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NATIONAL STANDARD

ANSI/CAN/UL 9540A:2025

STANDARD FOR SAFETY

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



ANSI/UL 9540A-2025



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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

Fifth Edition, Dated March 12, 2025

Summary of Topics

This Fifth Edition of ANSI/CAN/UL 9450A, Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems dated March 12, 2025, includes the following changes in requirements:

- Revised FTIR measurements to be optional and added hydrogen measurements at Unit Level Test: [8.2.14](#), [8.2.15](#), [9.2.23](#), [9.2.24](#), and [10.3.13](#).
- Clarified sample rest times after conditioning and charging: [7.2.2](#), [8.1.2](#), and [9.1.9](#).
- Corrected standard reference in [9.1.12](#): [3.2](#).
- Replaced reference to UL 1685 with UL 2556: [3.2](#) and [10.2.2](#).
- Revised Residential Unit Level Testing to remove the usage of the NFPA 286 test room and replaced with test wall: [9.1.2](#), [Figure 9.3](#), [9.2.6](#), [9.4.2](#), [9.4.3](#), [9.5.1](#), [9.5.2](#), and [10.3.3](#).
- Added option for continuous thermal ramp until thermal runaway: [7.3.1.5](#).
- Added NFPA 855 for applicable codes: [1.2](#) and [3.2](#).
- Clarified charging method for cells: [7.2.1](#) and [7.2.4](#).
- Revised location of thermocouples during cell testing and thermal ramp option: [7.3.1.2](#), [7.3.1.7](#) – [7.3.1.10](#).
- Clarified report if using a battery system as the BESS unit for testing: [7.7.1](#).
- Clarified establishing cell to cell propagation in the test method in [8.2](#): [8.2.3](#) – [8.2.7](#).
- Revised Module Level Performance Criteria: [8.5.1](#).
- Revised requirements to allow the use of Gardon heat flux gauge, revised sampling rate for heat flux and wall temperature, and added floor mounted residential system exceptions: [6.3](#), [6.4](#), [9.2.15](#), [9.2.17](#) – [9.2.20](#), [10.3.5](#), [10.3.6](#), [10.3.8](#) – [10.3.10](#).
- Revised egress path heat flux measurements for non-residential outdoor wall mount systems: [9.5.1](#) and [9.5.5](#).
- Removed noncombustible construction exception and clarified outdoor flame exception: [4.16](#), [9.1.1](#), [9.1.6](#), [9.2.19](#), [9.3.2](#), [9.6.1](#) – [9.6.5](#), [9.7.1](#), and [Table 9.1](#).
- Added test method for lead acid and nickel cadmium batteries: [3.2](#), [7.3.1.4](#), [7.3.3.1](#) – [7.3.3.8](#), [7.6.1](#), [7.6.2](#), [Table 7.1](#), [7.7.3](#), and [7.10.1](#) – [7.10.4](#).
- Revised flow battery requirements: [5.4.3](#), [7.1.1](#), [7.1.2](#), Section [7.3.2](#), [7.7.2](#), [7.9.1](#), [9.9.1](#), [9.9.4](#), [9.10.1](#), and [9.11.1](#).

