Fire Protection Association

RISCAuthority

Need to Know Guide RE2

Lithium-ion Battery Use and Storage

RISK INSIGHT, STRATEGY AND CONTROL AUTHORITY

REDUCING INSURABLE RISK THROUGH RESEARCH, ADVICE AND BEST PRACTICE

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Cover image: Getty/Petmal

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1 Introduction

Lithium-ion batteries are the predominant type of rechargeable battery used to power the devices and vehicles that we use as part of our daily lives. Many millions of lithium-ion batteries are in use and in storage around the world. Fortunately, fire related incidents with these batteries are infrequent, but the hazards associated with lithium-ion battery cells, which combine flammable electrolyte and significant stored energy, can lead to a fire or explosion from a single-point failure. These hazards need to be understood in order to suitably manage lithium-ion battery risks.

Other types of rechargeable battery are available which may have different properties that require separate consideration and are outside of the scope of this Need to Know Guide. General fire safety advice covering a range of battery technologies is provided in *RISCAuthority RC61 Recommendations for the storage, handling and use of batteries*. Specific guidance for fire safety when charging electric vehicles can be found in *RISCAuthority RC59 Fire safety when charging electric vehicles*.

2 Hazards

If a battery cell creates more heat than it can effectively dissipate, it can lead to a rapid uncontrolled release of heat energy, known as 'thermal runaway', that can result in a fire or explosion. This can occur as a result of an internal short circuit due to manufacturing defects, 'lithium plating' (formation of metallic lithium on an anode surface within a battery cell), or mechanical damage (e.g. piercing, dropping). Other possible causes of thermal runaway are exposure to heat from an external source or overcharging/ over-discharging.

There are four basic styles of lithium-ion rechargeable batteries: cylindrical, button, prismatic, and pouch cells. The cylindrical and button formats are inherently more robust than flat-format prismatic and pouch cells due to the structural properties of their shaped metal casings.

Prismatic and pouch cells are made up of many flat positive and negative electrodes sandwiched together. There are greater possibilities for deformation, short circuit, and irregularity with this arrangement when compared with cylindrical or button cells, that can lead to thermal runaway conditions. Pouch cells have outer surfaces made from flexible materials (e.g. aluminium-plastic composite film) and have the least mechanical resistance of these formats.

Thermal runaway can lead to the ejection of a range of gases from battery casings, such as hydrogen (extremely flammable), carbon monoxide (toxic, asphyxiant, and flammable), and hydrogen fluoride gas (acutely toxic and corrosive).

When a battery cell vents or ruptures due to thermal runaway, immediate ignition of the emitted gases can occur, especially for batteries with a high level of charge. Alternatively, the gases may spread-out unignited, with the potential for a deflagration (very rapid combustion) or explosion if an external ignition source is encountered.

In normal use, the highest risk of fire occurs when lithium batteries are being charged, particularly if a cell is defective and unable to correctly convert the supplied electrical energy into stored chemical energy. If a battery is damaged in normal use this can also lead to thermal runaway, so suitable protection measures should be implemented.

When lithium-ion batteries are damaged, they can still contain energy, and this 'stranded energy' should be dissipated prior to interaction or the removal of impacted cells. If not handled properly, the damaged batteries could cause injury, including electrical shock.

Other terms:

- **(Ah) or (mAh):** 'Amp Hours' or 'Mili-Amp Hours' is an indication of the maximum rated capacity of a battery in terms of current and time. For example, a battery rated to 20 Ah might be able to supply a current of 1 Amp for 20 hours, or 4 Amps for 5 hours.

- **SOC:** 'State of Charge' of a battery is an indication of its current level of charge relative to its maximum capacity, expressed as a percentage. A fully charged battery has an SOC of 100%. For lithium-ion batteries a reduced SOC lowers the likelihood of a thermal runaway event occurring when a cell is defective or becomes damaged. When transported by air, the maximum allowable SOC of lithium-ion batteries is 30% and for static storage the maximum recommended SOC is 60%, although lower values will further reduce the risk.

