JOINT CANADA-UNITED STATES
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

SCC FOREWORD

National Standard of Canada

A National Standard of Canada is a standard developed by a Standards Council of Canada (SCC) accredited Standards Development Organization, in compliance with requirements and guidance set out by SCC. More information on National Standards of Canada can be found at www.scc.ca.

SCC is a Crown corporation within the portfolio of Innovation, Science and Economic Development (ISED) Canada. With the goal of enhancing Canada's economic competitiveness and social well-being, SCC leads and facilitates the development and use of national and international standards. SCC also coordinates Canadian participation in standards development, and identifies strategies to advance Canadian standardization efforts.

Accreditation services are provided by SCC to various customers, including product certifiers, testing laboratories, and standards development organizations. A list of SCC programs and accredited bodies is publicly available at www.scc.ca.

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.

ANSI/UL 9540A-2025

MARCH 12, 2025

1

ANSI/CAN/UL 9540A:2025

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, 2019

Fifth Edition

March 12, 2025

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

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.

No Text on This Page

CONTENTS

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.

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

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

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

TC 9540 Membership

Name	Representing	Interest Category	Region
Robert Accosta Jr	Arup	General Interest	USA
Matt Allen	Country Fire Authority	Authorities Having Jurisdiction	Australia
Anujkumar Amin	CSA Group	Testing & Standards Org.	Ontario, Canada
Gary Balash	East Penn MFG Co Inc	Producer	USA
Mark Baldassari	Enphase Energy INC	Producer	USA
James Barrett	Enel-X	Producer	USA

TC 9540 Membership Continued on Next Page

TC 9540 Membership Continued

Name	Representing	Interest Category	Region
Michael Barry	Exponent INC	General Interest	USA
Arjun Bhattarai	VFlowTech Pte Ltd	Producer	Singapore
Mark Boone	AEGIS	General Interest	USA
Ward Bower	Ward Bower Innovations LLC	General Interest	USA
William Brooks	Brooks Engineering LLC	General Interest	USA
Troy Chatwin	GE Transportation A Wabtec Company	Producer	USA
Dan Cheddi	Electrical Safety Authority	Authorities Having Jurisdiction	Ontario, Canada
Among Chen	DEKRA	Testing & Standards Org.	China
Kristy Chen	Institution of Fire Engineers (Singapore)	General Interest	Singapore
Man Chen	CSG Power Generation Company	Commercial / Industrial User	China
Sicong Chen	Shanghai Testing & Inspection Institute of Electrical Equipment Co, Ltd	Testing & Standards Org.	China
Yonghan Ching	Cummins Power Generation	Producer	USA
Seong Il Cho	Samsung SDI Co Ltd	Producer	South Korea
Christopher Connell	Fronius USA LLC	Supply Chain	USA
Joshua Costello	County of Los Angeles Fire Department	Authorities Having Jurisdiction	USA
Thomas De Lucia	Ambri	Producer	USA
Kevin Digenova	Nova Quest, LLC	General Interest	USA
Benjamin Ditch	FM Global	Testing & Standards Org.	USA
Steve Douglas	QPS Evaluation Services	Testing & Standards Org.	Ontario, Canada
Ben Echeverria	Burns & McDonnell	Supply Chain	USA
Steve Edley	self	Producer	British Columbia, Canada
Erinc Eslik	Wartsila	Producer	USA
Zhu (Drew) Feng	Xiamen Ampace Technology Limited	Producer	China
Carl Ferlitch Jr	Chubb Insurance	General Interest	USA
Jason Fisher	Solar Technical Consulting LLC	General Interest	USA
Kevin Fok	LG Energy Solution Vertech	Supply Chain	USA
John Frasca	Zurich Insurance PLC	General Interest	USA
Pravinray Gandhi	self	General Interest	USA
Philip Gass	Iisd	General Interest	Switzerland
Kara Gerczynski	Elizabeth Fire Protection District	Authorities Having Jurisdiction	USA
Kevin Glubrecht	Alberta Municipal Affairs	Government	Alberta, Canada
Keith Goshia	EOS Energy	Producer	USA
Jason Haer	Lunar Energy	Producer	USA
Bryan Hardman	TMEIC Corp	Producer	USA
Robert Hattier	IBEW Local 134	General Interest	USA
Paul Hayes	American Fire Technologies Inc	Commercial / Industrial User	USA
Sha He	self	General Interest	Québec, Canada

TC 9540 Membership Continued on Next Page

TC 9540 Membership Continued

Name	Representing	Interest Category	Region
Manuel Hernandez	National Research Council Canada	Government	British Columbia, Canada
Martin Herzfeld	California Contractors	Supply Chain	USA
Asep Hidayat	PT International Chemical Industry (Representing BSN)	International Delegate	Indonesia
Steven Higgins	Surrette Battery	Supply Chain	Nova Scotia, Canada
Ken Hill	EnerSys Delaware Inc	Producer	USA
Zheng Huang	Svolt	Producer	China
Vitaliy Ilkiv	TÜV SÜD Canada	Testing & Standards Org.	Ontario, Canada
Aditya Iyer	Intertek Testing Services NA, Inc	Testing & Standards Org.	USA
Pete Jackson	City of Bakersfield	Authorities Having Jurisdiction	USA
Vikram Jayanath	Rolls-Royce Power Systems - Rolls-Royce Solutions America Inc	Producer	USA
Tracy Johnson	Zarges, Inc.	Supply Chain	USA
Vincent Jolissaint	Cobalt Power Systems	Supply Chain	USA
Jay Kadiwala	U.S. Consumer Product Safety Commission	Non-voting	USA
Omar Kalim Vazquez	SGS	Testing & Standards Org.	Spain
Larry Kane	IHI Energy Storage	Producer	USA
Chad Kennedy	Schneider Electric USA, Inc	Producer	USA
Richard Kluge	Ericsson INC	Commercial / Industrial User	USA
Jason Knedlhans	Peregrine Energy Solutions LLC	Commercial / Industrial User	USA
Andrew Laib	Safe Labs	Testing & Standards Org.	USA
Scott Lang	Honeywell International Inc	Producer	USA
Yan Li	State Grid Jiangsu Electric Power Co Ltd	Commercial / Industrial User	China
Haiwen Liu	TUV Rheinland Of North America Inc	Testing & Standards Org.	USA
Michael Maiz	FDNY	Authorities Having Jurisdiction	USA
Methode Maniraguha	self	General Interest	USA
Jonathan McCormick	Tesla Motors Inc	Producer	USA
Colin Mckean	Canadian Battery Association	General Interest	Ontario, Canada
Pierce Meier	Vistra Corporation	Commercial / Industrial User	USA
Andrew Miraldi	Miraldi Engineering - FZSONICK	Producer	USA
Alena Mitchell	Powin	Producer	USA
Kamran Moradi	8minute Solar Energy	Commercial / Industrial User	USA
Juergen Mueller	Kulr Technology	Supply Chain	USA
Randi K. Myers	UL Standards & Engagement	TC Chair – Non-voting	USA
Alli Nansel	Form Energy	Producer	USA
Brian O'Connor	National Fire Protection Association	Testing & Standards Org.	USA
Per Onnerud	Cadenza Innovation INC	Supply Chain	USA

TC 9540 Membership Continued on Next Page

TC 9540 Membership Continued

Name	Representing	Interest Category	Region
Steve Orlowski	Sundowne Building Code Consultants, LLC	General Interest	USA
Matthew Paiss	Pacific Northwest National Laboratory	Government	USA
Radhe Patel	Bureau Veritas	Testing & Standards Org.	USA
Justin Perry	Dominion Energy	Commercial / Industrial User	USA
Guy Pomerleau	Blue Solutions Canada Inc	Producer	Québec, Canada
Douglas Powell	Microvast / Energy Division	Producer	USA
Robert Richard	Hazmat Safety Consulting LLC	General Interest	USA
Richard Riley	Sonnen Inc	Producer	USA
Ronald Rispoli	Entergy Services	Commercial / Industrial User	USA
James Rogers	Town Of OAK Bluffs	Authorities Having Jurisdiction	USA
Paul Rogers	International Association Of Fire Fighters	General Interest	USA
David Rosewater	Sandia National Laboratories	Government	USA
Seth Sanders	Amber Kinetics Inc	Producer	USA
Steve Sappington	Caterpillar, Inc	Producer	USA
Michael Savage	Marion County, FL	Authorities Having Jurisdiction	USA
Ralf Schimanek	Fluence Energy LLC	Producer	Germany
Alejandro Schnakofsky	GritEnergy	General Interest	USA
Karl Schuetze	Active Power Inc	Producer	USA
LaTanya Schwalb	UL Solutions	Testing & Standards Org.	USA
Mayur Shinde	Rivian Automotive LLC	Producer	USA
Glenn Skutt	Fermata Energy	Supply Chain	USA
Douglas Smith	West Coast Code Consultants (WC3)	General Interest	USA
Tony Song	Invenergy	Commercial / Industrial User	USA
Jeffrey Spies	Planet Plan Sets	General Interest	USA
Mike Staples	City Of Victoria	Non-voting	British Columbia, Canada
Robert Steele	Columbia Power Systems Inc	Commercial / Industrial User	USA
Daniel Stevens	AXIS Capital	General Interest	United Kingdom
Leo Subbarao	Subbarao Technologies LLC	General Interest	USA
Samuel Sudler III	SEA LTD	General Interest	USA
Jin Suzuki	Tohoku Murata Manufacturing Co Ltd	Producer	Japan
Liang Tang	China Energy Storage Alliance (CNESA)	General Interest	China
Neelesh Thakkar	Thakkar Consulting LLC	General Interest	USA
Chris Thompson	Solaredge Technologies Inc	Producer	USA
Gary Thompson	Toronto Hydro	Commercial / Industrial User	Ontario, Canada
Lixia Tian	Shanghai Makesens Energy Storage Technology Co, Ltd	Supply Chain	China

