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Small craft — Lithium-ion batteries

Petits navires — Batteries lithium-ion

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 188 *Small craft*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 464, *Small Craft*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This first edition cancels and replaces ISO/TS 23625:2021, which has been technically revised.

The main changes are as follows:

— a terminological entry for "audible alarm" has been added;

— requirements to comply with IEC 62619 and IEC 62620 have been added;

— EMC requirements for BMS have been added;

— Annex A has been extended;

— Annexes B and C have been added.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Small craft — Lithium-ion batteries

WARNING — Lithium-ion batteries used in direct current (DC) electrical systems on boats that operate at potentials of 60 V or higher have additional safety requirements not addressed by this document. Refer to the battery manufacturer's recommendations.

1 Scope

This document specifies requirements and recommendations for the selection and installation of lithium-ion batteries for boats, as well as requirements for the safety information provided by the manufacturer.

This document is applicable to lithium-ion batteries and battery systems with a capacity greater than 500 Wh used on small craft for providing power for general electrical loads and/or to electric propulsion systems. It is primarily intended for manufacturers and battery installers.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8846, *Small craft — Electrical devices — Protection against ignition of surrounding flammable gases*

ISO 13297, *Small craft — Electrical systems — Alternating and direct current installations*

ISO 25197, *Small craft — Electrical/electronic control systems for steering, shift and throttle*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 62619, *Secondary cells and batteries containing alkaline or other non-acid electrolytes — Safety requirements for secondary lithium cells and batteries, for use in industrial applications*

IEC 62620, *Secondary cells and batteries containing alkaline or other non-acid electrolytes — Secondary lithium cells and batteries for use in industrial applications*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
ampere interrupt capacity
AIC
maximum current a circuit breaker or fuse is rated to safely interrupt at a specific voltage

3.2
battery
collection of *cells* (3.7) wired in series (or series/parallel) and constituting a single physical unit

3.3
battery bank
set of *batteries* (3.2) electrically connected (parallel/series) to increase capacity and/or voltage

3.4
battery capacity
C
amount of energy storage of the *battery* (3.2) from the manufacturer's specified fully charged to discharged voltage levels

Note 1 to entry: The battery capacity is expressed in ampere hours (Ah) at a nominal voltage or in watt hours (Wh).

Note 2 to entry: Ah and Wh capacity rating is at a given discharge rate or time.

3.5
battery management system
BMS
system designed to protect a lithium-ion *battery* (3.2) from potentially damaging events, such as *overcharging* (3.19) or *overdischarging* (3.20) and high and low temperatures

3.6
battery system
battery (3.2) or batteries and all ancillary components

3.7
cell
fundamental building block that is inside a lithium-ion *battery* (3.2) where electrical energy is derived from the insertion/extraction reactions of lithium ions or oxidation/reduction reaction of lithium between the negative electrode and the positive electrode

3.8
C rating
measure of *battery* (3.2) charge and discharge rating

Note 1 to entry: The C rating is expressed as a function of the rated ampere hours (Ah) *battery capacity* (3.4).

EXAMPLE A 100 Ah battery charged or discharged at 100 A is a 1C rate.

3.9
contactor
relay/switch controlled by the *battery management system* (3.5)

3.10
disconnect device
switch controlled by the *battery management system* (3.5) which disconnects a *battery* (3.2) or *battery bank* (3.3) from charge and discharge sources, and other batteries or battery banks

3.11
high voltage cutout
HVC
battery management system's (3.5) response to a *high voltage event* (3.12) that protects the *battery* (3.2) from *overcharging* (3.19)

3.12
high voltage event
HVE
condition where a *cell* (3.7) has been charged to a voltage above the manufacturer's cell maximum voltage limit

3.13
low voltage cutout
LVC
battery management system's (3.5) response to a *low voltage event* (3.14) that protects the *battery* (3.2) from *overdischarging* (3.20)

3.14
low voltage event
LVE
condition where a *cell* (3.7) has been discharged beyond the cell manufacturer's cell low voltage limit

