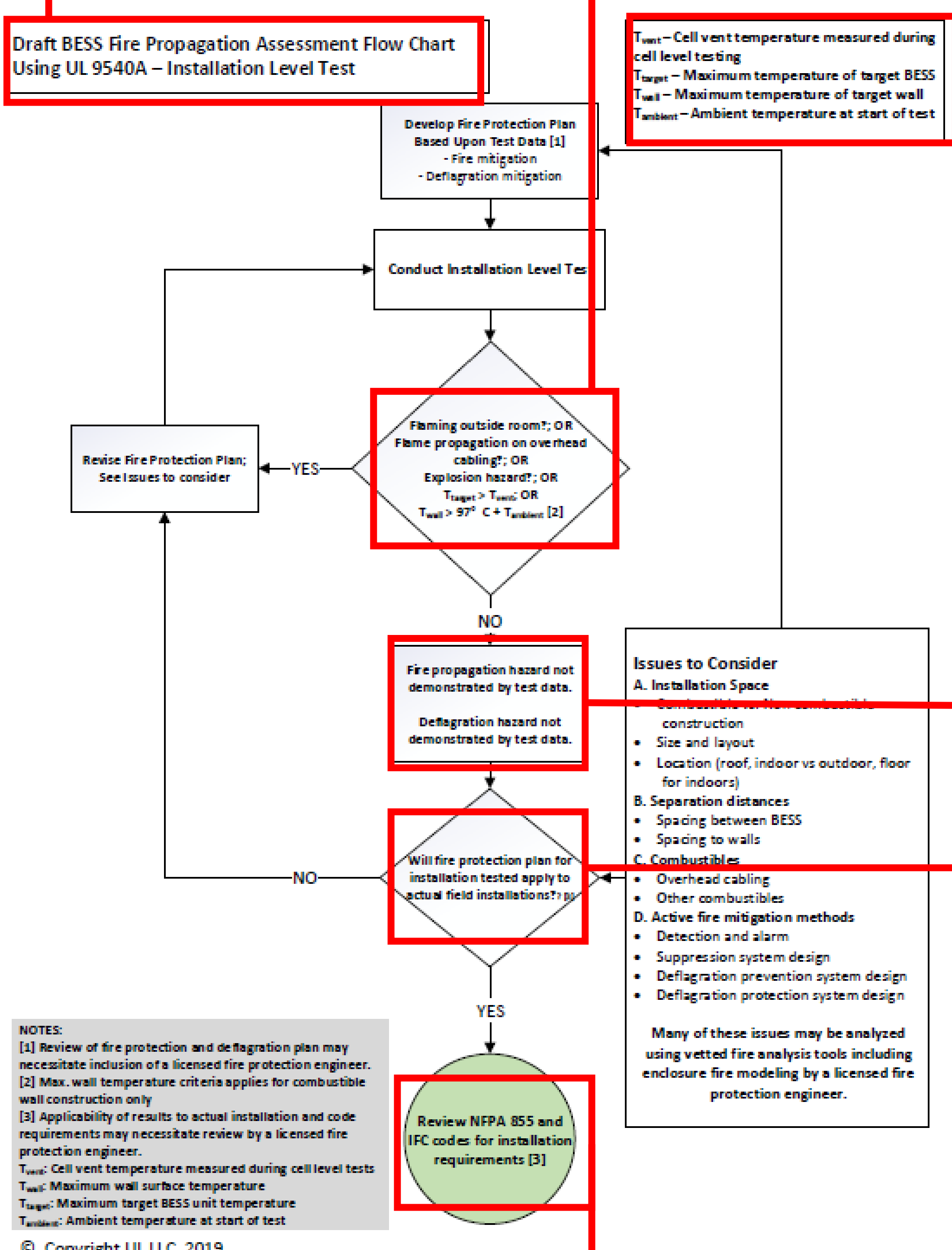
FIGURE 5

7. Reporting requirements
Any submitted fire spread analysis must include the following:
- Executive summary
- Methodology used (UL 9540A results or heat transfer calculations)
- Data input
- Result output
- Calculations and assumptions
- If model used, validation documentation
- Sign off on final design by NYS RA or PE

31, 33. Fire spread impact to neighboring batteries is tested. Spacing between battery racks is only determinable by testing aligned with UL 9540A (wherein temperature in adjacent unit reaches vent temp) through the unit level or installation level test.