TC 9540 Membership Continued on Next Page

TC 9540 Membership Continued

Name	Representing	Interest Category	Region
Chris Towski	Cambridge Fire Department/International Association of Fire Fighters	Authorities Having Jurisdiction	USA
Jordan Valentin	Nuvation	Supply Chain	Ontario, Canada
Megan Van Heirseele	UL Standards & Engagement	TC Project Manager – Non-voting	USA
Jinze Wang	Fortress Power	Producer	USA
Qingsong Wang	University of Science and Technology of China (USTC)	General Interest	China
Donald Warfield	Ameresco Solar	Producer	USA
Nicholas Warner	Energy Storage Response Group	General Interest	USA
Mike Watson	Mitsubishi Power Americas	Producer	USA
Jia Weimin	Beijing Much Fireproof & Insulation Materials Co Ltd	Supply Chain	China
Zak Wellman	Simpliphi Power	Producer	USA
Angie Wiese	City of St Paul	Authorities Having Jurisdiction	USA
Steven Wilkie	NEW York Power Authority	Government	USA
Robert Wills	Intergrid LLC	Producer	USA
Siew Wong	Power Automation PTE Ltd	General Interest	Singapore
Minje Woo	LG Energy Solution	Producer	South Korea
Steve Wurmlinger	SMA Solar Technology AG	Supply Chain	USA
Hongbin Xu	Guangzhou MCM Certification And Testing Co Ltd	Testing & Standards Org.	China
Xiao Yan	Volta Institute of Digital Battery Energy Storage	General Interest	China
Zhu Yunzheng	Zhejiang Lab/Intelligent Robot Research Center	General Interest	USA
Ang Zhu	Morningstar Corp	Supply Chain	USA

International Classification for Standards (ICS): 13.220; 27.100; 29.220

For information on ULSE Standards, visit https://www.shopulstandards.com, call toll free 1-888-853-3503 or email us at ClientService@shopULStandards.com.

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.

CETTE NORME NATIONALE DU CANADA EST DISPONIBLE EN VERSIONS FRANÇAISE ET ANGLAISE

No Text on This Page

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:

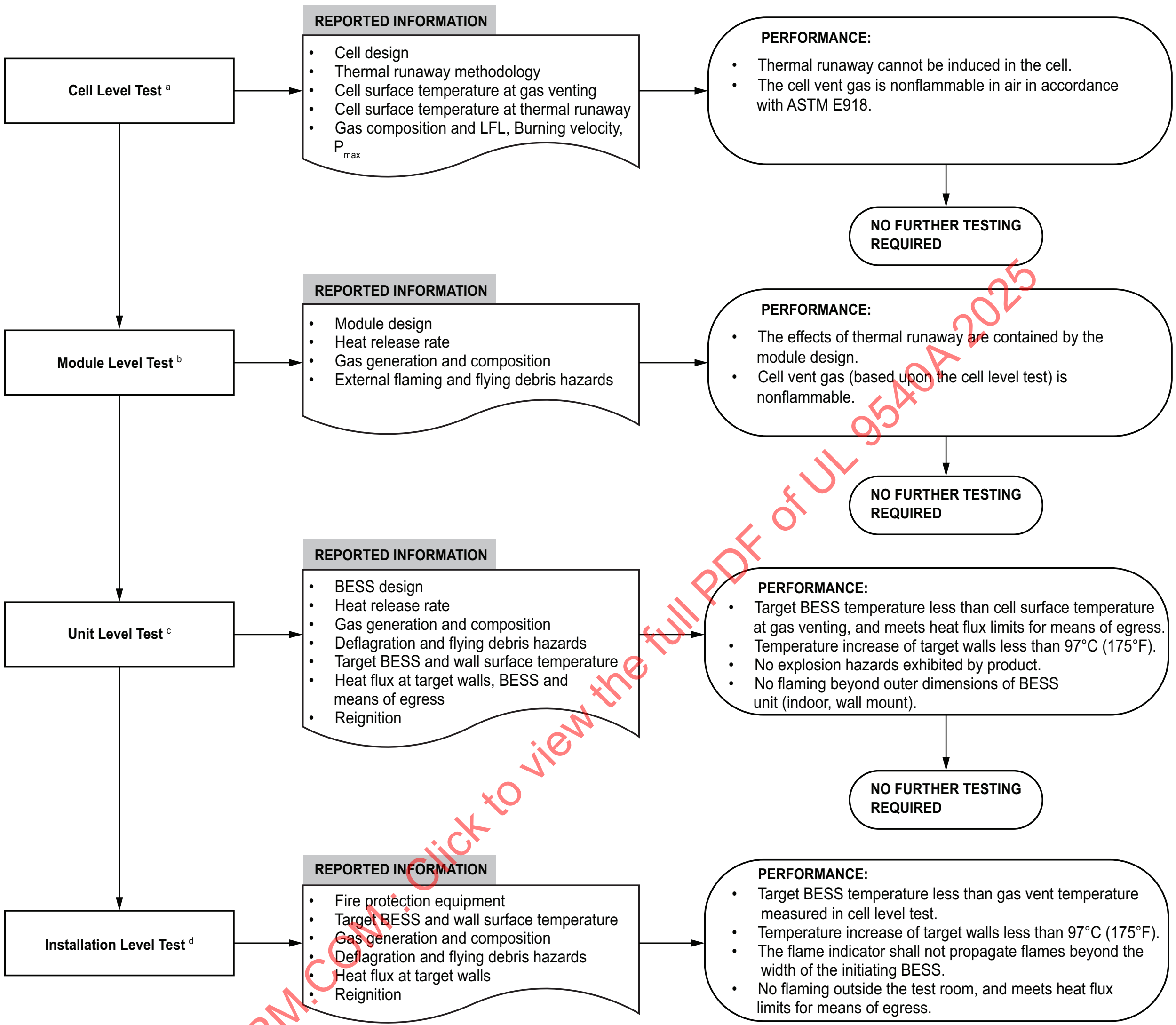
a) The purpose of the tests included in this Standard;

b) Explanation of individual tests; and

c) Interpretation and application of the results.

Figure 1.1

Schematic of Test Sequence



su3069d

[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 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 7.7.1 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.

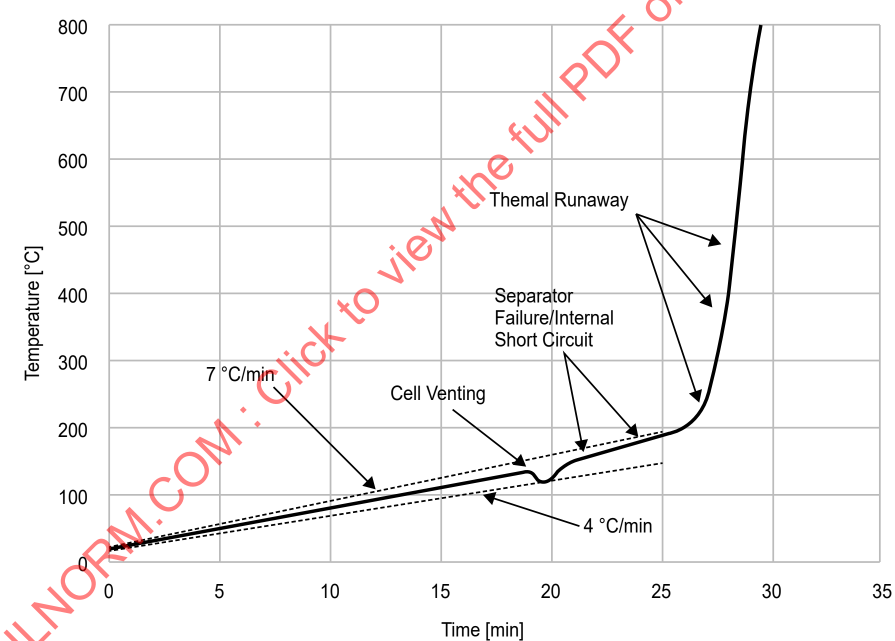
7.3.1.9 The thermocouple locations referenced in 7.3.1.7 and 7.3.1.8 shall not interfere with the cell operation for charging, discharging or the thermal runaway behavior of the cell. All thermocouple locations shall be documented.

7.3.1.10 The temperature and the time at which the cell vents due to internal pressure rise prior to thermal runway 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



su3433a

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 (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 (cell level test)

7.3.2.1 General

7.3.2.1.1 For flow battery technology, the propensity for thermal runaway shall be demonstrated by testing the energy reservoir according to the test methods of 7.3.2.1.2 or 7.3.2.1.3 as applicable to the flow battery technology to determine if the electrolytes are flammable. To conduct the testing of 7.3.2.1.2 and 7.3.2.1.3, a small representative flow battery test cell may be used to charge small quantities of electrolyte sufficient for testing purposes. The test shall be conducted in a fume hood if specified in the manufacturer's instructions for the test equipment.

NOTE 1: Some test equipment or test fixtures may off gas toxic vapors when heated above 200 °C (392 °F) due to their coatings. Also, some flow battery technologies may potentially off gas small amounts of toxic vapors during this testing. It is recommended that the test area be well ventilated or that testing be conducted under a laboratory hood and that appropriate personal protective equipment be worn.

NOTE 2: The selected test method may have additional requirements to provide a draft-free environment if tested in a fume hood.