3.15
high temperature cut-off
HTC
battery management system's (3.5) response to a *high temperature event* (3.16)

3.16
high temperature event
HTE
condition where a *cell* (3.7), parallel string or bank has a temperature above the manufacturer's maximum cell temperature limit

3.17
low temperature cut-off
LTC
battery management system's (3.5) response to a *low temperature event* (3.18)

3.18
low temperature event
LTE
condition where a *cell* (3.7), parallel string or bank has a temperature below the manufacturer's minimum cell temperature limit

3.19
overcharging
charging a *cell* (3.7) above the cell manufacturer's upper cell voltage limit, which can result in damage to the cell

Note 1 to entry: Overcharging can result in *thermal runaway* (3.24) or damage to the *battery* (3.2) or cells.

3.20
overdischarging
discharging a *battery* (3.2) or *cell* (3.7) below the manufacturer's minimum cell voltage limit

Note 1 to entry: Overdischarging can result in damage to the battery or cells and can include cell polarity reversal.

Note 2 to entry: Subsequent charging after overdischarging can result in *thermal runaway* (3.24).

3.21
readily accessible
capable of being reached quickly and safely for effective use under emergency conditions without the use of tools

3.22
safe operating limits
SOL
set of voltage, temperature and other parameters, within which the *battery* (3.2) is intended to be operated and which, if exceeded, initiates a *battery management system* (3.5) response to correct the problem or to shut the battery down

3.23
state of charge
SOC
indication of the amount of usable capacity available in the *battery* (3.2)

Note 1 to entry: SOC is expressed as a percentage.

EXAMPLE 0 % = empty; 100 % = full.

3.24
thermal runaway
potentially dangerous and self-propagating *battery* (3.2) heating condition that can occur within a *cell* (3.7) or cells

3.25
watertight
constructed so that water will not enter the enclosure

Note 1 to entry: Water integrity specifications can be found in IEC 60529.

3.26
weatherproof
constructed or protected so that exposure to the weather will not interfere with successful operation

Note 1 to entry: Water integrity specifications can be found in IEC 60529.

3.27
audible alarm
device with a sound pressure measured 1 m from the command station of at least 75 dB(A), but not greater than 85 dB(A)

4 System design requirements

4.1 Lithium-ion batteries and their systems shall be installed in accordance with the requirements of ISO 13297.

NOTE Lithium-ion batteries are not subject to routine electrolyte leakage or routine release of gas, therefore requirements regarding electrolyte containment and routine gas ventilation cannot apply to lithium-ion battery installations.

4.2 Lithium-ion battery systems shall be installed in accordance with the battery manufacturer's recommendations.

4.3 All battery system designs shall be done in a way that ensures that all installed lithium-ion batteries are kept within the battery manufacturer's specified SOL.

4.4 There shall be a BMS installed to control all installed lithium-ion batteries and maintain the battery manufacturer's specified SOL.

4.5 All battery systems shall have a BMS to provide for battery cut-off if hazardous conditions exist.

NOTE 1 A BMS can be external or internal to the battery.

NOTE 2 In the event of an individual BMS that disconnects, battery bank capacity can be reduced with no notification to the vessel operator.

4.6 Batteries shall meet the requirements of IEC 62619 and IEC 62620.

4.7 The battery system shall be sized in accordance with the application and the battery manufacturer's defined operating limits, and with the appropriate C rating listed in the battery specifications.

4.8 Output control from charging sources shall be within the battery manufacturer's specified ranges.

4.9 If a shut-down condition is approaching for propulsion systems or other critical system (equipment vital to safety), a BMS or system shall notify the operator with a visual and/or audible alarm, clearly perceptible from the main helm position, prior to disconnecting the battery from the DC system.

4.10 Batteries of different chemistries shall not be connected in series. A means shall be provided to prevent overcurrent conditions when connecting in parallel.

4.11 Multiple contactors are permitted (HVC, LVC, plus main), each providing specific protection from high voltage, low voltage and load isolation. A single contactor is permitted, if the control system provides for protection from all conditions.

