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/UL 9540A-2019

Standards Council of Canada
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SCC FOREWORD

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UL Standard for Safety for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, ANSI/CAN/UL 9540A:2019

Fourth Edition, Dated November 12, 2019

Summary of Topics

This Fourth Edition of ANSI/CAN/UL 9450A, Standard for Safety for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, has been issued to reflect the latest ANSI and SCC approval dates, and to incorporate the proposals dated March 29, 2019 and August 16, 2019.

The requirements are substantially in accordance with Proposal(s) on this subject dated March 29, 2019 and August 16, 2019.

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ANSI/CAN/UL 9540A:2019

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

First Edition – November, 2017
Second Edition – January, 2018
Third Edition – June, 2018

Fourth Edition

November 12, 2019

This ANSI/CAN/UL Safety Standard consists of the Fourth Edition.

The most recent designation of ANSI/UL 9540A as an American National Standard (ANSI) occurred on November 12, 2019. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, Preface or SCC Foreword.

This standard has been designated as a National Standard of Canada (NSC) on November 12, 2019.

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ANNEX A (INFORMATIVE) Test Concepts And Application Of Test Results To Installations

ANNEX B (INFORMATIVE) Safety Recommendations for Testing

Preface

This is the Fourth Edition of the ANSI/CAN/UL 9540A, Standard for Safety for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems.

UL is accredited by the American National Standards Institute (ANSI) and the Standards Council of Canada (SCC) as a Standards Development Organization (SDO).

This Standard has been developed in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization.

This ANSI/CAN/UL 9540A Standard is under continuous maintenance, whereby each revision is approved in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization. In the event that no revisions are issued for a period of four years from the date of publication, action to revise, reaffirm, or withdraw the standard shall be initiated.

In Canada, there are two official languages, English and French. All safety warnings must be in French and English. Attention is drawn to the possibility that some Canadian authorities may require additional markings and/or installation instructions to be in both official languages.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at http://csds.ul.com.

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This Edition of the Standard has been formally approved by the UL Standards Technical Panel (STP) on Energy Storage Systems and Equipment, STP 9540.

This list represents the STP 9540 membership when the final text in this standard was balloted. Since that time, changes in the membership may have occurred.

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This Standard is intended to be used for conformity assessment.

The intended primary application of this standard is stated in its scope. It is important to note that it remains the responsibility of the user of the standard to judge its suitability for this particular application.

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INTRODUCTION

1 Scope

1.1 The test methodology in this standard determines the capability of a battery technology to undergo thermal runaway and then evaluates the fire and explosion hazard characteristics of those battery energy storage systems that have demonstrated a capability to undergo thermal runaway.

1.2 The data generated will be used to determine the fire and explosion protection required for an installation of a battery energy storage system intended for installation, operation and maintenance in accordance with ICC IFC, NFPA 1, NFPA 70, IEEE C2, CAN/CSA C22.2 No. 0, and other codes affecting energy storage systems, and the manufacturer's installation instructions.

1.3 Fire protection requirements not related to battery energy storage system equipment are covered by appropriate installation codes.

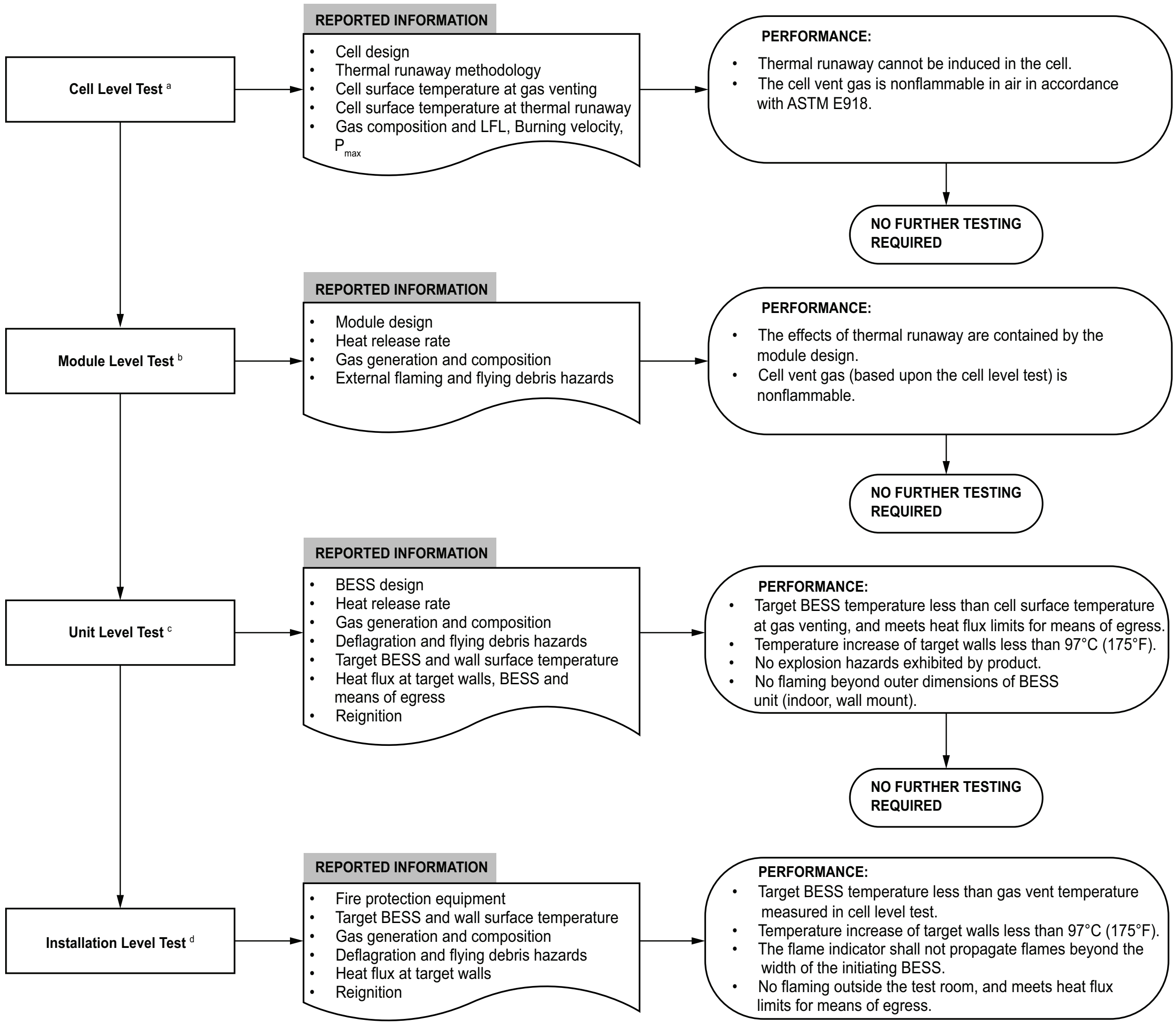
1.4 See Figure 1.1 for a schematic of the test sequence in this standard. See Annex A which explains:

a) The purpose of the tests included in this standard;

b) Explanation of individual tests; and

c) Interpretation and application of the results.

Figure 1.1
Schematic of Test Sequence



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[a] See Section 7.

[b] See Section 8.

[c] See Section 9.

[d] See Section 10.

2 Units of Measurement

2.1 Values stated without parentheses are the requirement. Values in parentheses are a soft conversion from SI to IP units of the requirement.

3 Normative References

3.1 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

3.2 The following model codes or standards are referenced in this standard.

ASHRAE 34, *Designation and Safety Classification of Refrigerants*

ASTM D93, *Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester*

ASTM D3828, *Standard Test Methods for Flash Point by Small Scale Closed Cup Tester*

ASTM E502, *Standard Test Method for Selection and Use of ASTM Standards for the Determination of Flash Point of Chemicals by Closed Cup Methods*

ASTM E918, *Standard Practice for Determining Limits of Flammability of Chemicals at Elevated Temperature and Pressure*

CSA C22.1, *Canadian Electrical Code, Part I Safety Standard for Electrical Installations*

CAN/CSA C22.2 No. 0, *General Requirements – Canadian Electrical Code, Part II*

EN 15967, *Determination of Maximum Explosion Pressure and the Maximum Rate of Pressure Rise of Gases and Vapours*

ICC IFC, *International Fire Code (IFC)*

IEEE C2, *National Electrical Safety Code (NESC)*

ISO 817, *Refrigerants – Designation and Safety Classification*

NFPA 1, *Fire Code*

NFPA 68, *Standard on Explosion Protection by Deflagration Venting*

NFPA 69, *Standard on Explosion Prevention Systems*

NFPA 70, *National Electrical Code*

NFPA 101, *Life Safety Code*

NFPA 220, *Standard on Types of Building Construction*

UL 746A, *Polymeric Materials – Short Term Property Evaluations*

UL 840, *Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment*

UL 1685, *Vertical-Tray Fire-Propagation and Smoke-Release Test for Electrical and Optical-Fiber Cables*

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

UL 9540, *Energy Storage Systems and Equipment*

UL 2591, *Battery Cell Separators*

4 Glossary

4.1 For the purpose of these requirements, the following definitions apply.

4.2 BATTERY ENERGY STORAGE SYSTEM (BESS) – Stationary equipment that receives electrical energy and then utilizes batteries to store that energy to supply electrical energy at some future time. The BESS, at a minimum consists of one or more modules, a power conditioning system (PCS), battery management system (BMS) and balance of plant components.

NOTE: For flow battery systems the energy is stored within one or more electrolyte storage tanks.

a) INITIATING BATTERY ENERGY STORAGE SYSTEM UNIT (INITIATING BESS) – A BESS unit which has been equipped with resistance heaters in order to create the internal fire condition necessary for the installation level test (Section 9).

b) TARGET BATTERY ENERGY STORAGE SYSTEM UNIT (TARGET BESS) – The enclosure and/or rack hardware that physically supports and/or contains the components that comprise a BESS. The target BESS unit does not contain energy storage components, but serves to enable instrumentation to measure the thermal exposure from the initiating BESS.

4.3 BATTERY SYSTEM – Is a component of a BESS and consists of one or more modules typically in a rack configuration, controls such as the BMS and components that make up the system such as cooling systems, disconnects and protection devices.

4.4 CELL – The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

4.5 DUT – Device under test.

4.6 ELECTRICAL RESISTANCE HEATERS – Devices that convert electrical energy supplied from a laboratory source into thermal energy.

4.7 END OF DISCHARGE VOLTAGE (EODV) – The manufacturer's specified minimum voltage level during discharge.

4.8 ENERGY RESERVOIR – The solution which stores the active energy in the flow battery energy storage system. This can be in the form of one electrolyte, two electrolytes, or one electrolyte with solid metal particles.

4.9 FLEXIBLE FILM HEATERS – Electrical resistance heaters of a film, tape or otherwise thin sheet like construction that easily conform to the surface of cells.

4.10 FLOW BATTERY – A battery technology that stores its active materials in the form of one or more electrolytes (with or without solid metal particles) within one or more storage tanks, and when operating, the electrolytes are transferred between the reactor (battery stacks) and the storage tanks.

NOTE 1: Three commercially available flow battery technologies are zinc air, zinc bromine and vanadium redox.

NOTE 2: Unlike a fuel cell system, a flow battery is a closed system and has no net consumption of fuel.

4.11 MAXIMUM SURFACE TEMPERATURE END POINT – The final hold temperature measured on the cell case after conducting the thermal ramp when using the external heater method to achieve thermal runaway of the cell.

4.12 MODULE – A subassembly that is a component of a BESS that consists of a group of cells or electrochemical capacitors connected together either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry.

4.13 MONOBLOC – A battery design with a common case containing one or more internal cells, electrolyte, a vent or pressure relief valve assembly, intercell connections and hardware. A typical example of a common monobloc battery is an SLI lead acid battery.

4.14 NON-RESIDENTIAL USE – Intended for use in commercial, industrial or utility owned locations.

4.15 RESIDENTIAL USE – In accordance with this standard, intended for use in one or two family homes and townhomes and individual dwelling units of multi-family dwellings.

4.16 STATE OF CHARGE (SOC) – The available capacity in a BESS, pack, module or cell expressed as a percentage of rated capacity.

4.17 THERMAL RUNAWAY – The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gas evolution.

4.18 UNIT – A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such a cells, modules, battery management systems, ventilation devices and other ancillary equipment.

CONSTRUCTION

5 General

5.1 Cell

5.1.1 The cells associated with the BESS that were tested shall be documented in the test report, including cell chemistry (e.g. NMC, LFP), the physical format of the cell (i.e. prismatic, cylindrical, pouch), cell electrical rating in capacity and nominal voltage, the overall dimensions of the cell, and weight.

5.1.2 The cell documentation included in the test report shall indicate if the cells associated with the BESS comply with UL 1973.

5.1.3 Refer to 7.6.1 for further details to be included in the cell level test report.

5.2 Module

5.2.1 The modules associated with the BESS that were tested shall be documented in the test report, including the generic (e.g., metallic or nonmetallic) enclosure material, the general layout of the module contents and the electrical configuration of the cells in the modules and the modules in the BESS.

5.2.2 The module documentation included in the test report shall indicate if the modules associated with the BESS comply with UL 1973.

5.2.3 Refer to 8.3 for further details to be included in the module level test report.

5.3 Battery energy storage system unit

5.3.1 The BESS unit documentation included in the test report shall indicate the units that comply with UL 9540 and include the manufacturer, model, electrical ratings, and energy capacity of all BESS.

5.3.2 For BESS units for which UL 9540 compliance cannot be determined, the documentation included in the test report shall include the number of modules in the BESS, electrical configuration of the module, and physical layout of the modules in the BESS, battery management system (BMS) and other major components of the BESS. The BESS enclosure overall dimensions and generic (e. g., metallic or nonmetallic) material used for the enclosure shall be documented. Depending upon the configuration of the BESS (e.g. the power conditioning system is external to the BESS enclosure), a battery system(s) can be tested as representative of the BESS. It shall be documented as to whether the battery system complies with UL 1973 in addition to the overall BESS compliance to UL 9540.

5.3.3 If applicable, the details of any fire detection and suppression systems that are an integral part of the BESS shall be noted in the test report.

5.3.4 Refer to 9.7, 10.4 and 10.7 for further details to be included in the unit level and if applicable, installation level test reports.

5.4 Flow Batteries

5.4.1 For flow batteries, the report will cover the chemistry (e.g. vanadium redox, zinc bromine, etc.), a generic description of the electrolyte (s), the overall dimensions of the individual stack as well as the electrical rating in capacity and nominal voltage of the cell stack. The report will also include information on the complete flow battery system including the manufacturer's name and model number of the system, the electrical rating in volts and rated storage capacity in Ah or Wh, the number of cells and stacks in the system, and the maximum volume of electrolyte(s) for the system.