7.3.2.1.2 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. The heating rate shall be permitted to be as low as 4 °C (7.2 °F) per minute unless the applicable test method specifies a higher rate. 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 and the testing can be concluded at this point. The flashpoint determination shall be conducted on charged electrolytes representing a fully charged state (100 % SOC). If discharging can occur due to natural mechanisms such as exposure to air over time, means to mitigate discharging as much as possible including conducting the flashpoint testing immediately after charging the electrolytes, shall be implemented.

Exception: Should a test method require a heating rate resulting in a temperature exceeding the limit of the coatings in the test instrument, the heating rate shall be 4 °C (7.2 °F).

7.3.2.1.3 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 7.3.2.1.2. If a flash point has been observed in 7.3.2.1.2, the propensity for thermal runaway shall be demonstrated by the test methods of 7.3.2.2.2 and comparing the temperatures recorded with the flash point temperature determined from 7.3.2.1.2.

7.3.2.2 Flow battery systems with two electrolytes

7.3.2.2.1 For flow battery systems with two electrolytes, the flammability of the liquid electrolytes shall be demonstrated by subjecting each charged electrolyte to the appropriate test method outlined in 7.3.2.1.2. If a flash point has been observed in 7.3.2.1.2, the propensity for thermal runaway shall additionally be demonstrated by the test methods of 7.3.2.2.2 and comparing the temperatures recorded during that test with the flash point temperature determined from 7.3.2.1.2.

7.3.2.2.2 The temperature increase possible due to a flow battery failure from a breakdown in the separation membrane where there are two electrolytes shall be demonstrated by charging the energy reservoirs in a test flow battery cell assembly to 100 % SOC, and then directly mixing an even amount of the two charged electrolyte materials in a closed container within approximately 1 minute. The amount of each electrolyte to be mixed shall not be less than 1.0 L of electrolyte. The closed container to be used for this test shall be sufficient to hold the total mixed quantity of electrolyte and shall be made of suitable materials to prevent a chemical reaction with the electrolyte mixture. The mixed solution temperature shall be measured continuously during the test. The test shall conclude when the temperature of the solution stabilizes for a minimum of 1 hour. The maximum mixing temperature of the sample shall be recorded and compared with the flash point temperature results from 7.3.2.1.2.

NOTE: The method of mixing the electrolytes can be accomplished through a number of methods including use of a magnetic stirrer, circulating pump or other mechanism to result in a mixed solution.

7.3.2.2.3 In addition, a test battery representative of the two electrolyte flow battery system shall be subjected to a unit level test in accordance with 9.9 and comparing the temperatures of the energy reservoir recorded during those tests with the flash point temperature determined from 7.3.2.1.2.

7.3.2.3 Flow battery systems with one electrolyte

7.3.2.3.1 For flow battery technologies with one active electrolyte containing solid metal particles the appropriate test method of 7.3.2.1.2 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 7.3.2.1.2, the propensity for thermal runaway shall be demonstrated by the flow battery module level test methods of 9.9 and comparing the temperatures of the energy reservoir recorded during those tests with the flash point temperature determined from 7.3.2.1.2.

7.3.3 Vented and valve regulated lead acid and Ni-Cd battery thermal runaway determination tests

7.3.3.1 Vented and valve regulated lead acid and Ni-Cd batteries shall be subjected to the Overcharge Thermal Runaway Test of Appendix H of UL 1973 and as noted 7.3.3.2 – 7.3.3.8. This test is conducted on 3 samples of a single cell or multi-cell monobloc battery and is intended to determine if the cell or battery can be driven into thermal runaway.

7.3.3.2 Prior to testing, testing the samples shall be conditioned in accordance to 7.2 and then discharged down to their specified end of discharge condition.

7.3.3.3 During the test, the samples shall be installed in an alcove painted black and separated from the wall by the minimum separation distances recommended by the manufacturer for the end use application. The DUT under test shall be surrounded by target cells or batteries spaced to represent the minimum clearance distances between cells or batteries specified by the manufacturer. Target cells or batteries may be either discharged samples or just the external casing of the cells or batteries.

7.3.3.4 Temperatures on the DUT case, the target cells or batteries and adjacent walls shall be measured during the test and the maximum measured temperatures shall be recorded.

7.3.3.5 During testing, the samples are draped in a single layer of cheesecloth indicator. Temperatures on the casing are monitored. The cheesecloth indicator 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.

7.3.3.6 During the test, temperatures on the cell or battery casings were measured and recorded.

7.3.3.7 The cells/batteries are to be charged at the maximum charging current at constant current charging until the maximum voltage as noted below in (a) and (b) is reached. The charging is then continued at constant voltage charging for 168 hours.

a) 2.50 V/cell for VLA and VRLA cells and batteries; or

b) 1.67 V/cell for nickel-cadmium cells and batteries.

7.3.3.8 After testing, the samples shall be examined for evidence of fire or explosion.

7.3.4 High temperature battery thermal runaway determination tests

7.3.4.1 The cell shall be charged in accordance with the manufacturer's specifications to 100 % state of charge. A minimum of three thermocouples shall be placed on the external surface of the cell with one located in the center of the long side of the cell and the other two spaced evenly and located on either side of the central thermal couple. The cells shall be heated to the manufacturer's specified operating temperature prior to failing the cell and shall remain heated throughout the test. The open circuit voltage of the cell shall be monitored during the test. A total of four cell samples are to be subjected to this test.

7.3.4.2 The fully charged cells shall be charged using the charging method outlined in the Single Cell Overcharge method in the Annex for Cell Failure Methods of UL 1973, until the cell voltage drops below the limit set by the cell manufacturer. The charging shall be stopped at this point and the cell's behavior as a result of the overcharge shall be observed. The external heating of the cell in accordance with the manufacturer's operating specifications shall be continued after this point.

Exception No. 1: Heating of the cell may also be discontinued after the charging has been stopped if the heater control cannot be maintained after the cell reaches thermal runaway.

Exception No. 2: If thermal runaway cannot be achieved through overcharging the cells, other methods such as a short circuit or nail penetration test as outlined in the Annex for Cell Failure Methods of UL 1973 shall be used to try to achieve thermal runaway.

7.3.4.3 When the cell surface temperature has returned to steady state, the external heating can be stopped and the cell shall be allowed to cool to room temperature and examined for evidence of rupture of the casing and release of internal active materials. The location of any rupture as the result of the test shall be examined and documented.

7.3.4.4 With reference to 7.3.4.3, steady state temperature is considered to have been achieved when three successive readings, taken at intervals of 10 % of the previously elapsed duration of the test, but not less than 5-minute intervals, indicates no increase.

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-gallon) 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.

Exception: High temperature batteries such as sodium beta and molten salt batteries typically are hermetically sealed and do not have vents or weakened areas to relieve pressure in the way cells such as lithium ion cells do. Upon failure, the casings may rupture and leak molten liquid or other internal contents *of the cell. Therefore, there is no vent gas to collect so gas collection in accordance with this clause is not required.*

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 7.3.2.1.2 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 7.3.2.2.2 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 Off gas composition for vented and valve regulated lead acid and Ni-Cd batteries

7.6.1 The cell vent gas composition test of 7.4 shall be conducted on a cell or monobloc battery driven into thermal runaway on a separate sample. If unable to capture the gas with the samples in the pressure vessel as noted in the 7.4 method, the gas shall be captured from the vent/valve assembly to a gas collection vessel.

Exception: Instead of the off gas testing outlined in 7.4, the combustible off gas composition from vented and valve regulated lead acid and Ni-Cd batteries under a thermal runaway condition may be determined through applicable calculations in accordance with IEEE 1635/ASHRAE Guide 21. The calculated off gassing can be determined in accordance with the values in Table 7.1. If using this calculation method, the LFL, burning velocity and P_{max} properties of the vented gas will be based upon the following Hydrogen gas properties in (a) – (c). The total volume of hydrogen in m^3 that is off gassed is determined using the calculated H_2 rate from the formulas above for a time period of 168 hours.

a) 4 % volume in air LFL;

b) 317 cm/s burning velocity; and

c) 7.9 ± 0.3 bar for P_{max}.

Table 7.1
Off Gassing Calculations

Battery type	Off gassing formula based upon test values used	
	Calculation using C_x (m^3/s)	Calculation Using P_{15} (m^3/s)
VLA, lead-calcium and pure lead	$H_{2\text{-rate}} = 1.99 \times 10^{-10} \times n_c \times C_8$	$H_{2\text{-rate}} = 1.53 \times 10^{-7} \times n_c \times P_{15}$
VLA, lead-antimony, EOL	$H_{2\text{-rate}} = 3.98 \times 10^{-9} \times n_c \times C_8$	$H_{2\text{-rate}} = 1.02 \times 10^{-6} \times n_c \times P_{15}$
VLA, lead-selenium, EOL	$H_{2\text{-rate}} = 5.47 \times 10^{-10} \times n_c \times C_8$	$H_{2\text{-rate}} = 1.40 \times 10^{-7} \times n_c \times P_{15}$
VLA, lead-selenium, EOL	$AsH_{3\text{-rate}} = 8.83 \times 10^{-15} \times n_c \times C_8$	$AsH_{3\text{-rate}} = 2.25 \times 10^{-12} \times n_c \times P_{15}$
VLA, lead-selenium, EOL	$SbH_{3\text{-rate}} = 1.02 \times 10^{-13} \times n_c \times C_8$	$SbH_{3\text{-rate}} = 2.60 \times 10^{-11} \times n_c \times P_{15}$
VRLA, AGM	$H_{2\text{-rate}} = 1.54 \times 10^{-10} \times n_c \times C_8$	$H_{2\text{-rate}} = 3.86 \times 10^{-8} \times n_c \times P_{15}$
VRLA, gel	$H_{2\text{-rate}} = 4.48 \times 10^{-10} \times n_c \times C_8$	$H_{2\text{-rate}} = 1.12 \times 10^{-7} \times n_c \times P_{15}$
Ni-Cd, sintered/PBE, pocket, fiber	$H_{2\text{-rate}} = 3.50 \times 10^{-9} \times n_c \times C_5$	–
Ni-Cd, foamed/PBE	$H_{2\text{-rate}} = 6.61 \times 10^{-10} \times n_c \times C_5$	–
Ni-Cd, partially recombinant	$H_{2\text{-rate}} = 1.74 \times 10^{-10} \times n_c \times C_5$	–