4.12 On installations greater than 1 500 Wh when used for propulsion, the battery system shall be capable of providing a state of health of the battery system compared to its original capacity.

NOTE This indication can be available as a service function.

5 Safe operating limits

5.1 The SOL of a lithium-ion battery are defined by the manufacturer and comprise high and low voltage limits, charging/discharging current limits, charging/discharging temperature limits, and installation specifications. The SOL shall be adhered to during the design, storage, installation and operation of a lithium-ion battery.

NOTE All lithium-ion batteries lose capacity through cycling and over time. Capacity is also adversely affected by operating at higher temperatures and maintaining a lithium-ion battery in a high SOC and/or extended periods at a low SOC. This needs to be taken into account in terms of the SOL.

5.2 Lithium-ion batteries have very strict temperature operating limits established by the battery/cell manufacturers. To prevent damage and potentially hazardous conditions, the system shall be operated within specified operating temperatures under all operating conditions.

For craft in long-term storage, the battery installation shall follow the manufacturer's recommended battery storage procedures, based on ambient temperature, connected charging sources and parasitic loads.

6 General lithium-ion battery installations

6.1 Lithium-ion batteries shall not be installed in locations where temperatures outside (high or low) acceptable parameters can occur. Battery manufacturer installation specifications shall be met. This shall extend to areas that can be heated from the sun or other heat sources.

6.2 System connections and BMS electronics shall be protected from corrosion.

6.3 Lithium-ion batteries shall be installed and restrained in locations that prevent damage from shock and vibration, unless batteries are designed specifically for that application by the battery manufacturer.

6.4 Lithium-ion battery systems shall be designed, constructed and installed so that they do not have their safe operation jeopardized, during normal craft operation, by the damaging effects of exposure to water.

6.4.1 Lithium-ion batteries and their system components installed in locations subject to flooding or momentary submersion shall be watertight under the test conditions specified in IEC 60529, IP67.

6.4.2 Lithium-ion batteries and their system components installed in locations not subject to flooding or momentary submersion shall be weatherproof under the test conditions specified in IEC 60529, IP55.

6.5 Lithium-ion batteries, their system components and their electrical connections shall be protected from corrosion.

6.6 Devices located in compartments that require ignition protection shall be protected against ignition in accordance with ISO 8846.

6.7 Lithium-ion battery connections: No electrical connections shall be made directly to a lithium-ion battery that would bypass the BMS or the protection devices, unless specified by the battery system manufacturer's instructions.

6.8 Overcurrent protection: All lithium-ion battery installations shall have overcurrent protection that does not exceed the current interrupting capacity of the BMS. Examples of overcurrent protection and overcurrent protective devices can be found in Annexes B and C.

6.9 Ampere interrupt capacity (AIC): If necessary, the lithium-ion battery bank shall be subdivided into units such that the AIC rating of fusing is not exceeded.

6.10 Series and paralleling installations shall comply with the lithium-ion battery manufacturer's specifications.

Appropriate measures shall be taken to allow for balancing and overcurrent protection between batteries, including the following:

— If used, automatic paralleling devices should have an appropriate current-limiting capability. Manual switches (e.g. a 1, 2, both switch or on/off switch) and automatic paralleling devices are not necessarily appropriate.

— Special attention to balancing is very important in larger battery banks.

6.11 If a battery manufacturer specifies a voltage deviation limit between individual battery voltages, it shall be met before the batteries are paralleled or connected in series to prevent excessive battery to battery current.

6.12 Charging sources shall be operated/controlled to meet the charging profile recommendations provided by the lithium-ion battery or cell manufacturer.

7 Fire protection and cell venting

7.1 Fire protection from thermal runaway: Lithium-ion batteries technologies have unique fire characteristics. See Annex A for more information.

7.2 The battery manufacturer's recommendation(s) shall be followed to protect against fire hazards, including venting and specific fire suppression mechanisms (e.g. specific fire-extinguishing medium).