- *Removed statement about installation in residential dwelling units.*
- *Added test procedure for high temperature batteries:* [7.1.3](#), [7.3.4.1](#) – [7.3.4.4](#), [7.4.1](#), [7.7.4](#), [7.11.1](#), [8.3.1](#) – [8.3.5](#), [8.4.2](#), [8.6.1](#), [9.1.3](#), [9.1.4](#), [10.2.3](#), [10.2.4](#), [Figure 10.3](#), [10.9.1](#) – [10.9.10](#), [10.10.1](#), [10.11.1](#) – [10.11.3](#)
- *Added deflagration considerations to Annex A:* [A3.3.1](#).
- *Clarified residential and non-residential use definition, revised test set-ups for the module and unit level testing, added to the module, unit, and installation level test reports:* [8.4.1](#), [9.5.2](#), [9.7.3](#), [10.4.1](#), and [10.7.1](#).
- *Clarified wording for cell, module and unit failure methodologies:* [7.3.1.2](#), [8.2.8](#), [8.2.14](#), [9.1.2](#), and [9.1.8](#).
- *Added a definition for “thermal runaway propagation” and revised the “thermal runaway” definition:* [4.16](#) and [4.19](#)
- *Revised the module surface temperature measurement range:* [9.7.3](#), [Table 9.1](#), and [10.5.2](#).
- *Revised requirements to align with the code on “Residential Use”:* [1.2](#), [3.2](#), [4.15](#), [4.17](#), [10.1.1](#), [10.1.2](#), and [A2.3.2](#).
- *Revised Unit Level Indoor and Outdoor Tests:* [4.2](#), [9.1.1](#), [9.1.2](#), [Figure 9.2](#), [Figure 9.3](#), [9.1.9](#), [9.2.1](#), [9.2.5](#), [9.2.6](#), [9.2.22](#), [9.2.25](#), [9.3.1](#), [9.5.1](#), [9.5.2](#), [9.7.3](#), [Table 9.1](#), [10.3.12](#), [10.5.6](#), [A2.5.2.2](#), and [A2.5.3.2](#).
- *Revised Installation Level Tests:* [10.5.7](#) and [A3.3.1](#)

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated September 29, 2023, June 28, 2024, October 4, 2024, and December 20, 2024.

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

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March 12, 2025

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The most recent designation of ANSI/UL 9540A as an American National Standard (ANSI) occurred on March 12, 2025. 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 March 12, 2025.

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Preface

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

ULSE 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.

Annexes [A](#) and [B](#), identified as Informative, is for information purposes only.

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.

This Fifth Edition joint American National Standard and National Standard of Canada is based on, and now supersedes, the Fourth Edition of UL 9540A.

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This Edition of the Standard has been formally approved by the Technical Committee (TC) on Energy Storage Systems and Equipment, TC 9540.

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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 support the manufacturer's installation instructions with regards to separation between individual battery energy storage systems and 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:

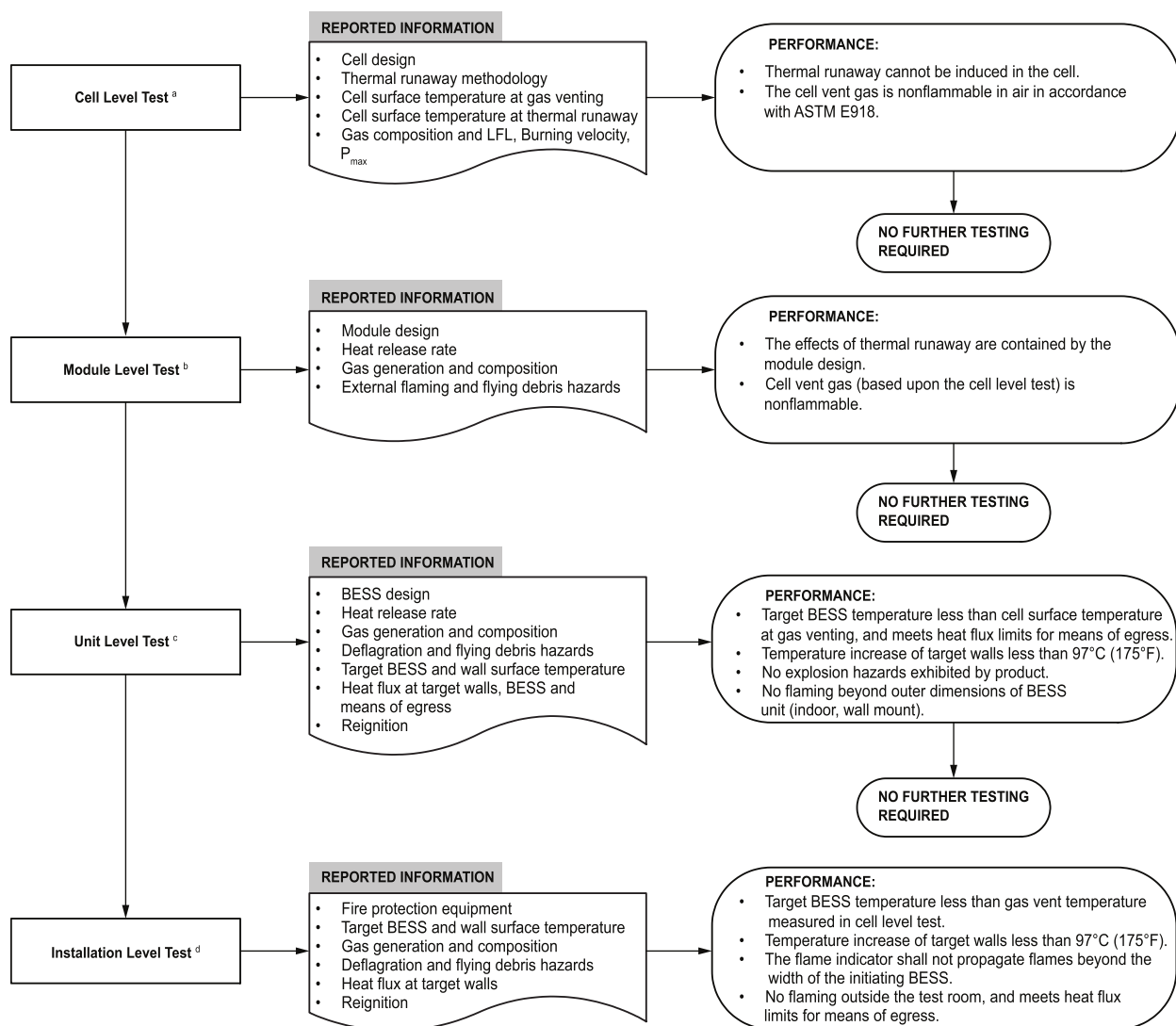
- a) The Standard for the Installation of Stationary Energy Storage Systems, NFPA 855;
- b) The National Electrical Code, NFPA 70;
- c) The Fire Code, NFPA 1;
- d) The Standard for Energy Storage Systems and Equipment, UL 9540;
- e) The Canadian Electrical Code, Part I, Safety Standard for Electrical Installations, CSA C22.1;
- f) The General Requirements – Canadian Electrical Code, Part II, CSA C22.2 No. 0;
- g) The National Electrical Safety Code, IEEE C2;
- h) The International Fire Code, ICC IFC;
- i) The International Residential Code, ICC IRC; and
- j) Other codes affecting energy storage systems.

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*

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)*

ICC IRC, *International Residential Code*

IEEE 1635/ASHRAE Guide 21, *Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications*

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

ISO 817, *Refrigerants – Designation and Safety Classification*

NFPA 1, *Fire Code*

NFPA 2, *Hydrogen Technologies 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*

NFPA 855, *Installation of Stationary Energy Storage Systems*

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

UL 864, *Control Units and Accessories for Fire Alarm Systems*

UL 1973, *Batteries for Use in Stationary and Motive Auxiliary Power Applications*

UL 2556, *Wire and Cable Test Methods*

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.

a) INITIATING BATTERY ENERGY STORAGE SYSTEM UNIT (INITIATING BESS) – A BESS unit which has been equipped with resistance heaters in order to create the cell to cell thermal runaway propagation 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.

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

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 CELL, INITIATING – The cell that is faulted through thermal, electrical or mechanical means, in order to establish a thermal runaway condition.

4.6 DUT – Device under test.

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

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

4.9 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.

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

4.11 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.

4.12 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.

4.13 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.

4.14 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.

4.15 NON-RESIDENTIAL USE – Equipment intended for use on or in structures other than those defined in [4.17](#).

4.16 OPEN PARKING GARAGE – A parking structure with openings on two or more sides that is used for the parking or storage of motor vehicles, designed to provide natural ventilation in accordance with local building code requirements.