$H_{2\text{-rate}}$ – The hydrogen gas release rate in m^3/s at standard sea level atmospheric pressure and 25 °C (77 °F)

$AsH_{3\text{-rate}}$ – The arsine gas release rate in m^3/s at standard sea level atmospheric pressure and 25 °C (77 °F)

$SbH_{3\text{-rate}}$ – The stibine gas release rate in m^3/s at standard sea level atmospheric pressure and 25 °C (77 °F)

VLA – Vented lead acid

EOL – End of Life *(considered worse case off gassing stage)*

VRLA – Valve regulated lead acid

PBE – Plastic Bonded Electrode

n_c – Number of cells in device under test

P_{15} – Is the 15 minute kW/cell rating of a lead-acid cell to 1.67 V at 25 °C (77 °F)

C_8 – Is the 8 hour ampere-hour rating of a lead-acid cell to 1.75 V at 25 °C (77 °F)

C_5 – Is the 5 hour ampere-hour rating of a NiCd cell to 1.0 V at 20 °C (68 °F)

NOTE: Lead acid batteries may also off gas H_2S towards the end of thermal runaway, but there is no calculation for this determination. The methods of 7.4 may be used if the volume of H_2S off gassed is requested.

7.6.2 The volume of hydrogen gas measured during the testing or calculated, shall be provided in the report. This value can be utilized in the end use to determine the suitable deflagration/explosion protection.

NOTE 1: Annex A outlines the approach to addressing the off gassing data to aid in determining the need for deflagration/explosion protection and to inform that design in accordance with NFPA 68 and NFPA 69. Information on explosion control addressing the unique properties for hydrogen can be found in the Hydrogen Explosion Control Annex of NFPA 2.

NOTE 2: The ICC IFC, NFPA 1 and NFPA 855 require that installations of these types of batteries be provided with ventilation in accordance with those codes.

7.7 Cell level test report

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

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

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

f) Methods attempted and used to initiate thermal runaway;

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

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

i) Flammable gas generation and composition measurements;

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

k) Burning velocity of the cell vent gas; and

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

7.7.2 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) Electrolyte(s) composition;

d) Electrolyte quantities used for testing (flashpoint test and mixing test if applicable);

e) Whether or not a flashpoint was determined;

f) Flash point temperatures determined for each charged electrolyte (if applicable);

g) Temperature of the mixed charged electrolytes (two electrolyte system if applicable); and

h) Flammable off gas generation and composition measurements.

7.7.3 The report on vented and valve regulated lead acid and Ni-Cd battery thermal runaway determination testing shall include the following:

a) Cell or monobloc manufacturer name and cell model number;

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

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

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

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

f) Open-circuit voltage of the cell or battery at initiation and end of test;

g) Overvoltage charge parameters 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 if gas is captured per 7.4;

Exception: The calculated value for total volume of hydrogen per the Exception to 7.6.1.

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

l) Burning velocity (S_u) of the cell or battery vent gas;

m) P_{max} of the cell or battery vent gas,

n) Separation distance from the initiating cell or battery to target walls;

o) Separation distance from the initiating cell or battery to target cell or battery;

p) The maximum wall surface and target cell or battery temperatures achieved during the test and the location of the measuring thermocouple.

7.7.4 The report on high temperature battery thermal runaway determination testing shall include the following:

a) Cell manufacturer name, cell chemistry and cell model number;

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

c) The nominal voltage and rated energy storage capacity of the cell (e.g. Ampere-hours);

d) Voltage, temperature and current obtained during conditioning of the cell;

e) Open-circuit voltage of the cell at initiation and end of test;

f) Overvoltage charge parameters used to initiate thermal runaway or details of other failure method(s) per exception of 7.3.4.2 used to initiate thermal runaway;

g) Surface temperature (and location of maximum temperature) prior to thermal runaway and average temperature of the samples tested;

h) Evidence of rupture or explosion of the cell shall be documented; and

i) The location of casing rupture and evidence of emission of molten active material shall be documented.

7.8 Performance – cell level test

7.8.1 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.

7.9 Performance – flow battery thermal runaway determination tests

7.9.1 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 7.3.2.1.2 do not ignite; and

b) For flow battery systems with two electrolytes, the maximum temperature of the mixed solution measured in accordance with 7.3.2.2.2 is lower than 200 °C (392 °F).

7.10 Performance – vented and valve regulated lead acid and Ni-Cd thermal runaway determination tests

7.10.1 For vented and valve regulated lead acid and Ni-Cd batteries, no further testing (i.e. unit level and installation level) is required if thermal runaway cannot be induced in the cell or monobloc battery during the vented and valve regulated lead acid and Ni-Cd battery thermal runaway determination test.

7.10.2 Surface temperature measurements on wall surfaces shall not exceed 97 °C (175 °F) of temperature rise above ambient.

7.10.3 Temperatures on the surface of the target battery cases shall not exceed the temperature rating of the casing material (RTI with impact) or the maximum temperature specification for short term operation, whichever is less.

7.10.4 The results from the thermal runaway determination test can be scaled in accordance with the smallest anticipated installation room or area.

7.11 Performance – High temperature battery thermal runaway determination tests

7.11.1 For high temperature batteries, no further testing (i.e. module level, unit level and installation level) is required if thermal runaway cannot be induced in the cell or there is no evidence of rupture of the cell casing and emission of cell internal contents.

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 hours 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 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.

8.1.3 Prior to initiating the test, the module voltage shall be measured at the module terminals and recorded. If the module is not in a fully charged condition, the module shall be charged again as noted in 8.1.2 and this value shall be recorded.

8.1.4 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 unless the module is consumed by fire, which shall be indicated in the report.

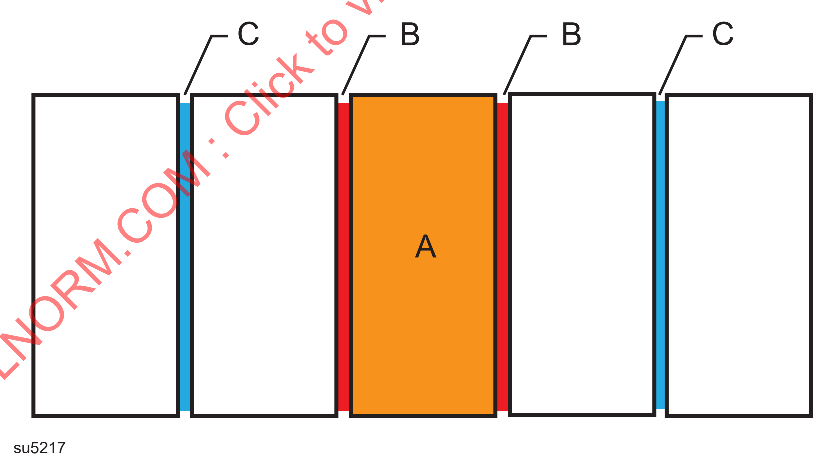
8.2.4 The number of cells within the module that are forced into thermal runaway can be one or multiple cells and is dependent upon the energy contained within the individual cells and the design of the module. The results of the cell test and the design of the module shall inform the approach taken with the goal to achieve cell to cell thermal runaway propagation within the module. 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 With reference to 8.2.4, a sufficient number of cells shall be forced into thermal runaway to create a condition of cell to cell thermal runaway propagation within the module. Cell to cell thermal runaway propagation occurs when at least one additional non-initiating cell goes into thermal runaway during the test. If non-initiating cells only vent during the test, this is not considered a thermal runaway propagation. If thermal runaway propagation is not achieved, the test shall be repeated with additional cells forced into thermal runaway. For example, module designs with a cell capacity larger than 10 Ah may need no more than 3 cells forced into thermal runaway, and module designs with a cell capacity less than 10 Ah may need no more than the equivalent of 30 Ah of cells forced into thermal runaway. Temperatures shall be measured on the initiating cells and nearby non-initiating cells to determine cell to cell thermal runaway propagation. If cell to cell thermal runaway propagation is not achieved with additional initiating cells, then it can be determined that thermal runaway propagation is not possible.

NOTE: To establish a cell to cell thermal runaway propagation event within a module, it may be necessary to remove any thermal insulator or electrical insulation between the heater and the initiating cell(s) to allow for placement of the heater without significantly altering the design of the module. See Figure 8.1.

Figure 8.1

Example of Initiating Cell in a Module Using a Flexible Film or External Heater



A – Initiating cell

B – Heater (shown in red) with thermal insulator or electrical insulation removed, as necessary, to accommodate heater placement

C – Thermal insulator or electrical insulation between cells (shown in blue)

8.2.6 With reference to 8.2.5, temperatures shall be measured on the initiating cells and nearby non-initiating cells to determine thermal runaway propagation. Temperatures shall also be measured on the exterior surface of the module enclosure in the area closest to the initiating cell location(s).

8.2.7 The methodology used for initiating thermal runaway in accordance with 7.3 shall be used to initiate thermal runaway within the module.

8.2.8 With reference to 8.2.7, occurrence of thermal runaway shall be verified by sustained temperature above the cell surface temperature at the onset of thermal runaway, as determined in 7.3.1.11.

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

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

8.2.11 The chemical heat release rate shall be measured for the duration of the test. See 8.2.12.

8.2.12 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 8.2.13.