The arrangement of the energy storage system spaces shall be such that the safety of passengers, crew and vessel is ensured. The safety philosophy for the energy storage space (ESS) shall be documented. The safety philosophy should cover all potential hazards represented by the type of ESS and cover at least:

— gas development hazard (toxic, flammable, corrosive);

— fire hazard;

— necessary detection, monitoring and alarm systems (off-gas detection, fire detection, etc.) and ventilation;

— explosion hazard;

— ventilation handling in case of off-gas release and/or fire;

— external hazards (fire, water ingress, etc.).

NOTE Lithium-ion batteries can emit toxic, flammable or explosive gases during a thermal runaway event.

7.3 Fire detection: Consideration shall be given to the installation of a fire detection system.

NOTE Requirements for fire protection are provided in ISO 9094.

7.4 Battery cell venting: In case of a failure mode that results in a cell venting, the battery installation shall allow for cell venting such that the safety of persons onboard is not endangered.

8 Battery management system and testing

8.1 The BMS shall be designed and tested to manage the following:

a) safety-related elements:

  1) overcharging, to protect the lithium-ion battery from excessive charging;

  2) overdischarging, to protect the lithium-ion battery from excessive discharging;

  3) over and under temperature, to protect the lithium-ion battery from excessive temperature extremes;

b) performance-related elements: balancing, to provide for automatic balancing of cells or strings of cells.

8.2 The BMS shall be equipped with HVC, LVC, HTC and LTC actions to prevent an HVE, LVE, HTE and LTE in the event the programmed functions in the charging sources, inverters or inverter/chargers fail to do so. Actions taken by the BMS shall be in addition to the programmed functions in the charging sources, inverters or inverter/chargers.

8.3 The BMS shall monitor cell voltage to determine if the battery is approaching an HVE or LVE condition.

8.4 HVE/HVC: The BMS shall protect a lithium-ion battery from an HVE by initiating a multistage HVC consisting of the following steps:

— it shall provide a stop charging signal to each charging source;

— if stopping the charging sources does not stop the HVE, an alarm (visual and/or audible) shall be provided for the operator, clearly perceptible from the main helm position;

— if the operator fails to stop the HVE, the BMS shall initiate an isolation of the sources that are creating the HVE.

8.5 LVE/LVC: The BMS shall protect the lithium-ion battery from an LVE by initiating a multistage LVC consisting of the following steps:

— it shall provide an audible and/or visual alarm to the operator, clearly perceptible from the main helm position, that indicates that the SOC of the lithium-ion battery bank is approaching the low SOC threshold specified by the manufacturer;

— if the operator fails to prevent the LVE, the BMS shall initiate the disconnection of non-essential electrical consumers;

— if this does not prevent the LVE, the BMS shall disconnect all electrical loads.

8.6 Temperature: The BMS shall respond to low or high temperature situations in a manner that ensures the battery cannot be driven into an unsafe condition. Temperature sensing shall be sufficient to monitor all potential areas of overheating.

8.7 A disconnect device shall be capable of disconnecting the output immediately when operating under the battery's or the battery system's maximum specified rate of discharge.

8.8 BMS(s) can suddenly and unexpectedly disconnect a battery from loads and charging sources in some conditions. Consideration shall be given for providing an alternative power source for critical systems (e.g. engine starting, propulsion, navigation lights) that can be affected if a BMS shuts down the battery. The alternative power source can be another lithium-ion battery.

8.9 Parasitic loads: The BMS and/or system design shall ensure that parasitic loads do not result in an LVE.

8.10 The BMS shall comply with the electromagnetic compatibility (EMC) requirements of ISO 25197.

9 Manufacturer's safety information and operator's manual

The battery manufacturer shall provide safety information, including:

— cell chemistry of negative active material (anode) (e.g. graphite, carbon, titanium), positive active material (cathode) (e.g. $LiCoO_2$, $LiMn_2O_4$, $LiNi_{0,85}Co_{0,1}Al_{0,05}O_2$, $LiNi_{0,33}Co_{0,33}Mn_{0,33}O_2$, $LiFePO_4$) and design (e.g. cylindrical, prismatic, pouch);