5.4.2 The flow battery documentation included in the test report shall indicate if the flow battery system complies with UL 1973.

5.4.3 See 7.6.2 for further details to be included in the flow battery thermal runaway determination level test report.

PERFORMANCE

6 General

6.1 The tests in this standard are extreme abuse conditions conducted on electrochemical energy storage devices that can result in fires, explosions, smoke, off gassing of flammable and toxic materials, exposure to toxic and corrosive liquids, and potential exposure to hazardous voltages and electrical energy. See Annex B for recommended testing practices.

6.2 At the conclusion of testing, samples shall be discharged in accordance with the manufacturer's specifications. All samples shall be disposed of in accordance with local regulations.

7 Cell Level

7.1 General

7.1.1 This portion of the test establishes effective methods for forcing a cell into thermal runaway in a repeatable manner. These methods shall be used at the module, unit and installation level of testing. During this portion of the testing, the vent gas composition shall be gathered and analyzed and cell temperatures shall be monitored to determine the temperature when the cell vents and to verify that thermal runaway as defined in this standard, has occurred.

7.2 Sample

7.2.1 Cell samples shall be conditioned, prior to testing, through charge and discharge cycles for a minimum of 2 cycles using a manufacturer specified methodology to verify that the cells are functional. Each cycle shall be defined as a charge to 100% SOC and then to an end of discharge voltage (EODV) specified by the cell manufacturer. During conditioning a relationship between open circuit voltage and SOC shall be determined through measurement of voltage and SOC. During conditioning the ambient temperature shall be maintained in accordance with the higher of the temperatures derived from 7.3.1.1 or the operating temperature in the cell manufacturer's specifications.

7.2.2 The cells to be tested shall be charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

7.2.3 Cells with flexible laminate casings shall be constrained during the test in the manner that simulates the constraint in the BESS module to prevent excessive swelling during the test.

7.3 Determination of thermal runaway methodology

7.3.1 General

7.3.1.1 Ambient indoor laboratory conditions shall be 25 ±5°C (77 ±9°F) and 50 ±25% RH at the initiation of the test.

7.3.1.2 The propensity of the cell to exhibit thermal runaway shall be demonstrated by heating the cell with externally applied flexible film heaters that cover as much of the cell case as possible without covering safety features or terminals, for consistent heating of the internal cell electrode assembly. A surface heating rate of 4°C (7.2°F) to 7°C (12.6°F) per minute shall be applied to the cell. Determination of a maximum surface temperature end point criteria shall be developed based upon a review of cell design and chemistry. If external heating with a flexible film heater does not cause the cell to exhibit thermal runaway, one of the following methods shall be employed to cause thermal runaway:

a) Mechanical (e.g. nail penetration);

b) Electrical stresses in the form of overcharging, over discharging or external short-circuiting; or

c) Use of alternate heating sources (e.g. oven).

7.3.1.3 With reference to 7.3.1.2, when using another cell abuse method to initiate thermal runaway, the details of that method shall be documented. See the Cell Failure Methods Appendix in UL 1973 for various cell abuse test methods that can be utilized.

7.3.1.4 With reference to 7.3.1.2, in the case of monobloc batteries such as lead acid or nickel cadmium, the monobloc battery can be treated as an individual cell for this testing.

7.3.1.5 Before beginning the test, a surface temperature shall be determined to approximate the temperature at which internal short circuiting within the cell will occur that could lead to a thermal runaway condition. For Li-ion cells, the surface temperature hold point shall be between 5°C (9°F) and 15°C (27°F) greater than the melting temperature of the cell separator material as determined from differential scanning calorimetry (DSC) data of the separator in accordance with UL 2591 (UL 746A). Thermal runaway may occur before this hold point temperature range is reached. However, if thermal runaway is not achieved at this hold point temperature after a period of 4 h, the cell heating rate according to 7.3.1.2 shall be reestablished until thermal runaway occurs or it is demonstrated that thermal runaway is not achievable by heating.

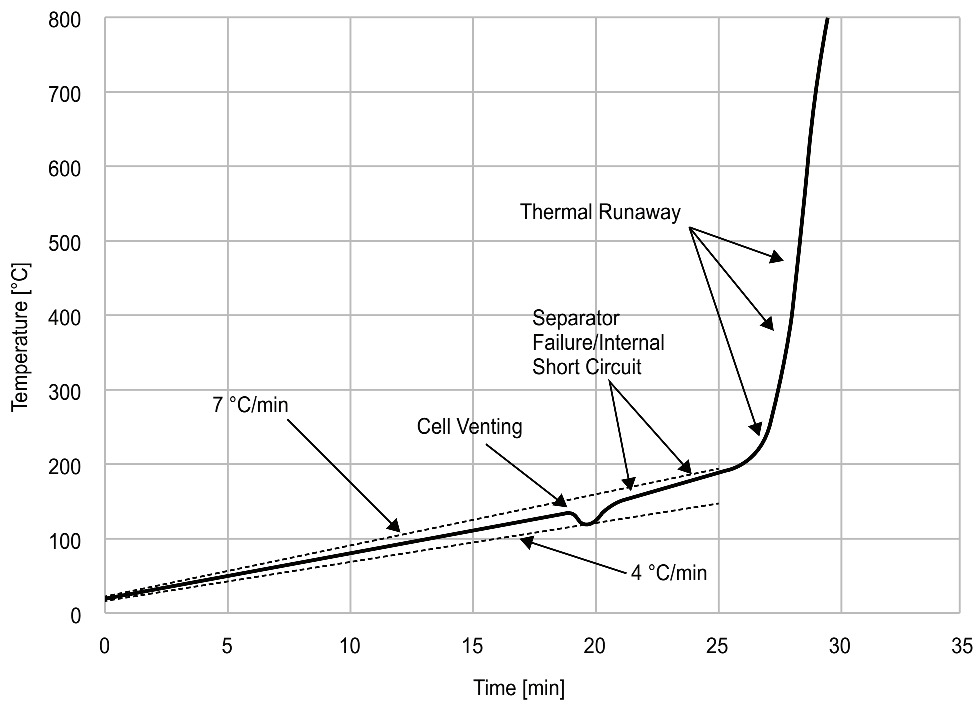
7.3.1.6 If the cell is susceptible to thermal runaway by external heating, the cell shall be heated until thermal runaway has occurred. If the cell is not susceptible to thermal runaway by heating with a film heater, another method included in 7.3.1.2 shall be employed. See 7.3.1.7 – 7.3.1.9. If using another external heating method, the temperature ramp and maximum surface temperature outlined in 7.3.1.2 and 7.3.1.5 shall be used.

7.3.1.7 The cell's exterior surface temperature shall be measured continuously through the cell test with a thermocouple junction formed from 24-gauge or smaller, Type-K thermocouple wire. The location(s) of thermocouple(s) shall be determined during a construction review. At least one thermocouple shall be located below the heater film at the center of the cell surface (if the cell is prismatic this would be the center of the wider side of the cell) and one near the positive cell terminals.

7.3.1.8 The temperature at which the cell case vents due to internal pressure rise shall be documented. The thermocouple located below the heater film at the center of the cell surface is used for this measurement. If using the other cell abuse methods, the thermocouples would be located at the same locations on the cells as noted in 7.3.1.7.

7.3.1.9 The temperature at the onset of thermal runaway shall be documented. Onset of thermal runaway shall be determined by the point at which the rate of change of the surface temperature of the cell exceeds that of the externally applied heat input if utilizing the external heater method. As defined in 4.17, thermal runaway is a condition where there is heating of the cell in an uncontrolled manner and should not be confused with overheating leading to venting only. Cell venting may occur first, but it is necessary to continue heating when using the heater method until thermal runaway occurs. With other stress methods, it will be necessary to continue applying the stress such as mechanical or electrical stress until onset of thermal runaway occurs. See Figure 7.1 for an illustrative example of a temperature curve of a cell that has undergone thermal runaway. If there is a transitory temperature dip during the cell venting, the heat input may need to be increased to bring it back to the heating rate range.

Figure 7.1
Illustrative Example of a Thermal Runaway Temperature Curve



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7.3.1.10 When using methods other than the heater method, the stresses (i.e. electrical or mechanical) shall be applied to the cell until thermal runaway occurs. Thermal runaway as defined in 4.17, is considered to have occurred, regardless of the method of stress chosen, when there is a rapid increase in temperature as shown in Figure 7.1 and should not be confused with simple overheating leading to venting.

7.3.1.11 If the cell exhibits thermal runaway behavior (using any method), 3 additional samples shall be tested using the same method and exhibit thermal runaway to demonstrate repeatability. The vent temperature and thermal runaway onset temperatures shall be averaged over the tested samples (excluding the gas vent capture sample). This average temperature shall be used to establish the temperature limits for the other test levels of this standard.

7.3.2 Flow battery thermal runaway determination tests

7.3.2.1 For flow battery technology, the propensity for thermal runaway shall be demonstrated by testing the energy reservoir according to the test methods of 7.3.2.2 through 7.3.2.6 as applicable to the flow battery technology.

7.3.2.2 The flammability of the electrolytes shall be determined based upon a suitable test method to determine flammability. There are several methods that can be used and the method of choice is based upon the viscosity of the liquid and its anticipated flash point temperature range. ASTM E502 provides guidance on choosing the appropriate test method. For liquids with anticipated higher flashpoints and viscosities at or below 9.5×10^{-6} m^2/s (9.5 cSt) at 25°C (77°F), ASTM D3828 or ASTM D93 shall be used. All components used in the test apparatus shall be of suitable materials to prevent their chemical reaction with the test solution. The volumes of solution tested shall be selected based upon what is practical for the solution and required for the test to determine results. The test shall be continued to a maximum solution temperature of 200°C (392°F) or sufficient to determine flammability of the liquid within the boundaries of the test method. The flash point temperature shall be recorded for each electrolyte tested. If no flashpoint is observed (i.e. no ignition occurs), this shall be recorded.

7.3.2.3 For flow battery systems with two electrolytes, the flammability of the liquid electrolytes shall be demonstrated by subjecting each electrolyte to the appropriate test method outlined in 7.3.2.2. If a flash point has been observed in 7.3.2.2, the propensity for thermal runaway shall be demonstrated by the test methods of 7.3.2.4 and comparing the temperatures recorded with the flash point temperature determined from 7.3.2.2.

7.3.2.4 The temperature increase possible due to a flow battery failure where there are two electrolytes shall be demonstrated by charging the energy reservoir in a test flow battery assembly to 100% SOC, and then directly mixing the two electrolyte materials in a closed container within approximately 1 min. The mixed solution temperature shall be measured during the test. The test shall conclude when the temperature of the solution stabilizes for a minimum of 1 h. The maximum mixing temperature of the sample shall be recorded and compared with the flash point temperature results from 7.3.2.2. In addition, a test battery representative of the flow battery system shall be subjected to an overcharge test and short circuit test in accordance with UL 1973 while monitoring the temperature of the energy reservoirs. The maximum temperature of the energy reservoirs during the testing shall be recorded and compared with the flash point temperature results from 7.3.2.2.

7.3.2.5 For flow battery technologies with one active electrolyte containing solid metal particles the appropriate test method of 7.3.2.2 is conducted to determine the flash point temperature. The electrolyte tested shall contain the rated concentration of metal particles present in the electrolyte of a fully charged system. If a flash point has been observed in 7.3.2.2, the propensity for thermal runaway shall be demonstrated by the test methods of 7.3.2.6 and comparing the temperatures of the energy reservoir recorded during those tests with the flash point temperature determined from 7.3.2.2.

7.3.2.6 If a flash point has been observed for a flow battery technology with one active electrolyte containing solid metal particles, a test battery representative of the flow battery system shall be subjected to an overcharge test and short circuit test in accordance with UL 1973 while monitoring the temperature of the energy reservoir. The maximum temperature of the energy reservoir during testing shall be recorded and compared with the flash point temperature results from 7.3.2.2.

7.4 Cell vent gas composition test

7.4.1 Cell vent gas shall be generated and captured by forcing a cell into thermal runaway with the methodology developed in 7.3, inside a pressure vessel, which is large enough to accommodate cells, but not so large as to influence measurement of the gas composition. An 82-L (21.7-gal) pressure vessel is recommended for this purpose for most sizes of commercially available cells. The test shall be initiated with an initial condition of atmospheric pressure and less than 1% oxygen by volume. The initial atmospheric conditions prior to testing shall be noted.

7.4.2 Cell vent gas composition shall be determined using Gas Chromatography (GC) with detection techniques for quantifying component gases or equivalent gas analysis techniques, to identify hydrocarbon gases that represent an ignition or explosion hazard as well as other additional gases requested to be measured. Hydrogen gas shall be measured with a sensor capable of measuring in excess of 30% by volume. The initial atmospheric conditions prior to testing shall be noted.

7.4.3 Upon determination of the cell vent gas composition per 7.4.2, the lower flammability limit of the cell vent gas shall be determined on samples of the synthetically replicated gas mixture in accordance with ASTM E918, testing at both ambient and cell vent temperatures.

7.4.4 The synthetically replicated gas mixture shall be used to determine gas burning velocity in accordance with the Method of Test for Burning Velocity Measurement of Flammable Gases Annex in ISO 817.

7.4.5 The synthetically replicated gas mixture shall be used to determine P_{max} in accordance with EN 15967.

7.5 Off gas composition for flow battery systems

7.5.1 The off gas composition from the flow battery testing of 7.3.2 shall be determined by conducting the test method of 7.3.2.2 in a closed container and capturing the off gasses generated, and by collecting the off gasses generated at vent openings and vent ducts during the overcharge and short circuit testing of 7.3.2.4 and 7.3.2.6 as applicable to the flow battery technology. Composition of these captured gases and their flammability limit shall be determined through the methods outlined in 7.4.2 and 7.4.3 at both ambient temperature and the maximum temperature measured.

7.5.2 The volume of flammable gases measured during the testing shall be scaled to the maximum energy reservoir for the intended flow battery system in order to determine the potential total flammable gas that can be produced by the system under a fault condition that leads to off gassing. This information shall be provided in the report.