8.2.13 With reference to 8.2.12, calculate the chemical heat release rate at each of the flows as follows:

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

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:

$$\phi = \frac{X^{\circ}_{O_2} \times [1 - X_{CO_2} - X_{CO}] - X_{O_2} \times [1 - X^{\circ}_{CO_2}]}{X^{\circ}_{O_2} \times [1 - X_{O_2} - X_{CO_2} - X_{CO}]}$$

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)

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

$X^{\circ}_{H_2O}$ = 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)

8.2.14 The hydrocarbon content of the vent gas shall be measured using flame ionization detection. Hydrogen gas shall be measured with an appropriate sensor for the anticipated range of gas as well as for exposure to anticipated contaminants, such as a palladium-nickel thin-film solid state sensor. This may require multiple sensors to cover a wider range of concentrations depending on the anticipated cell off gas.

8.2.15 At the request of the BESS manufacturer, the hydrocarbon components of the vent gas composition may additionally 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 feet), or an equivalent gas analyzer. Velocity and temperature measurements respectively shall be obtained in the exhaust duct of the heat release rate calorimeter using equipment specified in 8.2.12.

8.2.16 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 8.2.17.

8.2.17 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 test method for high temperature batteries

8.3.1 The module test procedure as outlined in 8.2 shall be modified as noted in 8.3.2 – 8.3.5. During the test, the module shall be placed on top of a noncombustible horizontal surface with the module orientation representative of its intended final installation.

8.3.2 The module shall be fully charged prior to testing and heated to the manufacturer's specified operating temperatures. The module shall be provided with electrical connections to the cell(s) to be failed in order to overcharge the cell(s).

8.3.3 The cell failure test method as outlined in 7.3.4 shall be conducted on at least one cell within the module. During the test, the voltage of the cell(s) being failed as well as temperatures on the failed cell(s) and surrounding cells shall be monitored and documented. The voltage of the module shall be monitored during the test.

8.3.4 Thermocouples shall be placed on the external casing of the module to monitor any breakdown of thermal insulation in the module case. The chemical heat release rate, smoke release rate and gas measurements are not conducted.

8.3.5 The results of the cell(s) failure shall be observed and documented.

8.4 Module level test report

8.4.1 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;

o) Video of the test; and

p) Cell level test report summary.

8.4.2 The report on the high temperature battery module level testing of 8.3 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 at start and end of test;

f) Overvoltage charge parameters used to initiate thermal runaway or details of other failure method(s) per exception of 7.3.4.2 used to initiate thermal runaway, including number and locations of cells for initiating thermal runaway;

g) Observation(s) of flying debris, module enclosure rupture or explosive discharge of gases;

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

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

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

k) Maximum temperature measured on module case; and

l) Video of the test.

8.5 Performance at module level testing

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

a) Vent gas is nonflammable as determined by the cell level test;

b) There is no spread of flame outside of the module; and

c) The module exterior surface temperature does not exceed the cell venting temperature as measured adjacent to the initiating cell where the greatest thermal exposure is anticipated.

8.6 Performance at high temperature module level testing

8.6.1 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) There was no leakage of hazardous materials, rupture of the module casing or explosion with flying debris.

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 may 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;

i) Rooftop non-residential use BESS;

j) Rooftop residential use BESS; and

k) Open parking garage non-residential use BESS installations.

9.1.2 The unit level test requires one initiating BESS unit, in which a thermal runaway condition resulting in cell to cell thermal runaway propagation in accordance with the module level test in 8.2.4 is initiated, and adjacent target BESS units representative of an installation. Tests conducted for indoor floor mounted installations for residential BESS may be considered representative of both indoor floor mounted and outdoor ground mounted installations. 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 for residential BESS may be considered to also represent an outdoor installation. Examples of potential test configurations are shown in Figure 9.1, Figure 9.2, and Figure 9.3.

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 For outdoor non-residential use High Temperature Batteries installed in a container, the unit level test is waived as there is no additional information to be collected at the unit level for this technology when it is utilized for outdoor use only. Instead, the installation level test shall be conducted in accordance with 10.9.

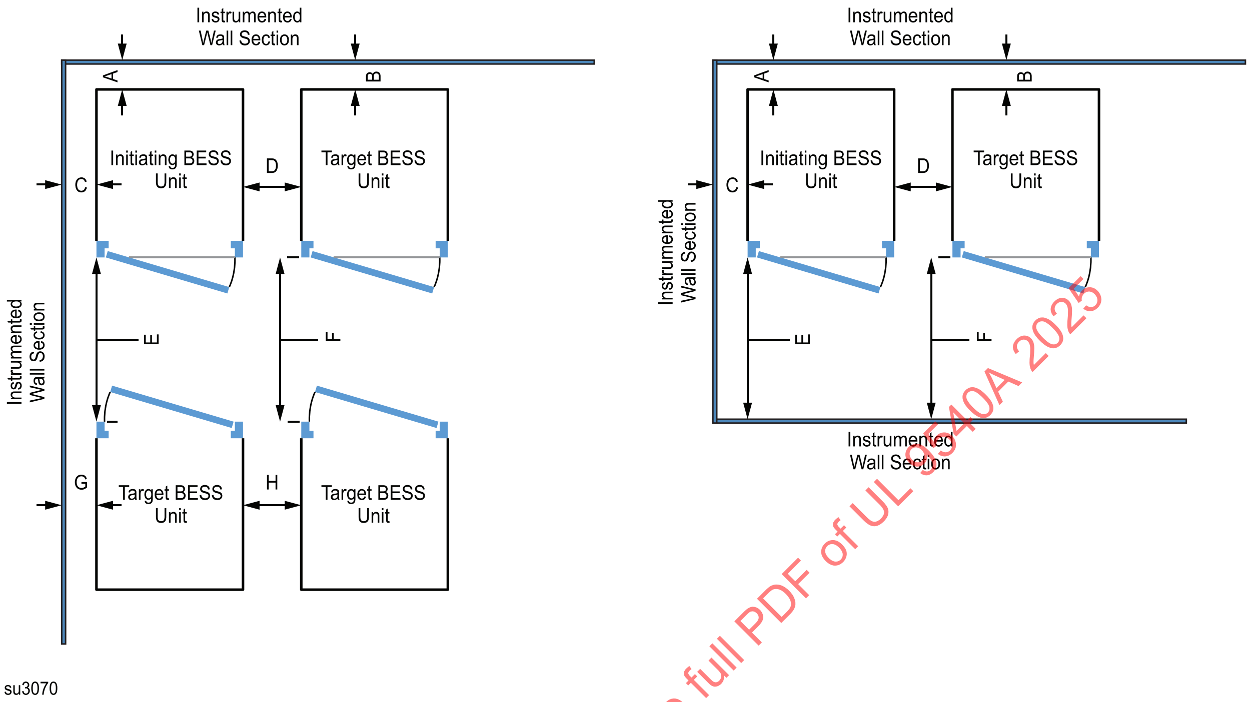
9.1.4 For installations, where the high temperature battery modules are not installed on racks but rather within separate compartments within the container, the module is considered the test unit for the test of 10.9. See 10.2.3 and 10.2.4.

9.1.5 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.

9.1.6 Where the manufacturer's instructions indicate that the BESS can be installed outdoors and in open parking garages less than 3 m (10 feet) from the means of egress or other exposures, testing shall be conducted as described in this Section.

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.

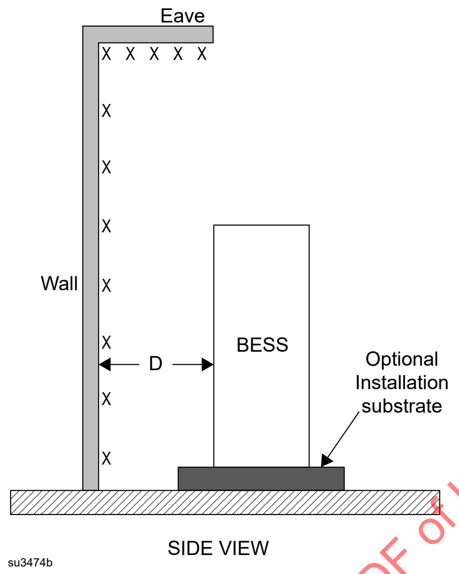
F = Separation distance between target BESS unit and target BESS unit or instrumented wall section.

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

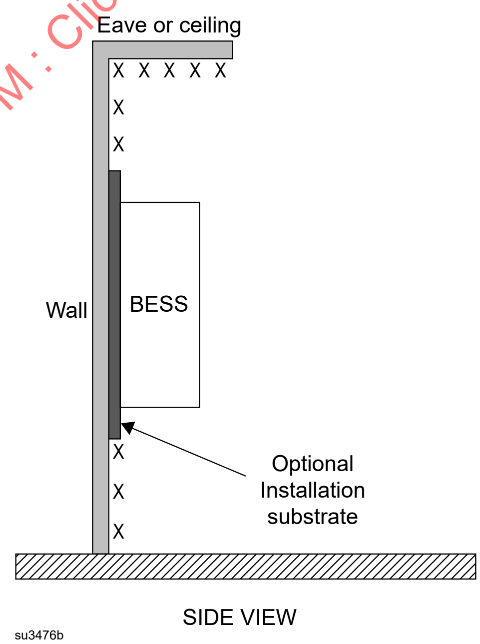


X – Denotes typical thermocouple locations, specific positions dependent on installation details.

D – Distance of ESS from external wall.

Figure 9.3

Example of Wall Mounted BESS Test Arrangement



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

9.1.7 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.

9.1.8 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 units may also include one live, populated module at the location of the highest anticipated temperature in the enclosure. The remaining target BESS unit module enclosures do not need to contain cells.