7. Fire spread impact to neighboring exposures (e.g., buildings or walls, other equipment that is not batteries, and egress pathways or public ways) may be calculated or observed during the test. If calculated, the assessment may consider that fire rated or non-combustible surfaces may not be impacted by temperatures equal to ambient temperature + 97C.

Conservative criteria are assessed in order to account for edge cases. Cell vent temperature ≠ thermal runaway temperature, but, if no mitigative actions are taken, indicates thermal runaway *potential*.



Minor differences between test set up and actual installation are expected and permitted. A NYS PE will be required to sign off on any differences, and comment on the test's continuing applicability.

30. NFPA 15 should be referenced for "dry pipe" water-based suppression systems, with 0.5 GPM/ft2 as the prescriptive requirement.
- *Small system (Li ion, 0 – 20 kWh):* No NFPA 15 requirement; DOB prescriptive requirements
- *Medium system (Li ion, 20 – 250 kWh):* No NFPA 15 requirement unless demonstrated as necessary by UL 9540A
- *Large system (Li ion, 250 kWh+):* Required unless demonstrated by UL 9540A as not necessary (variance process).

34. Fire rated materials' effectiveness are not directly tested in UL 9540A. As such, a site specific determination of necessary maximum temperatures on back of wall shall be indicated, with expected impact of materials taken into consideration and signed off on by a NYS licensed PE. It is recommended that autoignition temperatures and fire resistant materials ratings are taken into consideration.

27, 28. Fire threat should be assessed and documented by the NYS PE, but guidance for its definition and related minimum expectations include:

To buildings: The temperature at which the building will be affected beyond that deemed acceptable for the performance group (Ref: ICC 2009), with consideration for materials of and in building

Magnitude of event		Increasing level of performance			
		Performance Group I	Performance Group II	Performance Group III	Performance Group IV
	Very large (very rare)	Severe	Severe	High	Moderate
	Large (rare)	Severe	High	Moderate	Mild
	Medium (Less frequent)	High	Moderate	Mild	Mild
	Small (Frequent)	Moderate	Mild	Mild	Mild

To bystanders: Egress pathways are determined through prescriptive requirements, with 10 ft of spacing required between system and egress pathway.

To first responders: The heat flux at the fire department connection (FDC) should be demonstrated, through testing and analysis, as less than 2.5 kw/m2 based on the proposed siting (Ref: SFPE Handbook). The FDC shall be in no case less than 10 ft from the system.

Approximate Radiant Heat Flux (kW/m^2)	Comment or Observed Effect
170	Maximum heat flux as currently measured in a postflashover fire compartment.
80	Heat flux for protective clothing Thermal Protective Performance (TPP) Test.[a]
52	Fiberboard ignites spontaneously after 5 seconds.[b]
29	Wood ignites spontaneously after prolonged exposure.[b]
20	Heat flux on a residential family room floor at the beginning of flashover.[c]
20	Human skin experiences pain with a 2-second exposure and blisters in 4 seconds with second-degree burn injury.[d]
15	Human skin experiences pain with a 3-second exposure and blisters in 6 seconds with second-degree burn injury.[d]
12.5	Wood volatiles ignite with extended exposure[e] and piloted ignition.
10	Human skin experiences pain with a 5-second exposure and blisters in 10 seconds with second-degree burn injury.[d]
5	Human skin experiences pain with a 13-second exposure and blisters in 29 seconds with second-degree burn injury.[d]
2.5	Human skin experiences pain with a 33-second exposure and blisters in 79 seconds with second-degree burn injury.[d]
2.5	Common thermal radiation exposure while fire fighting.[f] This energy level may cause burn injuries with prolonged exposure.
1.0	Nominal solar constant on a clear summer day.[g]

FIGURE 6

3, 4, 5. Reporting requirements
Any submitted explosion analysis must include the following:
- Executive summary
- Methodology used (NFPA 68, NFPA 69, or equivalent)
- Data input
- Result output
- Calculations and assumptions
- If model used, validation documentation
- Sign off on final design by NYS RA or PE