7.6 Cell level test report

7.6.1 The report on cell level testing shall include the following:

a) Cell manufacturer name and cell model number;

b) Cell details per 5.1 (and whether UL 1973 compliant);

c) Energy storage technology (and whether UL 9540 compliant);

d) The rated energy storage capacity of the cell (e.g. Ampere-hours);

e) Voltage and current obtained during conditioning of the cell;

f) Open-circuit voltage of the cell at initiation of test;

g) Methods attempted and used to initiate thermal runaway;

h) Surface temperature at which gases are first vented and the average temperature of the samples tested excluding the gas collection sample;

i) Surface temperature (and location of maximum temperature) prior to thermal runaway and average temperature of the samples tested excluding the gas collection sample;

j) Flammable gas generation and composition measurements;

k) The lower flammability limit of the cell vent gas;

l) Burning velocity of the cell vent gas; and

m) P_{max} of the cell vent gas.

7.6.2 The report on flow battery thermal runaway determination testing shall include the following:

a) Flow battery system manufacturer name and model number (and whether UL 1973 compliant);

b) Cell stack details per 5.4;

c) Energy storage technology (and whether UL 9540 compliant);

d) The rated energy storage capacity of the flow battery (e.g. Ampere-hours or Watt-hours);

e) Electrolyte(s) composition and quantity in the system

f) Flash point temperatures of each electrolyte

g) Highest temperatures measured during abnormal conditions of:

1) Mixed electrolytes for two electrolyte systems; and

2) Electrolyte during the battery system overcharge and short circuit test;

h) Flammable off gas generation and composition measurements;

i) The lower flammability limit of the flammable off gas at both ambient and abnormal test temperatures;

j) Burning velocity of the flammable off gas; and

k) P_{max} of the flammable off gas.

7.7 Performance – cell level test

7.7.1 Module level testing in Section 8 is not required if the following performance conditions are met:

a) Thermal runaway cannot be induced in the cell; and

b) The cell vent gas does not present a flammability hazard when mixed with any volume of air, as determined in accordance with ASTM E918 at both ambient and vent temperatures.

7.7.2 BESS that contain cells that all comply with the criteria in 7.7.1 shall be suitable for installation in residential dwelling units.

7.8 Performance – flow battery thermal runaway determination tests

7.8.1 For flow batteries, no further testing is required if the following performance conditions are met during the flow battery thermal runaway determination test:

a) The electrolyte(s) subjected to the test method in accordance with 7.3.2.2 does not ignite; or

b) The flash point temperature(s) measured in the test of 7.3.2.2 exceed the maximum temperature measured on the energy reservoir during the overcharge and short circuit tests of 7.3.2.4 or 7.3.2.6 by at least 5°C (9°F); and

c) The flash point temperature(s) measured in the test of 7.3.2.2 exceed the maximum temperature of the mixed solution measured in accordance with 7.3.2.4 by at least 5°C (9°F) for systems with two active electrolytes.

7.8.2 Flammable off gassing during the abnormal tests are addressed as outlined in 7.5.2 by scaling the results in accordance with the largest anticipated flow battery energy reservoir.

8 Module Level

8.1 Sample

8.1.1 Module samples shall be conditioned, prior to testing, through charge and discharge cycles for a minimum of 2 cycles, using a manufacturer specified methodology to verify that the module is functional. Each cycle shall be defined as a charge to 100% SOC and allowed to rest a maximum of 8 h and then discharged to an end of discharge voltage (EODV) specified by the module manufacturer. During conditioning the ambient temperature and conditions shall be maintained in accordance with 8.2.1.

8.1.2 The module to be tested shall be charged to 100% SOC and allowed to rest a maximum of 8 h before the start of the test. The module voltage shall be determined by measuring at the module terminals after charging up to the fully charged condition and before beginning testing. The sample module shall stabilize for a minimum of one hour prior to testing.

8.1.3 Electronics and software controls such as the battery management system (BMS) are not relied upon for this testing.

8.2 Test method

8.2.1 Ambient indoor laboratory conditions shall be 25 ±5°C (77 ±9°F) and 50 ±25% RH at the initiation of the test.

8.2.2 The test shall be conducted under a smoke collection hood that is sized appropriately to collect the gasses generated from the module.

8.2.3 The weight of the module shall be recorded before and after testing is completed to determine weight loss.

8.2.4 The number of cells within the module that are forced into thermal runaway can be one or multiple cells, and is dependent upon the energy contained within the individual cells. A sufficient number of cells shall be forced into thermal runaway to create a condition of cell to cell propagation within the module. For example, it may be necessary to force nine, 3-Ah cells into thermal runaway as opposed to one, 30-Ah cell in order to get cell to cell propagation. The location of the cell (s) forced into thermal runaway shall be selected to present the greatest thermal exposure to adjacent cells that are not forced into thermal runaway. Factors to be taken into consideration shall include selecting locations within the module where heat transfer is maximized to other cells, cooling by ventilation is restricted or limited, and thermal sensors, detection and suppression discharge points are remote.

8.2.5 The methodology used for initiating thermal runaway pursuant to 7.2 shall be used to initiate thermal runaway within the module.

8.2.6 With reference to 8.2.5, occurrence of thermal runaway shall be verified by sustained temperature above the cell surface temperature at the onset of thermal runaway, as determined in Section 7.

8.2.7 The module shall be placed on top of a noncombustible horizontal surface with the module orientation representative of its intended final installation.

8.2.8 The chemical heat release rate of the module in thermal runaway shall be measured with oxygen consumption calorimetry.

8.2.9 The chemical heat release rate shall be measured for the duration of the test. See 8.2.10.

8.2.10 The chemical heat release rate shall be measured by a measurement system consisting of a paramagnetic oxygen analyzer, non-dispersive infrared carbon dioxide and carbon monoxide analyzer, velocity probe, and a Type K thermocouple. The instrumentation shall be located in the exhaust duct of the heat release rate calorimeter at a location that minimizes the influence of bends or exhaust devices. See 8.2.11.

8.2.11 With reference to 8.2.10, calculate the chemical heat release rate at each of the flows as follows:

$$HRR_1 = \left[E \times \varphi - (E_{co} - E) \times \frac{1-\varphi}{2} \times \frac{X_{co}}{X_{O_2}}\right] \times \frac{\dot{m}_e}{1+\varphi \times (\alpha - 1)} \times \frac{M_{O_2}}{M_a} \times (1 - X^o_{H_2O}) \times X^o_{O_2}$$

In which:

HRR_t = total heat release rate, as a function of time (kW)

E = Net heat released for complete combustion per unit of oxygen consumed (adjusted for oxygen contained within cell chemistry, 13,100 kJ/kg)

E_{CO} = Net heat released for complete combustion per unit of oxygen consumed, for CO (adjusted for oxygen contained within cell chemistry, 17,600 kJ/kg)

φ = Oxygen depletion factor (non-dimensional), where:

$$\varphi = \frac{X^o_{O_2} \times [1 - X_{CO_2} - X_{CO}] - X_{O_2} \times [1 - X^o_{CO_2}]}{X^o_{O_2} \times [1 - X_{O_2} - X_{CO_2} - X_{CO}]}$$

X_{CO} = Measured mole fraction of CO in exhaust flow (non-dimensional)

X_{CO_2} Measured mole fraction of CO_2 in exhaust flow (non-dimensional)

$X°_{CO_2}$ = Measured mole fraction of CO_2 in incoming air (non-dimensional)

$X°_{H_2O}$ = Measured mole fraction of H_2O in incoming air (non-dimensional)

X_{O_2} = Measured mole fraction of O_2 in exhaust flow (non-dimensional)

$X°_{O_2}$ = Measured mole fraction of O_2 in incoming air (non-dimensional)

α = Combustion expansion factor (non-dimensional; normally a value of 1.105)

M_a = Molecular weight of incoming and exhaust air (29 kg/kmol)

M_{O_2} = Molecular weight of oxygen (32 kg/kmol)

$\dot{m}_e$ = Mass flow rate in exhaust duct (kg/s), in which:

$$\dot{m}_e = C \times \sqrt{\frac{\Delta p}{T_e}}$$

or

$$\dot{m}_e = 26.54 \times \frac{A \times k_c}{f(\mathrm{Re})} \times \sqrt{\frac{\Delta p}{T_e}}$$

C = Orifice plate coefficient (in $kg^{1/2}m^{1/2}K^{1/2}$)

Δp = Pressure drop across orifice plate or bidirectional probe (Pa)

T_e = Combustion gas temperature at orifice plate or bidirectional probe (K)

A = Cross sectional area of the duct (m^2)

k_c = Velocity profile shape factor (non-dimensional)

$f(Re)$ = Reynolds number correction (non-dimensional)

8.2.12 Vent gas composition shall be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm^{-1} and a path length of at least 2 m (6.6 ft), or equivalent gas analyzer, and velocity and temperature measurements respectively shall be obtained in the exhaust duct of the heat release rate calorimeter using equipment specified in 8.2.10.

8.2.13 The hydrocarbon content of the vent gas shall be measure using flame ionization detection. Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor.

8.2.14 The light transmission in the exhaust duct of the heat release rate calorimeter shall be measured using a white light source and photo detector for the duration of the test, and the smoke release rate shall be calculated. See 8.2.15.

8.2.15 Smoke release rate shall be calculated as follows:

$$SRR = 2.303\left(\frac{V}{D}\right)Log_{10}\left(\frac{I_o}{I}\right)$$

Where:

SRR = Smoke release rate (m^2/s)

V = Volumetric exhaust duct flow rate (m^3/s)

D = duct diameter (m)

I_o = Light transmission signal of clear (pre-test) beam (V)

I = Light transmission signal during test (V)

8.3 Module level test report

8.3.1 The report on module level testing shall include the following:

a) Module manufacturer name and model number (and whether UL 1973 compliant);

b) Number of cells in module;

c) Module configuration with cells in series and parallel;

d) Module construction features per 5.2;

e) Module voltage corresponding to the tested SOC;

f) Thermal runaway initiation method used including number and locations of cells for initiating thermal runaway;

g) Heat release rate versus time data;

h) Flammable gas generation and composition data;

i) Peak smoke release rate and total smoke release data.

j) Observation(s) of flying debris or explosive discharge of gases;

k) Observation(s) of sparks, electrical arcs, or other electrical events;

l) Identification/location of cells(s) that exhibited thermal runaway within the module;

m) Locations and visual estimations of flame extension and duration from the module shall be documented;

n) Module weight loss based on measurements per 8.2.3; and

o) Video of the test.

8.4 Performance at module level testing

8.4.1 Unit level testing in Section 9 is not required if the following performance conditions are met during the module level test:

a) Thermal runaway is contained by module design; and

b) Cell vent gas is nonflammable as determined by the cell level test.

9 Unit Level

9.1 Sample and test configuration

9.1.1 The unit level test shall be conducted with BESS units installed as described in the manufacturer's instructions and this section. Test configurations include the following:

a) Indoor floor mounted non-residential use BESS;

b) Indoor floor mounted residential use BESS;

c) Outdoor ground mounted non-residential use BESS;

d) Outdoor ground mounted residential use BESS;

e) Indoor wall mounted non-residential use BESS;

f) Indoor wall mounted residential use BESS;

g) Outdoor wall mounted non-residential use BESS;

h) Outdoor wall mounted residential use BESS; and

i) Rooftop and open garage non-residential use BESS installations.

9.1.2 The unit level test requires one initiating BESS unit in which an internal fire condition in accordance with the module level test is initiated and target adjacent BESS units representative of an installation. Tests conducted for indoor floor mounted installations shall be considered representative of both indoor floor mounted and outdoor ground mounted installations with fire propagation hazards and separation distances between initiating and target units representative of the installation. Tests shall be conducted indoors with fire propagation hazards and separation distances between initiating and target units representative of the installation. The results of such tests shall be considered to also represent an outdoor installation. Examples of potential test configurations are shown in Figure 9.1, Figure 9.2, Figure 9.3, and Figure 9.4.

Exception: Testing can be conducted outdoors for outdoor only installations if there are the following controls and environmental conditions in place:

a) Wind screens are utilized with a maximum wind speed maintained at ≤ 12 mph;

b) The temperature range is within 10°C to 40°C (50°F to 104°F);

c) The humidity is < 90% RH;

d) There is sufficient light to observe the testing;

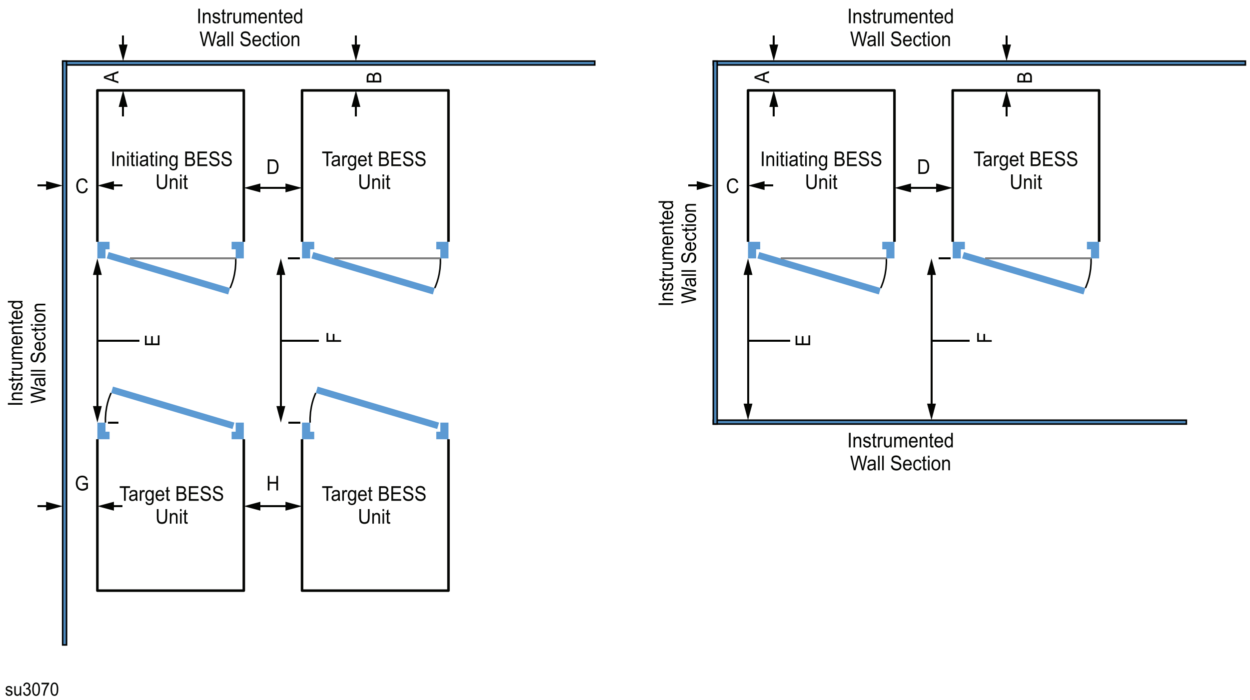
e) There is no precipitation during the testing;

f) There is control of vegetation and combustibles in the test area to prevent any impact on the testing and to prevent inadvertent fire spread from the test area; and

g) There are protection mechanisms in place to prevent inadvertent access by unauthorized persons in the test area and to prevent exposure of persons to any hazards as a result of testing.