9.1.9 The initiating BESS unit shall be brought to the maximum operating state of charge (MOSOC) in accordance with the manufacturer's specifications and allowed to rest for a minimum of 1 hour at room ambient before the start of the test.

9.1.10 Prior to initiating the test, the voltage of the initiating module shall be measured and recorded. If the voltage drop is greater than 0.1 % of the fully charged voltage of the module, then the initiating BESS shall be charged again as noted in 9.1.9 and the voltage of the initiating BESS shall be recorded.

9.1.11 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.

9.1.12 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 864 that is external to the BESS, but provided as part of an integral fire suppression system per 9.1.11.

9.2 Test method – Indoor floor mounted BESS units

9.2.1 During an indoor 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 feet) horizontally beyond the exterior of the target BESS units.

9.2.5 Instrumented wall sections shall be at least 0.61-m (2-feet) taller than the BESS unit height, and not less than 2.13 m (7 feet) in height above the floor.

9.2.6 The surface of the instrumented wall sections shall be covered with gypsum wall board and painted flat black. An incremental visual reference shall be provided on the instrumented wall sections for scale so that flame extension can be accurately measured if applicable. The gypsum wall board shall be 13-mm (1/2-inch) thick at minimum.

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 8.2.17.

9.2.9 The chemical and convective heat release rates shall be measured for the duration of the test, using the methodologies specified in 8.2.13 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 $C_p = A_0 + A_1 T + A_2 T^2 + A_3 T^3$, 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 temperatures shall be measured in vertical array(s) at 152-mm (6-inch) 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. Temperatures shall be measured continuously, averaging over every 60-second interval per 6.3. The maximum of these averages shall be documented for each thermocouple location.

9.2.16 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.

9.2.17 Heat flux shall be measured with the sensing element of at least two water-cooled Schmidt-Boelter or Gardon gauges at the surface of each instrumented wall as follows in (a) – (c). Heat flux shall be measured continuously, averaging over every 60-second interval per 6.4. The maximum of these averages shall be documented for each gauge location.

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.

Exception: If (b) and (c) are deemed to be at the same location based on a construction review, only one gauge is required.

9.2.18 Heat flux shall be measured with the sensing element of at least two water-cooled Schmidt-Boelter or Gardon gauges at the surface of each adjacent target BESS unit that faces the initiating BESS unit as follows in (a) and (b). Heat flux shall be measured continuously, averaging over every 60-second interval per 6.4. The maximum of these averages shall be documented for each gauge location.

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.

Exception: If (a) and (b) are deemed to be at the same location based on a construction review, only one gauge may be installed on the target unit for the measurement.

9.2.19 For BESS intended for installation outdoors or in open parking garages covered by 9.1.6, heat flux shall be measured with the sensing element of at least one water-cooled Schmidt-Boelter or Gardon gauge positioned at the mid height of the initiating unit at the minimum horizontal distance from the BESS specified by the manufacturer or the point where the majority of off-gas venting is expected from the initiating unit. Heat flux shall be measured continuously, averaging over every 60-second interval per 6.4.

9.2.20 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. Temperatures shall be measured continuously, averaging over every 60-second interval per 6.3. The maximum of these averages shall be documented for each thermocouple location.

9.2.21 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.

9.2.22 Cell to cell thermal runaway propagation in accordance with the module level test in 8.2.4 shall be established 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).

9.2.23 The composition, velocity and temperature of the initiating BESS unit vent gases shall be measured within the calorimeter's exhaust duct as outlined in 8.2.12. The hydrocarbon content of the vent gas shall be measured using flame ionization detection. Hydrogen gas shall be measured with a palladium-nickel thin-film solid state analyzer. Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.

9.2.24 At the request of the BESS manufacturer, the hydrocarbon content of the vent gas may additionally 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 feet), or equivalent gas analyzer.

9.2.25 The test shall be terminated if:

a) There are three consecutive temperature readings measured inside each module within the initiating BESS unit that are determined to be falling over 15-minute intervals;

b) The modules return to a temperature less than 60 °C (140 °F);

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

d) A condition hazardous to test staff or the test facility requires mitigation; or

e) Flaming outside the test room is observed.

9.2.26 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 9.2. If intended for outdoor use only installations, including rooftop 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 9.2 except as noted in 9.3.3 and 9.3.4. 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-feet) tall with a 0.3-m (1-foot) 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-inch) plywood installed on wood studs and painted flat black. The instrumented wall shall extend not less than 0.49-m (1.6-feet) 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 9.2.15 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 BESS intended for wall mount installations shall only be tested using instrumented wall sections not less than 2.44 m (8 feet) in height and width, and with a 0.3-m (1-foot) wide horizontal ceiling as shown in Figure 9.3. The walls and ceiling shall be constructed with gypsum wall board installed on wood studs and painted flat black. The gypsum wall board shall be 13-mm (1/2-inch) thick at minimum. The instrumented wall shall extend not less than 0.49-m (1.6-feet) horizontally beyond the exterior of the target BESS units. The No. 24-gauge or smaller, Type-K exposed junction thermocouple array on the walls shall extend to the surface of the ceiling as shown in Figure 9.3.

9.4.3 When BESS are tested in accordance with 9.4.2, the initiating BESS unit shall be positioned with the center located 1.22-m (4-feet) above the floor or at a height in accordance with the manufacturer's installation instructions, 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 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 residential and non-residential BESS shall be in accordance with 9.2, except as modified in this section. See Figure 9.3. 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. Heat flux measurements for the accessible means of egress or in front of the BESS shall be measured in accordance with 9.2.19.

9.5.2 Test samples shall be mounted on an instrumented wall section that is a minimum of 3.66-m (12-feet) tall with a 0.3-m (1-foot) wide horizontal soffit (undersurface of the eave shown in Figure 9.3. The wall and soffit shall be constructed with 19.05-mm (3/4-inch) plywood installed on wood studs and painted flat black. An optional substrate of 13-mm (1/2-inch) or 16-mm (5/8-inch) exterior gypsum sheathing shall be permitted to be installed on the plywood. The instrumented wall shall extend not less than 0.49-m (1.6-feet) 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 9.2.15 shall extend to the surface of the soffit as shown in Figure 9.3.

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.

9.5.3 The initiating BESS unit shall be positioned on the instrumented wall, with its center located 1.22-m (4-feet) 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, and the soffit in the case of residential use BESS, shall be instrumented in accordance with 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 parking garage installations

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

9.6.2 If intended for rooftop and open parking 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.

9.6.3 BESS intended for installation on combustible roofs shall be mounted on constructed with 13-mm (1/2-inch) gypsum wall board painted flat black, or the mounting surface recommended by the manufacturer, also painted flat black.

9.6.4 Temperatures on the surface of the combustible roof assembly shall be measured under the center of the BESS and in horizontal array(s) at 152-mm (6-inch) intervals for a minimum 1 m (3.3 feet) from the edge of the initiating BESS unit using No. 24-gauge or smaller, Type-K exposed junction thermocouples. The thermocouples for measuring the temperature on roof surfaces shall be positioned in the roof locations anticipated to receive the greatest thermal exposure from the initiating BESS unit.

9.6.5 If the BESS is intended to be installed on combustible roof assemblies beneath PV panels, combustible materials, or other obstructions, the test shall be conducted with the ESS mounted underneath the obstructions, as specified by the manufacturer. The type of overhead obstruction used in the test shall be that which is anticipated to provide the greatest fire challenge. The vertical distances between the rooftop and the ESS, and between the ESS and the overhead obstruction shall be the minimum specified by the manufacturer. The overhead obstruction shall extend horizontally a minimum 2 m (6.6 feet) in all directions from the edges of the target BESS, unless lesser distances are specified by the manufacturer’s installation instructions.

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 parking 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, soffits as applicable, and thermocouples;

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) and target heat flux gauges;

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;

NOTE: The maximum target BESS temperature is averaged over 60 seconds.

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 if conducted indoors;

r) Peak smoke release rate and total smoke release data if conducted indoors;

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 unless mitigated by an engineered deflagration protection system;

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;

x) Photos and video of the test;

y) If the test is terminated in accordance with 9.2.25, the circumstances of the termination; and

z) Module level test report summary and cell level test report summary.

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[3)] 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 7.3.1.10; c) Surface temperature measurements on wall surfaces do not exceed 97 °C (175 °F) of temperature rise above ambient; d) Explosion hazards are not observed, including deflagration or detonation.
Outdoor Ground Mounted[1)]	a) Surface temperatures of modules[3)] 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 7.3.1.10; b) 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; c) Explosion hazards are not observed, including deflagration or detonation; and d) Heat flux measured at the minimum distance to a means of egress[2)] specified by the manufacturer 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[3)] 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 7.3.1.10; c) Surface temperature measurements on wall surfaces do not exceed 97 °C (175 °F) of temperature rise above ambient; and d) Explosion hazards are not observed, including deflagration or detonation.
Outdoor Wall Mounted	a) Surface temperatures of modules[3)] 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 7.3.1.10; b) Surface temperature measurements on wall surfaces do not exceed 97 °C (175 °F) of temperature rise above ambient; c) Explosion hazards are not observed, including deflagration or detonation; and d) Heat flux measured at the minimum distance to a means of egress[2)] specified by the manufacturer shall not exceed 1.3 kW/m^2.
Rooftop and Open Parking Garages	a) Surface temperatures of modules[3)] 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 7.3.1.10; b) Surface temperature measurements on wall surfaces do not exceed 97 °C (175 °F) of temperature rise above ambient; c) For BESS units intended for installation on combustible roof constructions, surface temperature measurements on roof surfaces do not exceed 97 °C (175 °F) temperature rise above ambient per 9.6.5; d) Explosion hazards are not observed, including deflagration or detonation; and e) For BESS units intended for installation in open parking garages, heat flux measured at the distance from the BESS to the means of egress[2)] shall not exceed 1.3 kW/m^2.
Residential Installations	
Indoor Floor Mounted	a) Charring or ignition of the cheesecloth indicator is not observed; b) Surface temperatures of modules[3)] 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 7.3.1.10; c) Surface temperature measurements on wall surfaces do not exceed 97 °C (175 °F) of temperature rise above ambient; d) Explosion hazards are not observed, including deflagration or detonation; and e) The concentration of flammable gas does not exceed 25 % LFL in air for the smallest specified room installation size.