4.17 RESIDENTIAL USE – Equipment suitable for use on or in detached one- and two-family dwellings and townhouses.

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

4.19 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, and/or explosion, and/or gas evolution.

4.20 THERMAL RUNAWAY PROPAGATION – The transfer of energy released from one or more cells undergoing thermal runaway that induces thermal runaway of other cell(s) without any additional initiating mechanism(s).

4.21 UNIT – A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such as 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 [7.7.1](#) 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 [8.4](#) 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 [7.7.2](#) for further details to be included in the flow battery cell level test report and [9.10](#) for further details to be included in the flow battery unit 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.

6.3 Temperatures on parts and surfaces shall be measured continuously, taking the average over every 60 seconds through the test with a thermocouple junction formed from 24-gauge or smaller, Type-K thermocouple wire unless noted otherwise in the specific test. The maximum of these averages shall be documented for each thermocouple location. Cell surface temperatures shall be measured continuously, but not averaged over every 60 seconds as the other temperature measurements are.

6.4 When heat flux measurements are taken, they shall be measured continuously, taking the average over every 60-second interval. The maximum of these averages shall be documented for each gauge location.

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.

7.1.2 For flow batteries, the test procedures in this Standard are based on the premise that flow batteries have their energy stored separately from their stacks. This gives such systems the ability to shut off the flow of electrolyte to control any type of failure and prevent it from propagating into a thermal runaway. The ability of flow batteries to detect a failure and shut down the flow of electrolyte is covered by the construction and test requirements of UL 1973. The test procedures in this Standard evaluate thermal and explosive risks associated with the stored electrolyte(s) as a result of abnormal conditions and exposure to fire. It also evaluates the risks associated with membrane failures that can result in mixing of electrolytes.

NOTE: Some flow battery technologies emit explosive gas at a rate which can be controlled. The test procedures in this Standard do not address electrolysis or corrosion driven gas evolution rates.

7.1.3 High temperature batteries such as sodium beta or other molten salt batteries operate at temperatures in a range of 260 °C to 600 °C (500 °F to 1112 °F) and would not be readily impacted by a thermal ramp test. These batteries shall be tested in accordance with [7.3.4](#) instead.

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 the ambient temperature shall be maintained in accordance with [7.3.1.1](#).

7.2.2 The cells to be tested shall be charged to 100 % SOC or to the manufacturer's specification for a fully charged voltage and allowed to rest for a minimum of 1 hour before the start of the test.

7.2.3 Prior to initiating the test, the cell voltage shall be measured and recorded. If the cell is not in a fully charged condition, the cell shall be charged again as noted in [7.2.2](#) and this value shall be recorded.

7.2.4 Cells with flexible laminate casings and prismatic cells shall be constrained during the test in a 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 heating ramp rate of 4 °C (7.2 °F) to 7 °C (12.6 °F) per minute shall be applied to the cell surface. A thermocouple shall be placed centrally under the heater(s) to verify that the heating ramp rate of the heater(s) is achieved and maintained. The cell surface temperature shall be determined by a separate thermocouple placed in a representative position to ensure measurement of the cell surface which is least influenced by the heater. In cases where flexible film heaters do not cause the cell to exhibit thermal runaway, one of the following methods shall be employed as needed until the cell exhibits thermal runaway:

- a) Electrical stress on the cell (e.g. overcharge of a cell or an external short-circuit on a cell or over-discharge of a cell or other method based on cell chemistry and design);
- b) Alternate heating method (e.g. conductive heat in another form including partial coverage of the cell with thin film heaters, the use of cartridge heaters inserted between the cells, the use of ceramic heaters or heated plates on the battery module, or convective heat of the battery through the use of an oven or other method); or
- c) Mechanical abuse such as nail penetration or other failure modes that result in an internal short-circuit.

Exception No. 1: The heating rate of 4 °C (7.2 °F) to 7 °C (12.6 °F) per minute may not apply when an electrical stress in (a) is used for causing thermal runaway in a cell.