9.1.3 Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), this testing to determine fire characterization can be done at the battery system level. The suitability of this approach shall be determined based upon the overall design of the BESS and an analysis of the battery system as representative of the overall BESS for fire characterization concerns.

Figure 9.1
Examples of Indoor Floor Mounted BESS Test Arrangements



Left: Layout of BESS units of two or more rows.

Right: Layout of BESS units of a single row.

A = Separation distance between the initiating BESS unit and instrumented wall section behind the initiating BESS unit.

B = Separation distance between the target BESS unit and instrumented wall section behind the target BESS unit.

C = Separation distance between the initiating BESS unit and instrumented wall section to the side of the initiating BESS unit.

D = Separation distance between initiating BESS unit and target BESS unit.

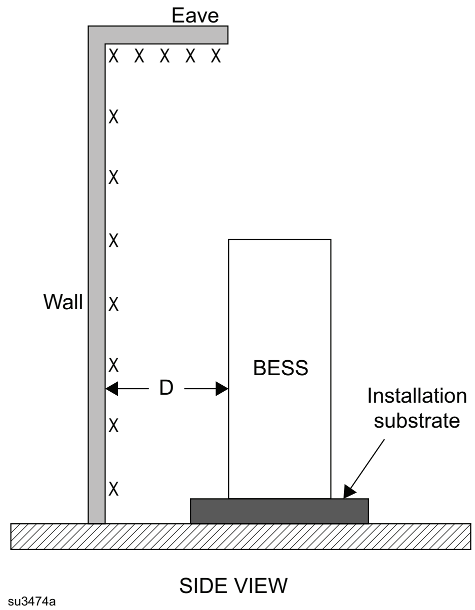
E = Separation distance between initiating BESS unit and target BESS unit or instrumented wall section.

F = Separation distance between target BESS unit and target BESS unit or instrumented wall section.

G = Separation distance between target BESS unit and instrumented wall section.

H = Separation distance between target BESS units.

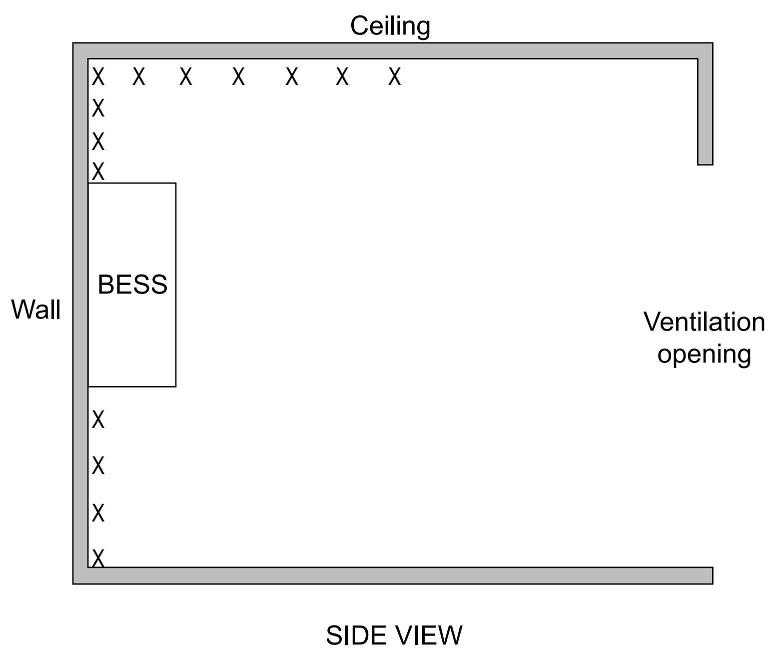
Figure 9.2
Example of Outdoor Ground Mounted Residential Use BESS Test Arrangement



X – Denotes typical thermocouple locations, specific positions dependent on installation details.

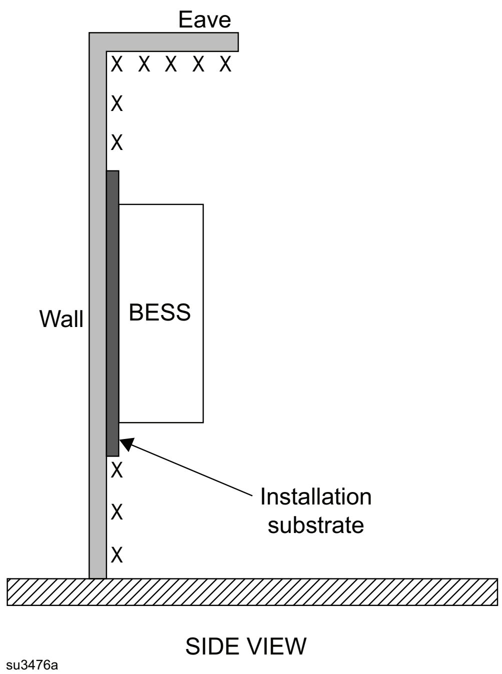
D – Distance of ESS from external wall.

Figure 9.3
Example of Indoor Wall Mounted BESS Test Arrangement



X – Denotes typical thermocouple locations, specific positions dependent on installation details.

Figure 9.4
Example of Outdoor Wall Mounted BESS Test Arrangement



X – Denotes typical thermocouple locations, specific positions dependent on installation details.

9.1.4 The initiating BESS unit shall contain components representative of a BESS unit in a complete installation. Combustible components that interconnect the initiating and target BESS units shall be included.

9.1.5 Target BESS units shall include the outer cabinet (if part of the design), racking, module enclosures, and components that retain cells components. The target BESS unit module enclosures do not need to contain cells.

9.1.6 The initiating BESS unit shall be at the maximum operating state of charge (MOSOC), in accordance with the manufacturer's specifications, for conducting the tests in this standard. After charging and prior to testing, the initiating BESS shall rest for a maximum period of 8 h at room ambient.

9.1.7 If a BESS unit includes an integral fire suppression system, there is an option of providing this with the DUT. If the BESS unit is provided with an optional integral fire suppression system, the system shall not be provided on the DUT.

9.1.8 Electronics and software controls such as the battery management system (BMS) in the BESS are not relied upon for this testing. This does not include a fire suppression control in accordance with UL 840 that is external to the BESS, but provided as part of an integral fire suppression system per 9.1.7.

9.2 Test method – Indoor floor mounted BESS units

9.2.1 Samples and test configurations are in accordance with 9.1. During the test, the test room environment shall be controlled to prevent drafts that may affect test results. At the start of the test, the room ambient temperature shall not be less than 10°C (50°F) nor more than 32°C (90°F).

9.2.2 Any access door(s) or panels on the initiating BESS unit and adjacent target BESS units shall be closed, latched and locked at the beginning and duration of the test.

9.2.3 The initiating BESS unit shall be positioned adjacent to two instrumented wall sections.

9.2.4 Instrumented wall sections shall extend not less than 0.49 m (1.6 ft) horizontally beyond the exterior of the target BESS units.

9.2.5 Instrumented wall sections shall be at least 0.61-m (2-ft) taller than the BESS unit height, but not less than 3.66 m (12 ft) in height above the bottom surface of the unit.

9.2.6 The surface of the instrumented wall sections shall be covered with 16-mm (5/8-in) gypsum wall board and painted flat black.

9.2.7 The initiating BESS unit shall be centered underneath an appropriately sized smoke collection hood of an oxygen consumption calorimeter.

9.2.8 The light transmission in the calorimeter's exhaust duct shall be measured using a white light source and photo detector for the duration of the test, and the smoke release rate shall be calculated as described in 8.2.15.

9.2.9 The chemical and convective heat release rates shall be measured for the duration of the test, using the methodologies specified in 8.2.11 and 9.2.12, respectively.

9.2.10 With reference to 9.2.9, the heat release rate measurement system shall be calibrated using an atomized heptane diffusion burner. The calibration shall be performed using flows of 3.8, 7.6, 11.4 and 15.2 L/min (1, 2, 3 and 4 gpm) of heptane.

9.2.11 With reference to 9.2.9, the convective heat release rate shall be measured using thermopile, a velocity probe, and a Type K thermocouple, located in the exhaust system of the exhaust duct. See 9.2.12.

9.2.12 With reference to 9.2.9, the convective heat release rate shall be calculated using the following equation:

$$HRR_c = V_e A \frac{353.22}{T_e} \int_{T_o}^{T} C_p dT$$

Where:

HRR_c = The convective heat release rate (kW)

V_e = The exhaust velocity (m/s)

A = The exhaust duct cross sectional area (m^2)

T_e = The temperature at the location where exhaust velocity is measured (K)

$353.22/T_e$ = The density of air at the velocity measurement location (kg/m^3)

T_o = The ambient temperature (K) in the test room

T = The thermopile temperature (K)

$$\int_{T_o}^{T} C_p dT = A_0(T - T_o) + A_1 / 2(T^2 - T_o^2) + A_2 / 3(T^3 - T_o^3) + A_3 / 4(T^4 - T_o^4)$$

*C*p = Specific heat of air (kJ/kg-K), given as $\boldsymbol{C_p = A_0 + A_1 T + A_2 T^2 + A_3 T^3}$, where:

A_0 = *0.9950*

A_1 = *-5.29933E-05*

A_2 = *3.21022E-07*

A_3 = *-1.22004E-10*

9.2.13 The physical spacing between BESS units (both initiating and target) and adjacent walls shall be representative of the intended installation as noted in 9.1.

9.2.14 Separation distances shall be specified by the manufacturer for distance between:

a) The BESS units and the instrumented wall sections; and

b) Adjacent BESS units.

9.2.15 Wall surface temperature measurements shall be collected for BESS intended for installation in locations with combustible construction. If the intended installation is composed completely of noncombustible construction in which wall assemblies, cables, wiring and any other combustible materials are not to be present in the BESS installation, then the report should note that the installation shall contain no combustible construction and that surface temperature rises can be deemed not applicable.

9.2.16 Wall surface temperatures shall be measured in vertical array(s) at 152-mm (6-in) intervals for the full height of the instrumented wall sections using No. 24-gauge or smaller, Type-K exposed junction thermocouples. The thermocouples for measuring the temperature on wall surfaces shall be horizontally positioned in the wall locations anticipated to receive the greatest thermal exposure from the initiating BESS unit.

9.2.17 Thermocouples shall be secured to gypsum surfaces by the use of staples placed over the insulated portion of the wires. The thermocouple tip shall be depressed into the gypsum so as to be flush with the gypsum surface at the point of measurement and held in thermal contact with the surface at that point by the use of pressure-sensitive paper tape.

9.2.18 Heat flux shall be measured with the sensing element of at least two water-cooled Schmidt-Boelter gauges at the surface of each instrumented wall:

a) Both are collinear with the vertical thermocouple array;

b) One is positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module; and

c) One is positioned at the elevation estimated to receive the greatest heat flux during potential propagation of thermal runaway within the initiating BESS unit.

9.2.19 Heat flux shall be measured with the sensing element of at least two water-cooled Schmidt-Boelter gauges at the surface of each adjacent target BESS unit that faces the initiating BESS unit:

a) One is positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module within the initiating BESS; and

b) One is positioned at the elevation estimated to receive the greatest surface heat flux due to the thermal runaway of the initiating BESS.

9.2.20 For non-residential use BESS, heat flux shall be measured with the sensing element of at least one water-cooled Schmidt-Boelter gauge positioned at the mid height of the initiating unit in the center of the accessible means of egress.

9.2.21 No. 24-gauge or smaller, Type-K exposed junction thermocouples shall be installed to measure the temperature of the surface proximate to the cells and between the cells and exposed face of the initiating module. Each non-initiating module enclosure within the initiating BESS unit shall be instrumented with at least one No. 24-gauge or smaller Type-K thermocouple(s) to provide data to monitor the thermal conditions within non-initiating modules. Additional thermocouples shall be placed to account for convoluted enclosure interior geometries.

9.2.22 For residential use BESS, the DUT shall be covered with a single layer of cheese cloth ignition indicator. The cheesecloth shall be untreated cotton cloth running 26 – 28 m^2/kg with a count of 28 – 32 threads in either direction within a 6.45 cm^2 (1 in^2) area.

9.2.23 An internal fire condition in accordance with the module level test shall be created within a single module in the initiating BESS unit:

a) The position of the module shall be selected to present the greatest thermal exposure to adjacent modules (e.g. above, below, laterally), based on the results from the module level test; and

b) The setup (i.e. type, quantity and positioning) of equipment for initiating thermal runaway in the module shall be the same as that used to initiate and propagate thermal runaway within the module level test (Section 8).

9.2.24 The composition, velocity and temperature of the initiating BESS unit vent gases shall be measured within the calorimeter's exhaust duct. Gas composition shall be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm^{-1} and a path length of at least 2.0 m (6.6 ft), or equivalent gas analyzer. Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.

9.2.25 The hydrocarbon content of the vent gas shall be measured using flame ionization detection.

9.2.26 The test shall be terminated if:

a) Temperatures measured inside each module within the initiating BESS unit return to ambient temperature;

b) The fire propagates to adjacent units or to adjacent walls; or

c) A condition hazardous to test staff or the test facility requires mitigation.

9.2.27 For residential use systems, the gas collection data gathered in 9.2 shall be compared to the smallest room installation specified by the manufacturer to determine if the flammable gas collected exceeds 25% LFL in air.

9.3 Test method – Outdoor ground mounted units

9.3.1 Outdoor ground mounted non-residential use BESS being evaluated for installation in close proximity to buildings and structures shall use the test method described in Section 9.2. If intended for outdoor use only installations, the smoke release rate, the convective and chemical heat release rate and content, velocity and temperature of the released vent gases need not be measured.

9.3.2 Outdoor ground mounted residential use BESS being evaluated for installation in close proximity to buildings and structures shall use the test method described in Section 9.2 except as noted in 9.3.3 and 9.3.4. Heat flux measurements for the accessible means of egress shall be measured in accordance with 9.2.20. If intended for outdoor use only installations, the smoke release rate, the convective and chemical heat release rate and content, velocity and temperature of the released vent gases need not be measured.