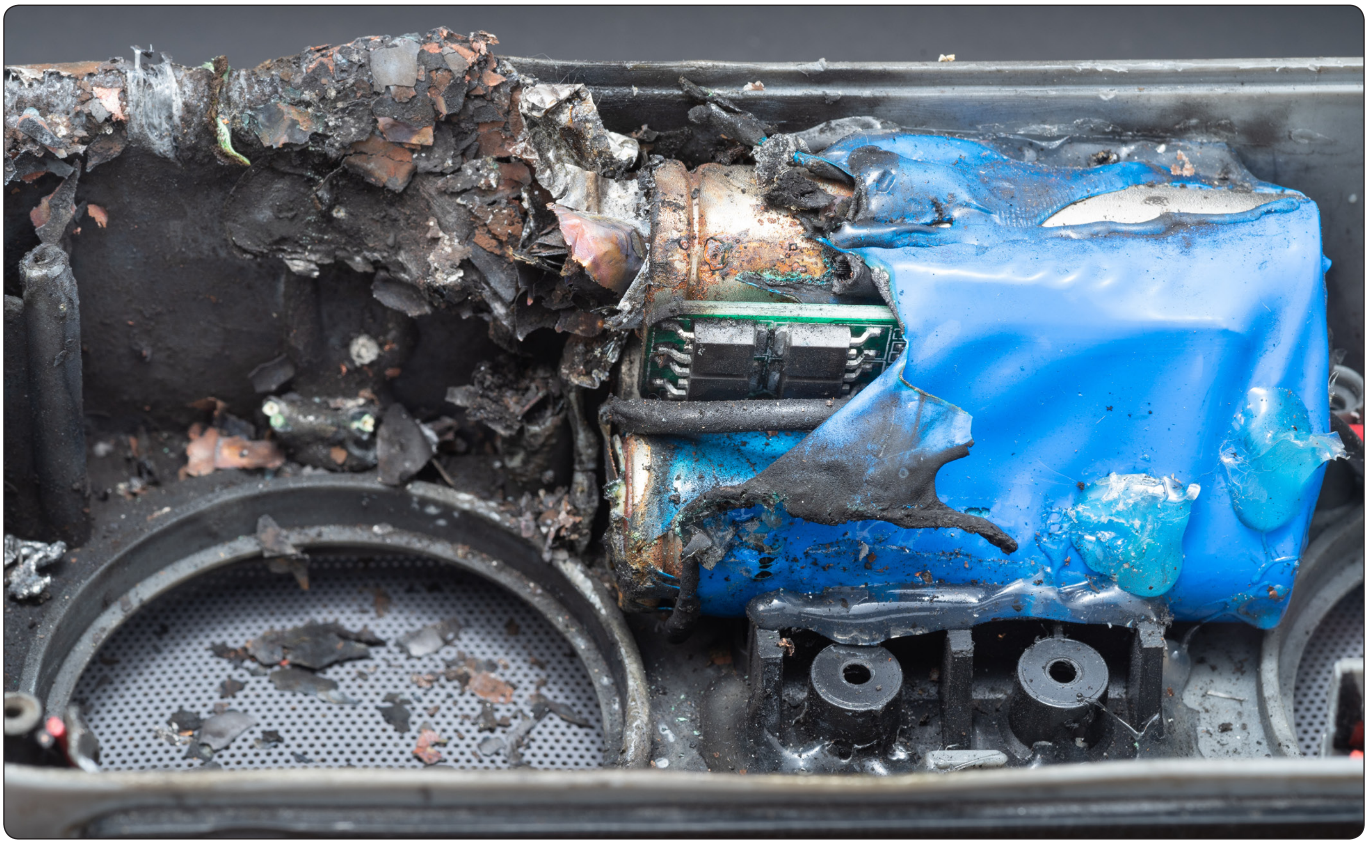
3 Risk control recommendations for lithium-ion batteries

The scale of use and storage of lithium-ion batteries will vary considerably from site to site. Fire safety controls and protection measures should be commensurate with the level of hazard presented.