Table 9.1 Continued on Next Page

Table 9.1 Continued

Installation	Performance Criteria
Outdoor Ground Mounted	a) Flaming outside the initiating BESS unit is not observed. b) Surface temperatures of modules[3)] 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 7.3.1.10; 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; d) Explosion hazards are not observed, including deflagration or detonation; and e) Heat flux measured at the minimum distance to a 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[3)] 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 7.3.1.10; c) Surface temperature measurements on wall surfaces do not exceed 97 °C (175 °F) of temperature rise above ambient; d) Explosion hazards are not observed, including deflagration or detonation; and e) The concentration of flammable gas does not exceed 25 % LFL for the smallest intended room installation size.
Outdoor Wall Mounted	a) Charring or ignition of the cheesecloth indicator is not observed; b) Surface temperatures of modules[3)] 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 7.3.1.10; c) Surface temperature measurements on wall surfaces do not exceed 97 °C (175 °F) of temperature rise above ambient; d) Explosion hazards are not observed, including deflagration or detonation; and e) Heat flux measured at the minimum distance to a means of egress[2)] shall not exceed 1.3 kW/m^2.

[1)] Outdoor installation near exposures are those that are located at ≤ 3.48 m (10 feet) 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 the IFC and is essentially a continuous and unobstructed way of travel for persons that provides an access to a safe area.

[3)] The surface temperature of the modules is averaged over 60 seconds.

9.9 Flow battery unit tests

9.9.1 For those flow battery systems that do not meet the performance criteria of 7.9, unit level test using a test battery representative of the complete flow battery system but at a scale small enough to fit under the smoke collection hood of the calorimeter.

9.9.2 The test flow battery system shall be subjected to each of the following tests while monitoring the temperature of the electrolyte at a location in the fluid system that is anticipated to be the hottest. Where test data is not already available from UL 1973 testing, the test methods referenced below shall be applied and incorporated into this test Standard:

a) The Overcharge Test in accordance with the Performance Electrical Tests of UL 1973;

b) The High Rate Charge test in accordance with the Performance Electrical Tests of UL 1973; and

c) The Short Circuit Test in accordance with the Performance Electrical Tests of UL 1973.

NOTE: The electrolyte from the outlet of the stacks or within the stacks would be an appropriate location for sampling the temperature during these tests.

9.9.3 If the temperatures of the electrolytes during the tests of 9.9.2 do not exceed the flashpoint temperature determined in 7.3.2.1.2 the testing is concluded at the unit level. If the temperatures of the electrolytes during the tests of 9.9.2 exceed the flashpoint temperature determined during 7.3.2.1.2, the flow battery system is considered noncompliant and would need to be revised and retested.

9.9.4 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. The gas data collected can be scaled to the largest representative system.

9.10 Flow battery unit level test report

9.10.1 The report on flow battery unit testing shall include the following:

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

b) System 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 maximum quantity in the systems;

f) Test cell stack details per 5.4;

g) Electrolyte quantities in the representative test flow battery system;

h) Maximum charge voltage and charge current during the overcharge test;

i) External short circuit resistance applied and maximum short-circuit current measured during the short circuit test;

j) Flash point temperatures determined for each charged electrolyte (if applicable);

k) Maximum electrolyte temperature measured during the overcharge tests;

l) Maximum electrolyte temperature measured during the short circuit test;

m) Maximum electrolyte temperature measured during the High Rate Charge test;

n) Volume of gas measured with representative test flow battery system and scaled volume of gas based on full-size flow battery system;

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

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

q) Video of the test.

9.11 Flow battery unit level performance criteria

9.11.1 The flow battery performance level criteria is met if:

a) The flash point temperature(s) measured in the test of 7.3.2.1.2 exceed the maximum temperature measured on the energy reservoir during each of the tests of 9.9.2 by at least 5 °C (9 °F); and

b) For flow battery systems with two electrolytes, the flash point temperature(s) measured in the test of 7.3.2.1.2 exceed the maximum temperature of the mixed solution measured in accordance with 7.3.2.2.2 by at least 5 °C (9 °F).

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. However, units intended to be installed in residential occupancies other than detached one or two-family dwellings and townhouses shall be permitted to perform the installation level test to determine sprinkler effectiveness.

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 as defined in 4.17.

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.

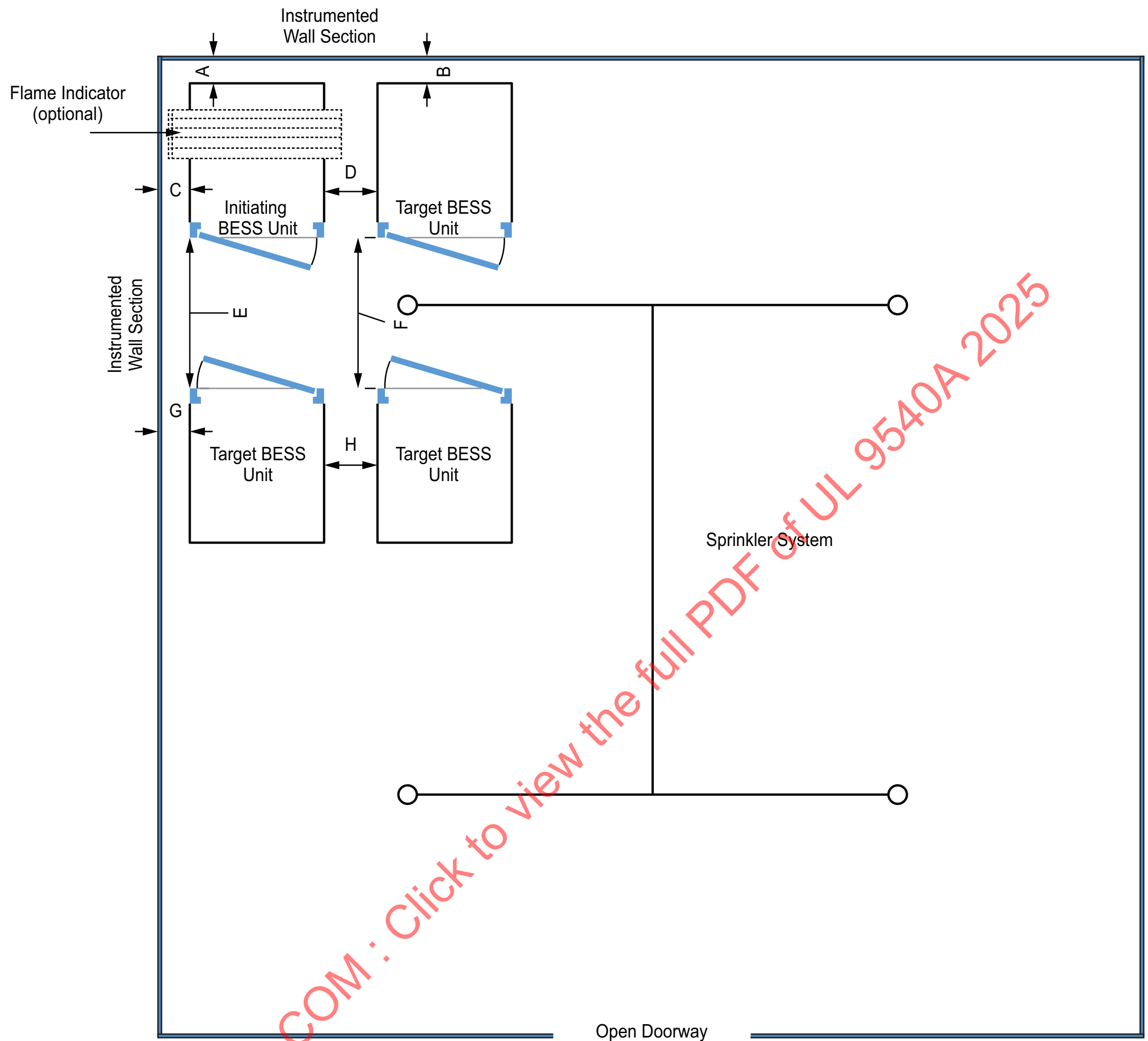
10.2.2 A flame indicator consisting of a cable tray with fire rated cables that complies with UL 2556 and representative of the installation per the manufacturer's specifications shall be deployed above the BESS at a distance specified by end-use installation. If the installation requires that cabling be installed below the BESS, then the flame indicator is not needed. See Figure 10.1 and Figure 10.2.

10.2.3 The test installation set up for outdoor non-residential use high temperature batteries installed in a container shall be in accordance with the manufacture's specified installation layout within the container.

10.2.4 An example of a test layout where the BESS modules are installed within separate compartments rather than as multiple modules on a rack with the module considered as an individual test unit, is shown in Figure 10.3.

Figure 10.1

Example of Arrangement for Effectiveness of Sprinklers Test



su3071a

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.