9.3.3 Test samples shall be installed as shown in Figure 9.2 in proximity to an instrumented wall section that is 3.66-m (12-ft) tall with a 0.3-m (1-ft) wide horizontal soffit (undersurface of the eave shown in Figure 9.2). The sample shall be mounted on a support substrate and spaced from the wall in accordance with the minimum separation distances specified by the manufacturer. The wall and soffit shall be constructed with 19.05-mm (3/4-in) plywood installed on wood studs and painted flat black. The instrumented wall shall extend not less than 0.49-m (1.6-ft) horizontally beyond the exterior of the target BESS units. The No. 24-gauge or smaller, Type-K exposed junction thermocouple array on the walls as noted in 9.2.16 shall extend to the surface of the soffit as shown in Figure 9.2.

Exception: If the manufacturer requires installation against non-flammable material, the test setup may include manufacturer recommended backing material between the unit and plywood wall.

9.3.4 Target BESS shall be installed on each side of the initiating BESS in accordance with the manufacturer's installation specifications. The physical spacing between BESS units (both initiating and target) shall be the minimum separation distances specified by the manufacturer.

9.4 Test Method – Indoor wall mounted units

9.4.1 Testing of indoor wall mounted BESS shall be in accordance with Section 9.2, except as modified in this section. See Figure 9.3.

9.4.2 The test shall be conducted in a standard NFPA 286 fire test room, 3.66 × 2.44 × 2.44-m (12 × 8 × 8-ft) high, with a 0.76 × 2.13-m (2-1/2 × 7-ft) high opening. The room shall be constructed with 16-mm (5/8-in) gypsum wall board installed on wood studs and painted flat black.

9.4.3 The initiating BESS unit shall be positioned on the wall opposite of the door opening, with the center located 1.22-m (4-ft) above the floor, and halfway between adjacent walls.

9.4.4 Target BESS shall be installed on the wall on each side of the initiating BESS, at the same height above the floor as the initiating BESS. The physical spacing between BESS units (both initiating and target) shall be the minimum separation distances specified by the manufacturer.

9.4.5 The wall on which the initiating and target BESS units are mounted shall be instrumented in accordance with Section 9.2.

9.4.6 The gas collection methods shall be in accordance with 9.2. For residential use systems, the gas collection data gathered in 9.2 shall be compared to the smallest room installation specified by the manufacturer to determine if the flammable gas collected exceeds 25% LFL in air.

9.4.7 For residential use BESS, the DUT shall be covered with a single layer of cheese cloth ignition indicator. The cheesecloth shall be untreated cotton cloth running 26 – 28 m^2/kg with a count of 28 – 32 threads in either direction within a 6.45 cm^2 (1 in^2) area.

9.5 Test Method – Outdoor wall mounted units

9.5.1 Testing of outdoor wall mounted BESS shall be in accordance with Section 9.2, except as modified in this section. See Figure 9.4. If intended for outdoor use only wall mount installations, the smoke release rate, the convective and chemical heat release rate; and the content, velocity and temperature of the released vent gases need not be measured.

9.5.2 Test samples shall be mounted on an instrumented wall section that is 3.66-m (12-ft) tall with a 0.3-m (1-ft) wide horizontal soffit (undersurface of the eave shown in Figure 9.4). The wall and soffit shall be constructed with 19.05-mm (3/4-in) plywood installed on wood studs and painted flat black. The instrumented wall shall extend not less than 0.49-m (1.6-ft) horizontally beyond the exterior of the target BESS units. The No. 24-gauge or smaller, Type-K exposed junction thermocouple array on the walls as noted in 9.2.16 shall extend to the surface of the soffit as shown in Figure 9.4.

9.5.3 The initiating BESS unit shall be positioned on the instrumented wall, with its center located 1.22-m (4-ft) above the floor, and halfway between wall edges.

9.5.4 Target BESS shall be installed on the wall on each side of the initiating BESS, at the same height above the floor as the initiating BESS. The physical spacing between BESS units (both initiating and target) shall be the minimum separation distances specified by the manufacturer.

9.5.5 The wall on which the initiating and target BESS units are mounted shall be instrumented in accordance with Section 9.2.

9.5.6 For residential use BESS, the DUT shall be covered with a single layer of cheese cloth ignition indicator. The cheesecloth shall be untreated cotton cloth running 26 – 28 m^2/kg with a count of 28 – 32 threads in either direction within a 6.45 cm^2 (1 in^2) area .

9.6 Rooftop and open garage installations

9.6.1 Testing of BESS intended for non-residential use rooftop or open garage installations shall be in accordance with 9.2.

9.6.2 If intended for rooftop and open garage use only installations, the smoke release rate, the convective and chemical heat release rate and content, velocity and temperature of the released vent gases need not be measured.

9.7 Unit level test report

9.7.1 The report on the unit level testing shall identify the type of installation being tested, as follows:

a) Indoor floor mounted non-residential use BESS;

b) Indoor floor mounted residential use BESS;

c) Outdoor ground mounted non-residential use BESS;

d) Outdoor ground mounted residential use BESS;

e) Indoor wall mounted non-residential use BESS;

f) Indoor wall mounted residential use BESS;

g) Outdoor wall mounted non-residential use BESS;

h) Outdoor wall mounted residential use BESS;

i) Rooftop installed non-residential use BESS; or

j) Open garage installed non-residential use BESS.

9.7.2 With reference to 9.7.1, if testing is intended to represent more than one installation type, this shall be noted in the report.

9.7.3 The report shall include the following, as applicable:

a) Unit manufacturer name and model number (and whether UL 9540 compliant);

b) Number of modules in the initiating BESS unit;

c) The construction of the initiating BESS unit per 5.3;

d) Fire protection features/detection/suppression systems within unit;

e) Module voltage(s) corresponding to the tested SOC;

f) The thermal runaway initiation method used;

g) Location of the initiating module within the BESS unit;

h) Diagram and dimensions of the test setup including mounting location of the initiating and target BESS units, and the locations of walls, ceilings, and soffits;

i) Observation of any flaming outside the initiating BESS enclosure and the maximum flame extension;

j) Chemical and convective heat release rate versus time data;

k) Separation distances from the initiating BESS unit to target walls (e. g. distances A and C in Figure 9.1);

l) Separation distances from the initiating BESS unit to target BESS units (e.g. distances D and H in Figure 9.1);

m) The maximum wall surface and target BESS temperatures achieved during the test and the location of the measuring thermocouple;

n) The maximum ceiling or soffit surface temperatures achieved during the indoor or outdoor wall mounted test and the location of the measuring thermocouple;

o) The maximum incident heat flux on target wall surfaces and target BESS units;

p) The maximum incident heat flux on target ceiling or soffit surfaces achieved during the indoor or outdoor wall mounted test;

q) Gas generation and composition data;

r) Peak smoke release rate and total smoke release data;

s) Indication of the activation of integral fire protection systems and if activated the time into the test at which activation occurred;

t) Observation of flying debris or explosive discharge of gases;

u) Observation of re-ignition(s) from thermal runaway events;

v) Observation(s) of sparks, electrical arcs, or other electrical events;

w) Observations of the damage to:

1) The initiating BESS unit;

2) Target BESS units;

3) Adjacent walls, ceilings, or soffits; and

x) Photos and video of the test.

9.8 Performance at unit level testing

9.8.1 Installation level testing in Section 10 is not required if the following performance conditions outlined in Table 9.1 are met during the unit level test.

Table 9.1
Unit Level Performance Criteria

Installation	Performance Criteria
	Non-Residential Installations
Indoor Floor Mounted	a) Flaming outside the initiating BESS unit is not observed; b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; c) For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15; d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and e) Heat flux in the center of the accessible means of egress[2)] shall not exceed 1.3 kW/m^2.
Outdoor Ground Mounted[1)]	a) If flaming outside of the unit is observed, separation distances to exposures shall be determined by greatest flame extension observed during test. b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; c) For BESS units intended for installation near exposures, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15; d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and e) Heat flux in the center of the accessible means of egress[2)] shall not exceed 1.3 kW/m^2.
Indoor Wall Mounted	a) Flaming outside the initiating BESS unit is not observed; b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15;

Table 9.1 Continued on Next Page

Table 9.1 Continued

Installation	Performance Criteria
	d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and e) Heat flux in the center of the accessible means of egress[2)] shall not exceed 1.3 kW/m^2.
Outdoor Wall Mounted	a) Flaming outside the initiating BESS unit is not observed; b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; c) For BESS units intended for installation on walls with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15; d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and e) Heat flux in the center of the accessible means of egress[2)] shall not exceed 1.3 kW/m^2.
Rooftop and Open Garages	a) If flaming outside the unit is observed, separation distances to exposures shall be determined by greatest flame extension observed during test; b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15; d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and e) Heat flux in the center of the accessible means of egress[2)] shall not exceed 1.3 kW/m^2.
Residential Installations	
Indoor Floor Mounted	a) Flaming outside the initiating BESS unit is not observed as demonstrated by no flaming or charring of the cheesecloth indicator; b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15; d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and e) The concentration of flammable gas does not exceed 25% LFL in air for the smallest specified room installation size.
Outdoor Ground Mounted	a) If flaming outside the unit is observed, separation distances to exposures shall be determined by greatest flame extension observed during test. b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; c) For BESS units intended for near exposures, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15; d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and e) Heat flux in the center of the accessible means of egress[2)] shall not exceed 1.3 kW/m^2.
Indoor Wall Mounted	a) Flaming outside the initiating BESS unit is not observed as demonstrated by no flaming or charring of the cheesecloth indicator; b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15; d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and

Table 9.1 Continued on Next Page

Table 9.1 Continued

Installation	Performance Criteria
	e) The concentration of flammable gas does not exceed 25% LFL for the smallest intended room installation size.
Outdoor Wall Mounted	a) Flaming outside the initiating BESS unit is not observed as demonstrated by no flaming or charring of the cheesecloth indicator; b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15; and d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases.
[1] Outdoor installation near exposures are those that are located at ≤ 3.48 m (10 ft) from buildings, lot lines that can be built upon, public ways, stored combustible materials, high piled stock, hazardous materials and other exposure hazards as defined in the codes. [2] Accessible means of egress is defined in NFPA 101 and is essentially a continuous and unobstructed way of travel for persons that provides an access to a safe area.	

10 Installation Level

10.1 General

10.1.1 The installation level test method assesses the effectiveness of the fire and explosion mitigation methods for the BESS in its intended installation. The installation level testing does not apply to residential use BESS.

a) Test Method 1 – "Effectiveness of sprinklers" is used to evaluate the effectiveness of sprinkler fire protection and explosion mitigation methods installed in accordance with code requirements.

b) Test Method 2 – "Effectiveness of fire protection plan" is used to evaluate the effectiveness of other fire and explosion mitigation methods (e. g., gaseous agents, water mist systems, combination systems).

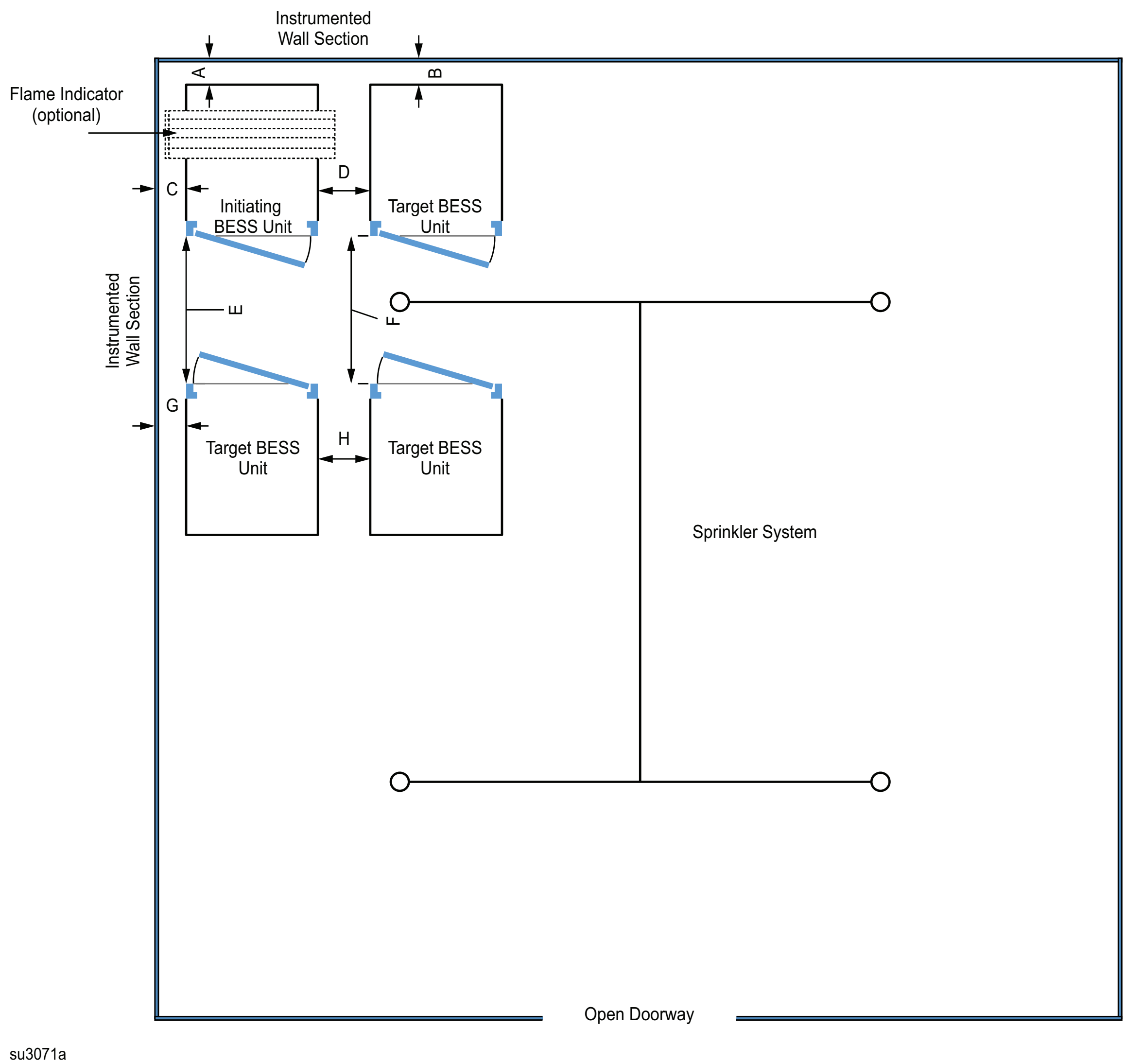
10.1.2 Installation level testing is not appropriate for units only intended for outdoor use or residential use.