— capacity ratings including a discharge rate or time, and temperature;

— a description of the primary features of the battery with regard to safety (e.g. use of touch-safe covers, operation of the BMS, cell venting, manual service disconnects);

— reset procedures for the battery system if a shutdown event occurs;

— a detailed description of operating requirements necessary to ensure safe operation, with details of the SOL, including high and low voltage limits, relevant charge and discharge characteristics and temperature limits, and any external relays and other features necessary to ensure operation within the SOL;

— requirements, if any, for the control of charging sources;

— the effects of an external fire or excessive external heating, together with a description of measures to be taken, if any, to guard against external hazards such as fire and impact, including any venting and specific fire suppression mechanisms (e.g. specific fire-extinguishing medium);

— information about the toxic, flammable or explosive gases that can be released given a thermal runaway event;

— a description on the limits to connecting batteries in series and parallel, and a description of a safe means of making the connections up to the specified limits, including overcurrent and other required protective mechanisms;

— a description of the hazards, if any, that occur with submersion in freshwater and saltwater;

— battery short circuit current or the rating of the overcurrent protection device to protect the circuit;

— requirements for restraining the battery in the craft, including information about shock and vibration and movement limits of the battery;

— storage and winterization procedures;

— any limitations on the working angle of the battery system;

— information regarding the recycling and/or disposal of lithium-ion batteries;

— caution about combining different battery types.

Annex A
(informative)

Battery thermal runaway

Lithium-ion batteries are unlike lead-acid batteries in the following two important respects:

a) Gases that are released during cell failure, and the electrolytes within most lithium-ion batteries are flammable.

b) Under certain fault conditions, lithium-ion batteries can enter a condition known as "thermal runaway", which results in rapid internal heating that, once initiated, is a self-perpetuating exothermic reaction that is difficult to halt. Examples of the causes and impact of cell chemistry on thermal runaway are given in Figures A.1 and A.2. The rate of temperature rise during thermal runaway, and the peak temperature reached, vary widely depending on the particular chemistry used in the battery (e.g. lithium iron phosphate (LFP), nickel manganese cobalt (NMC) or some other chemistry) and numerous construction features (e.g. cylindrical cells versus flat plate, different separator materials, chemical doping).

During a thermal runaway, some batteries can reach high enough temperatures to ignite the battery's electrolyte, whereas others do not. In all cases, internal cell pressures rise, which can result in venting of gases and electrolyte from the cell(s) experiencing thermal runaway. The flammability of the vented materials varies widely depending on chemistry, cell doping and other features. During thermal runaway, even if the internal temperature is not high enough to cause ignition, any kind of spark or fire source is likely to cause ignition. Once ignited, because of the exothermic (self-perpetuating) nature of the chemical reaction fuelling the thermal runaway, a lithium-ion battery fire is difficult to extinguish. Typically, the best approach is to remove heat as fast as possible, which in turn is most effectively done by flooding the battery with water, although this can have serious consequences in terms of the boat's stability, electrical systems, flotation, etc.

The over-arching goal of this document is to ensure that the construction and installation of lithium-ion batteries in boats is such that a thermal runaway does not occur, including under any reasonably foreseeable fault conditions. Nevertheless, some thought should be given to:

— additional protection for the boat in the event the various battery protection mechanisms fail and a thermal runaway event occurs;

— a situation in which external heat sources initiate thermal runaway in the battery.

Some batteries are assembled inside metal cases that are designed to contain any thermal runaway event. Some of these cases are hermetically sealed and designed to prevent venting, while others have vents. Some batteries consist of multiple small cylindrical cells, with each cell designed to contain a thermal event and to shut the battery down so that the event does not propagate. Other batteries have the cells assembled inside a plastic housing that cannot contain a serious thermal runaway event. The level of resistance to fire of plastic cases varies. Regardless of construction, in all thermal runaway events, venting of gases is likely. These gases vary significantly in their volatility, flammability, mass (e.g. lighter or heavier than air) and level of hazard.