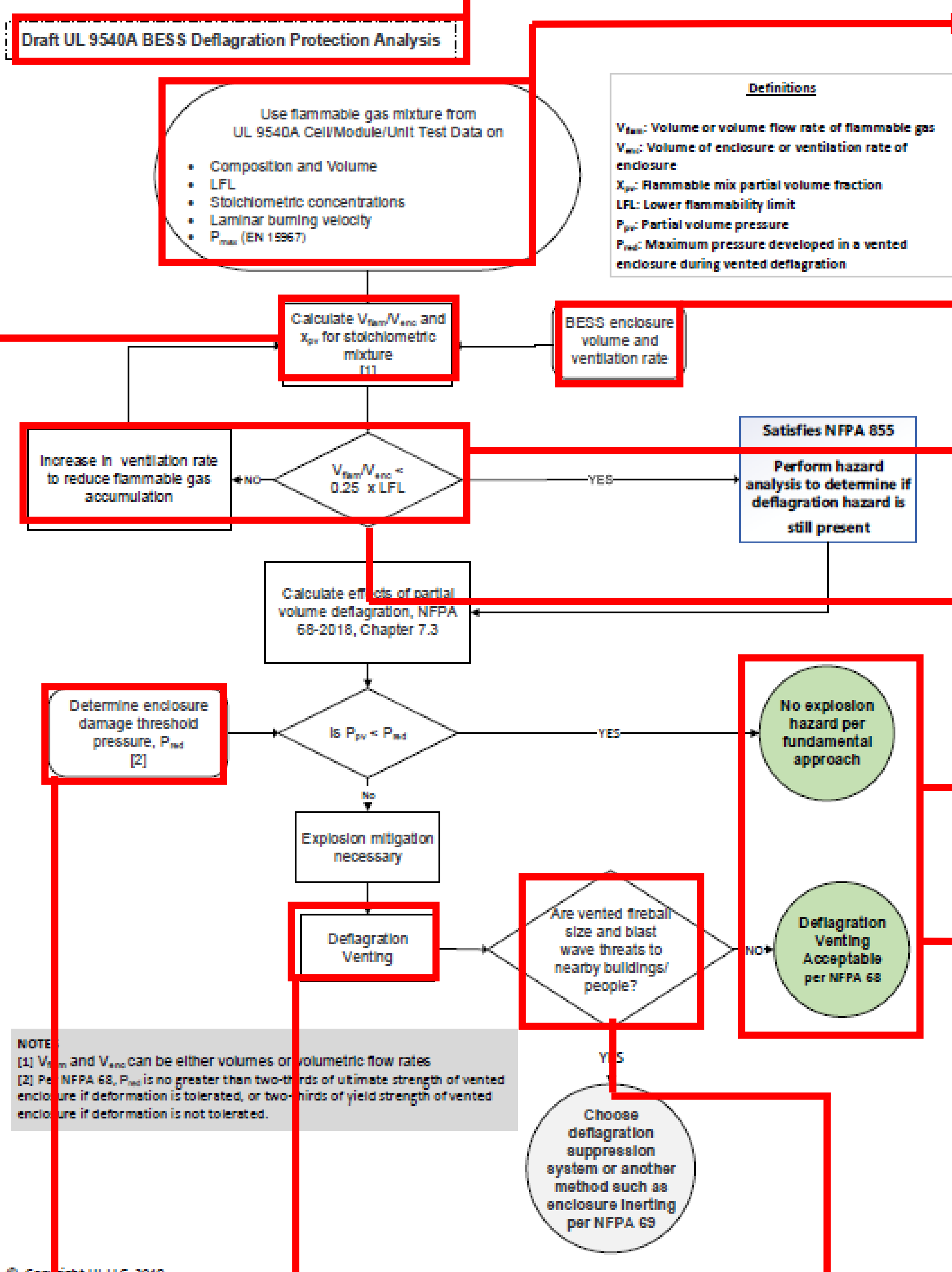
13. Input data for analysis.
- Cell level gas composition data
  - Pmax (EN 15967)
  - LFL (ASTM 918 or ASTM E681)
  - Burning velocity (ASHRAE 34 or ISO 817)
- Unit level total volume and release rate of *pre-flaming* gas

Cell level gas characteristics should be applied to the unit volumetric release rate, with composition remaining constant (well-mixed).

20. Test termination does not invalidate results. Test data may be used for explosion analysis, up to the point the test ended.