10.2 Sample

10.2.1 The samples (initiating BESS and target BESS) and their preparation for testing, including separation distances from walls, shall be identical to that used for the unit level test in Section 9.

10.2.2 A flame indicator consisting of a cable tray with fire rated cables that complies with UL 1685 and representative of the installation per the manufacturer's specifications shall be deployed above the BESS at a distance specified by end-use installation. If the installation requires that cabling be installed below the BESS, then the flame indicator is not needed. See Figure 10.1 and Figure 10.2.

Figure 10.1
Example of Arrangement for Effectiveness of Sprinklers Test



A = Separation distance between the initiating BESS unit and instrumented wall section behind the initiating BESS unit.

B = Separation distance between the target BESS unit and instrumented wall section behind the target BESS unit.

C = Separation distance between the initiating BESS unit and instrumented wall section to the side of the initiating BESS unit.

D = Separation distance between initiating BESS unit and target BESS unit.

E = Separation distance between initiating BESS unit and target BESS unit.

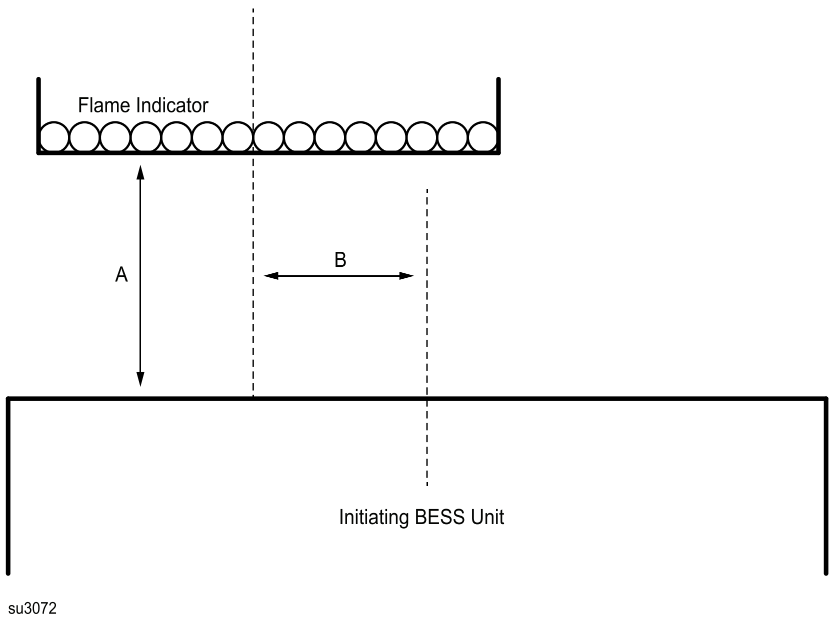
F = Separation distance between target BESS unit and target BESS unit.

G = Separation distance between target BESS unit and instrumented wall section.

H = Separation distance between target BESS units.

See Figure 10.2 for an example of the location of a flame indicating unit above the BESS.

Figure 10.2
Example of Flame Indicating Unit above BESS



A = Distance of the flame indicator above the BESS.

B = Distance between centerlines of initiating BESS unit and flame indicator.

10.3 Test method 1 – Effectiveness of sprinklers

10.3.1 For BESS units with a height of 2.44 m (8 ft) or less, the test shall be conducted in a 6.10 × 6.10 × 3.05-m (20 × 20 × 10-ft) high test room with one open 1.22 × 2.13-m (4 × 7-ft) high doorway or a room representative of the installation configuration as specified by the manufacturer. The largest test room anticipated by the manufacturer for BESS deployments, including footprint and ceiling height, shall be tested. For BESS units taller than 2.44 m (8 ft), the ceiling height shall be increased to be at least 0.61-m (2-ft) higher than the BESS units under test. The explosion mitigation methods shall be installed in the test installation in accordance with the manufacturer's specifications.

10.3.2 The test room shall be fitted with four sprinklers at 3.05-m (10-ft) spacing in the center of the test room. The sprinkler shall be standard spray, standard response with a temperature rating of 93°C (200°F), a nominal K-factor of 5.6, and sprinkler water density of 12.22 L/m^2/min (0.3 gpm/ft^2). If different specifications for the sprinklers with other densities, ratings and K-factors are indicated in the installation specifications, those shall be used for the installation test instead. See Figure 10.1.

10.3.3 Walls shall be constructed with 16-mm (5/8-in) gypsum wall board. Instrumented wall sections shall be painted flat black.

10.3.4 The initiating BESS unit shall be positioned at manufacturer specified distances from test room instrumented walls and target BESS units. For example, Figure 10.1 shows a potential layout of BESS units in the test room.

10.3.5 Temperature measurements at the ceiling locations directly above the initiating and target BESS unit shall be collected by an array of thermocouples located 25-mm (1-in) below the ceiling and at 152-mm (6-in) intervals using No. 24-gauge Type-K exposed junction thermocouples.

10.3.6 Instrumented wall surface temperature measurements shall be collected in a vertical array at 152-mm (6-in) intervals for the full height of the instrumented wall sections using No. 24-gauge Type-K exposed junction thermocouples to measure wall surface temperatures. Thermocouples shall be positioned in the wall locations anticipated to receive the greatest thermal exposure from the initiating BESS unit.

10.3.7 Thermocouples for wall surface temperature measurements shall be secured to gypsum surfaces by the use of staples placed over the insulated portion of the wires. The thermocouple tip shall be depressed into the gypsum so as to be flush with the gypsum surface at the point of measurement and held in thermal contact with the surface at that point by the use of pressure-sensitive paper tape.

10.3.8 Heat flux shall be measured with the sensing element of at least two water-cooled Schmidt-Boelter gauges at the surface of each instrumented wall:

a) Both are collinear with the vertical thermocouple array;

b) One is positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module; and

c) One is positioned at the elevation estimated to receive the greatest heat flux during potential propagation of thermal runaway within the initiating BESS unit.

10.3.9 Heat flux shall be measured with at least two sensing water-cooled Schmidt-Boelter gauges at the surface of each adjacent target BESS unit that faces the initiating BESS unit:

a) One is positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module within the initiating BESS; and

b) One is positioned at the elevation estimated to receive the greatest surface heat flux due to the thermal runaway of the initiating BESS.

10.3.10 The heat flux shall be measured with the sensing element of at least one water-cooled Schmidt-Boelter gauge positioned at the mid height of the initiating unit in the center of the accessible means of egress.

10.3.11 No. 24-gauge or smaller Type-K exposed junction thermocouples shall be installed to measure the surface temperature of module enclosures within target BESS units. Three thermocouples shall be located at positions on the exterior of each module enclosure, nearest to the initiating BESS unit. A minimum of two, No. 24-gauge or smaller Type-K thermocouples shall be placed within each module to provide data to monitor the thermal conditions within non-initiating modules. Additional thermocouples may be placed to account for convoluted enclosure interior geometries.

10.3.12 An internal fire condition in accordance with the module level test shall be created within a single module in the initiating BESS unit:

a) The position of the module shall be selected to present the greatest thermal exposure to adjacent modules (e.g. above, below, laterally), based on the results from the module level test; and

b) The setup (i.e. type, quantity and positioning) of equipment for initiating thermal runaway in the module shall be the same as that used to initiate and propagate thermal runaway within the module level test (Section 8).

10.3.13 The composition of BESS unit vent gases shall be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm^{-1} and a path length of at least 2.0 m (6.6 ft), total hydrocarbon analyzer, and hydrogen analyzer. The gas composition sampling port shall be located in the ceiling jet, 25-mm (1-in) below the ceiling.

10.3.14 The test shall be terminated if:

a) Temperatures measured inside each module of the initiating BESS return to below the cell vent temperature;

b) The fire propagates to adjacent units or to adjacent walls; or

c) A condition hazardous to test staff or the test facility requires mitigation.

10.3.15 The initiating unit shall be under observation for 24 h after conclusion of the installation test to determine that re-ignition does not occur.

10.4 Installation level test report – Test method 1 – Effectiveness of sprinklers

10.4.1 The report on installation level testing shall include the following:

a) Unit manufacturer name and model number (and whether compliant with UL 9540);

b) Number of modules in the initiating BESS unit;

c) The construction of the initiating BESS unit per 5.3;

d) Module voltage(s) of initiating BESS corresponding to the tested SOC;

e) The thermal runaway initiation method used;

f) Diagram and dimensions of the test setup including location of the initiating and target BESS units, and the locations of walls and ceilings;

g) Location of initiating module within the BESS unit;

h) Separation distances from the initiating BESS unit to (e.g. distances A and C in Figure 10.1);

i) Separation distances from the initiating BESS unit to target BESS units (e.g. distances D and E in Figure 10.1);

j) Distances of the flame indicator (if used) with respect to the BESS (e.g. distances A and B in Figure 10.2);

k) Maximum temperature at the ceiling;

l) Distance of fire spread within the flame indicator;

m) The maximum wall surface and target BESS unit temperatures achieved during the test and the location of the measuring thermocouple;

n) The maximum incident heat flux on target wall surfaces and target BESS units;

o) Voltages of initiating BESS;

p) Total number of sprinklers that operated and length of time the sprinklers operated during the test;

q) Gas generation and composition data, if measured;

r) Observation of flaming outside of the test room;

s) Observation of flying debris or explosive discharge of gases;

t) Observation of re-ignition(s) from thermal runaway events;

u) Observations of the damage to:

1) The initiating BESS unit;

2) Target BESS units; and

3) Adjacent walls;

v) Photos and video of the test;

w) Fire protection features/detection/suppression systems within unit; and

x) Sprinkler K-factor, RTI, manufacturer and model, number of sprinklers and layout.

10.5 Performance – Test method 1 – Effectiveness of sprinklers

10.5.1 For BESS units intended for installation in locations with combustible construction, surface temperature measurements along instrumented wall surfaces shall not exceed a temperature rise of 97°C (175°F) above ambient. Surface temperature rise is not applicable if the intended installation is composed completely of noncombustible materials in which wall assemblies, cables, wiring and any other combustible materials are not to be present in the BESS installation. In this case, the report shall note that the installation shall contain no combustible materials.

10.5.2 The surface temperature of modules within the BESS units adjacent to the initiating BESS unit shall not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8.

10.5.3 The fire spread on the cables in the flame indicator shall not extend horizontally beyond the initiating BESS enclosure dimensions.

10.5.4 There shall be no flaming outside the test room.

10.5.5 There is no observation of detonation. There is no observation of deflagration unless mitigated by an engineered deflagration protection system.

10.5.6 Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m^2.

10.5.7 There shall be no observation of re-ignition within the initiating unit after the installation test had been concluded and the sprinkler operation was discontinued.

10.5.8 An installation level test that does not meet the applicable performance criteria noted above is considered noncompliant and would need to be revised and retested.

10.6 Test method 2 – Effectiveness of fire protection plan

10.6.1 The test method 2 test set-up and test procedures are identical to that in 10.3, except instead of the sprinkler system set up of 10.3.2, the room shall be fitted with the specified fire protection and explosion mitigation equipment representative of a planned installation for the tested BESS system.

10.7 Installation level test report – Test method 2 – Effectiveness of fire protection plan

10.7.1 The report on installation level testing shall include the following:

a) The report information in 10.4.1 items (a) – (u), and (v) if applicable;

b) Fire protection features/detection/suppression systems within installation; and

c) Length of time of operation of the clean agent, or other suppression system in addition to any sprinklers used.

10.8 Performance – Test method 2 – Effectiveness of fire protection plan

10.8.1 See 10.5 for performance criteria.

ANNEX A (INFORMATIVE)
Test Concepts And Application Of Test Results To Installations

A1 Introduction

A1.1 This Annex is designed to help test sponsors, designers, owners, insurance companies and code authorities understand:

a) The purpose of the tests included in this standard;

b) How the individual tests relate to each other; and

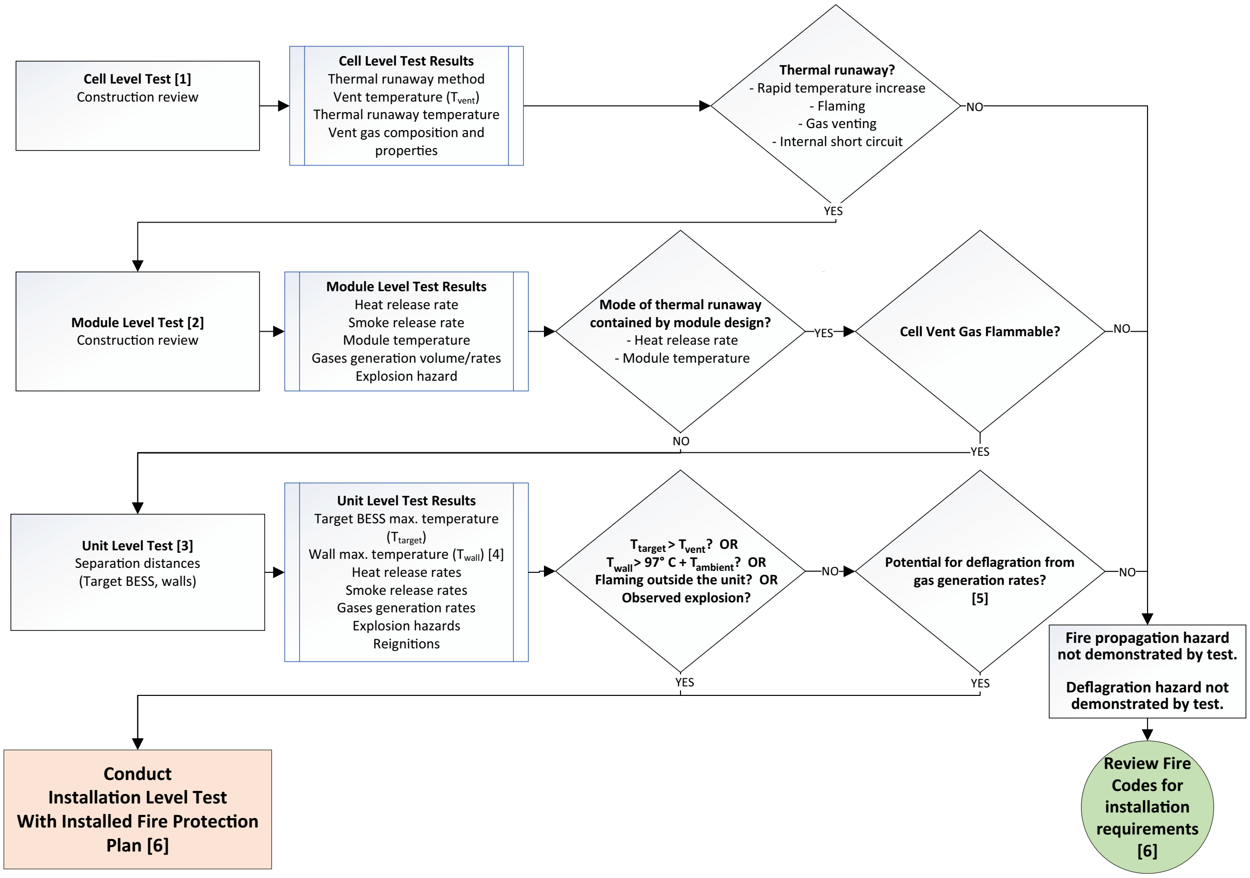
c) How to interpret and apply the results to achieve a code compliant installation.