Exception No. 2: The heating rate can be greater than 4 °C (7.2 °F) to 7 °C (12.6 °F) per minute based on the heating method or device used in (b).

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. See [7.3.3](#) for an alternative method for testing vented and valve regulated lead acid and nickel cadmium (Ni-Cd).

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 at least 5 °C (9 °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 hours, 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.

Exception: If the separator information is not available or at the manufacturer's discretion, the thermal ramp can be conducted continuously without a hold point until thermal runaway.

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](#) – [7.3.1.11](#). 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 Determination of a maximum surface temperature end point criteria shall be developed based upon a review of cell design and chemistry. 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 minimum, thermocouples shall be placed at the following locations on the cell (see also [7.3.1.8](#)):

- a) Under the heater that is placed on the cell surface to measure the surface heating rate as noted in [7.3.1.2](#);
- b) Cell surface near the heater to measure the temperature of the cell surface and to measure the temperature of the cell surface at the time of venting. This thermocouple shall not be covered by the heater; and
- c) Cell vent area (if any) to indicate the time when the cell vents. Based on the cell design, this thermocouple location may be the same as (b) above.

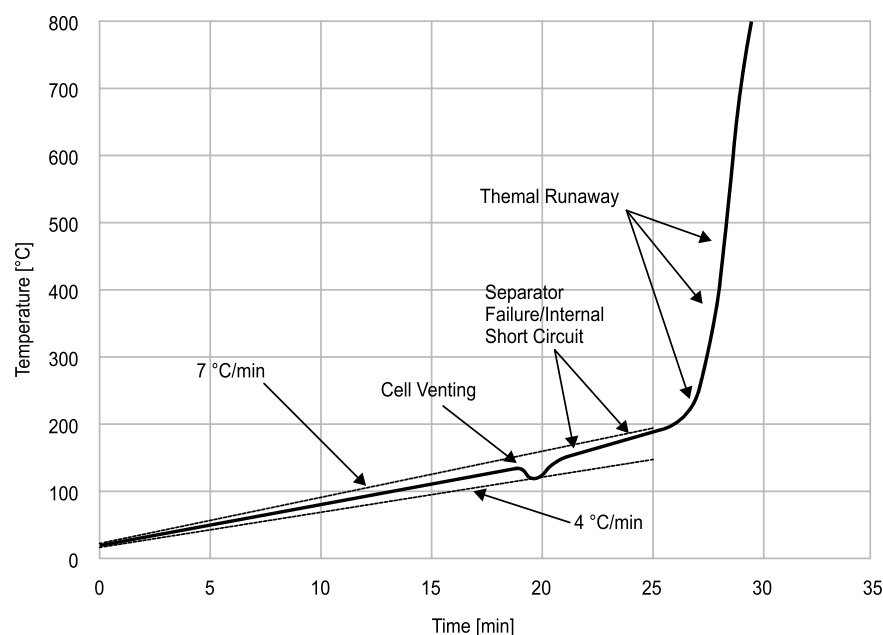
7.3.1.8 With reference to [7.3.1.7](#), the specific locations in (a) – (c) may not be achievable based on the cell design. Therefore, additional or alternate thermocouple locations shall be selected to measure heater ramp rate, cell surface temperature, and to identify the time of cell venting and the cell surface temperature at the time of venting.

7.3.1.9 The thermocouple locations referenced in [7.3.1.7](#) and [7.3.1.8](#) shall not interfere with the cell operation for charging, discharging or the thermal runaway behavior of the cell. All thermocouple locations shall be documented.

7.3.1.10 The temperature and the time at which the cell vents due to internal pressure rise prior to thermal runaway shall be documented. If using the other cell abuse methods, the thermocouples shall be located at the same locations on the cells as noted in [7.3.1.7](#) or [7.3.1.8](#), as applicable.

7.3.1.11 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 [4.19](#), 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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7.3.1.12 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 [4.19](#), 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.

7.3.1.13 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