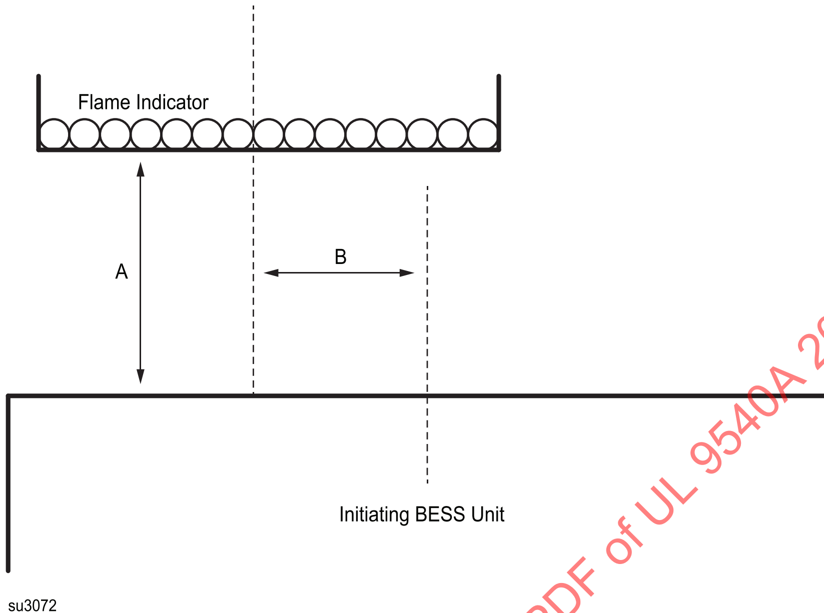
G = Separation distance between target BESS unit and instrumented wall section.

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

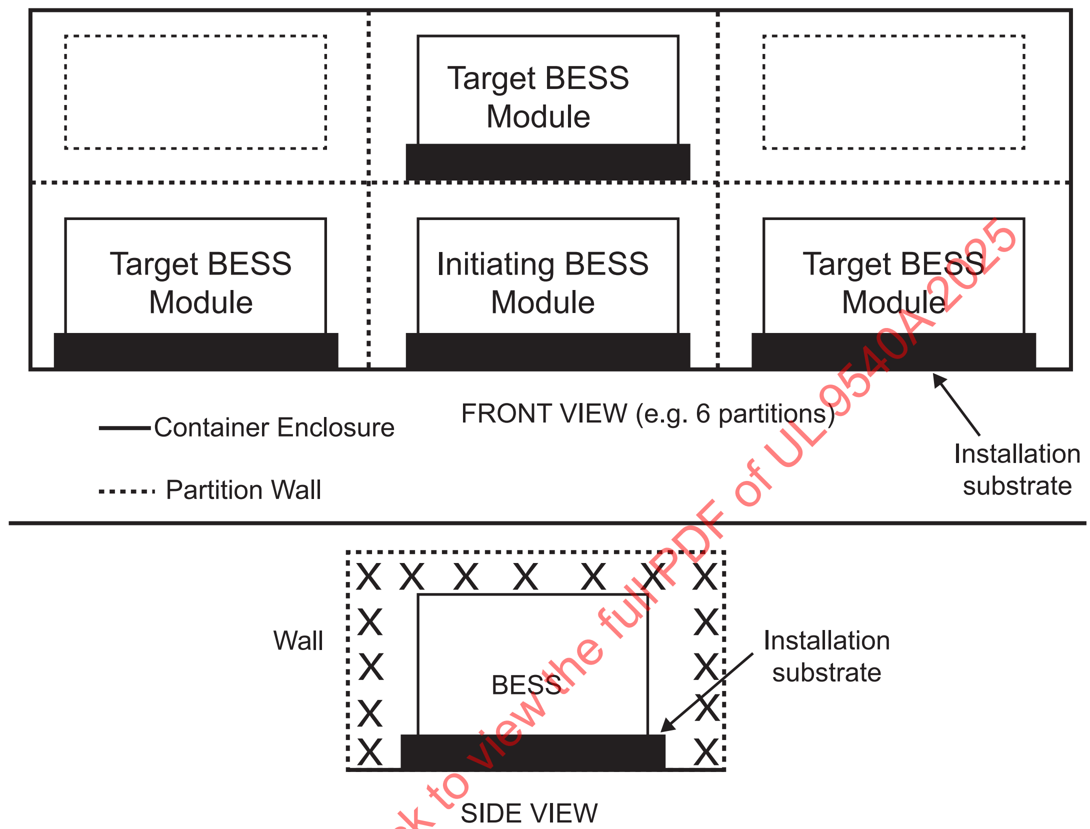


A = Distance of the flame indicator above the BESS.

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

Figure 10.3

Example of High Temperature Battery Container System Modules Located in Compartments with Interior Wall Partitions



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

10.3 Test method 1 – Effectiveness of sprinklers

10.3.1 For BESS units with a height of 2.44 m (8 feet) or less, the test shall be conducted in a 6.10 × 6.10 × 3.05-m (20 × 20 × 10-feet) high test room with one open 1.22 × 2.13-m (4 × 7-feet) 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 feet), the ceiling height shall be increased to be at least 0.61-m (2-feet) 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-feet) 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 gypsum wall board. Instrumented wall sections shall be painted flat black. The gypsum wall board shall be 13-mm (1/2-inch) thick at minimum.

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-inch) below the ceiling and at 152-mm (6-inch) intervals using No. 24-gauge Type-K exposed junction thermocouples. Temperatures shall be measured continuously, averaging over every 60-second interval per 6.3. The maximum of these averages shall be documented for each thermocouple location.

10.3.6 Instrumented wall surface temperature measurements shall be collected in a vertical array at 152-mm (6-inch) 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. Temperatures shall be measured continuously, averaging over every 60-second interval per 6.3. The maximum of these averages shall be documented for each thermocouple location.

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 or Gardon gauges at the surface of each instrumented wall as follows in (a) – (c). Heat flux shall be measured continuously, averaging over every 60-second interval per 6.4. The maximum of these averages shall be documented for each gauge location.

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 or Gardon gauges at the surface of each adjacent target BESS unit that faces the initiating BESS unit as follows in (a) and (b). Heat flux shall be measured continuously, averaging over every 60-second interval per 6.4. The maximum of these averages shall be documented for each gauge location.

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.

Exception: If (a) and (b) are deemed to be at the same location based on a construction review, only one gauge may be installed on the target unit for the measurement.

10.3.10 The heat flux shall be measured with the sensing element of at least one water-cooled Schmidt-Boelter or Gardon gauge positioned at the mid height of the initiating unit or the point where the majority of off-gas venting is expected from the initiating unit in the center of the accessible means of egress. Heat flux shall be measured continuously, averaging over every 60-second interval per 6.4. The maximum of these averages shall be documented.

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 Cell to cell thermal runaway propagation in accordance with the module level test shall be created within a single module in the initiating BESS unit:

a) Outdoor installation near exposures are those that are located at ≤ 3.48 m (10 feet) 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.

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 as outlined in 9.2.23. At the request of the BESS manufacturer, the hydrocarbon content may additionally be measured as outlined in accordance with 9.2.24. The gas composition sampling port shall be located in the ceiling jet, 25-mm (1-inch) 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;

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

y) If the test is terminated in accordance with 10.3.14, the circumstances of the termination; and

z) Unit level test report summary, module level test report summary, and cell level test report summary.

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 7.3.1.10.

NOTE: The surface temperature of the modules is averaged over 60 seconds.

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 measured at the minimum distance specified by the manufacturer to a means of egress shall not exceed 1.3 kW/m^2.

10.5.7 Observation of re-ignition within the initiating unit after the installation test had been concluded and the sprinkler operation was discontinued shall be recorded.

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 (a) – (u), (y) and (z), 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.

10.9 Test method – Installation level test for high temperature battery container system BESS for outdoor non-residential use

10.9.1 Samples and test configurations are in accordance with the intended installation as outlined in 10.2.3 and 10.2.4 by using a representative container assembly with an installed high temperature battery initiating unit surrounded by target units in accordance with the manufacturer's specified layout. The BESS container shall include the outer cabinet (if part of the design), partitions, and components that retain the units as well as any protective features such as deflagration panels or other protection features including fire protection systems intended to be installed in the container. Any wiring within the container either intended to be installed above the units or along them horizontally, that can be a source of fire spread, should be included in the container for the test. Equipment mounted to openings in the container that may impact air flow and therefore test results, should be included in the installation for the test. Internal equipment such as a power conditioning/conversion system or switchgear, can be represented by their enclosures or other simulation means for temperature measurement purposes.

10.9.2 The container shall include one initiating BESS unit in which an internal fire condition in accordance with the module level test is initiated, and adjacent target BESS units representative of the installation. An example of a test configuration where the module is considered the unit as described in 10.2.4 is shown in Figure 10.3. The target BESS unit enclosures do not need to contain cells nor be heated to the manufacturer's specified operating temperature.

10.9.3 The initiating BESS unit shall be fully charged prior to testing and shall be heated to the manufacturer's specified operating temperature. The initiating module shall be provided with electrical connections to the cell(s) that will be forced into thermal runaway using the overcharging method applied at the module level test.

10.9.4 The cell failure test method outlined in 7.3.4 shall be conducted within the initiating module. During the test, the voltage and temperatures of the cell(s) being forced into failure as well as the voltage of the surrounding cells shall be monitored and documented. The voltage of the initiating module shall be also monitored during the test.

10.9.5 Temperatures of partitioned wall surfaces shall be measured in vertical array(s) at 152-mm (6 inch) intervals for the full height of the instrumented wall sections using No. 24-gauge or smaller, Type-K exposed junction thermocouples. The thermocouples used in 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 module.

10.9.6 Thermocouples shall be placed on the external casing of the module to monitor any breakdown of thermal insulation in the module case. 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.

10.9.7 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 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.

10.9.8 The installation shall include any exposures representing major components (e.g. battery system racks, power conditioning system, HVAC, etc.) installed within the container system. Temperatures shall