A1.2 Model fire codes and energy storage system standards require energy storage systems to comply with UL 9540, which in turn requires battery cells and modules to comply with UL 1973. Compliance with these standards reduces the risk of batteries and battery energy storage systems (BESS) creating fire, shock or personal injury hazards. However, they don't evaluate the ability of the BESS installed as intended and with fire suppression mechanisms in place if necessary, from contributing to a fire or explosion in the end use installations.

A1.3 To address these fire and explosion hazards associated with the installation of a BESS, the fire and other codes require energy storage systems to meet certain location, separation, fire suppression and other criteria. Those codes also provide a means to provide an equivalent level of safety based on large scale fire testing of anticipated BESS installations. This standard is intended to provide a test method that can be used as a basis for validating the safety of a BESS installation in lieu of meeting the specific criteria provided in those codes.

A1.4 Flow charts that capture the various steps of the tests and how the data obtained is to be used to evaluate the installation are provided in Figure A.1 – Figure A.3.

Figure A.1
BESS Fire Propagation Assessment Flow Chart – Cell, Module and BESS Unit Level Test



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Where:

T_{vent} – Cell vent temperature measured during cell level testing.

T_{target} – Maximum temperature of BESS.

T_{wall} – Maximum temperature of target wall.

$T_{ambient}$ – Ambient temperature at start of test.

NOTES:

[1] Cell shall comply with UL 1973.

[2] Module shall comply with UL 1973.

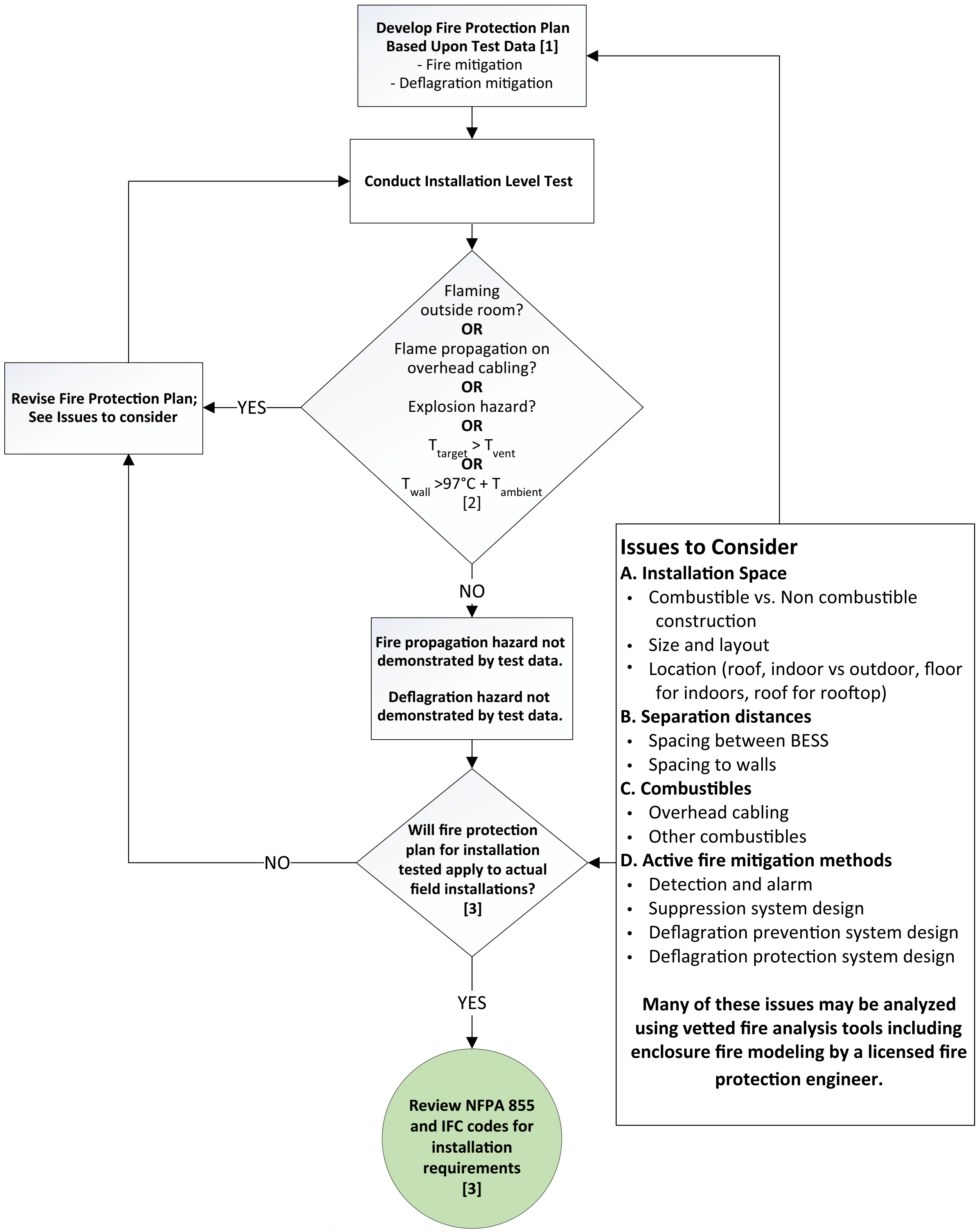
[3] Unit shall comply with the requirements of UL 1973 if it contains only batteries and/or to UL 9540 if an energy storage system.

[4] Maximum wall temperature criteria applies for combustible wall construction only.

[5] Use procedure in Deflagration Analysis.

[6] Review of fire protection plan and code requirements may necessitate a review by a licensed fire protection engineer.

Figure A.2
BESS Fire Propagation Assessment Flow Chart – Installation Level Test



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Where:

T_{vent} – *Cell vent temperature measured during cell level testing.*

T_{target} – *Maximum temperature of target BESS.*

T_{wall} – *Maximum temperature of target wall.*

$T_{ambient}$ – *Ambient temperature at start of test.*

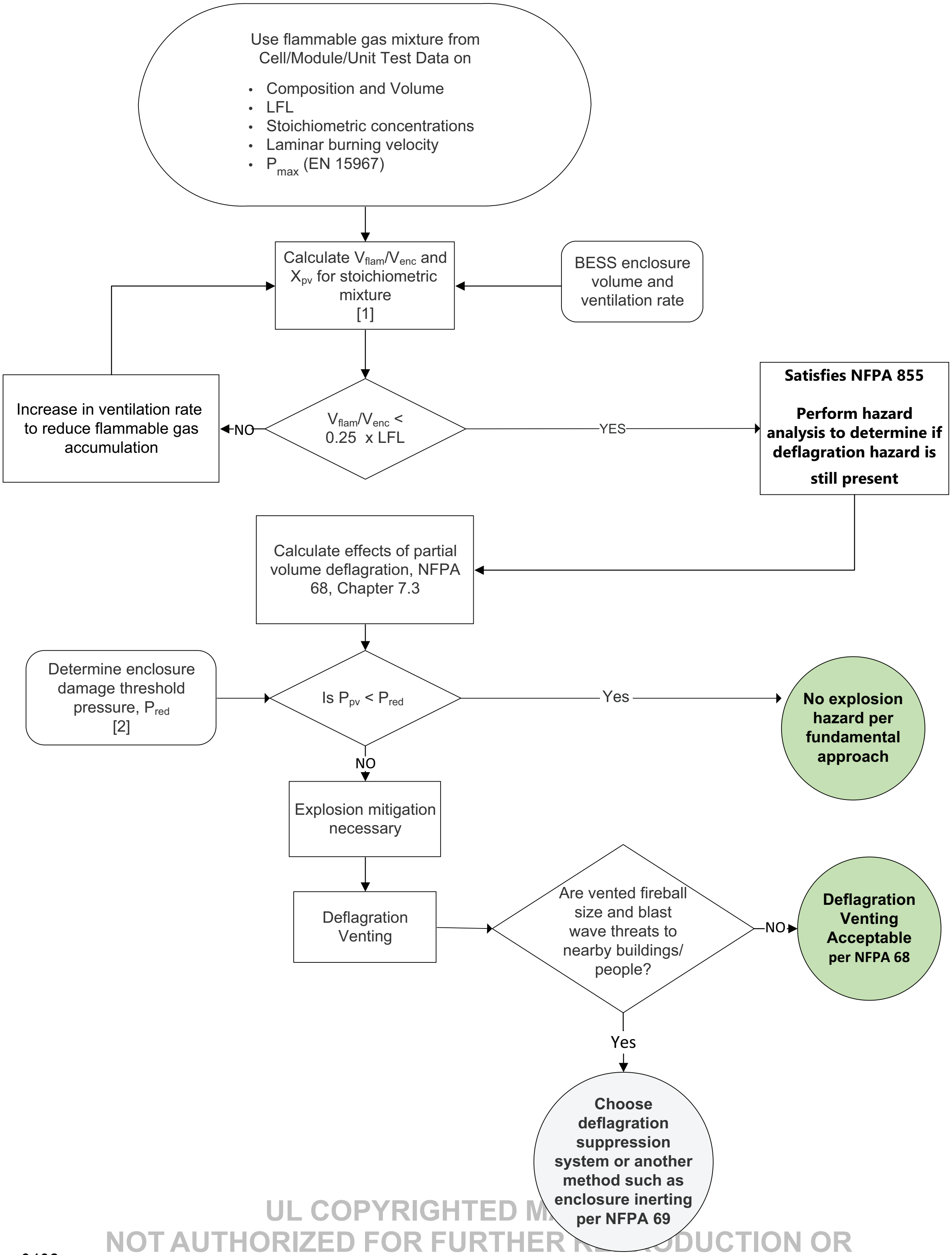
NOTES:

[1] Review of fire protection and deflagration plan may necessitate inclusion of a licensed fire protection engineer.

[2] Maximum 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.

Figure A.3
BESS Deflagration Protection Analysis



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Where:

V_{flam} – Volume or volume flow rate of flammable gas.

V_{enc} – Volume of enclosure or ventilation rate of enclosure.

X_{pv} – Flammable mix partial volume fraction.

LFL – Lower flammability limit.

P_{pv} – Partial volume pressure.

P_{max} – Maximum pressure from cell vent gas composition (EN 15967).

P_{red} – Maximum pressure developed in a vented enclosure during vented deflagration.

NOTES:

[1] V_{flam} and V_{enc} can be either volumes or volumetric flow rates.

[2] Per NFPA 68, Pred is no greater than two-thirds of ultimate strength of vented enclosure if deformation is tolerated, or two-thirds of yield strength of vented enclosure if deformation is not tolerated.

A2 Test Methodology and Purpose

A2.1 General

A2.1.1 The cell, module unit and installation tests in this standard are the steps designed to accomplish the purpose of this standard as described in A2.2 – A2.5.

A2.2 Cell level testing

A2.2.1 This testing is conducted on individual cells and uses various stress conditions such as external heating to force the cells into thermal runaway. Once the stress mechanism is induced, the test measures the temperature at which the cell vents and then the temperature at which thermal runaway occurs. The test also measures the volume and pressure of the vent gases that are released from the cells, and the composition of the vent gases. Cell vent gas with flammable components in its composition should have the following parameters characterized in order to enable deflagration venting design:

a) Measurement of fundamental burning velocity by the vertical tube method described in the Method of Test for Burning Velocity Measurement of Flammable Gases Annex in ISO 817, or the estimation of fundamental burning velocity per the Annex for Estimating Fundamental Burning Velocity in NFPA 68; and

b) Maximum pressure developed in a contained deflagration of an optimum mixture per EN 15967.

A2.2.2 Cell level testing performed on the cells used within a BESS module establishes a base line fire test performance that can be evaluated against the fire performance of other battery cells the BESS manufacturer may choose to use within the unit's modules.

A2.2.3 If none of the cell samples can be forced into thermal runaway and none of the cell samples vent flammable gases as determined by the ASTM E918 test, during any of the cell level tests, it is not necessary to conduct additional module or unit level testing on BESS that utilize these cells.

A2.3 Module level testing

A2.3.1 This testing is conducted on battery modules, which are in turn installed in an enclosure or in an open rack system to form a BESS unit.

A2.3.2 This test uses applied stresses determined during the cell level test to force a selected number of battery cells within the module into thermal runaway. If there is fire that results from the cell being driven into thermal runaway, the fire is allowed to progress within the module. The test measures the chemical heat release rate, smoke release rate, maximum temperature, and vent gas composition; and documents the module enclosure integrity after the test, any explosions or hazardous ejection of parts outside of the module enclosure, and the extent and duration of any flame propagation outside of the module.

A2.3.3 The module level testing establishes a base line fire test performance that can be evaluated against the fire performance of other battery modules the BESS manufacturer may choose to use within the system. Testing can be discontinued after the module level testing if the effects of thermal runaway (fire and explosion) are contained by the module design and the cell vent gas (as determined by the cell level testing) is non-flammable.

A2.4 Unit level testing

A2.4.1 Unit level testing corresponds with the testing anticipated by fire codes and other codes impacting energy storage system installations to evaluate the large scale fire performance of BESS units installed in, on or adjacent to buildings or in other areas and their resultant performance to qualify for exceptions to limits in the codes imposed on these installations. The limitations where exceptions may be sought are limitations on the size of the individual BESS units, the total number of BESS units installed within a room, and the separation distances between BESS units and between BESS units and walls of the building.

A2.4.2 In this test the initiating BESS unit is placed a set distance from target BESS units simulating BESS units identical to the initiating BESS unit, and from simulated walls representative on the installation. A thermal runaway is induced in cells, using the same approach as used in the module level testing within one of the modules in the initiating BESS, and a variety of measurements are taken. The results are intended to be used to verify that a fire within a single BESS unit will not spread to other units, nor breach the walls or the BESS enclosure (if provided), and there shall be no flying debris or explosive discharge of gases.