18. First responder impact may not be considered to impact analysis, either positively (e.g., application of water prevents further cascading failure) or negatively (e.g., exhaust activation precipitates explosion)

21. Volume of enclosure is defined as:
- Full volume of space minus obstruction volume (e.g., racks). Dead space between cells/modules is included with obstruction volume.



22. Ventilation rate impact is calculated rather than tested, as the UL 9540A test method includes a vent to gather gas data which will not be present in actual installations. CFD analysis is not required but is accepted as best practices; a simple mass flow calculation can be conducted instead.

6. NFPA 68 or NFPA 69 are both industry accepted for explosion analysis and design. Currently, NFPA 68 is required by NYC code, while NFPA 69 is optional.

19. For energy storage systems which do not output gases under normal conditions (e.g., Li ion), it is not necessary to reduce LFL below 25% if NFPA 69 is not being pursued. While it is accepted as best practice to reduce the gas concentration to as low as possible through ventilation, but it is recognized that in some scenarios it may not be possible to hit 25% LFL. **Batteries which may generate gases under normal conditions (e.g., lead acid), must comply with the 25% LFL requirement, per code.**

29. Generally, gas detection equipment is recognized as non-standardized/not certified for continuous operation during Li-ion failures. As such, gas detection equipment is not required for outdoor systems. Indoor system gas detection requirements are still under consideration.

Fireball from the explosion threat should be assessed and documented by the NYS PE based on NFPA 68 method, ensuring that the FDC and building are beyond the "hazard zone".

7.6* Fireball Dimensions.

7.6.1 The hazard zone from a vented gas deflagration shall be calculated by the following equation:

$$D = 3.1 \cdot \left(\frac{V}{n}\right)^{0.402} \quad [7.6.1]$$

where:
D = axial distance (front-centerline) from vent (m)
V = volume of vented enclosure (m³)
n = number of evenly distributed vents

7.6.2 The hazard zone measured radially (to the sides, measured from the centerline of the vent) shall be calculated as $0.5D$.

24. Deformation of containers is permissible. Strength of the enclosure should be calculated using method described in NFPA 68.

17. Deflagration vents will always be designed with upwards pressure release.

25. Model-based design is permitted. Design methods which are demonstrated to meet or exceed NFPA 68 are acceptable, given demonstrated through acceptance by a NYS PE and documentation of assumptions/calculations/research or testing support.

23. Management of the projectile threat should be done in an NFPA 68 compliant method. No obstructions which are not securely mounted should be installed near the deflagration vents. The deflagration panels should be securely fastened to the container, to ensure that they do not become projectiles. Listed deflagration panel equipment by itself does not guarantee this; a design engineer should specify that equipment is designed to be tethered or hinged to container.

Pressure waves from the explosion threat should be assessed and documented by the NYS PE, but guidance for its definition and related minimum expectations include:

To buildings: The pressures at which the building will be affected beyond that deemed acceptable for the performance group (Ref: ICC 2009), with consideration for building materials and occupancy

Magnitude of event	Increasing level of performance: Performance Group I	Performance Group II	Performance Group III	Performance Group IV
Very large (very rare)	Severe	Severe	High	Moderate
Large (rare)	Severe	High	Moderate	Mild
Medium (Less frequent)	High	Moderate	Mild	Mild
Small (Frequent)	Moderate	Mild	Mild	Mild

To bystanders: Egress pathways are determined through prescriptive requirements, with 10 ft of spacing required between system and egress pathway.

To first responders: The overpressure at the fire department connection (FDC) should be demonstrated, through testing and analysis, as less than 1 psig based on the proposed siting (Ref: SFPE Handbook).) The FDC shall be in no case less than 10 ft from the system.

Table 5-13.4 *Explosion Overpressure Damage Estimates*

Overpressure (psig)	Characteristic damage: To Equipment	To People
2.5–5	Heavy damage to buildings and to process equipment	1% death from lung damage >50% eardrum rupture >50% serious wounds from flying objects
1–2.4	Repairable damage to buildings and damage to the facades of dwellings	1% eardrum rupture 1% serious wounds from flying objects
0.5–1	Glass damage	Injury from flying glass
0.15–0.30	Glass damage to about 10% of panes	Slight injury from flying glass