Because of the wide variations in terms of battery chemistries, construction, volatility and responses to a thermal runaway event, it is not possible to issue a generic prescription for battery compartment design and ventilation, and for fire containment and fire-fighting mechanisms in the event the latter are considered to be necessary. It is incumbent on the boatbuilder and battery installer to consult with the battery manufacturer and supplier to determine an appropriate compartment design and venting mechanism, and appropriate fire containment and fire-fighting mechanisms, if considered necessary.

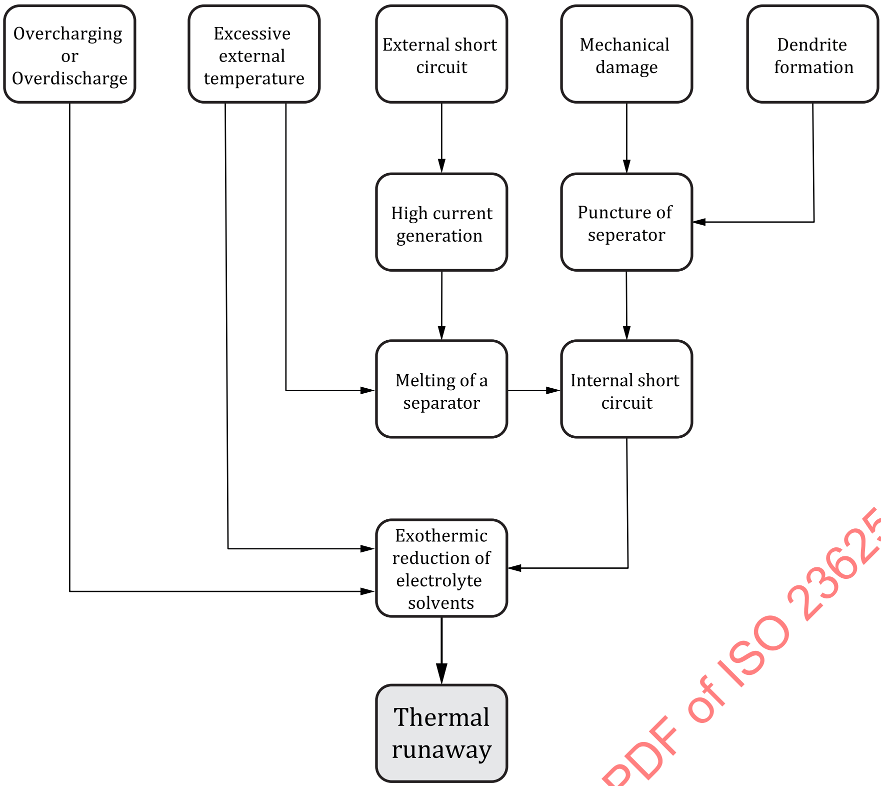
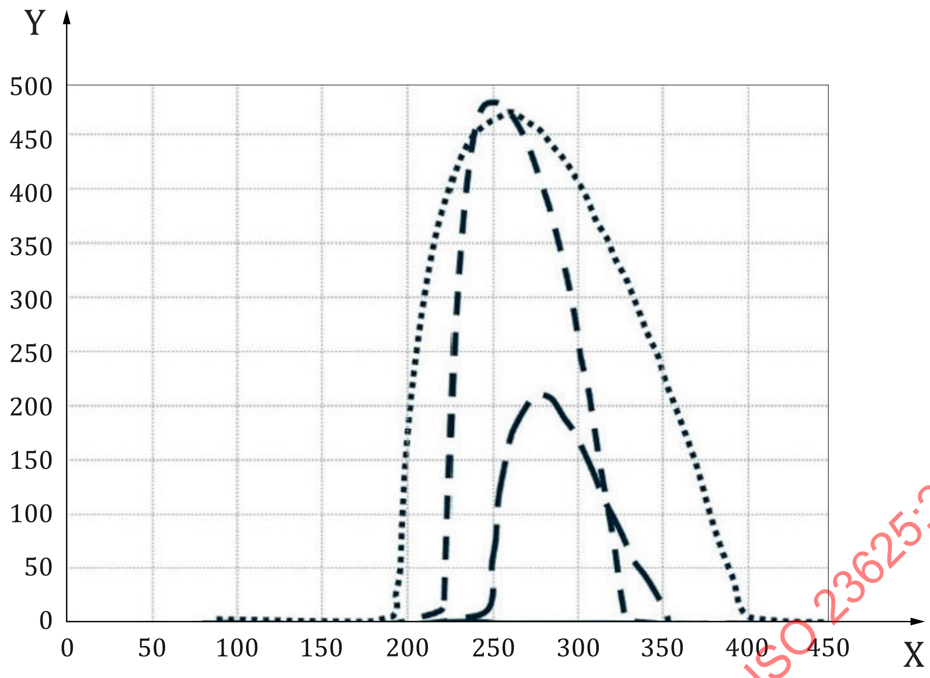
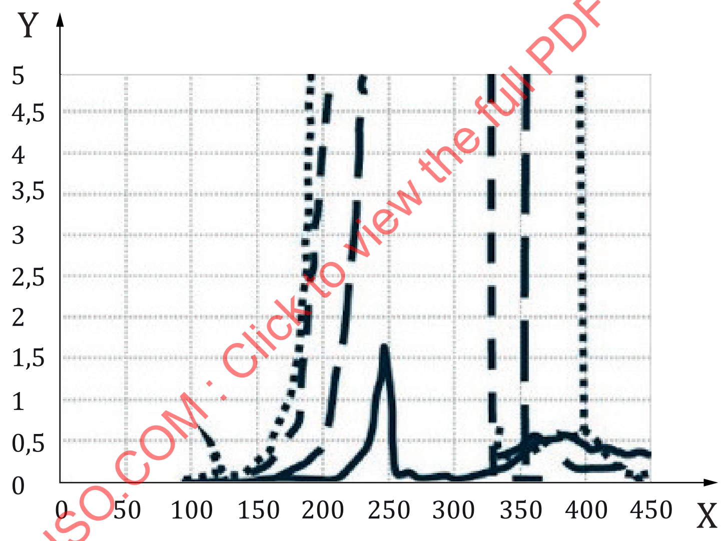