A2.4.3 The test arrangement should include the largest (energy) BESS unit for the installation to be represented by the test, and minimum spacing to adjacent walls and BESS units. The BESS may be tested with an internal fire suppression system provided by the manufacturer if that fire suppression system is required to be installed in the BESS. Optional internal fire suppression systems are not included in the unit level testing.

A2.4.4 The test monitors the fire behavior of the BESS unit and measures heat release rates (convective and chemical); gas generation and composition; smoke release rate; maximum heat flux on the target BESS units, wall surfaces and within the accessible means of egress; maximum surface temperatures of the walls and modules within the target BESS units; and documents any explosions, deflagrations and flying debris from the BESS under test. If the unit level test meets the performance criteria for that test per Table 9.1, the testing can be concluded at the unit level.

A2.4.5 If BESS installations comply with all performance criteria in Table 9.1, this provides technical justification for the authority having jurisdiction to consider to allow sprinkler protection with less than 12.22-L/m^2/min (0.3-gpm/ft^2) density, or other fire suppression systems, to be used to protect the battery room or area.

A2.4.6 Residential use BESS must meet the unit level performance criteria for residential installations in Table 9.1, as there is no installation level test option for these applications.

A2.5 Installation level testing

A2.5.1 General

A2.5.1.1 If the results from the unit level test did not meet the performance criteria for that level as provided in Table 9.1, than an installation test is conducted. This test is essentially a repeat of the unit level test with the intended fire suppression system installed and operating to determine if performance criteria are met.

A2.5.1.2 There are two options for the installation level testing depending upon the type of fire suppression systems used, Test method 1 effectiveness of sprinklers and Test method 2 – Effectiveness of fire protection plan.

A2.5.1.3 For either test method used, the test measures gas generation and composition (unless previously measured in a unit level test), maximum heat flux on the target BESS units and wall surfaces, maximum surface temperatures of the walls and modules within the target BESS units; and documents any explosions, deflagrations and flying debris from the BESS under test. Although the set-up is essentially the same as the unit level test with regard to the layout of the initiating BESS and target BESS units, this test is done within a test room (instead of adjacent walls), with any overhead cabling installed as a flame spread indicator and the fire suppression set up (whether sprinklers or other type) as intended in the installation.

A2.5.1.4 The test monitors the fire behavior of the BESS unit and any fire spread to the flame indictor and test room. It also measures the maximum heat flux on the target BESS units, wall surfaces and within the accessible means of egress; maximum surface temperatures of the walls and modules within the target BESS units; and documents any explosions, deflagrations and flying debris as well as re-ignition from the BESS under test. If the results from the installation level test meets the performance criteria for that test, the testing is completed.

A2.5.2 Test method 1 – Effectiveness of sprinklers

A2.5.2.1 This test is conducted to evaluate overall protection methods for an entire BESS room or area. In particular it can evaluate the sprinkler design density and characteristics of the automatic sprinklers used to provide code mandated protection in the room or area in which the BESS is to be installed. The test can also evaluate the extent of damage that the fire within the BESS produces on an exposed cable tray (flame indicator) positioned over the BESS unit under test.

A2.5.2.2 The test is conducted in a 6.10 × 6.10-m (20 × 20-ft) high test room that is 0.61-m (2-ft) higher than the BESS unit but not less than 2.44 m (8 ft) in height with a 1.22 × 2.13-m (4 × 7-ft) high doorway opening, and the room is outfitted with four sprinklers at 3.05-m (10-ft) spacing in the center of the test room. The sprinkler type (K-factor, sprinkler activation temperature) and sprinkler water density shall be specified in accordance with installation specifications. An internal fire condition is created within a single module in the initiating BESS unit in accordance with the module level test and the fire is allowed to proceed as in the unit level testing.

A2.5.3 Test method 2 – Effectiveness of fire protection plan

A2.5.3.1 This test is used to evaluate the effectiveness of other fire mitigation methods (e.g., gaseous agents, water mist systems, combination systems) other than the sprinkler suppression evaluated in Test method 1. The test also evaluates the extent of flame propagation that the fire within the BESS unit produces on an exposed cable tray (flame indicator) positioned over the BESS unit under test.

A2.5.3.2 The test is conducted in a 6.10 × 6.10-m (20 × 20-ft) high test room that is 0.61-m (2-ft) higher than the BESS unit but not less than 2.44 m (8 ft) in height with a 1.22 × 2.13-m (4 × 7-ft) high doorway opening, and the room is outfitted with the fire protection equipment representative of a planned installation for the tested BESS system. An internal fire condition is created within a single module in the initiating BESS unit in accordance with the module level test and the fire is allowed to proceed as in the unit level testing.

A3 Evaluating the Results

A3.1 General

A3.1.1 This section provides suggestions on how code authorities, owners, insurance interests and designers can interpret and use the results of these tests to document and verify compliance with codes for covering the fire-safety related performance of BESS installations.

A3.2 Documentation

A3.2.1 The first step in the evaluation process is to obtain complete documentation on the proposed installation. Among other things this will include the following:

a) Code mandated construction and commissioning documents;

b) A complete copy of the large scale fire test report;

c) Complete description of the BESS to be installed, including manufacturer's name and models, energy (kWh or MWh) ratings, number and model of battery modules within the BESS unit(s), and manufacturer, model and number of battery cells in each module;

d) Information on the compliance status with UL 9540 and UL 1973 of each BESS unit, module and battery cells;

e) Description of any integral fire suppression systems to be provided in each BESS unit;

f) A scale drawing of the room, space or area, showing BESS unit placement, minimum spacing between BESS units, and between BESS units and adjacent walls and locations of accessible means of egress;

g) Sprinkler design information or other fire suppression system design information for the room, space or area in which the BESS is installed;

h) Description of any ventilation, exhaust and deflagration protection to be provided in the room;

i) Description and location of power and communication cables within the room or area containing the BESS, and presence of combustible materials and construction above and below the BESS;

j) Contact information for qualified personnel that can be contacted with BESS related questions; and

k) A Hazard Mitigation Analysis (HMA) outlining the basic risks from the system and common failure modes. This may also include language and recommendations useful in the development of first responder SOPs.

A3.3 Choosing appropriate tests

A3.3.1 For most new BESS installations that require large scale fire testing in accordance with codes addressing fire-safety, the initial focus should be on the Unit Level Test and the Installation Level Test. The Cell Level Test and Module Level Test are steps towards conducting the unit and installation levels tests, but are also of value in determining the acceptability of alternate cells and modules for application in a BESS. The cell level testing can demonstrate if a BESS for residential use can be installed within the dwelling based upon meeting the cell level performance criteria of 7.7.1. The following considerations apply primarily to evaluation of the proposed installation using Unit Level Test results:

a) Does the test cover the BESS models proposed for installation: The BESS units (model numbers, modules and cells) proposed for installation should match the units described in the test report prepared in accordance with this standard. If different BESS units, modules, battery cells or other modifications are apparent, additional testing might be necessary, such as cell level or module level testing.

b) Are the BESS units compliant with UL 9540 with battery systems compliant to UL 1973: Documentation should be provided that the BESS units to be installed are compliant with UL 9540.

c) Maximum BESS energy considerations: The energy capacity of the BESS units to be installed in the battery room or area should not exceed the energy capacity (kWh, MWh) of the BESS unit subjected to the unit level test.

d) Spacing: The spacing between individual BESS units and between BESS units and fire-resistance rated walls enclosing the room, space or area where the BESS is installed, should not be less than the corresponding spacing in the unit level test.

e) Extent of thermal runaway: During the unit level test and installation level test, it should be confirmed that the thermal runaway induced on the module being subjected to the fault condition produced thermal runaway within the initiating module, which would represent the method employed at the module level test. The location of the initiating module was chosen based upon what was considered the most vulnerable location for module to module thermal runaway propagation within the BESS.

f) Integral fire suppression systems: If the unit level test was conducted with an internal fire suppression systems in the BESS unit, all BESS units to be installed should be equipped with the suppression system. Documentation in the commissioning plan should also include criteria for initial and periodic testing and maintenance of the suppression system in accordance with the manufacturer's instructions and applicable NFPA standards.

g) Row oriented BESS installations: Where BESS units are intended to be installed back to back, and in continuous rows with aisles in between, they should be tested in such an arrangement with zero clearances to target BESS units.

h) Door and access opening securement: The unit level test was conducted with these openings secured shut, which serve to help contain fires within the BESS unit. The openings should not be allowed to remain open in actual service, except possibly for short durations while the units are being serviced.

i) Temperature evaluation: The unit level temperature measurements should be reviewed to verify that temperature rises on the instrumented wall do not exceed 97°C (175°F) above ambient, and that temperatures on the BESS target unit modules do not exceed temperature at which battery cells vented during the cell level tests. If the temperature rise on the instrumented wall does not exceed 97°C (175°F), separation distances to walls of combustible construction at the distance tested should be considered acceptable to the code authority.

j) Flammable gas evaluation: If flammable gases were measured escaping from battery modules in the BESS unit during the unit level test, the code authority should determine if the escaping gases are capable of building up flammable gas concentrations in excess of 25% LFL anywhere in the room, space or area in which the equipment is to be installed. If these concentrations can be reached in the end use installation the code authority should determine if explosion control measures such as deflagration venting systems or deflagration prevention systems need to be provided.

k) Flying debris and BESS enclosure breaching: If these conditions were produced during the unit level or installation level testing the installation should not be approved.

l) Flaming from the doorway: If this condition was produced during the installation level testing the installation should not be approved. If there is evidence of re-ignition after it appears that the flaming through the unit is ebbing, this should be documented. If this occurs after the conclusion of the installation level testing, the installation should not be approved.

m) BESS re-ignition: If there is evidence of re-ignition of the BESS after it appears that the flaming through the unit is ebbing, this should be documented. If this occurs after the conclusion of the installation level testing, the installation should not be approved.

n) Alternate battery cells and BESS modules: If the battery cells and/or modules installed in the BESS units differ from those included in the samples subjected to unit level testing, two things should be considered:

1) Confirmation should be provided that the cells or modules to be provided comply with UL 1973 (UL 9540 requires that cells and modules comply with UL 1973); and

2) Additional cell level and module level testing, and possibly other additional testing should be conducted and verified in the report that the fire performance of the new cells and

modules in the BESS units is comparable to the fire performance in the unit level fire test report under consideration.

o) Sprinkler considerations: The installation level test method 1 is specifically designed to evaluate the effectiveness of automatic fire sprinklers for protecting an operating BESS installation. The sprinkler system to be provided should meet or exceed the parameters of the system that was tested.

p) Alternate extinguishing systems: The installation level test method 2 is specifically designed to evaluate the effectiveness of alternate extinguishing systems for protecting the BESS room or area. The alternate extinguishing system to be provided should meet or exceed the parameters of the system that was tested.

q) Power and communication cables: The installation level test includes an optional flame indicator deployed above the BESS which can be used to help determine if a fire within the BESS can propagate into open cable trays or other combustibles located above the BESS. If cable trays or combustibles are to be placed above the BESS in the installation, the flame indicator should have been included in the test, and the test results should show that fire spread in the flame indicator does not extend horizontally beyond the enclosure dimensions. If the test was not conducted or acceptable results were not obtained, exposed conductors and combustibles should not be installed above the BESS, or they should be protected by suitable fire resistive construction.

r) Combustibles under the unit: This standard does not evaluate the impact that a fire within the BESS has on cabling or other combustible materials and construction installed under the BESS, or on the mounting surfaces under the BESS.

s) Ventilation restrictions: Sometimes shields or barriers (such as polycarbonate sheets or sheet metal) that are not part of the UL 9540 compliant BESS, are provided in close proximity to the BESS to prevent personnel from accessing live parts or controls, or to prevent pipes from leaking onto electrical equipment. If such barriers are provided the impact they have on flame spread, restricting ventilation, sprinkler discharge, or extinguishing agents should be considered prior to approving the installation.

t) Outdoor installations: The tests in this standard are conducted indoors, but the results can be used to evaluate outdoor installations, since the energy released from a burning BESS may be more readily dispersed in an outdoor environment where it is not contained within an indoor room, space or area. Allowance is made for testing outdoor use only systems outdoors based upon the documented environmental controls in place. If using indoor testing to evaluate outdoor use systems, consider the following:

1) If the unit level test (without fire suppression) provided acceptable results when the BESS was located a specified distance from a wall, it is reasonable to assume that the BESS located outdoors can be positioned the same distance from an exterior wall with no openings in the vicinity.

2) Codes do not allow combustibles to be stored in indoor BESS rooms or areas. However, for exterior locations, combustibles are allowed in the vicinity of BESS installations (clearances to exposure requirements), which allow decreased spacings due to large scale fire tests. It is reasonable to use the clearance to wall distances established during the indoor unit level tests to justify acceptable distances to exterior exposures, provided that the materials subject to exposure are not more susceptible to ignition than wall materials (such as flammable liquids, hazardous materials, insulating foam products, etc.). Increased setback distances would be reasonable for those types of exposures, as determined by the code authority.

ANNEX B (INFORMATIVE)
Safety Recommendations for Testing

B1 General

B1.1 The tests in this standard are extreme abuse conditions conducted on electrochemical energy storage devices that can result in extensive fires, explosions, off gassing of flammable and toxic materials, exposure to toxic and corrosive liquids, and potential exposure to hazardous voltages and electrical energy.

B1.2 Facilities used for this testing should be capable of handling these events in a controlled manner that does not result in hazards to staff and facilities. There should be battery handling and testing SOPs to address procedures for handling, storing, testing and disposing of batteries. All testing should be done in test areas separate from where staff are observing the tests to prevent injuries to staff from occurring due to unplanned failures. Sufficient fire suppression means suitable to the energy storage technology being tested should be available to control fires. With the exception of designated, trained fire-fighting staff tasked with putting out uncontrolled fires, staff should not enter test rooms until after the sample has stabilized and returned to near ambient conditions. Suitable personal protection equipment (PPE) should be worn at all times by staff handling and testing samples to prevent injuries from occurring. Facilities should have adequate means to ventilate hazardous materials from combustion to prevent toxic and combustible concentrations in accordance with local codes.

B1.3 At the conclusion of testing, samples shall be discharged in accordance with the manufacturer's specifications. All handling before and post testing should be in accordance with the manufacturer's recommendations and the facility SOPs. All samples shall be disposed of in accordance with local regulations.

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