3.1 Fire-safety considerations for general use

The following basic fire safety controls should always be applied for areas of laboratories, workshops, and similar occupancies, where lithium-ion batteries are used, charged, or stored:

- Only use batteries purchased from a reputable manufacturer or supplier.
- Do not leave/store batteries in contact with conductive materials.
- Always inspect batteries for any signs of damage before use and never use damaged or defective batteries.
- Only charge batteries with a suitable OEM (original equipment manufacturer) or compatible charger designed to safely charge the specific battery cells or battery packs in use.
- Do not leave batteries charging in unoccupied locations and disconnect/remove batteries from chargers after charging is complete.



- Handle batteries in well-ventilated areas and only use and store batteries in dry and reasonably cool locations, i.e. avoiding excessive humidity and heat. Avoid placing batteries in direct sunlight.
- Keep battery handling areas free from flammable or combustible materials, and free from sharp objects that may puncture battery cells.
- When not in use, lithium-ion batteries should ideally be kept in a bespoke enclosure such as a proprietary metal battery storage cabinet or fireproof safety bag.
- Provide smoke detection (ideally combined smoke and carbon monoxide (CO) detection).
- Fire Risk Assessments should cover handling, storage, use, and charging of lithium-ion batteries and be undertaken by a competent person.
- Emergency procedures and staff training should include specific instructions for dealing with damaged or faulty batteries.

Further reading: *Lithium Ion Battery Safety Guidance* published by the Massachusetts Institute of Technology (MIT): https://ehs.mit.edu/wp-content/uploads/2019/09/Lithium_Battery_Safety_Guidance.pdf

3.2 Manual control of small fires

Lithium-ion battery fires currently have no discrete fire classification, spanning several fire classes (A, B, C). Fire control strategies are combinations of containment, reduction of fire intensity by smothering (reducing oxygen levels), and cooling with water, to inhibit fire spread whilst the original cell fire burns out. In all circumstances only suitably trained personnel/emergency responders should attempt to extinguish early stage (incipient) fires, when it is safe to do so.

A relatively recent development are Aqueous Vermiculite Dispersion (AVD) fire extinguishers that can be applied directly to the cells of a battery, providing a combination of cooling and oxygen depletion. This type of extinguisher delivers a thermally insulating and water-retaining film that reduces the risk of thermal runaway propagation to adjacent cells.

Whilst AVD fire extinguishers are currently non-compliant under BS 5306 (Fire extinguishing installations and equipment on premises), they may be considered fit-for-purpose as a first-aid firefighting tool for incipient fires, subject to a suitable fire risk assessment undertaken by a competent person, training for staff, and appropriate servicing.

For lithium-ion batteries for small/mobile devices that are starting to overheat but can still be safely handled (before there is an impending fire hazard), proprietary fire containment bags are available. These should only be used by trained personnel with appropriate PPE.

3.3 Storage

There are currently no specific UK or European guidelines for fire protection of lithium-ion batteries storage. However, practical guidance is available in the following FM Global documents and is summarised below:

- FM DS 3-26 *Fire protection for non-storage occupancies* (Section 3.3 Lithium-ion batteries), 2021
- FM DS 8.1 *Commodity classification* (Section 2.4.2 Lithium-ion batteries), 2021

When incidental levels of lithium-ion batteries are stored in areas that are sprinkler protected for ordinary hazard occupancy†:

- Limit storage area to no greater than $20m^2$
- Limit storage height to 1.8m
- Separate multiple storage areas by aisles not less than 3.0m wide.
- Maintain a battery state of charge ≤60%

For sprinkler protected areas where the above incidental storage criteria are exceeded:

- Sprinkler specification: Twelve K320 or K360 sprinklers, operating at 2.4 bar

† Protection based on storage of lithium-ion batteries presenting a hazard no greater than the general occupancy hazard, a maximum ceiling height of 9 metres, and CMDA sprinkler protection designed to provide 12mm/min over an assumed fire area of $230m^2$ for wet systems: 12mm/min over $330m^2$ for dry systems. (Based on FM HC-3 occupancies)

- Limit storage to three tiers high (maximum 4.5m high in racks or palletized)
- No other storage is permitted above the batteries
- Maximum ceiling height 12m

The packaging arrangements of lithium-ion of batteries is a key element in the success or failure of sprinkler protection. Fire control is achieved when sprinklers wet and cool cardboard packaging such that chain thermal runaway reactions are prevented and fire spread contained.

Fire control for stored lithium-ion batteries is reliant on the following elements:

- Cardboard packaging with cellulosic and/or unexpanded plastic internal packaging only
- Battery state of charge ≤60%
- Battery electrolyte weight ≤20%
- Battery capacity ≤41 Ah

‡ RISCAuthority 'Need to Know Guide RE1: Battery Energy Storage Systems (BESS) – Commercial Lithium-ion Battery Installations'

For storage of lithium-ion batteries in non-sprinklered facilities, fire protection measures similar to those for Battery Energy Storage Systems (BESS) are recommended‡, including:

- Lithium-ion batteries storage rooms and buildings shall be dedicated-use, i.e. not used for any other purpose.
- Containers or enclosures sited externally, used for lithium-ion batteries storage, should be non-combustible and positioned at least 3m from other equipment, buildings, structures, and storage.
  Note: greater separation distances may be appropriate from critical buildings and installations and to meet specified strategic spatial fire separation expectations
- Lithium-ion batteries storage in rooms forming part of buildings should be separated from other areas by minimum 2-hour fire rated construction.
- Smoke detection systems (ideally combined smoke and carbon monoxide (CO) detection) should be provided for all lithium-ion batteries storage rooms and compartments. This may be combined with deployment of an extinguishing agent flooding system (based on the fire control strategy).

Note: Battery Energy Storage Systems (BESS) are devices or groups of devices that enable energy from intermittent renewable energy sources (such as solar and wind power) to be stored and then released when customers need power most. They are constructed of successive battery packs wired together to create modules that are connected within racks to create an energy storage array.

3.4 Dealing with damaged or defective cells

Defective or damaged lithium-ion batteries that are awaiting removal from a site, should be packed in compliance with the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations (CDG) and the European agreement 'Accord européen elative au transport international des marchandises dangereuses par route' (ADR) ready for safe shipping.

The packaging should be leak-proof, with suitable inner and outer containers as per the regulations. The defective/damaged batteries should be encased in a non-combustible and electrically non-conductive thermal insulation material (typically vermiculite).

This packing will reduce vibration and shocks during transit and provide protection against any heat release that might occur. These shipping boxes should be stored in a separate building, within a 2-hour fire rated room/enclosure, or non-combustible outside container (minimum 6m separation from buildings), awaiting removal.

An appropriate frequency of removal by a licenced carrier should be established to avoid excessive accumulations on site.

Relevant Carriage of Dangerous Goods by Road regulations:

- Damaged or defective batteries – ADR SV 376, P908
- Critically defective batteries – ADR SV 376, P911
- Batteries for disposal and recycling – ADR P909

4 References

- *CFPA bulletin: An extinguishing agent specifically developed for lithium-ion battery fires*, 2020
- Fire Protection Association, *Fire Safety Advice and Guidance, 'Who is responsible for using a fire extinguisher?'*, 2022
- *'Fire Protection Strategies for Energy Storage Systems'*, *Fire Protection Engineering* (journal), issue 94, February 2022
- Fire Industry Association (FIA) *'Guidance on lithium-ion battery fires'*, 2020
- EURALARM *'Guidance on integrated fire protection solutions for lithium-ion batteries'*, 2022

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