Figure A.1 — Causes of thermal runaway



a) Accelerating rate calorimetry (ARC) of 18650 cells with different positive active materials (cathode)



b) Enlarged view

Key

....	$LiCo0^2$	X	temperature (°C)
- - - -	NMC	Y	normalized heating rate (°C/min-Ah)
— —	NMC (111)		
——	LFPSS		

NOTE 1 All measurement at 100 % SOC and for cells with 1,2 M $LipF_6$ in EC:EMC (3:7).

NOTE 2 Differences in runaway profiles are related to oxygen release and combustion at different positive active materials (cathode).

NOTE 3 SOURCE: Reference [4], © 2021 The Author(s). Published on behalf of The Electrochemical Society by IOP Publishing Limited. This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 License (CC BY, http://creativecommons. org/licenses/by/4. 0/), which permits unrestricted reuse of the work in any medium, provided the original work is properly cited. [DOI: 10.1149/1945-7111/ac0699].

Figure A.2 — Impact of cell chemistry on thermal runaway

Annex B
(informative)

Protection devices

The information in this document conveys the operational and functional requirements for the BMS and cells that constitute a lithium-ion battery for marine small craft. These requirements are agnostic of voltage and system configuration.

The disconnect device, managed by the BMS, is the primary device responsible for ensuring the lithium battery is maintained within functional parameters.

Additional protection devices, not covered in this document, are required for the complete battery system to facilitate service and functional safety requirements. Examples of such devices consist of, but are not limited to: isolating disconnectors, fuses, circuit breakers, pyro fuses, safety interlocks, connectors and battery switches.

Protection devices, being dependent upon the voltage and system configuration, are governed by applicable system and wiring standards.

NOTE Requirements for protection devices are found in ISO 16315, ISO 13297 and IEC 60092-507.